WERI SCIENTIFIC ADVISORY PAPER

NITRATE OCCURRENCE AND TRENDS IN THE NORTHERN GUAM LENS AQUIFER (NGLA): OBSERVATIONS AND FINDINGS TO DATE

Purpose: This paper summarizes observations to date from ongoing research at WERI to characterize the occurrence and trends in dissolved nitrate in the freshwater lens of the NGLA. WERI Scientific Advisory Papers are written to provide local water resource engineers, managers, regulators, and policy-makers with carefully-researched, independent, objective data, observations, and findings upon which to build scientifically-informed, reliable, and sustainable engineering solutions, management practices, regulations, and public policies for successful management of local water resources.

Records/Sources. WERI has compiled historical (quarterly to annual) measurements of nitrate concentrations (mg/L or ppm) from GWA records for 146 wells from across the aquifer dating from the mid-1980s.[1] Figure 1 shows the current (January 2019) concentrations in each of the 146 wells.

Trends. Table 1 summarizes the observed trends. Nitrate concentrations at the beginning of the records were nearly all below 2.0 mg/L (ppm).[2] Concentrations have risen steadily in 84 (58%) of the 146 wells, with 64 to 68 of them (44 to 47%) showing steadily increasing trends across the entire period of record, up to present (trend-line intercept) values of 1.5 to 5.1 mg/L. The other 20 to 16 (14 to 11%) of these wells show steady increases up to about the middle of the record, with the trend flattening thereafter to 2.9 to 5.4 mg/L.[3] Fifty-five (38%) of the 146 wells show no significant trend in nitrate concentrations from the beginning to the end of the record. The remaining seven (5%) of the wells show decreasing trends or anomalous behaviors. Beneath Table 1 is an example of each of the four types of trends described above. The map at Figure 2 shows the current (January 2019) trend at each well: increasing, flat, or decreasing.

General Observations. Patterns of spatial variations and trends in nitrate concentrations, as is apparent in a quick review of the map at Figure 2, are complex. Patterns, trends, and their relationships to the locations and histories of sewer lines and septic tanks are subjects of ongoing or future research.[4] The general observation, however, that nitrate concentrations have risen over the past four decades in nearly 60% of the 146 wells, and that they are continuing to rise in at least 44% of the wells, indicates that there are widely—if complexly—distributed sources of nitrate that have, and continue, to contribute steady-to-increasing amounts of nitrate to the aquifer.

Inferred Sources of Nitrate. The most likely sources of increased and increasing nitrate concentrations in the groundwater over the past four decades—which have seen economic growth with increased urban concentrations, along with new and expanded residential developments above the aquifer—are sewage

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[1] Source: GWA Compliance Laboratory, Point of Contact: N'tasha L. Perez, 671-300-6340 x7758.

[2] Nitrate concentrations referred to in this paper are in terms of nitrate-N, which is based on the molecular weight of only the nitrogen in the nitrate ion, NO_3. Nitrate-N is thus 1/4.427 × Nitrate-NO_3. Natural background concentration in groundwater is typically no more than about 2 mg/L as nitrate-N, or 8.9 mg/L as nitrate-NO_3 (water.usgs.gov/nawqa/nutrients/pubs/wcp_v39_no12/). The USEPA maximum contaminant level (MCL) is 10 mg/L as nitrate-N, or 45 mg/L as nitrate-NO_3.

[3] For at least four wells, it is difficult to determine whether the data exhibit a subtle upward trend or a flattening trend.

[4] Research questions, for example, include spatial relationships of nitrate concentrations to natural geological features and engineered infrastructure (such as sinkholes and ponding basins, respectively) and to land-use (e.g., urban vs. rural). Temporal relationships that are yet to be systematically studied include correlations with storms and seasonal-to-interannual variations in rainfall.

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accidentally percolating from leaking sewage lines and effluent discharging from conventional septic tanks.[5] The map at Figure 1 shows current configurations of sewer lines and septic tanks above the aquifer. As noted above, spatial and temporal correlations between the locations of sewage lines, septic tanks, and nitrate concentrations in surrounding wells are complex, and it is not yet possible with the data at hand to precisely measure the absolute or relative contributions of sewage line leaks and septic tank discharge at any given location or to the total amount of nitrate entering the groundwater. Long-term approaches for management of nitrate contamination should thus address both.

Nitrate Management Considerations. The following generalizations—based on the data described above and on wastewater infrastructure development, maintenance, and management histories on the Northern Guam Plateau during the data periods-of-record—are pertinent to management, regulatory, and policy decisions directed at controlling, reducing, or eliminating nitrate discharge into the NGLA:

1. More than half (58%) of 146 well records together spanning more than 30 years show historical increases in nitrate concentrations, and nearly half (44 to 47%) show steady and ongoing increases.
2. Both leaking sewage lines and active conventional septic tanks have been and continue to be sources of nitrate contamination in the NGLA.
3. During the past two decades,[6] GWA has made deliberate, steady, and increasing investments to eliminate or reduce sewerage leakage by installing, expanding, repairing, and maintaining municipal sewerage systems, including upgrade and expansion of the Northern District Sewerage System.[7]
4. Aging of sewerage infrastructure can contribute to the introduction of contaminants into the subsurface. There is currently, however, an ongoing systematic program for routine inspection, scheduled preventive maintenance, and timely repair of all of the sewerage systems.[8]
5. There still exists a large, and probably growing, number of conventional individual disposal and household septic systems above the NGLA. Nitrate discharge from these systems can be eliminated only by replacing them—either by connecting households to non-leaking sewerage systems, or by replacing conventional septic tanks with modern, advanced individual treatment systems that can reduce nitrate to nitrogen gas, N_2 (which is expelled into the air). Like sewer lines, such systems require systematic preventive maintenance and timely repair to remain functional and effective.

[5] J.F. Mink ("Groundwater Resources of Guam: Occurrence and Development," *WERI Technical Report #1*, 1976) noted "unusually high" (8 to 9 mg/L) nitrate concentrations reported for NGLA well water and suggested they might be explained by excess fixed nitrogen leached from the root zone of the tangan-tangan (*Leucaena glauca*) that is ubiquitous on the limestone plateau. This hypothesis is not supported by subsequent analyses, which show initial concentrations (as nitrate-N) in the late 1970s to mid-1980s to have been on the order of 2 mg/L or below. Moreover, there is no obvious way in which tangan-tangan could account for *rising* concentrations in subsequent time-series data, especially given that wild vegetation is generally removed as land is cleared for development and urbanized. (It is also noted that the values cited by Mink came from reports prepared several years earlier by the drilling companies that installed the wells. It is uncertain whether the reported high values (of 8 to 9 mg/L) were nitrate-N or nitrate-NO_3; in the latter case they would be consistent with nitrate-N values of about 2 mg/L.)
[6] Widely-publicized system failures in the 1990s (such as the contamination of nearby wells from sewage spills at the Chaot and Mamajanao Sewage Pump Stations) culminated in EPA Safe Drinking Water Act/Clean Water Act enforcement actions, which (along with other events) prompted establishment of GWA in 1997 and the CCU in 2002. These reforms empowered water resource managers with the authority, accountability, resources, and policy support to systematically rehabilitate and upgrade existing, aging systems, and to install, expand, and maintain new, modern systems.
[7] The Northern District Sewerage system--which serves Dededo, Yigo, Andersen AFB and surrounding areas—is comprised of a collection system (sewer laterals, mains, trunk lines and pump stations) and the Northern District Wastewater Treatment Plant (NDWWTP,) originally constructed over 30 years ago. There is a current provision in GWA's Capital Improvement Program for expanding the Northern District Sewerage System by 5,000 linear feet per year. (Source: GWA.)
[8] GWA recently completed a $30M rehabilitation of more than nine miles of collection-system trunk lines, which has resulted in a demonstrated reduction of wet-weather infiltration, as observed at the NDWWTP. GWA also has an ongoing program of cleaning and CCTV inspection of collection-system laterals and mains, which will inform prioritization of rehabilitation and upgrade projects currently in GWA's funded 5-year Capital Improvement Program and 20-year Master Plan. (Source: GWA.)

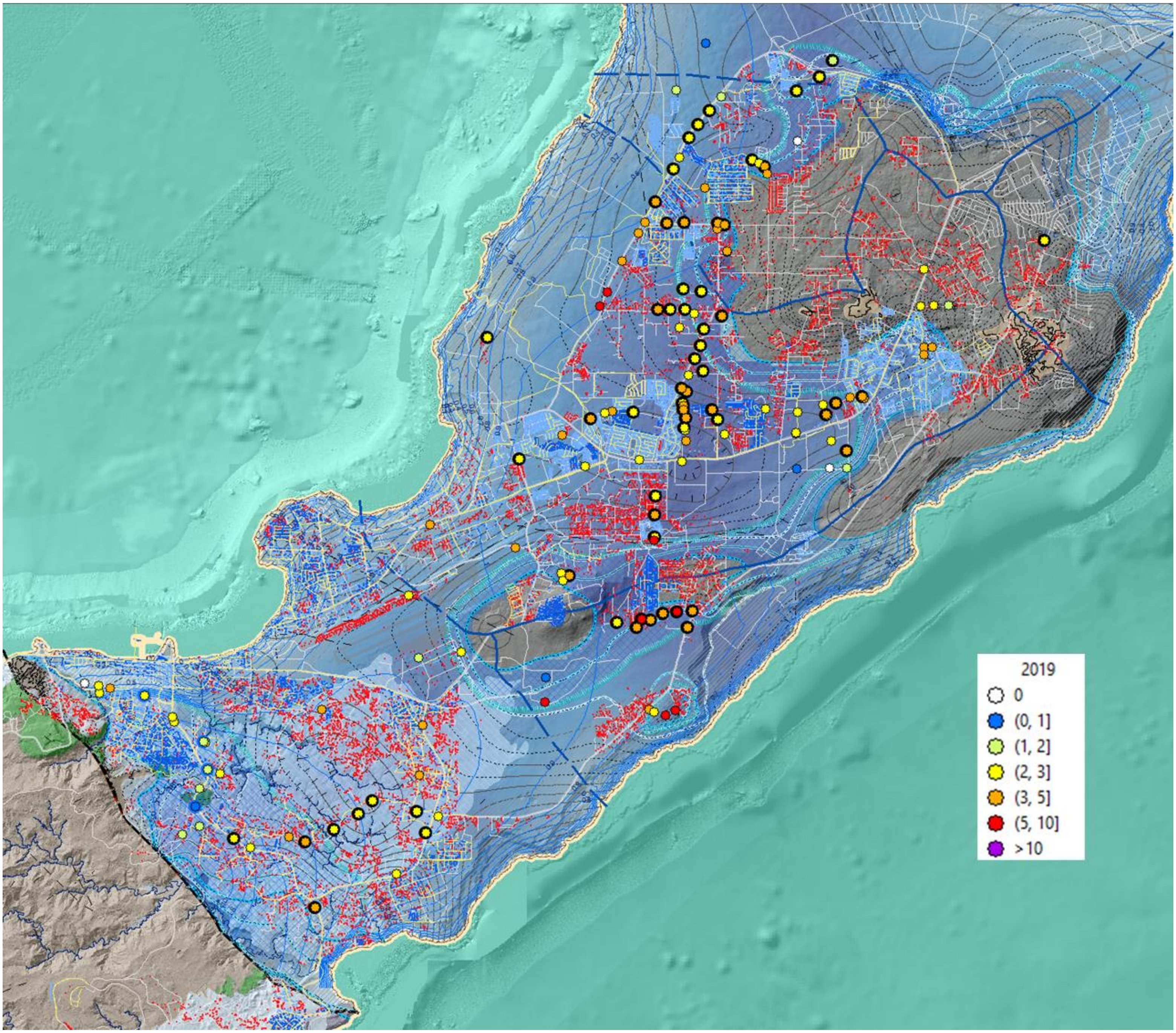

Figure 1. Map of wells, showing nitrate concentrations (as nitrate-N) as of January 2019 in mg/L. Yellow lines show existing sewerage systems. Red dots are mapped septic tanks. Thick blue lines (solid and dashed) are the boundaries of the hydrologically separate groundwater basins within the aquifer (analogous to separate surface watersheds). Thin blue lines are the water-table contours. Groundwater flows from the interior of each basin toward the coast, perpendicular to the water-table contour lines.

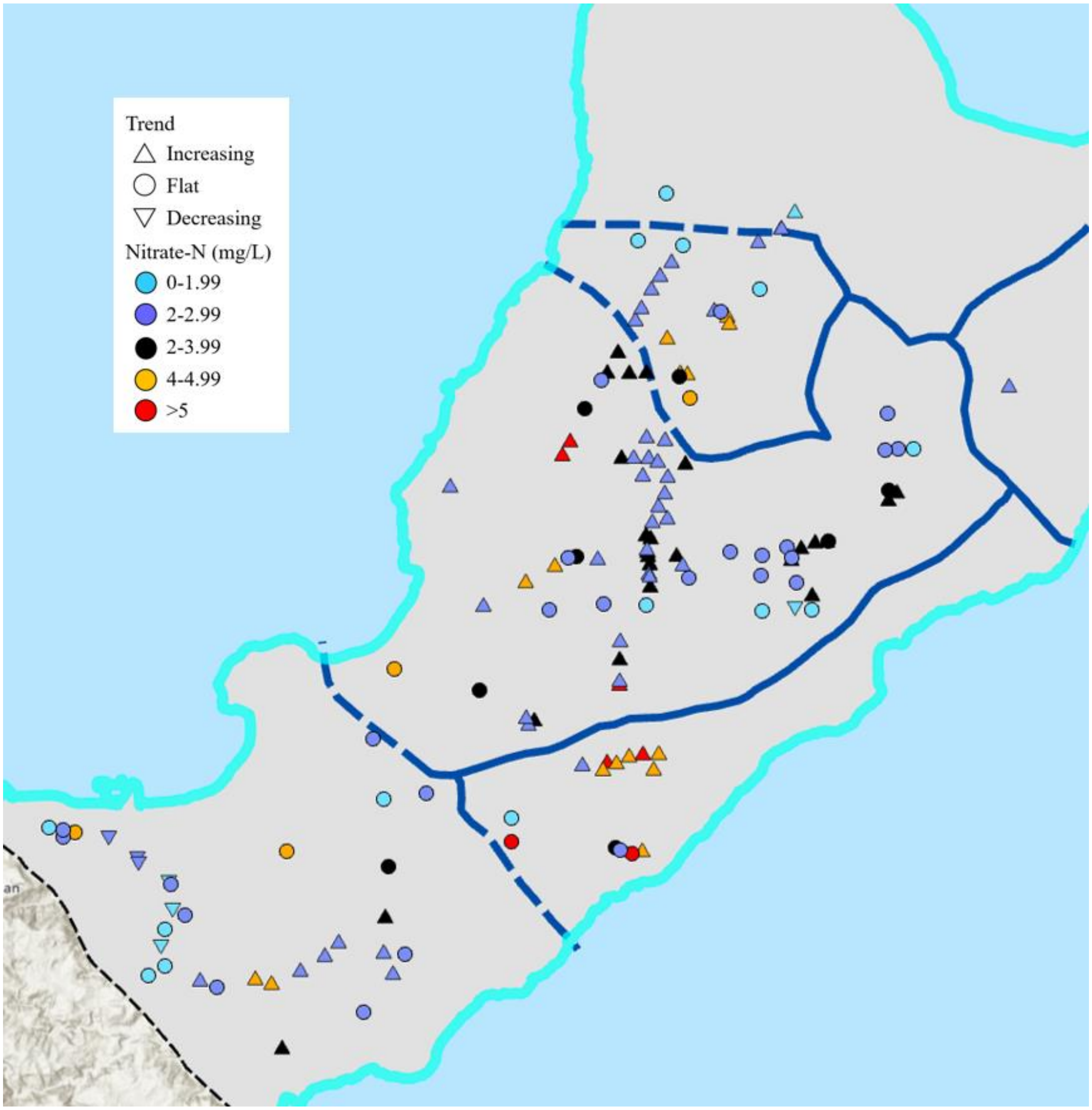

Figure 2. Map of wells, showing nitrate concentrations (as nitrate-N), by color, in mg/L, and trends (upward-pointing triangle for increasing trend, circle for flat (insignificant trend), downward-pointing triangle for decreasing trend) as of January 2019. Thick blue lines (solid and dashed) are the hydrologic basin boundaries.

trends (ca. 1986 - 2019)	number of wells	percent of wells	2019 nitrate concentrations (mg/L or ppm) (trend line)						example
			min	well	max	well	range	mean	
increasing over entire record	64 to 68	44 to 47	1.5	D-15	5.1	NCS-5	3.6	3.2	M-15
increasing, then flattened	20 to 16	14 to 11	2.9	D-21	5.4	F-18	2.5	3.9	EX-11
total	84	58	---	---	---	---	---	---	---
stable	55	38	0.4	MW-8	6.0	NCS-3	5.6	2.7	A-6
decreasing	7	5	0.6	A-3	2.8	A-25	2.2	2.0	A-31
TOTAL	146	---	---	---	---	---	---	---	---

Table 1. Summary of trends in nitrate concentrations (as nitrate-N).

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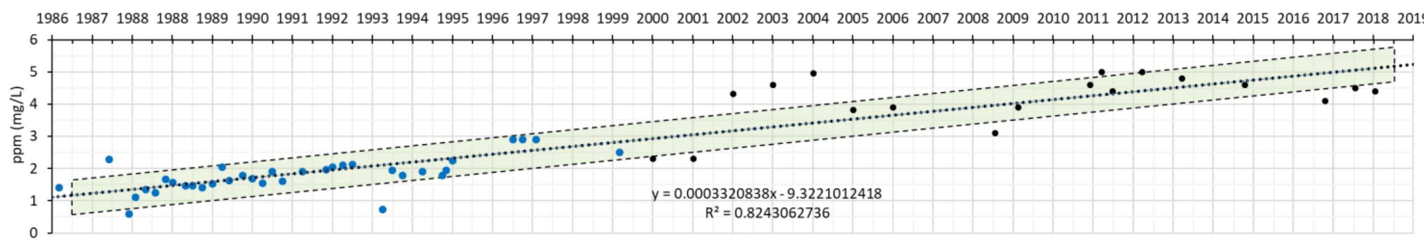
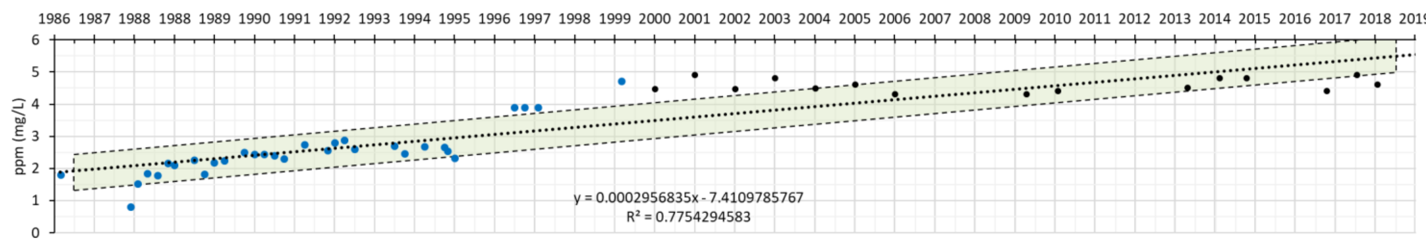


EX-11



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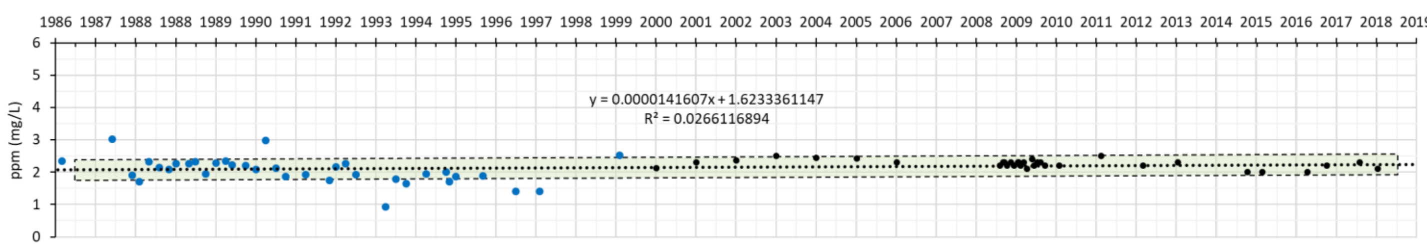

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