Comparative Trends Across Four Basins and Updated Chloride Concentration Analysis

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TECHNICAL REPORT NO. 188

MAY 2026

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by

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Technical Report No. 188

May 2026

The research described in this report was funded, in part, by the U.S. Department of the Interior, Geological Survey, and Guam Hydrological Survey through the University of Guam Water and Environmental Research Institute of the Western Pacific.

Contents

1. Introduction

This report presents an updated assessment of chloride concentration trends and production patterns in the Finagua'yok, Tomhom, Hagåtña, and Mangilao Basins, building upon the findings of four previous technical reports. The primary objective is to provide a consistent, basin-scale evaluation of recent data, highlighting changes over the past decade and ongoing patterns in groundwater quality and well production.

The analysis integrates updated decadal statistics, spatial mapping of chloride trends, updated statistical analysis (Mann-Kendall and STL decomposition), and evaluation of pumping practices relative to NGLS recommendations. By comparing the most recent decade with the preceding decade, this report identifies wells that have maintained stable conditions as well as those exhibiting changes in chloride concentrations or production rates. Summary tables and maps are used to support these assessments, providing a clear view of temporal and spatial patterns that may inform water management decisions.

This updated evaluation is intended to serve as a reference for ongoing monitoring, management planning, and decision-making in the Northern Guam Lens Aquifer, complementing the prior reports while emphasizing recent trends and emerging areas of concern.

2. Study Area

This report encompasses updates for the four basins of the Finagua'yok, Tomhom, Hagåtña, and Mangilao basins. The Finagua'yok basin (previously referred to as the Finegayan basin) is the smallest basin in the NGLA. Twenty-one production wells were analyzed in WERI Technical Report No. 177, titled *Geospatial and Temporal Analysis of Patterns and Trends of Salinity in Finegayan Basin*. The Yigo-Tumon basin (previously referred to as the Tomhom basin) is the largest basin of the six NGLA basins and is the most productive basin. WERI Technical Report No. 178, titled *Geospatial and Temporal Analysis of Patterns and Trends of Salinity in Yigo-Tumon Basin* was the most recent analysis report of production wells. The Hagåtña basin is the southernmost and second largest basin of the NGLA. WERI Technical Report No. 182, titled *Geospatial and Temporal Analysis of Patterns and Trends of Salinity in Hagåtña Basin*, reports on 30 total production wells. The Mangilao Basin has groundwater production concentrated in a relatively small area compared to the overall size of the basin. WERI Technical Report No. 184, titled *Geospatial and Temporal Analysis of Patterns and Trends of Salinity in the Mangilao Basin*, reports on 7 production wells.

3. Methods

3.1. Data Sources

Chloride concentration data for the Finagua'yok, Tomhom, Hagåtña, and Mangilao basins were obtained from the Guam Waterworks Authority (GWA) in the form of Excel workbooks. These datasets contain chloride concentrations and production rates collected from monitoring wells within each basin. The datasets include both monthly sampling from 1973 to 1983 and quarterly sampling from 1984 to the present. Blank entries in the dataset were marked as NA values to facilitate processing in RStudio. Previous technical reports were also referenced to update long-term trends.

3.2. Decadal Statistics

Decadal summary statistics were compiled for all basins as part of this updated analysis. These summary tables were updated to reflect data through March 2025 and include two main categories: production statistics and chloride statistics.

The production statistics include:

- Groundwater zone classification (basal, para-basal, or supra-basal)
- Well depth (feet and meters)
- NGLS maximum recommended bottom elevation (feet)
- Well screen length (feet)
- Well construction year
- Well status and final year of production (if applicable)
- NGLS maximum recommended pump rate (gpm)
- Mean pump rate (Mgal/month) for the time periods of 1973-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 2020-3/2025

The chloride statistics include:

- Total number of chloride samples collected
- Minimum chloride concentration (mg/L)
- Maximum chloride concentration (mg/L)
- Standard deviation of chloride concentration
- Mean chloride concentration (mg/L) calculated for the time periods of 1973-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 2020-3/2025

All calculations were performed in Excel using standard summary functions (AVERAGE, MIN, MAX, STDEV).

3.3. Mapping and Visualization

Spatial analysis and visualization were conducted using ArcGIS Pro to assess well locations and patterns in chloride concentration across the study basins. Wells were color-coded by trend classification, and symbols were used to represent chloride concentration ranges. In addition to traditional mapping, decadal maps were generated to compare the last full decade (2010-2019) with the current ongoing decade (2020-March 2025).

A table of chloride benchmark labels and corresponding color codes is included to standardize visual interpretation across figures (Table 1) from Simard (2015) based on chloride benchmarks from McDonald and Jenson (2003).

Table 1: Color Codes for Chloride Concentration Benchmarks

McDonald and Jenson (2003) Chloride Benchmark	Proposed Chloride Benchmark Label	Chloride Concentration Range (mg/L)	Color Code
Para-basal	Exceptional	<30	Light Blue
Saltwater toe	Good	30 – 70	Green
Basal	Standard	70 – 150	Yellow
Saltwater Up-coning	Marginal	150 – 250	Orange
SDW Guideline	Out of Standard	>250	Red

3.4. Production Rate Comparison

To evaluate the relationship between chloride concentration and well production, decadal statistics for average production rates (gallons per minute) were compiled for each well. Production in the last full decade was compared with the current ongoing decade to assess changes over time. Wells were categorized based on both chloride concentration and production relative to the Northern Guam Lens Study (NGLS) recommended maximum pump rates for their respective groundwater zones. Categories included:

- <150 mg/L chloride (local MCL) and the production below NGLS recommendation
- <150 mg/L chloride and production at NGLS recommendation
- <150 mg/L chloride and production above NGLS recommendation
- 150-250 mg/L chloride and production below NGLS recommendation
- 150-250 mg/L chloride and production above NGLS recommendation
- >250 mg/L chloride and production below NGLS recommendation
- >250 mg/L chloride and production above NGLS recommendation

Summary tables were created to show which wells fall into each category by decade. This framework allows for comparison of wells over time, highlighting the instances where changes in production coincide with shifts in chloride concentrations. While this categorization illustrates potential patterns, no causal inferences were made without supporting hydrologic data.

3.5. Linear Regression

Long-term trends in chloride concentration were assessed using linear regression. Time was treated as the independent variable (X), expressed in decimal years, and chloride concentration (mg/L) was the dependent variable (Y). Regression was performed using Microsoft Excel's Data Analysis Toolpak. For each well, the slope (m), coefficient of determination (R^2), F-statistic, and p-value were recorded from the regression output.

Trends were classified according to statistical significance and slope direction as follows:

- Increasing trend: positive slope ($m > 0$) and $p < 0.05$
- Decreasing trend: negative slope ($m < 0$) and $p < 0.05$
- Plateau: $p \geq 0.05$, indicating no statistically significant change in chloride concentration over time

3.6. Mann-Kendall Test

To verify long-term trends that are independent of linear assumptions, a non-parametric Mann-Kendall trend test was applied to each well's chloride concentration time series using the trend package in RStudio (Pohlert, 2023). This test is specifically designed to detect monotonic trends, that is, values that tend to increase or decrease over time—even if the pattern is not perfectly linear. As it is a non-parametric test, it doesn't require the data to follow a normal distribution or meet other assumptions of linear regression, making it especially useful for environmental datasets that may contain variability, outliers, or irregular patterns. For each well, the test returned a standardized test statistic *(z)* and a *p*-value, which were used to determine both the direction of the trend (increasing or decreasing) and whether the trend was statistically significant ($p < 0.05$). Results were summarized in a table listing each well's *z*-statistic, *p*-value, trend direction, and significance status. The Mann-Kendall test was used alongside linear regression to provide a more robust evaluation of chloride trends, particularly in cases where the time series appeared non-linear or highly variable. For example, in a well where chloride concentrations rose sharply during the early years and then leveled off, the Mann-Kendall test could still identify a statistically significant increasing trend, even if the linear regression slope was weak or inconsistent due to changes in trend strength over time.

3.7. Time Series Decomposition

To better understand how chloride concentrations have changed over time in different wells, time series decomposition was also used. This technique isolates patterns within a dataset collected over regular time intervals. Importantly, this analysis was conducted using only the observed chloride concentration values, without incorporating any outside variables such as rainfall, pumping rates, or climate indices.

The stl() function in RStudio was used, which performs Seasonal and Trend decomposition using Loess (Cleveland et al., 1990). This method separates the chloride concentration time series into:

- Trend: the long-term direction of chloride concentrations over multiple decades
- Seasonal: repeating cyclical patterns that occur at the same frequency (quarterly or annually)
- Remainder (residuals): irregular variation that does not follow a predictable pattern and that is not explained by the trend or seasonal cycle.

Decomposition relies solely on the chloride measurements over time therefore the results reflect intrinsic patterns in the water quality data itself. This allows for the identification of:

- Primary trends (long-term directionality)
- Secondary trends (multi-year to interdecadal fluctuations), and
- Tertiary trends (short-term cycles, such as wet/dry season signals or operational variability).

STL is a flexible, non-parametric method that does not assume a specific functional form, allowing chloride trends to be interpreted without imposing linear or sinusoidal constraints.

Seasonal components were interpreted with respect to Guam's bimodal climate (wet and dry seasons), and detected high-frequency cycles (quarterly) were considered in the context of operational, hydroclimatic, or ENSO-related influences.

Quarterly chloride concentration data for each well was first gap-filled using linear interpolation to address missing values. Specifically, the na.approx() function from the zoo package in R was applied to linearly interpolate short gaps within each well's dataset. This approach helps preserve the integrity of longer-term patterns while filling minor data gaps. Wells that still contained missing values after interpolation, due to extended periods without measurements or gaps at the beginning or end of the record, were excluded from the STL decomposition analysis. These excluded wells were documented in a "Skipped Wells" table to maintain transparency about data omissions and their reasons. For wells passing this screening, STL decomposition was performed to extract trend, seasonal, and residual components. Numerical metrics such as seasonal strength and trend direction were calculated and reported alongside each decomposition plot.

Seasonal strength quantifies the degree of seasonality present in a time series, ranging from 0 (no seasonality to 1 (perfectly seasonal). Seasonal strength values were interpreted using the thresholds shown in the table (Table 2) below:

Table 2: Seasonal strength value interpretations

Seasonal Strength Value	Interpretation
> 0.5	Strong seasonal pattern
0.2 – 0.5	Moderate seasonality
< 0.2	Weak or negligible seasonality

This classification allowed assessment of how strongly seasonal cycles influenced chloride concentrations across the wells studied.

4. Results and Discussion

4.1 Updated Decadal Statistics

Decadal statistics for chloride concentrations and production rates were compiled for each well across the Finagua'yok, Tomhom, Hagåtña, and Mangilao Basins. These statistics provide a summary of long-term trends highlighting wells and basins were chloride levels have remained stable, increased, or decreased over time, alongside changes in pumping volumes. The complete set of decadal statistics is provided in Appendix A.

4.2 Spatial Patterns

To assess the spatial distribution of these trends, decadal maps were generated for the last full decade and current ongoing decade. Wells are color-coded by chloride trend classification, with an additional symbol denoting wells pumping at or below the NGLS recommended maximum rate while maintaining chloride concentrations at various benchmarks. These maps illustrate basin-wide patterns in salinity and production practices, highlighting areas of stable groundwater quality as well as zones where elevated chloride levels or high pumping may indicate potential stress. Decadal maps are present in Appendix B.

4.2.1 Finagua'yok Basin

When comparing the 2010-2019 decade and the current decade, chloride concentrations remain lower or the same in all wells except for an increase in D24 and F15. Wells that were in the out of standard chloride concentration in the 2010-2019 decade, F10 and F13, have moved down to marginal chloride concentrations.

4.2.2 Tomhom Basin

The wells in the basin have retained chloride concentrations in their respective benchmark classifications between both basins.

4.2.3 Hagåtña Basin

Between the two decades, some wells do not have decadal chloride concentrations in the current decade (A02, A23, A25, A26, and A29). Well A09 has increased in chloride concentration falling into the out of standard category while A14 and A19 have moved down to the marginal category. The wells on the east side of the basin still have higher chloride concentrations as compared to the west side of the basin.

4.2.4 Mangilao Basin

In the current decade, chloride concentrations have either remained the same or gotten better (M01 going from marginal to good groundwater quality and M02 going from standard to good groundwater quality).

4.3 Production Rate Comparison

Summary tables comparing wells between the last full decade and the current ongoing decade were prepared to illustrate changes in chloride concentrations in relation to production rates. These tables highlight wells that have maintained low chloride concentrations under recommended pumping, as well as wells where chloride levels have increased or production has exceeded recommended limits. Comparing decades makes it possible to identify wells that have moved between categories, provided insight into how pumping practices may correspond with changes in water quality across the basins.

4.3.1 Finagua'yok Basin

Table 3. Finagua'yok Basin - Production Rate Comparison by Decade

Category	2010-2019 Wells	2020-3/2025 Wells
< 150 mg/L - Below NGLS	D24, F02, F03, F08, F12, F15, F16, F17, F18	D24, F01, F02, F03, F08, F11, F12, F15, F16, F17, F18
< 150 mg/L - Above NGLS	HGC2	F04, HGC2
150 - 250 mg/L - Below NGLS	F01, F11	F10
150 - 250 mg/L - Above NGLS		F13
> 250 mg/L - Below NGLS	F10	
> 250 mg/L Above NGLS	F13	
No NGLS set	D22A	
Missing Data	F04	

Note: "Below NGLS" and "Above NGLS" refer to production relative to the NGLS recommended maximum pump rate for the well's groundwater zone.

When comparing production rates by decade (Table 3), the following reveals several key patterns.

- Stable, low-chloride wells: Most wells maintaining chloride concentrations below 150 mg/L remain below NGLS recommended production rates. Some wells that were previously below NGLS but within the chloride concentration range of 150 – 250 mg/L in 2010-2019 (e.g., F01, F11) now operate in a lower chloride concentration category.
- High-chloride wells: Wells F10 and F13, which had chloride concentrations above 250 mg/L in 2010-2019, no longer appear in that category in 2020-3/2025, suggesting either reduced chloride trends or adjustments in production rates.
- Wells without NGLS benchmarks: D22A is uncategorized as it is a supra-basal well and there is an absence of an established NGLS production recommendation.

Below are the decadal maps (Figure 1 and Figure 2, respectively) that display the 2010-2019 and present decade.

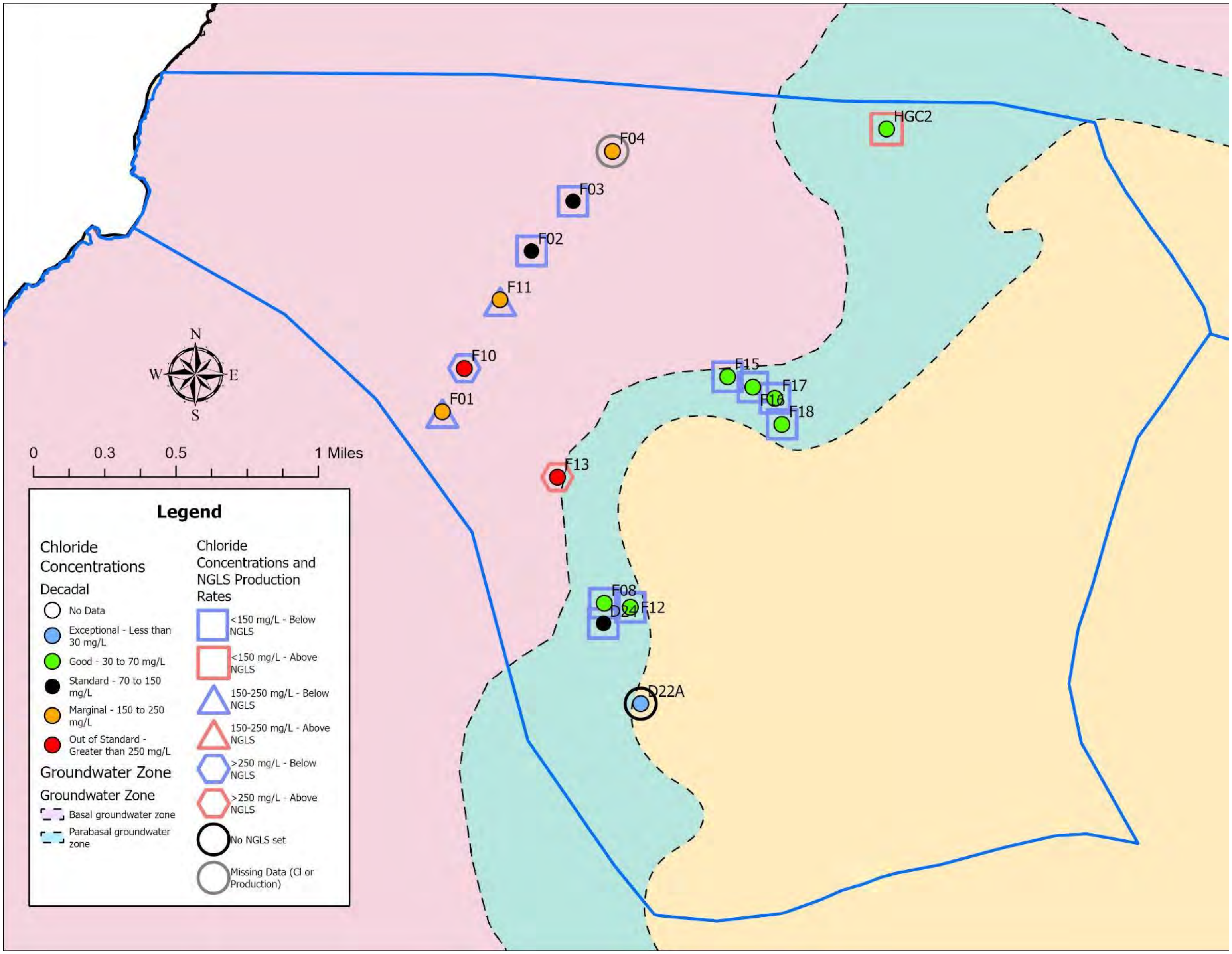

Figure 1: 2010-2019 Decade Chloride Concentrations and NGLS Production Rates for the Finagua'yok Basin

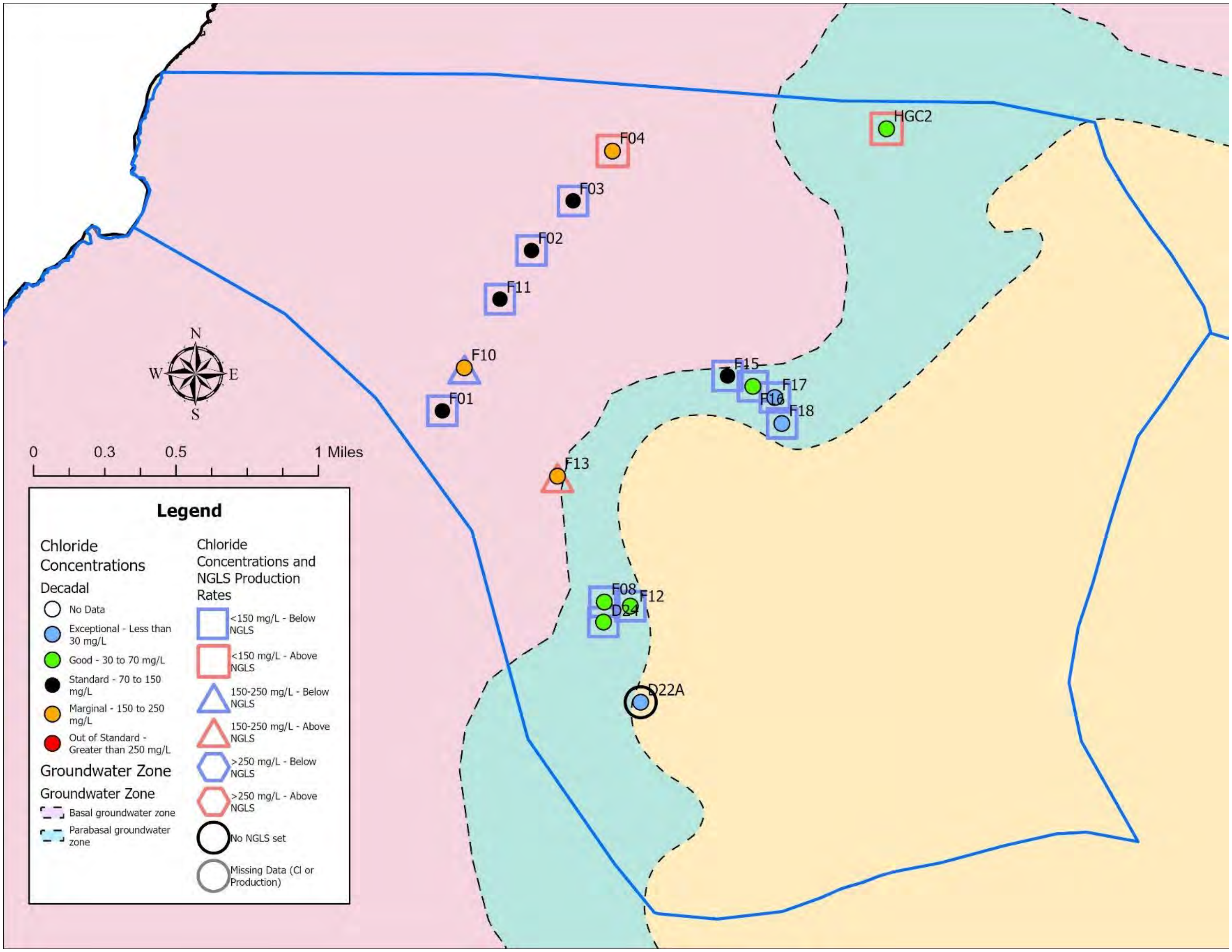

Figure 2:Current Decade (2020-3/2025) Chloride Concentrations and NGLS Production Rates for the Finagua'yok Basin

4.3.2 Tomhom Basin

Table 4: Tomhom Basin - Production Rate Comparison by Decade

Category	2010-2019 Wells	2020-3/2025 Wells
< 150 mg/L - Below NGLS	D05, D11, D12, D15, D16, D17A, D18B, D21, D25, D27, F05, F07, F09, G501, M05, M07, M12, M15, M17A, M17B, M18, M20A, Y01, Y02, Y03, Y04A, Y06	D02, D12, D14, D15, D21, D25, D27, F05, F07, F09, M06, M07, M12, M15, M17A, M17B, M18, M20A, Y01, Y02, Y03, Y04A, Y05, Y06
< 150 mg/L - at NGLS	D07, D14	D11
< 150 mg/L - Above NGLS	D01, D02, D04, D06, D10, D19, D20, D28, EX05A, M06, M21, Y05, Y07, Y09, Y10, Y12, Y14, Y16, Y18, Y19, Y20, Y22, Y23	D01, D04, D06, D07, D10, D14, D16, D17A, D18B, D19, D20, D28, EX05A, G501, H01, M05, M21, Y07, Y09, Y10, Y12, Y14, Y16, Y18, Y19, Y20, Y21, Y22, Y23
150 - 250 mg/L - Below NGLS	D08, D26	D08, D26
150 - 250 mg/L - Above NGLS	D09, H01	D09
> 250 mg/L - Below NGLS	F06	F06
> 250 mg/L Above NGLS	F19, F20	F19, F20
No NGLS set	Y17, Maui	Maui
Missing Data (Cl or Prod)	D03A, D13, M14, Y21	D03A, D05, D13, M14

Comparison of decades for the Tomhom Basin (Table 4) reveals several key patterns:

- Stable, low-chloride wells: A substantial number of wells have maintained chloride concentrations below 150 mg/L while operating below NGLS recommended production rates.
- Increased production or chloride: Several wells moved into higher categories either by exceeding NGLS recommendations or by showing higher chloride concentrations while remaining within NGLS limits.
- High-chloride wells: F06, F19, and F20 consistently remain in the >250 mg/L categories across both decades, indicating persistent elevated chloride levels.
- Wells without NGLS benchmarks: Wells such as Maui (horizontal well) and Y17 (supra-basal well remain uncategorized due to the absence of NGLS recommendations.
- Missing data: Some wells have had missing chloride or production data in one or both decades (e.g., D03A, D05, D13, M14, Y21), limiting their inclusion in the comparison.

Below are the decadal maps (Figure 3 and Figure 4, respectively) that display the 2010-2019 and present decade.

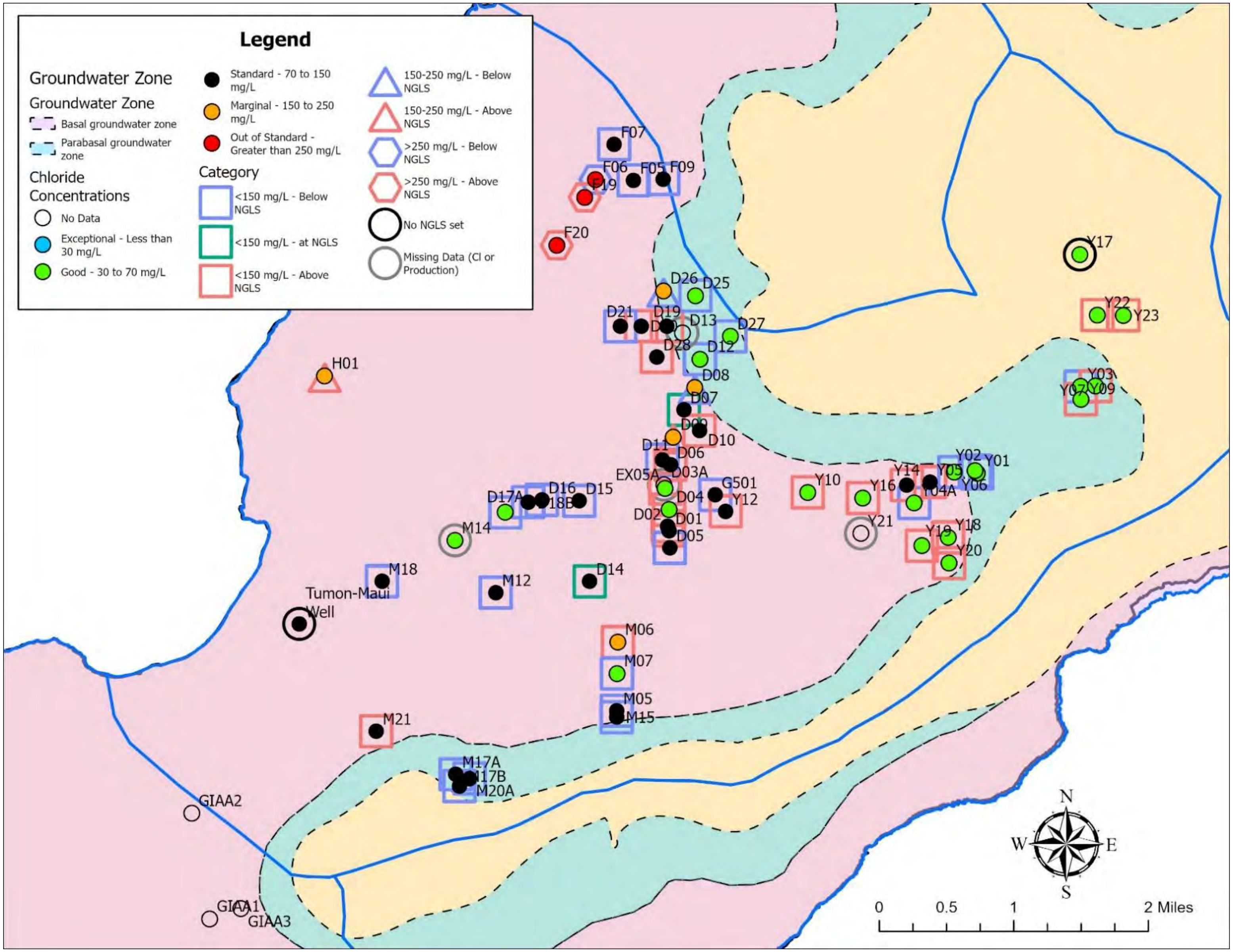

Figure 3: 2010-2019 Decade Chloride Concentrations and NGLS Production Rates for the Tomhom Basin

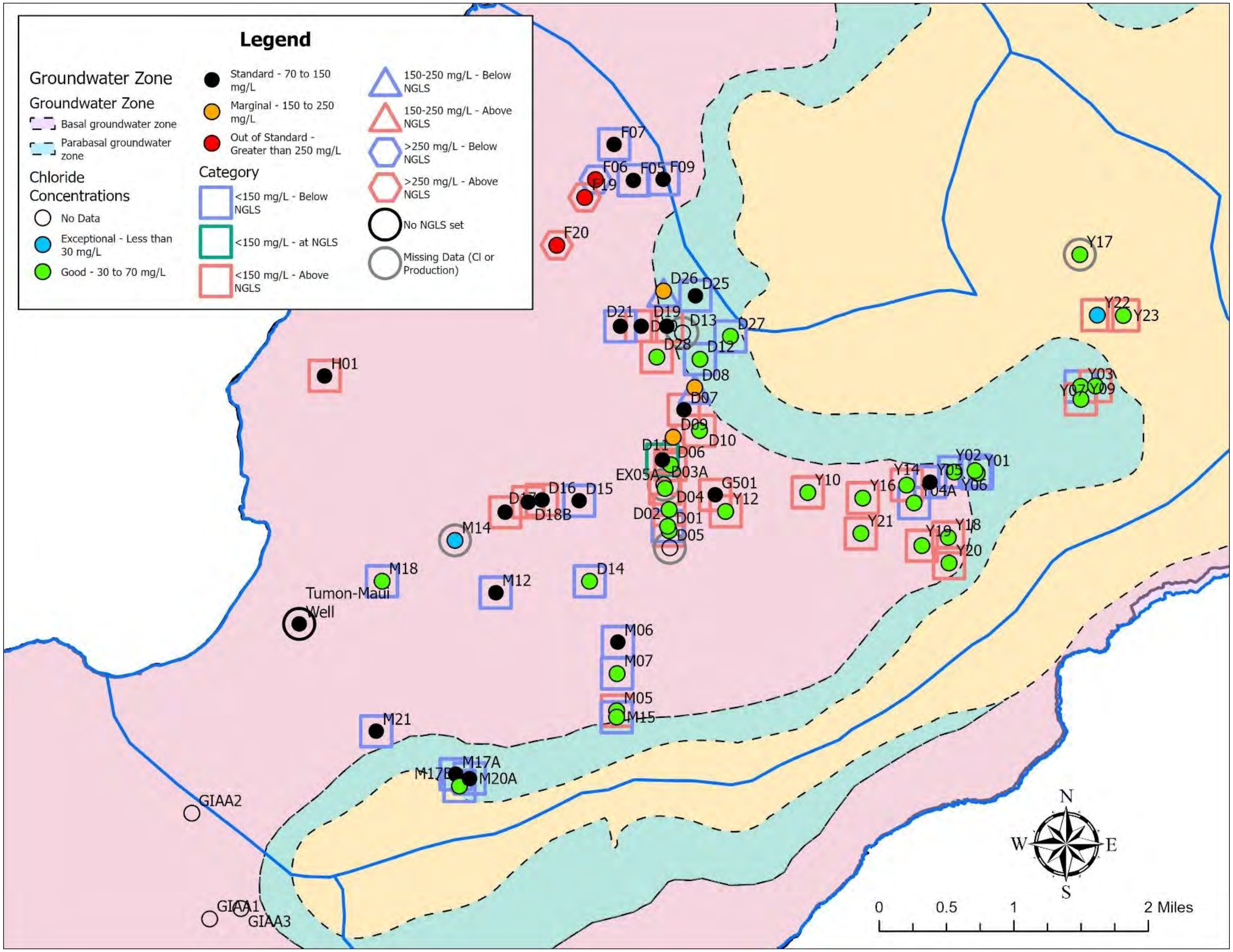

Figure 4: Current Decade (2020-3/2025) Chloride Concentrations and NGLS Production Rates for the Tomhom Basin

4.3.3 Hagåtña Basin

Table 5: Hagåtña Basin - Production Rate Comparison by Decade

Category	2010-2019	2020-3/2025
< 150 mg/L - Below NGLS	A01, A02, A03, A04, A05, A06, A08, A12, A23, A25, A26, A29, A31, A32	A01, A03, A04, A05, A06, A08, A12, A32
< 150 mg/L - Above NGLS	A30	A15, A30, A31
150 - 250 mg/L - Below NGLS		A14, A19
150 - 250 mg/L - Above NGLS	A09, A15	
> 250 mg/L - Below NGLS	A13, A14, A19	A13
> 250 mg/L - Above NGLS	A10, A17, A18, A21	A09, A10, A17, A18, A21
No NGLS set	EX11, NAS01	
Missing Data	A07, A28	A02, A07, A23, A25, A26, A28, A29

Key observations when comparing the decades (Table 5):

- Most wells remain in the <150 mg/L categories, though one well (A31) has shifted between "Below NGLS" and "Above NGLS" designations.
- A few wells have moved into the 150-250 mg/L or >250 mg/L categories, indicating localized increases in chloride concentrations.
- Some wells have missing data in one or both decades, limiting direct comparison

Below are the decadal maps (Figure 5 and Figure 6, respectively) that display the 2010-2019 and present decade.

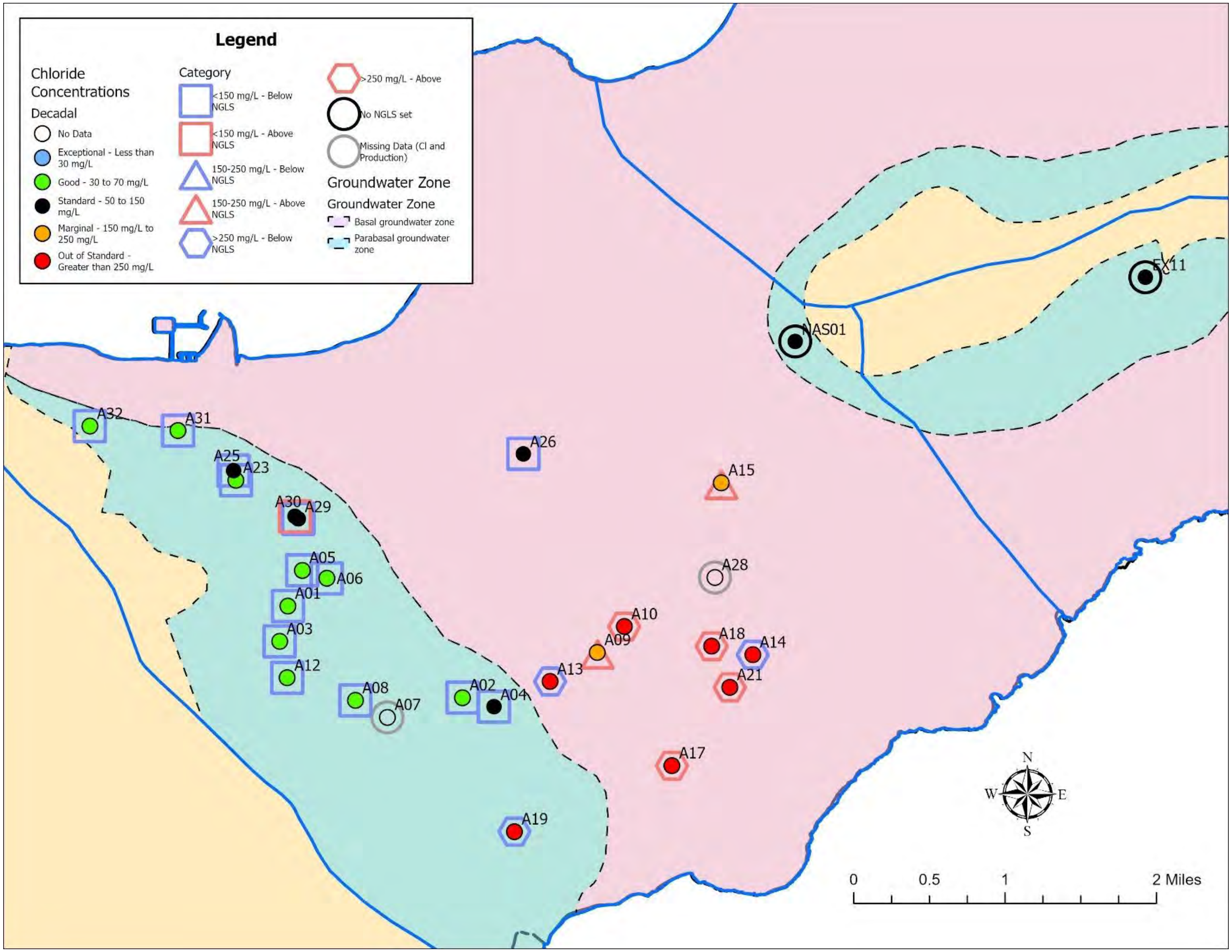

Figure 5: 2010-2019 Decade Chloride Concentrations and NGLS Production Rates for the Hagåtña Basin

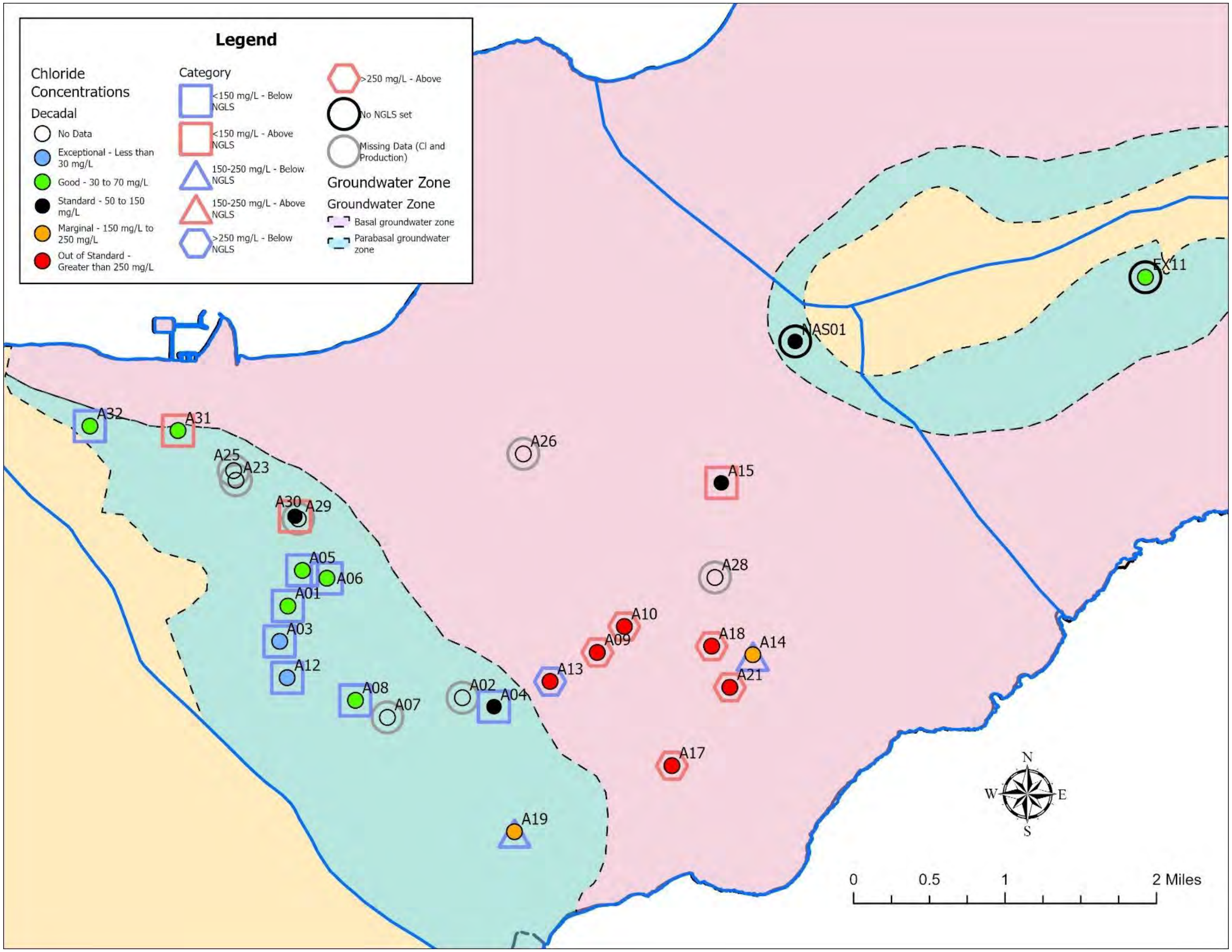

Figure 6: Current Decade (2020-3/2025) Chloride Concentrations and NGLS Production Rates for the Hagåtña Basin

4.3.4 Mangilao Basin

Table 6: Mangilao Basin – Production Rate Comparison by Decade

Category	2010-2019 Wells	2020-3/2025 Wells
< 150 mg/L - Below NGLS	M02, M03, M04, M08, M23	M01, M02, M03, M04, M08, M23
< 150 mg/L - Above NGLS		
150 - 250 mg/L - Below NGLS	M01, M09	M09
150 - 250 mg/L - Above NGLS		
> 250 mg/L - Below NGLS		
> 250 mg/L Above NGLS		
No NGLS set		

Key observations in analyzing the production rates (Table 6):

- Most wells maintain chloride concentrations below 150 mg/L, with only minor shifts in production relative to NGLS.
- M09 moved into the 150-250 mg/L category.
- Overall, the Mangilao Basin shows relatively stable low-chloride conditions compared to other basins.

Below are the decadal maps (Figure 7 and Figure 8, respectively) that display the 2010-2019 and present decade.

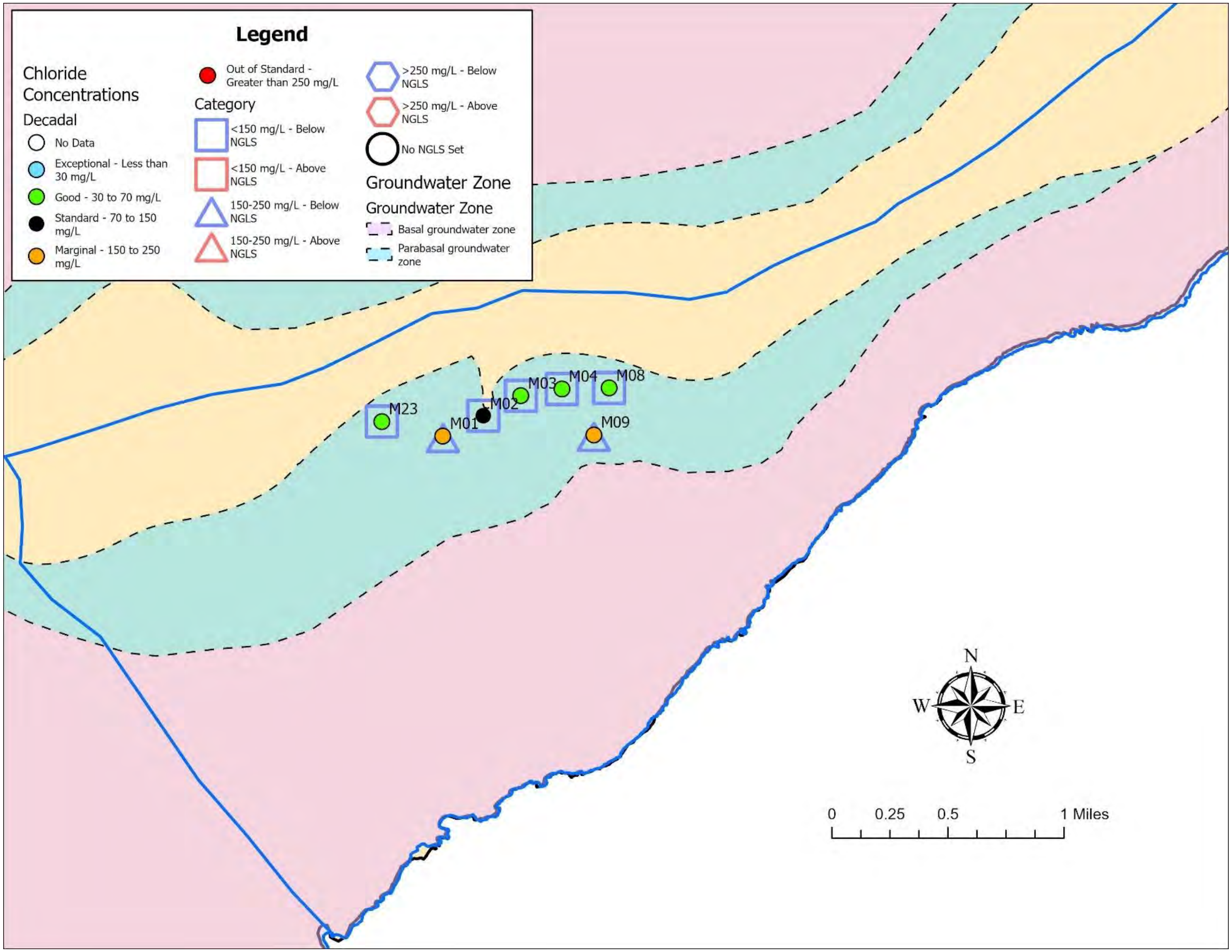

Figure 7: 2010-2019 Decade Chloride Concentrations and NGLS Production Rates for the Mangilao Basin

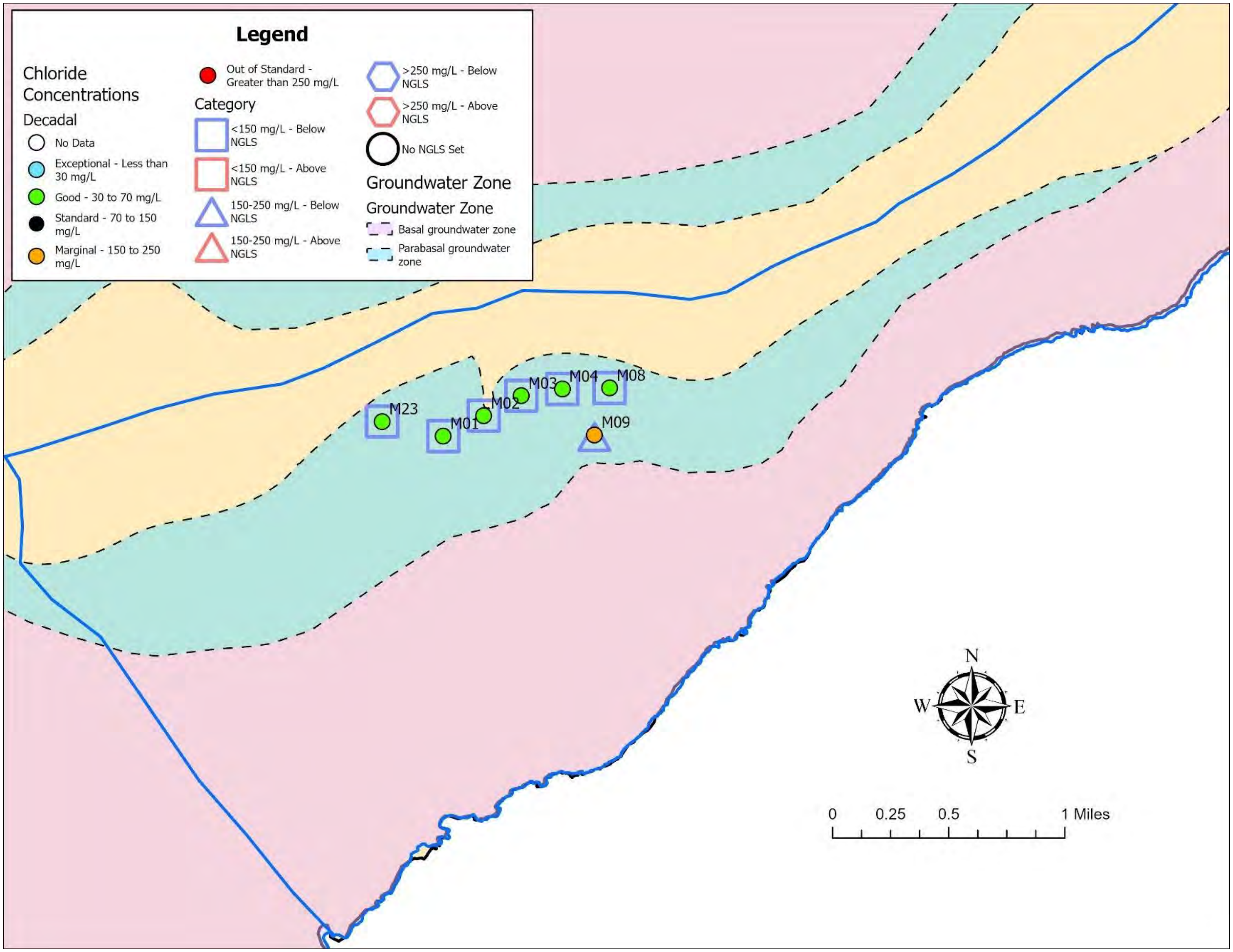

Figure 8: Current Decade (2020-3/2025) Chloride Concentrations and NGLS Production Rates for the Mangilao Basin

4.3.5 Summary

Comparing the four basins highlights differences in chloride concentrations and production patterns:

- Finagua'yok Basin: Most wells remain <150 mg/L. F10 and F13 previously exceeded 250 mg/L but have shifted to lower categories.
- Tomhom Basin: A large number of wells remain <150 mg/L, but there is a notable number of wells exceeding NGLS or shifting into higher chloride categories, indicating localized stress. Persistent high-chloride wells (F06, F19, F20) remain in >250 mg/L categories.
- Hagåtña Basin: Many wells are <150 mg/L, though several wells have shifted between production categories or increased chloride concentrations into 150-250 mg/L and >250 mg/L ranges.
- Mangilao Basin: The majority of wells remain <150 mg/L and within NGLS recommendations, with only minor shifts into 150-250 mg/L, indicating generally stable conditions.

Overall, the Mangilao and Finagua'yok basins show the greatest number of wells maintaining low chloride concentrations under recommended pumping, while Tomhom and Hagåtña basins exhibit more variability, with several wells showing increasing chloride concentrations or production above recommended limits. These comparisons provide a basin-level perspective on groundwater quality and management priorities.

4.4. Linear Regression

Linear regression was used to evaluate trends in chloride concentrations over time. For each well, regression lines were fitted to determine the rate of change (slope, in mg/L per year) and the strength of the trend (via R^2 and p-value). Where large data gaps were present, wells were split into separate time periods to better capture distinct trends without introducing bias from prolonged missing intervals.

This analysis served as a foundational tool to identify wells with strong upward or downward trends and to quantify the magnitude of change. Results from the Mann-Kendall test and STL decomposition were later used to validate or supplement the findings presented here. The summary tables per basin are included in Appendix C.

4.4.1 Finagua'yok Basin

Most wells in Finagua'yok show statistically significant positive slopes, indicating increasing chloride concentrations over time. Notably:

- F08 exhibited the steepest increase (slope +181.4 mg/L/yr, $R^2 = 0.36$), followed closely by F02 and F01.
- Several wells (F01-F04, F08, F10, HGC2) showed moderate to strong R^2 values (>0.25), suggesting consistent long-term trends.

- F17 was one of the few wells with a significant negative slope (-44.57 mg/L/yr), indicating a declining chloride trend during the observed period.
- Wells like F13 and F18 showed weak trends with low explanatory power, highlighting local variability or stable conditions.

4.4.2 Tomhom Basin

Tomhom had the broadest range of linear regression results, with many wells showing very strong positive trends:

- The highest rates of increase were seen in Y04A, Y01, Y02, and D04, with slopes exceeding +300 mg/L/yr and R^2 values above 0.44.
- Several wells (e.g., D09, D14, Y05) showed strong explanatory power ($R^2 > 0.5$), indicating sustained increases in chloride over decades.
- Several split wells (e.g., D17A, M17A, D18B, Y07) revealed that trends in chloride concentrations have shifted over time, sometimes reversing direction.
- A small number of wells (e.g., G501, M18) showed significant negative slopes, suggesting localized improvements or recharge-driven dilution.
- Other wells had minimal or statistically insignificant slopes, which may indicate stable conditions or noisy data.

4.4.3 Hagåtña Basin

Wells in the Hagåtña Basin generally show moderate to strong increasing trends:

- A02 and A03 had the most rapid increases (+336.15 and +341.88 mg/L/yr, respectively) with $R^2 > 0.34$
- Older monitoring periods (e.g., A04, A05, A06 from the 1970s-1990s) had strong upward trends, while more recent monitoring often showed weak or declining trends (e.g., A05 recent: slope -8.59 mg/L/yr).
- While some wells show different slopes when comparing full-period regressions to recent data, these differences may reflect variability introduced by the shorter duration of the more recent records. As such, although a possible temporal shift in chloride dynamics cannot be ruled out, any interpretation of causality (e.g., changes in pumping, land use, or recharge) must be made with caution due to the inconsistent length and density of the data subsets.
- Despite some weak regressions (e.g., A28, A30), many wells in this basin demonstrate a clear pattern of salinization over the long term.

4.4.4 Mangilao Basin

Linear trends in Mangilao were more limited in number but still informative:

- Wells M03-M08 showed strong increasing trends ($R^2 \approx 0.35$-0.38; slopes between +211 and +249 mg/L/yr), suggesting consistent chloride accumulation.
- M09 showed a weak but positive trend in earlier data (1973-1983) and a weekly negative trend in recent years, highlighting the potential for localized recovery or system changes.

- M23 exhibited a weak negative slope, though not statistically significant, reflecting relatively stable chloride concentrations in that part of the basin.

4.4.5 Summary
Overall, most wells exhibit long-term increasing trends in chloride concentrations, with some exceeding +300 mg/L per year. High R^2 values in many wells suggest persistent directional trends, likely reflecting long-term salinization due to pumping, land development, or saltwater intrusion. Where split regressions were applied, emphasizing the importance or temporal resolution in long-term groundwater quality monitoring.

4.5. Mann-Kendall Results and Discussion
The Mann-Kendall test identified widespread monotonic trends in chloride concentrations across all four study basins. Most wells exhibited statistically significant increasing trends, suggesting that salinization is occurring throughout the NGLA. Results are summarized by basin and discussed in the context of regional hydrogeologic conditions and potential influencing factors. Summary tables of Mann-Kendall results for each basin are provided in Appendix D.

4.5.1 Finagua'yok Basin
Out of 16 wells analyzed in the Finagua'yok Basin, 13 showed statistically significant trends ($p < 0.05$), most of which were increasing. Wells such as F01, F02, F04, F08, and F10 displayed particularly strong increasing trends. These patterns may reflect rising chloride concentrations associated with long-term pumping, reduced recharge, or lateral saltwater movement in coastal areas. One well, F17, showed a significant decreasing trend, possibly due to local recharge or operational changes. Three wells (D22A, D24, F18) showed non-significant results, and F13 showed no trend ($z \approx 0$).

4.5.2 Tomhom Basin
In the Tomhom Basin, 50 out of the 64 wells showed statistically significant increasing trends, several of which were extremely strong (e.g., D14 and Y02 with $z > 15$). This basin, which includes much of the urbanized Tumon area, may be particularly vulnerable to salinization due to a combination of high groundwater withdrawals and limited recharge from impervious surfaces. Six wells (D26, G501, M18, Y17, Y23, Maui Well) exhibited significant decreasing trends, which may be linked to reduced pumping or local hydrologic conditions. The remaining wells displayed either weak or non-significant trends.

4.5.3 Hagåtña Basin
Of the 28 wells tested in the Hagåtña Basin, 24 showed statistically significant increasing trends. Notably, A04 had the strongest trend across all basins ($z = 18.33$, $p < 1\times10^{-74}$). The concentration of rising trends in this basin may be attributed to its low elevation, proximity to the coast and thinner freshwater lens. Only one well (A28) showed a significant decreasing trend, while two others (A29 and A30) were non-significant.

4.5.4 Mangilao Basin

The Mangilao Basin had fewer wells (n = 7), but 5 showed significant increasing trends, including M03, M04, and M08. The two wells with decreasing trends, M09 and M23, were not statistically significant. Although limited in scope, the results suggest a similar pattern of rising chloride concentrations seen in the other basins.

4.5.5 Interpretation and Implications

Overall, increasing chloride trends dominate across all four basins, suggesting progressive salinization of the NGLA. This likely reflects a combination of high or sustained pumping, reduced recharge, and gradual saltwater intrusion, especially in coastal and urbanized zones. Although isolated wells show decreasing or stable chloride trends, these are not widespread and may be explained by localized factors such as recharge potential, well construction, or changes in operation.

These findings have important implications for water resource sustainability in Guam. Increasing salinity poses a growing risk to water quality, particularly in wells that are approaching or exceeding chloride thresholds. Long-term management strategies should incorporate trend analysis, well-specific vulnerabilities, protection of recharge zones, and consideration of alternative water sources. Further analysis integrating pumping records, aquifer properties, and climate variability may provide additional insight into the drivers behind these trends.

4.6. STL Decomposition: Results and Discussion

To evaluate intra-annual patterns and underlying long-term behavior in chloride concentrations, Seasonal-Trend decomposition using LOESS (STL) was applied to wells with sufficient data quality. The decomposition separated each time series into seasonal, trend, and residual components, allowing assessment of seasonal strength and characterization of trend behavior. Complete summary tables by basin and a compiled table of skipped wells are provided in Appendix E.

4.6.1 Finagua'yok Basin

Among the 11 wells successfully analyzed, HGC2 was the only one that exhibited moderate seasonality (seasonal strength = 0.203). All other wells showed weak or negligible seasonal behavior, with seasonal strength values ranging from 0.008 to 0.07. This pattern suggests that in Finagua'yok, chloride variability is driven more by long-term or stochastic processes than predictable seasonal cycles. Five wells (F01, F02, F03, F04, and F08) were excluded due to remaining missing values even after interpolation, which limits spatial representation across the basin. Nonetheless, the predominance of weak seasonal signatures is consistent with earlier Mann-Kendall results showing long-term monotonic trends, rather than short-term cyclical behavior.

4.6.2 Tomhom Basin

In Tomhom, STL decomposition was performed on 37 wells. The vast majority (34 wells) exhibited weak or negligible seasonality, with seasonal strength values generally below 0.1. Only three wells (M18; 0.214, Y14; 0.151, and Y21; 0.260), showed moderate seasonality, possibly reflecting more stable hydrologic responses or stronger seasonal forcing in those locations (e.g., rainfall-recharge coupling, operational cycles). Many wells, 26, were excluded due to persistent missing data, particularly among older or high-frequency monitoring wells (e.g., D01-D14, Maui Well, and Y02). This filtering likely biased the analysis toward more stable and complete records, but overall finding is consistent: chloride fluctuations in Tomhom are generally not strongly seasonal and are instead indicative of long-term change or variable recharge/pumping dynamics.

4.6.3 Hagåtña Basin

Of the 11 wells included from Hagåtña, three (A07, A26, A31) showed moderate seasonality with seasonal strength values between 0.12 and 0.13, while the remaining wells displayed weak or negligible seasonal variation. Interestingly, A30 and A25 had relatively high seasonal strength values (0.325 and 0.289, respectively) but were still classified as having "weak" seasonality due to thresholds used. This suggests a spectrum of behavior rather than a sharp seasonal/no-seasonal divide. As with other basins, the prevalence of weak seasonal signals suggests that long-term salinization trends, rather than predictable annual cycles, dominate chloride dynamics. Sixteen wells in the basin were excluded due to missing data.

4.6.4 Mangilao Basin

Only M23 met data completeness thresholds for STL analysis in the Mangilao Basin. It exhibited no detectable seasonality (seasonal strength = 0.000), suggesting highly irregular or trend-dominated chloride behavior at that site. Six other wells in the basin were excluded from analysis due to persistent missing values, which limits interpretability for this basin.

4.6.5 Overall Interpretation

Across all basins, STL decomposition confirms the dominance of long-term monotonic trends over short-term seasonal cycles in chloride concentrations. While Guam experiences distinct wet and dry seasons, the quarterly resolution of the chloride data may limit the ability to detect fine-scale seasonal signals. Additionally, this analysis did not incorporate rainfall data directly, so potential correlations between recharge patterns and chloride variability remain unexplored in this approach.

The observed predominance of weak or negligible seasonality suggests that regular seasonal forcing, such as annual rainfall cycles, is not the primary driver of chloride variability in most wells. Instead, the results reinforce the Mann-Kendall findings that point to persistent, directional changes in chloride levels over time, likely influenced by long-term factors such as sustained pumping, gradual saltwater intrusion, or land-use changes affecting recharge.

A small number of wells (e.g., HGC2, M18, Y21, A07) did exhibit moderate seasonality, which may reflect more consistent recharge responses, influence from tidal cycles, or even operational patterns like seasonal pumping. However, these wells are exceptions, not the norm.

It is also worth noting that a significant number of wells were excluded from STL analysis due to persistent missing values, reducing spatial coverage and limiting the resolution of seasonal assessments. Improving data completeness, through consistent monitoring and recovery of historical records, would allow for more robust analysis of both seasonal and long-term trends in the future.

5. Conclusion and Recommendations

This study employed three complementary analytic approaches, linear regression (Reg), the Mann-Kendall test (MK), and STL decomposition, to assess long-term chloride concentration trends in the Finagua'yok, Tomhom, Hagåtña, and Mangilao Basins. Together, these methods offered both statistical rigor and interpretive nuance, enabling a robust evaluation of salinity trends from multiple perspectives.

Linear regression quantified the direction and magnitude of chloride changes, identifying that most wells, especially in Tomhom and Hagåtña Basins, exhibited statistically significant increasing slopes, some exceeding +300 mg/L per year. This indicates areas of rapid salinization; however, due to its assumption of linearity and sensitivity to outliers, linear regression alone may not fully capture complex or nonlinear patterns.

The Mann-Kendall test, a non-parametric, rank-based method, served as a crucial verification tool. It confirmed statistically significant monotonic upward trends in chloride concentrations across nearly all basins, including wells where regression slopes were moderate or data variability was high. Importantly, wells where both linear regression and Mann-Kendall tests showed statistically significant increases were considered to have the strongest evidence of persistent chloride rise. This agreement between methods increases confidence in identifying wells truly experiencing long-term salinization. Conversely, wells with conflicting results suggest more complex chloride dynamics or potential data limitations, warranting further investigation.

STL decomposition added interpretive depth by separating long-term trends from seasonal variations. Across all basins, seasonal signals were generally weak or negligible, indicating that chloride concentration changes are driven by sustained processes, such as groundwater pumping, saltwater intrusion, or recharge alterations, rather than predictable seasonal cycles. A few wells exhibited moderate seasonality, likely reflecting local hydrologic or operational factors.

Overall, the convergence of these analytical approaches reveals a clear pattern of widespread, persistent chloride concentration increases throughout the NGLA, with the Tomhom and Hagåtña Basins demonstrating the most pronounced upward trends. Finagua'yok and Mangilao Basins showed mixed behavior, with some wells plateauing or even showing signs of recovery. This consistent, multi-method evidence highlights the critical need to address groundwater salinity in regional water management.

Despite limitations including quarterly sampling frequency, occasional data gaps, lack of integrated pumping and rainfall data, and uneven spatial well coverage, the strong agreement among independent methods reinforces the conclusion that chloride concentrations are rising in much of the NGLA. Proactive monitoring, updated management strategies, and targeted mitigation efforts are recommended to protect Guam's vital freshwater resources from further salinization risks.

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Appendix A: Updated Decadal Statistics

A.1 Finagua'yok Basin

Production Statistics		D22A	D24	F01	F02	F03	F04
Groundwater Zone		Supra-basal	Para-basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	5.91	-63.02	-35.74	-40.76	-55.77	-37.74
	Meters	1.80	-19.21	-10.89	-12.42	-17.00	-11.50
NGLS Max. Recommended Bottom Elevation (feet)		NA	-50	-40	-40	-40	-40
Well Screen Length (feet)		Unknown	Unknown	45	Unknown	40	40
Well Construction Year		1996	1995	1969	1971	1975	1975
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		NA	500	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989			159	167	117	137
	1990-1999	117	116	141	120	147	132
	2000-2009	152	183	155	138	149	151
	2010-2019	93	188	112	134	182	129
	2020-3/2025	114	177	152	152	157	143
Chloride Statistics		**D22A**	**D24**	**F01**	**F02**	**F03**	**F04**
Total Number of Chloride Samples		61	87	263	252	245	244
Minimum Concentration (mg/L)		10	28	54	11	16	16
Maximum Concentration (mg/L)		219	206	234	238	184	364
Standard Deviation		30.26	26.92	40.57	25.47	23.64	71.58
Mean Chloride Concentration (mg/L)	1973-1979			73	103	92	82
	1980-1989			87	113	106	139
	1990-1999	31	43	99	118	107	167
	2000-2009	48	86	145	145	124	180
	2010-2019	26	85	153	144	124	212
	2020-3/2025	30	69	125	133	110	181

(cont.)

Production Statistics		F08	F10	F11	F12	F13	F15
Groundwater Zone		Para-basal	Basal	Basal	Para-basal	Basal	Para-basal
Well Depth Elevation	Feet	-18.34	-47.29	-47.06	-41.33	-53.78	-51.47
	Meters	-5.59	-14.41	-14.34	-12.60	-16.39	-15.69
NGLS Max. Recommended Bottom Elevation (feet)		-50	-40	-40	-50	-40	-50
Well Screen Length (feet)		30	40	40	40	Unknown	Unknown
Well Construction Year		1976	1978	1978	1990	1992	1995
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		500	200	200	500	200	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	135	165	155			
	1990-1999	147	147	147	142	228	357
	2000-2009	153	197	169	190	247	238
	2010-2019	166	160	142	189	234	239
	2020-3/2025	155	175	126	189	342	427
Chloride Statistics		**F08**	**F10**	**F11**	**F12**	**F13**	**F15**
Total Number of Chloride Samples		238	192	210	134	100	110
Minimum Concentration (mg/L)		12	24	72	12	22	22
Maximum Concentration (mg/L)		143	468	257	273	395	156
Standard Deviation		19.02	90.45	43.38	26.14	75.93	20.96
Mean Chloride Concentration (mg/L)	1973-1979	17	146	110			
	1980-1989	24	163	110			
	1990-1999	25	190	127	25	201	58
	2000-2009	55	280	169	50	257	62
	2010-2019	51	303	168	39	270	63
	2020-3/2025	37	208	129	34	224	77

(cont.)

Production Statistics		F16	F17	F18	HGC2
Groundwater Zone		Para-basal	Para-basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-50.14	-62.80	-62.93	-81.95
	Meters	-15.28	-19.14	-19.08	-24.98
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-50	-50
Well Screen Length (feet)		Unknown	Unknown	Unknown	60
Well Construction Year		1995	1995	1995	1987
Status/Final Year of Production		Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		500	500	500	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979				
	1980-1989				
	1990-1999	160		200	394
	2000-2009	326		316	517
	2010-2019	211	243	270	540
	2020-3/2025	228	264	257	501
Chloride Statistics		**F16**	**F17**	**F18**	**HGC2**
Total Number of Chloride Samples		112	58	108	126
Minimum Concentration (mg/L)		6	8	10	11
Maximum Concentration (mg/L)		85	60	110	75
Standard Deviation		14.44	11.92	12.84	13.14
Mean Chloride Concentration (mg/L)	1973-1979				
	1980-1989				
	1990-1999	21		18	22
	2000-2009	39		34	37
	2010-2019	39	34	33	40
	2020-3/2025	35	29	27	32

A.2 Tomhom Basin

Production Statistics		D01	D02	D03A	D04	D05	D06
Groundwater Zone		Basal	Basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-38.10	-35.17	-23.34	-24.50	-31.81	-26.29
	Meters	-11.61	-10.20	-7.11	-7.47	-9.70	-8.01
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-40	-40
Well Screen Length (feet)		35	35	35	25	40	40
Well Construction Year		1973	1973	1973	1973	1973	1973
Status/Final Year of Production		GM - 5/2021	Operational	GM - 1/2023	Operational	OOC - 1/2022	GM - 9/2024
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	177	183	140	155	134	161
	1990-1999	212	199	162	152	173	205
	2000-2009	228	203		263	162	273
	2010-2019	252	226	135	254	170	229
	2020-3/2025	240	192	213	211		208
Chloride Statistics		**D01**	**D02**	**D03A**	**D04**	**D05**	**D06**
Total Number of Chloride Samples		260	266	185	270	232	266
Minimum Concentration (mg/L)		24	24	22	22	34	29
Maximum Concentration (mg/L)		144	110	66	86	96	181
Standard Deviation		14.02	13.26	6.21	11.92	10.75	15.30
Mean Chloride Concentration (mg/L)	1973-1979	55	55	36	39	59	51
	1980-1989	59	62	37	44	63	50
	1990-1999	64	62	38	41	58	56
	2000-2009	74	73	45	58	71	69
	2010-2019	81	81		63	82	77
	2020-3/2025	63	69		53		60

(cont.)

Production Statistics		D07	D08	D09	D10	D11	D12
Groundwater Zone		Basal	Basal	Basal	Basal	Basal	Para-basal
Well Depth Elevation	Feet	-48.98	-53.68	-27.52	-25.09	-37.00	-48.20
	Meters	-14.93	-10.88	-8.39	-7.65	-11.28	-14.69
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-40	-50
Well Screen Length (feet)		60	40	35	35	50	50
Well Construction Year		1973	1973	1973	1973	1973	1973
Status/Final Year of Production		Operational	GM - 9/2024	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	200	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	147	137	168	161	165	145
	1990-1999	194	193	190	196	230	172
	2000-2009	212	185	227	234	200	197
	2010-2019	200	169	201	221	171	195
	2020-3/2025	206	163	206	226	221	210
Chloride Statistics		**D07**	**D08**	**D09**	**D10**	**D11**	**D12**
Total Number of Chloride Samples		277	275	263	258	270	273
Minimum Concentration (mg/L)		30	55	11	26	34	6
Maximum Concentration (mg/L)		234	532	289	210	214	172
Standard Deviation		20.23	75.25	41.71	20.09	20.23	15.87
Mean Chloride Concentration (mg/L)	1973-1979	51	135	111	39	82	18
	1980-1989	52	170	132	40	74	21
	1990-1999	58	228	157	42	94	26
	2000-2009	81	282	177	62	91	36
	2010-2019	83	242	196	79	83	43
	2020-3/2025	71	169	177	58	82	34

(cont.)

Production Statistics		D13	D14	D15	D16	D17A	D18B
Groundwater Zone		Para-basal	Basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-50.88	-55.75	-93.12	-58.40	-35.60	-59.63
	Meters	-15.51	-16.99	-23.38	-17.80	-10.85	-18.18
NGLS Max. Recommended Bottom Elevation (feet)		-50	-40	-40	-40	-40	-40
Well Screen Length (feet)		40	40	40	40	35	Unknown
Well Construction Year		1974	1973	1974	1979	1979	1980
Status/Final Year of Production		OOC - 1/2022	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		500	200	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	144	167	161	189	149	178
	1990-1999	163	197	204	197	198	188
	2000-2009	181	260	247	229		
	2010-2019		200	171	202	131	181
	2020-3/2025		194	171	201	201	248
Chloride Statistics		**D13**	**D14**	**D15**	**D16**	**D17A**	**D18B**
Total Number of Chloride Samples		200	269	249	203	147	124
Minimum Concentration (mg/L)		39	22	51	45	8	36
Maximum Concentration (mg/L)		917	135	230	215	280	204
Standard Deviation		176.09	24.66	21.30	19.55	69.31	20.83
Mean Chloride Concentration (mg/L)	1973-1979	276	33	80	78	23	
	1980-1989	242	42	87	79	61	71
	1990-1999	308	62	97	88	183	86
	2000-2009	518	87	97	94	171	83
	2010-2019		85	97	107	36	89
	2020-3/2025		60	82	80	86	100

(cont.)

Production Statistics		D19	D20	D21	D25	D26	D27
Groundwater Zone		Basal	Basal	Basal	Para-basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-49.84	-50.23	-56.93	-85.20	-44.81	-64.33
	Meters	-15.19	-15.31	-17.35	-25.97	-13.66	-19.61
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-50	-50	-50
Well Screen Length (feet)		Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Well Construction Year		1984	1984	1984	2004	2004	2004
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	500	500	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	204	223	180			
	1990-1999	200	190	155			
	2000-2009	206	217	189	352	214	338
	2010-2019	206	202	114	347	253	430
	2020-3/2025	244	201	188	459	273	418
Chloride Statistics		**D19**	**D20**	**D21**	**D25**	**D26**	**D27**
Total Number of Chloride Samples		159	159	155	84	79	83
Minimum Concentration (mg/L)		14	42	32	24	82	15
Maximum Concentration (mg/L)		118	111	151	115	388	105
Standard Deviation		15.36	17.76	15.67	17.36	74.10	15.46
Mean Chloride Concentration (mg/L)	1973-1979						
	1980-1989	67	60	72			
	1990-1999	64	61	73			
	2000-2009	76	88	91	51	238	32
	2010-2019	86	91	89	55	233	38
	2020-3/2025	74	84	75	77	214	39

(cont.)

Production Statistics		D28	EX05A	F05	F06	F07	F09
Groundwater Zone		Basal	Basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-47.92	-39.81	-35.65	-24.58	-24.16	-49.37
	Meters	-14.61	-12.13	-10.87	-7.49	-7.36	-15.05
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-40	-40
Well Screen Length (feet)		Unknown	Unknown	40	30	70	50
Well Construction Year		2004	1985	1975	1975	1975	1978
Status/Final Year of Production		Operational	GM - 12/2024	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989		208	133	124	129	163
	1990-1999		215	154	159	175	138
	2000-2009	167	358	197	215	182	159
	2010-2019	208	318	179	168	175	148
	2020-3/2025	225	274	171	183	196	171
Chloride Statistics		**D28**	**EX05A**	**F05**	**F06**	**F07**	**F09**
Total Number of Chloride Samples		77	157	248	231	249	209
Minimum Concentration (mg/L)		26	24	8	32	19	38
Maximum Concentration (mg/L)		97	125	334	661	246	200
Standard Deviation		13.72	14.20	41.01	128.49	37.78	23.29
Mean Chloride Concentration (mg/L)	1973-1979			51	124	53	74
	1980-1989		39	65	173	66	64
	1990-1999		42	92	205	85	60
	2000-2009	61	58	138	340	128	96
	2010-2019	76	65	121	388	133	82
	2020-3/2025	66	56	83	279	98	71

(cont.)

Production Statistics		F19	F20	G501	H01	M05	M06
Groundwater Zone		Basal	Basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-46.00	-63.50	-46.95	-50.05	-92.09	-85.93
	Meters	-14.02	-19.35	-14.31	-15.26	28.07	-26.19
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-40	-40
Well Screen Length (feet)		Unknown	Unknown	Unknown	Unknown	70	85
Well Construction Year		1996	1996	1983	1945	1973	1973
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989			169	179	149	132
	1990-1999			177	247	164	189
	2000-2009	180	192	152	288	217	218
	2010-2019	218	218	197	265	198	146
	2020-3/2025	244	232	203	223	220	141
Chloride Statistics		**F19**	**F20**	**G501**	**H01**	**M05**	**M06**
Total Number of Chloride Samples		77	71	54	239	254	256
Minimum Concentration (mg/L)		153	5	55	52	14	16
Maximum Concentration (mg/L)		549	770	238	278	105	324
Standard Deviation		99.33	110.71	45.44	52.98	16.07	56.74
Mean Chloride Concentration (mg/L)	1973-1979				77	39	63
	1980-1989				113	47	61
	1990-1999				130	55	80
	2000-2009	243	258		170	67	119
	2010-2019	338	328	146	211	72	184
	2020-3/2025	298	288	102	142	58	88

(cont.)

Production Statistics		M07	M12	M14	M15	M17A	M17B
Groundwater Zone		Basal	Basal	Basal	Basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-55.34	-53.11	-40.98	-51.21	-54.49	-41.28
	Meters	-16.87	-16.19	-12.49	-15.61	-16.61	-12.58
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-50	-50
Well Screen Length (feet)		50	60	40	40	Unknown	40
Well Construction Year		1973	1973	1974	1983	1990	1990
Status/Final Year of Production		Operational	Operational	OOC - 1/2022	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	500	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979		66				
	1980-1989	181	96	176	175		
	1990-1999	172	104	225	190	199	288
	2000-2009	209	114	159	248		284
	2010-2019	196	95		197	274	216
	2020-3/2025	164	109		149	230	369
Chloride Statistics		**M07**	**M12**	**M14**	**M15**	**M17A**	**M17B**
Total Number of Chloride Samples		254	131	179	169	67	135
Minimum Concentration (mg/L)		4	25	14	20	23	11
Maximum Concentration (mg/L)		100	252	127	159	116	106
Standard Deviation		14.04	28.70	19.88	30.82	18.12	14.55
Mean Chloride Concentration (mg/L)	1973-1979	33		35			
	1980-1989	38	95	39	42		
	1990-1999	41	92	52	47	71	61
	2000-2009	55	111	47	72	90	67
	2010-2019	61	118	70	87	78	74
	2020-3/2025	53	92	22	51	79	70

(cont.)

Production Statistics		M18	M20A	M21	Y01	Y02	Y03
Groundwater Zone		Basal	Para-basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-40.36	-21.40	-34.85	-35.16	-52.17	-25.39
	Meters	-12.30	-6.52	-10.62	-10.72	-15.90	-25.39
NGLS Max. Recommended Bottom Elevation (feet)		-12.3	-6.52	-10.62	-10.72	-15.9	-7.74
Well Screen Length (feet)		Unknown	Unknown	Unknown	40	70	Unknown
Well Construction Year		1997	1996	1998	1973	1973	1973
Status/Final Year of Production		Operational	Operational	SCM - 12/2024	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	500	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989				142	158	118
	1990-1999	372	258		135	157	155
	2000-2009	279	255	290	193	198	204
	2010-2019	261	257	263	196	177	166
	2020-3/2025	330	351	201	198	171	161
Chloride Statistics		**M18**	**M20A**	**M21**	**Y01**	**Y02**	**Y03**
Total Number of Chloride Samples		57	112	99	268	274	267
Minimum Concentration (mg/L)		40	43	45	12	13	10
Maximum Concentration (mg/L)		108	151	191	80	94	117
Standard Deviation		15.90	20.87	33.28	12.15	13.39	12.79
Mean Chloride Concentration (mg/L)	1973-1979				19	19	17
	1980-1989				23	24	22
	1990-1999		69	64	24	25	23
	2000-2009		80	109	33	36	35
	2010-2019	73	89	126	45	45	40
	2020-3/2025	57	73	91	40	40	32

(cont.)

Production Statistics		Y04A	Y05	Y06	Y07	Y09	Y10
Groundwater Zone		Basal	Basal	Basal	Basal	Basal	Basal
Well Depth Elevation	Feet	-52.97	-47.40	-47.27	-30.70	-50.57	-54.99
	Meters	-16.15	-14.45	-14.41	-9.36	-15.41	-16.76
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	-40	-40	-40
Well Screen Length (feet)		Unknown	35	Unknown	30	Unknown	Unknown
Well Construction Year		1994	1979	1980	1983	1988	1997
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	200	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	127	150	141	361	422	
	1990-1999	141	147	158	339	318	182
	2000-2009	223	188	238	191	484	239
	2010-2019	192	207	184	463	473	220
	2020-3/2025	195	193	176	452	480	214
Chloride Statistics		**Y04A**	**Y05**	**Y06**	**Y07**	**Y09**	**Y10**
Total Number of Chloride Samples		224	212	195	141	145	103
Minimum Concentration (mg/L)		13	16	12	14	7	27
Maximum Concentration (mg/L)		85	124	90	70	80	89
Standard Deviation		13.29	23.83	13.81	10.94	12.01	14.21
Mean Chloride Concentration (mg/L)	1973-1979	21	31				
	1980-1989	25	36	22	22	21	
	1990-1999	29	46	24	23	22	36
	2000-2009	38	72	35	33	35	58
	2010-2019	48	88	42	40	40	64
	2020-3/2025	45	74	43	32	32	51

(cont.)

Production Statistics		Y12	Y14	Y16	Y17	Y18	Y19
Groundwater Zone		Basal	Basal	Basal	Supra-basal	Basal	Basal
Well Depth Elevation	Feet	-40.91	-37.78	-41.06	194.13	-46.37	-41.70
	Meters	-12.47	-11.52	-12.52	59.17	-14.13	-12.71
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	NA	-40	-40
Well Screen Length (feet)		Unknown	Unknown	Unknown	Unknown	40	40
Well Construction Year		1996	1998	2001	2002	2004	2004
Status/Final Year of Production		Operational	Operational	GM - 1/2022	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	NA	200	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989						
	1990-1999	280	250				
	2000-2009	318	325	295	317	198	408
	2010-2019	342	416	333	275	285	566
	2020-3/2025	333	454	327	309	302	616
Chloride Statistics		**Y12**	**Y14**	**Y16**	**Y17**	**Y18**	**Y19**
Total Number of Chloride Samples		109	74	77	90	81	80
Minimum Concentration (mg/L)		21	32	14	14	24	20
Maximum Concentration (mg/L)		116	96	71	90	85	80
Standard Deviation		15.14	14.84	11.58	13.80	14.69	13.69
Mean Chloride Concentration (mg/L)	1973-1979						
	1980-1989						
	1990-1999	55	44				
	2000-2009	72	52	47	37	34	45
	2010-2019	74	73	51	38	52	54
	2020-3/2025	61	66	45	31	43	40

(cont.)

Production Statistics		Y20	Y21	Y22	Y23	Maui Well
Groundwater Zone		Basal	Basal	Basal	Supra-basal	
Well Depth Elevation	Feet	-45.04	-37.06	-57.31	87.25	
	Meters	-13.73	-11.30	-17.47	26.59	
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-40	NA	
Well Screen Length (feet)		40	Unknown	Unknown	Unknown	
Well Construction Year		2004	2001	2004	2002	
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200	NA	NA
Mean Pump Rate (gpm) (Mgal/month)	1973-1979					
	1980-1989					
	1990-1999					
	2000-2009	482		236	312	
	2010-2019	654		296	278	712
	2020-3/2025	541	419	389	300	664
Chloride Statistics		**Y20**	**Y21**	**Y22**	**Y23**	**Maui Well**
Total Number of Chloride Samples		70	15	83	90	32
Minimum Concentration (mg/L)		20	29	15	18	65
Maximum Concentration (mg/L)		85	75	75	80	122
Standard Deviation		14.41	13.01	11.68	12.13	12.78
Mean Chloride Concentration (mg/L)	1973-1979					
	1980-1989					
	1990-1999					
	2000-2009	36		29	41	
	2010-2019	52		36	39	106
	2020-3/2025	44	41	28	38	91

A.3 Hagåtña Basin

Production Statistics		A01	A02	A03	A04	A05	A06
Groundwater Zone		Para-basal	Basal	Para-basal	Basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-153.30	-54.04	-262.52	-159.75	-196.04	-152.86
	Meters	-46.73	-16.47	-80.02	-48.69	-56.70	-46.59
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-50	-50	-50	-50
Well Screen Length (feet)		50	60	Unknown	160	Unknown	170
Well Construction Year		1965	1965	1967	1967	1969	1967
Status/Final Year of Production		Operational	2012	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200 (350**)	350	200 (350**)	350	200 (350**)	200 (350**)
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	206	198	185	185	195	211
	1990-1999	250	236	232	232	235	272
	2000-2009	270	230	318	318	259	306
	2010-2019	294	241	251	306	232	279
	2020-3/2025	335		254	312	308	184
Chloride Statistics		**A01**	**A02**	**A03**	**A04**	**A05**	**A06**
Total Number of Chloride Samples		240	217	259	285	282	288
Minimum Concentration (mg/L)		4	10	3	15	4	11
Maximum Concentration (mg/L)		90	84	75	131	70	82
Standard Deviation		11.95	9.41	10.11	37.17	10.64	14
Mean Chloride Concentration (mg/L)	1973-1979	18	18	17	19	17	17
	1980-1989	18	21	18	33	20	24
	1990-1999	20	23	19	92	36	43
	2000-2009	28	37	29			
	2010-2019	37	41	33	104	36	43
	2020-3/2025	32		30	94	32	35

(cont.)

Production Statistics		A07	A08	A09	A10	A12	A13
Groundwater Zone		Para-basal	Para-basal	Basal	Basal	Para-basal	Basal
Well Depth Elevation	Feet	-52.74	-175.09	-52.85	-23.99	-190.00	-287.20
	Meters	-16.08	-53.37	-16.11	-7.31	-57.91	-87.54
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-40	-40	-50	-50
Well Screen Length (feet)		70	205	73	44	225	213
Well Construction Year		1967	1968	1967	1967	1968	1968
Status/Final Year of Production		2004	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200 (350**)	200 (350**)	200	200	200 (350**)	350
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	195	200	175	184	215	173
	1990-1999	147	231	214	211	188	230
	2000-2009		240	300	282	194	301
	2010-2019		197	256	215	162	175
	2020-3/2025		290	289	303	244	158
Chloride Statistics		**A07**	**A08**	**A09**	**A10**	**A12**	**A13**
Total Number of Chloride Samples		181	276	264	261	247	269
Minimum Concentration (mg/L)		16	0	36	28	10	46
Maximum Concentration (mg/L)		60	235	420	481	192	693
Standard Deviation		6.33	18.48	46.24	88.49	16.37	117.03
Mean Chloride Concentration (mg/L)	1973-1979	20	17	155	188	17	270
	1980-1989	25	25	165	204	19	323
	1990-1999	38	35	187	285	20	373
	2000-2009			209	335	38	409
	2010-2019		37	246	370	41	538
	2020-3/2025		31	252	349	29	441

(cont.)

Production Statistics		A14	A15	A17	A18	A19	A21
Groundwater Zone		Basal	Basal	Para-basal	Basal	Para-basal	Basal
Well Depth Elevation	Feet	-64.16	-52.24	-47.70	-52.06	-37.72	-66.25
	Meters	-19.56	-15.92	-14.54	-15.87	-11.50	-20.19
NGLS Max. Recommended Bottom Elevation (feet)		-40	-40	-50	-40	-50	-40
Well Screen Length (feet)		40	40	40	40	20	36
Well Construction Year		1973	1973	1973	1973	1973	1973
Status/Final Year of Production		Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200	200	200 (350**)	200	200 (350**)	200
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	179	171	168	162	119	170
	1990-1999	208	240	216	207	175	199
	2000-2009	270	292	242	286	200	271
	2010-2019	160	280	173	221	203	253
	2020-3/2025	137	279	209	251	170	246
Chloride Statistics		**A14**	**A15**	**A17**	**A18**	**A19**	**A21**
Total Number of Chloride Samples		262	262	256	240	248	258
Minimum Concentration (mg/L)		100	17	88	94	32	41
Maximum Concentration (mg/L)		394	274	791	520	525	514
Standard Deviation		50.85	32.42	110.82	77.62	110.54	95.37
Mean Chloride Concentration (mg/L)	1973-1979	236	135	281	230	283	204
	1980-1989	280	145	307	269	231	269
	1990-1999	295	145	346	389	355	353
	2000-2009	314	157	415	365	397	394
	2010-2019	267	178	368	315	447	398
	2020-3/2025	219	147	252	269	246	331

(cont.)

Production Statistics		A23	A25	A26	A28	A29	A30
Groundwater Zone		Para-basal	Para-basal	Basal	Basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-42.60	-52.26	-49.29	-40.00	-45.36	-23.44
	Meters	-12.98	-15.93	-15.02	-15.19	-13.83	-7.14
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-40	-40	-50	-50
Well Screen Length (feet)		Unknown	40	Unknown	Unknown	40	40
Well Construction Year		1983	1984	1983	1983	1988	1988
Status/Final Year of Production		PCA - 2016	PCA - 2016	GM - 11/6/2017	2008	2022	Operational
NGLS Max. Recommended Pump Rate (gpm)		200 (350**)	200 (350**)	200	200	200 (350**)	200 (350**)
Mean Pump Rate (gpm) (Mgal/month)	1973-1979						
	1980-1989	235	216	109	189		
	1990-1999	296	260	58	227	340	680
	2000-2009	338	323	54	410	289	722
	2010-2019	299	327	48		38	722
	2020-3/2025						799
Chloride Statistics		**A23**	**A25**	**A26**	**A28**	**A29**	**A30**
Total Number of Chloride Samples		127	123	89	81	48	137
Minimum Concentration (mg/L)		11	17	38	22	12	17
Maximum Concentration (mg/L)		103	144	556	349	162	300
Standard Deviation		22.74	29.03	57.89	43.56	33.87	48.85
Mean Chloride Concentration (mg/L)	1973-1979						
	1980-1989	22	25	150	190		
	1990-1999	38	49	82	172	64	103
	2000-2009	61	75	99	175	69	84
	2010-2019	59	72	127		72	81
	2020-3/2025						78

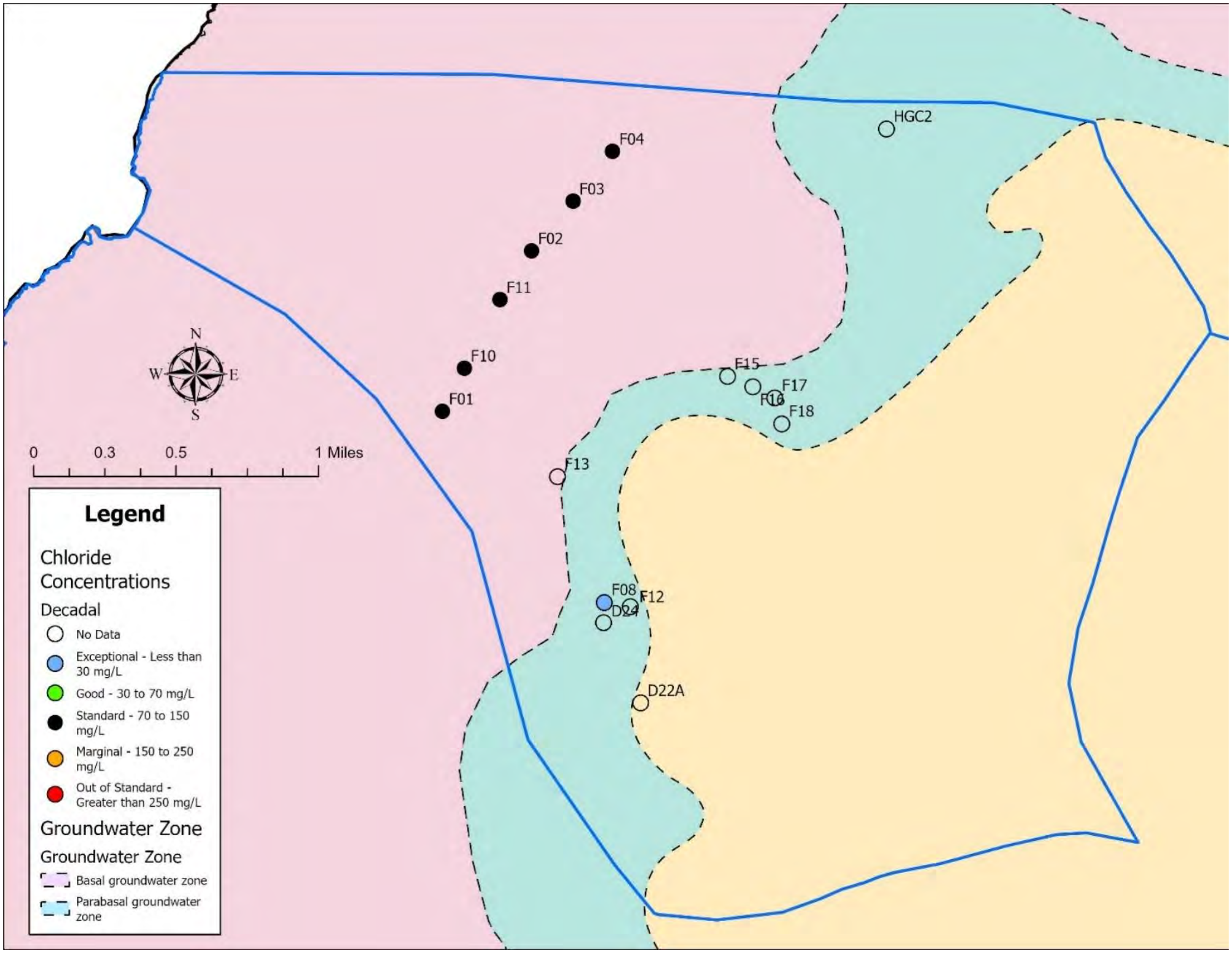
(cont.)

Production Statistics		A31	A32	EX11	NAS01
Groundwater Zone		Para-basal	Para-basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-55.20	-56.15	-73.26	-67.67
	Meters	-16.82	-17.11	-22.33	-20.63
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-50	-50
Well Screen Length (feet)		Unknown	40	Unknown	Unknown
Well Construction Year		1989	1989	1982	1973
Status/Final Year of Production		Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		200 (350**)	200 (350**)		
Mean Pump Rate (gpm) (Mgal/month)	1973-1979				
	1980-1989			184	
	1990-1999	257	134	183	
	2000-2009	316	233	196	259
	2010-2019	311	262	225	226
	2020-3/2025	421	312	206	217
Chloride Statistics		**A31**	**A32**	**EX11**	**NAS01**
Total Number of Chloride Samples		140	123	155	92
Minimum Concentration (mg/L)		5	17	17	24
Maximum Concentration (mg/L)		75	70	198	237
Standard Deviation		12.41	12.31	24.15	48.37
Mean Chloride Concentration (mg/L)	1973-1979				
	1980-1989	24		39	
	1990-1999	32	25	49	61
	2000-2009	48	38	62	99
	2010-2019	50	41	78	144
	2020-3/2025	41	35	53	95

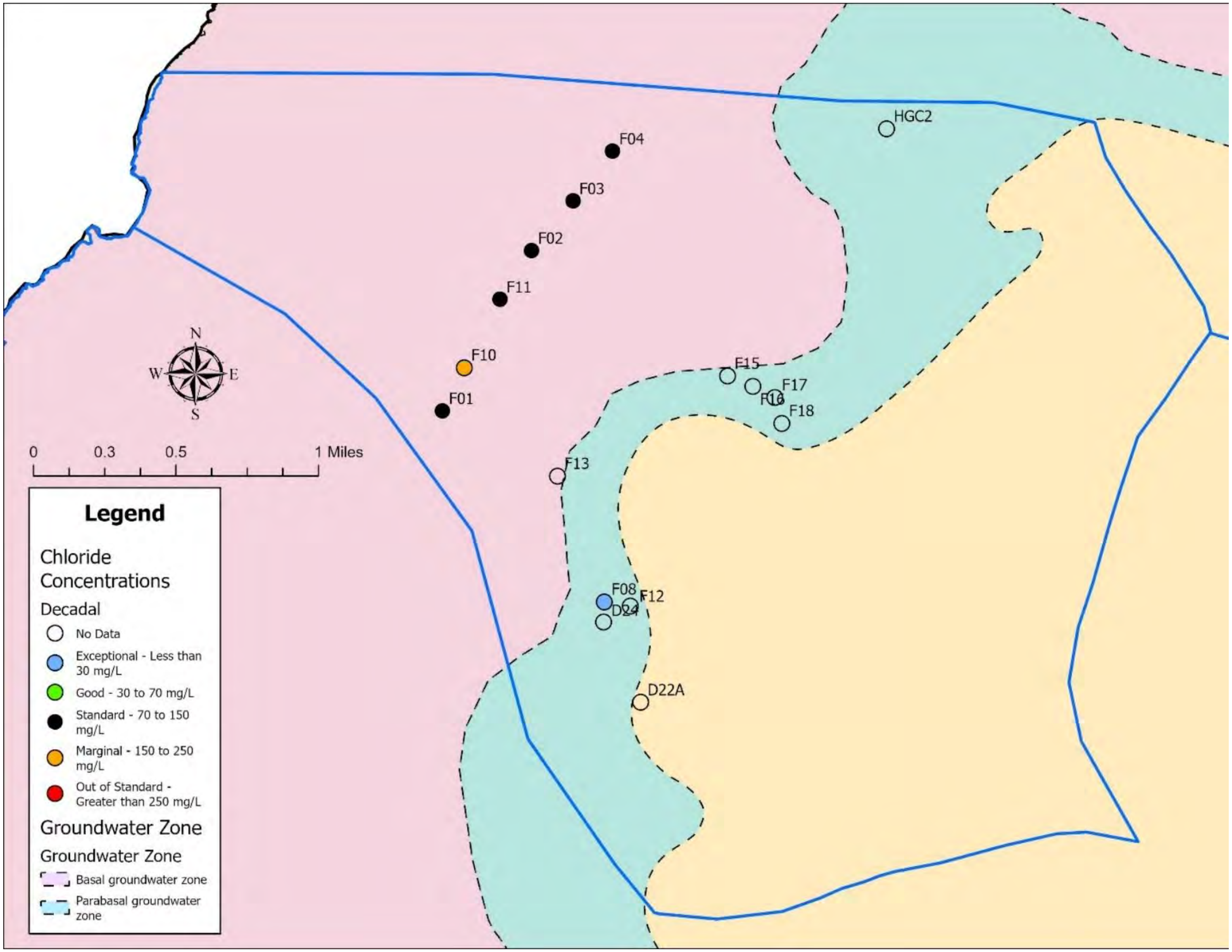
A.4 Mangilao Basin

Production Statistics		M01	M02	M03	M04	M08	M09	M23
Groundwater Zone		Para-basal	Para-basal	Para-basal	Para-basal	Para-basal	Para-basal	Para-basal
Well Depth Elevation	Feet	-35.30	-59.80	-52.81	-50.38	-38.92	-52.20	-77.00
	Meters	-10.76	-18.23	-16.10	-15.36	-11.86	-15.91	-23.47
NGLS Max. Recommended Bottom Elevation (feet)		-50	-50	-50	-50	-50	-50	-50
Well Screen Length (feet)		Unknown	Unknown	60	60	40	40	Unknown
Well Construction Year		1965	1968	1967	1967	1970	1970	1998
Status/Final Year of Production		OOC - 8/2023	Operational	Operational	Operational	Operational	Operational	Operational
NGLS Max. Recommended Pump Rate (gpm)		500	500	500	500	500	500	500
Mean Pump Rate (gpm) (Mgal/month)	1973-1979							
	1980-1989	157	146	207	154	152	156	
	1990-1999	126	179	193	160	168	156	
	2000-2009	223	192	232	196	198	151	252
	2010-2019	99	187	195	228	164	140	296
	2020-3/2025	58	204	200	182	137	214	331
Chloride Statistics		**M01**	**M02**	**M03**	**M04**	**M08**	**M09**	**M23**
Total Number of Chloride Samples		260	219	272	271	275	162	94
Minimum Concentration (mg/L)		13	20	16	4	14	28	20
Maximum Concentration (mg/L)		285	215	101	129	129	504	144
Standard Deviation		47.92	40.27	16.41	14.60	14.03	75.57	17.12
Mean Chloride Concentration (mg/L)	1973-1979	140	68	25	22	21	200	
	1980-1989	165	103	24	21	22	258	
	1990-1999	184	119	29	27	26		
	2000-2009	157	143	46	41	40		51
	2010-2019	198	111	58	49	47	177	57
	2020-3/2025	58	70	37	36	34	151	48

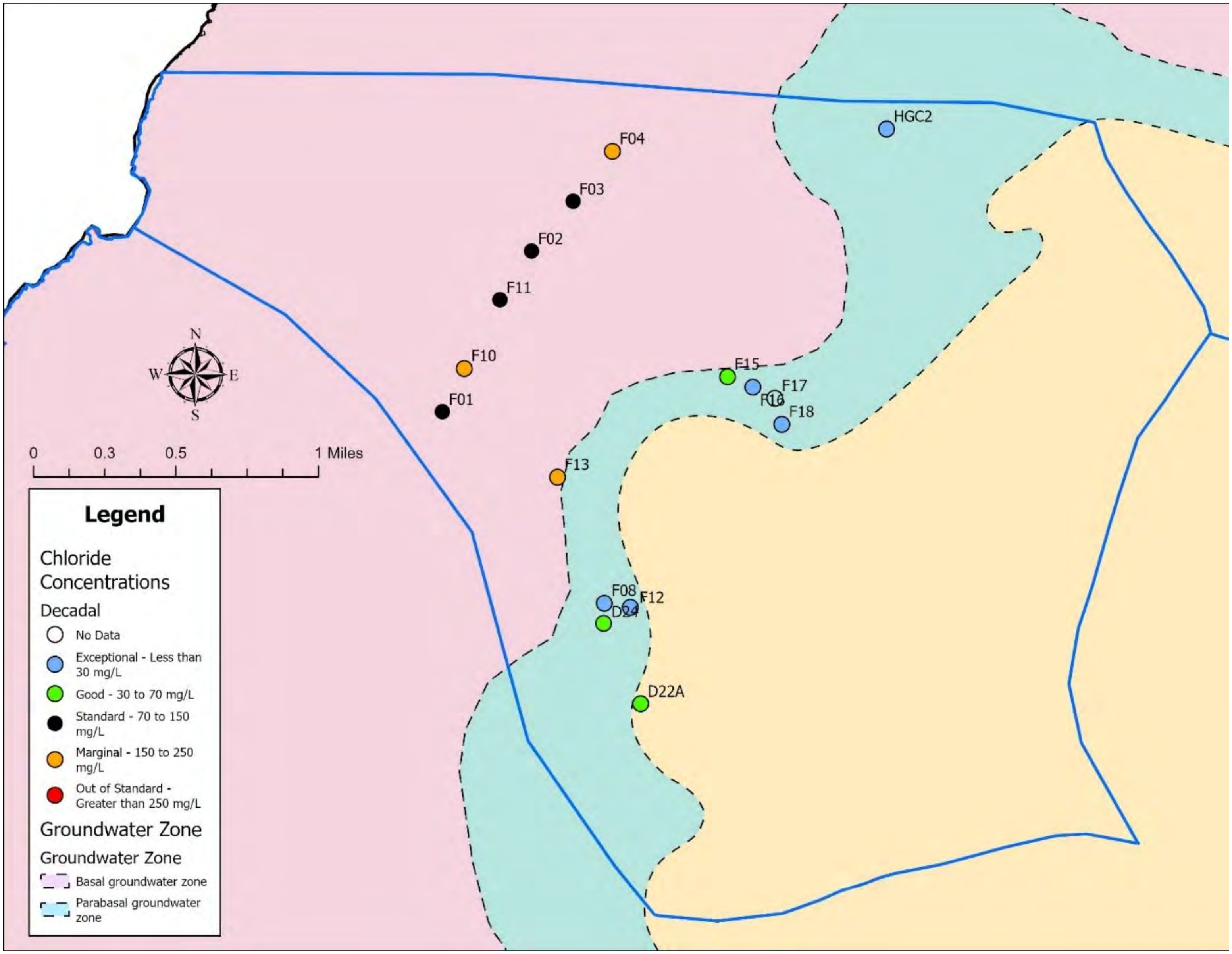
Appendix B: Updated Decadal Maps
B.1 Finagua'yok Basin



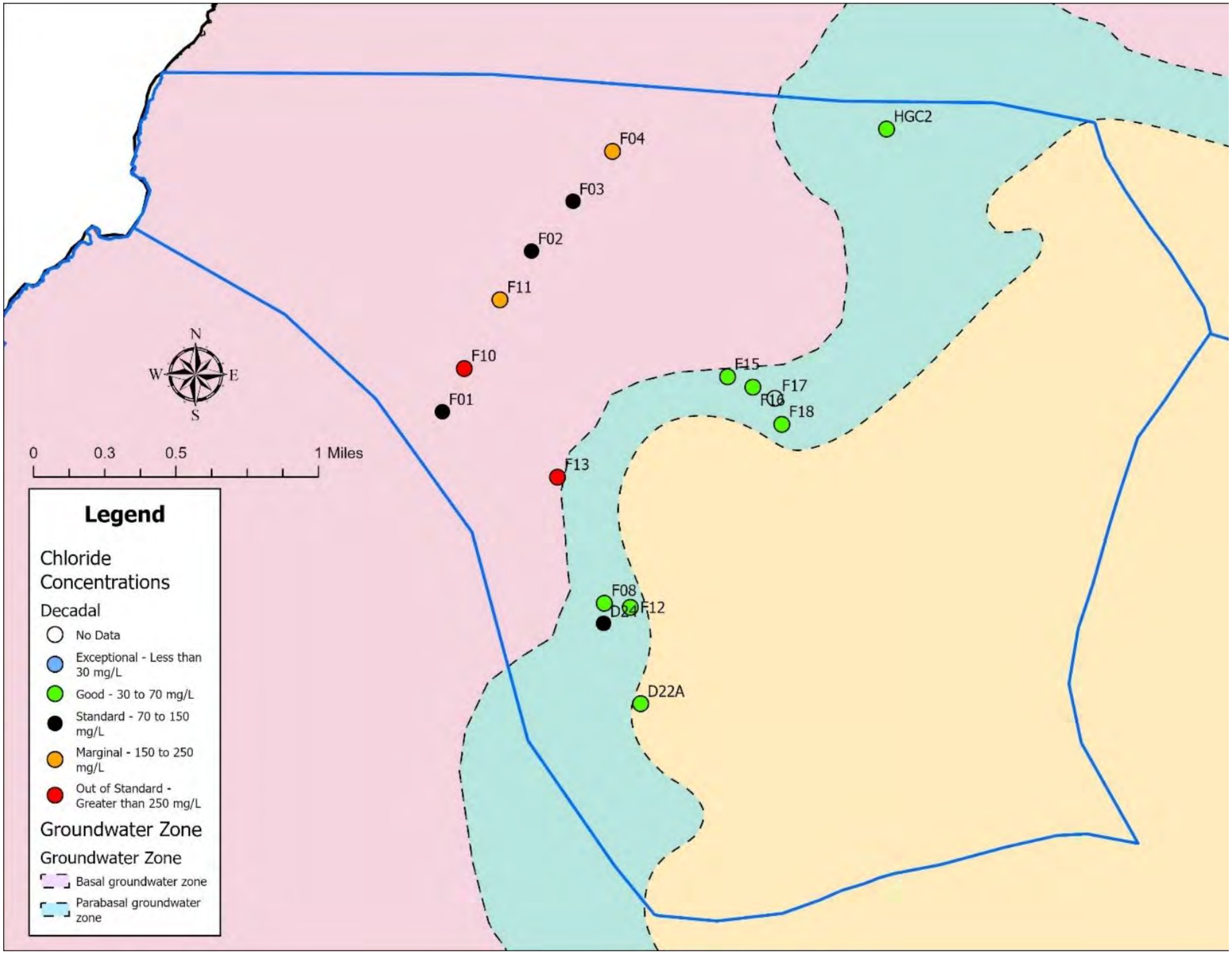
B.1.1: Average chloride concentrations for the 1973-1979 decade in the Finagua'yok Basin.



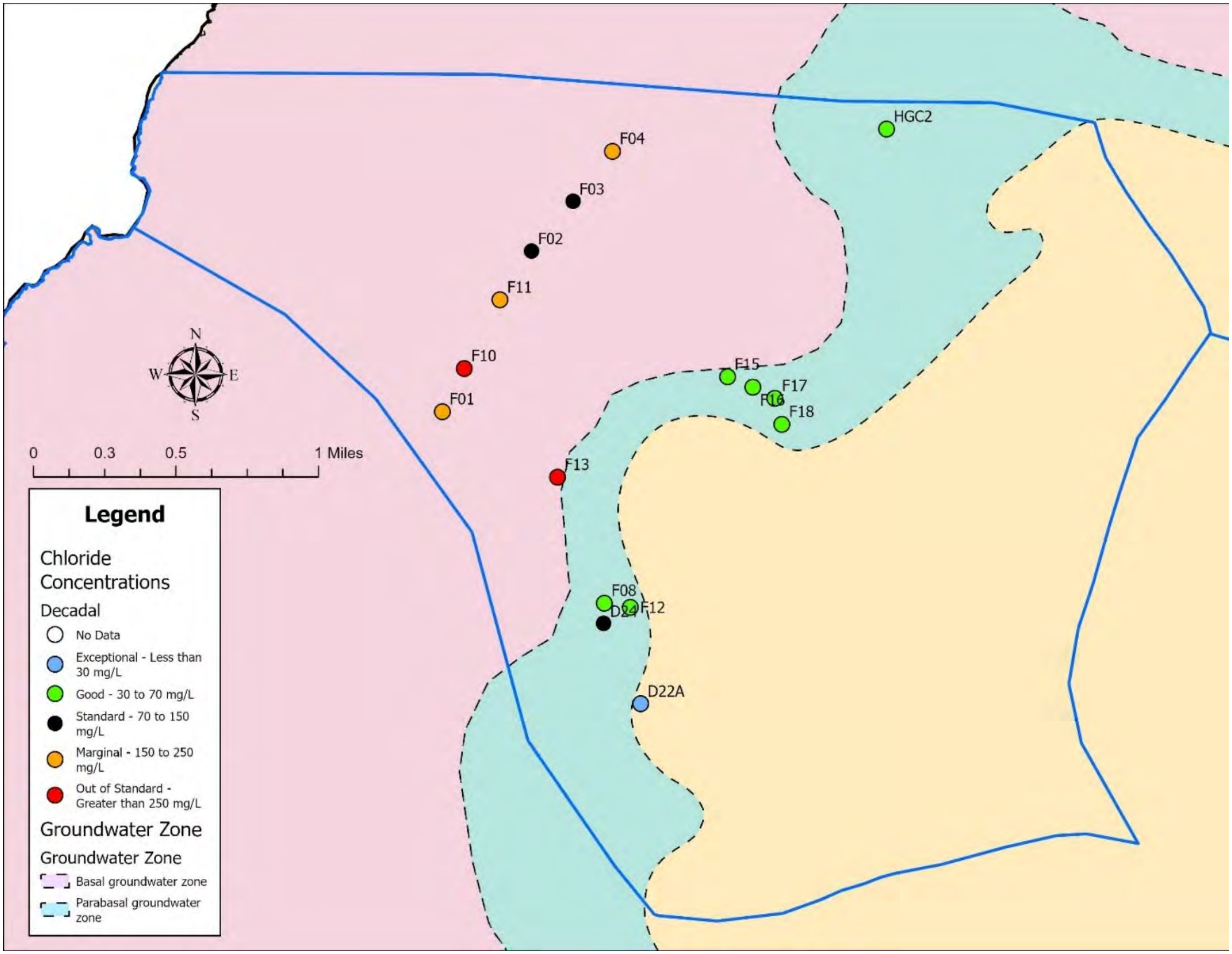
B.1.2: Average chloride concentrations for the 1980-1989 decade in the Finagua'yok Basin.



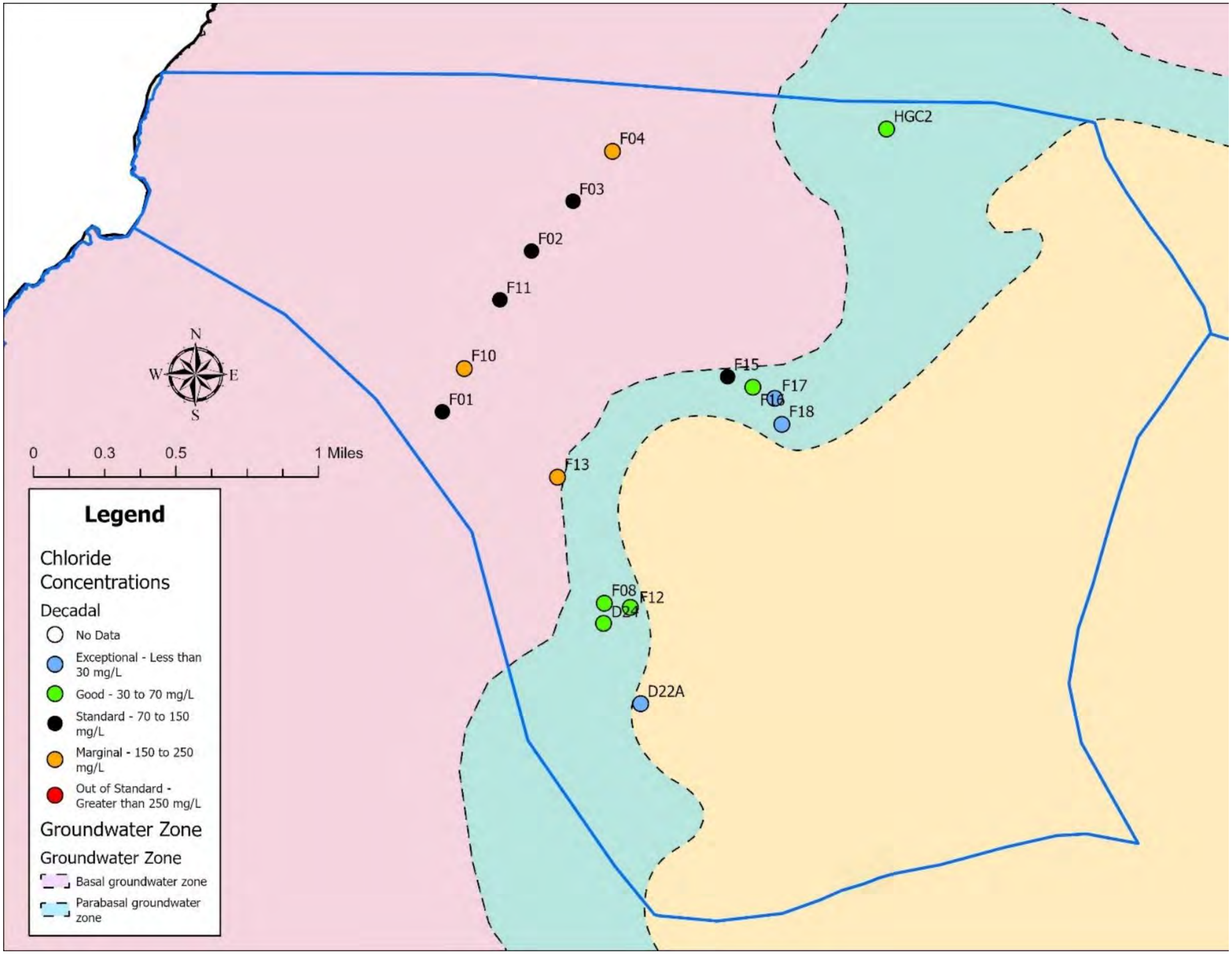
B.1.3: Average chloride concentrations for the 1990-1999 decade in the Finagua'yok Basin.



B.1.4: Average chloride concentrations for the 2000-2009 decade in the Finagua'yok Basin.

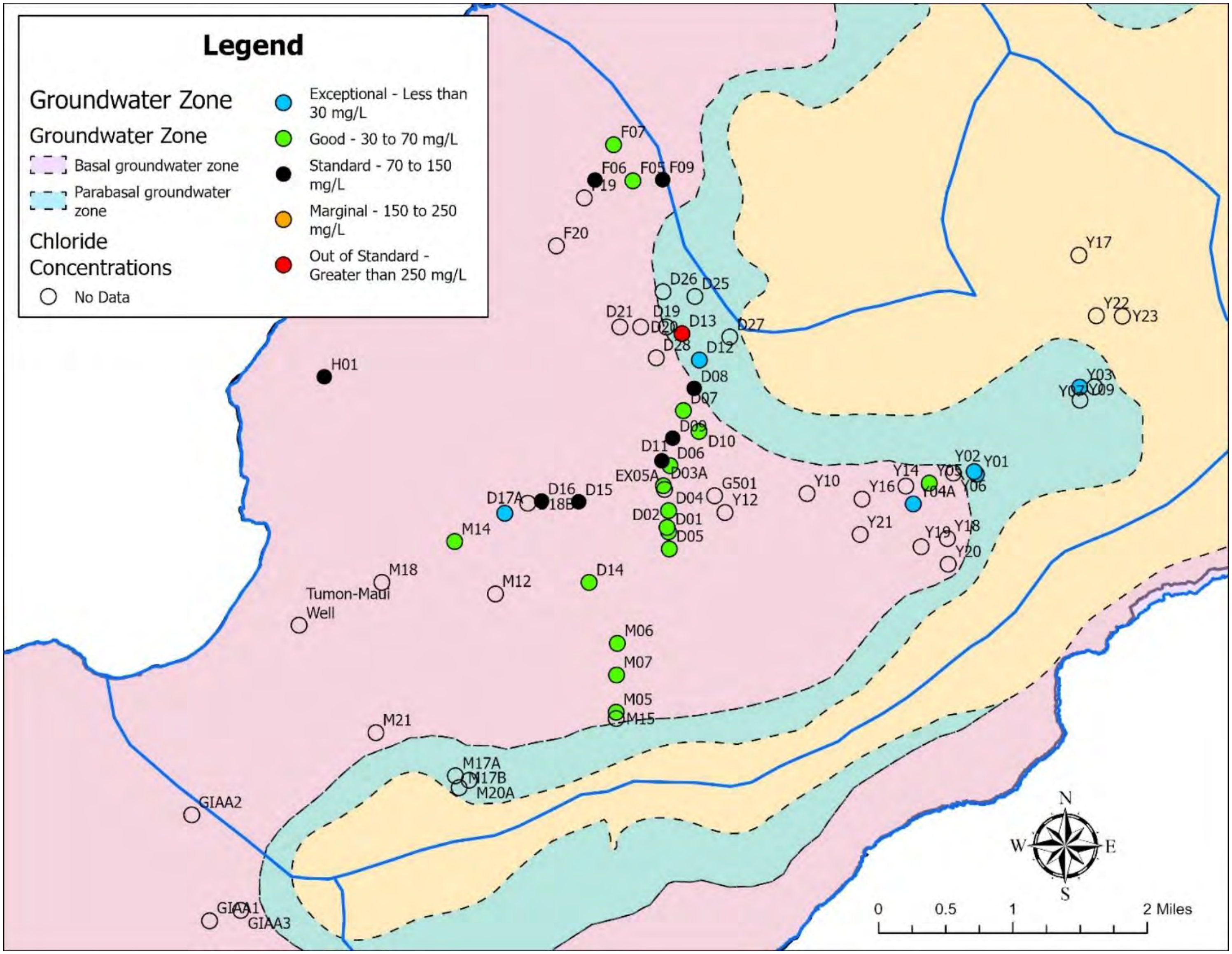


B.1.5: Average chloride concentrations for the 2000-2019 decade in the Finagua'yok Basin.

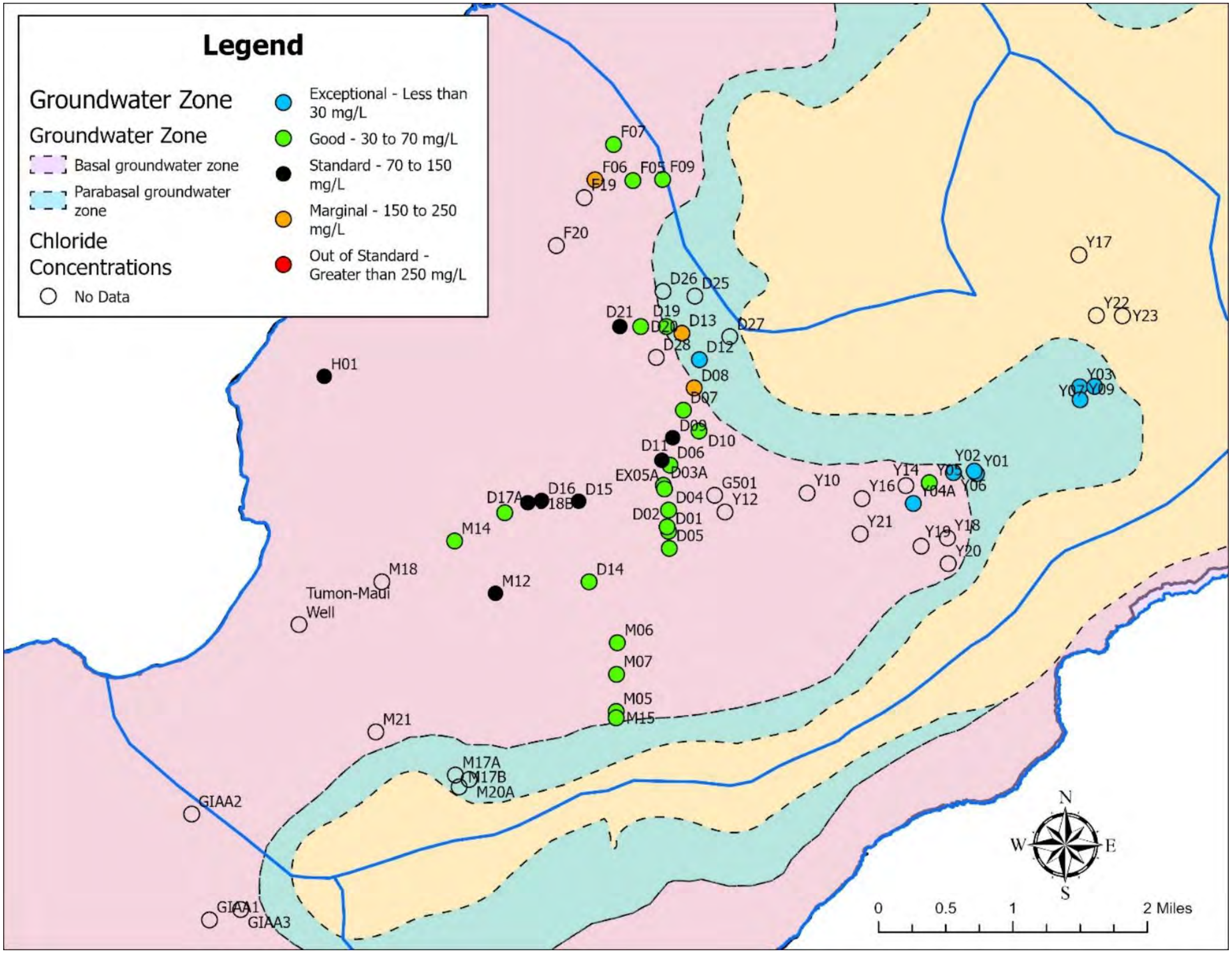


B.1.6: Average chloride concentrations for the current (2020-3/2025) decade in the Finagua'yok Basin.

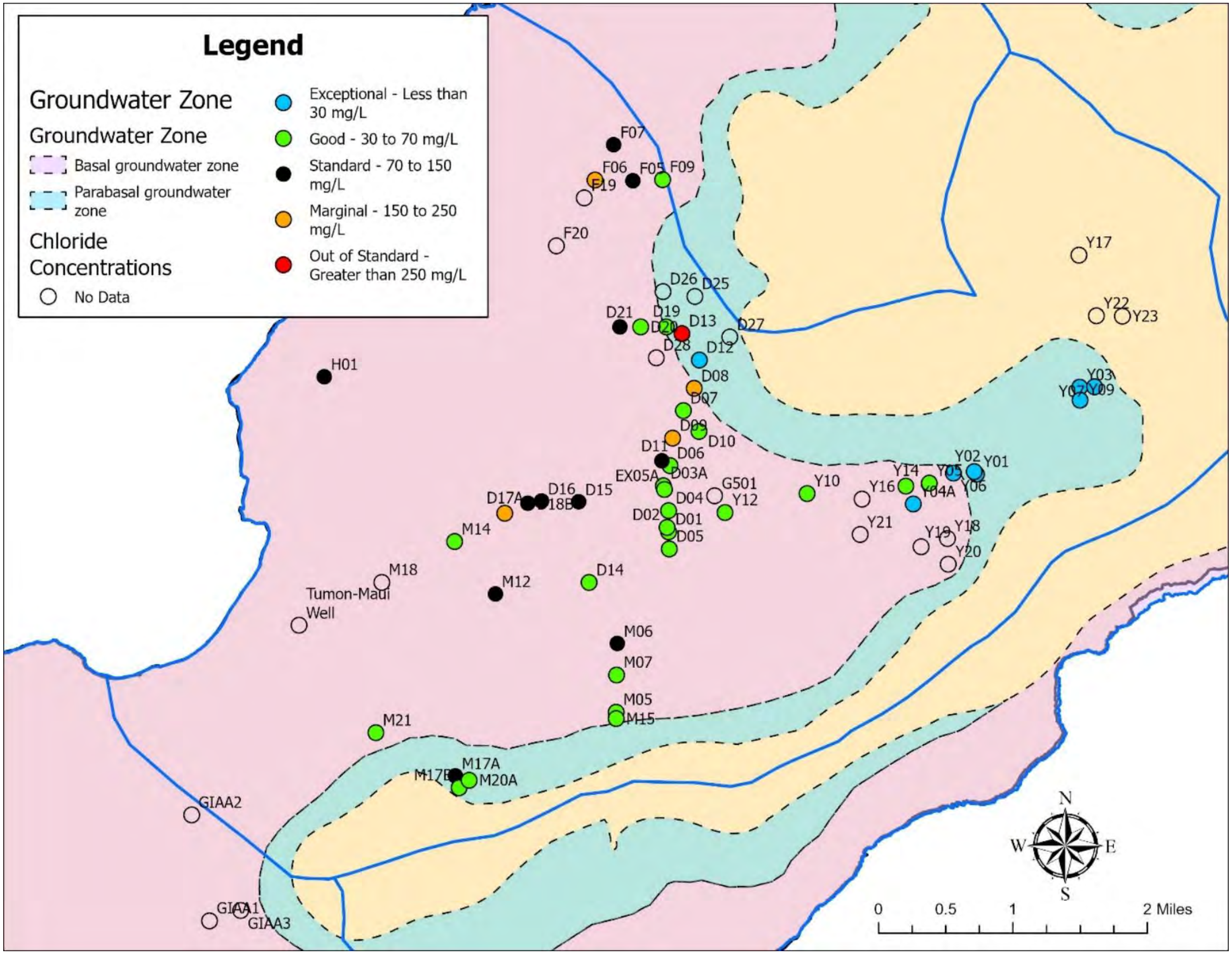
B.2 Tomhom Basin



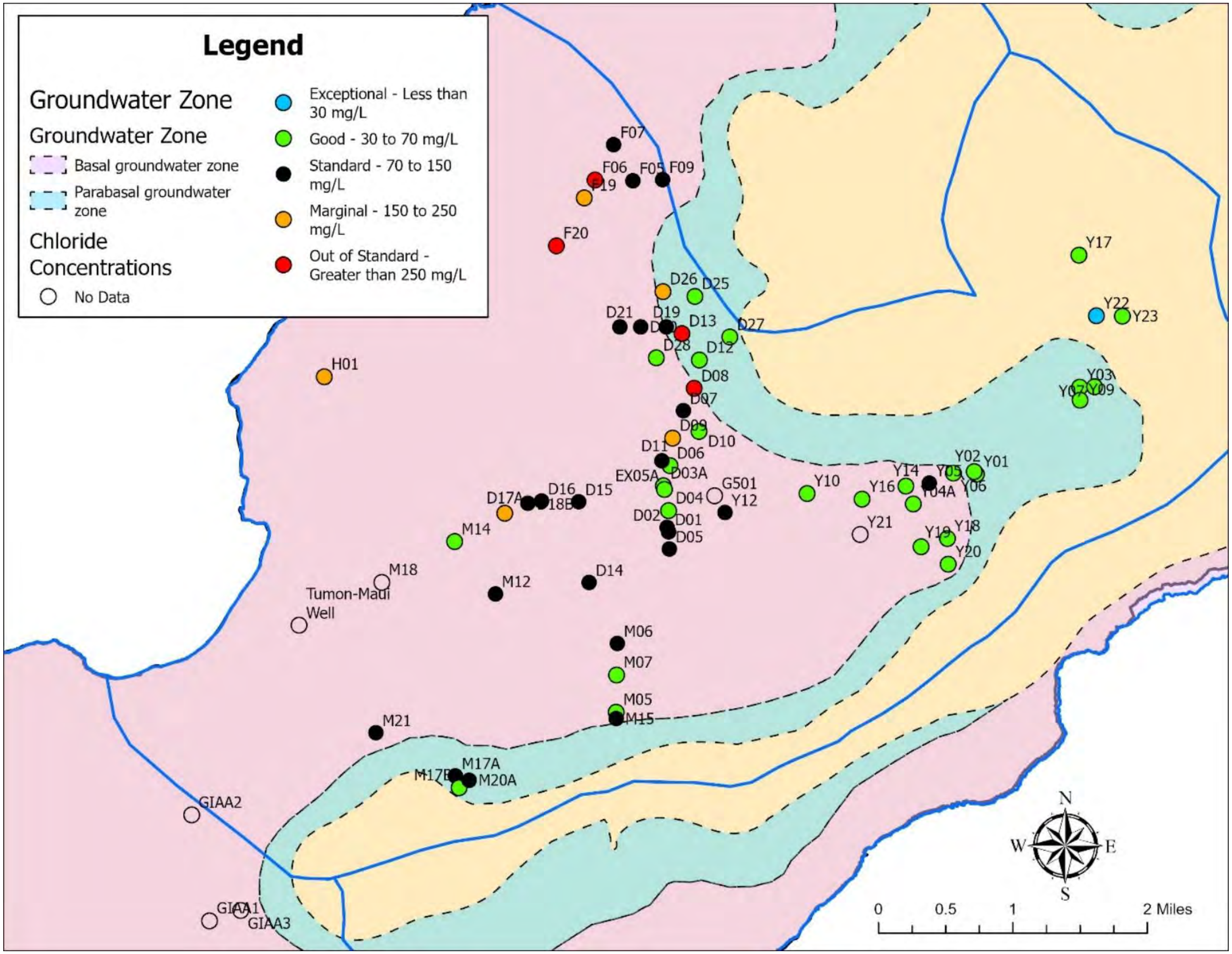
B.2.1: Average chloride concentrations for the 1973-1979 decade in the Tomhom Basin.



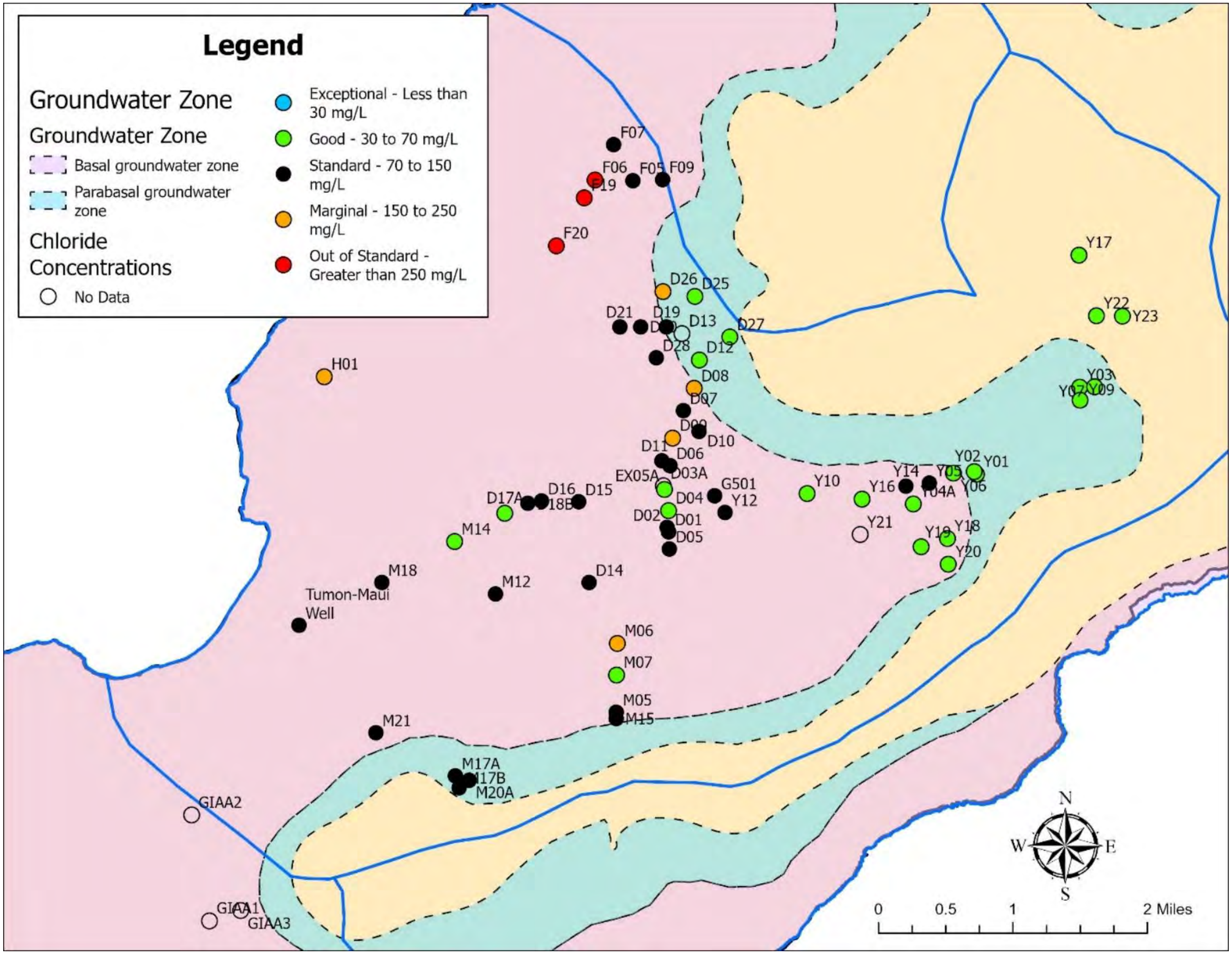
B.2.2: Average chloride concentrations for the 1980-1989 decade in the Tomhom Basin.



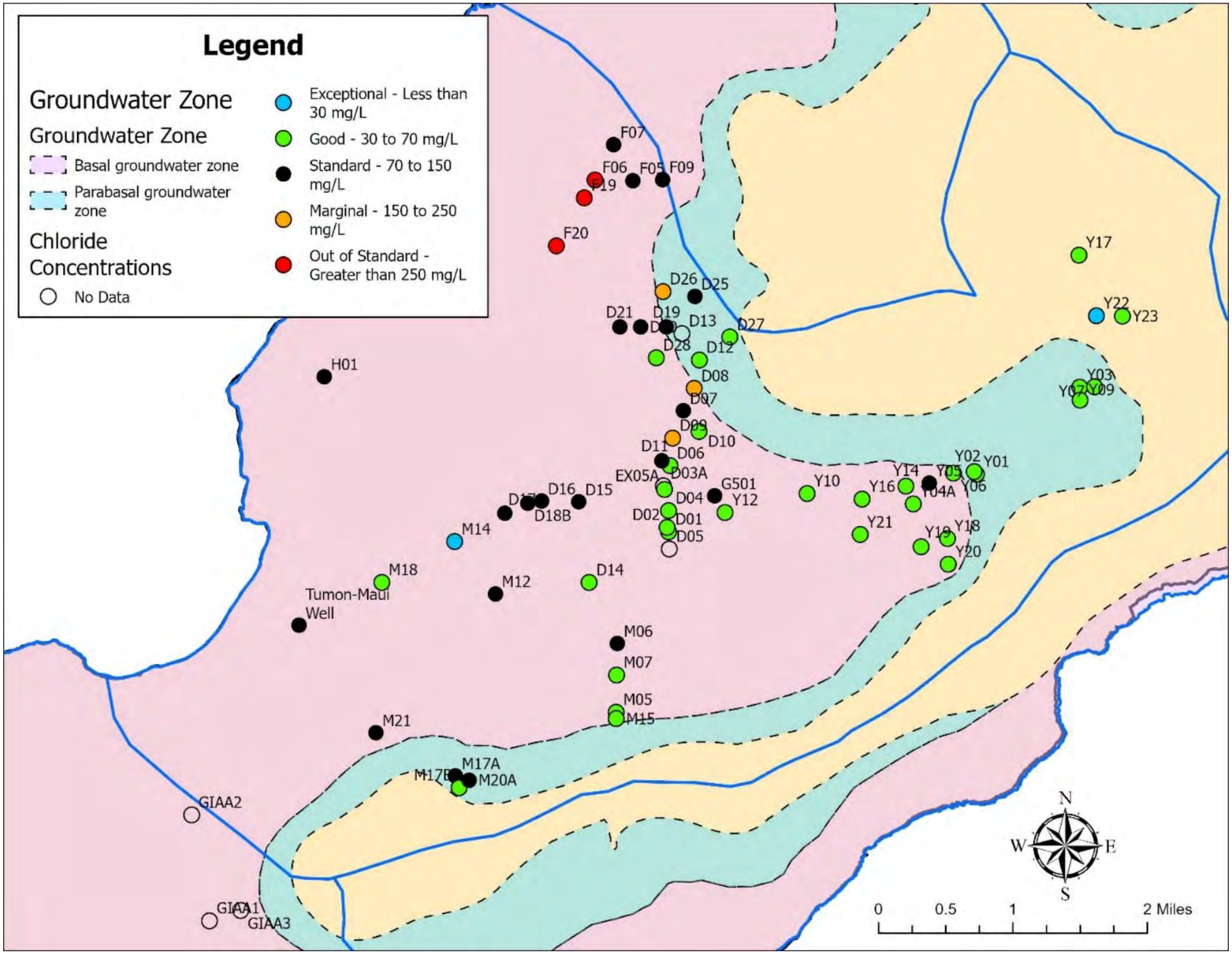
B.2.3: Average chloride concentrations for the 1990-1999 decade in the Tomhom Basin.



B.2.4: Average chloride concentrations for the 2000-2009 decade in the Tomhom Basin.

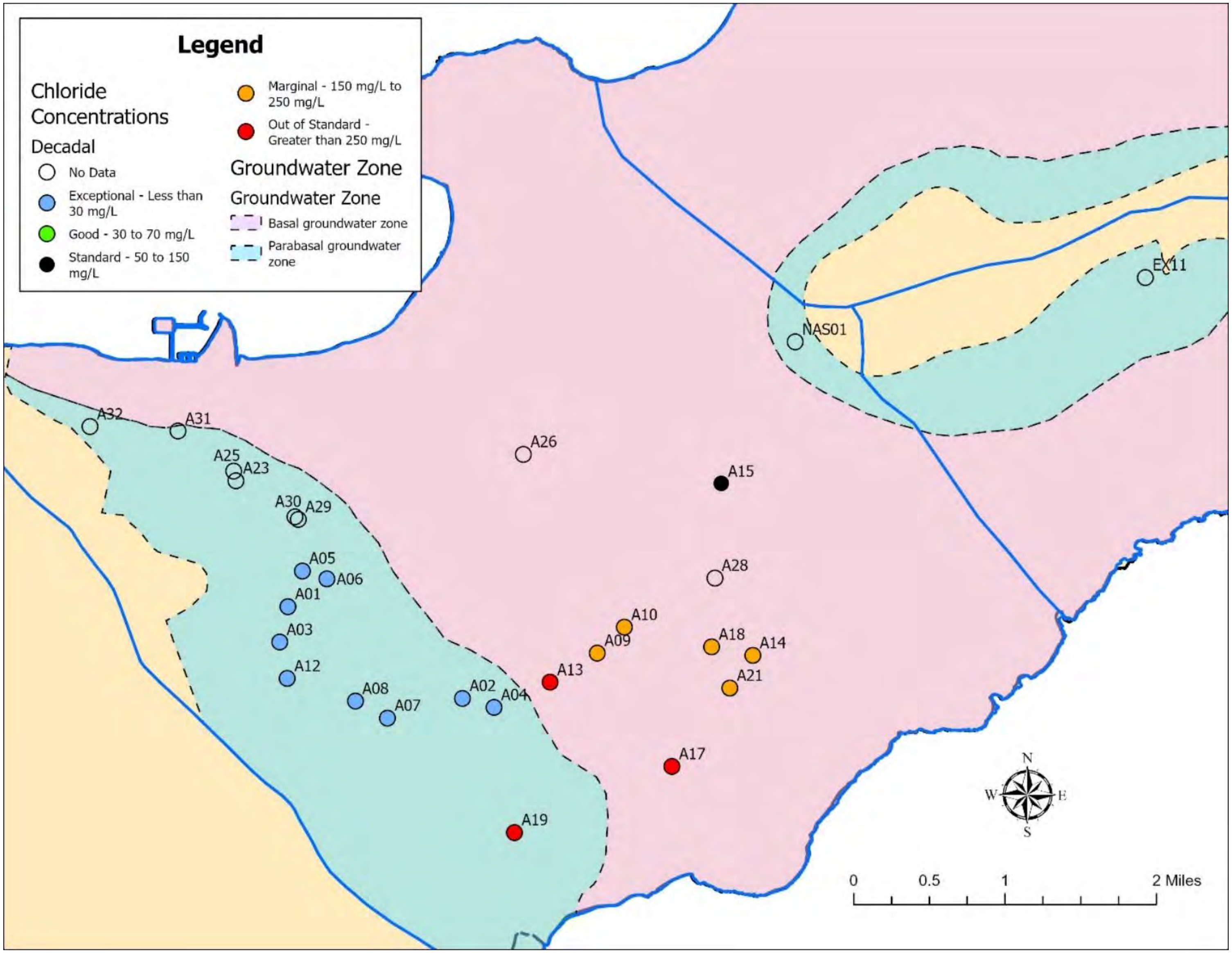


B.2.5: Average chloride concentrations for the 2010-2019 decade in the Tomhom Basin.

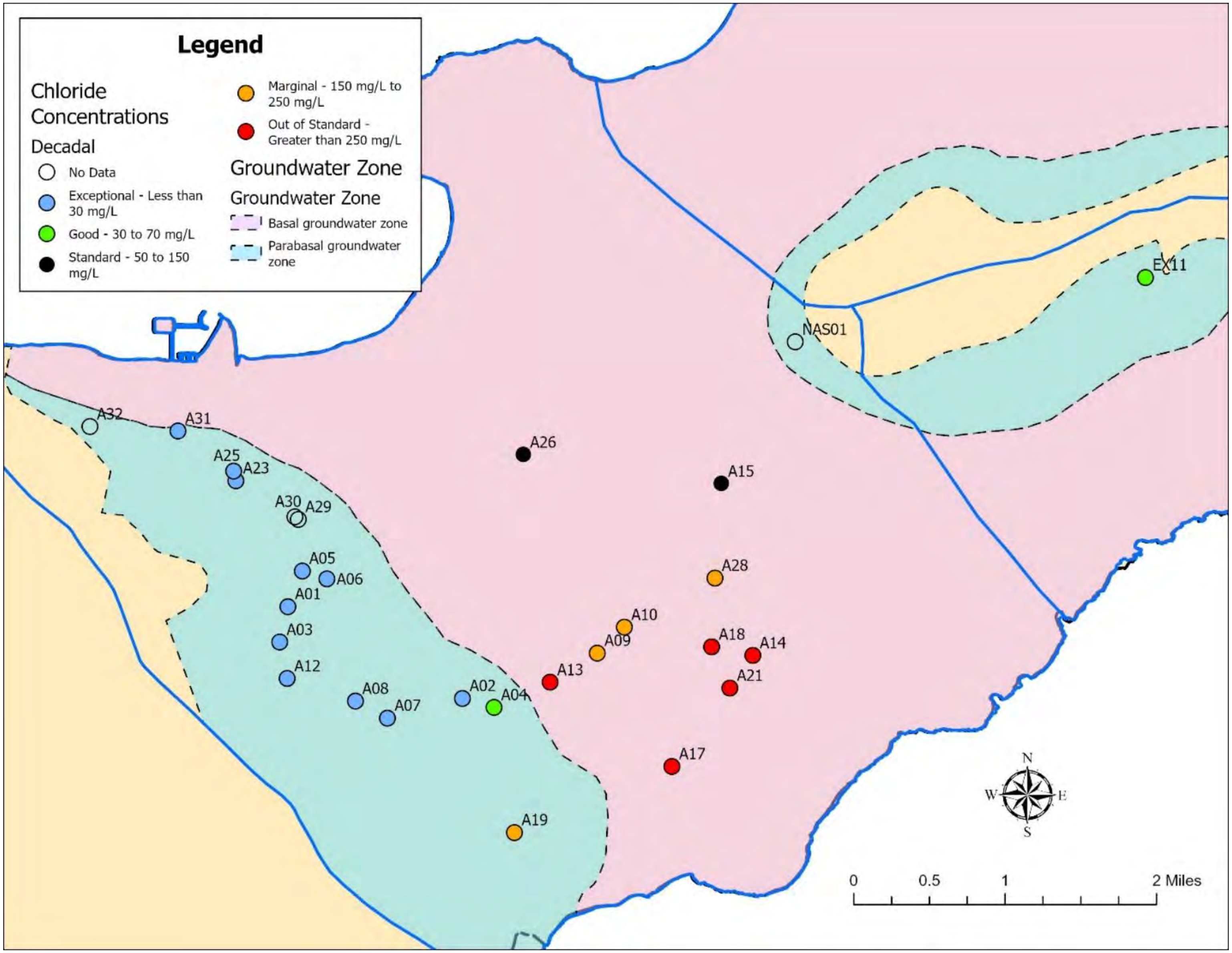


B.2.6: Average chloride concentrations for the current (22020-3/2025) decade in the Tomhom Basin.

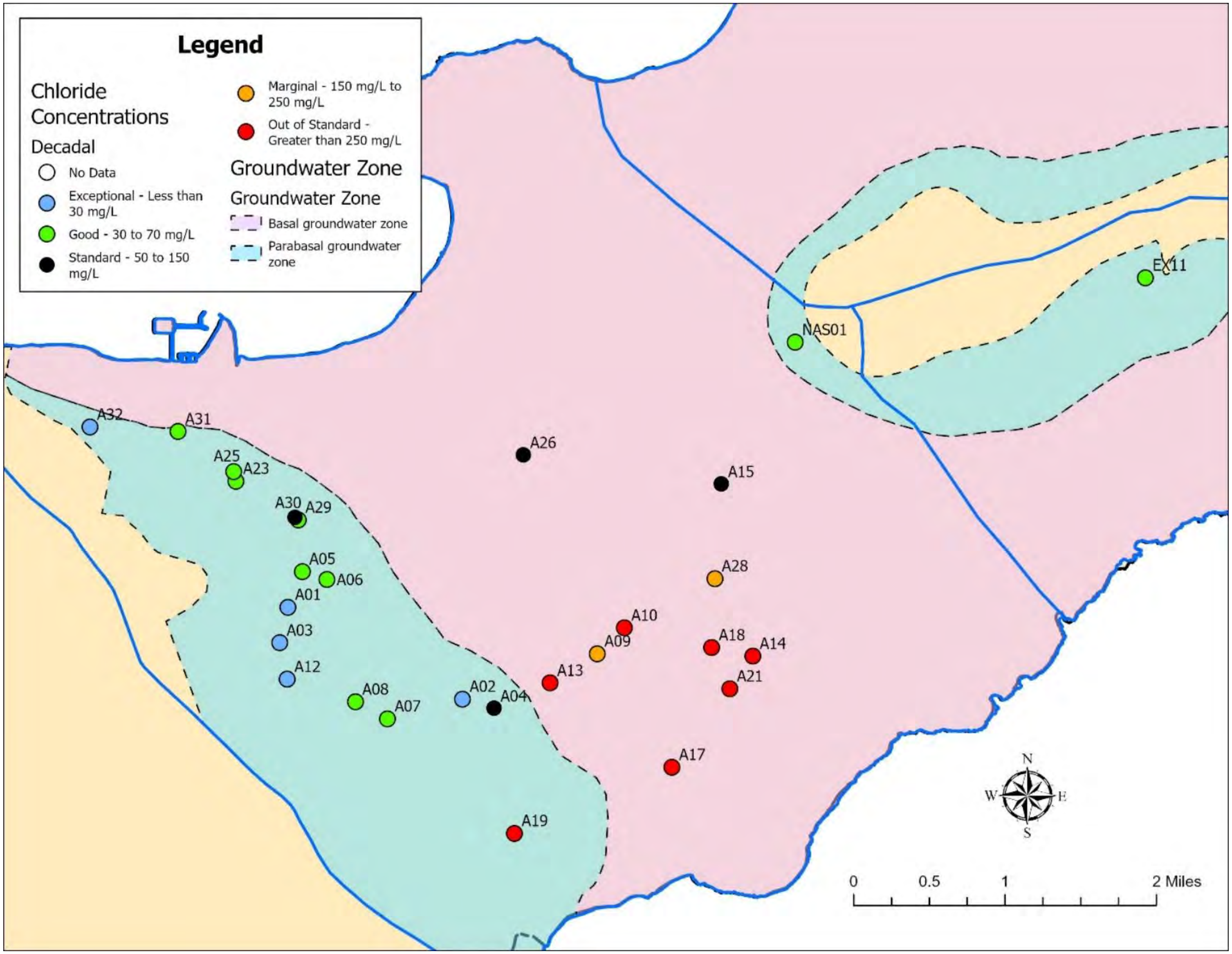
B.3 Hagåtña Basin



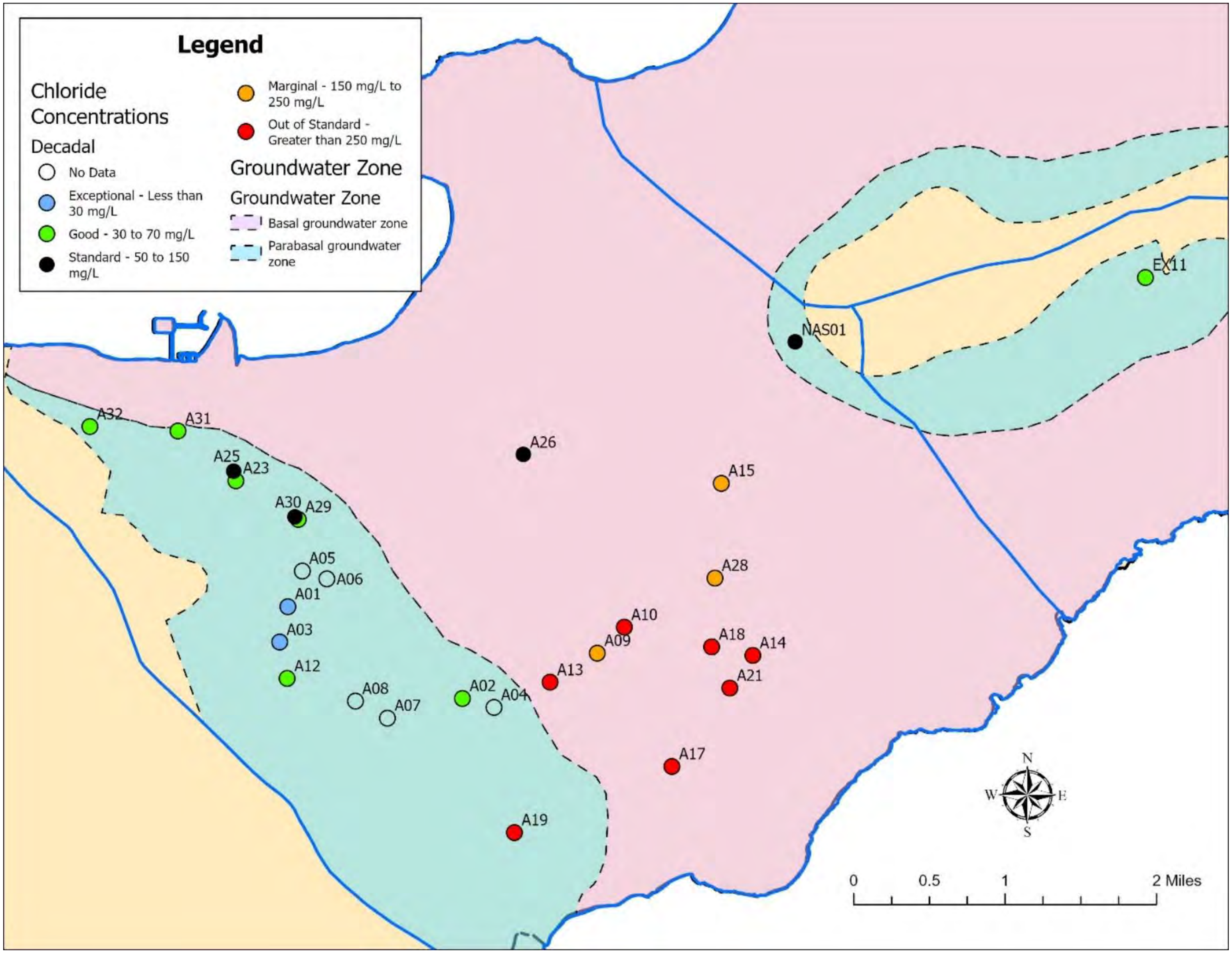
B.3.1: Average chloride concentrations for the 1973-1979 decade in the Hagåtña Basin.



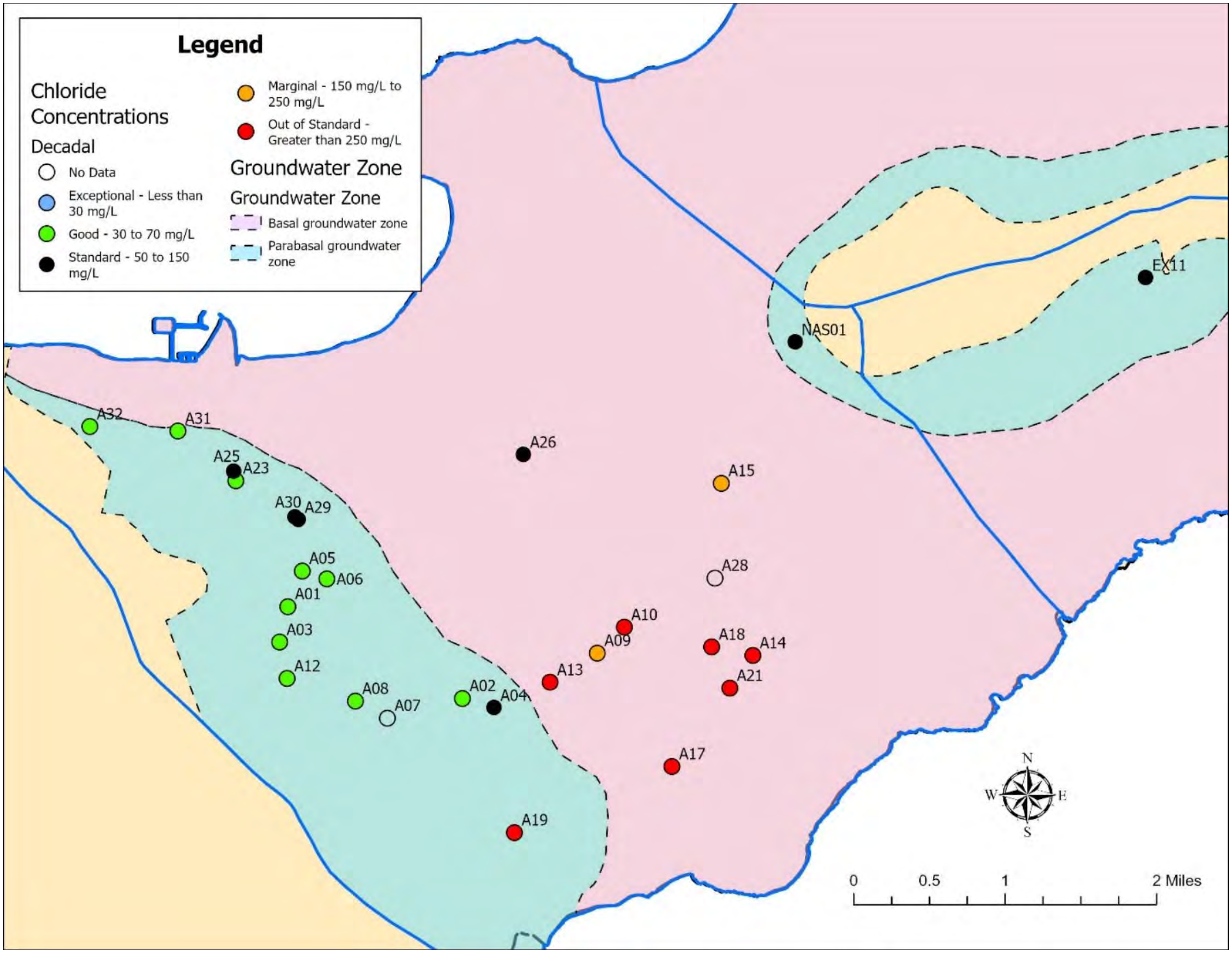
B.3.1: Average chloride concentrations for the 1980-1989 decade in the Hagåtña Basin.



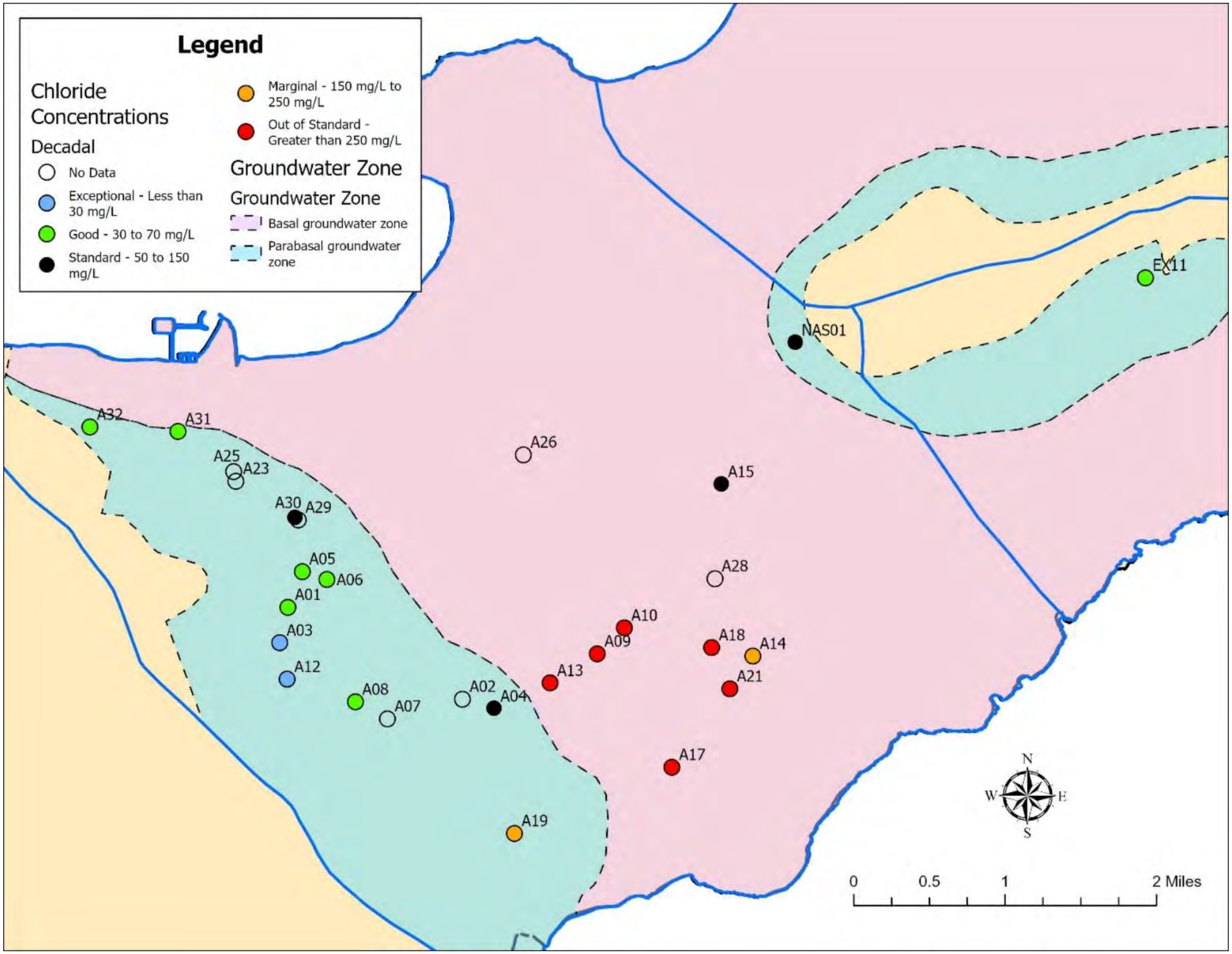
B.3.3: Average chloride concentrations for the 1990-1999 decade in the Hagåtña Basin.



B.3.4: Average chloride concentrations for the 2000-2009 decade in the Hagåtña Basin.

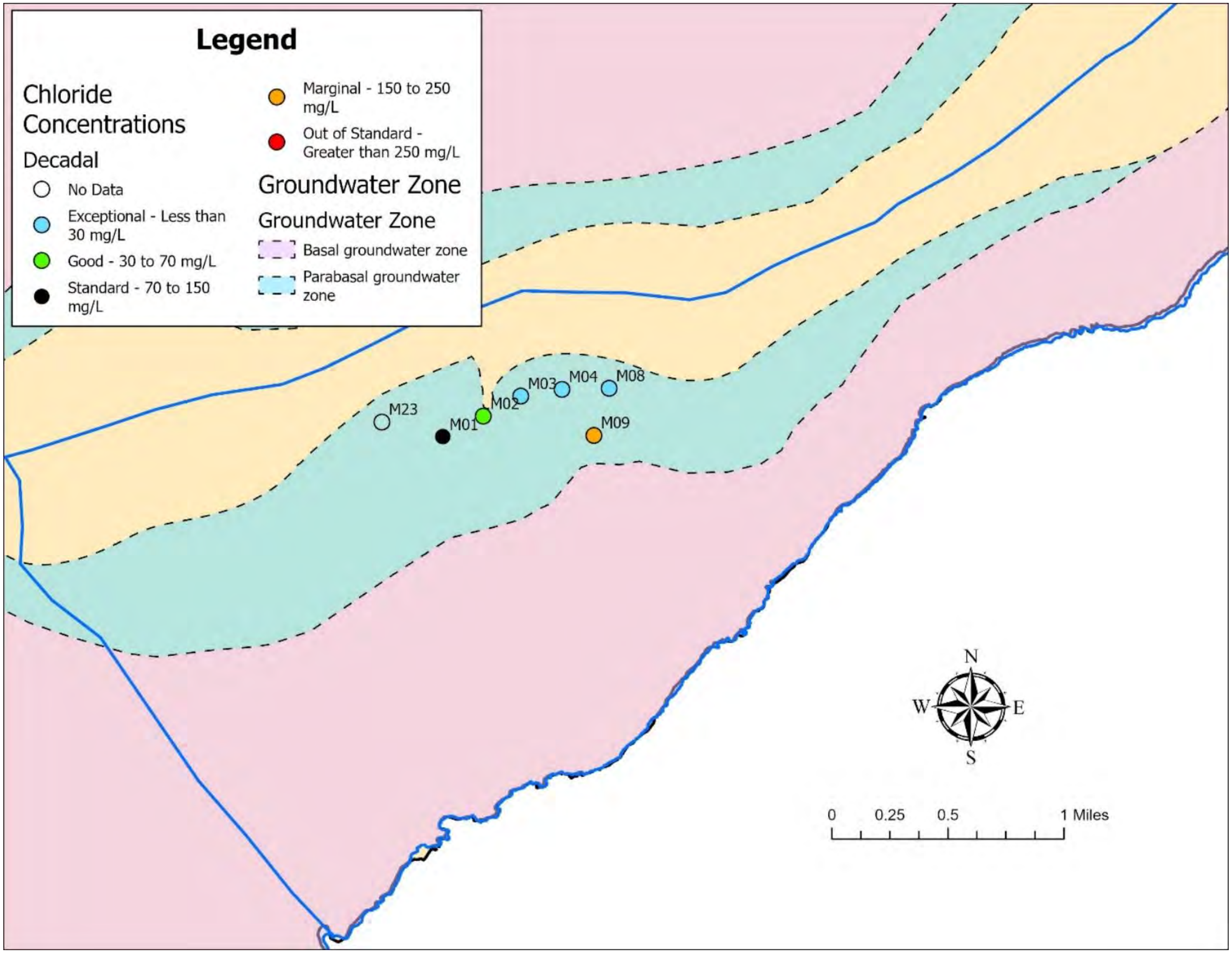


B.3.5: Average chloride concentrations for the 2010-2019 decade in the Hagåtña Basin.

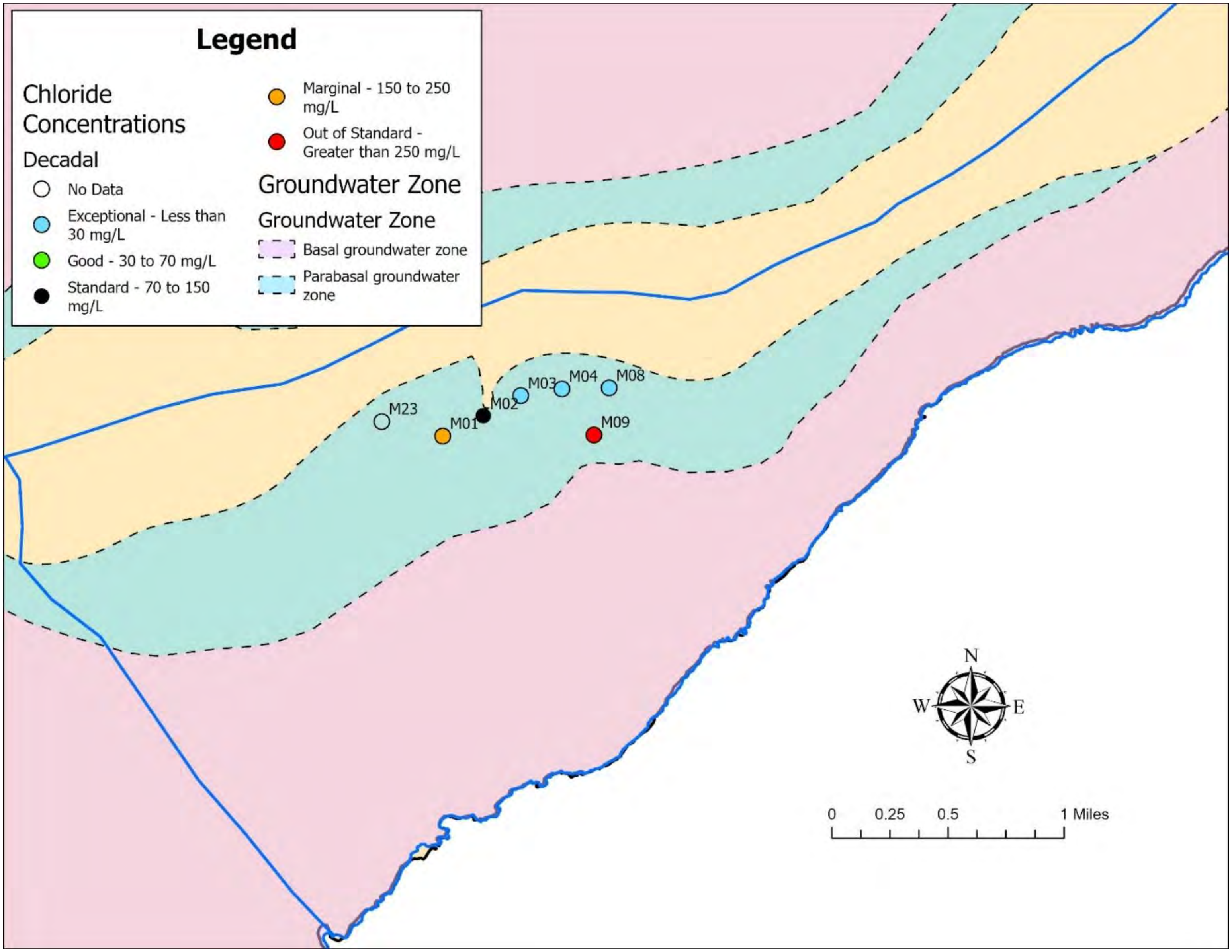


B.3.6: Average chloride concentrations for the current (2020-3/2025) decade in the Hagåtña Basin.

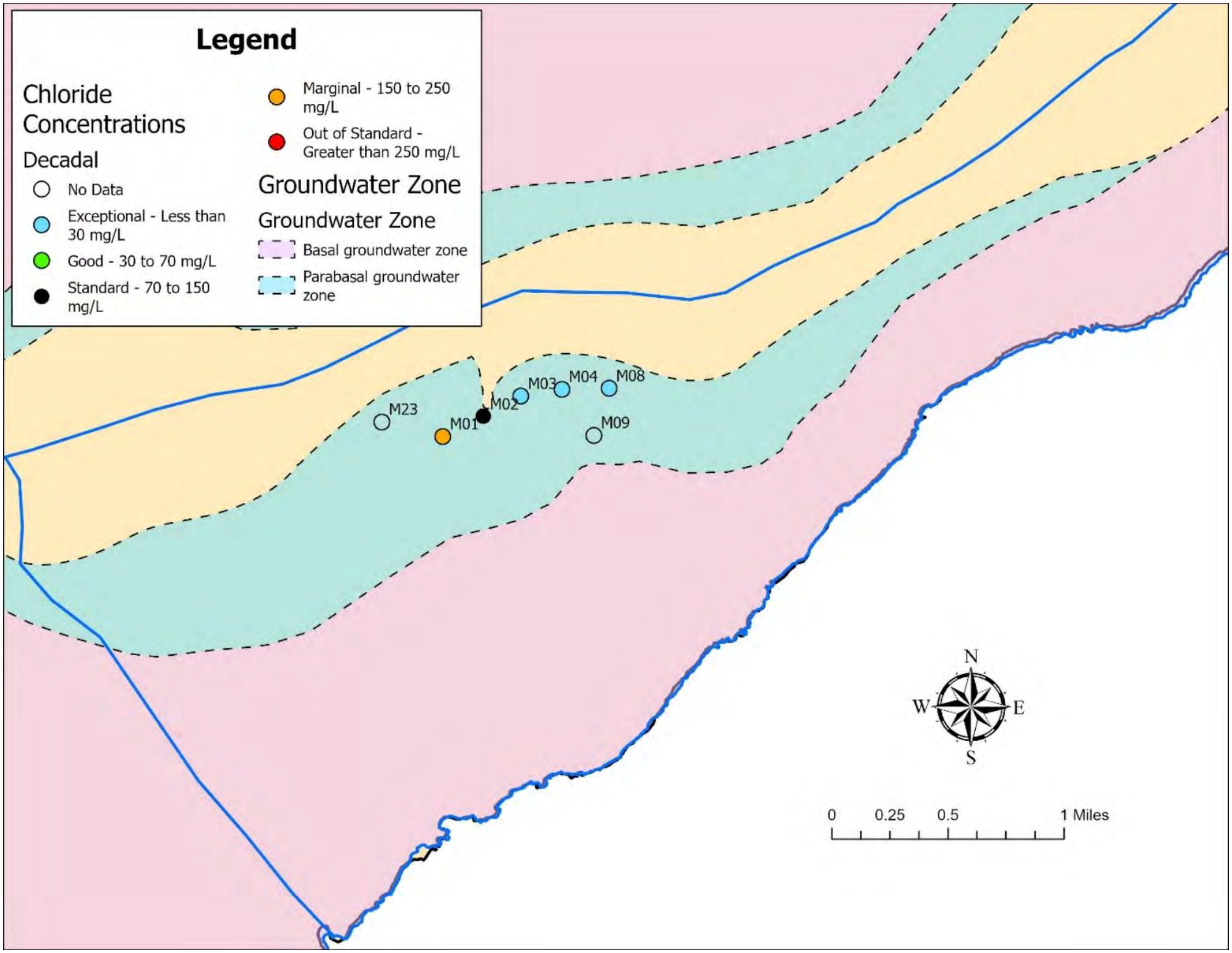
B.4 Mangilao Basin



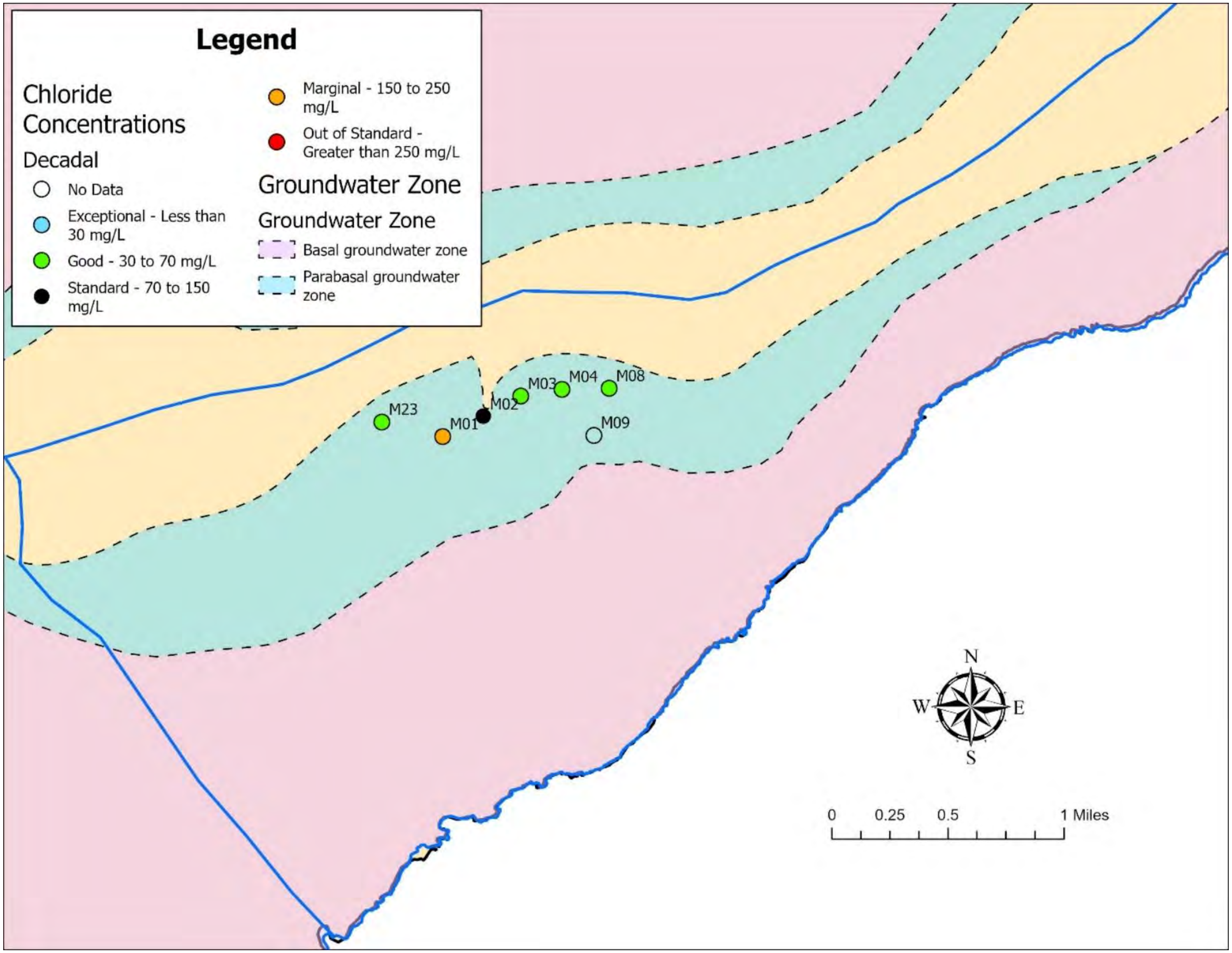
9: Average chloride concentrations for the 1973-1979 decade in the Mangilao Basin.



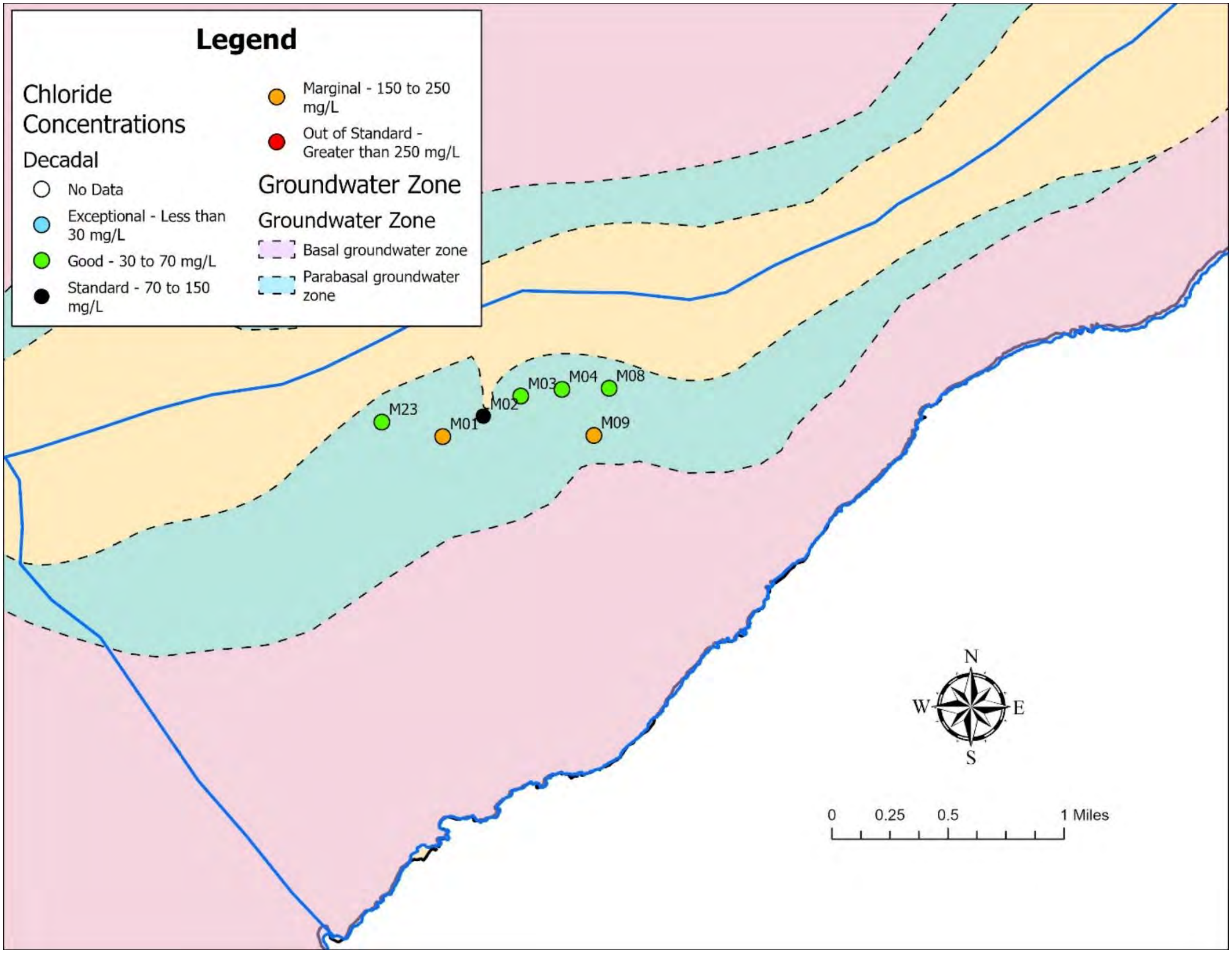
B.4.2: Average chloride concentrations for the 1980-1989 decade in the Mangilao Basin.



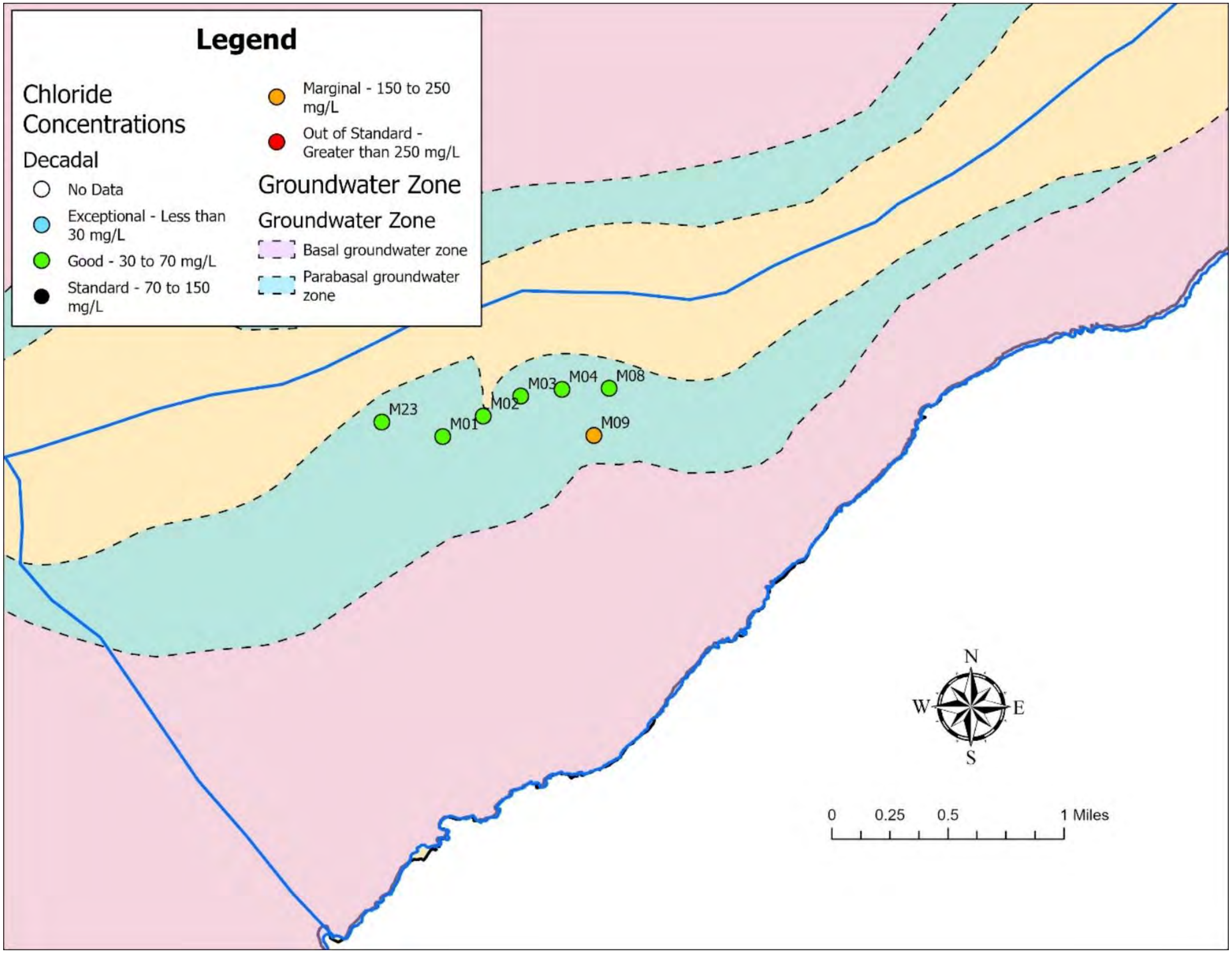
B.4.3: Average chloride concentrations for the 1990-1999 decade in the Mangilao Basin.



B.4.4: Average chloride concentrations for the 2000-2009 decade in the Mangilao Basin.



B.4.5: Average chloride concentrations for the 2010-2019 decade in the Mangilao Basin.



B.4.6: Average chloride concentrations for the current (2020-3/2025) decade in the Mangilao Basin.

Appendix C: Linear Regression Summary Tables

C.1 Finagua'yok Basin

Well ID	R Square	F-statistic	p-value	slope
D22A	0.026	1.602	0.211	-19.25
D24	0.095	8.935	0.004	39.14
F01	0.474	235.6	2.51E-38	96.95
F02	0.312	113.6	4.19E-22	121.71
F03	0.115	31.56	5.28E-08	80.83
F04	0.259	84.43	1.87E-17	40.51
F08	0.363	134.7	6.28E-25	181.4
F10	0.290	77.66	7.70E-16	29.85
F11	0.167	41.84	6.97E-10	49.59
F12	0.012	1.599	0.208	15.45
F13	7.87E-07	7.72E-05	0.993	0.034
F15	0.040	4.535	0.035	29.93
F16	0.061	7.198	0.008	54.32
F17	0.108	6.792	0.012	-44.57
F18	0.004	0.400	0.528	14.26
HGC2	0.113	15.77	1.210E-04	90.26

C.2 Tomhom Basin

Well ID	R Square	F-statistic	p-value	slope
D01	0.407	176.94	4.27E-31	241.09
D02	0.366	152.55	5.77E-28	261.68
D03A	0.086	17.31	4.87E-05	146.35
D04	0.428	200.21	2.52E-34	321.88
D05	0.191	54.42	2.92E-12	178.50
D06	0.312	119.67	3.23E-23	208
D07	0.318	128.33	1.14E-24	162.10
D08	0.202	68.97	4.70E-15	34.50
D09	0.509	270.17	3.69E-42	97.54
D10	0.334	128.53	2.07E-24	158.40
D11	0.023	6.38	1.20E-02	43.85
D12	0.298	115.25	1.23E-22	199.46
D13	0.192	47.04	8.69E-11	9.43
D14	0.546	320.85	1.15E-47	171.09
D15	0.033	8.43	4.02E-03	48.90
D16	0.097	21.70	5.79E-06	83.58
D17A (9/1979-5/1/2002)	0.701	274.38	1.84E-32	29.05
D17A (5/2018-Present)	0.809	110.45	7.45E-11	22.01
D18B (5/1980-5/2000)	0.217	26.67	1.30E-06	50.71
D18B (11/2018-Present)	0.01	0.24	6.29E-01	-6.03
D19	0.153	28.31	3.51E-07	109.71
D20	0.426	116.45	1.17E-20	157.16
D21	0.061	9.95	1.93E-03	66.91
D25	0.344	42.96	4.63E-09	75.63
D26	0.077	6.40	1.35E-02	-8.32
D27	0.029	2.40	1.25E-01	24.48
D28	0.009	0.66	4.20E-01	14.91
EX05	0.333	77.26	2.67E-15	172.72
F05	0.315	112.91	5.96E-22	77.34
F06	0.419	165.29	7.74E-29	27.54
F07	0.482	230.19	3.47E-37	103.57
F09	0.070	15.58	1.08E-04	60.38
F19	0.002	0.15	6.96E-01	1.02
F20	0.001	0.07	7.93E-01	-0.66
G501	0.630	88.39	8.38E-13	-27.64
H01	0.589	340.18	1.05E-47	87.66
M05	0.472	225.34	8.06E-37	238.17
M06	0.250	84.68	1.33E-17	50.71
M07	0.449	205.13	1.92E-34	280.10
M12	0.015	1.93	1.68E-01	18.10

(cont.)

Well ID	R Square	F-statistic	p-value	slope
M14	0.115	22.90	3.58E-06	61.51
M15	0.108	20.21	1.29E-05	48.26
M17A (2/1990-5/2002)	0.027	1.21	2.77E-01	10.67
M17A (1/2019-Present)	0.005	0.09	7.71E-01	-5.59
M17B	0.043	6.02	1.54E-02	53.44
M18	0.375	32.97	4.19E-07	-58.34
M20A	0.003	0.38	5.37E-01	-8.50
M21	0.011	1.11	2.95E-01	-8.60
Y01	0.473	238.62	7.32E-39	322.30
Y02	0.441	214.43	3.36E-36	288.58
Y03	0.320	124.67	5.57E-24	255.24
Y04A	0.571	295.87	1.04E-42	330.08
Y05	0.648	385.80	1.91E-49	176.56
Y06	0.368	112.22	5.79E-21	220.07
Y07 (2/1983-5/2002)	0.148	13.75	3.87E-04	153.38
Y07 (5/2010-Present)	0.094	6.01	1.70E-02	-39.96
Y09	0.224	41.25	1.86E-09	155.80
Y10	0.020	2.07	1.50E-01	28.37
Y12	0.003	0.36	5.52E-01	11.78
Y14	0.126	10.42	1.88E-03	53.88
Y16	0.001	0.07	7.90E-01	5.46
Y17	0.014	1.21	2.80E-01	-20.22
Y18	0.059	4.93	2.93E-02	36.83
Y19	0.010	0.76	3.86E-01	-15.90
Y20	0.012	0.86	3.58E-01	16.56
Y21	0.217	3.61	8.00E-02	16.19
Y22	3.28E-05	0.00	9.59E-01	-1.10
Y23	0.020	1.76	1.88E-01	-27.60
Maui	0.460	25.54	2.00E-05	-49.03

C.3 Hagåtña Basin

Well ID	R Square	F-statistic	p-value	slope
A01	0.288	96.48	2.46E-19	261.89
A02	0.556	269.43	8.63E-40	336.15
A03	0.344	134.89	2.40E-25	341.88
A04 (1/1973-3/1994)	0.688	498.31	4.44E-59	59.77
A04 (2/2011-Present)	0.155	10.08	0.002	-36.60
A05 (1/1973-3/1994)	0.473	200.33	7.00E-33	166.74
A05 (2/2011-Present)	0.003	0.18	0.674	-8.59
A06 (1/1973 - 3/1994)	0.558	289.34	1.67E-42	137.68
A06 (2/2011-Present)	0.023	1.30	0.260	-16.33
A07	0.288	72.36	6.97E-15	154.13
A08 (1/1973-3/1994)	0.127	31.66	5.63E-08	42.66
A08 (2/2011-Present)	0.004	0.23	6.31E-01	-6.64
A09	0.608	406.17	3.44E-55	100.19
A10	0.649	479.06	7.80E-61	52.47
A12	0.202	61.99	1.12E-13	155.28
A13	0.517	286.01	4.11E-44	36.26
A14	0.008	2.21	1.38E-01	10.57
A15	0.100	28.96	1.65E-07	57.30
A17	0.029	7.58	6.32E-03	8.98
A18	0.140	38.88	2.03E-09	27.43
A19	0.198	60.91	1.71E-13	23.60
A21	0.418	184.23	5.60E-32	39.18
A23	0.411	87.34	4.55E-16	98.11
A25	0.362	68.54	1.91E-13	69.96
A26	0.002	0.19	6.60E-01	-2.27
A28	0.012	0.97	3.28E-01	-5.71
A29	0.032	1.53	2.23E-01	10.78
A30	0.016	2.22	1.38E-01	-9.66
A31	0.134	21.44	8.36E-06	112.05
A32	0.170	24.70	2.23E-06	128.61
EX11	0.129	22.59	4.59E-06	66.59
NAS01	0.012	1.08	3.02E-01	6.50

C.4 Mangilao Basin

Well ID	R Square	F-statistic	p-value	slope
M01	0.001	0.22	0.639	3.39
M02	0.059	13.68	2.74E-04	36.85
M03	0.356	149.37	1.23E-27	211.39
M04	0.375	161.41	2.76E-29	242.16
M08	0.358	151.98	4.66E-28	248.82
M09 (1/1973-12/1983)	0.297	45.16	9.13E-10	8.10
M09 (5/2011-Present)	0.073	4.01	5.00E-02	-7.14
M23	0.020	1.89	1.72E-01	-21.03

Appendix D: Mann-Kendall Summary Tables

D.1 Finagua'yok Basin

Well	z	p-value	Direction	Significant
D22A	-0.79692923	4.25E-01	Decreasing	No
D24	1.290890847	1.97E-01	Increasing	No
F01	11.79088732	4.35E-32	Increasing	Yes
F02	10.78964261	3.85E-27	Increasing	Yes
F03	6.805609359	1.01E-11	Increasing	Yes
F04	9.795911587	1.17E-22	Increasing	Yes
F08	13.10466372	3.10E-39	Increasing	Yes
F10	7.862089838	3.78E-15	Increasing	Yes
F11	6.133009488	8.62E-10	Increasing	Yes
F12	4.073635341	4.63E-05	Increasing	Yes
F13	0.008934932	9.93E-01	Increasing	No
F15	2.195947493	2.81E-02	Increasing	Yes
F16	2.537858216	1.12E-02	Increasing	Yes
F17	-3.147863698	1.64E-03	Decreasing	Yes
F18	1.346738248	1.78E-01	Increasing	No
HGC2	4.116009329	3.85E-05	Increasing	Yes

D.2 Tomhom Basin

Well	z-value	p-value	Trend Direction	Significance
D01	11.61398	3.50E-31	Increasing	Yes
D02	11.00748	3.52E-28	Increasing	Yes
D03A	3.72134	0.000198	Increasing	Yes
D04	11.64283	2.50E-31	Increasing	Yes
D05	5.809788	6.26E-09	Increasing	Yes
D06	10.32308	5.54E-25	Increasing	Yes
D07	11.50557	1.24E-30	Increasing	Yes
D08	9.767073	1.56E-22	Increasing	Yes
D09	12.94192	2.61E-38	Increasing	Yes
D10	12.03272	2.39E-33	Increasing	Yes
D11	1.388673	0.164932	Increasing	No
D12	12.89116	5.05E-38	Increasing	Yes
D13	4.709952	2.48E-06	Increasing	Yes
D14	15.01499	5.86E-51	Increasing	Yes
D15	3.4785	0.000504	Increasing	Yes
D16	4.92953	8.24E-07	Increasing	Yes
D17A	7.290997	3.08E-13	Increasing	Yes
D18B	7.140989	9.27E-13	Increasing	Yes
D19	5.711594	1.12E-08	Increasing	Yes
D20	8.128242	4.36E-16	Increasing	Yes
D21	2.647263	0.008115	Increasing	Yes
D25	5.364755	8.11E-08	Increasing	Yes
D26	-2.13384	0.032856	Decreasing	Yes
D27	1.188096	0.234796	Increasing	No
D28	0.734721	0.462509	Increasing	No
EX05	7.947377	1.91E-15	Increasing	Yes
F05	11.82027	3.07E-32	Increasing	Yes
F06	11.49565	1.39E-30	Increasing	Yes
F07	14.51733	9.41E-48	Increasing	Yes
F09	3.390311	0.000698	Increasing	Yes
F19	1.161254	0.245539	Increasing	No
F20	0.863757	0.387722	Increasing	No
G501	-6.47851	9.26E-11	Decreasing	Yes
H01	14.92976	2.11E-50	Increasing	Yes
M05	12.5529	3.83E-36	Increasing	Yes
M06	7.221901	5.13E-13	Increasing	Yes
M07	12.29805	9.28E-35	Increasing	Yes
M12	-0.64678	0.517775	Decreasing	No
M14	5.215587	1.83E-07	Increasing	Yes
M15	4.623728	3.77E-06	Increasing	Yes

(cont.)

Well	z-value	p-value	Trend Direction	Significance
M17A	1.267522	0.204969	Increasing	No
M17B	2.068472	0.038596	Increasing	Yes
M18	-5.06371	4.11E-07	Decreasing	Yes
M20A	0	1	Decreasing	No
M21	-0.71377	0.475372	Decreasing	No
Y01	14.62232	2.02E-48	Increasing	Yes
Y02	15.34077	4.08E-53	Increasing	Yes
Y03	12.61499	1.75E-36	Increasing	Yes
Y04A	13.77168	3.77E-43	Increasing	Yes
Y05	13.34953	1.19E-40	Increasing	Yes
Y06	9.413736	4.79E-21	Increasing	Yes
Y07	5.737829	9.59E-09	Increasing	Yes
Y09	6.218908	5.01E-10	Increasing	Yes
Y10	0.612858	0.53997	Increasing	No
Y12	0.455763	0.64856	Increasing	No
Y14	2.377	0.017454	Increasing	Yes
Y16	0.475147	0.634682	Increasing	No
Y17	-2.82474	0.004732	Decreasing	Yes
Y18	1.627862	0.103554	Increasing	No
Y19	-1.16807	0.242778	Decreasing	No
Y20	0.491915	0.622779	Increasing	No
Y21	1.491599	0.135804	Increasing	No
Y22	-1.19696	0.23132	Decreasing	No
Y23	-3.16589	0.001546	Decreasing	Yes
Maui Well	-3.89939	9.64E-05	Decreasing	Yes

D.3 Hagåtña Basin

Well	z Statistic	p-value	Trend Direction	Significant
A01	9.157441	5.31E-20	Increasing	Yes
A02	13.30176	2.26E-40	Increasing	Yes
A03	10.67418	1.34E-26	Increasing	Yes
A04	18.33347	4.47E-75	Increasing	Yes
A05	13.08158	4.20E-39	Increasing	Yes
A06	14.3381	1.26E-46	Increasing	Yes
A07	9.126625	7.07E-20	Increasing	Yes
A08	12.65123	1.10E-36	Increasing	Yes
A09	15.38587	2.04E-53	Increasing	Yes
A10	13.85141	1.25E-43	Increasing	Yes
A12	11.68897	1.45E-31	Increasing	Yes
A13	13.30181	2.26E-40	Increasing	Yes
A14	3.697127	0.000218054	Increasing	Yes
A15	7.457858	8.79E-14	Increasing	Yes
A17	2.846021	0.004426927	Increasing	Yes
A18	7.124512	1.04E-12	Increasing	Yes
A19	7.321586	2.45E-13	Increasing	Yes
A21	12.11477	8.82E-34	Increasing	Yes
A23	7.790581	6.67E-15	Increasing	Yes
A25	6.848649	7.46E-12	Increasing	Yes
A26	2.913886	0.003569601	Increasing	Yes
A28	-2.45605	0.014047284	Decreasing	Yes
A29	1.645111	0.099946975	Increasing	No
A30	-0.48571	0.627171632	Decreasing	No
A31	4.581406	4.62E-06	Increasing	Yes
A32	4.692348	2.70E-06	Increasing	Yes
EX11	5.902365	3.58E-09	Increasing	Yes
NAS01	0.364349	0.715597499	Increasing	No

D.4 Mangilao Basin

Well	z-statistic	p-value	Trend Direction	Significant
M01	2.788597	0.005294	Increasing	Yes
M02	4.213446	2.52E-05	Increasing	Yes
M03	10.31965	5.74E-25	Increasing	Yes
M04	11.68808	1.47E-31	Increasing	Yes
M08	12.33728	5.70E-35	Increasing	Yes
M09	-0.03331	0.973424	Decreasing	No
M23	-1.65353	0.098222	Decreasing	No

Appendix E: STL Decomposition Summary Tables

E.1 Finagua'yok Basin

STL Decomposition Summary Table for the Finagua'yok Basin

Well ID	Seasonal Strength	Trend Class
D22A	0.012	Weak or negligible seasonality
D24	0.009	Weak or negligible seasonality
F10	0.029	Weak or negligible seasonality
F11	0.037	Weak or negligible seasonality
F12	0.052	Weak or negligible seasonality
F13	0.04	Weak or negligible seasonality
F15	0.07	Weak or negligible seasonality
F16	0.008	Weak or negligible seasonality
F17	0.009	Weak or negligible seasonality
F18	0.016	Weak or negligible seasonality
HGC2	0.203	Moderate seasonality

List of skipped wells in the Finagua'yok Basin

Well ID	Reason
F01	Missing values remained after interpolation
F02	Missing values remained after interpolation
F03	Missing values remained after interpolation
F04	Missing values remained after interpolation
F08	Missing values remained after interpolation

E.2 Tomhom Basin

STL Decomposition Summary Table for the Tomhom Basin

Well ID	Seasonal Strength	Trend Class
D15	0.019	Weak or negligible seasonality
D18B	0.047	Weak or negligible seasonality
D19	0.013	Weak or negligible seasonality
D20	0.008	Weak or negligible seasonality
D21	0.028	Weak or negligible seasonality
D25	0.082	Weak or negligible seasonality
D26	0.064	Weak or negligible seasonality
D27	0.103	Weak or negligible seasonality
D28	0.045	Weak or negligible seasonality
EX05	0.063	Weak or negligible seasonality
F05	0.035	Weak or negligible seasonality
F06	0.029	Weak or negligible seasonality
F07	0.03	Weak or negligible seasonality
F09	0.038	Weak or negligible seasonality
F19	0.068	Weak or negligible seasonality
F20	0.013	Weak or negligible seasonality
G501	0.086	Weak or negligible seasonality
M15	0.007	Weak or negligible seasonality
M17A	0.024	Weak or negligible seasonality
M17B	0.096	Weak or negligible seasonality
M18	0.214	Moderate seasonality
M20A	0.043	Weak or negligible seasonality
M21	0.024	Weak or negligible seasonality
Y03	0.051	Weak or negligible seasonality
Y05	0.083	Weak or negligible seasonality
Y07	0.003	Weak or negligible seasonality
Y09	0.016	Weak or negligible seasonality
Y10	0.039	Weak or negligible seasonality
Y12	0.077	Weak or negligible seasonality
Y14	0.151	Weak or negligible seasonality
Y16	0.063	Weak or negligible seasonality
Y17	0.023	Weak or negligible seasonality
Y18	0.039	Weak or negligible seasonality
Y19	0.004	Weak or negligible seasonality
Y20	0.002	Weak or negligible seasonality
Y21	0.26	Moderate seasonality
Y22	0.073	Weak or negligible seasonality
Y23	0.024	Weak or negligible seasonality

List of skipped wells in the Tomhom Basin.

Well ID	Reason
D01	Missing values remained after interpolation
D02	Missing values remained after interpolation
D03A	Missing values remained after interpolation
D04	Missing values remained after interpolation
D05	Missing values remained after interpolation
D06	Missing values remained after interpolation
D07	Missing values remained after interpolation
D08	Missing values remained after interpolation
D09	Missing values remained after interpolation
D10	Missing values remained after interpolation
D11	Missing values remained after interpolation
D12	Missing values remained after interpolation
D13	Missing values remained after interpolation
D14	Missing values remained after interpolation
D16	Missing values remained after interpolation
D17A	Missing values remained after interpolation
H01	Missing values remained after interpolation
M05	Missing values remained after interpolation
M06	Missing values remained after interpolation
M07	Missing values remained after interpolation
M12	Missing values remained after interpolation
M14	Missing values remained after interpolation
Maui Well	Missing values remained after interpolation
Y01	Missing values remained after interpolation
Y02	Missing values remained after interpolation
Y04A	Missing values remained after interpolation
Y06	Missing values remained after interpolation

E.3 Hagåtña Basin

STL Decomposition Summary Table for the Hagåtña Basin

Well ID	Seasonal Strength	Trend Class
A07	0.125	Moderate seasonality
A08	0.061	Weak or negligible seasonality
A21	0.073	Weak or negligible seasonality
A25	0.289	Weak or negligible seasonality
A26	0.123	Moderate seasonality
A28	0.02	Weak or negligible seasonality
A29	0.113	Weak or negligible seasonality
A30	0.325	Weak or negligible seasonality
A31	0.057	Moderate seasonality
A32	0.092	Weak or negligible seasonality
NAS01	0.09	Weak or negligible seasonality

List of skipped wells in the Hagåtña Basin

Well ID	Reason
A01	Missing values remained after interpolation
A02	Missing values remained after interpolation
A03	Missing values remained after interpolation
A04	Missing values remained after interpolation
A05	Missing values remained after interpolation
A06	Missing values remained after interpolation
A09	Missing values remained after interpolation
A10	Missing values remained after interpolation
A12	Missing values remained after interpolation
A13	Missing values remained after interpolation
A14	Missing values remained after interpolation
A15	Missing values remained after interpolation
A17	Missing values remained after interpolation
A18	Missing values remained after interpolation
A19	Missing values remained after interpolation
A23	Missing values remained after interpolation
EX11	Missing values remained after interpolation

E.4 Mangilao Basin

STL Decomposition Summary Table for the Mangilao Basin

Well ID	Seasonal Strength	Trend Class
M23	0	Weak or negligible seasonality

List of skipped wells in the Mangilao Basin

Well ID	Reason
M01	Missing values remained after interpolation
M02	Missing values remained after interpolation
M03	Missing values remained after interpolation
M04	Missing values remained after interpolation
M08	Missing values remained after interpolation
M09	Missing values remained after interpolation