December 23, 2024

DRAFT Memorandum

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From: Gus Yates, PG, CHG, Senior Hydrologist

Re: **County of Mendocino Coastal Groundwater Study -Application of Modeling Tools to Groundwater Planning and Management in the Coastal Area of Mendocino County**

INTRODUCTION

To assess the availability of groundwater supplies for land use planning, the County has relied on mapping of "water availability zones" from the Mendocino Coastal Ground Water Study prepared by the California Department of Water Resources in 1982. Because the County currently faces increasing challenges of drought and dry wells, and substantial new data are now available, the County wishes to update its understanding of coastal groundwater resources and to develop new tools to help implement proof of water procedures. Todd Groundwater (Todd) has prepared this report to address that update. It focuses on water-level effects that can become part of the proof of water testing procedures.

For this Coastal Groundwater Study, Todd developed four modeling tools to investigate factors associated with the occurrence of low groundwater levels and dry wells during droughts. This information can be used to update the Mendocino County's proof of water testing and analysis procedures prior to issuing development permits. In addition to providing adequate yield in gallons per minute, a well needs to be able to continue producing water when water levels are lower during droughts. The models identify factors affecting dry-season and drought-year water level declines. The models can also be used to identify geographic patterns that could be a basis for future groundwater planning and management. The four models include a 1) groundwater storage model, 2) rainfall-runoff-recharge model, 3) climate change model, and 4) seawater intrusion model. Highlights of the modeling results are described below, with additional technical details supplied in appendices.

In 2021, 19 wells in the coastal area of Mendocino County stopped producing water according to self-reported information provided by well owners to the California Department of Water

Resources' (DWR's) on-line Dry Well Reporting System[1], and an additional 18 dry wells were reported in inland parts of the County. Water years 2020-2021 were the driest 2-year sequence in the rainfall record at Fort Bragg, as shown in **Figure 1** (2020-2021 highlighted in red). Water years 2007-2009 and 2013-2014 were also recent significant droughts. The Dry Well Reporting System was not active until late 2014, and there is no documented record of whether or how many Mendocino County wells experienced a loss of production during prior droughts.

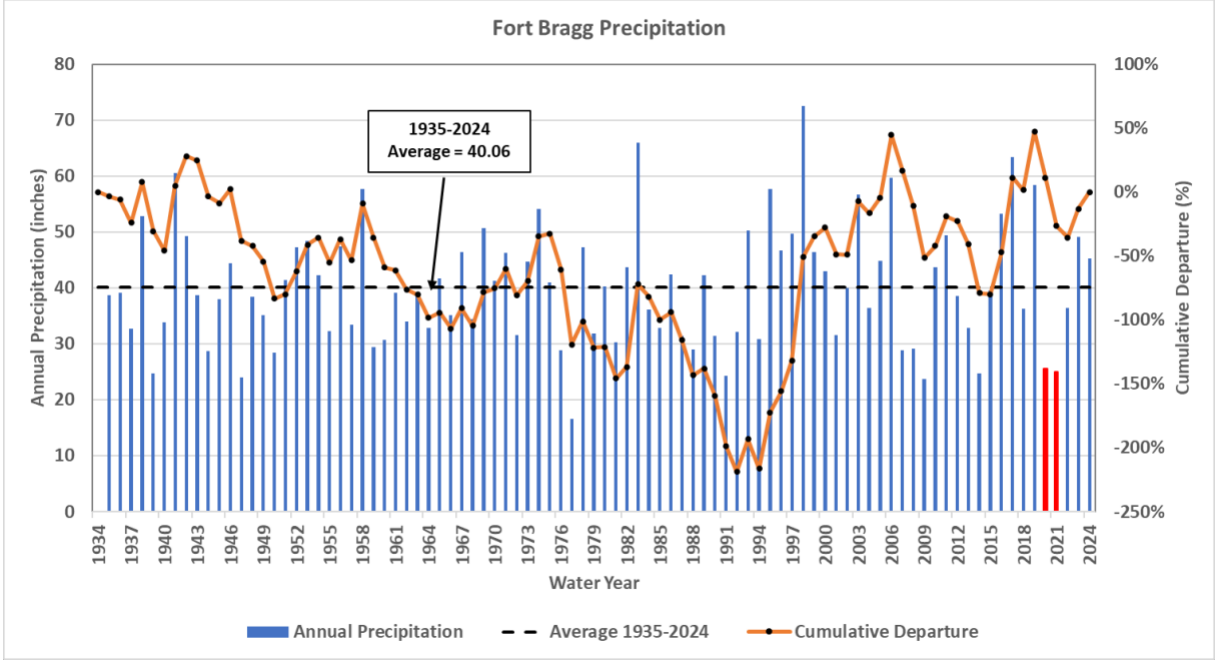


Figure 1. Annual Precipitation at Fort Bragg 1935-2024

Wells lose production when the water level in the well falls below the level of the pump intake. Well owners might describe their well as having gone dry at that point, even if there is water in the well from the pump down to the bottom of the well. In extreme cases, the water level might fall below the bottom of the well. Well owners typically do not know where the pump is set in the well, so the Dry Well Reporting System is likely to include many wells where the water level was below the pump but above the bottom of the well. Nevertheless, those wells are referred to as "dry" wells in this report.

HYDROGEOLOGIC CONCEPTUAL MODEL

Surficial Geology

A conceptual model of groundwater recharge and flow was the starting point for evaluating factors contributing to low groundwater levels. Water levels rise during the wet season—generally October-March—when most rainfall occurs and losses to evapotranspiration (ET) are small. Conversely,

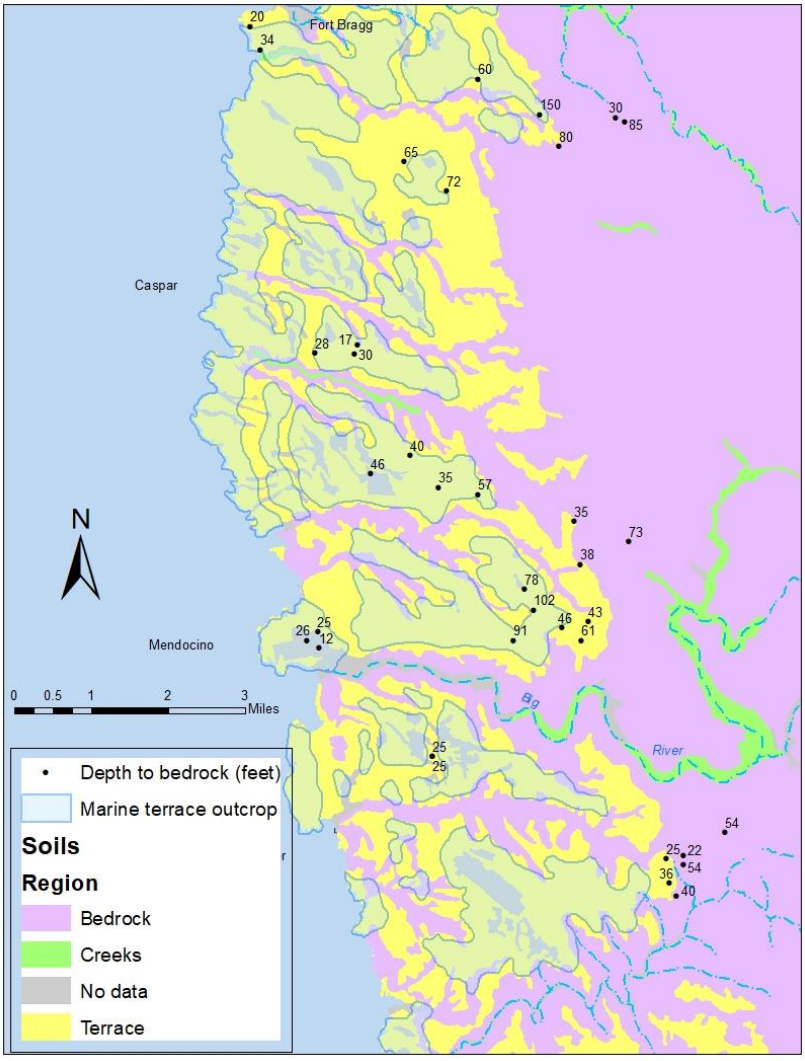
[1] DWR Dry Well Reporting System: https://mydrywatersupply.water.ca.gov/report/ accessed 5/15/2024

water levels fall during the dry season (April-September), due to negligible rainfall, seasonally high evapotranspiration and pumping, and natural outflow to creeks, rivers and the ocean. In terms of geology, the coastal groundwater system is composed of two principal formations: bedrock and terrace deposits.

The entire coastal and inland region is underlain by fractured bedrock. Unweathered bedrock stores and transmits relatively small amounts of groundwater in fractures. North of Point Arena, bedrock comprises the Franciscan Formation, which consists of sediments of various textures that have been converted into solid rock through metamorphosis and deformation over the past 66 or more million years. Between Point Arena and Gualala, the coastal area is underlain by a series of younger bedrock units decreasing in age from approximately 66 to 23 million years old. This "Gualala Block" bedrock similarly stores and transmits groundwater primarily in fractures.

The strip of relatively flat terrain present along much of the Mendocino County coastline was formed by wave action that eroded benches in the bedrock during high stands of sea level over the past 2 million years. Marine sediments were deposited on the benches and remain as marine terrace deposits discontinuously covering much of the coastal strip. The terrace deposits are variable in texture, thickness and elevation (DWR, 1982). The most common texture is sand or silty sand. Thicknesses range up to 140 ft but more commonly are a few tens of feet. Elevations range from 40 to 650 ft above sea level but are more common toward the low end of that range. From a groundwater standpoint, the marine terrace deposits are unconsolidated and as such are distinct from bedrock in having primary porosity, which is void space between the mineral grains that can store water. The 1982 report considered the marine terrace deposits to hold almost all of the usable groundwater storage in the coastal area.

Differences between the marine terrace areas and bedrock areas are not as clear-cut as suggested by the 1982 report. This is true from a mapping perspective and on the basis of well completion reports. Geologists, soil scientists and drillers disagree on the geographic locations of marine terrace deposits and on the presence of consolidated bedrock in the shallow subsurface. **Figure 2** is a map of part of the coastal region illustrating the differences. The blue-outlined polygons are outcrops of marine terrace deposits as shown in the Ukiah sheet of the Geologic Atlas of California (Jennings and Strand, 1960). The yellow shaded regions are where the U.S. Natural Resources Conservation Service mapped soils with bedrock at a depth greater than 5 feet in the county soil survey (SSURGO database) (NRCS, 2024). Those soils are located in the same general areas as the marine terrace outcrops but are in many cases more extensive. The purple shaded region contains soils mapped as having bedrock less than 5 feet below the ground surface. Finally, the black points are the locations of wells with well completion reports that include accurate location information (street address) and a clear demarcation between unconsolidated surficial deposits and consolidated bedrock. The point labels indicate the depth to bedrock reported by the driller. For points within the purple soil region, bedrock is almost always much greater than 5 feet below the ground surface.



Sources: Jennings and Strand (1960) for geology; NRCS (2024) for soils; this study for depth to bedrock

Figure 2. Map of Marine Terrace Deposits and Depth to Bedrock

The well completion reports suggest that in areas where the surficial geologic unit is bedrock, the solid rock is mantled by unconsolidated, weathered material. Importantly, that material may have primary porosity much like the marine terrace deposits, in which case water-level patterns might not be that different between the two regions. The thickness of surficial unconsolidated material in bedrock regions is further illustrated by **Figure 3**, which shows the cumulative distribution of depths to bedrock as reported by drillers on well completion report for wells in the purple region in Figure 2 (bedrock region defined by soils map) and for wells outside the marine terrace outcrops (bedrock region defined by geologic map). Both definitions of the bedrock region produced nearly identical results, with a uniform distribution of bedrock depths over a range of 0-80 feet.

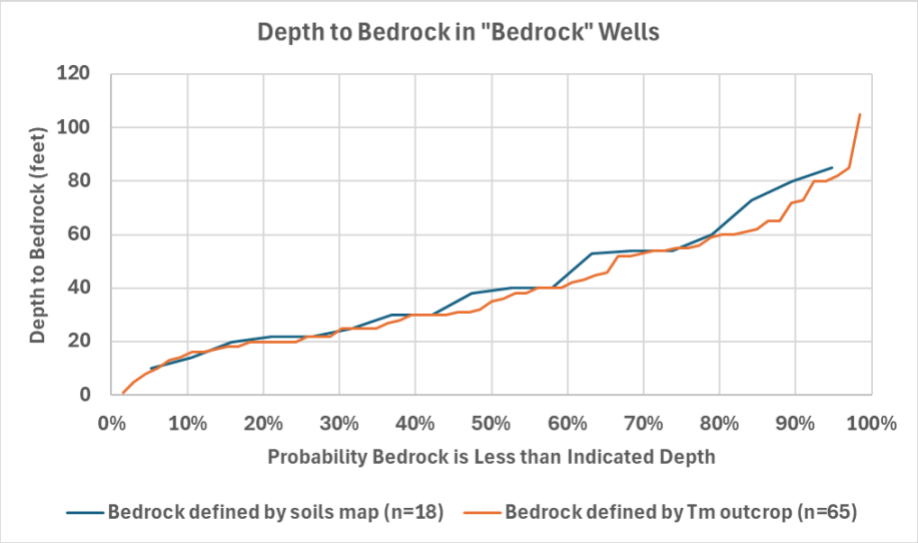


Figure 3. Cumulative Distribution of Depth to Bedrock in Bedrock Region Wells

These data indicate that groundwater storage and water levels in near-surface deposits might not be that different between areas mapped as marine terrace deposits and areas mapped as bedrock. This hypothesis was tested using the groundwater storage model described in a later section of this report.

Groundwater Storage Units

A component of the hydrogeologic conceptual model is that groundwater storage and flow in the coastal area is subdivided into functionally separate small storage units bounded by deeply incised streams. These streams function as natural drainage boundaries for groundwater storage in areas between the streams. The ocean functions as a similar boundary to the west. Wells that pump water from depths less than the depth of a nearby incised stream intercept groundwater that would naturally flow into that stream. Because the streams are hydraulically connected to groundwater and can supply as well as receive water to and from aquifers, pumping on one side of a stream would have little or no effect on groundwater storage and water levels on the opposite side.

Almost all domestic wells in the coastal area are less than 200 feet deep as shown by the cumulative distribution of well depths plotted in **Figure 4.** For all three of the well categories (terrace, bedrock and dry), 90 percent of the wells are less than 200 feet deep. The "dry well" category includes a mix of terrace and bedrock wells. Accordingly, streams incised 200 feet or more below the surrounding terrain were mapped as drainage boundaries to subdivide the coastal area into groundwater storage units. Long, narrow storage units—such as occur along mountain slopes bordering a major creek—were additionally subdivided into roughly square segments to better reflect the region over which a well could access groundwater storage and affect water levels. This produced 211 groundwater storage units. An excerpt showing units in the Fort Bragg-Mendocino area is shown in **Figure 5**, and a complete map is provided in **Appendix A**.

The large number and small size of the groundwater storage units demonstrate that the relevant scale for considering groundwater balances is local. The rainfall-runoff-recharge model was used to develop estimates of recharge for each storage unit.

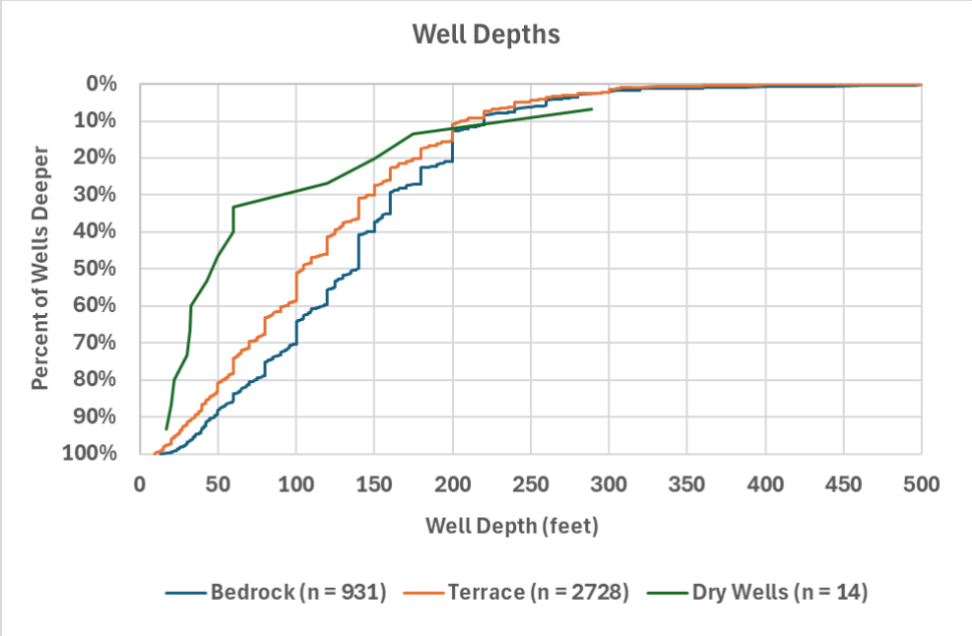


Figure 4. Cumulative Distribution of Well Depths

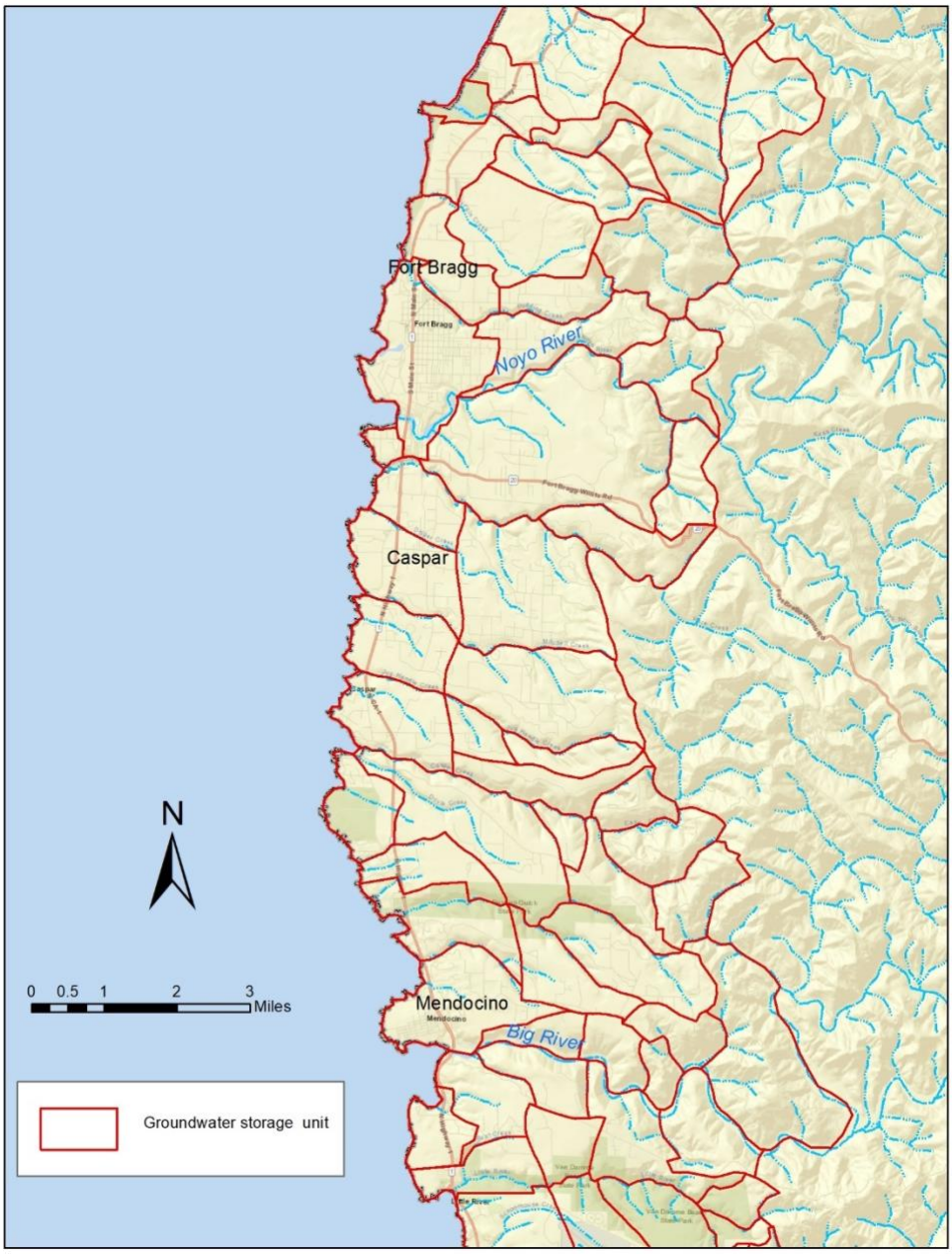


Figure 5. Map of Groundwater Storage Units

Groundwater Recharge and Discharge

Groundwater recharge in the storage units derives almost entirely from infiltrated rainfall, which raises the water table and increases groundwater storage during the wet season. During the dry season, storage declines due to pumping, evaptranspiration by deep-rooted plants and natural drainage to the creeks and ocean. In wet years, recharge is greater, and available storage is relatively high at the beginning of the dry season. In dry years with less winter recharge, available storage is smaller, and water levels decline farther during the dry season. In two successive dry years, cumulative water level declines can be large enough to cause some wells to stop producing

water. This occurred during 2020-2021. **Figure 6** shows a cross-sectional diagram of this conceptual model of water table profiles and flow paths.

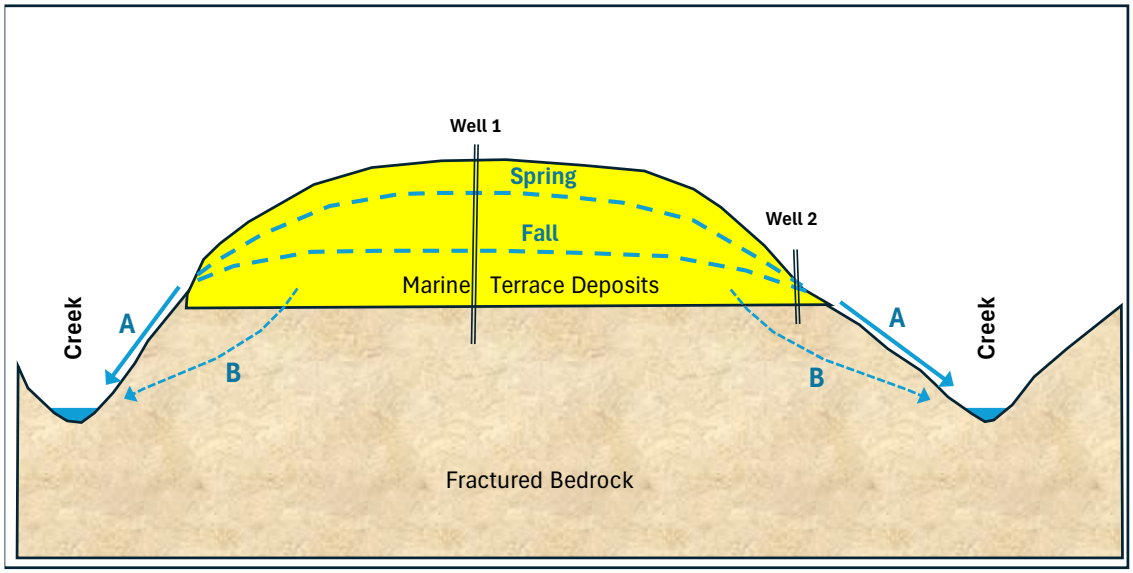


Figure 6. Cross-Sectional Diagram of Storage Unit Flow and Water Levels

Because of the high contrast in permeability between marine terrace (or weathered bedrock) deposits and the underlying unweathered bedrock, groundwater in the terrace deposits typically flows horizontally faster than it percolates downward into bedrock fractures. The horizontal flow emerges as springs and seeps along the contact between the two geologic units, represented by flow path A in the diagram. This flow path is illustrated by the photograph of a coastal bluff at the Mendocino Headlands shown in **Figure 7**. The marine terrace deposits appear as an orange layer overlying the dark gray bedrock. The photograph was taken in March 2024, and water can be seen emerging along the contact and cascading down to the beach below. Groundwater in fractured bedrock also gradually discharges to incised streams or directly to the ocean, as represented by flow path B in the diagram.



Photo credit: Gus Yates

Figure 7. Photograph of Groundwater Discharge along Coastal Bluff at Mendocino Headlands

GROUNDWATER STORAGE MODEL

The groundwater storage conceptual model involves a set of graphs (linear regression tests) and maps that use available data to show the relationships between annual and seasonal changes in groundwater levels and to examine various factors that could explain those changes based on the hydrogeologic conceptual model. Groundwater storage is directly related to groundwater levels. Both decline during dry periods, such that limitations on groundwater availability and the occurrence of "dry" wells are both linked to low groundwater levels.

Four water-level data sets were used to quantify the effects of various factors on seasonal and annual water-level changes and on the occurrence of dry wells. The four data sets are described below, and the corresponding well locations were shown on maps included in the Task 1-2 report for the 2024 Coastal Groundwater Study:

- **Geotracker.** A geodatabase was constructed for this project and populated with water level and well depth information from multiple public agency databases including the State Water Resources Control Board's (SWRCB's) Geotracker database, the California Department of Water Resources' (DWR's) CASGEM database and Sustainable Groundwater Management Act database, SWRCB's Drought & Conservation Reporting Program (SAFER

database), and the U.S. Geological Survey's National Water Information System database.[2] For convenience, the geodatabase is referred to as the Geotracker database in this report. This database includes data for 19 coastal wells with accurate location information and 4 or more years of water-level data. A map of well locations is included in Appendix A.

- **MCCSD.** The Mendocino City Community Services District (MCCSD) data set includes 20 wells in Mendocino City with approximately biweekly measurements during 2002-2009 and approximately monthly measurements from 2010 to the present (Rhoades, 2024). A map of well locations is included in Appendix A.
- **Dry Wells.** DWR's Dry Well Reporting System has information for 19 wells in the coastal area of Mendocino County that stopped producing water in 2021 according to the well owners. The database includes self-reported well locations and depths.[3]
- **Volunteer Wells.** A public outreach effort in spring 2024 fielded 24 private well owners willing to measure depth to water in their well monthly for one year. Simple weighted-string measuring devices were provided, and 16 of the individuals followed through with the measurement program.

Using the available data, fifteen statistical and mapping tests were conducted to systematically examine the relationships of groundwater levels to various factors. Water-level patterns that were examined included:

- Spring depth to water (distance from the ground surface down to the water surface in the well)
- Spring-to-spring water-level change
- Spring-to-fall water-level decline
- Occurrence of "Dry" wells in 2020-2021

Factors that were tested for correlation with those patterns included:

- Current-year precipitation
- Wellhead elevation
- Surficial geology (marine terrace deposits versus bedrock)
- Distance to geologic or flow boundary
- Water-level gradient to geologic or flow boundary
- Surrounding development density
- Average annual recharge
- Well depth
- Water availability zone

[2] Geotracker: https://geotracker.waterboards.ca.gov/ accessed 3/25/2024
CASGEM: https://casgem.water.ca.gov/ accessed 3/25/2024
SGMA: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels accessed 3/22/2024
SAFER: https://www.waterboards.ca.gov/safer/safer_data.html accessed 3/26/2024
NWIS: https://waterdata.usgs.gov/nwis/gw accessed 3/26/2024

[3] DWR dry well data: https://data.cnra.ca.gov/dataset/dry-well-reporting-system-data accessed 10/10/2023

The fifteen tests are documented below, and the importance of major and minor factors are summarized in **Table 2** following this section. The purpose of the tests is to identify factors that substantially affect groundwater levels, so that management efforts can focus on those factors that lead to unusually low water levels. In a well that normally provides adequate yield, problems only occur when water levels drop to unusually low levels.

Many of the tests are linear regression tests, which essentially fit a line through a scatterplot of data points relating the two variables. This is a common and standard method to compare the relationship between two variales. If the regression line is horizontal, the variables are unrelated. In many cases, the regression line has a slope, but the slope is not statistically different than zero (horizontal). The significance test is a t-test based on the ratio of the slope of the line to the standard deviation of the data points. The ratio is compared with tables that indicate the probability that the slope is significantly different from zero. For this study probability thresholds of 90 percent and 95 percent were evaluated, which are commonly used thresholds of significance. To be significant, the slope of the line must be large relative to the scatter in the data.

Test 1. Spring-to-Spring Water-Level Change Versus Precipitation

It is logical to expect spring groundwater elevations to be higher (that is, depths to water to be smaller) following a wet winter than a dry winter. The relationship between spring-to-spring change in depth to water and water-year annual precipitation at Fort Bragg is shown for a well in the Geotracker database in **Figure 8**. Water years begin in October and end the following September and are numbered by the calendar year in which they end. Annual water-year precipitation is a reasonable surrogate for precipitation prior to spring water level measurements because on average 85 percent of annual precipitation falls during October-March. It is also reasonable to use the Fort Bragg station as representative of annual variations in precipitation because storm systems are usually regional in scale and a dry or wet year in Fort Bragg would also be a dry or wet year at other locations along the Mendocino County Coast.

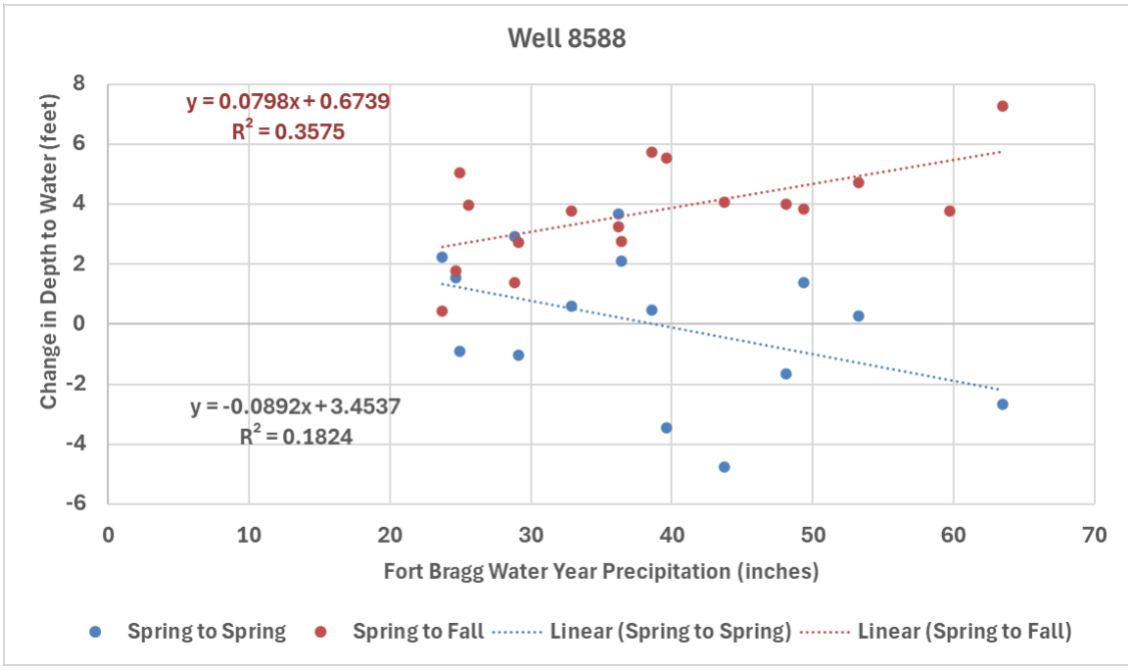


Figure 8. Relationship between Spring Depth to Water and Water-Year Precipitation

The spring-to-spring change in water level is indicated by the blue points and regression line in Figure 8. (A regression line through the data shows the relationship between the two variables). As expected, the slope is negative, meaning that higher amounts of winter precipitation resulted in smaller depths to water in spring. In the above example, the regression slope of -0.089 indicates that for every additional inch of precipitation in winter, the depth to water in the well the following spring is typically 0.089 foot less than it was the previous spring. This pattern of significant negative regression slopes was very consistent across both data sets: in 18 of the 19 Geotracker wells and all 20 of the MCCSD wells. For most of the wells the period of record is too short (i.e. too few data points in the scatterplot) for the slope to be statistically significant. However, the nearly universal negative slope direction among the wells indicates a meaningful relationship.

Test 2. Spring-to-Fall Water-Level Decline Versus Precipitation

If water-level declines during the summer dry season are due primarily to groundwater pumping, the spring-to-fall water-level would be similar every year, because indoor water use is essentially the same every year and irrigation demand varies much less from year to year than precipitation does. On the other hand, if spring-to-fall water-level declines are primarily due to groundwater outflow at the boundaries of the groundwater storage units, declines would be greater in wet years than dry years. This is because the outflow rate is head-dependent, which means that higher spring water levels (higher hydraulic head) in the interior parts of the storage unit create a steeper hydraulic gradient toward the outflow boundary (which has essentially a constant elevation). The steeper gradient causes increased flow rates and consequently greater water-level declines.

To determine which pattern was most common, spring-to-fall water level declines were plotted against annual rainfall. Figure 8 shows the data as red points and red regression line. The data are also shown on the plots for all Geotracker and MCCSD water-level wells in Appendix A. The head-dependent outflow hypothesis would be corroborated by positive regression slopes, indicating larger spring-to-fall declines in wet years. This was the case in most wells: 16 of 19 wells in the Geotracker data set and 16 of 20 wells in the MCCSD data set. Notably, the four wells that showed an opposite trend (e.g., smaller spring-to-fall declines in wet years) were four of the five wells located east of Highway 1 in steeper terrain dominated by bedrock.

The MCCSD data set differs from the Geotracker data set in some ways, one of which is that the intensity of groundwater pumping is relatively high in Mendocino City. In spite of the intense pumping, the positive slopes of the regression line relating spring-to-fall water level decline to annual precipitation indicate that natural groundwater drainage along the perimeter of the marine terrace outcrop is still significant.

Test 3. Spring Depth to Water Versus Wellhead Elevation

Inland of the coastal plain, there are high, steep ridges between the creeks. Marine terrace deposits are less common in these interior areas, so groundwater flow is in most cases through fractured bedrock and some thickness of surficial weathered bedrock. If the permeability of bedrock is relatively high, the spring water table would be far below the ridgetops because groundwater would flow out to the creeks more easily, which would limit the amount of water-table mounding beneath

the ridges. Conversely, if permeability is low, the spring water table would follow the land surface more closely.

This issue was investigated using a comparison of spring depth-to-water and wellhead elevation, assuming wellhead elevation generally correlates with topographic position on the ridges. The Geotracker data set was used for this test because the MCCSD wells are almost all on the coastal plain. In this test, there is one data point per well, which is the average spring depth to water over the period of record for that well. There were enough wells that the significance of the regression slope could be tested more reliably. The results are shown in **Figure 9**. The regression line suggests a slight correlation between spring depth-to-water and wellhead elevation, but the slope is not statistically different from zero. In other words, the slope of the regression line is not steep enough to statistically overpower the large degree of scatter in the data (low r-squared value). This supports a conclusion that bedrock permeability is relatively low.

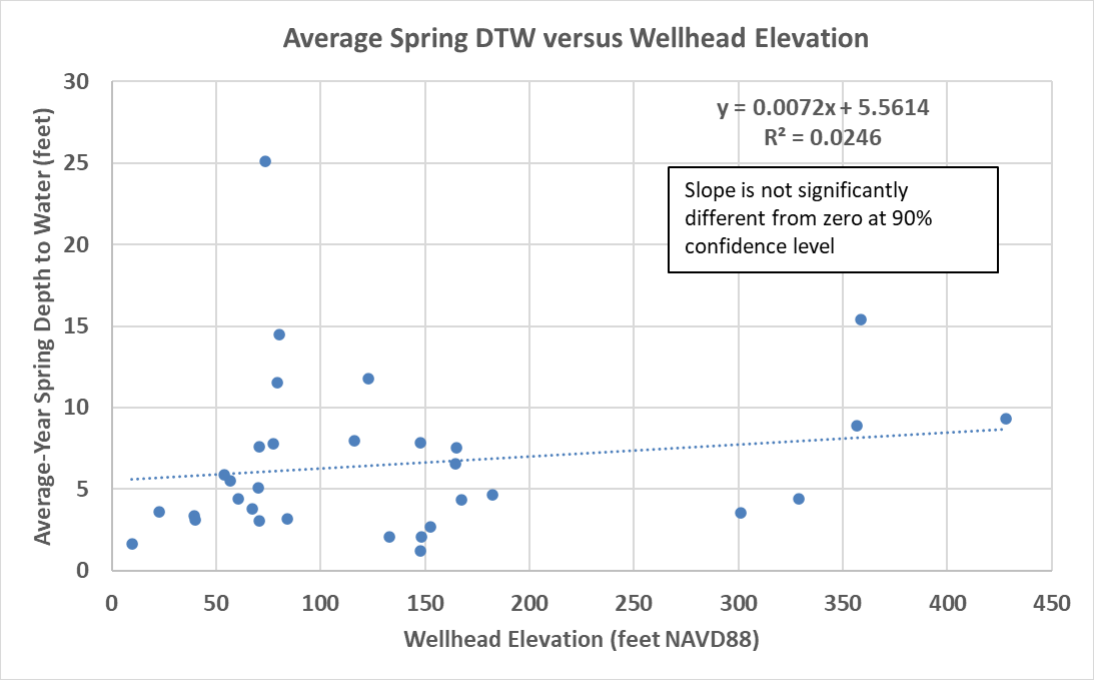


Figure 9. Relationship of Spring Depth to Water and Wellhead Elevation

Test 4. Spring-to-Fall Water-Level Decline Versus Wellhead Elevation

Unlike spring depth-to-water, the amount of dry-season water-level decline does correlate with wellhead elevation. This is demonstrated by the graph in **Figure 10**, which is a scatterplot of spring-to-fall water-level decline versus wellhead elevation for the Geotracker wells. These two patterns are consistent if bedrock permeability and storativity are relatively low and precipitation is relatively high at high elevations. Under those conditions, rainfall recharge is able to raise the water table to within 15 feet of the land surface at all elevations in most years (see Figure 9). During the dry season, groundwater at high elevations flows toward the creeks that form the drainage boundaries of the groundwater storage units. The flow from higher elevations replaces groundwater from

slightly lower elevations that is also flowing toward those same boundaries. So, the largest dry-season water-level declines occur at the highest elevations, beneath the ridge crests. This suggests that elevation might be a factor to consider in land use planning related to groundwater. However, the elevation effect is not large. Over a range of 350 feet of elevation, the difference in average dry-season water-level decline is approximately 4 feet.

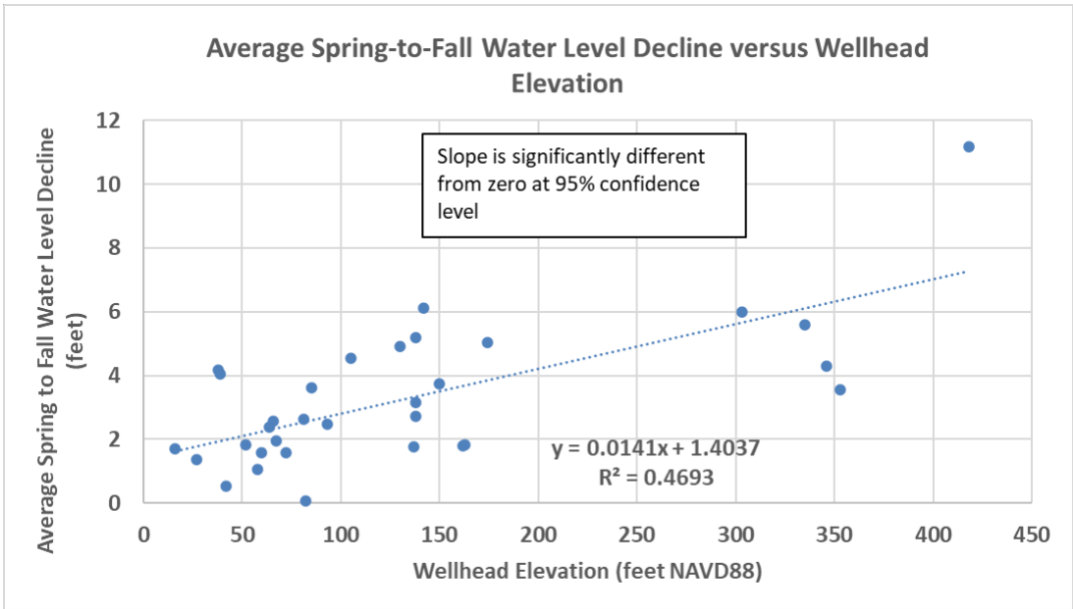


Figure 10. Relationship of Spring-to-Fall Water-Level Decline and Wellhead Elevation

Test 5. Spring-to-Fall Water-Level Decline Versus Distance to Boundary

If groundwater drains toward the edges of the groundwater storage units, one would expect the largest dry-season water-level declines to occur near the center of the storage units, far from the boundaries. In contrast, water levels in wells close to the drainage boundaries are expected to remain relatively stable because the drainage boundary elevation (creek or ocean elevation) is essentially constant and groundwater near the discharge boundary is supplied by inflow from upgradient areas. A simple test is to plot dry-season water-level decline versus distance to the drainage boundary. This is shown in **Figure 11** for the Geotracker well data set.

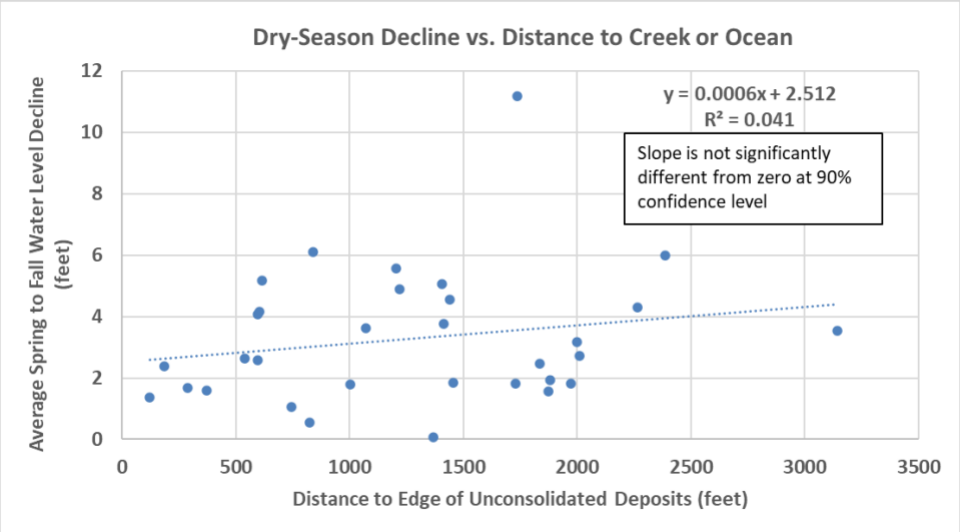


Figure 11. Relationship of Spring-to-Fall Water-Level Decline and Distance from Boundary

Although the data showed a slightly positive slope, it was not statistically significant. Two measurement issues could have contributed to the lack of correlation. First, at coastal bluffs the distance to the edge of the marine terrace outcrop is nearly the same as the distance to the ocean boundary. The dry-season water-level decline would be different depending on whether groundwater flow is controlled by the elevation of the terrace-bedrock contact or elevation of the ocean. Second, the boundaries of the yellow-shaded soil units in Figure 2—which were assumed to be the discharge boundaries—are convoluted, and accurately selecting a distance to the boundary is consequently difficult.

Test 6. Spring-to-Fall Water-Level Decline Versus Gradient to Boundary

Groundwater flows in proportion to the water-level gradient. Thus, dry-season water level declines should correlate more highly with the water-level gradient between a well and the discharge boundary than with the distance to the boundary. For this test, creek and ocean elevations were used to define the hydraulic gradients rather than the estimated elevation of the terrace-bedrock contact. This enabled more accurate estimates of distances and elevations. The results for the Geotracker data set are shown in the scatterplot in **Figure 12.** These data exhibit a statistically significant correlation.

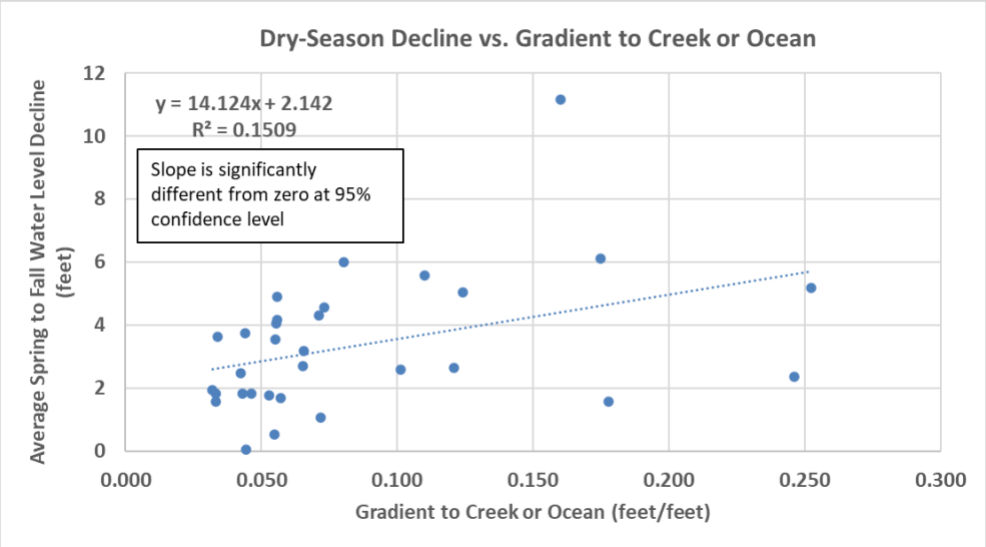


Figure 12. Relationship of Spring-to-Fall Water-Level Decline and Gradient to the Flow Boundary

Test 7. Spring-to-Fall Water-Level Decline Versus Surficial Geology

The 1982 groundwater study and well completion reports paint very different pictures of near-surface geology. The 1982 study asserted a very high contrast between areas mapped as marine terrace deposits and areas mapped as bedrock. The assumption was that bedrock areas have very little groundwater storage capacity. Well completion reports, on the other hand, commonly show up to 80 feet of unconsolidated material—probably weathered bedrock—extending down from the ground surface to the contact with solid, unweathered bedrock. If the surficial materials in those areas also have primary porosity and significant groundwater storage capacity, water-level patterns for the two geologic areas—marine terraces and bedrock—might be similar.

This issue was tested by comparing the average spring-to-fall water-level decline for wells in marine terrace areas with the average for wells in bedrock areas. In this case, the marine terrace outcrops from the geologic map were used to classify the wells (see Figure 2). The distributions of average dry-season water-level declines for wells in the two regions are compared as boxplots in **Figure 13**. Boxplots illustrate the range and distribution of data around the median value, including outliers. Visually, declines appear to be generally larger in bedrock regions than in marine terrace regions. The mean values for the two groups were barely different statistically (only for a one-tailed test at a 90 percent confidence level, not for a two-tailed test or 95 percent confidence level). This supports a conclusion that surficial groundwater storativity is generally higher in marine terrace outcrop areas but not by as much as was assumed in the 1982 study.

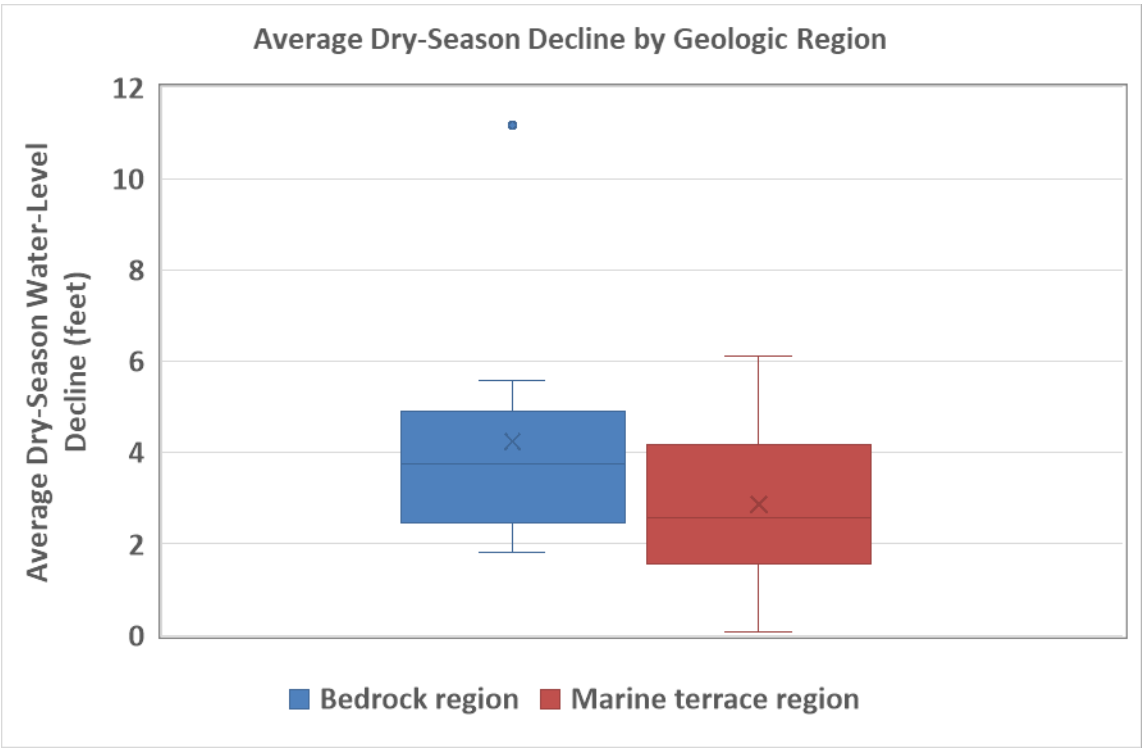


Figure 13. Relationship of Spring-to-Fall Water-Level Decline and Geologic Region

Test 8. Effect of Rural Residential Development on Groundwater Budget

It is commonly assumed that land development decreases groundwater recharge, but this is not necessarily the case. Groundwater recharge in rural residential areas can be the same as or higher than occurred prior to development. It is useful to consider the overall groundwater balance when comparing the natural condition with the post-development condition. The differences are illustrated schematically in **Figure 14**. Under natural conditions (upper plot), deep percolation occurs when infiltrated rainfall fills the soil moisture storage capacity of the vegetation root zone. Deep percolation recharges a shallow groundwater zone that gradually drains toward creeks or the ocean.

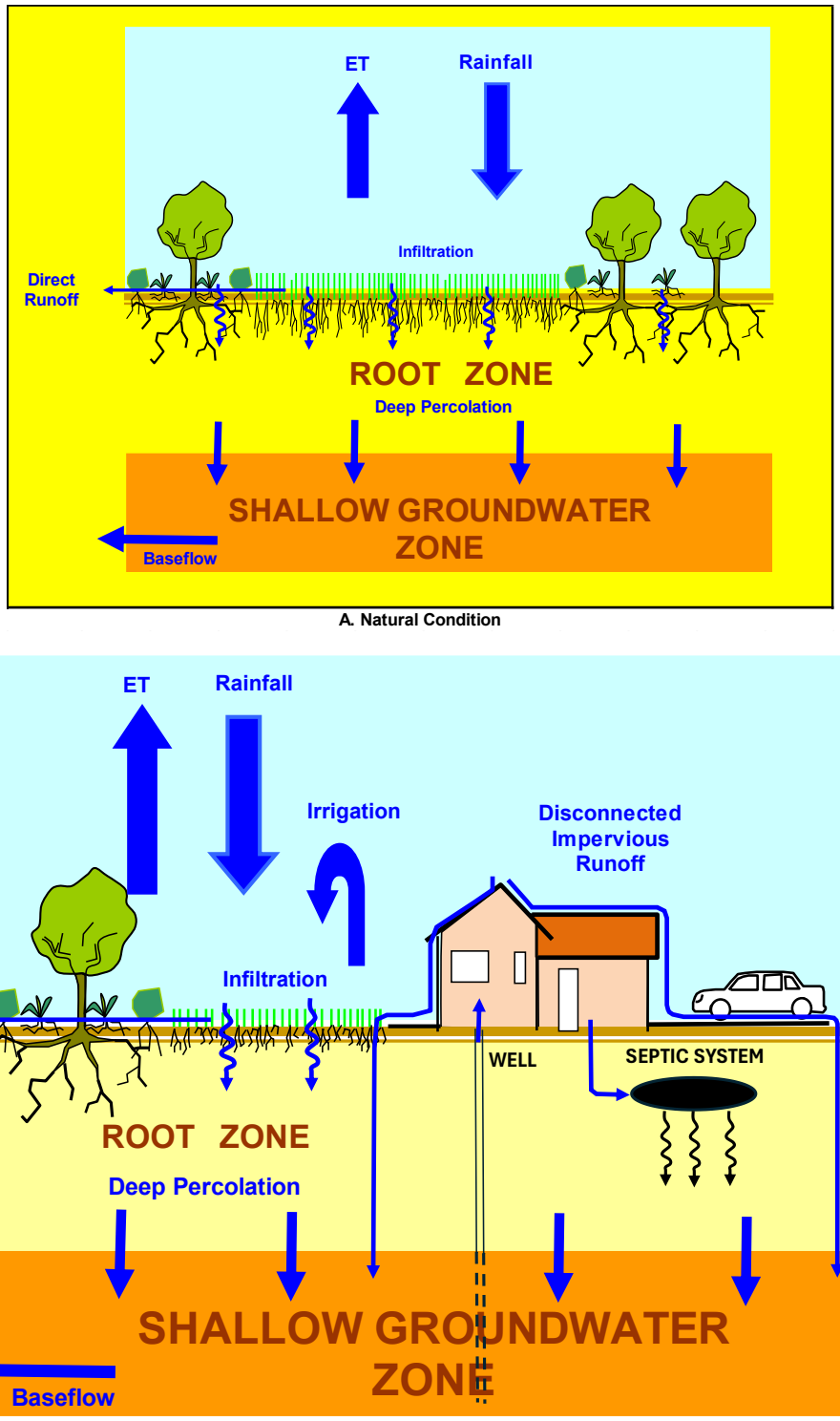


Figure 14. Effect of Rural Residential Development on Groundwater Budget

Rural residential development creates new recharge flows and alters others. An on-site well supplies indoor and outdoor water uses. Nearly all indoor use returns to the aquifer as percolation

from the on-site septic system leach field. Development replaces vegetated areas with impervious surfaces. In rural residential development, rainfall runoff from rooftops, driveways, patios and roads flows toward adjacent soil areas, where it infiltrates and adds to the infiltration from rain falling directly on those areas. This concentrated infiltration tends to rapidly fill the soil moisture storage capacity and generate deep percolation out of the root zone. Consequently, a relatively high percentage of impervious surface runoff can become recharge. Much of that is water that would have been transpired by vegetation in the locations of the impervious surfaces. If landscape vegetation around the house has shallower roots than natural vegetation—the likely case for turf, flowers and vegetables—rainfall recharge is also higher because the root zone storage capacity is smaller. Less cumulative rainfall is needed during the wet season to saturate the root zone and initiate deep percolation. Runoff from streets that flows down unlined roadside ditches also has an opportunity to percolate before reaching a large creek that conveys it out of the area.

The diagram shows three aspects of development that can strongly influence the local groundwater balance:

- **Sewering.** If septic systems are replaced by sewers that convey the wastewater to an off-site treatment plant, a major source of groundwater recharge is removed.
- **Irrigation.** Irrigation results in consumptive use of groundwater and has a negative impact on the groundwater balance. Google Earth imagery and interviews with some rural residents in the coastal area indicate that most rural residences have only small amounts of irrigated area, commonly for vegetable gardens.
- **Stormwater infrastructure.** If runoff from impervious areas is directed to gutters, culverts and lined channels, it has no opportunity to infiltrate and contribute to groundwater recharge. This type of stormwater infrastructure eliminates a significant source of recharge.

The benefit of percolating runoff from impervious surfaces can be demonstrated by comparing recharge when land is covered with natural vegetation with runoff after that land is converted to impervious surfaces. If most of the impervious runoff percolates nearby, total recharge is greater than under the natural condition. This is illustrated for a hypothetical conversion of 2,000 square feet of grassland or forest to impervious surfaces using results from the rainfall-runoff-recharge model discussed in a later section of this memorandum. **Figure 15** compares average annual rainfall recharge for grassland and forest vegetation with impervious runoff for two hydrologic periods. The average for water years 1975-2024 represents average annual conditions and the average for 2020-2021 represents extremely dry conditions. The results were for grassland and forest areas in the coastal plain with average annual rainfall of 43 in/yr.

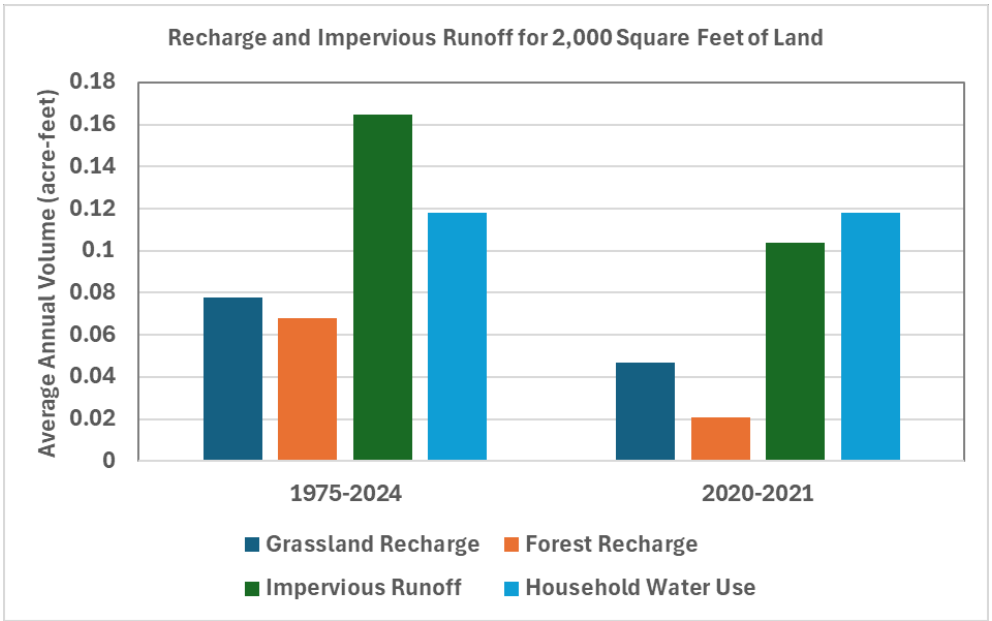


Figure 15. Comparison of Recharge, Runoff and Water Use

Runoff from impervious surfaces is much greater than recharge beneath an equal area of vegetation because there is no loss of water to evapotranspiration. Recharge is smaller under forested conditions relative to grassland conditions because the larger root depths of trees allow a greater percentage of infiltrated rainfall to be transpired over the course of a year. On an average annual basis, total recharge on the site increases if half or more of the impervious runoff infiltrates and percolates past the root zone in soil areas next to the impervious surface. The contrast is greater under drought conditions because vegetation can capture and use a greater percentage of annual rainfall. Under 2020-2021 conditions, total recharge on the site increases relative to grassland if only 45 percent of impervious runoff becomes recharge, and it increases relative to forest if only 20 percent of impervious runoff becomes recharge.

The additional increment of recharge that can be obtained from infiltrating impervious runoff is a significant percentage of typical household water use. Water use data for 21 public water systems in the coastal area were obtained from SWRCB's SAFER database or directly from the purveyors. The data are summarized in **Table 1**. For systems using only groundwater, per-capita water use averaged 35 gallons per day (gpcd). Assuming three residents per rural household, annual household water use would be 0.118 AFY and is shown as the light blue bars in Figure 15. The potential additional recharge from infiltrating impervious runoff equals 74-82 percent of annual household water use on a long-term average basis and 48-70 percent under 2020-2021 conditions. It is unlikely that all of the impervious runoff would infiltrate and percolate past the root zone, but even a moderate capture efficiency would provide volumes of recharge that are on the same order of magnitude as natural recharge and household water demand.

Table 1. Total and Per Capita Water Use in Coastal Small Water Systems

System Name	Population Served	Annual Water Use in Calendar Year 2023 (acre-feet)			Per Capita Groundwater Pumping (gal/person/day)
		Groundwater	Surface Water	Total	
ALBION MUTUAL WATER COMPANY	56	1.43	0.00	1.43	22.9
BELLA SHORES MOBILE HOME PARK	80	3.86	0.00	3.86	43.1
BIG RIVER VISTA MUTUAL WATER COMPANY	36	1.41	0.00	1.41	34.9
CASPAR SOUTH SERVICE COMPANY	188	8.08	0.00	8.08	38.3
DOLPHIN ISLE MARINA	560	4.52	0.00	4.52	7.2
ELK COUNTY WATER DISTRICT	380	24.06	0.00	24.06	56.5
FORT BRAGG, CITY OF	6,000	0.00	645.00	645.00	
HILLS RANCH MUTUAL WATER COMPANY	79	4.71	0.00	4.71	53.2
HOLLY RANCH VILLAGE	50	1.94	0.00	1.94	34.7
IRISH BEACH WATER DISTRICT	254	1.71	15.42	17.13	
MANCHESTER UNION ELEMENTARY SCHOOL	75	0.23	0.00	0.23	2.7
MENDOCINO SCHOOL DISTRICT- MENDOCINO	579	5.15	0.00	5.15	7.9
MENDOCINO SCHOOL DISTRICT-ALBION SCHOOL	25	0.15	0.00	0.15	5.3
MONTESSORI DEL MAR LEARNING CENTER	50	0.15	0.00	0.15	2.6
NORTH GUALALA WATER COMPANY	2,593	119.47	29.36	148.83	
POINT ARENA, CITY OF	415	25.20	0.00	25.20	54.2
POINT CABRILLO HIGHLANDS	42	0.86	0.00	0.86	18.4
SEAFAIR ROAD AND WATER COMPANY	50	3.43	0.00	3.43	61.2
SHORELANDS ROAD & WATER COMPANY	78	6.65	0.00	6.65	76.1
WOODS, THE (MENDOCINO)	157	11.90	0.00	11.90	67.6
WESTPORT COUNTY WATER DISTRICT	369	0.00	11.11	11.11	
TOTAL	**12,116**	**225**	**701**	**926**	**Average = 35**

Notes:
Populations are as of 2020. City populations might not equal service area populations.

Test 9. Effect of Nearby Development Density on Seasonal Water-Level Declines

The effect of development on the local groundwater budget was investigated by comparing the amount of dry-season water-level decline in wells over a range of nearby development densities. Development density was represented by the number of buildings within 1,000 feet of each Geotracker water-level well. Using Google Earth imagery, all residences, commercial buildings and large agricultural buildings visible in rural areas throughout the coastal region were digitized as points. It is reasonable to assume that those buildings are occupied by people and have an on-site well supplying domestic or commercial water demands. This produced a digital map of 4,856 probable wells located outside the 51 public water system service areas in the coastal region. An excerpt of the map is shown in **Figure 16**, including the locations of several Geotracker wells. Buildings within 1,000 ft of the Geotracker wells are indicated by a different color.

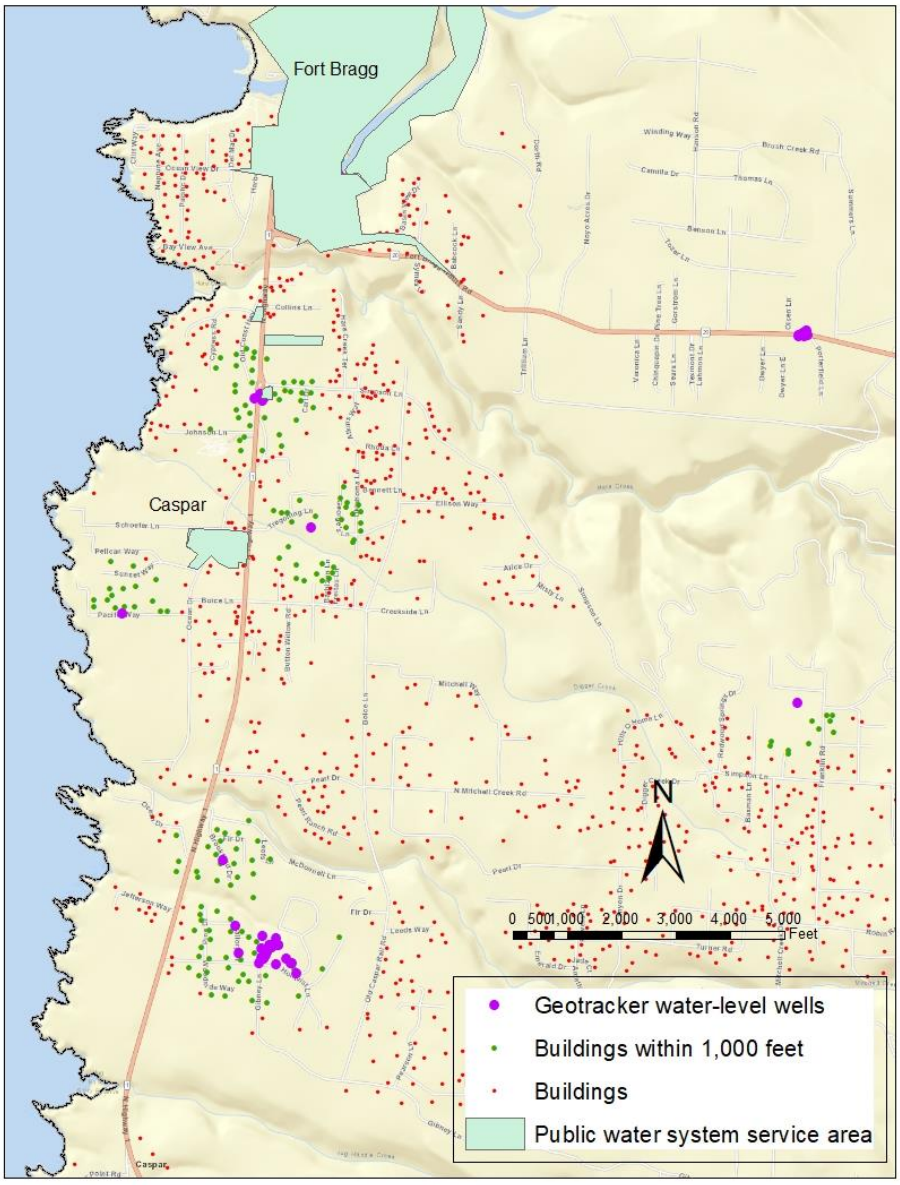


Figure 16. Map Illustrating Buildings Within 1,000 Feet of a Water-Level Analysis Well

If rural development has a negative impact on the local groundwater budget, one would expect higher development density to be associated with larger dry-season water-level declines. This hypothesis was tested by plotting the average dry-season water-level decline for Geotracker water-level wells against the number of buildings within 1,000 feet of the well. The resulting plot is shown in **Figure 17**. The relationship is the opposite of the hypothesis. Dry-season declines were the same or smaller in higher-density areas than in lower-density ones. This substantiates the previous discussion asserting that rural residential development can increase groundwater recharge by way of infiltrating runoff from impervious surfaces onto adjacent pervious soils.

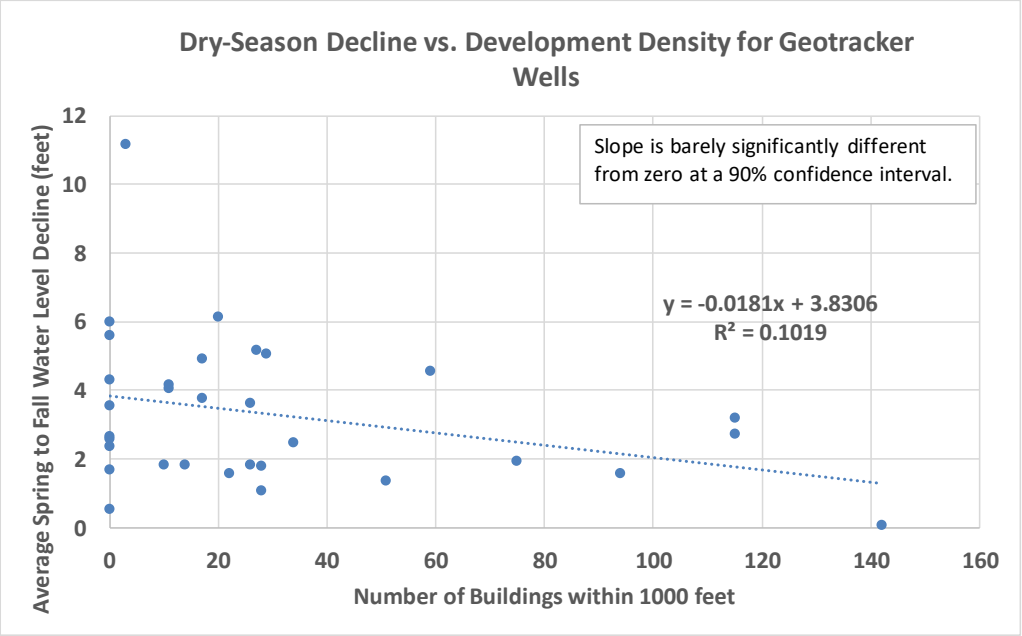


Figure 17. Relationship of Spring-to-Fall Water-Level Decline and Development Density

Test 10. Spring-to-Fall Water-Level Decline Versus Average Annual Recharge

The rainfall-runoff-recharge model described in a later section of this memorandum produced estimates of average annual groundwater recharge from rainfall and irrigation deep percolation for each of the groundwater storage units along the coast. Simulated recharge was strongly influenced by precipitation and land cover. **Figure 18** shows average annual simulated recharge versus average annual precipitation, with points color-coded by land cover category. Each land use category is visible as an elongated cluster of points. As expected, recharge within each category increased with higher precipitation. For similar amounts of precipitation (for example 40 in/yr), recharge was lowest for forest land cover and increased sequentially through grassland, rural residential, urban, irrigated and beach categories.

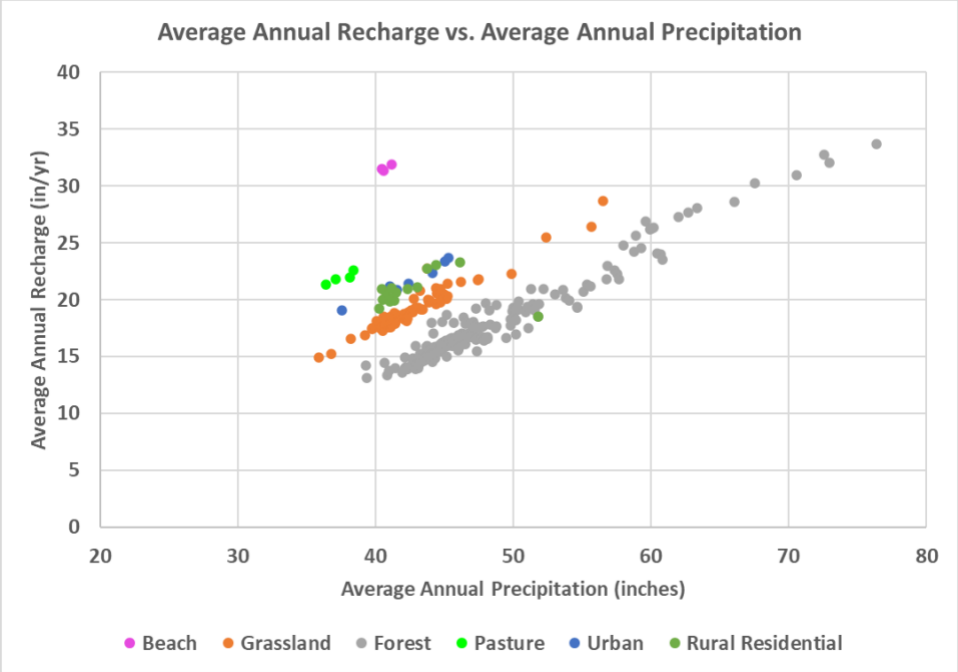


Figure 18. Average Annual Recharge by Land Cover Category

However, spring-to-fall water-level declines did not correlate with average annual recharge, as shown in **Figure 19**. The scatterplot relates spring-to-fall water-level decline to one-dimensional average annual recharge in inches per year. The group of wells within Fort Bragg were divided between two recharge analysis zones with substantially different recharge rates. Even within those zones, there was a large amount of variation in spring-to-fall water-level decline. Results were similar when water-level declines were plotted against volumetric recharge (in acre-feet per year) for the groundwater storage units. The results indicate that large amounts of average annual recharge are not linked to relatively small dry-season water-level declines.

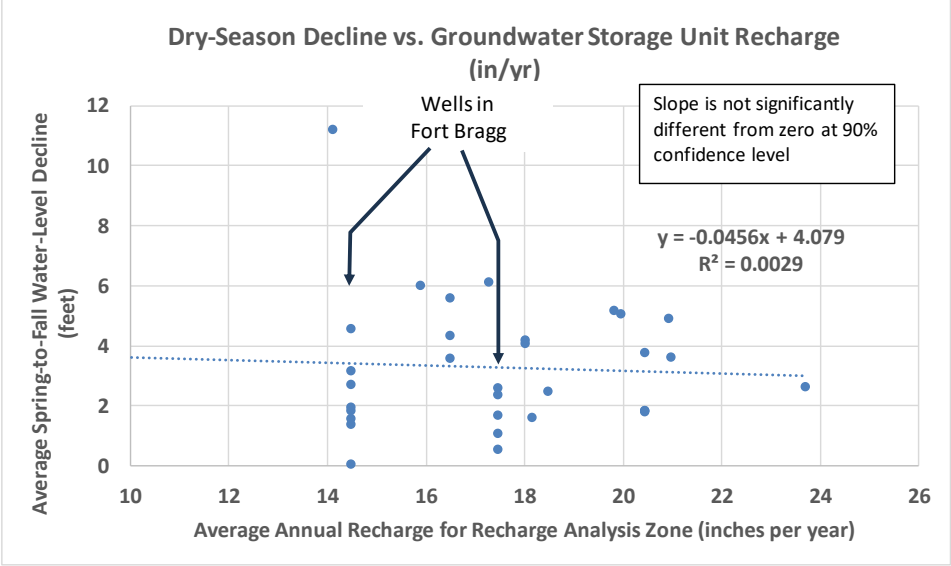


Figure 19. Relationship of Spring-to-Fall Water-Level Decline and Storage Unit Recharge

Tests 11 and 12. Dry Well Occurrence Versus Well Depth and Surficial Geology

The locations of wells that stopped producing water during 2020-2021 can be compared with potential causes that also have geographic variation. Owners of 19 of the "dry" wells in the coastal area provided well depth information. The depths of those wells are shown in **Figure 20**, ranked from shallowest to deepest and color-coded by the surficial geologic unit at the well location. Half of the "dry" wells were less than 50 feet deep, which increases the risk that the water table would fall below the pump intake after two consecutive very dry years. However, wells 50-289 feet deep also went "dry". If the pumps in deep wells were set high up in the well, the well would stop producing water if the water table dropped below the level of the pump intake. The well owner would perceive the well as having gone "dry" even though there was water in the well between the pump and the bottom of the well. The depth at which a pump is placed in a well is not regulated and is commonly done by a different contractor than the well drilling contractor. In the coastal part of Mendocino County, pumps are almost always set near the bottom of the well (Estabrook, 2024). In that case, the deep wells went dry in 2021 because all or most of the inflow to the well was from the surficial unconsolidated deposits or shallow fracture systems in bedrock. The remaining depth of the borehole penetrated essentially unfractured bedrock that produced no water. Drillers cannot necessarily determine at what depths water is entering the borehole while they are drilling it.

A review of 30 well completion reports for wells throughout the coastal region showed that when bedrock was less than 50 feet below the ground surface, drillers almost always continued drilling through bedrock to 100-300 feet below ground surface. Presumably, the drillers expected the bedrock interval to penetrate enough fractures to provide a reliable well yield even if static water levels declined below the bottom of the unconsolidated materials during droughts. In most cases, this strategy works, and the well does not cease to produce water when water levels decline. In some cases, however, the lower part of the borehole produces no water, and the pump simply pumps out the standing water in the casing if the near-surface aquifer dries up.

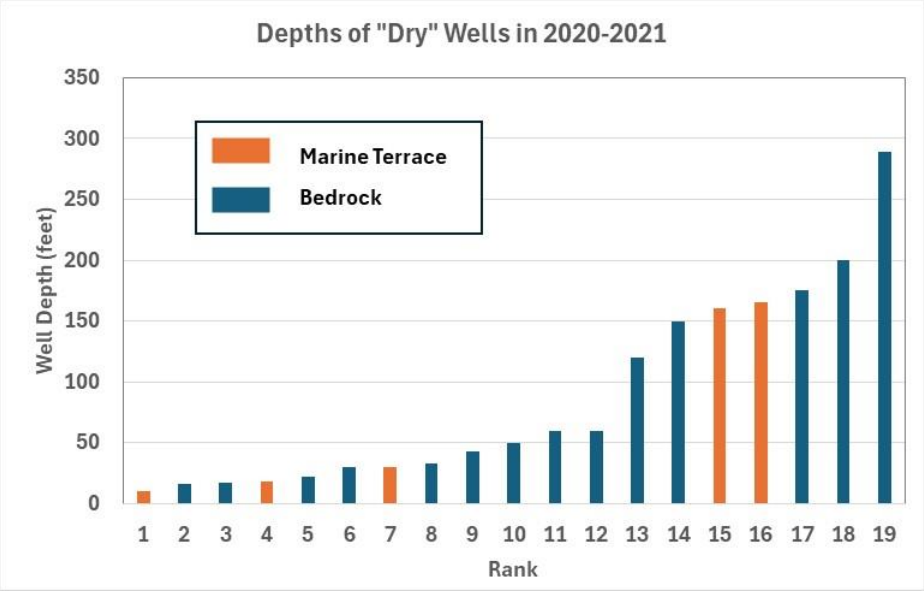


Figure 20. Depth and Surficial Geology of Wells Reported as Dry in 2020-2021

The bar colors in the figure show no clear association of “dry” well occurrence and surficial geology. Wells of various depths were in areas mapped as marine terrace deposits, and the wells in areas mapped as bedrock exhibited a similar range of depths. Thus, there appears to be no obvious correlation between surficial geology and the occurrence of “dry” wells.

Test 13. Dry Well Occurrence by Water Availability Zone

The DWR (1982) groundwater study included a map assigning broad regions of the coastal area to different categories of water availability. An excerpt of the map illustrating the scale and pattern of the regions is shown in **Figure 21**. The regions were delineated based on the ratio of average spring-to-fall water level decline to average thickness of the marine terrace deposits. Larger ratios were interpreted as indicating less reliable groundwater availability. Availability was divided into four categories: sufficient, marginal, critical and critical-bedrock. All bedrock regions were considered to have critically limited groundwater availability due to the small storage capacity per foot of depth of unweathered bedrock.

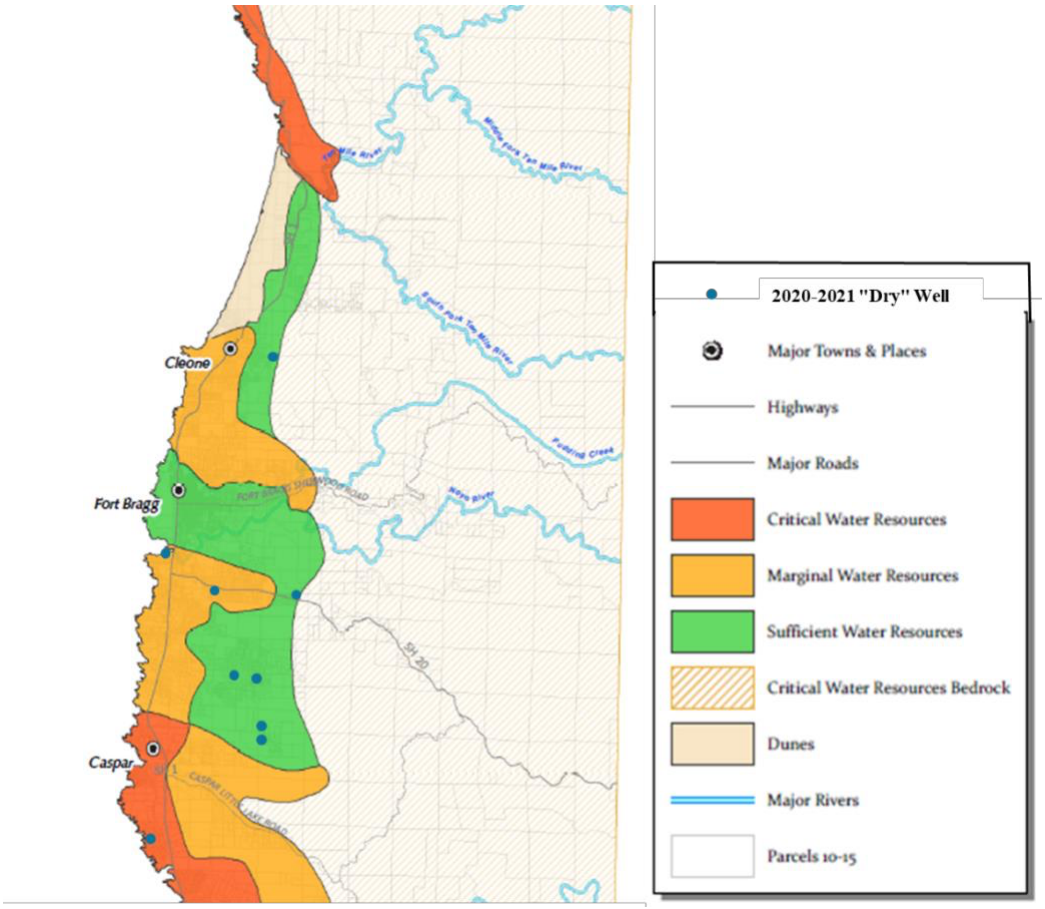


Figure 21. Map of 1982 Water Availability Zones

If the 1982 groundwater availability mapping is correct, one would expect the great majority of “dry” wells reported in 2020-2021 to be in areas mapped as having critical or marginal groundwater availability. Also shown in Figure 21 are the locations of “dry” wells reported in that part of the coastal area. There is no obvious visual correlation between the locations of “dry” wells and the

water availability zones. **Figure 22** shows the number of "dry" wells in each water availability zone for the entire coastal area. Although the greatest numbers of "dry" wells were in the critical zone, six of those nine wells were a cluster in the City of Mendocino. Groundwater conditions there are unusual because wastewater is exported by sewer while water-supply pumping remains local. This increases dry-season water-level declines and the risk of wells going dry. If the Mendocino City wells are excluded, most of the "dry" wells were in areas mapped as having sufficient or marginal groundwater availability. None were in bedrock areas. It is clear that the 1982 water availability zones were of no value in predicting where wells would go dry in 2020-2021.

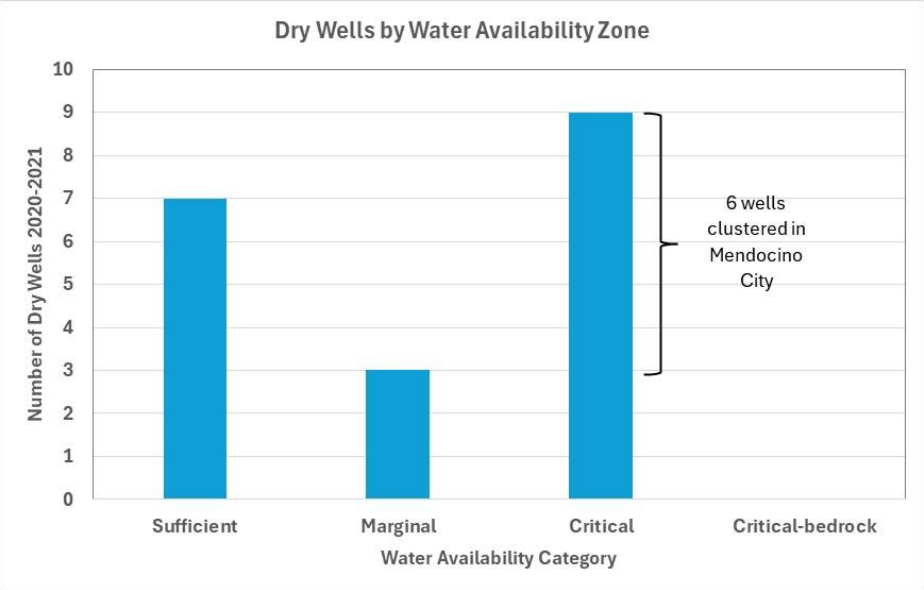


Figure 22. Number of 2020-2021 "Dry" Wells in Each Water Availability Zone

Test 14. Dry Well Occurrence Versus Nearby Development Density

The dry-well database can be used to test the effect of development density on water levels. As with the Geotracker database test described above, this test involved tabulating the number of buildings (presumed to all have on-site wells) within 1,000 feet of each of the wells reported as "dry" in 2020-2021. The number of buildings near each of the 19 "dry" wells in the coastal region is shown in **Figure 23**. The five wells with unusually large numbers of nearby buildings are all in the City of Mendocino, where export of wastewater increases dry-season water-level declines and increases the risk of wells going dry. For the remaining wells, there is a broad range of development densities. Half the wells have 0-2 buildings within 1,000 feet, which represents essentially undeveloped surroundings. These results are consistent with the lack of correlation between dry-season water-level decline and development density described earlier for the Geotracker database wells.

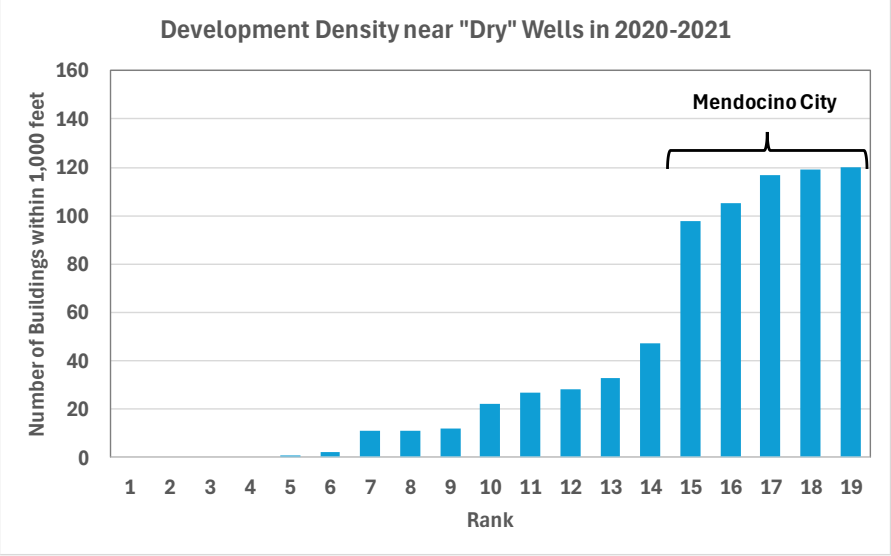


Figure 23. Development Density near "Dry" Wells

Test 15. Effects of Irrigation, Stormwater Infrastructure and Sewering

In the earlier discussion of the effects of development on groundwater levels and budgets, it was noted that irrigation, stormwater infrastructure and sewering all have a negative impact on the local groundwater budget and increase the likelihood of large water-level declines during the dry season and during droughts. However, data were not available to assess irrigation and stormwater effects. The only large, irrigated region is along the Garcia River floodplain between Point Arena and Manchester. The three Geotracker water-level wells near that area have only a single measurement apiece, which is not enough to ascertain dry-season water-level declines. Stormwater infrastructure is likely present only within areas that are also served by a public water system. Thus, there would also be no local pumping, so it would be difficult to differentiate between the effects of low pumping and the effects of exporting stormwater runoff from impervious surfaces.

The only one of the three variables that could be tested with available data was the effect of sewering. The City of Mendocino is unusual in that water supply is still obtained from on-site wells near buildings but wastewater is exported by sewers to a municipal wastewater treatment plant. The lack of septic system recharge produces a noticeable increase in average dry-season water-level decline. This is demonstrated by the large difference between the cumulative distributions of average spring-to-fall water level declines for MCCSD wells compared to Geotracker wells, as shown in **Figure 24**. Average spring-to-fall declines in MCCSD wells are 3-10 feet larger than in Geotracker wells throughout the range of declines.

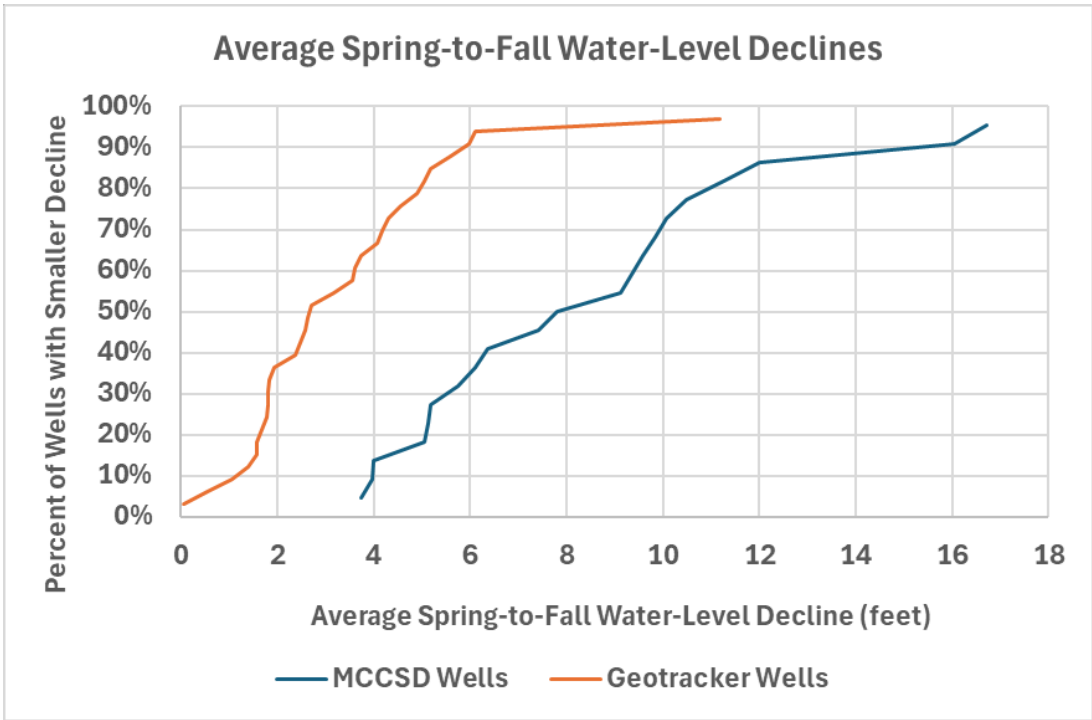
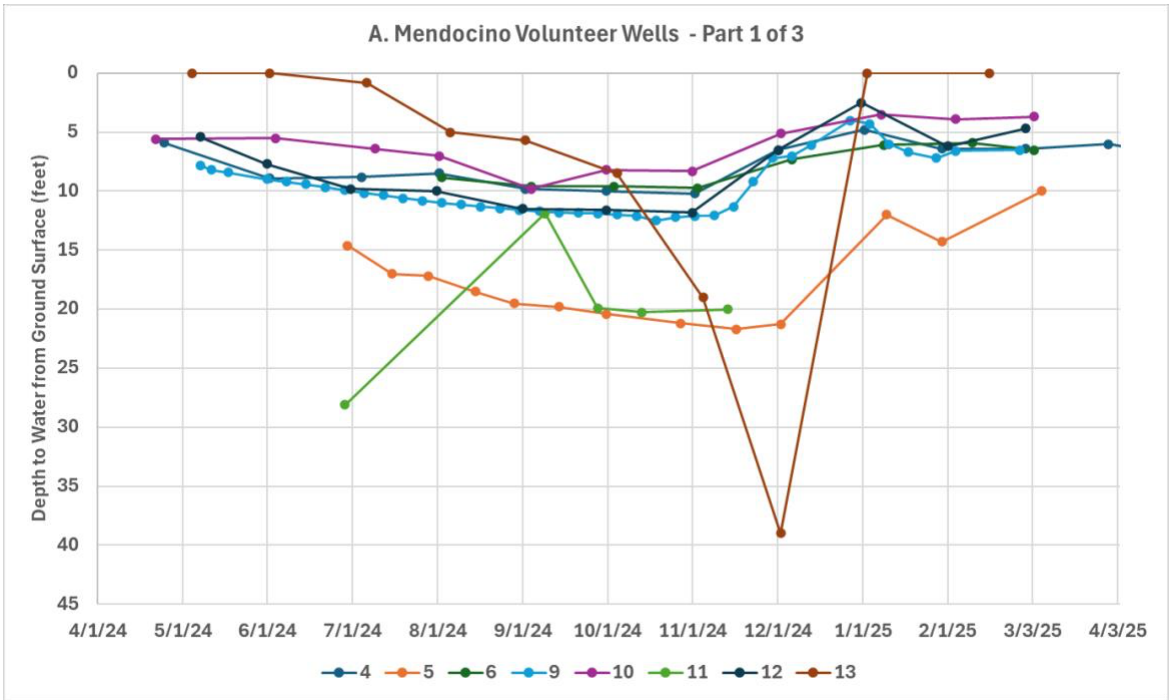
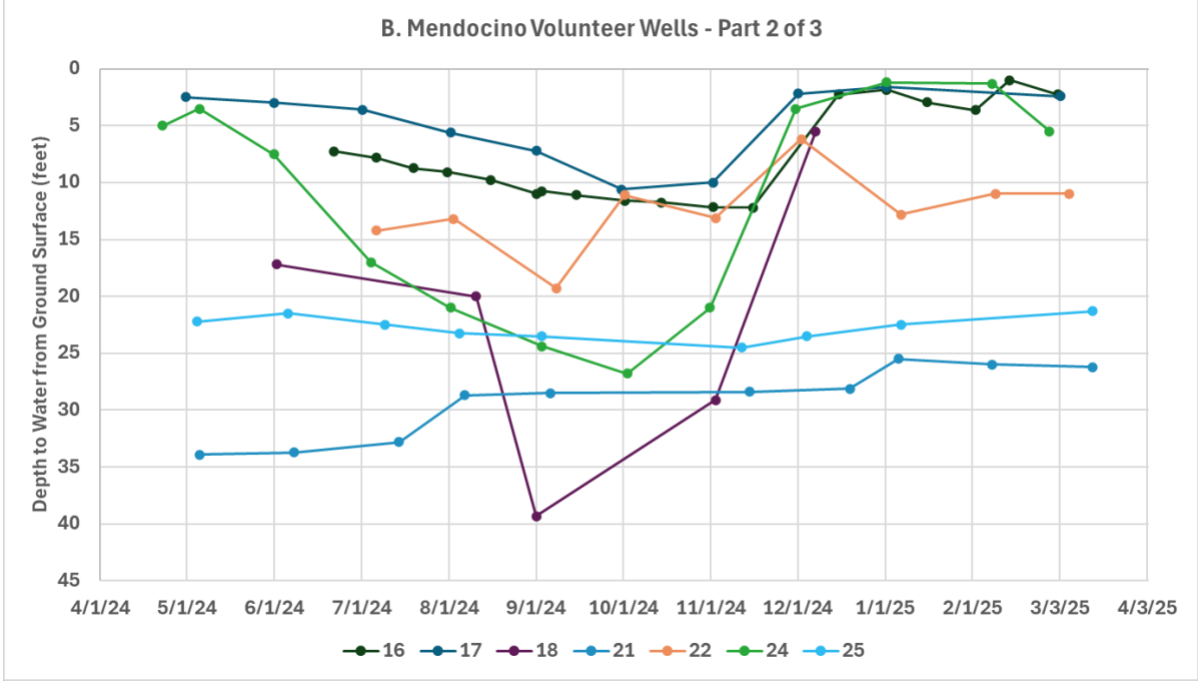


Figure 24. Spring-to-Fall Water-Level Decline Comparison

Summary of Volunteer Water Levels

Hydrographs of the monthly depth to water measurements collected by the volunteer well owners are shown in **Figures 25 a-c**. Monitoring started in May-June of 2024, which was after the season of highest water levels (smallest depth to water). However, the recovery from fall 2024 to winter-spring 2025 indicated the magnitude of seasonal fluctuation in a moderately wet water year (125 percent of long-term average water-year precipitation at Fort Bragg, as of May 2025). Importantly, the data reveal considerable variability among the wells. Eleven of the 16 wells exhibited the expected pattern of gradual water-level decline during spring-fall followed by a more rapid recovery in winter. However, the rates and magnitudes of those seasonal variations were quite different. For example, well 25 had very gradual decline and recovery totaling only 3 feet of seasonal variation. In contrast, well 24 experienced 23 feet of dry-season water-level decline, all of which was recovered in the first two months of winter.


A. Mendocino Volunteer Wells - Part 1 of 3
Depth to Water from Ground Surface (feet)
0
5
10
15
20
25
30
35
40
45
4/1/24
5/1/24
6/1/24
7/1/24
8/1/24
9/1/24
10/1/24
11/1/24
12/1/24
1/1/25
2/1/25
3/3/25
4/3/25
4
5
6
9
10
11
12
13


B. Mendocino Volunteer Wells - Part 2 of 3
Depth to Water from Ground Surface (feet)
0
5
10
15
20
25
30
35
40
45
4/1/24
5/1/24
6/1/24
7/1/24
8/1/24
9/1/24
10/1/24
11/1/24
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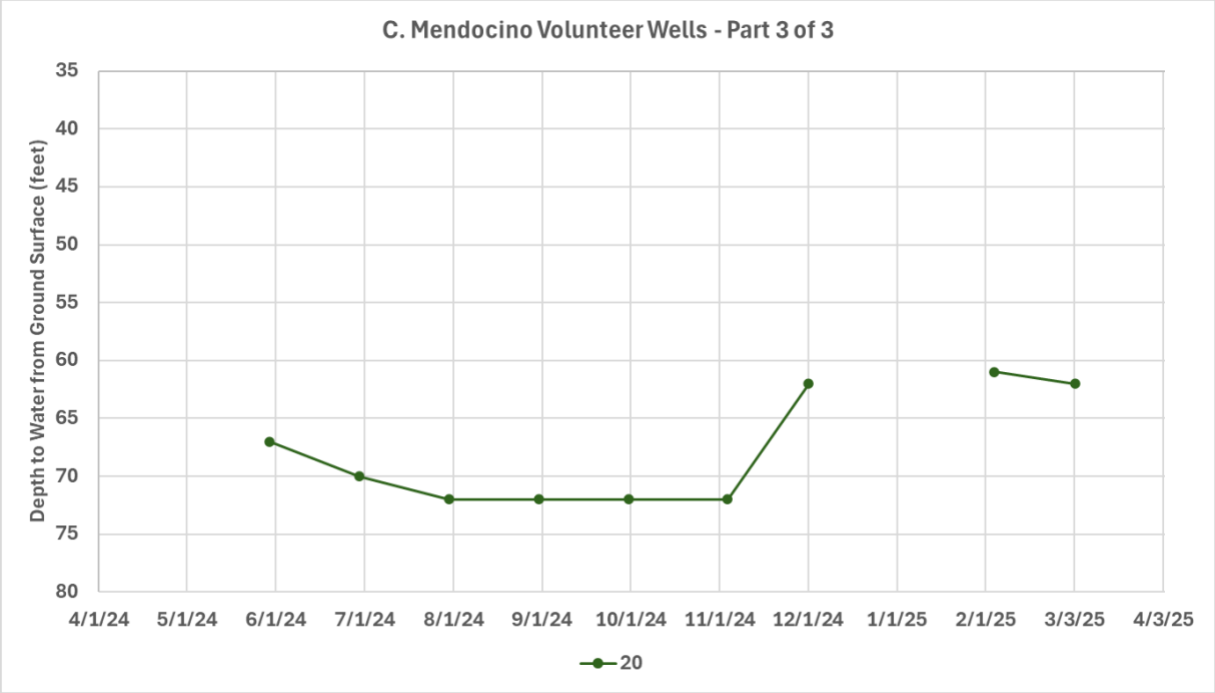


Figure 25. Hydrographs of Water Levels in Volunteer Wells

The other five wells (11, 13, 18, 21 and 22) exhibited non-conforming patterns such as steady increases, accelerating declines during the dry season, or large fluctuations not related to season.

These results demonstrate that estimating the risk of future dry wells based on a data from a single well or even an average of multiple wells is likely to leave a large percentage of wells at risk. Also, any standardized drought risk evaluation procedure might not produce reliable results for all wells.

Summary of Factors Correlated with Low Water Levels

The correlation tests described in the preceding sections are summarized in **Table 2**. Most of the factors did not exhibit a statistically significant correlation with depth to water, spring-to-fall water level decline or the occurrence of "dry" wells in 2020-2021. The factors that exhibited a strong correlation with water levels were current-year precipitation and wastewater export. Variables that exhibited correlation in some tests but not others were wellhead elevation, water-level gradient to the nearest discharge boundary, and location inside a marine terrace outcrop. Variables that did not appear to correlate with water levels were development density, land cover, distance to the nearest discharge boundary, average annual groundwater recharge, and water availability zone.

Limitations of the Groundwater Storage Model

The greatest weakness of the regression tests and location-based parameters of the groundwater storage model is probably a lack of broad geographic coverage. The numerous wells in the MCCSD data set are all within the City of Mendocino. That was useful for some tests, but it is not representative of the overall coastal area. The Geotracker data set wells are more widely distributed—from Gualala to Westport—but unevenly so. For example, only 34 of the 413 wells had 4 or more years of record and were used for statistical analysis, and 12 of those were in Fort Bragg.

There is local clustering, too, since Geotracker includes monitoring wells that commonly are clustered around contamination sites.

More wells with a longer period of record would also improve the geographic range and robustness of the statistical analysis. For this study, four years of data was considered the minimum period of record for implementing statistical tests.

Table 2. Results of Water Level Correlation Tests

Dependent Variable	Independent Variable	Significantly Correlated		Regression Slope
		Yes	No	
Spring depth to water	Wellhead elevation		✓	n.a.
Spring-to-spring water-level change	Current-year precipitation	✓		Varies by well. Slope is negative in 38 of 39 wells.
Average annual recharge	Land cover	✓		Relative order of average annual recharge for same average annual precipitation: forest<grassland<rural residential<urban<pasture<beach
Spring-to-fall water-level decline	Current-year precipitation	✓		Varies by well. Slope is positive in 32 of 39 wells.
	Gradient to groundwater discharge boundary	✓		Not significant for MCCSD wells. For Geotracker wells, spring-to-fall decline increases by 0.71 foot for every 0.050 ft/ft increase in gradient.
	Wastewater export	✓		n.a. Spring-to-fall decline approximately 2.5 times greater for MCCSD wells (in wastewater export area) than for Geotracker wells (in septic system areas).
	Wellhead elevation	✓		Spring-to-fall decline increases by 1.4 feet for every 100 feet of wellhead elevation.
	Location inside marine terrace outcrop	✓		Relationship is relatively weak. Sample means are different only for one-tailed test at 90% confidence. Not for two-tailed test or for 95% confidence.
	Development density		✓	n.a.
	Distance to groundwater discharge boundary		✓	n.a.
	Storage unit average annual recharge		✓	n.a.
2020-2021 "Dry" Wells	Well depth		✓	n.a.
	Location inside marine terrace outcrop		✓	n.a.
	Development density		✓	n.a.
	Water availability zone		✓	n.a.

Note: gray checkmark indicates mixed correlation results. n.a. = not applicable

RAINFALL-RUNOFF-RECHARGE MODEL

The rainfall-runoff-recharge model served several purposes for the coastal groundwater study. First, it provided estimates of groundwater recharge by land use category, which could potentially support land use planning efforts linked to water availability. Second, it provided recharge estimates for each groundwater storage unit, potentially allowing development proposals that would increase consumptive use of groundwater to be evaluated in the context of the local groundwater balance. Finally, it served as a tool to translate future changes in climate to future changes in groundwater recharge.

Model Structure, Assumptions and Input

The second of the four models developed to provide a basis for future groundwater planning and management is the rainfall-runoff-recharge model (RRR model). This RRR model simulates hydrologic processes at the land surface and in the shallow subsurface that produce recharge to underlying aquifers. Highlights of the model are presented here, with additional details presented in **Appendix B**.

The core of the RRR model is a soil moisture balance of the root zone, with daily simulation of precipitation, interception, direct runoff, infiltration, soil moisture storage in the root zone, evapotranspiration, irrigation, deep percolation to a conceptual shallow groundwater storage unit, and outflow from that unit to stream base flow (see diagram in Figure 14). Calculations are one-dimensional and applied to geographic polygons with unique combinations of land use, soils, vegetation, development, precipitation and other factors affecting recharge. The model software was developed by Todd Groundwater and has been adapted and applied to numerous groundwater basin studies over three decades.

The coastal area of Mendocino County was divided into 274 recharge analysis polygons based on local differences in variables known to have a strong influence on simulated recharge. First, the coastal plain was divided into segments representing local groundwater storage units separated by creeks incised 200 feet or more relative to the surrounding terrain. Those creeks function as drains to the adjacent groundwater system, with the result that groundwater pumping in the storage unit on one side of the creek has little or no interaction with groundwater levels or water balance in the storage unit on the opposite side.

Recharge analysis polygons were further delineated on the basis of vegetation, average annual precipitation and service area boundaries of public water and sewer systems. Overall, the delineation of analysis polygons extended inland until it encompassed the entire jurisdictional coastal zone administered by the California Coastal Commission. For example, vegetation categories and public water system service areas along part of the coast are shown in **Figure 26**. A complete map of land cover for the recharge analysis polygons is included in Appendix B.

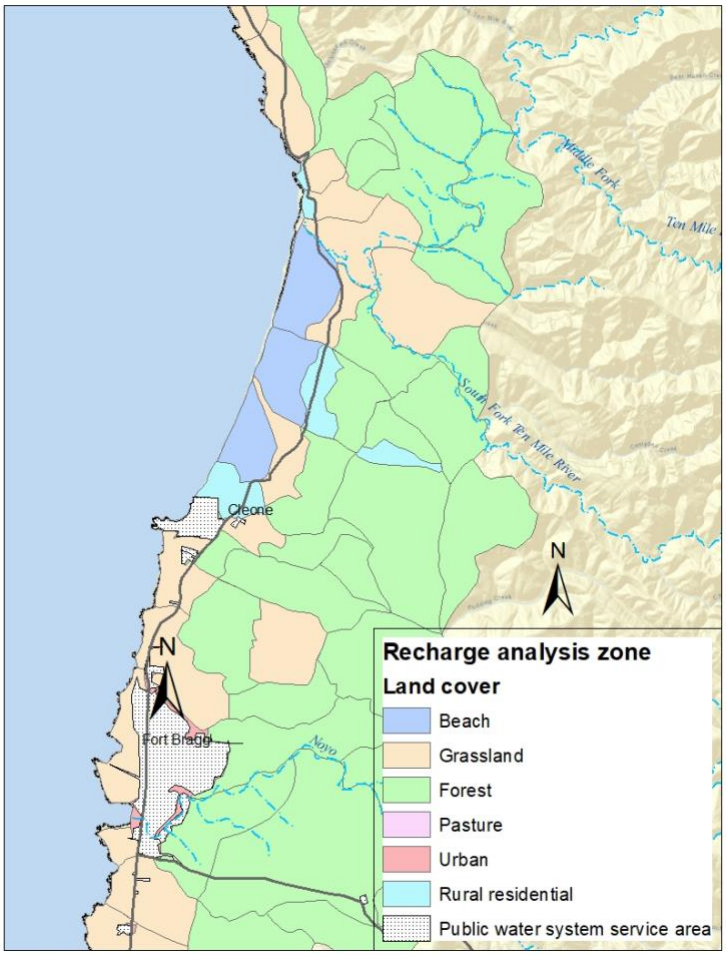


Figure 26. Land Cover in Recharge Analysis Polygons

Hydrologic processes were simulated at a daily time step for water years 1975-2024. Transient inputs to the RRR model (those changing over time) are daily precipitation and daily reference evapotranspiration (ET0). Daily precipitation data for Fort Bragg and Fort Ross were obtained from the National Climatic Data Center.[4] A complete time series of precipitation at Fort Bragg for water years 1935-2024 was prepared by filling periods of missing record with data from Fort Ross (70 miles south; same average annual precipitation). This period was selected because it includes several droughts of various durations and intensities, which are periods when groundwater availability is lowest. The driest year in that period of record was 1977, and the driest 2-year period was 2020-2021.

Groundwater storage capacity of the surficial layers of marine terrace and weathered bedrock materials is limited. Rainfall is more than sufficient to fully recharge those geologic units in most years. Recharge is diminished in dry years, and two consecutive years of very low rainfall result in substantial water-level declines. This occurred during 2020-2021, when 19 well owners in the coastal area reported to DWR that their wells had stopped producing water.

[4] https://www.ncdc.noaa.gov/cdo-web/search accessed 4/10/2024.

The Fort Bragg gage is considered an adequate indicator of the timing and relative magnitudes of precipitation events throughout the coastal area because most precipitation occurs when regional storm systems pass through the area. At each analysis polygon, the amount of precipitation falling each day equaled the amount at Fort Bragg scaled by the ratio of local average annual precipitation to average annual precipitation at Fort Bragg.

Average annual precipitation at each analysis polygon was obtained by contouring a grid of 30-year average annual precipitation developed by the PRISM Climate Group at Oregon State University. The 1990-2020 normals are reported as values for a grid with cells approximately 4 x 4 kilometers in size. The grid values were developed by the PRISM Group using models that account for all available station data, topography, prevailing wind directions and other factors that influence precipitation patterns. The resulting contours of average annual precipitation throughout the coastal area are shown on a map in Appendix B.

There are no local gages measuring ET0, such as the ones operated throughout California for the California Irrigation Management Information System (CIMIS)[5]. However, the CIMIS program has developed a statewide map of ET0 zones using station data and geospatial modeling. A prominent feature is the coastal fog belt (ET0 zone 1), where the common occurrence of fog along the coast greatly reduces ET0 in early to mid-summer. The transition to sunnier, hotter conditions (ET0 zones 3 or 4) farther inland is more a function of elevation than distance. For the RRR model, recharge polygons less than 500 ft in average elevation were assigned to ET0 zone 1, zones greater than 1,000 ft in average elevation were assigned to ET0 zone 4, and intermediate elevations were assigned intermediate values of annual ET0. Daily ET0 was estimated by relating it to maximum daily air temperature using data from the nearest CIMIS station located in the coastal fog belt, which is near Pescadero in San Mateo County. The slope of the relationship was similar in all seasons, so the relationship based on data for all months was used and is shown in **Figure 27.**

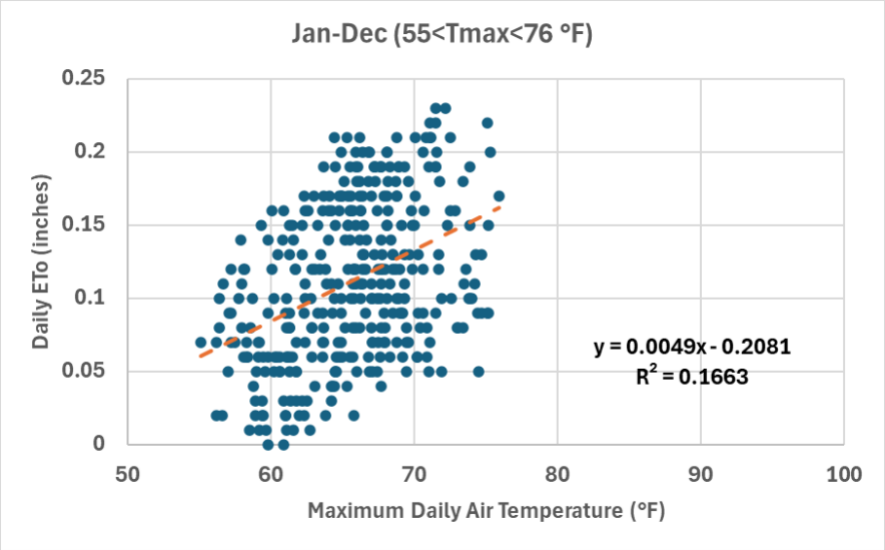


Figure 27. Relationship of ET0 and Temperature at Pescadero CIMIS Station

[5] https://wwwcimis.water.ca.gov/ accessed 4/10/2024.

The values of RRR model parameters that remain constant over time are listed in **Table 3**.

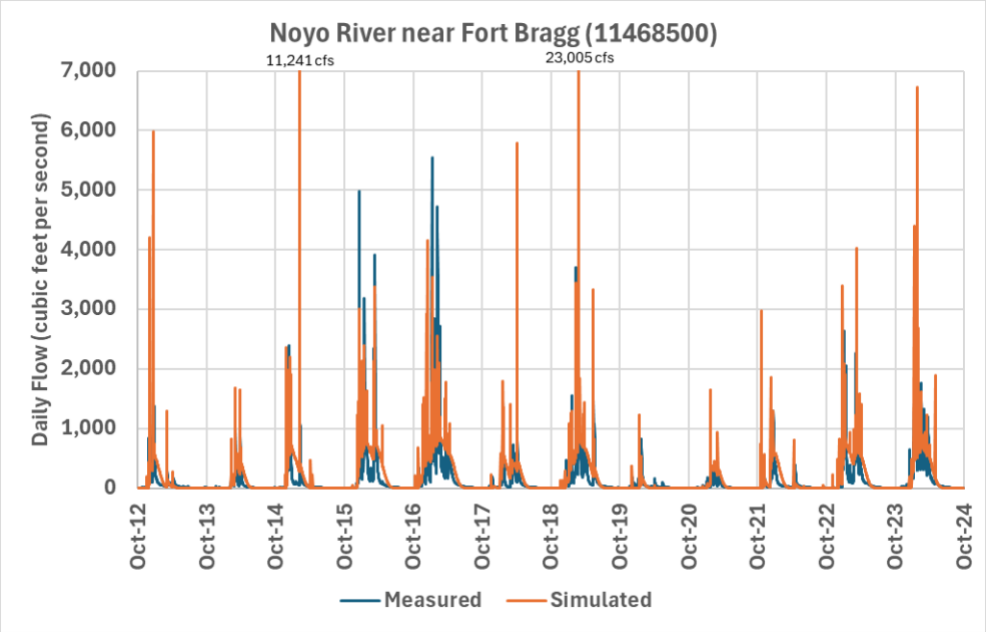
Table 3. Input Parameters for RRR Model

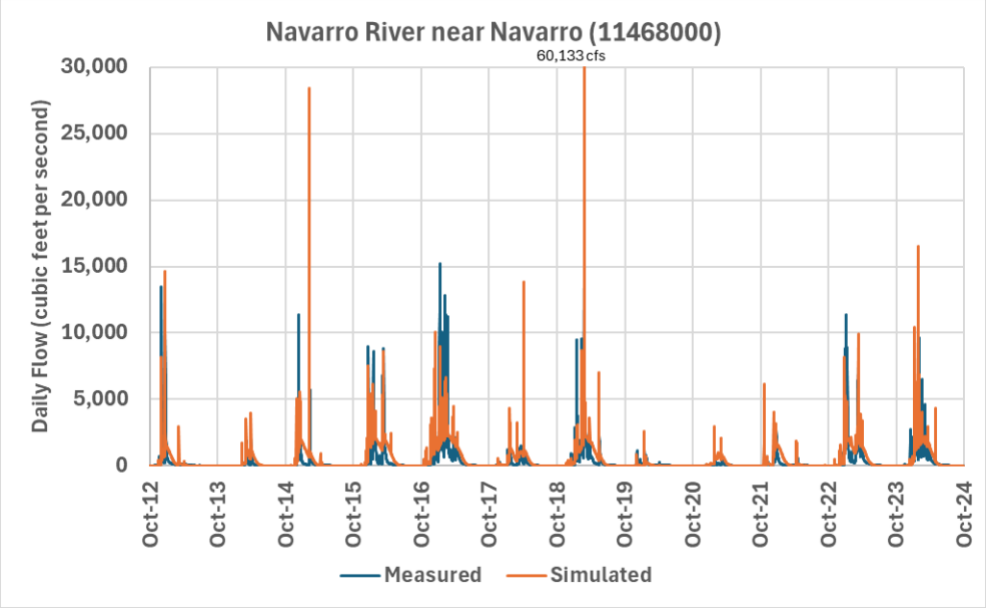
RRR Model Parameter	Beach	Forest	Grassland	Pasture	Rural Residential	Urban
Percent impervious	0%	0%	0%	0%	10%	30%
Fraction of impervious runoff that becomes deep percolation	100%	100%	100%	100%	90%	50%
Percent irrigated	0%	0%	0%	90%	5%	10%
Interception (inches)	0	0.08	0.04	0.04	0.04	0.05
Rainfall threshold to initiate runoff (inches)	3	1.3	1.3	1.1	1.3	0.9
Infiltration of rainfall exceeding threshold (%)	92%	88%	92%	96%	92%	88%
Root depth (inches)	6	72	36	36	36	40
Base flow daily % of groundwater storage	10%	10%	10%	10%	10%	10%

The available water capacity of the root zone was obtained from the Natural Resources Conservation Service's SSURGO data set. The average value for each RRR model polygon was estimated as the area-weighted average available water capacity of the soil mapping units within it. Soil mapping units were almost always smaller than the analysis zones. Values ranged from 0.07-0.16 inch/inch and averaged 0.13 inch/inch.

RRR Model Calibration

Deep percolation beneath the root zone over broad areas is not directly measurable. In the hydrogeologic conceptual model of the coastal region, deep percolation accrues to shallow groundwater that discharges as base flow to creeks or to the ocean. Combining the direct runoff and base flow outputs of the RRR model produces an estimate of daily stream flow generated by the recharge analysis polygon. The only stream flow records available for comparison with RRR model results are for three major rivers: Noyo, Navarro and Garcia. The watersheds of those rivers extend far inland beyond the coastal area covered by the RRR polygons. Accordingly, separate RRR model simulations were prepared of the three river watersheds for the purpose of calibrating several of the RRR model parameters. The calibration process adjusted those parameters to achieve a reasonably close match between average annual river discharge and the shape of stream flow recession in spring and summer. The periods of record for the Noyo and Navarro gages covered the entire 1975-2024 RRR simulation period, and the Garcia River period of record ended in 1983. After calibration, simulated average annual discharge was 95-101 percent of the measured volumes for the three gages. **Figure 28** shows hydrographs of measured and RRR simulated daily flow for each of the rivers to illustrate the reasonable match between measured and simulated base flow recession.


Noyo River near Fort Bragg (11468500)
11,241 cfs
23,005 cfs
Daily Flow (cubic feet per second)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Oct-12
Oct-13
Oct-14
Oct-15
Oct-16
Oct-17
Oct-18
Oct-19
Oct-20
Oct-21
Oct-22
Oct-23
Oct-24
Measured
Simulated


Navarro River near Navarro (11468000)
60,133 cfs
Daily Flow (cubic feet per second)
30,000
25,000
20,000
15,000
10,000
5,000
0
Oct-12
Oct-13
Oct-14
Oct-15
Oct-16
Oct-17
Oct-18
Oct-19
Oct-20
Oct-21
Oct-22
Oct-23
Oct-24
Measured
Simulated

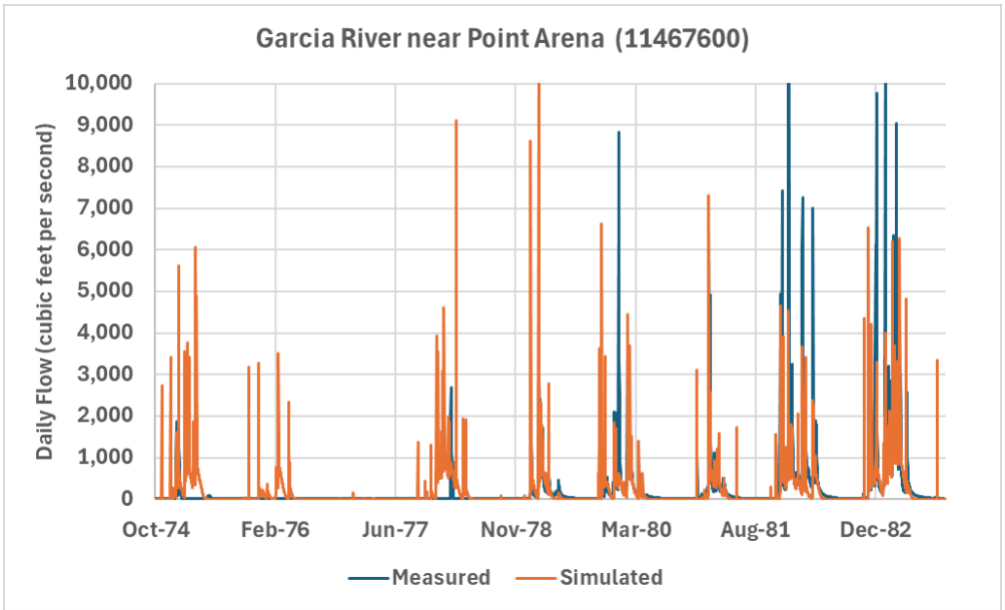


Figure 28. Measured and Simulated Flows in Noyo, Navarro and Garcia Rivers

The values of parameters that were adjusted during calibration are shown in **Table 4**. Values for the Noyo and Navarro Rivers were similar and were applied to the RRR analysis polygons along the coast. Flow at the Garcia River gage included unusually sustained low flows in summer. This pattern is typically associated with wastewater discharges or reservoir releases, although none are known to be present upstream of the gage. Consequently, the Noyo and Navarro River results were favored for selecting parameter values for RRR polygons in the coastal area.

Table 4. Calibrated Parameters from Simulation of Noyo, Navarro and Garcia River Flows

RRR Model Parameter	Calibrated Parameter Value		
	Noyo River near Fort Bragg	Navarro River near Navarro	Garcia River near Point Arena
Forest root depth (inches)	72	84	54
Maximum daily infiltration (inches)	3	3	1.5
Infiltration of rainfall exceeding runoff threshold (%)	0.9	0.9	0.82
Base flow daily % of groundwater storage	0.1	0.1	0.16
Available water capacity (in/in)	0.135	0.125	0.105

Direct runoff and base flow simulated by the RRR model were also compared with results from the Basin Characterization Model (BCM model) for the coastal area. The BCM model is a finely-gridded (raster-based) hydrologic simulation model developed by the U.S. Geological Survey that covers the State of California and is calibrated to over 250 stream gages (throughout the state (Flint and others, 2021). BCM model raster values for the coastal area were averaged over each RRR polygon to obtain flows that could be compared between the models. Overall, the BCM model produced

relatively high amounts of direct runoff, low amounts of base flow and less total flow compared to the RRR model. Comparisons by land cover category are shown in **Figure 29**.

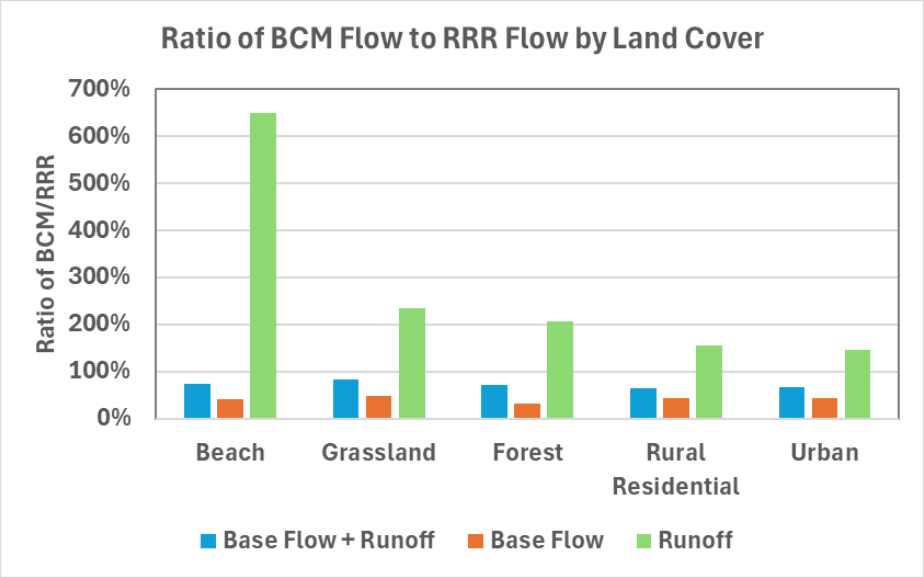


Figure 29. Comparison of Stream Flows Simulated by RRR and BCM Models

The discrepancies were smaller in areas with greater precipitation, which could reflect the fact that the BCM model is calibrated to stream gages draining interior watersheds with relatively high precipitation. This effect can be seen in **Figure 30**. The models produce similar amounts of annual stream flow for areas where annual precipitation averages approximately 60 in/yr.

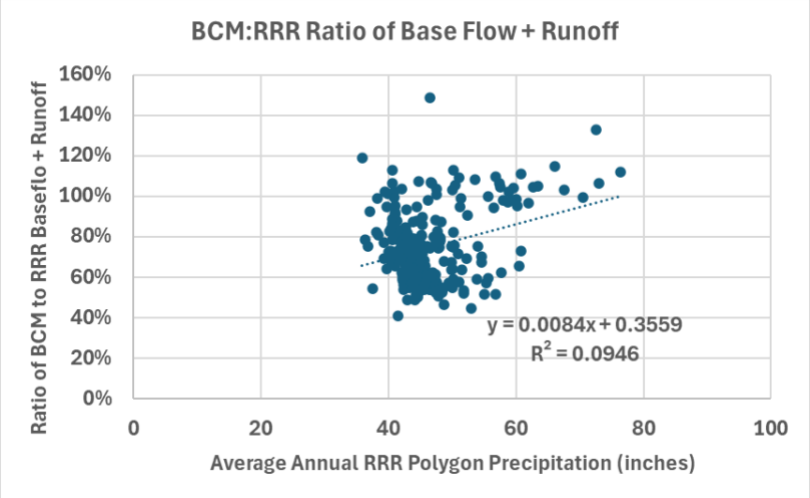


Figure 30. Relationship of BCM:RRR Simulated Stream Flow Ratio to Annual Precipitation

Neither model is presumptively correct. On close inspection, RRR-simulated base flows for the three rivers tend to be lower than the measured flows. Thus, it is unlikely that the even-lower BCM-simulated base flows are more correct. Similarly, the good match between measured annual discharge in the three rivers and discharge simulated using the RRR model suggests greater

accuracy of the RRR simulated discharge than the BCM-simulated total flows, which were 18-34 percent lower.

RRR Model Results

The RRR model output of greatest interest for this study is the simulated recharge, which was evaluated in terms of geographic patterns and correlations with land cover. **Figure 31** is a map showing simulated average annual recharge in inches for RRR model analysis zones along a segment of the coast. A complete map is included in **Appendix B**. Note that recharge in urban areas is not simulated in full detail, which would require estimation of leaks from water and sewer pipes and more accurate estimation of water use for landscape irrigation. The focus of this study is on future domestic and commercial wells in rural areas. It was assumed that few residents in areas served by public water systems would apply to install a well.

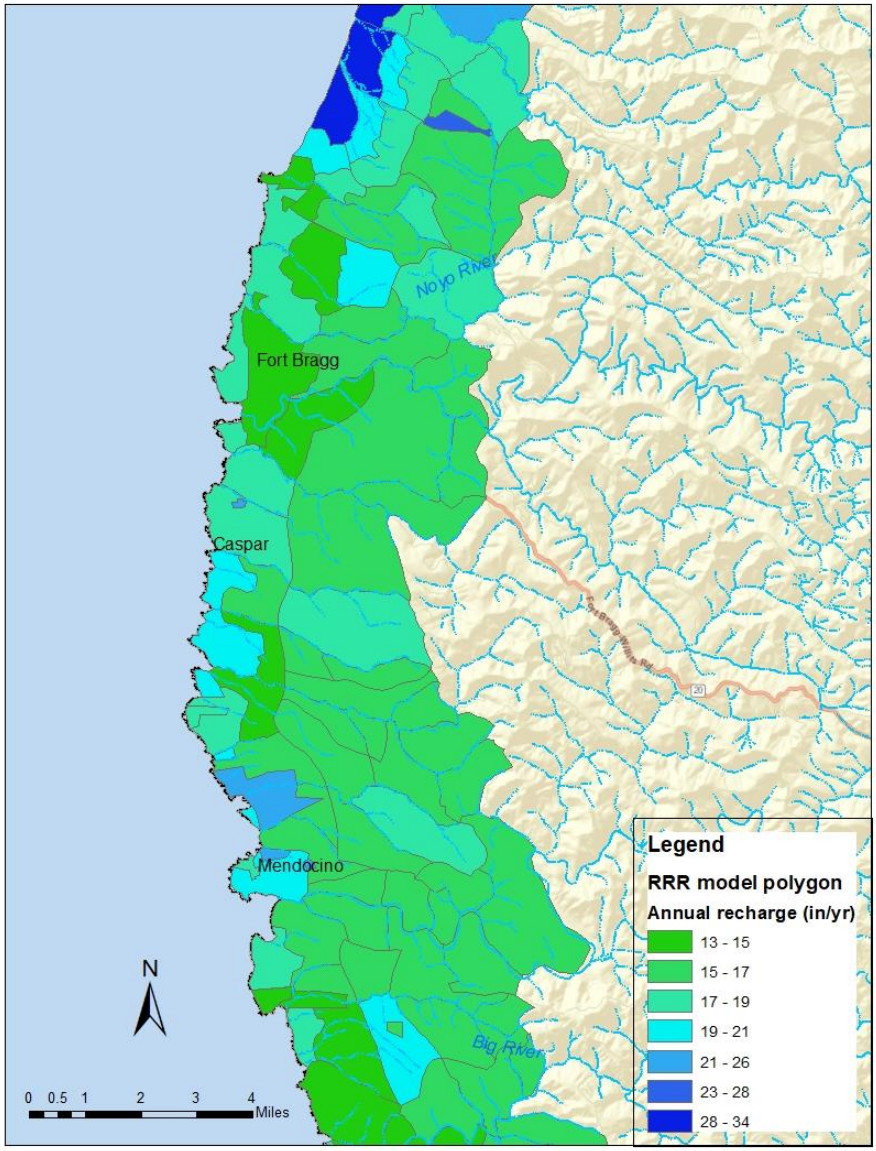


Figure 31. Map of Average Annual Recharge Simulated by RRR Model

Excluding urban areas, values ranged from 13.1-33.7 in/yr and averaged 18.8 in/yr for the region overall. Average annual recharge is correlated with precipitation and land cover (Figure 18). It is higher in zones with relatively high precipitation, which tend to be inland and at higher elevation than zones on the coastal plain. The land use categories ranked from lowest to highest average annual recharge are forest, grassland, rural residential, urban, pasture and beach. Forest land cover had the lowest simulated recharge due to the relatively deep roots of trees. Deeper roots result in a larger root zone storage capacity, which increases the ability of the plant to use the cumulative volume of precipitation infiltrated during the wet season. Rural residential land use had higher average recharge than grassland or forest due to the assumption that most runoff from impervious surfaces infiltrates on nearby soils and becomes recharge. Recharge on pasture is high because it includes irrigation return flow and because irrigation leaves the soil profile relatively wet going into the wet season. Less rainfall infiltration is needed in that case to reach the threshold to initiate deep percolation. The very high recharge rates on beaches results from the high infiltration capacity of sand and the lack of evapotranspiration by plants.

The RRR model results also indicate the amount by which recharge is diminished during droughts. Annual recharge during 2020-2021 averaged 12-54 percent of the 1975-2024 average. For land cover categories other than forest, recharge was 30-54 percent of the longer-term average. All of the polygons with larger decreases (to 12-30 percent) were covered with forest. The cumulative departure of annual recharge is also useful for identifying the reduction in recharge during multi-year droughts. **Figure 32** shows the cumulative departure of annual recharge for grassland, forest and rural residential polygons near each other on the coastal plain where precipitation averages 41 in/yr.

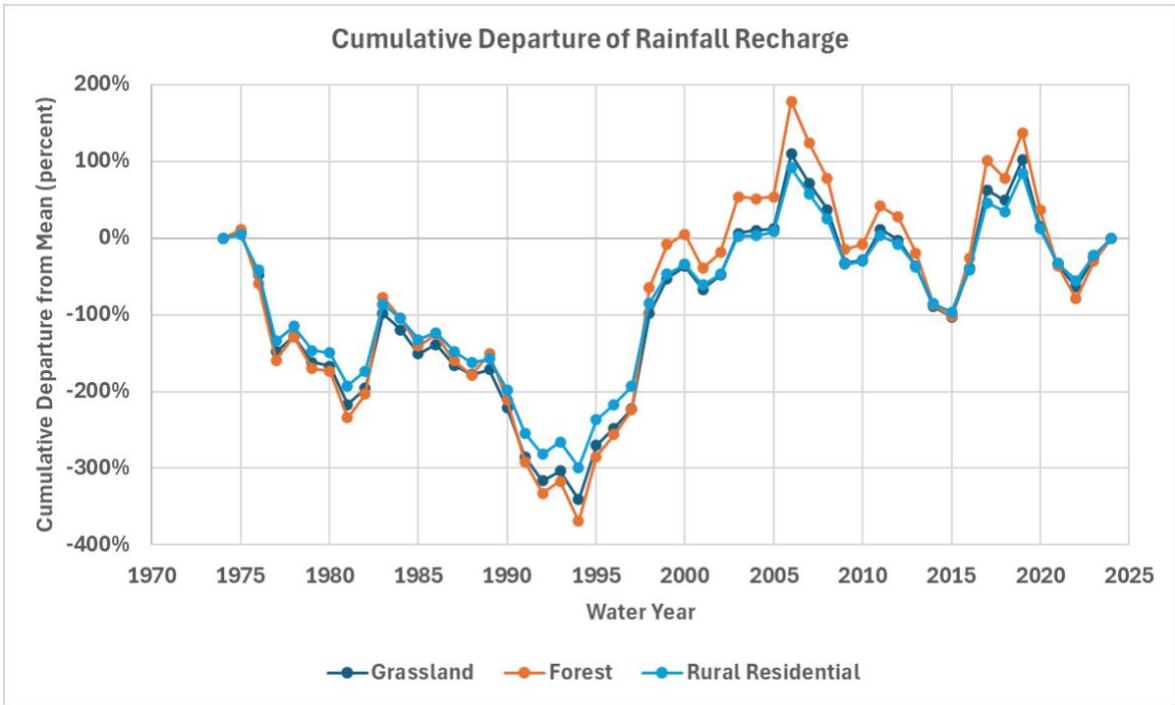


Figure 32. Cumulative Departure of Annual Recharge by Land Cover Category

Droughts are indicated by the falling segments of the curve and wet periods by rising segments. For example, the extreme drought of the 1970s was followed by the wet years of the early 1980s and the prolonged drought from 1984 to 1994.

Average recharge in the coastal area is sufficient to supply existing groundwater demands. Prolonged but not intense dry periods –such as water years 1984-1994—do not necessarily pose a water-supply problem as long as most of those years supply enough recharge to meet demand. Short, intense droughts are the critical problem, given the relatively small amount of groundwater storage capacity in the marine terrace deposits and bedrock. Drought intensity is visible in the cumulative departure graph by the steepness of declining segments of the curves. For example, average recharge during 2020-2021 proved not to be the driest 2-year period in terms of recharge. Recharge was 32 percent of average during that 2-year period, compared with 22 percent of average during 1976-1977.

The cumulative departure of recharge did not vary significantly by land cover category. Forest land cover had slightly higher peaks and lower troughs in its cumulative departure curve compared to the curves for other land cover categories. This means that relative to average recharge, wet periods are slightly wetter and dry periods slightly drier in terms of recharge, but the differences were small compared to the overall magnitude of the departures.

Limitations of the Rainfall-Runoff-Recharge Model

Much of the RRR model output simply reflects assumptions regarding input parameters for which measured data were not available. These include rainfall-runoff relationships and their variation by vegetation cover and ground slope, root depths of all categories of land cover, and the amount of impervious runoff that percolates nearby before reaching a stream channel. Stream gage data for small coastal sub-watersheds would be useful for improving model calibration.

CLIMATE CHANGE MODEL

The third of the four models developed to provide a basis for future groundwater planning and management is the climate change model. The potential effects of climate change on groundwater supply were investigated by modifying the RRR model to represent conditions in 2070. In the simulated scenario, land cover was assumed to be the same as existing land cover, but precipitation and ET_0 were adjusted to reflect climatic conditions in 2070.

To support climate change planning in California, DWR provided downscaled results from a set of global circulation models and developed a set of monthly multipliers that could convert a historical time series of precipitation and ET_0 to a time series representative of 2070 climate conditions. This approach allows changes in the variability of precipitation and ET_0 to be investigated in addition to changes in the averages. DWR developed separate time series of multipliers for a grid of approximately 4 x 4 square kilometer “variable infiltration capacity” (VIC) cells covering the entire State. For this study, values were downloaded for the 22 grid cells overlying the Mendocino coastal area from a DWR website (DWR 2024a). Daily precipitation and ET_0 values in the RRR model were multiplied by the factors for that month and VIC cell. The model retained the underlying water year 1975-2024 hydrologic time series.

In the climate change model, average annual precipitation increased by an average of about 2 inches over the study area. The increase was due primarily to increased precipitation during large storm events, as shown in **Figure 33**.

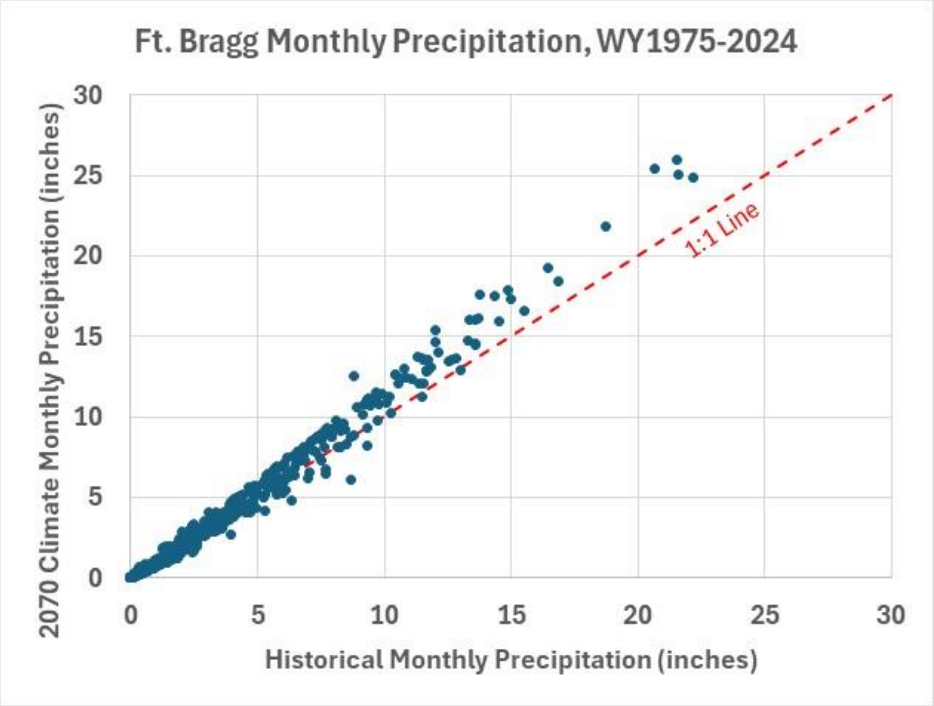


Figure 33. Relationship of 2070 Climate Precipitation to Existing Precipitation at Fort Bragg

2070 ET_0 conditions are best illustrated by the monthly multipliers used to convert historical ET_0 to estimated ET_0 under 2070 conditions. As shown in **Figure 34**, monthly ET_0 multipliers averaged over the 22 VIC cells are all greater than 1.0 and average 1.09. The increase is due to globally warmer temperatures.

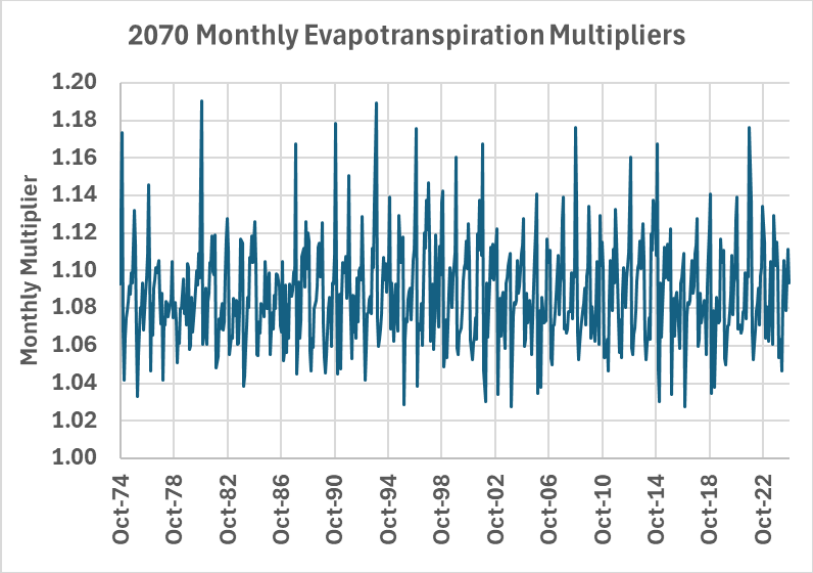


Figure 34. Multipliers for Converting Historical ET_0 to ET_0 under 2070 Climate Conditions

The net effect of the warmer, wetter conditions expected in 2070 on simulated groundwater recharge is shown in **Figure 35** grouped by land cover category. Averaged over all 50 years and all polygons in each category, simulated recharge under 2070 conditions was 7 to 14 percent greater than under existing conditions.

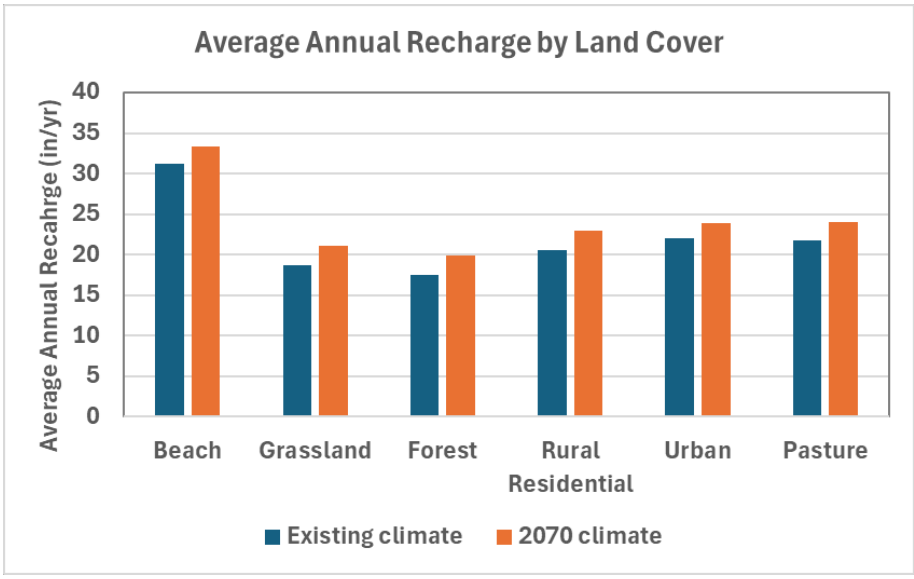


Figure 35. Comparison of Recharge under Existing and 2070 Climate Conditions

The increase in recharge was further investigated by averaging over polygons and over years, as shown in **Figure 36**. The upper plot shows the increase in recharge averaged over all polygons for each of the 50 years of simulation. The lower plot shows the increase averaged over all 50 years for each polygon. This shows that the variability from year to year is much greater than the variability

among polygons. Of particular note are the very small increases in recharge in exceptionally dry years such as 1977 and 2022. This means that the increase in average annual recharge does not translate to an increase in recharge during droughts. This could increase dry-season water level declines in areas where warmer temperatures increase groundwater pumping, such as irrigated pasture polygons. In rural residential areas, irrigation is a small fraction of dry-season water demand, so dry-season pumping and water-level declines would not increase as much as in fully irrigated areas.

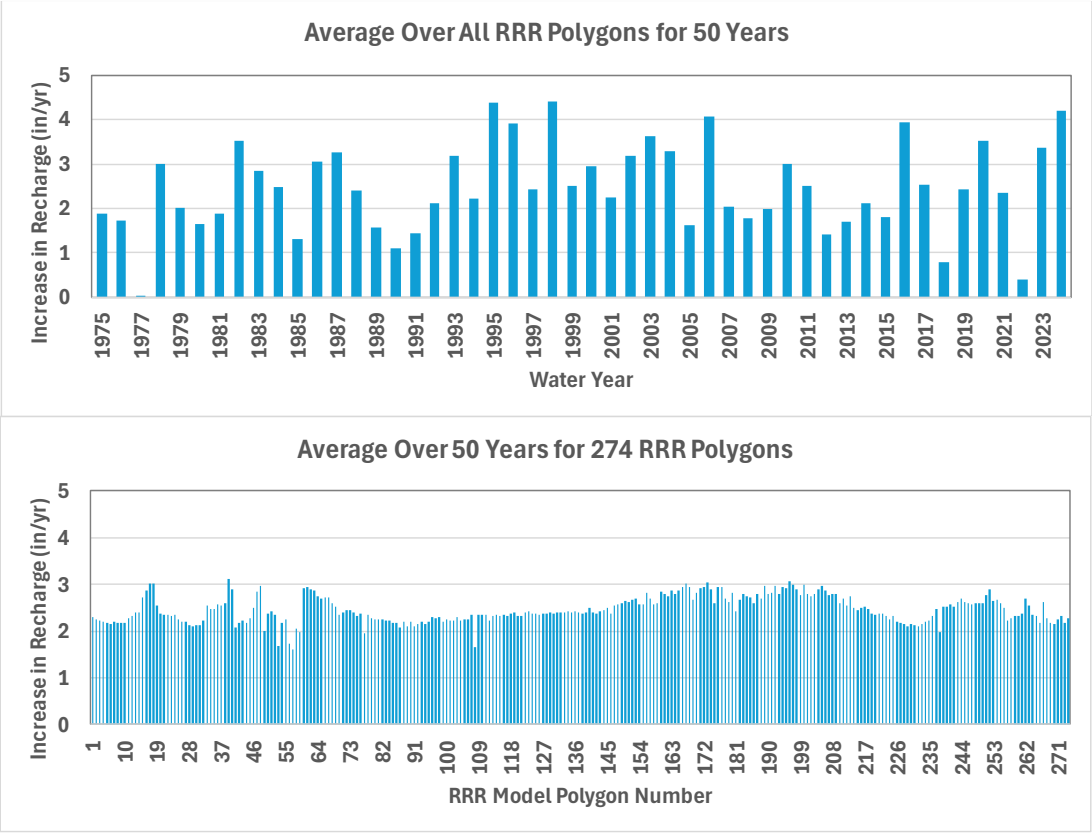


Figure 36. Increase in Recharge from Existing to 2070 Conditions by Year and Polygon

SEAWATER INTRUSION MODEL

The fourth of the four models developed to provide a basis for future groundwater planning and management is the seawater intrusion model. There are two mechanisms by which seawater could enter a well: if a well close to the coast is drilled too deep or if sea level rise pushes saltwater farther up rivers to areas where adjacent groundwater was previously all fresh water. The risk to a deep well near the coast can be approximated based on the estimated depth of the saltwater-freshwater interface in the groundwater flow system. Seawater is 2.5 percent (or 1/40th) denser than fresh groundwater, so it will tend to push inland from the coast underneath the fresh groundwater that is flowing toward the coast. The depth of the interface at any distance inland is proportional to the height of the overlying water table. This is illustrated schematically (not to scale) in **Figure 37**. In

the absence of layering or pumping, the interface will be 40 times farther below sea level (distance 2 in the figure) than the water table is above sea level (distance 1). This is known as the Ghyben-Herzberg principle.

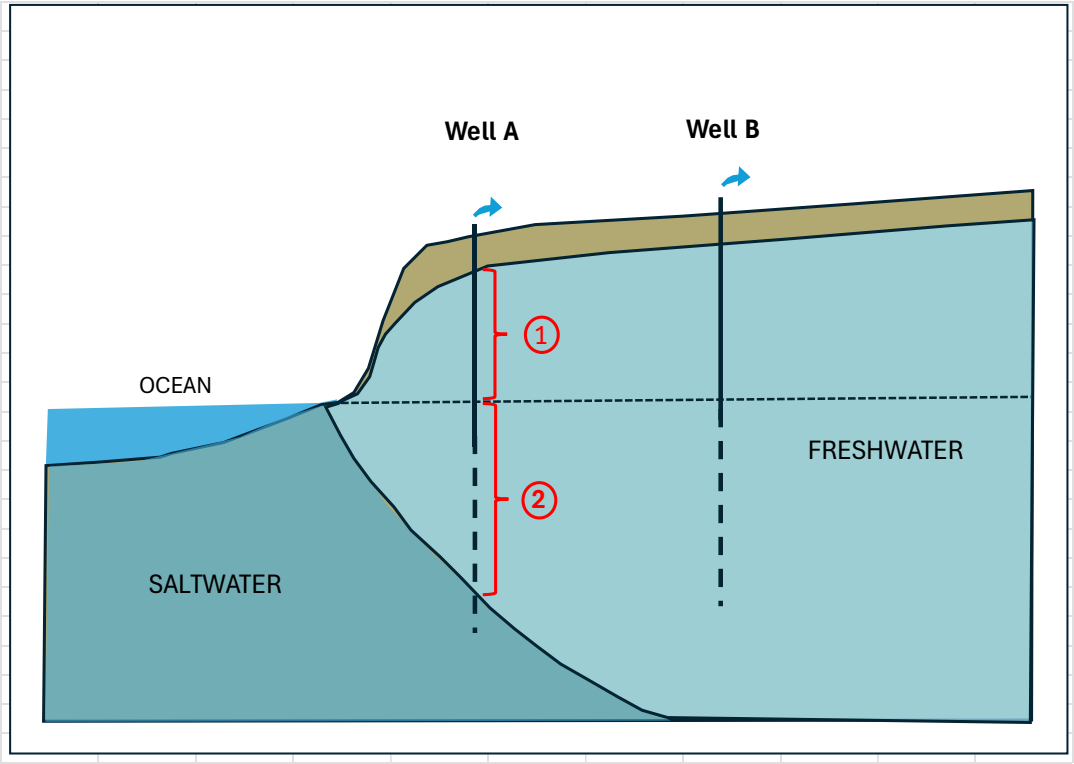


Figure 37. Cross-Sectional Diagram of Saltwater-Freshwater Interface near the Coast

The ground elevation below which a well might be at risk of intersecting the saltwater interface can be calculated using typical well depths and spring depth to water in coastal wells. Approximately 90 percent of existing wells in the coastal area are less than 200 feet deep, and the spring depth to water is less than 20 feet in 95 percent of the wells in the Geotracker database. A typical spring-to-fall water-level decline is 10 feet, so the depth to the water table in fall is conservatively estimated as 30 feet. With these assumptions (well depth of 200 feet and depth to water of 30 feet), the water table elevation at which the saltwater interface would be 200 feet below ground surface is 4 feet above sea level, and the ground surface elevation is 34 feet.

Elevations in Mendocino County are generally referenced to the NAVD88 vertical datum, with mean sea level at +3.25 ft NAVD88. Thus, the protective ground surface elevation is 37.25 feet NAVD88. This means that almost all wells drilled where the ground surface elevation is greater than 37.25 ft NAVD88 will not likely be impacted by saltwater intrusion. This difference is illustrated by Well A (at risk) and Well B (not at risk) in Figure 37.

Locations Currently at Risk of Intrusion

Figure 38 shows a map of the largest area along the coastline where the ground surface elevation is less than 37.25 ft NAVD88. The largest area is the Garcia River floodplain between Point Arena and Manchester. Because the coastal bluffs elsewhere are often more than 37 feet high, the remaining

areas where the ground surface elevation is less than 37 feet are narrow ribbons along rivers and creeks. A complete map of low-elevation areas along the Mendocino County coast is included in Appendix A. For the larger rivers, those ribbons extend as much as 9 miles inland. Thus, wells at low elevation along the rivers are at risk of saltwater intrusion. Because flat ground is uncommon in those areas and flooding and erosion risks are relatively high, few wells are located close to the riverbanks.



Figure 38. Map of 37-Foot Elevation Contour Near Point Arena

These results are similar to the findings in the DWR (1982) report, which mentioned only a single well with confirmed saltwater intrusion. It was near Point Arena, within 400 feet of the coast and screened at least partly below sea level. The report noted that marine terrace deposits are almost all more than 40 feet above sea level and thus not at risk of intrusion. In addition to the Manchester-

Point Arena area, the report mentioned the Ten Mile River-Cleone area as potentially at risk of seawater intrusion. The current analysis shows elevations below 37.25 feet NAVD88 extending approximately 3 miles up both forks of Ten Mile River and approximately 1 mile up Mill Creek south of Cleone.

Effect of Sea Level Rise

DWR (2024b) estimates that sea level will rise 1.6-3.1 feet by 2100. This will raise the water-table profile extending inland from the coast by a similar amount at the shoreline and increasingly smaller amounts farther inland as the flow system also interacts with creeks and rivers. This will not adversely affect wells except ones at low elevation very close to the coast as described above. At those wells, the protective minimum elevation for an average well would increase to approximately 40 feet NAVD88.

A rise in sea level would also push saltwater significantly farther up major rivers and creeks if their thalweg (riverbed) profiles are flat. This would impact wells and surface water intakes along those reaches. The potential inland advance associated with a 3-foot rise in sea level was evaluated by plotting the thalweg elevation profiles of nine major rivers and creeks using elevations obtained from the 10-meter resolution National Elevation Dataset[6]. The profiles are shown in **Figure 39**.

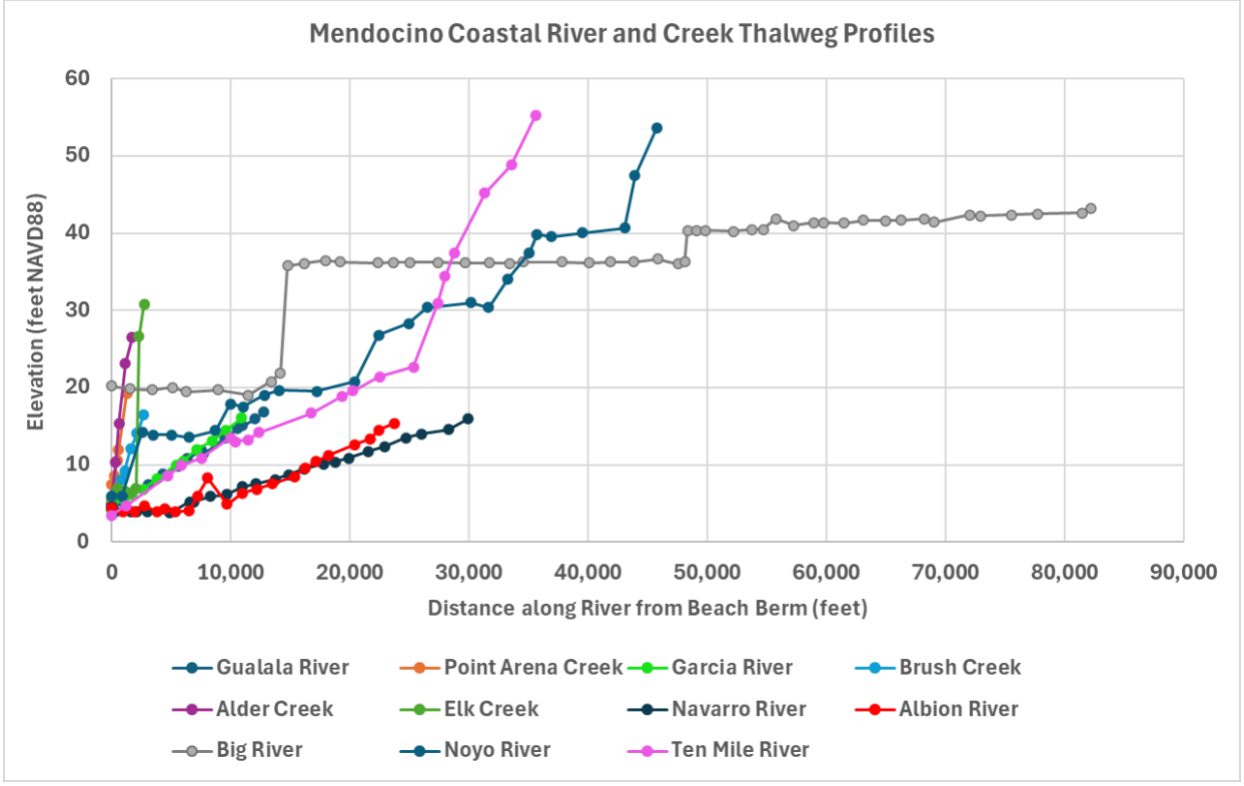


Figure 39. Thalweg Elevation Profiles of Major Rivers and Creeks

[6] https://gdg.sc.egov.usda.gov/Catalog/ProductDescription/NED.html accessed 10/11/2023

The rivers with the flattest profiles are the Albion and Navarro Rivers, where a 3-foot rise in sea level could push saltwater 7,000 feet and 6,000 feet inland, respectively. The Garcia and Gualala Rivers have the next steepest profiles, with a possible inland advance of 3,000 feet. The elevation data along Big River are suspect due to the apparent sudden jumps in profile elevation. Taking the average thalweg slope over the lower 75,000 feet of river, the inland advance of saltwater could be 10,000 feet.

CONCLUSIONS

The primary purpose of this memorandum is to identify factors that contribute to low groundwater levels and loss of production in wells ("dry" wells) during droughts. The factors that exhibited a strong correlation with water levels were current-year precipitation and wastewater export. Variables that exhibited correlation in some tests but not others were wellhead elevation, water-level gradient to the nearest discharge boundary, and location inside a marine terrace outcrop. Variables that did not appear to correlate with water levels were development density, land cover, distance to the nearest discharge boundary, average annual groundwater recharge, and water availability zone. Similarly, the occurrence of "dry" wells in 2020-2021 did not correlate with well depth, surficial geology, water availability zone, or surrounding development density. The risk of a well going dry appears to hinge more on the local hydrogeologic conditions at the drill site than on broader geographic patterns.

The key issue is whether the principal water-yielding depth intervals will remain saturated under drought conditions. If the principal water-yielding interval is surficial marine terrace deposits or unconsolidated weathered bedrock, then the correlations and regression equations presented in this memorandum can be used to estimate whether water levels will decline so much that that interval would become dewatered under future drought conditions such as occurred in 2020-2021.

The situation is more challenging to predict if the principal water-yielding interval consists of a few fractures in bedrock, because it can be difficult to determine while drilling which fractures produce water. If the water-yielding fractures are distributed throughout the depth of the well, then a deeper well will continue producing some water even when water levels are low. If the water-yielding fractures are near the surface and the lower part of the borehole is in solid, unfractured bedrock or has only fractures that produce no water, additional depth provides no additional yield. Under that circumstance, a pump set near the bottom of a deep well can still go "dry" if the shallower intervals dry up. This could be what happened at the six wells 150-300 feet deep that were reported as going dry in 2021 (see Figure 20).

Using information in this memorandum, the County could provide drillers and pump installers an estimate of depth to water under future drought conditions to use as guides in determining how deep to drill a well and/or how deep to set the pump. Approximately half the wells in the coastal area are drilled with the air rotary method, which often allows drillers to detect when they encounter fractures that produce water. With that information, they can estimate whether additional borehole depth is contributing additional yield. The remaining wells are mostly drilled with the mud rotary method, which does not readily allow water-producing fractures to be detected. Both methods can detect the transition from unconsolidated materials to solid bedrock, which is an important factor to compare with estimated future drought water levels.

Some factors related to water levels could be considered on a mapping basis. One useful factor that could be mapped and used for planning purposes is low-elevation areas along the coast and rivers, where there is a risk that a well of average depth might intersect the onshore saltwater-freshwater interface. However, that factor could just as easily be considered by obtaining the ground elevation for a proposed well site. Current-year precipitation is not mappable because it varies over time, not space. Wastewater export is a design feature of a proposed development project, not an inherent landscape characteristic.

Wellhead elevation, water-level gradient from a proposed well site to the nearest groundwater discharge boundary (creek or ocean) and the locations of marine terrace deposits could be mapped. However, those variables only contribute approximately 6 feet, 3 feet and 1 foot of water-level difference, respectively, over the ranges of data for the Geotracker database wells. Thus, the potential effects of those three variables could be accounted for by instructing drillers and pump installers to allow for an extra 10 feet of water-level decline when selecting well and pump depths.

The projected change in climate to warmer, wetter conditions by 2070 is not likely to adversely impact the performance of domestic wells. Simulation results of 50 years of future climatic conditions indicated that the wetter and warmer future climate did not significantly increase groundwater recharge during droughts, which is when groundwater availability is a constraint. Water used indoors does not vary with temperature and is almost entirely returned to the aquifer via the septic system. In contrast, irrigation wells are more at risk of supply shortages under future climate conditions because hotter air temperatures will increase consumptive use of water by the irrigated plants.

The local groundwater balance can have a strong effect on groundwater levels. Three aspects of land development that could have significant negative impacts on the local groundwater balance are exporting stormwater, exporting wastewater, and using large amounts of groundwater for irrigation. Development that includes any of those characteristics is at greater risk of experiencing low water levels and loss of well production.

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Appendix A: Supplemental Figures

Map of Groundwater Storage Units

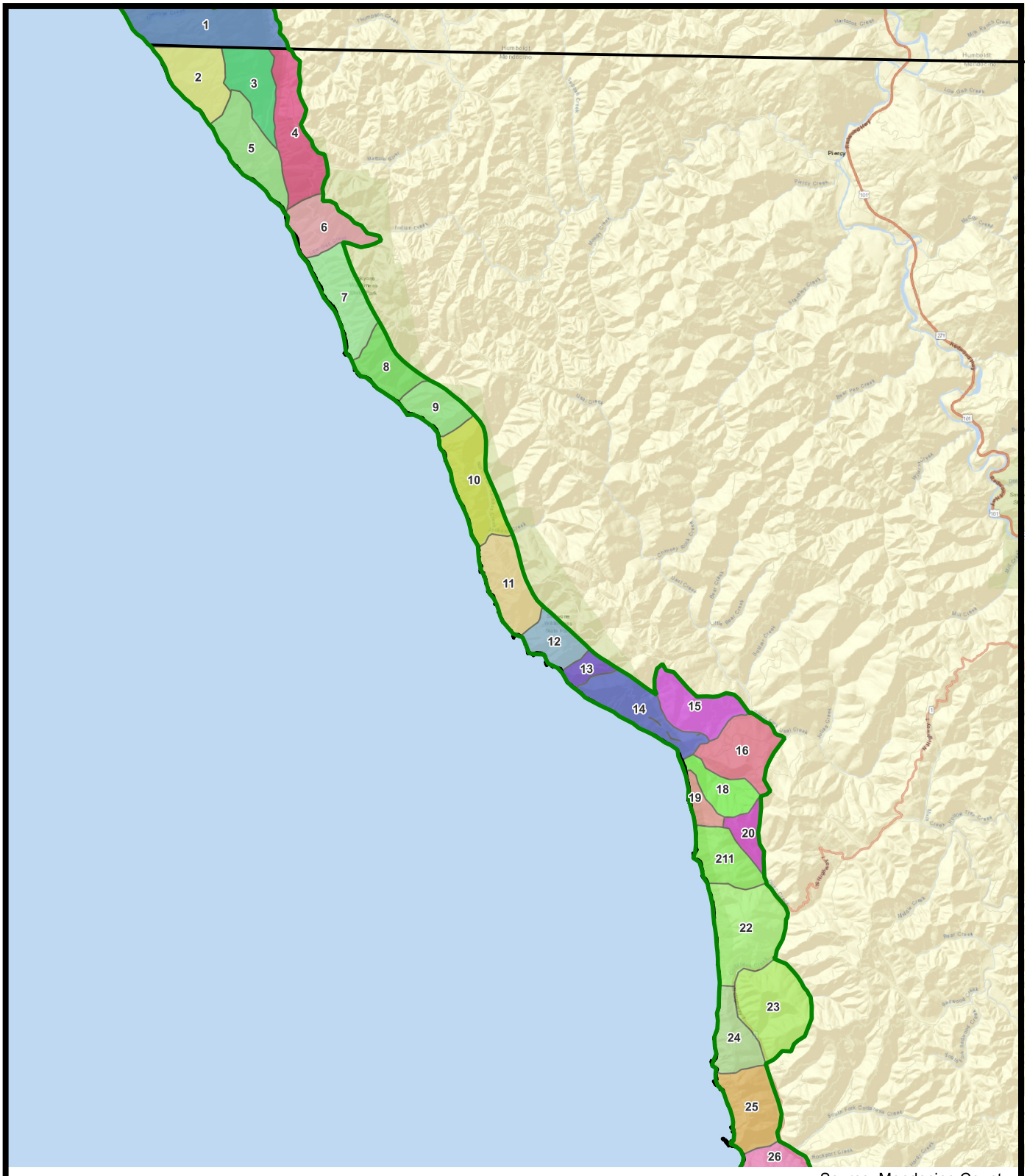
Map of Water-Level Wells: Mendocino City CSD

Map of Water-Level Wells: Geotracker

Spring-to-Fall Correlation with Current-Year Precipitation: MCCSD Wells

Spring-to-Fall Correlation with Current-Year Precipitation: Geotracker Wells

Map of Areas at Elevations Below 37 Feet NAVD88



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

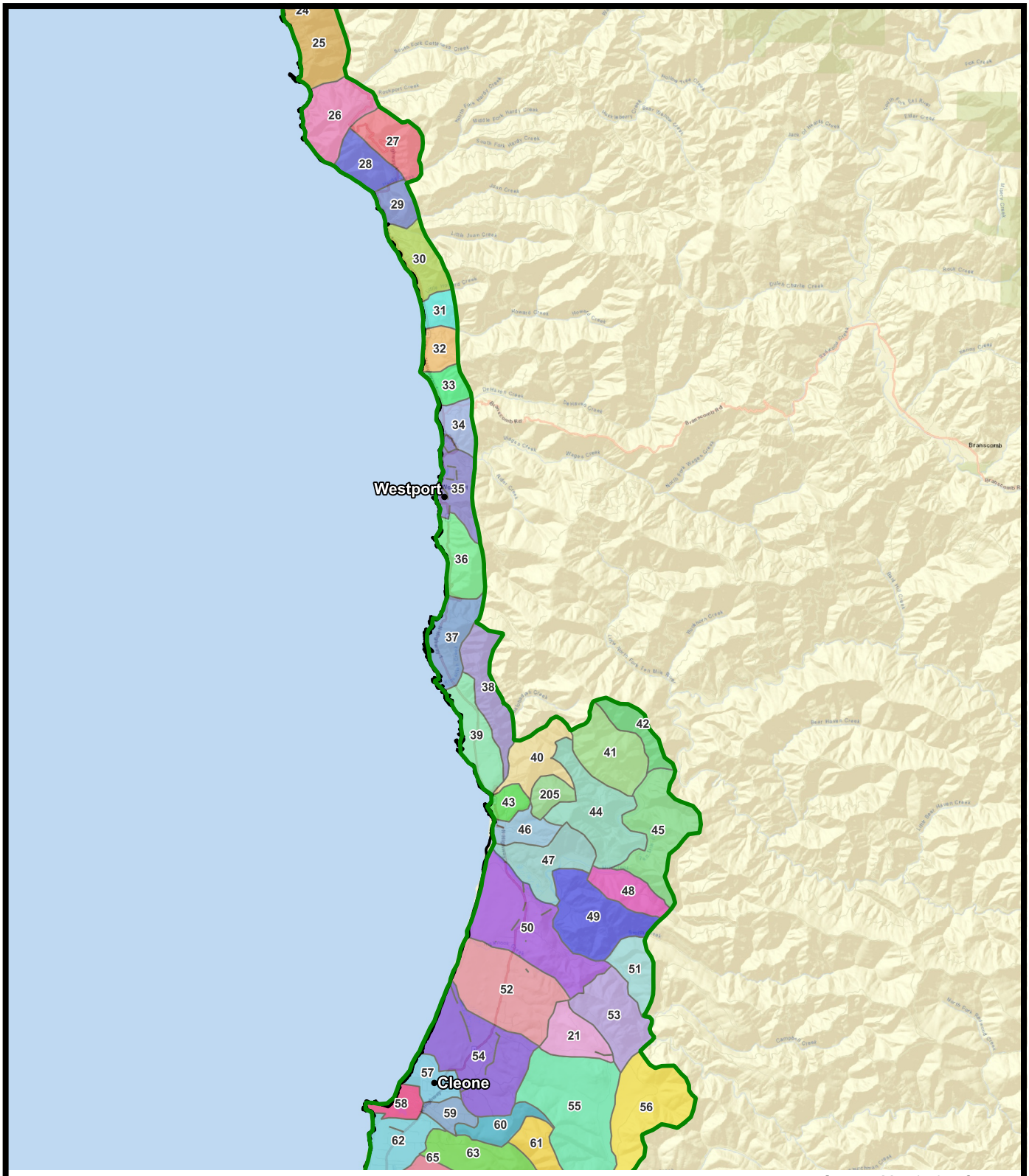
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units
North Coast (Northern)

09/04/2024 PN 594.03

Figure A-57

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | City or Town

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

0 1 2 mi

N

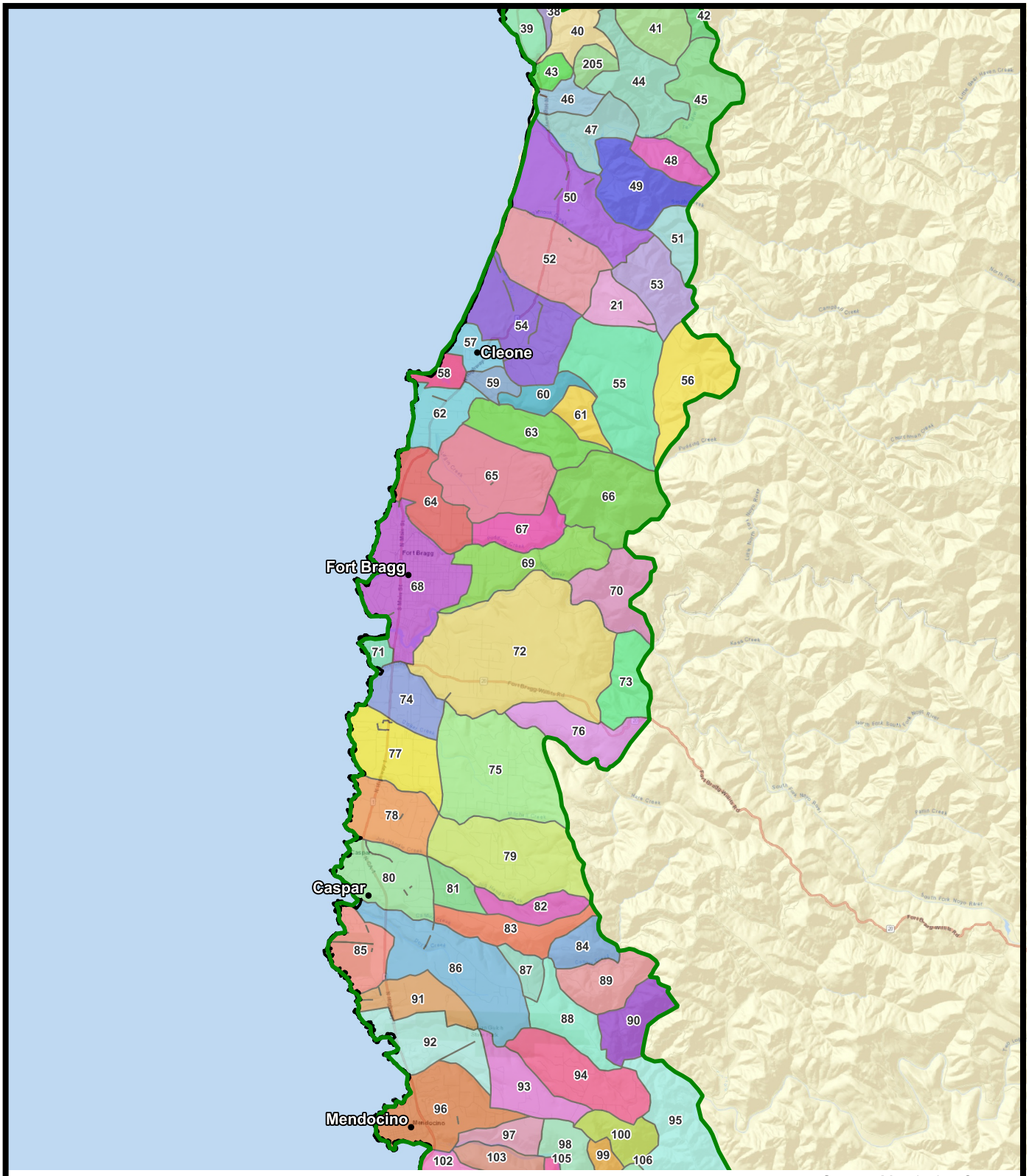
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units
North Coast (Southern)

09/04/2024 PN 594.03

Figure A-58

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | City or Town

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

0 1 2 mi

N

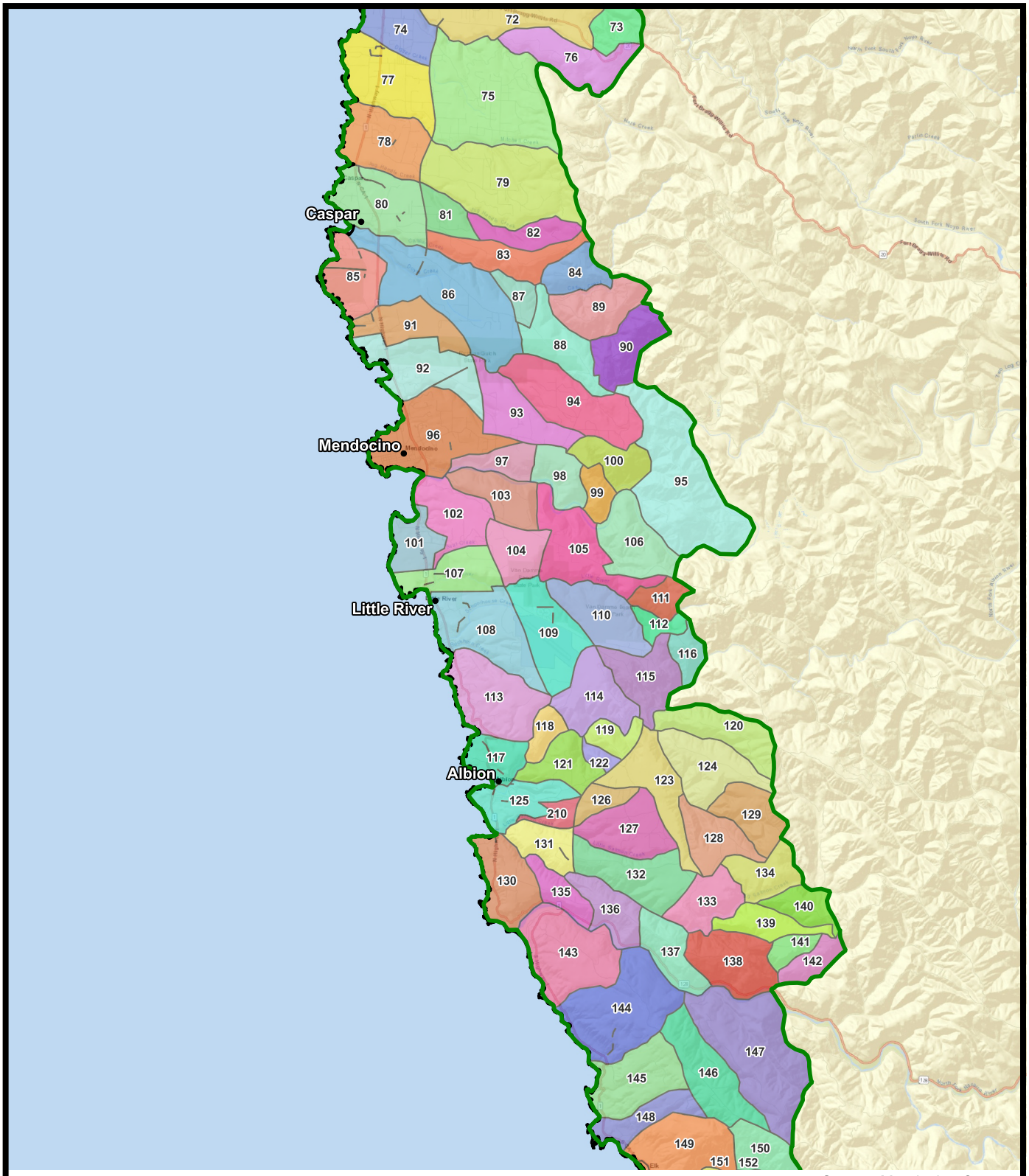
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units
North Central Coast

09/04/2024 PN 594.03

Figure A-59

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | City or Town

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

0 1 2 mi

N

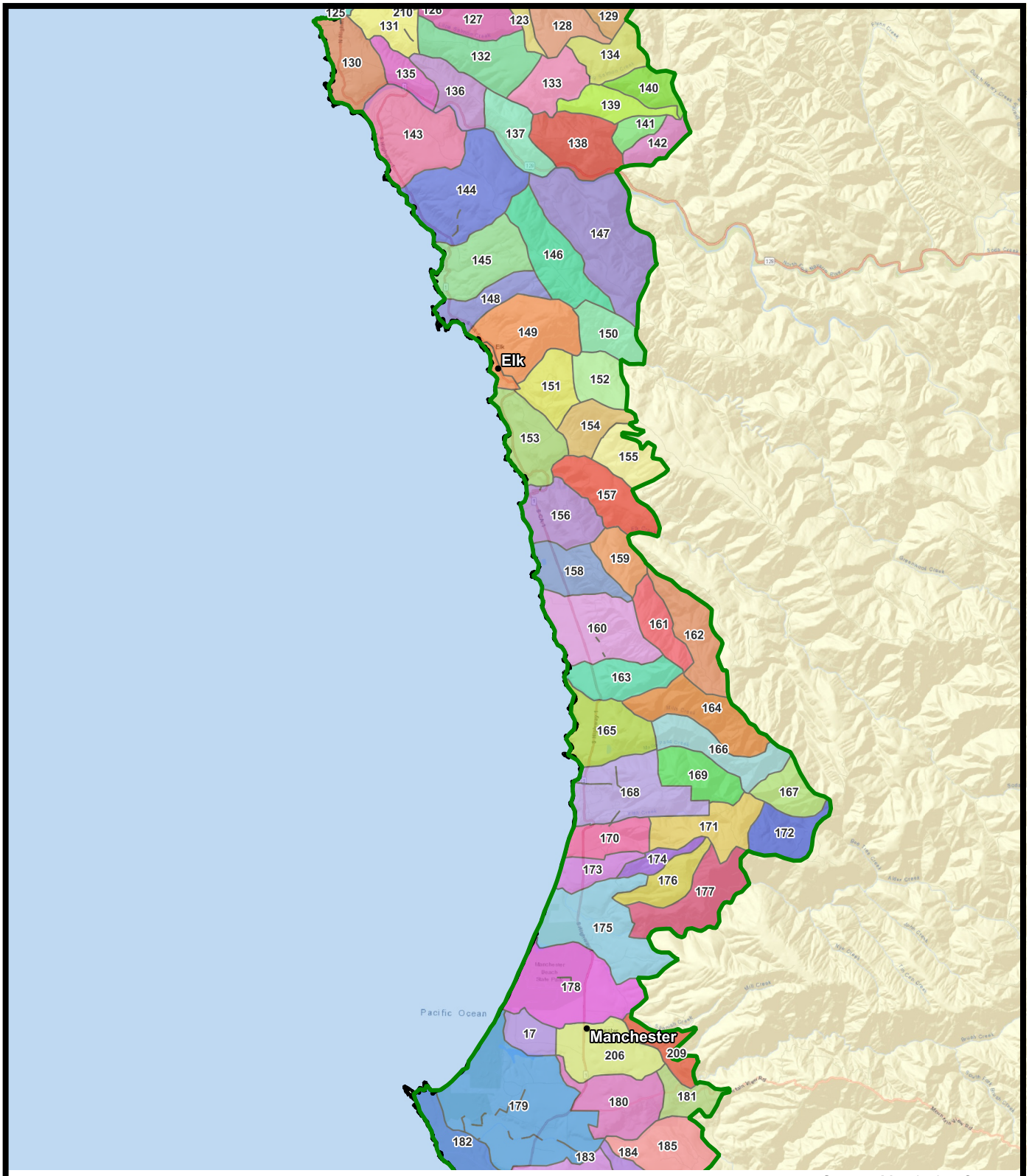
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units
South Central Coast

09/04/2024 PN 594.03

Figure A-60

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | • City or Town

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

0 1 2 mi

N

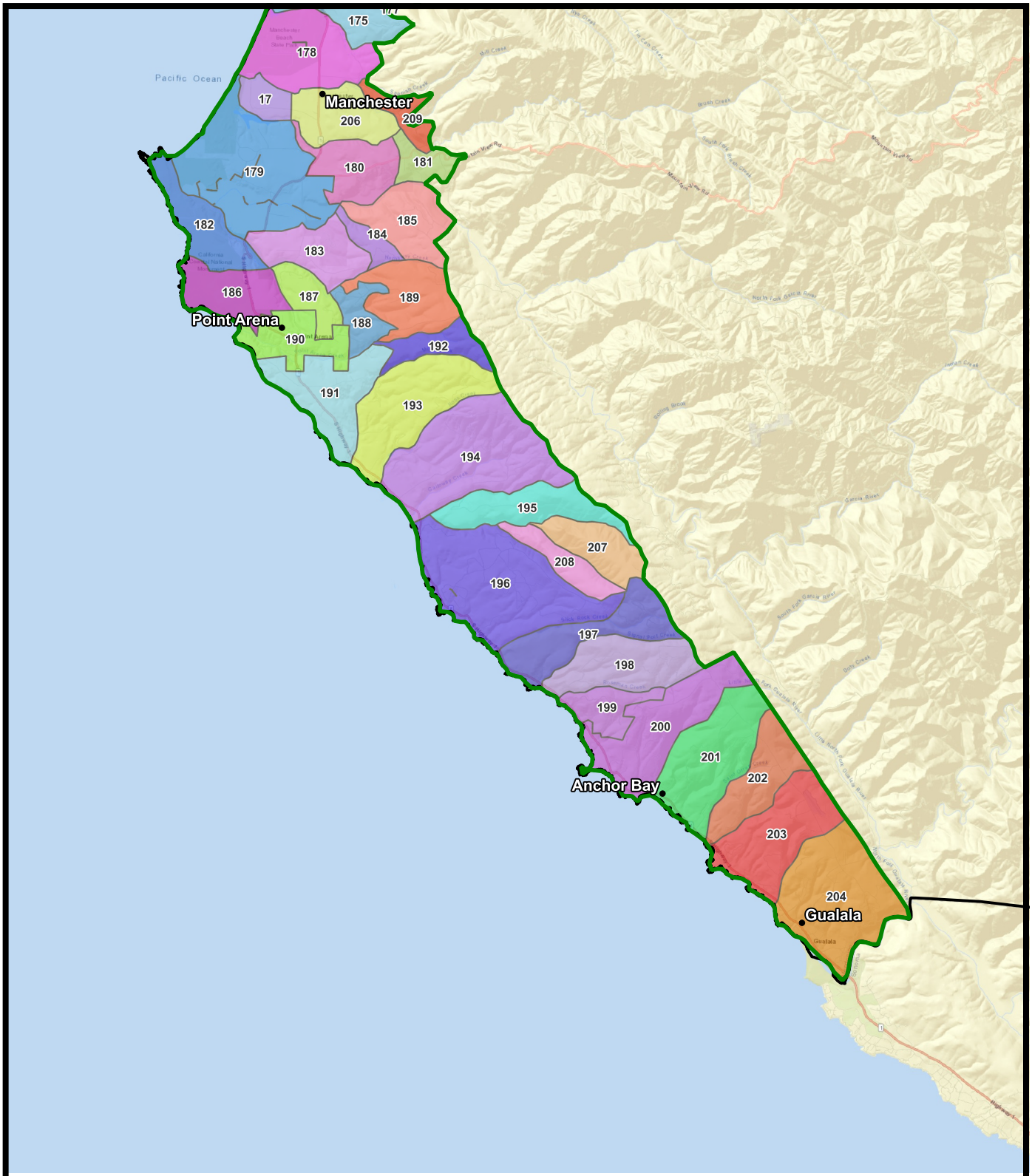
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units South Coast (Northern)

09/04/2024 PN 594.03

Figure A-61

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Source: Mendocino County

Groundwater Storage Unit | RRR Model Domain | Mendocino County | City or Town

Notes:
1. RRR = Rainfall-Runoff-Recharge.
2. Label indicates groundwater storage unit number.

0 1 2 mi

N

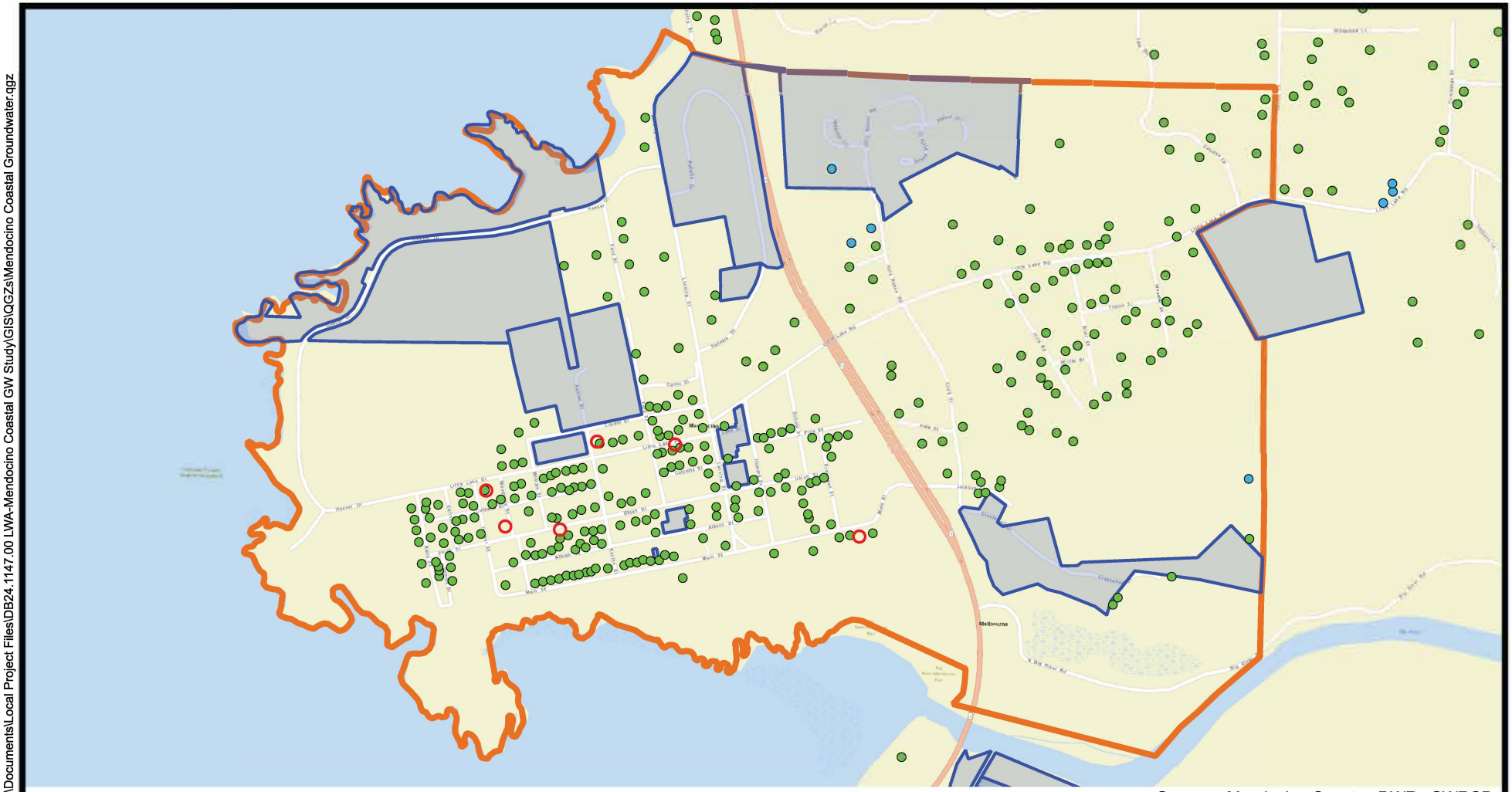
COASTAL GROUNDWATER STUDY

RRR Model Groundwater Storage Units
South Coast (Southern)

09/04/2024 PN 594.03

Figure A-62

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

- Big River Sub CAC Planning Area
- Public Water System Service Area
- Reported Dry Well
- Public Supply Well
- Domestic or Commercial Well

0 500 1,000 ft

N

Sources: Mendocino County; DWR; SWRCB

Notes:
1. DWR dry well database accessed July 27, 2024.
2. Domestic or commercial well locations based on presence of buildings outside public water system service areas. These buildings are assumed to be supplied by on-site wells.
3. Wells within public water system service areas omitted.

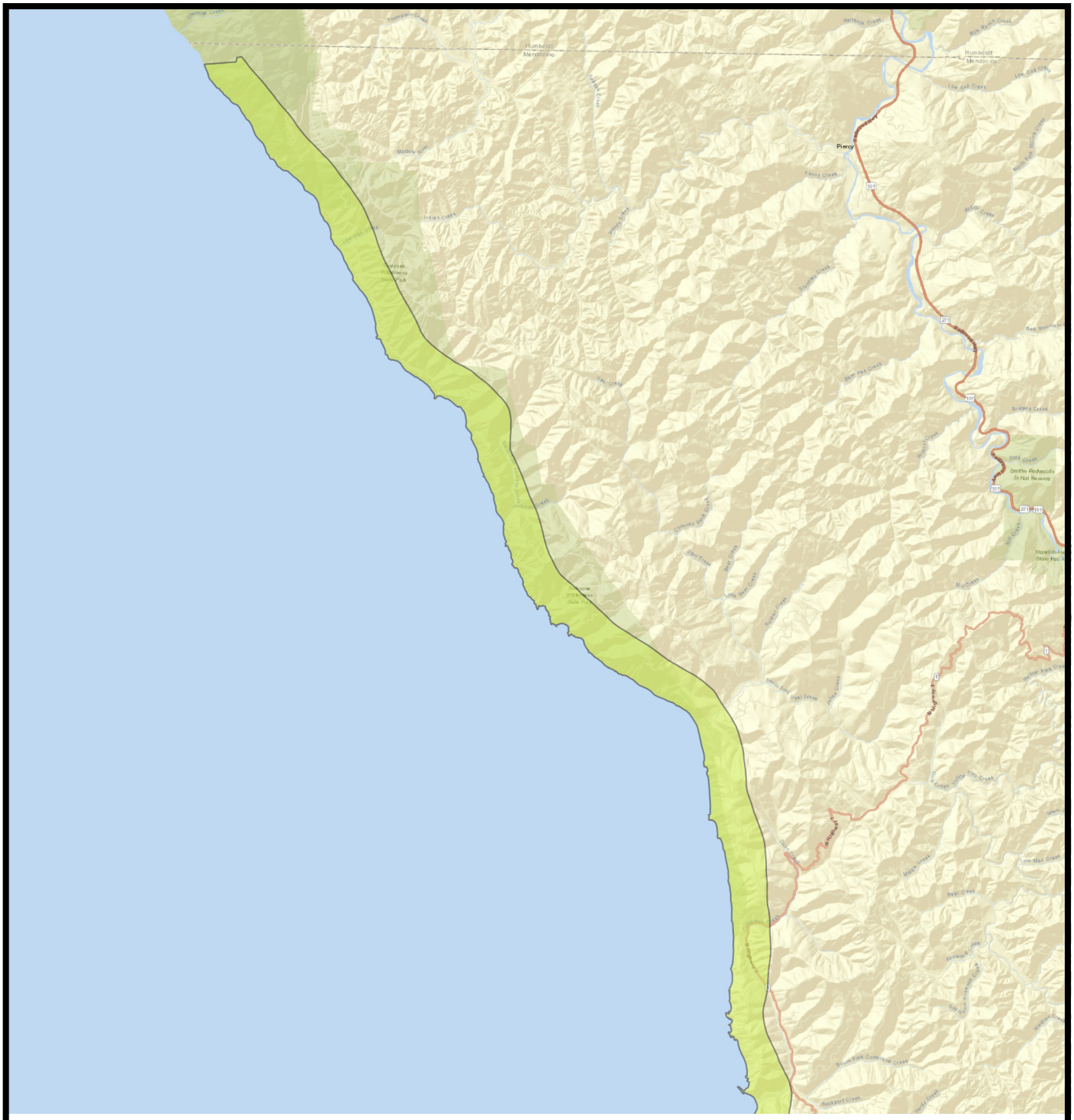
COASTAL GROUNDWATER STUDY

Water Supply Wells
Big River Sub CAC

09/04/2024 PN 594.03

Figure A-32

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

Explanation

CAC Planning Area

North Coast

0 1 2 mi

N

Notes:

1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

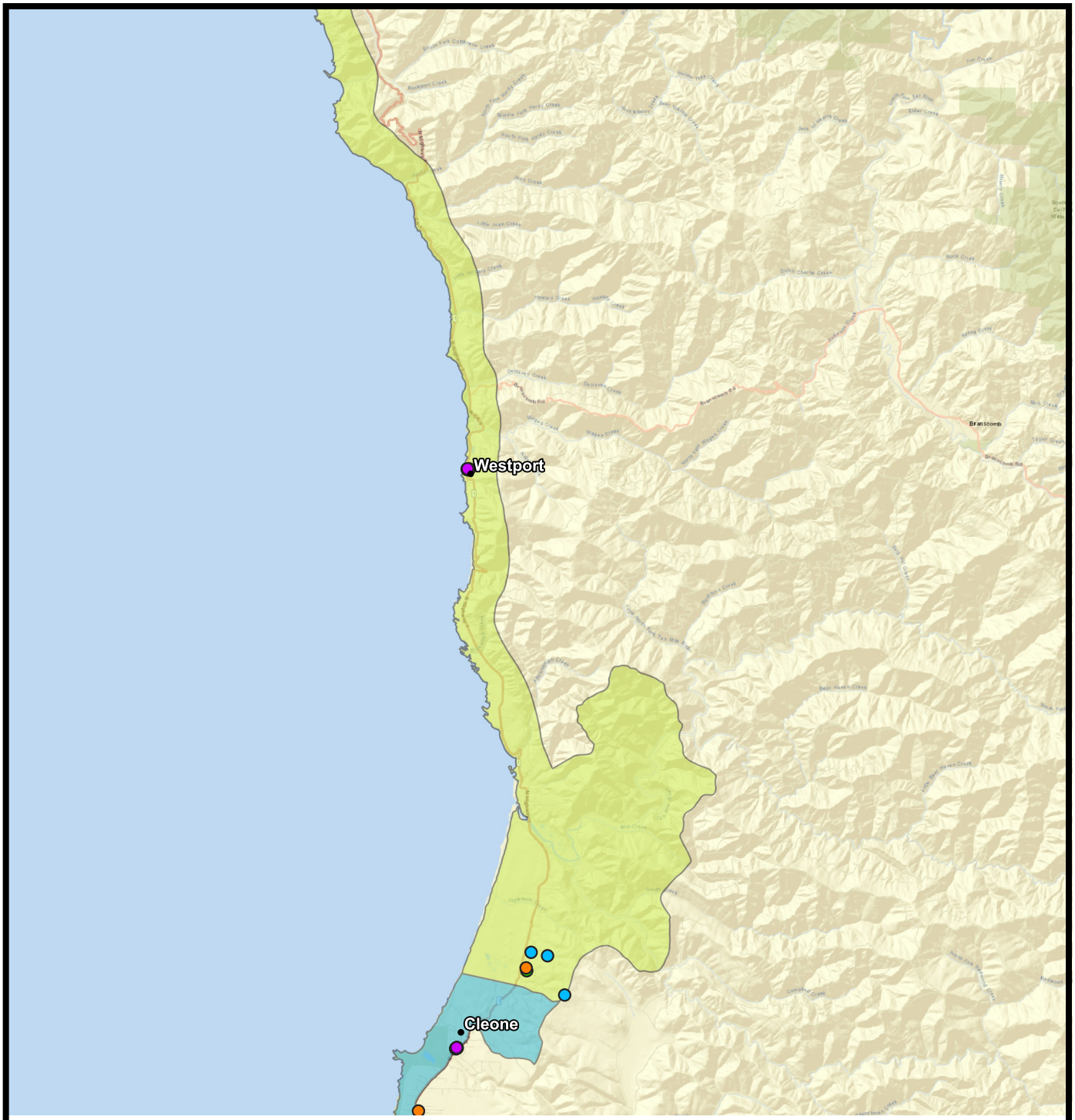
COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements North Coast (Northern)

09/04/2024 PN 594.03

Figure A-63

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

CAC Planning Area
- North Coast
- North Central Coast

Data Source
- DWR
- GeoTracker
- USGS
- Voluntary Monitoring Program

- City or Town

0 1 2 mi

N

Notes:
1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

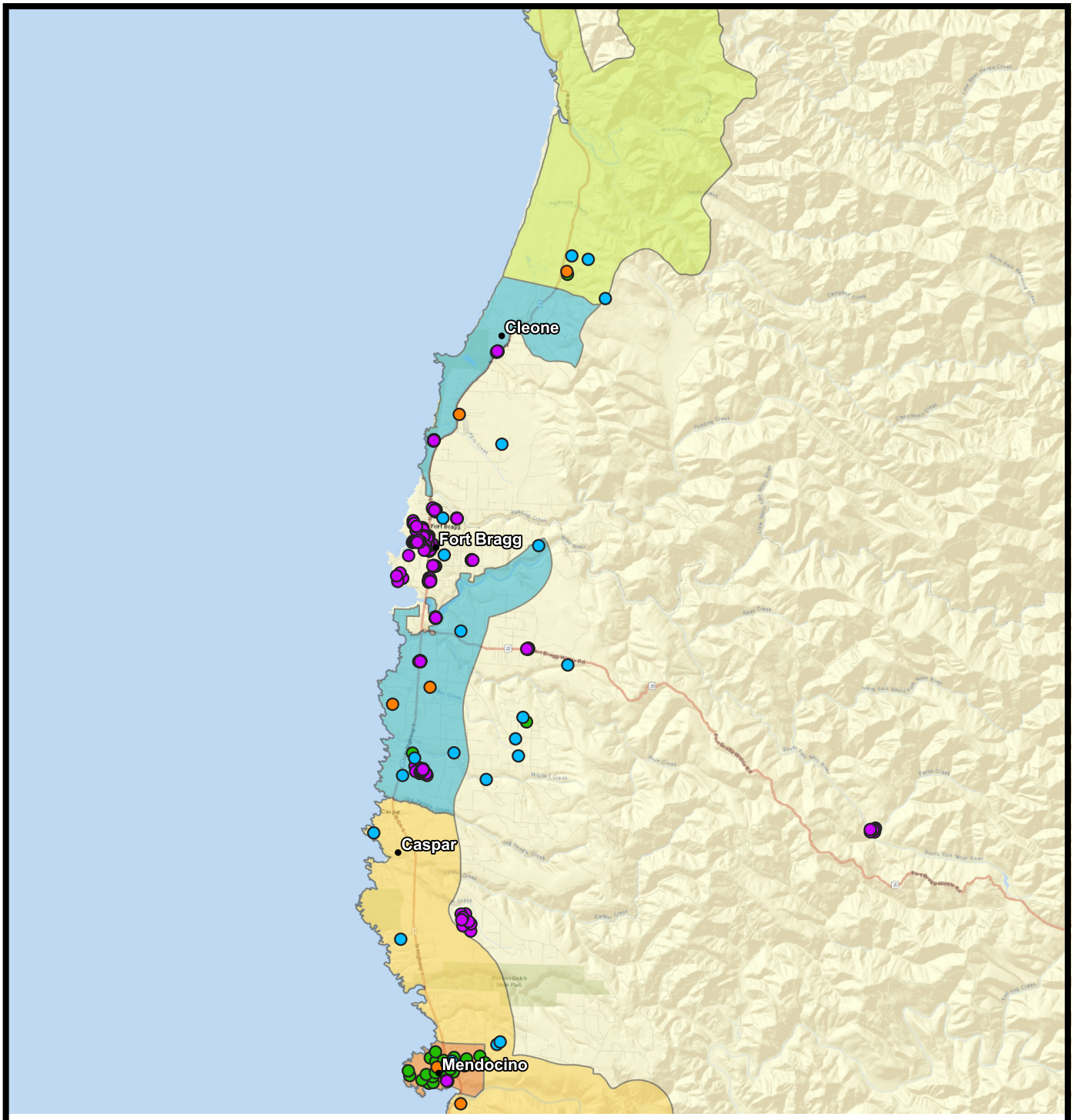
COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements North Coast (Southern)

09/04/2024 PN 594.03

Figure A-64

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

CAC Planning Area
- North Coast
- North Central Coast
- South Central Coast
- Big River Sub CAC

Data Source
- DWR
- GeoTracker
- USGS
- Voluntary Monitoring Program

- City or Town

0 1 2 mi

N

Notes:
1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

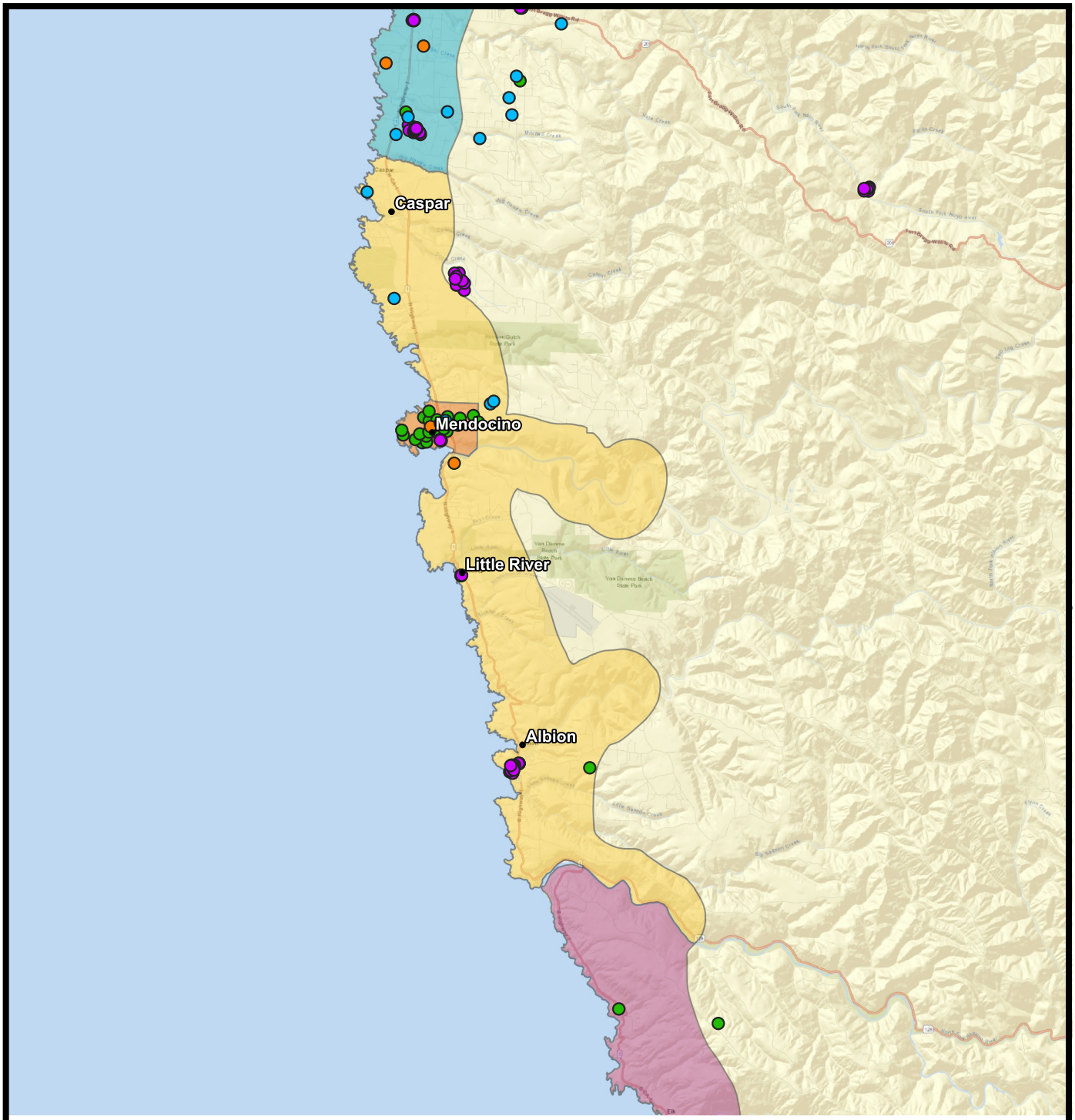
COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements
North Central Coast

09/04/2024 PN 594.03

Figure A-65

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

CAC Planning Area
- North Central Coast
- South Central Coast
- Big River Sub CAC
- South Coast

Data Source
- DWR
- GeoTracker
- USGS
- Voluntary Monitoring Program

- City or Town

0 1 2 mi

N

Notes:
1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

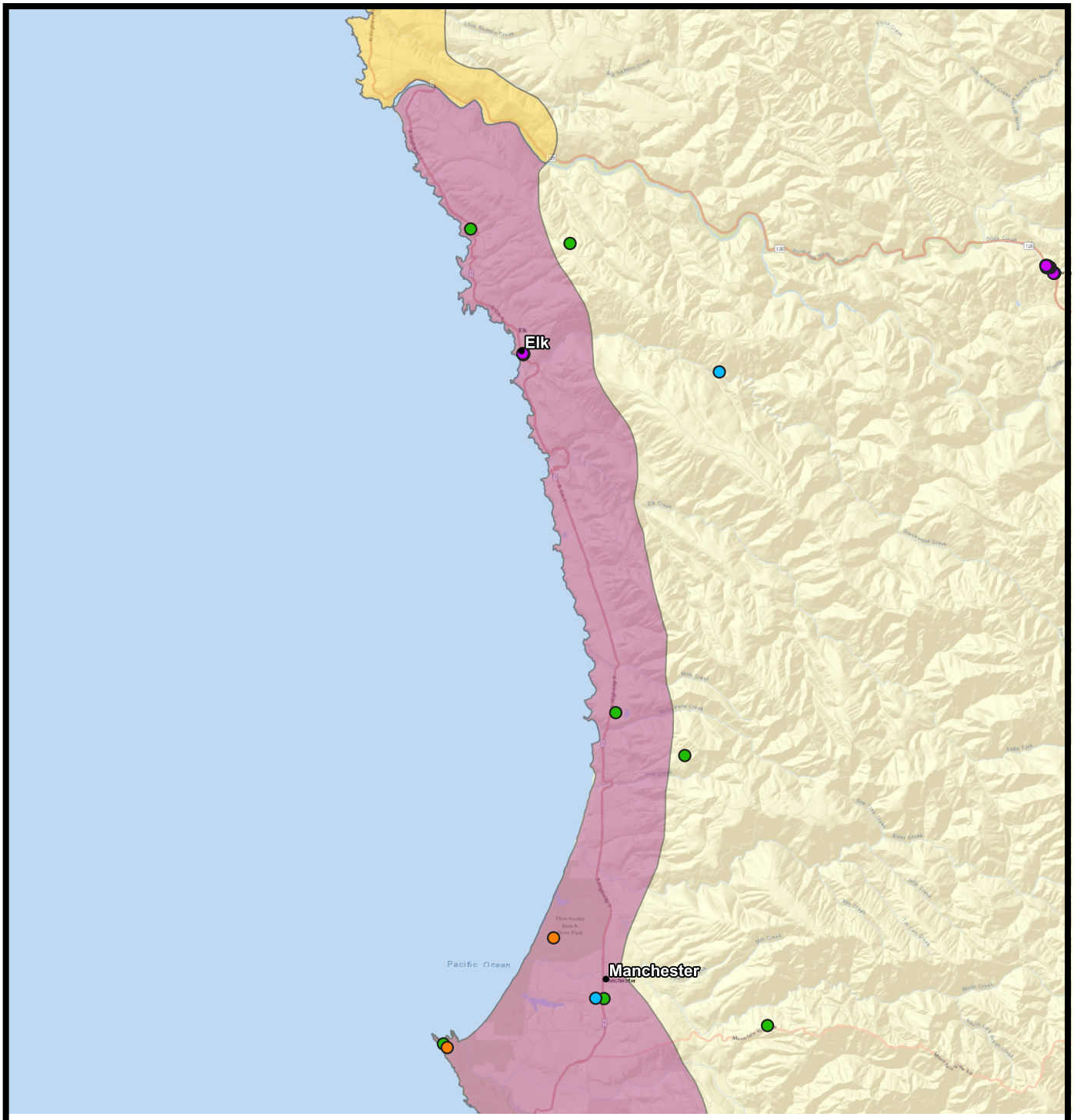
COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements
South Central Coast

09/04/2024 PN 594.03

Figure A-66

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Explanation

Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

CAC Planning Area
- South Central Coast
- South Coast

Data Source
- DWR
- GeoTracker
- USGS
- Voluntary Monitoring Program

- City or Town

0 1 2 mi

N

Notes:
1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

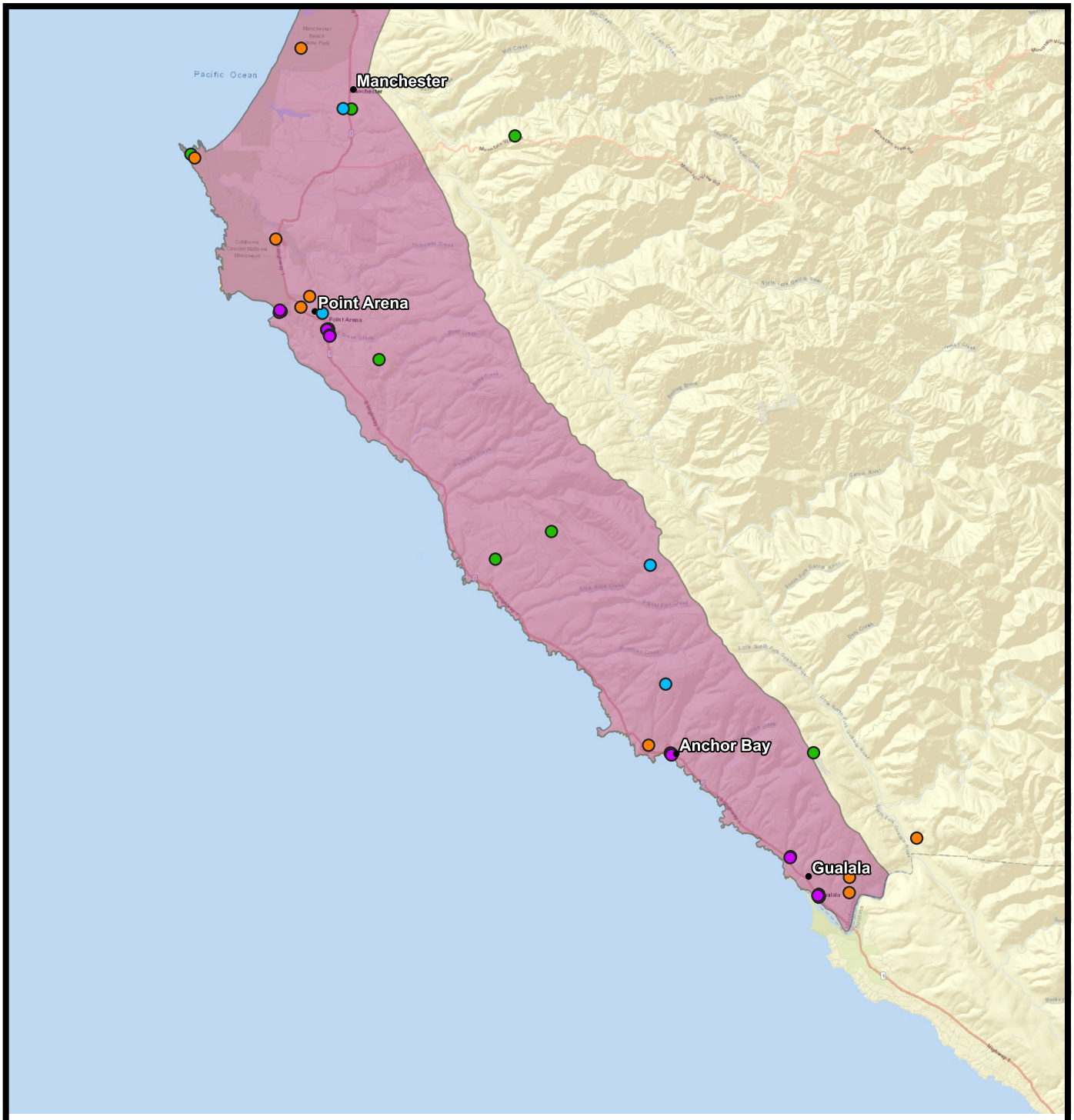
COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements South Coast (Northern)

09/04/2024 PN 594.03

Figure A-67

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Explanation

Sources: DWR; CASGEM; GeoTracker; USGS; SWRCB; Mendocino County

CAC Planning Area
- South Coast

Data Source
- DWR
- GeoTracker
- USGS
- Voluntary Monitoring Program

- City or Town

0 1 2 mi

N

Notes:
1. Only wells with more than five measurements collected over a period greater than one year shown (excluding voluntary monitoring program wells).

COASTAL GROUNDWATER STUDY

Wells with Groundwater Level Measurements
South Coast (Southern)

09/04/2024 PN 594.03

Figure A-68

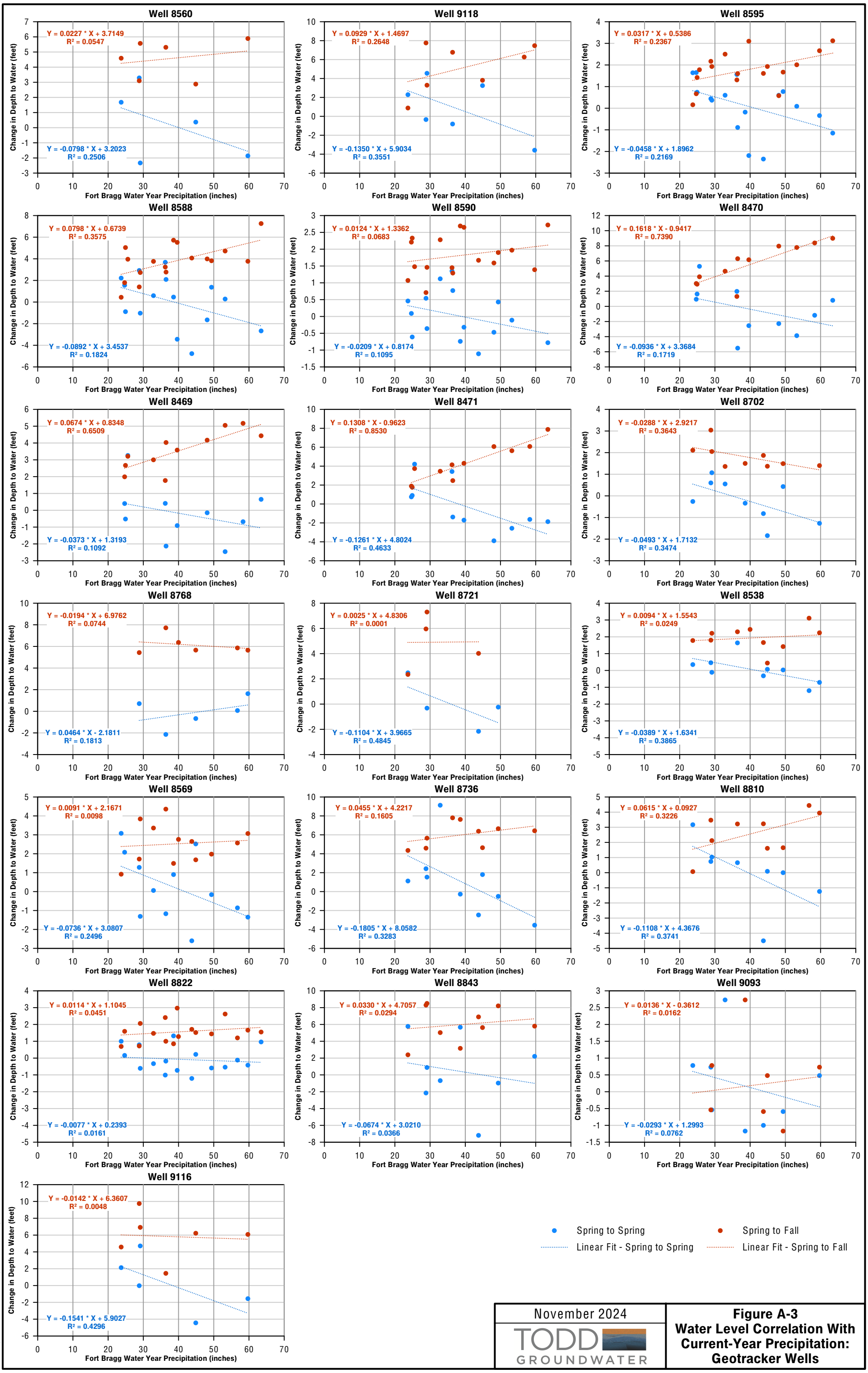
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Figure A-2
Water Level Correlation With Current-Year Precipitation: MCCSD Wells

November 2024

TODD GROUNDWATER



November 2024

TODD GROUNDWATER

Figure A-3
Water Level Correlation With Current-Year Precipitation: Geotracker Wells



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

37 ft Elevation Contour (NADV88)

Subwatershed

CAC Planning Area

0 1 2 mi

N

Notes:

1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

COASTAL GROUNDWATER STUDY

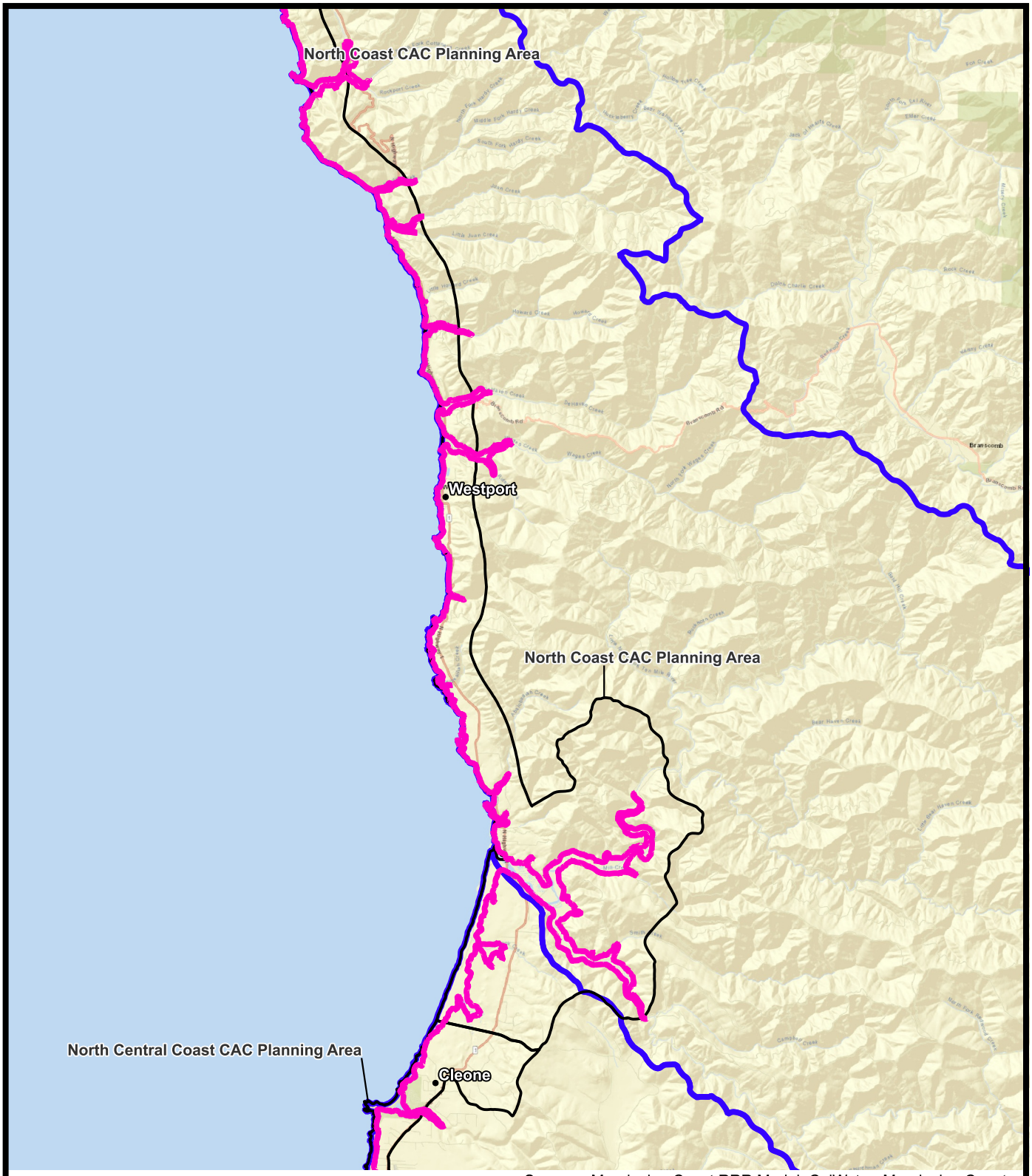
Seawater Intrusion Risk

North Coast (Northern)

11/21/2024 PN 594.03

Figure 7

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

37 ft Elevation Contour (NADV88) | Subwatershed | CAC Planning Area | City or Town

0 1 2 mi

N

Notes:

1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

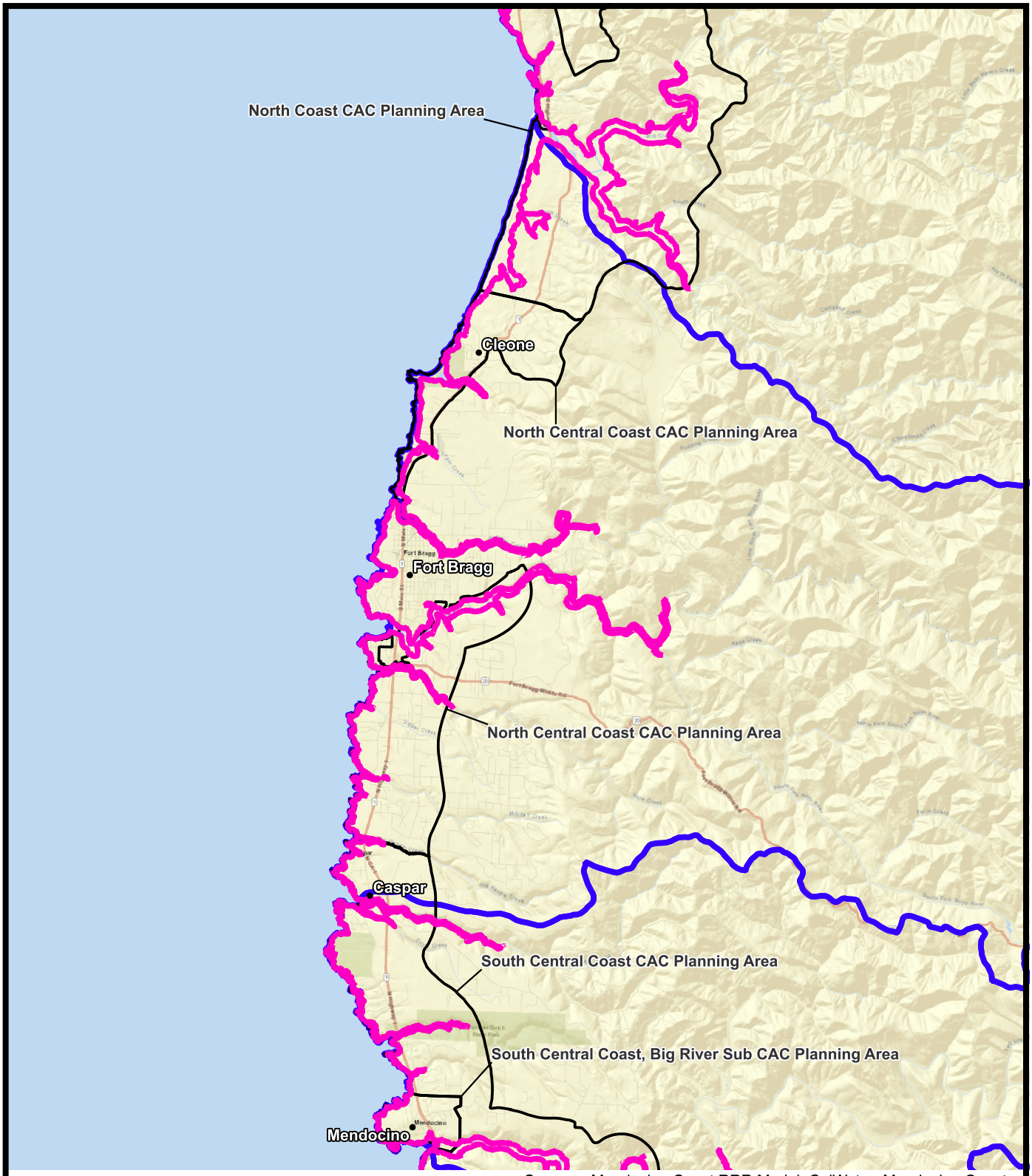
COASTAL GROUNDWATER STUDY

Seawater Intrusion Risk North Coast (Southern)

11/21/2024 PN 594.03

Figure 8

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

37 ft Elevation Contour (NADV88) | Subwatershed | CAC Planning Area | City or Town

0 1 2 mi

N

Notes:

1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

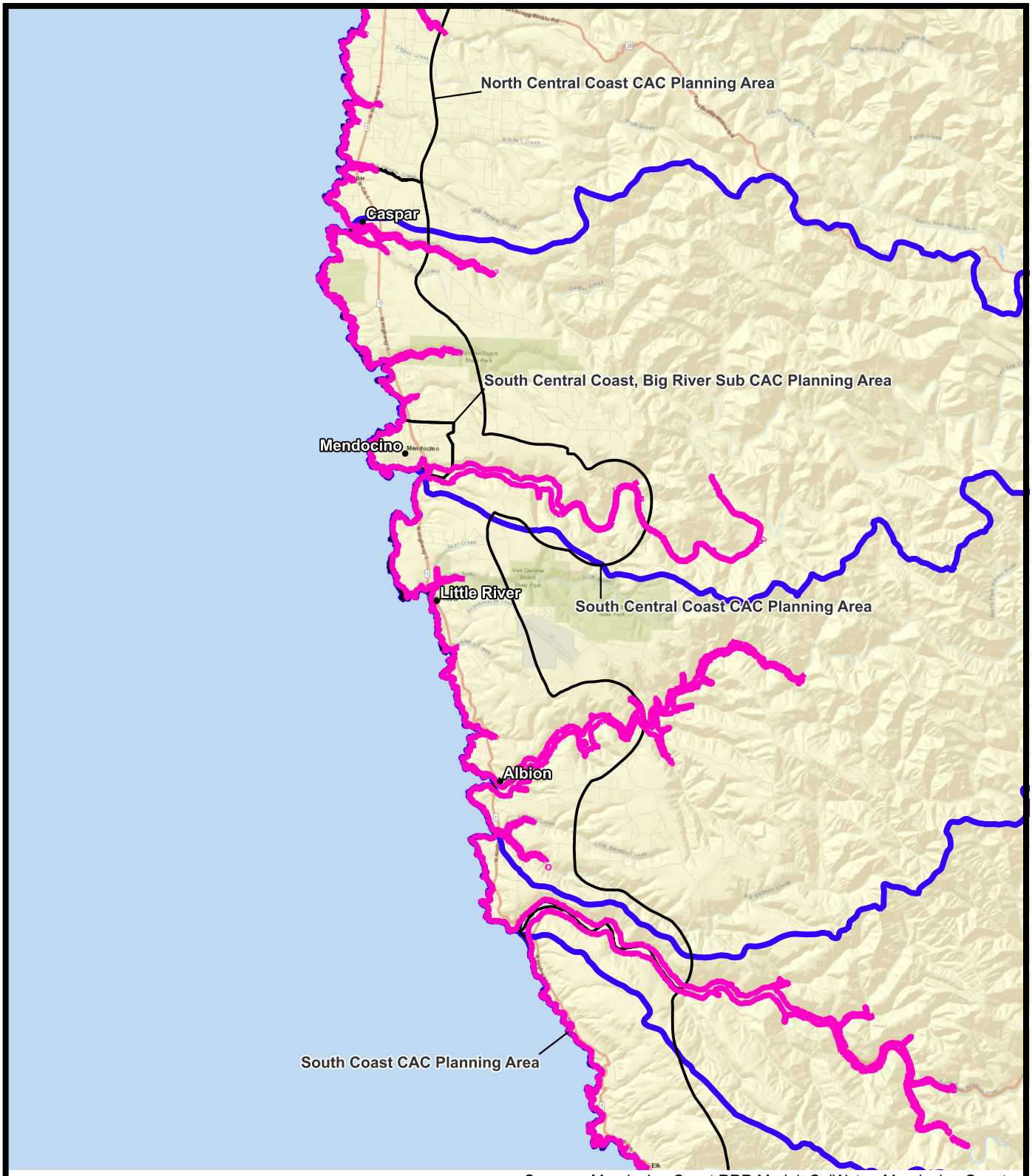
COASTAL GROUNDWATER STUDY

Seawater Intrusion Risk North Central Coast

11/21/2024 PN 594.03

Figure 9

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

37 ft Elevation Contour (NADV88) | Subwatershed | CAC Planning Area | City or Town

0 1 2 mi

N

Notes:

1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

COASTAL GROUNDWATER STUDY

Seawater Intrusion Risk South Central Coast

11/21/2024 PN 594.03

Figure 10

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

37 ft Elevation Contour (NADV88) | Subwatershed | CAC Planning Area | City or Town

0 1 2 mi

N

Notes:
1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

COASTAL GROUNDWATER STUDY

Seawater Intrusion Risk South Coast (Northern)

11/21/2024 PN 594.03

Figure 11

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

37 ft Elevation Contour (NADV88) | Subwatershed | CAC Planning Area | City or Town

0 1 2 mi

N

Notes:
1. CAC = Citizen Advisory Committee
2. Wells up to 200 ft deep located in areas with a surface elevation less than 37 ft feet above mean sea level are considered susceptible to impacts from seawater intrusion.

COASTAL GROUNDWATER STUDY

Seawater Intrusion Risk South Coast (Southern)

11/21/2024 PN 594.03

Figure 12

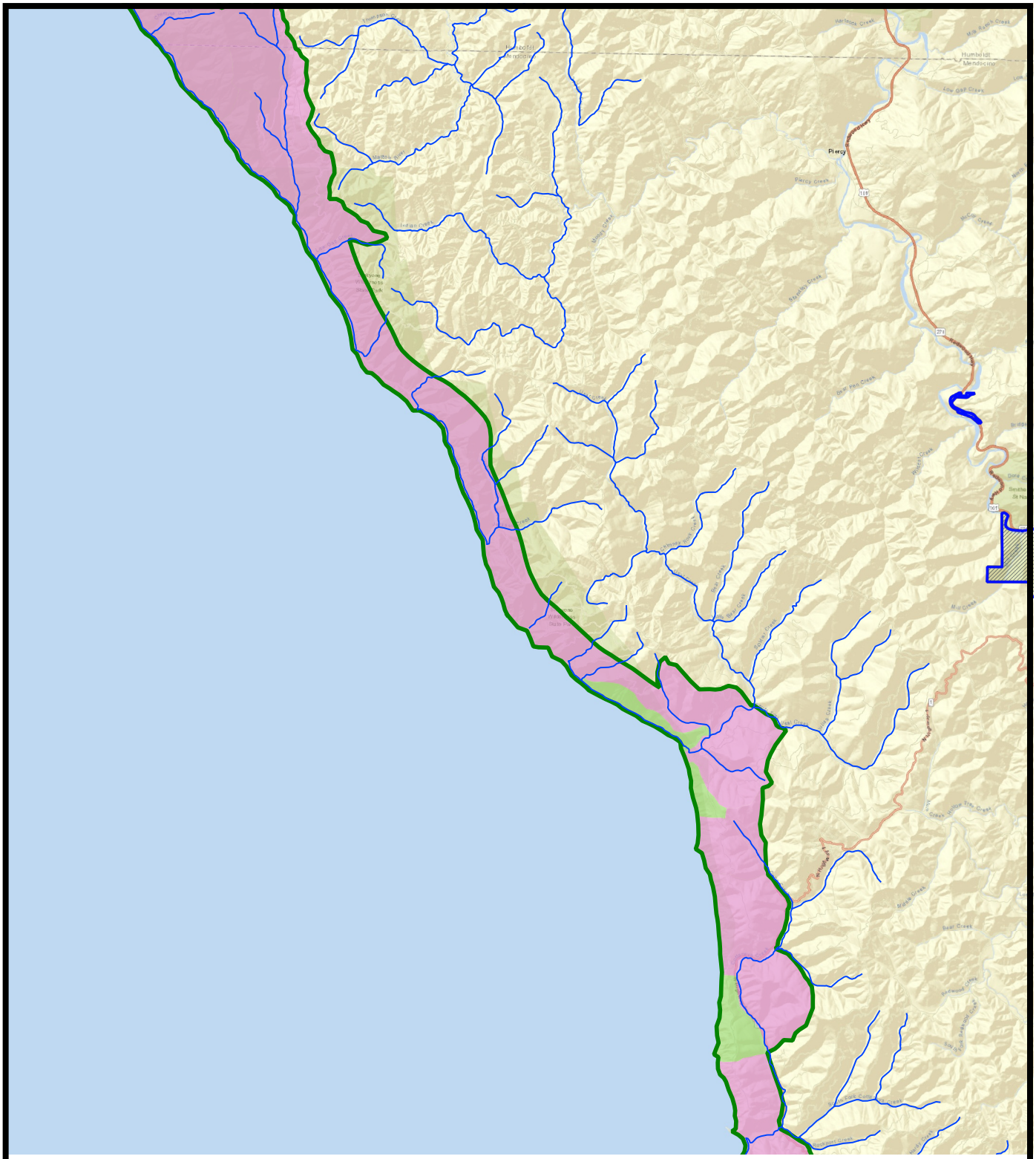
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Appendix B: Rainfall-Runoff-Recharge Model Details

Map of Land Cover in Recharge Analysis Polygons

Contours of Average Annual Precipitation

Map of Simulated Average Annual Recharge



COASTAL GROUNDWATER STUDY

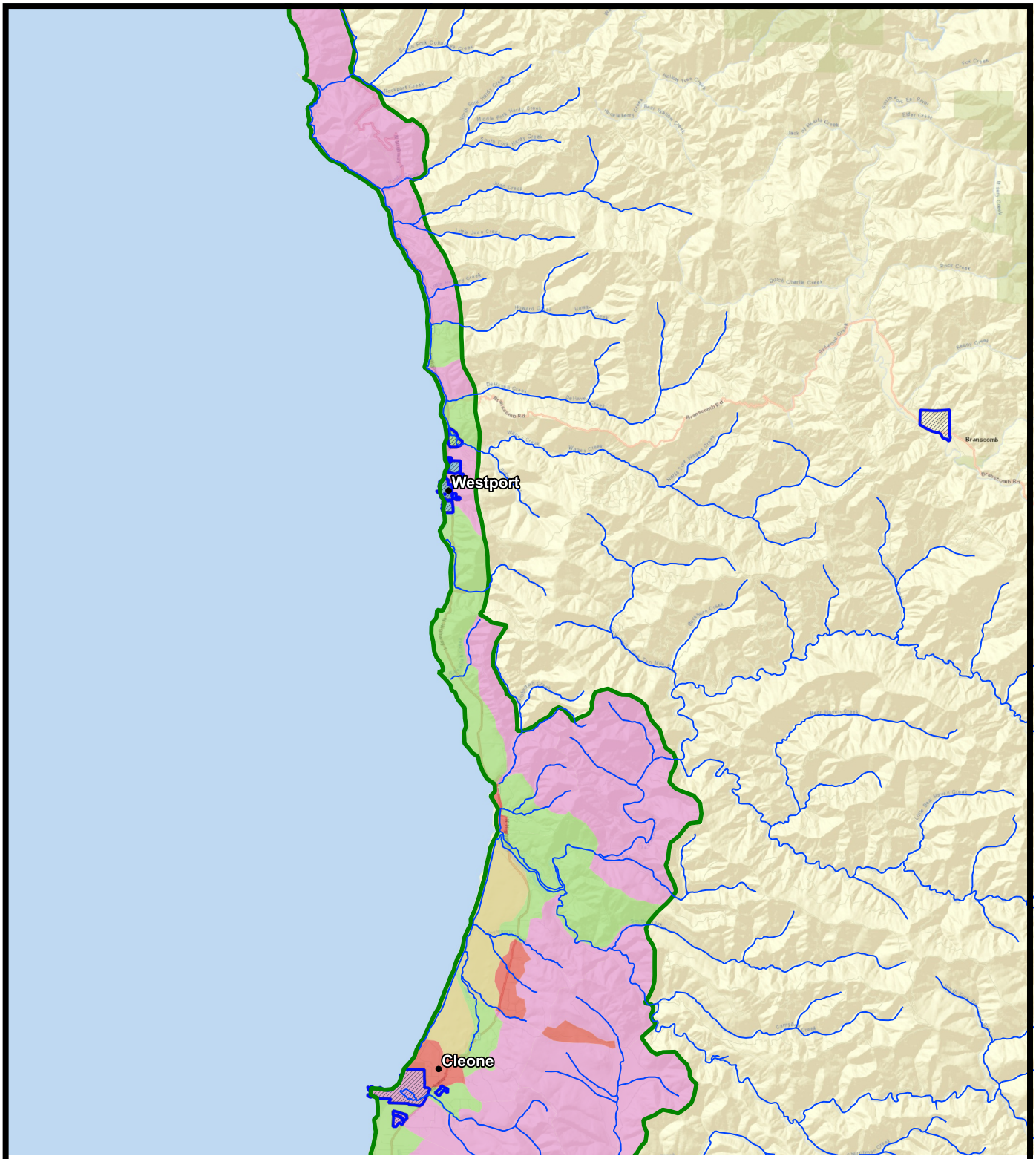
RRR Model Domain and Landcover
North Coast (Northern)

Notes:
1. RRR = Rainfall-Runoff-Recharge.

09/04/2024 PN 594.03

Figure A-51

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Modeled Landcover
- Beach
- Grassland
- Forest
- Urban

- Rural Residential
- RRR Model Domain
- Public Water System Service Area
- Stream
- City or Town

Sources: USGS; SWRCB

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.

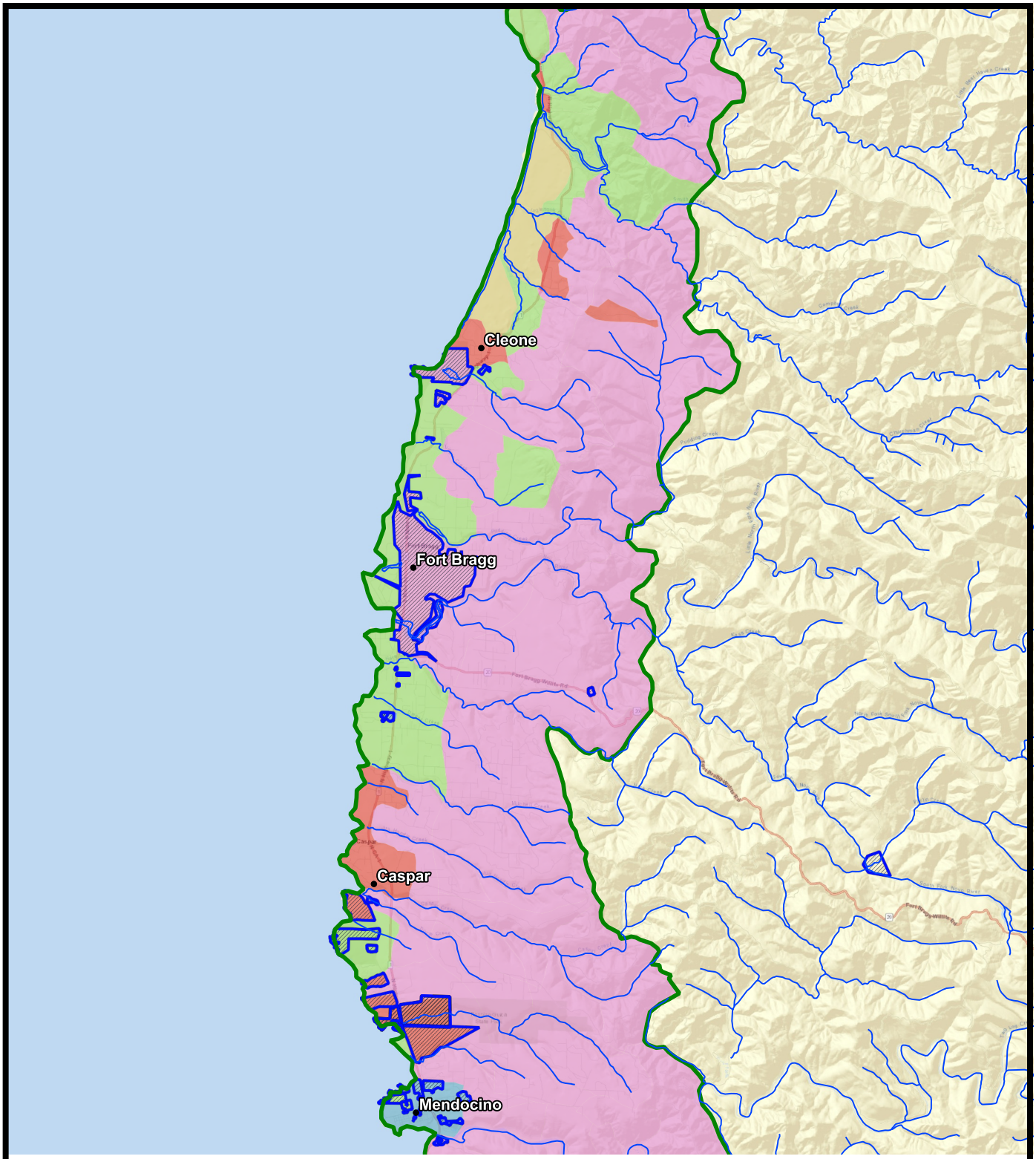
COASTAL GROUNDWATER STUDY

RRR Model Domain and Landcover
North Coast (Southern)

09/04/2024 PN 594.03

Figure A-52

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Modeled Landcover
- Beach
- Grassland
- Forest
- Urban

- Rural Residential
- RRR Model Domain
- Public Water System Service Area
- Stream
- City or Town

Sources: USGS; SWRCB

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.

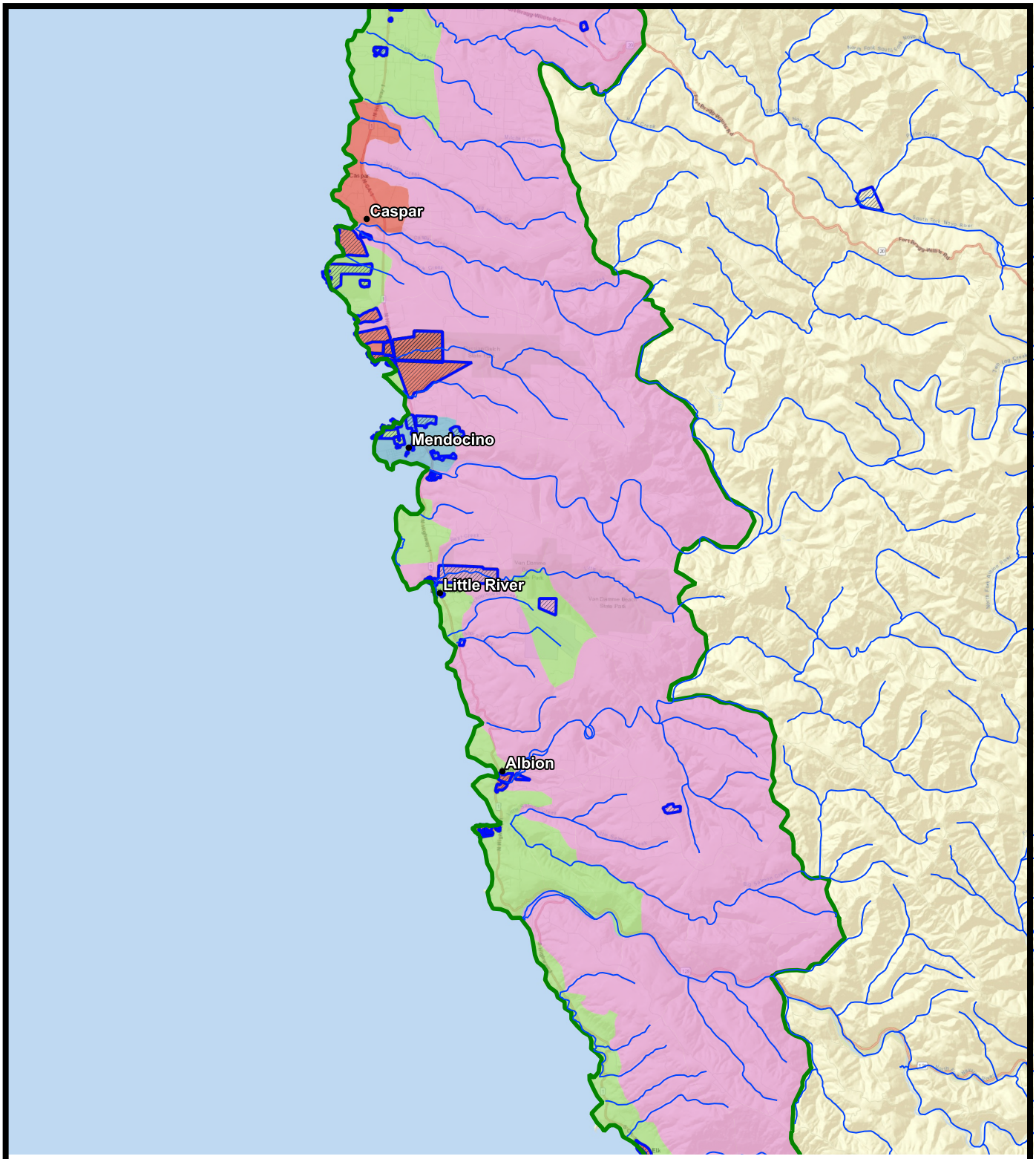
COASTAL GROUNDWATER STUDY

RRR Model Domain and Landcover
North Central Coast

09/04/2024 PN 594.03

Figure A-53

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Modeled Landcover
- Grassland
- Forest
- Urban

- Rural Residential
- RRR Model Domain
- Public Water System Service Area
- Stream
- City or Town

Sources: USGS; SWRCB

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.

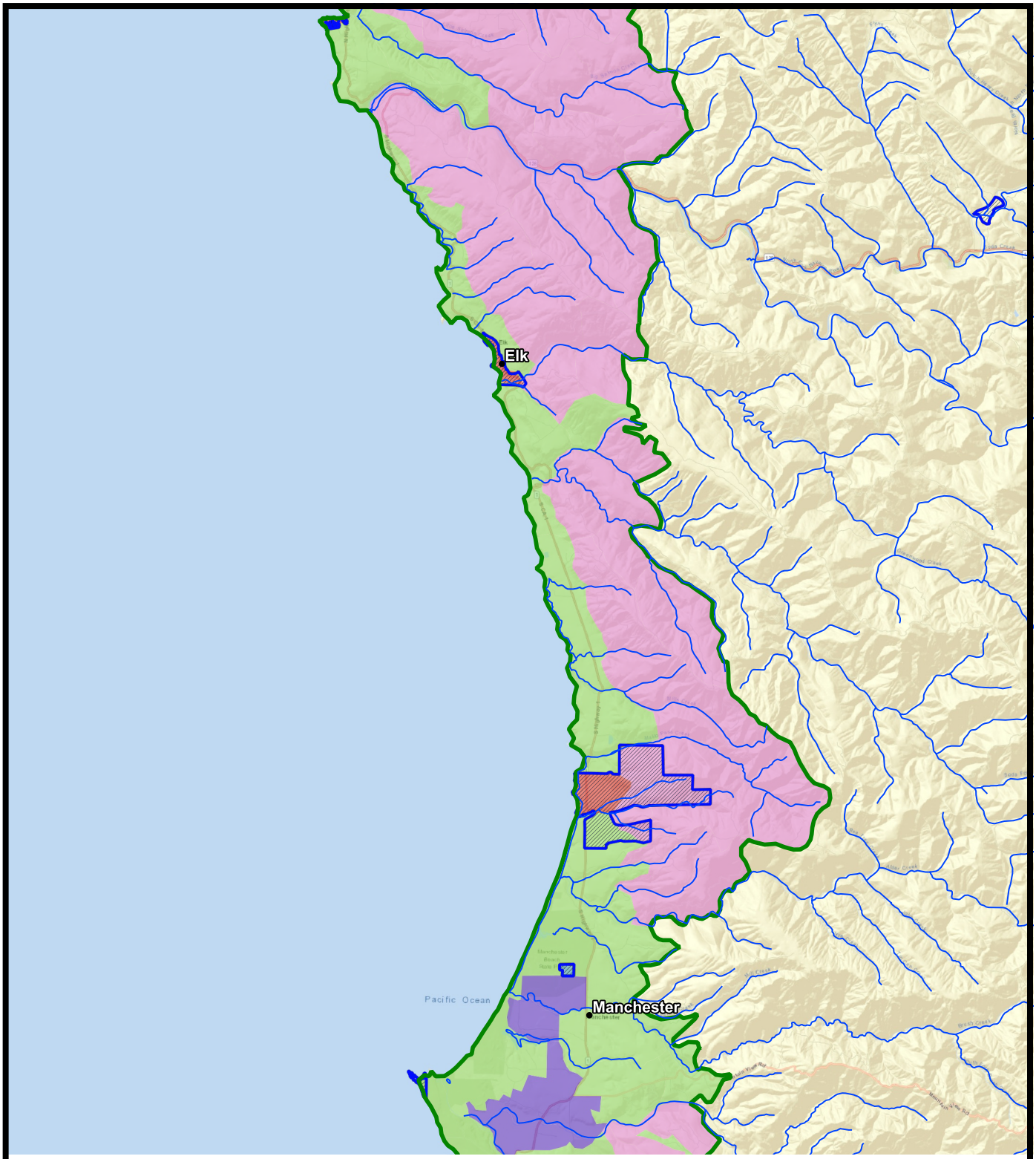
COASTAL GROUNDWATER STUDY

RRR Model Domain and Landcover
South Central Coast

09/04/2024 PN 594.03

Figure A-54

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Modeled Landcover
- Grassland
- Forest
- Pasture
- Urban

- Rural Residential
- RRR Model Domain
- Public Water System Service Area
- Stream
- City or Town

Sources: USGS; SWRCB

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.

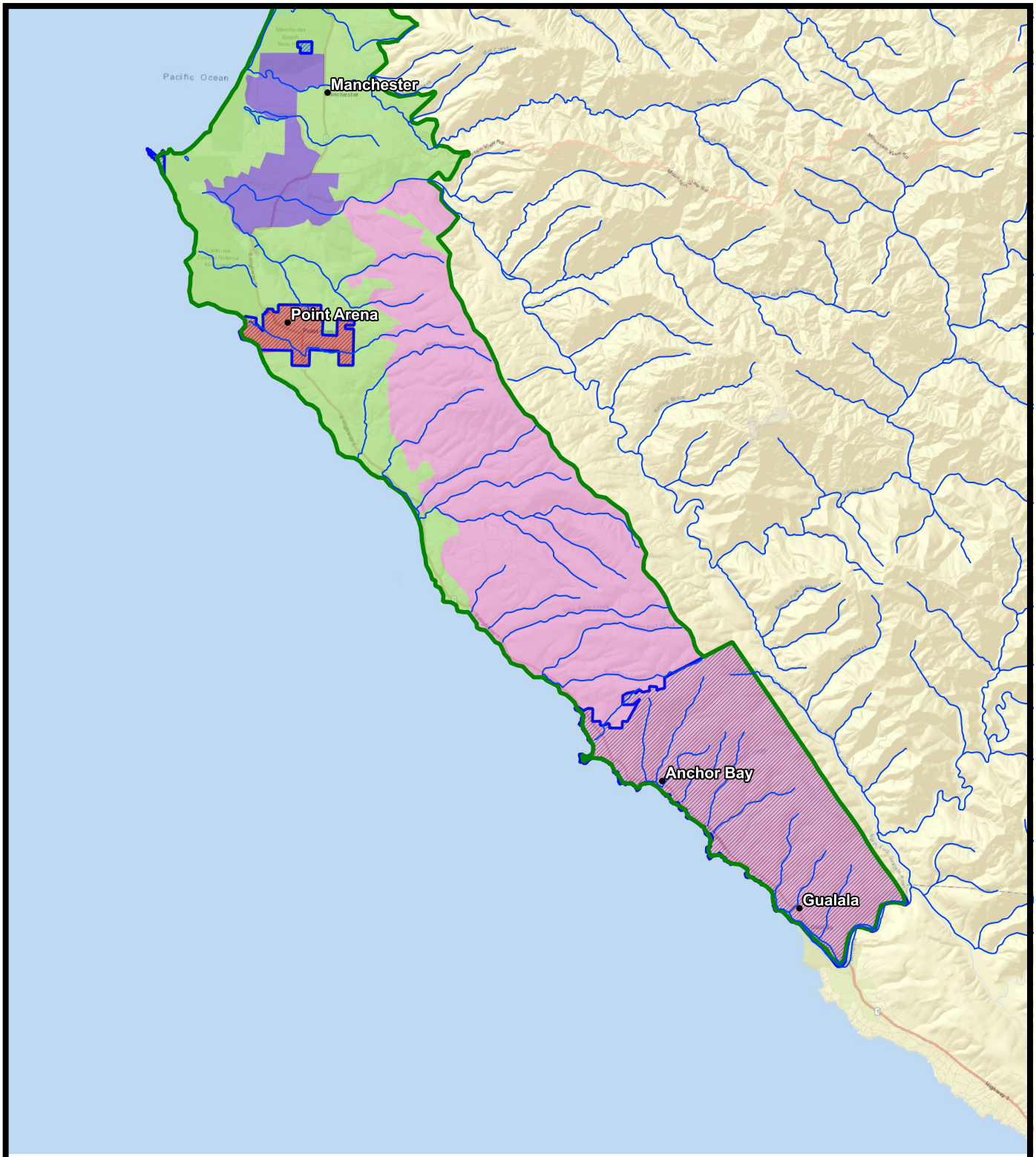
COASTAL GROUNDWATER STUDY

RRR Model Domain and Landcover South Coast (Northern)

09/04/2024 PN 594.03

Figure A-55

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Explanation

Modeled Landcover
- Grassland
- Forest
- Pasture
- Urban

- Rural Residential
- RRR Model Domain
- Public Water System Service Area
- Stream
- City or Town

Sources: USGS; SWRCB

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge.

COASTAL GROUNDWATER STUDY

RRR Model Domain and Landcover
South Coast (Southern)

09/04/2024 PN 594.03

Figure A-56

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Sources: PRISM; CalWater; Mendocino County

Explanation

Precipitation Contour (in/yr)

Subwatershed

CAC Planning Area

North Coast

N

0 1 2 mi

Notes:

1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

COASTAL GROUNDWATER STUDY

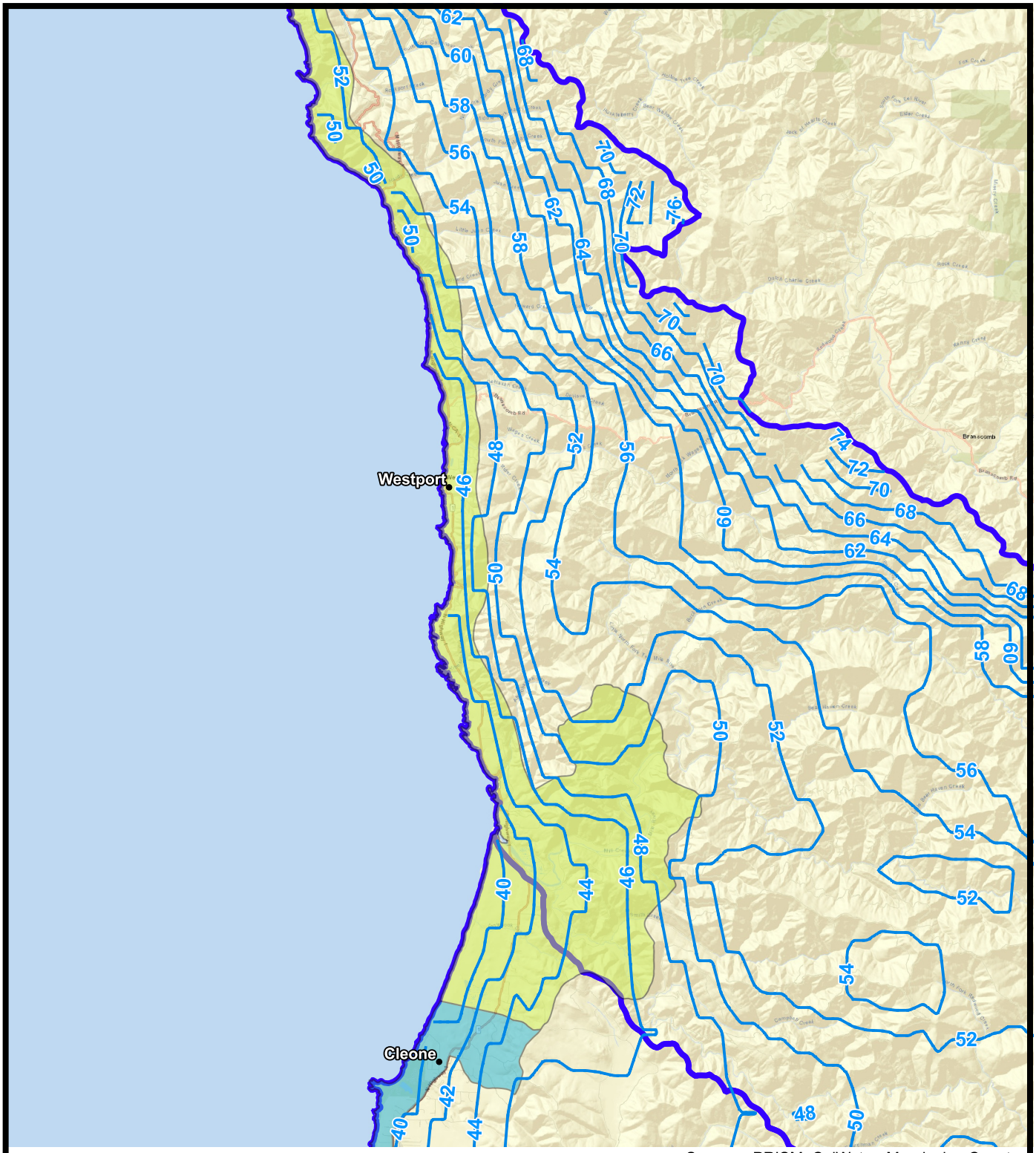
Precipitation

North Coast (Northern)

11/21/2024 PN 594.03

Figure 7

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: PRISM; CalWater; Mendocino County

Explanation

- Precipitation Contour (in/yr)
- Subwatershed
- City or Town

CAC Planning Area
- North Coast
- North Central Coast

N

0 1 2 mi

Notes:
1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

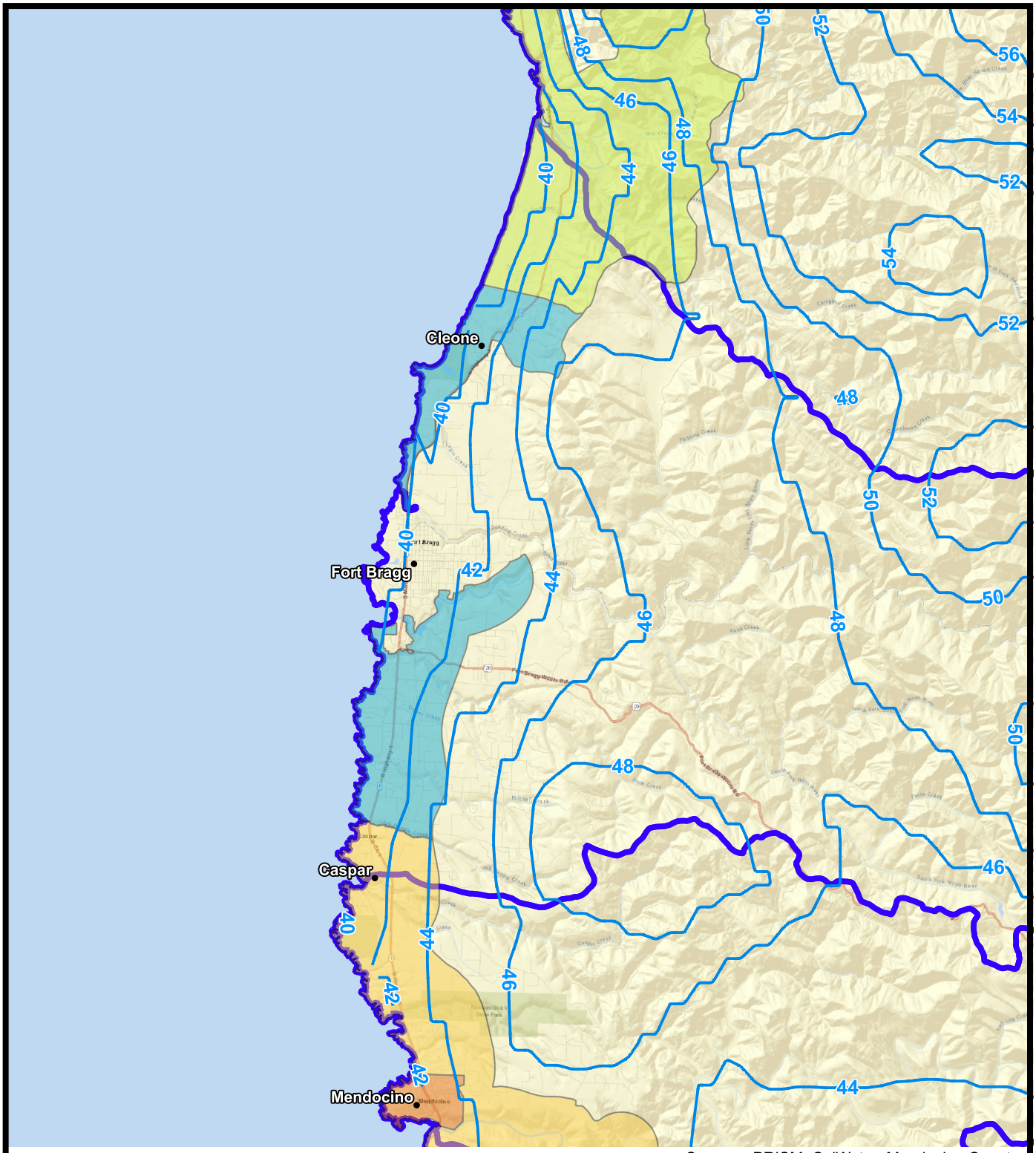
COASTAL GROUNDWATER STUDY

Precipitation
North Coast (Southern)

11/21/2024 PN 594.03

Figure 8

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Sources: PRISM; CalWater; Mendocino County

Explanation

- Precipitation Contour (in/yr)
- Subwatershed
- City or Town

CAC Planning Area

- North Coast
- North Central Coast
- South Central Coast
- South Central Coast Big River Sub CAC

N

0 1 2 mi

Notes:

1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

COASTAL GROUNDWATER STUDY

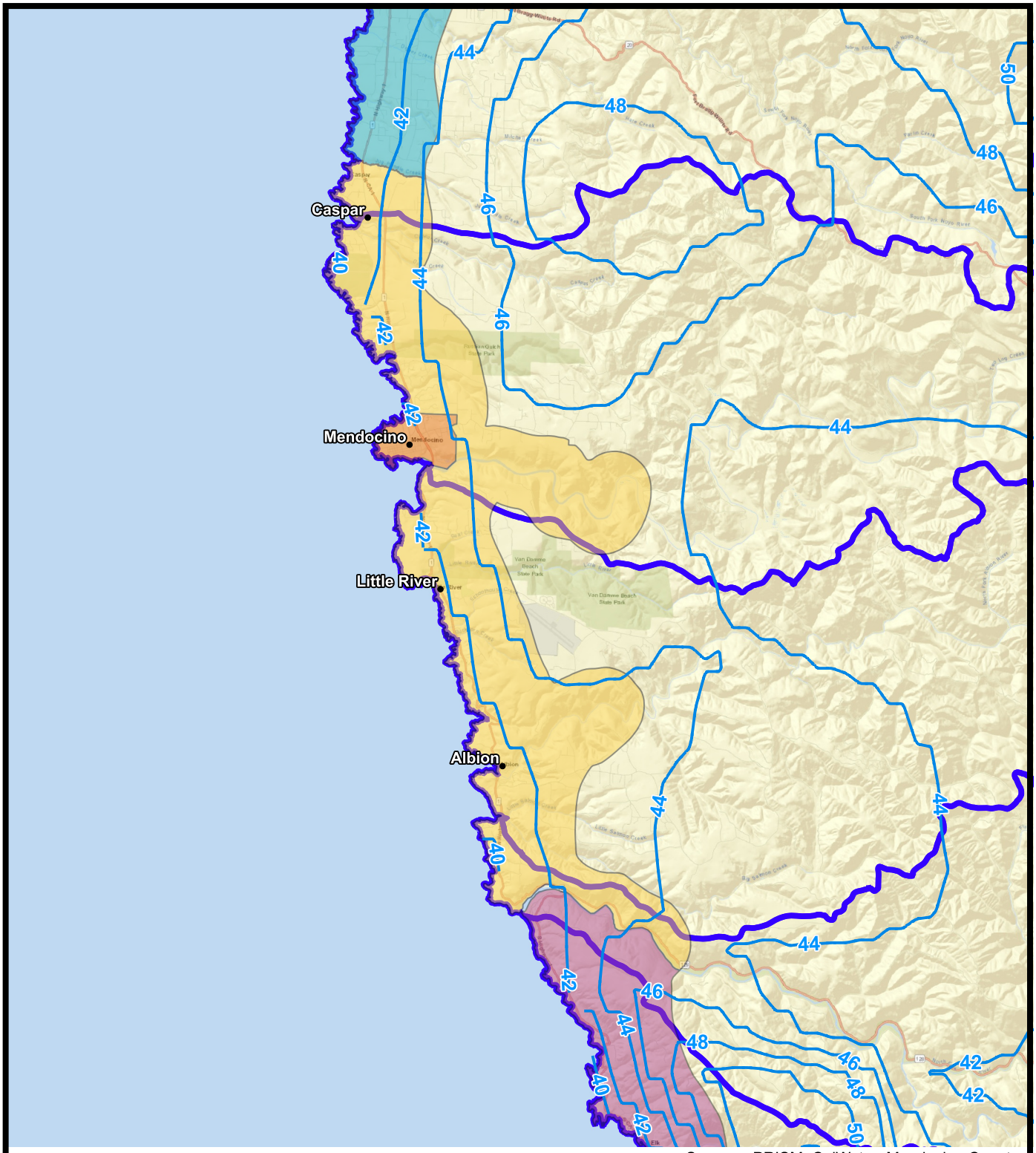
Precipitation

North Central Coast

11/21/2024 PN 594.03

Figure 9

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

- Precipitation Contour (in/yr)
- Subwatershed
- City or Town

CAC Planning Area

- North Central Coast
- South Central Coast
- South Central Coast Big River Sub CAC
- South Coast

Sources: PRISM; CalWater; Mendocino County

N

0 1 2 mi

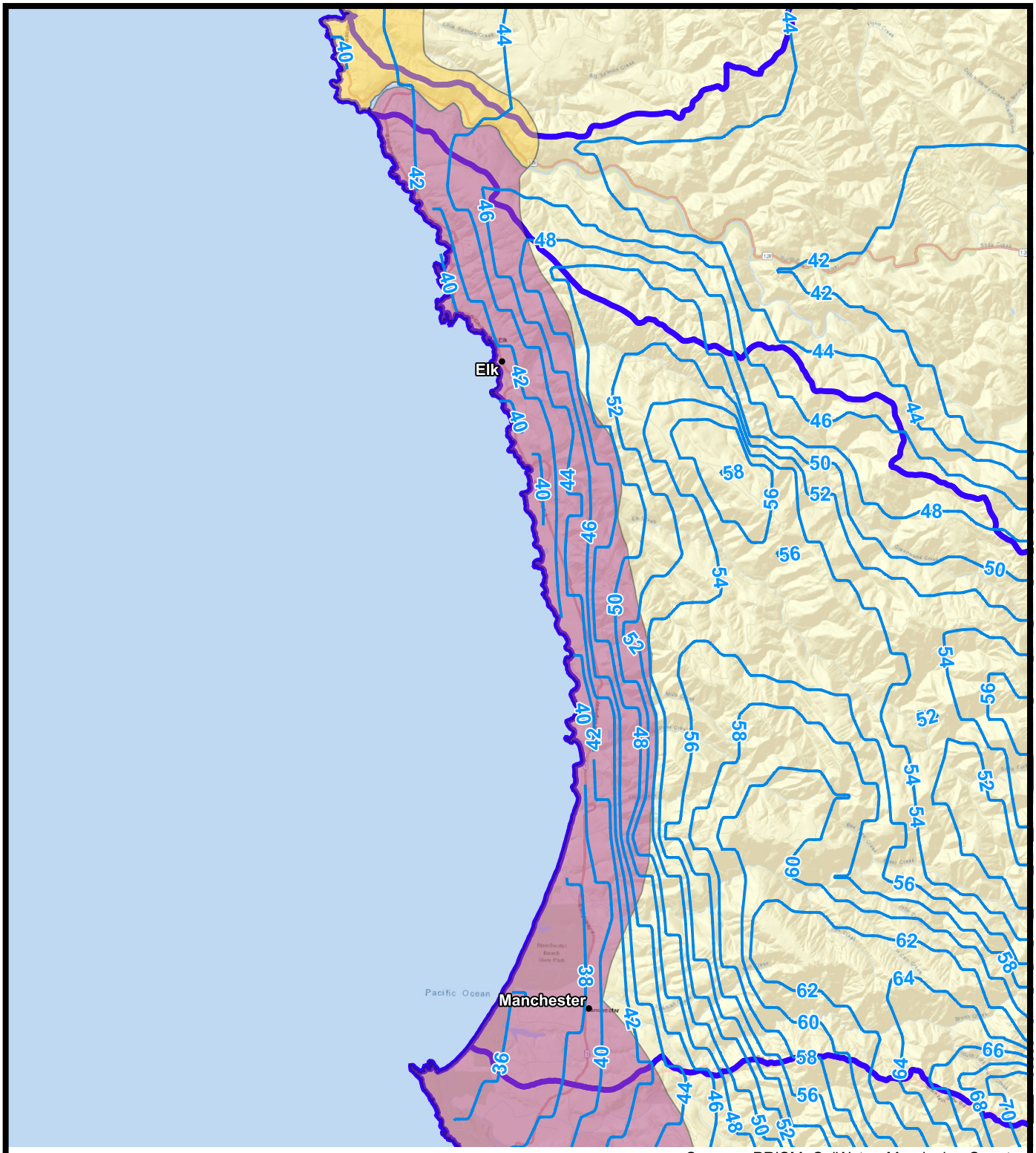
Notes:
1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

COASTAL GROUNDWATER STUDY
Precipitation
South Central Coast

11/21/2024 PN 594.03

Figure 10

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Sources: PRISM; CalWater; Mendocino County

Explanation

- Precipitation Contour (in/yr)
- Subwatershed
- City or Town

CAC Planning Area
- South Central Coast
- South Coast

N

0 1 2 mi

Notes:
1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

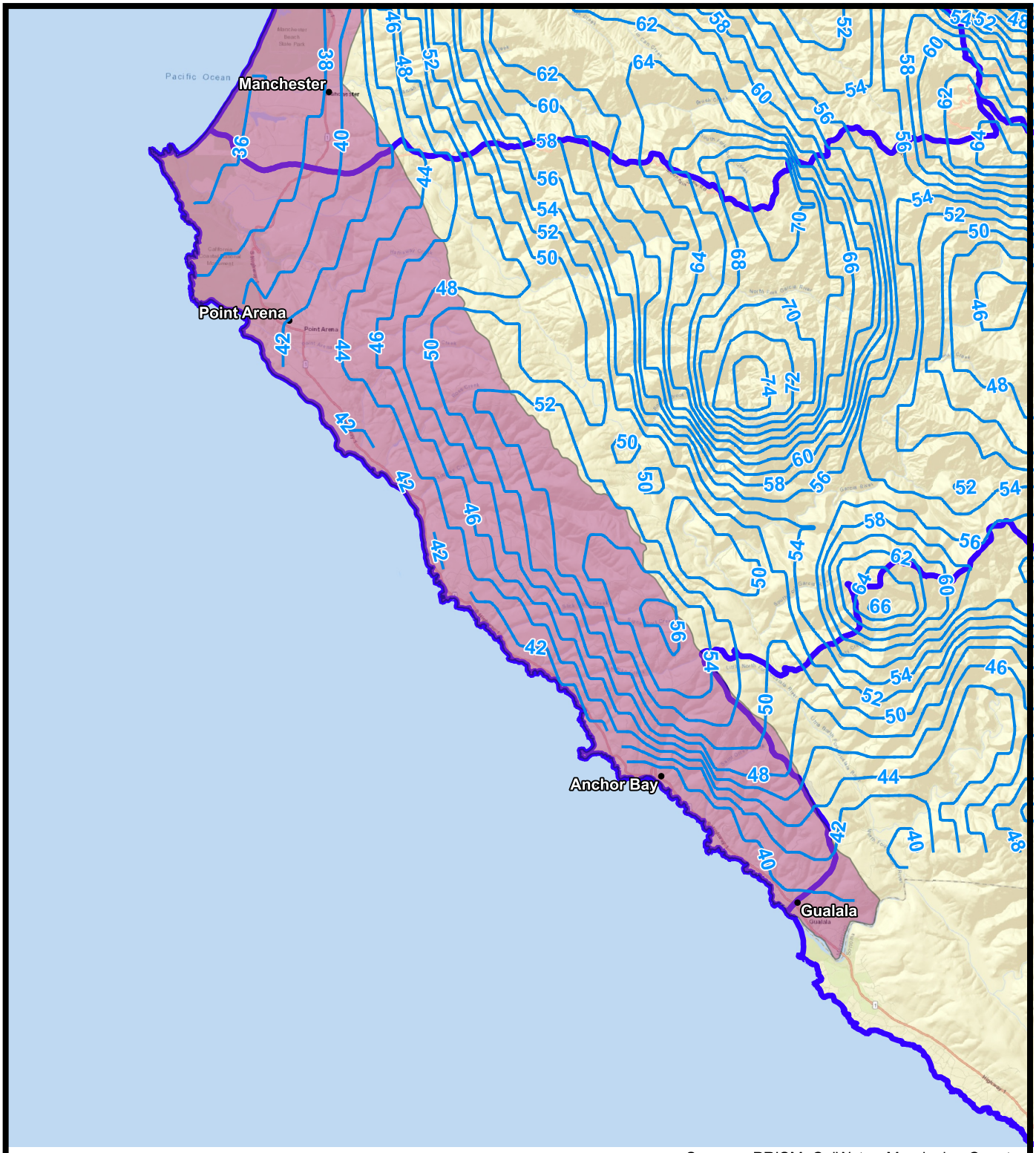
COASTAL GROUNDWATER STUDY

Precipitation
South Coast (Northern)

11/21/2024 PN 594.03

Figure 11

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Explanation

Precipitation Contour (in/yr)

Subwatershed

City or Town

CAC Planning Area

South Coast

Sources: PRISM; CalWater; Mendocino County

N

0 1 2 mi

Notes:
1. CAC = Citizen Advisory Committee
2. PRISM = Parameter-elevation Regressions on Independent Slopes Model
3. PRISM 30-year (1990-2020) normals shown

COASTAL GROUNDWATER STUDY

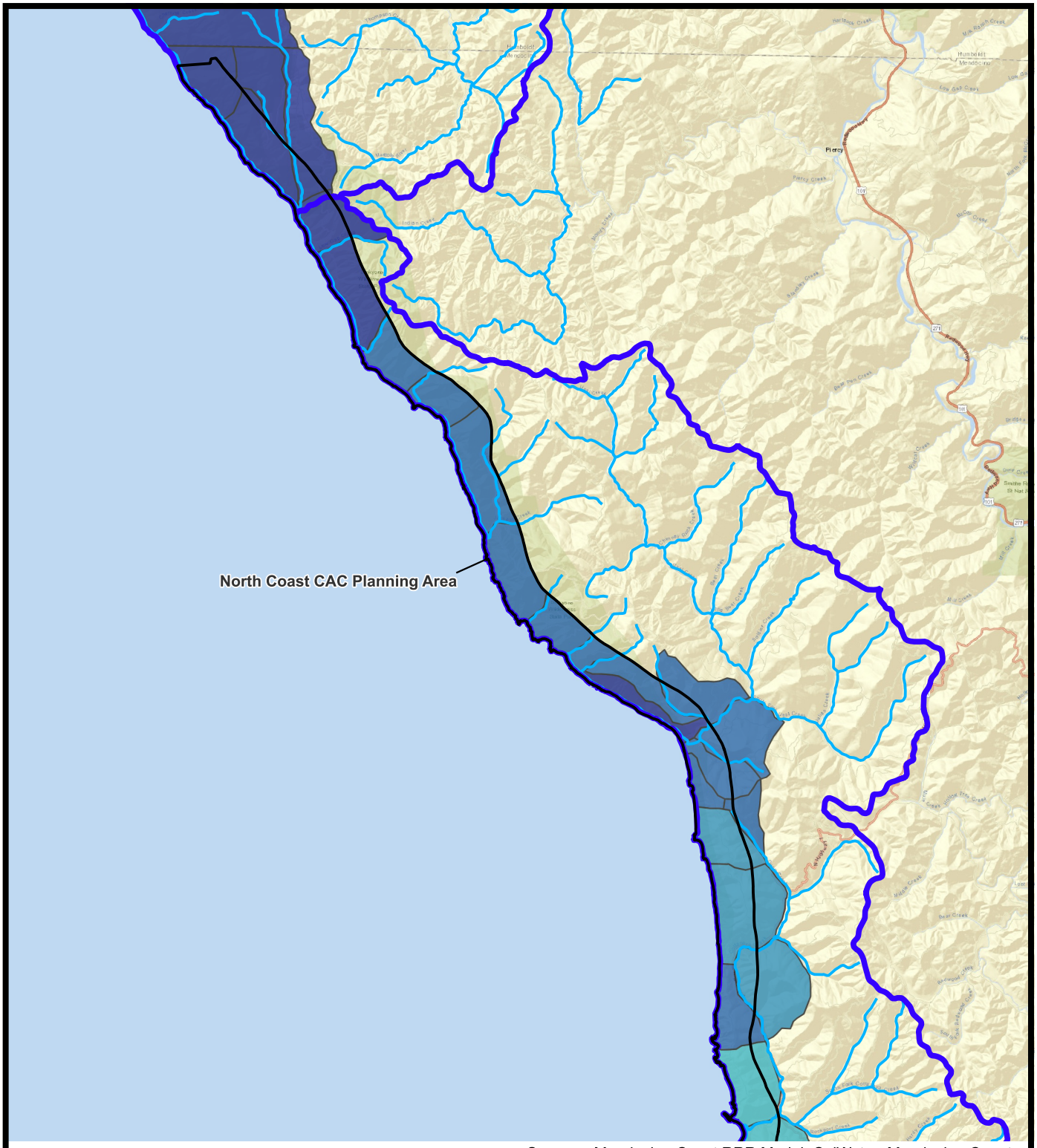
Precipitation

South Coast (Southern)

11/21/2024 PN 594.03

Figure 12

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

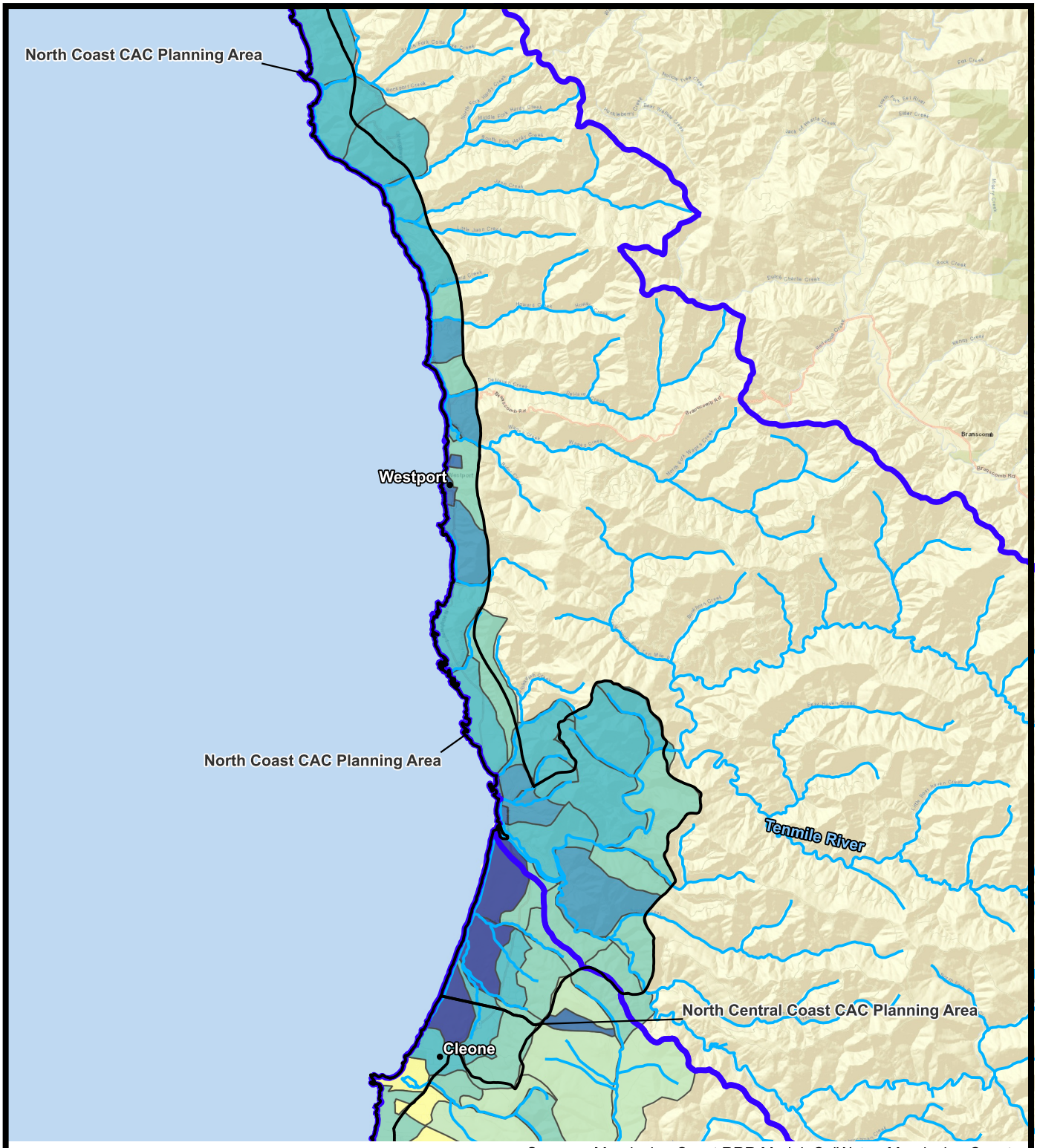
COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge North Coast (Northern)

11/21/2024 PN 594.03

Figure 1

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

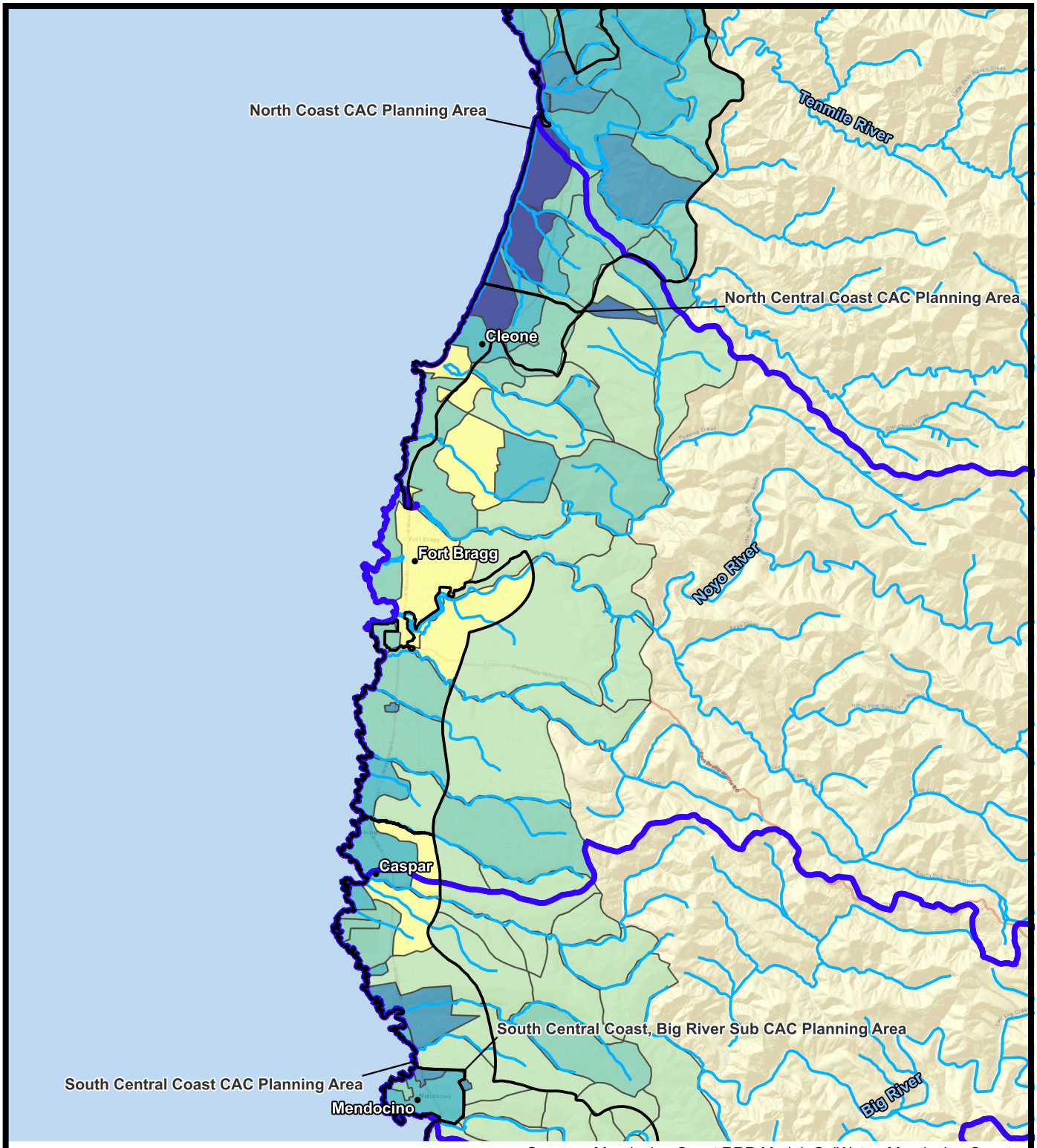
COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge
North Coast (Southern)

11/21/2024 PN 594.03

Figure 2

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

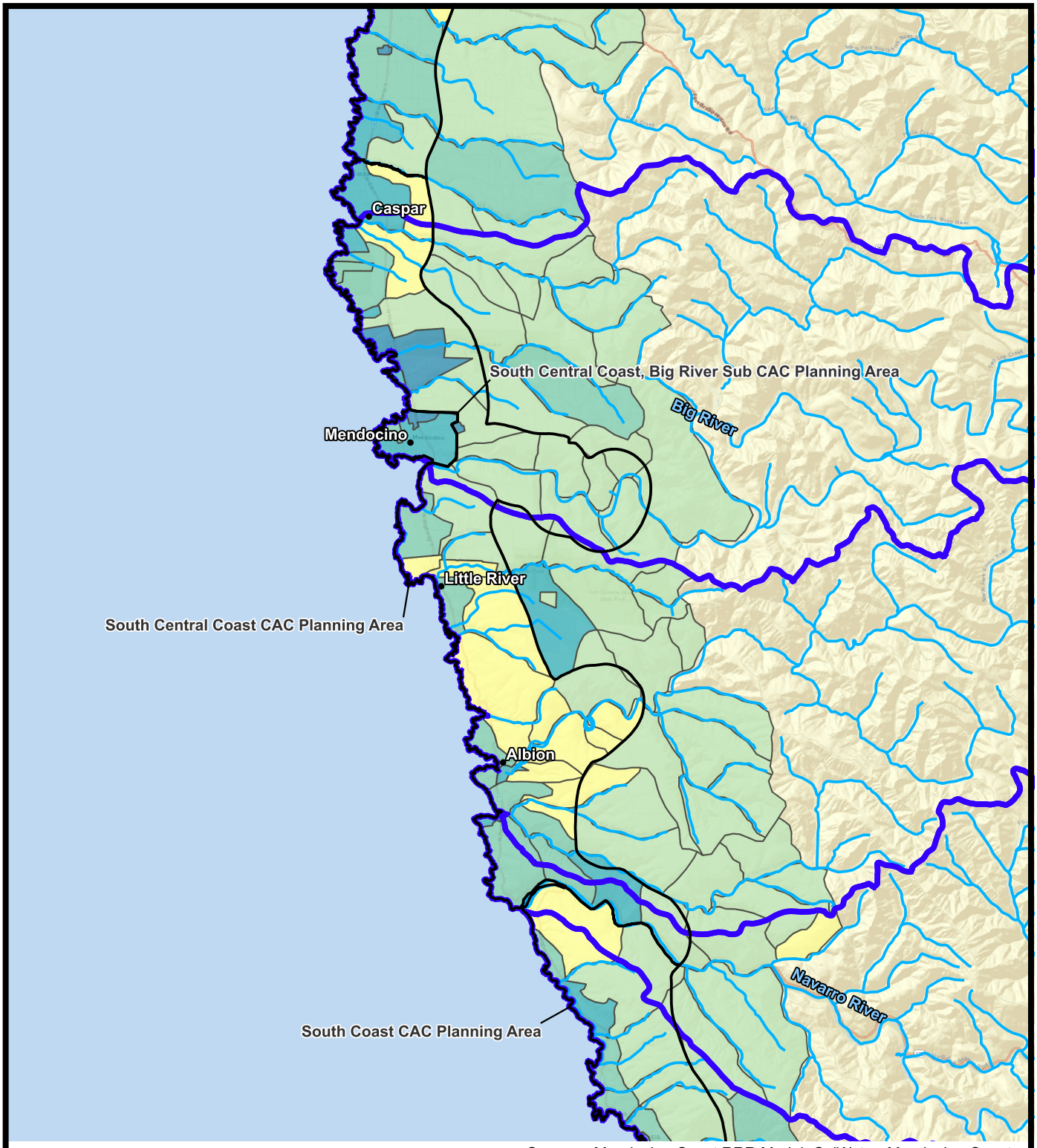
COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge North Central Coast

11/21/2024 PN 594.03

Figure 3

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Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

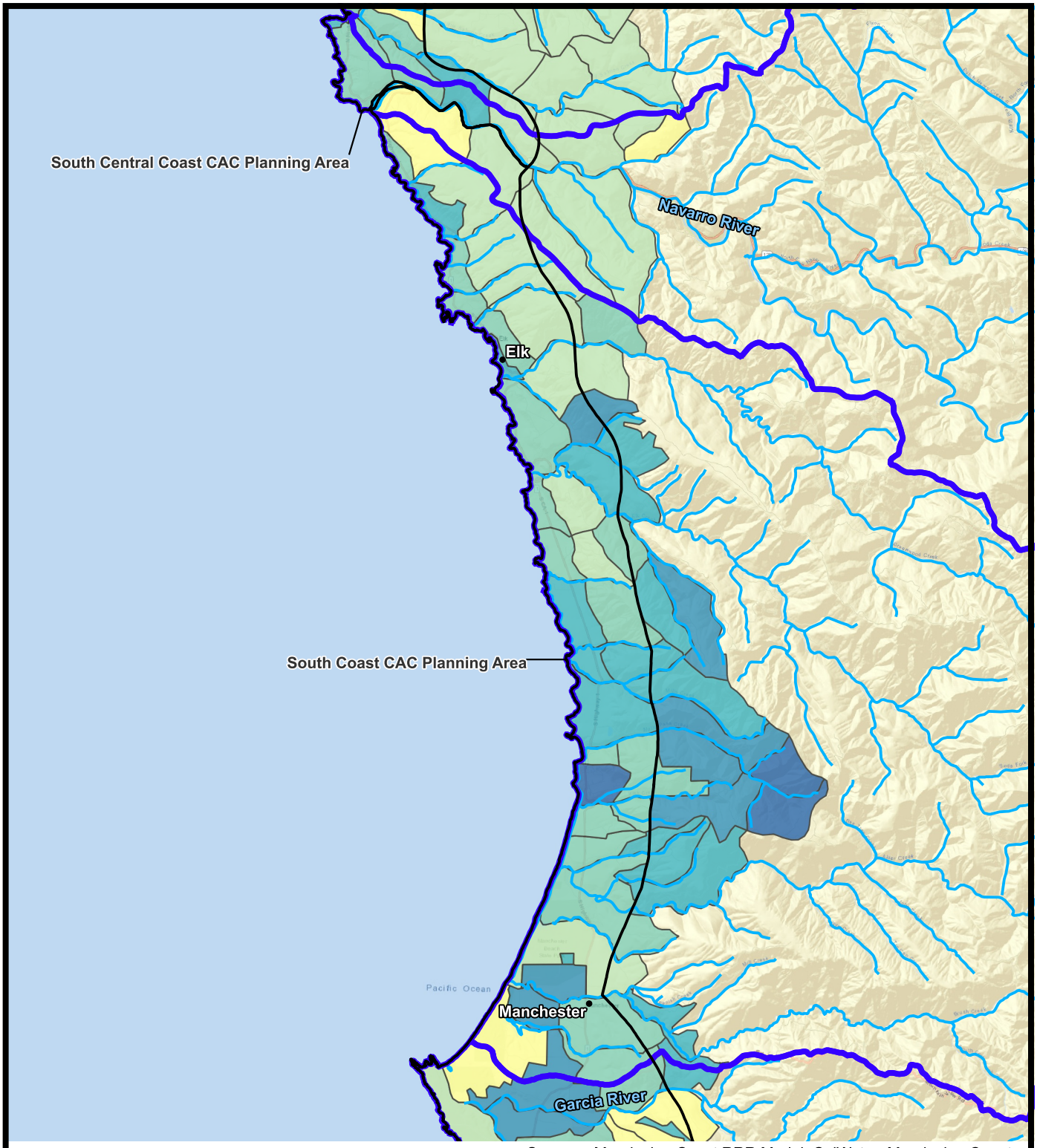
COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge
South Central Coast

11/21/2024 PN 594.03

Figure 4

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Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

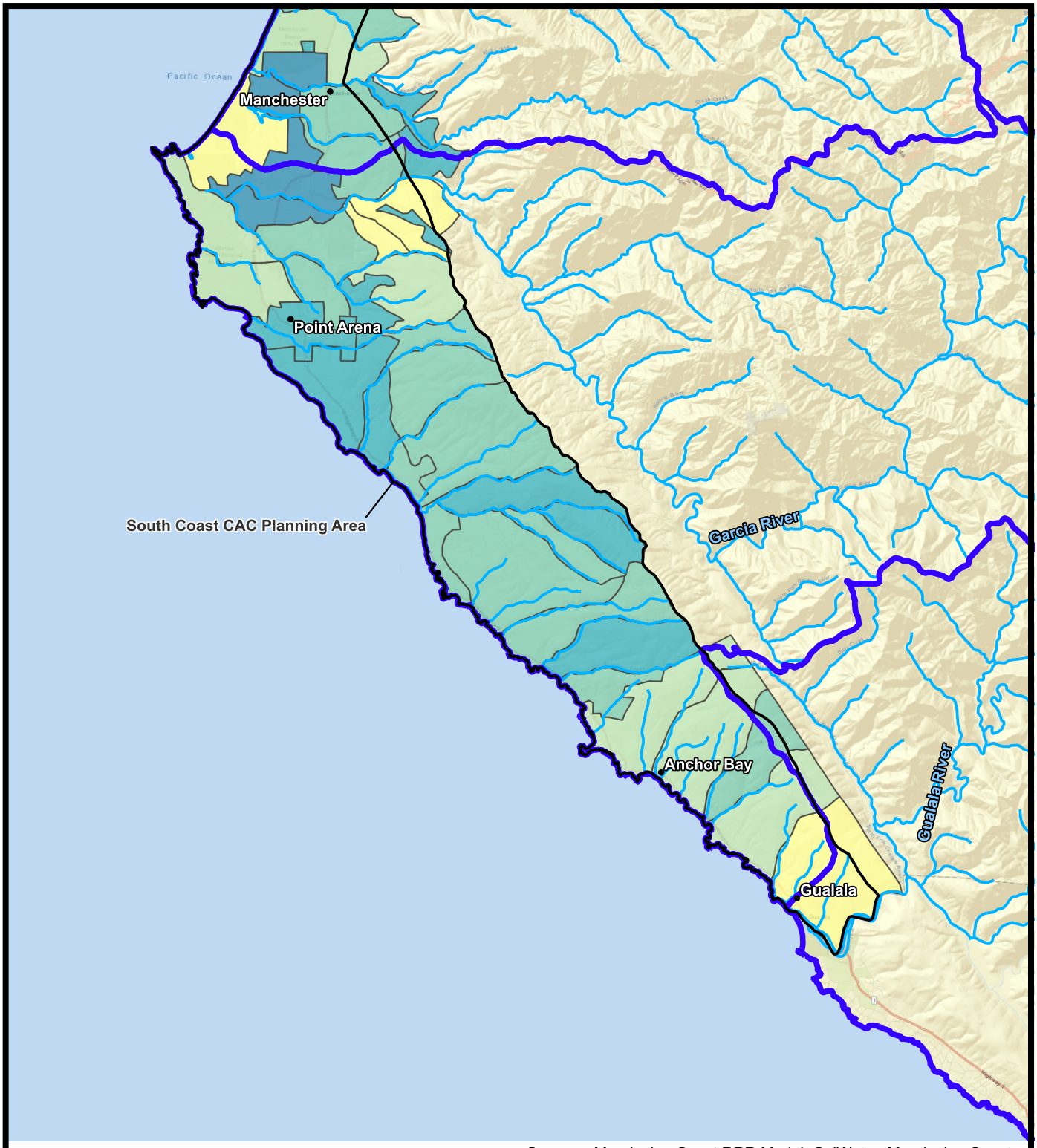
COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge
South Coast (Northern)

11/21/2024 PN 594.03

Figure 5

C:\Users\500\OneDrive - Geo-Logic Associates Inc\Documents\Local Project Files\DB24.1147.00 LWA-Mendocino Coastal GW Study\GIS\QGZs\Mendocino Coastal Groundwater.qgz



Sources: Mendocino Coast RRR Model; CalWater; Mendocino County

Explanation

Simulated Average Annual Recharge (in/yr)

- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 28
- 28 - 34

- Subwatershed
- CAC Planning Area
- Stream
- City or Town

0 1 2 mi

N

Notes:
1. RRR = Rainfall-Runoff-Recharge
2. CAC = Citizen Advisory Committee

COASTAL GROUNDWATER STUDY

Simulated Average Annual Recharge South Coast (Southern)

11/21/2024 PN 594.03

Figure 6

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