DRAFT METHODOLOGY FOR STATEWIDE DRINKING WATER QUALITY INDICATOR FOR CALENVIROSCREEN VERSION 2.0

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I. INTRODUCTION

Californians receive their drinking water from a wide variety of sources and distribution systems. Drinking water quality varies with location, water source, treatment method, and the ability of the water purveyor to remove contaminants before distribution. Because water is universally consumed, drinking water contamination has the potential for widespread effects on health. This has been demonstrated through episodes of water supply contamination by chemical leaks and releases.

The lack of a drinking water quality indicator as an exposure component of pollution burden was identified as a limitation in previous versions of CalEnviroScreen. The following document provides a detailed account of the methodology used to approximate the quality of delivered drinking water across the state at the census-tract scale. By these methods, the Office of Environmental Health Hazard Assessment (OEHHA) developed a drinking water indicator as an exposure component of pollution burden, and used the indicator in the calculation of overall CalEnviroScreen scores in Version 2.0.

This drinking water quality indicator is a tool that compares census tracts across California based on the areas' reported drinking water quality data. This analysis takes into account information on whether multiple contaminants are present, the measured level of contaminants in water, and the contaminants' relative toxicity. This indicator does not measure a water service provider's compliance with regulations. A water system can comply with all state regulations and its associated tract(s) might still show a relatively high score in CalEnviroScreen for this indicator depending on how the factors cited above compare with those of other census tracts in California.

Our goal is to assign water quality to areas of California at the census-tract scale that represent water that people are drinking. We were able to accomplish this using the following broad steps:

I. Drinking water system boundaries were identified based upon established boundaries or, where necessary, approximated boundaries.
II. Drinking water data were associated with each water system for a select group of contaminants.
III. Drinking water quality indices were calculated for these contaminants, evaluating cancer-causing and non-cancer contaminants separately for each system.
IV. The systems' water quality was re-allocated from the system boundaries to census tracts, and the indices for cancer and non-cancer causing contaminants were combined.

II. ESTABLISHING DRINKING WATER SYSTEM SERVICE BOUNDARIES

The development of the drinking water quality indicator required identifying the areas of the state that are served by different drinking water systems. Information on the area served by a water system is available for many of the public water systems in the state (serving more than 90 percent of the population). In other places, we needed to approximate the areas served by individual water systems. We applied different methodologies for systems that have service boundary information reported to the California Department of Public Health (CDPH) compared to those for which we have less information available (service boundaries not reported to CDPH). For areas without reported water systems, we created boundaries based on groundwater basins. Figure 1 depicts our method for identifying or allocating water system boundaries based on the amount of information available for different areas of the state.

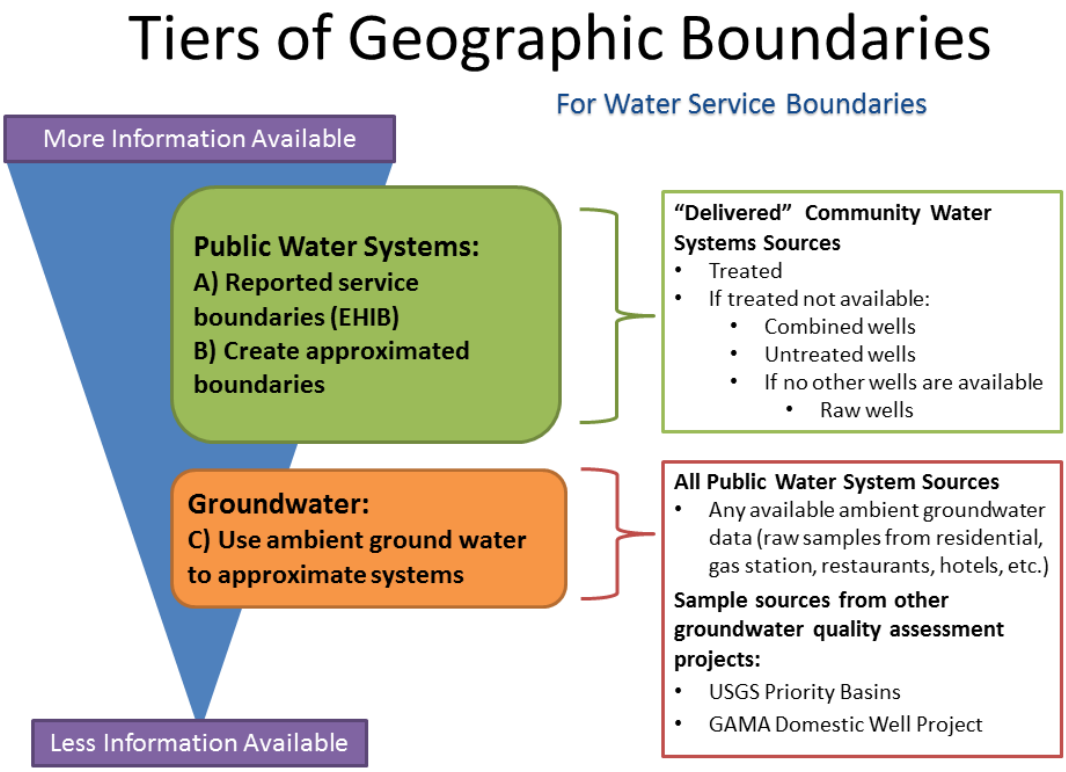

Figure 1: Process of developing geographic boundaries based on currently accessible information.

Definitions:

The word "source" in the context of the Permits, Inspection, Compliance, Monitoring and Enforcement Database (PICME)[1] indicates a location where a water-quality sample was obtained, rather than a water source. For example, a source might be a spigot on a line in a treatment plant, or it could be a grab sample location in a stream, or a well-head tap.

[1] Permitting, Inspections, Compliance, Monitoring and Enforcement (PICME) database, California Department of Public Health.

In the context of this analysis, we used the following PICME definitions, which categorize the sources sampled in water systems:

Treated sources:	Sources that represent water after treatment.
Untreated sources:	Sources of water that will not be treated prior to delivery.
Raw sources:	Sources of water that will be subsequently treated. (Any water system with raw sources should have treated sources, too.)

A. Reported Water System Boundaries

Water system operators upload water system service boundaries to the CDPH website on a voluntary basis along with the population served by the system. Water system boundaries are publicly available on the California Department of Public Health's (CDPH) Geographic Reporting Tool, also known as the Water Boundary Tool.[2] Approximately 1,500 water systems serving as much as 91 percent of California's population have uploaded boundary information to the Water Boundary Tool. An example of an uploaded water system on the Water Boundary Tool is shown in Figure 2.

We only considered community[3] or state small water systems[4] for analysis in CalEnviroScreen. The boundaries dataset was downloaded from the Water Boundary Tool on November 11, 2013. For the purpose of assigning boundaries to areas, we only used retail water system boundaries that are currently active. We were able to extract this information, along with population served information, from the Safe Drinking Water Information System (SDWIS) database.[5]

[2] Drinking Water Systems Geographic Reporting Tool, California Environmental Health Tracking Program, California Department of Public Health (CDPH). http://www.ehib.org/page.jsp?page_key=61
[3] A "community water system" refers to a public water system that serves at least 15 service connections used by yearlong residents or regularly serves at least 25 yearlong residents of the area served by the system.
[4] A "state small water system" refers to a system that serves 5-14 service connections, less than 25 people, and less than 60 days of the year.

[5] Safe Drinking Water Information System, U.S. Environmental Protection Agency http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/index.cfm

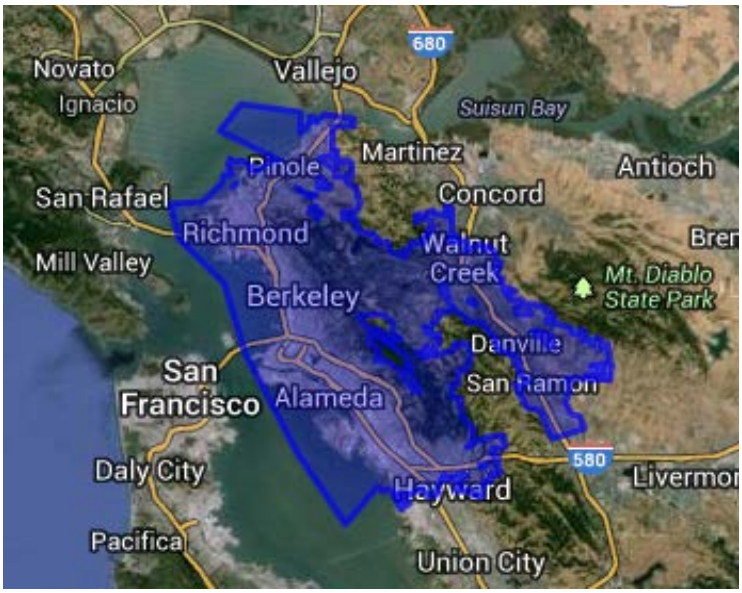

Figure 2: Example of a water system uploaded to the Water Boundary Tool. This system is East Bay Municipal Utility District (Water System No. CA0110005).

Populated census blocks were linked to the water system boundary that they fell within. If a system partially covered a census block, then the census block was divided accordingly. The number of people was assigned to each portion by area weighting.
Assumptions:

- Boundaries uploaded to CDPH are accurate.
- All persons living within the boundary are served by that water system.
- Service areas have been constant over the six year time period evaluated (2008 to 2013).

Data gaps and limitations:

- Only about one-half of public water systems have boundaries uploaded to this database, possibly because the Water Boundary Tool is relatively new, having been compiled for the first time in 2011. (As stated above, the systems that have uploaded their boundaries serve more than 90 percent of California's population.)
- Some small water systems for which no boundary data are available are likely to be within the boundaries (e.g., many small systems in local primacy agency (LPA) counties[6] and unregulated systems).
- The dataset is known to have missing, incomplete, and incorrect service area boundary shapes resulting from human error in the manual service area delineation process and non-participation by water system operators.

[6] CDPH, under the provisions of Section 116330 of the California Health and Safety Code, has delegated primacy to 31 local primacy agencies (LPAs) for the regulation of public water systems serving fewer than 200 service connections [http://www.cdph.ca.gov/certlic/drinkingwater/Pages/Smallwatersystems.aspx].

- The Water Boundary Tool dataset includes spatial anomalies such as overlapping service areas of different systems, multiple service areas for a single system, and other boundary area errors.
    - Using ArcGIS software, these problems were resolved in the least invasive manner available. Geometry issues were resolved by running the "Repair Geometry" tool. The function of the ArcMap Repair Geometry tool is described in the ArcGIS documentation.[7] To resolve the problem of multiple features, the union of all features attributed to a single system was used in every case. This results in the largest possible (most inclusive) system boundary for each system. Overlapping regions of multiple systems were assigned to the system with the smallest service area.
- Service providers may report a population representing a combination of community and transient water systems generally resulting in an overestimation of people served.
- For small water systems, based on our preliminary analysis, we found that local primacy agencies (LPAs)[8] may not upload their water service boundaries.

B. Approximated Water System Service Areas

In some cases, even though a system has no boundary uploaded on the Water Boundary Tool, it still reports a population served. Approximately 1250 small water systems serving 565,000 people (about 1.5 percent of California's population) did not upload their boundaries. Based on population served by a system and estimates of where that system is most likely located, we approximated system boundaries. The approximate location for these systems was determined by conducting online research, using the U.S. Census Bureau's Census Designated Places as a guide, or by developing a geographic centroid where sample source locations were available.

The boundaries for these systems were created using an ArcMap model. Since there is no publicly available information that tells us exactly where people live within a census block, a randomly-distributed population within each block was generated. The ArcGIS model creates a boundary around these randomly placed "people" nearest to the system location. The model captures only the total number of people that are served by the water system. Areas already covered by reported systems (above) were not captured. The captured area was then used as the system's approximated boundary.

Assumptions:

- Service areas for water systems without reported boundaries, but with reported source locations, are near those sources.
- The model used in this methodology captures people and areas that are being served by the system.
- Source locations are accurate.
- Estimates of the population served by a water system are accurate.

Data Gaps and Limitations:

- The population assigned by this methodology to be associated with a system may not reside close to the system.

[7] http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00170000003v000000
[8] http://www.cdph.ca.gov/certlic/drinkingwater/Pages/Smallwatersystems.aspx

- Human errors introduced by manually researching probable system locations.
- Approximately 200 to 300 public water systems do not have source location data available.
- Captured areas may not be accurate. Areas relatively far from the sources may be captured, especially if reported system boundaries are nearby (displacement).
- Source locations may change over time.

C. *Other Areas within Groundwater Basins*

Due to the lack of available data, we assume that the remaining populated areas that are not within a public water system boundary, but exist above groundwater basins, are provided drinking water by groundwater wells. This covers approximately 1.5 million people, or about 4 percent of the state's population. To account for this population in the drinking water indicator, we combined maps of groundwater basins, provided by the Department of Water Resources' Bulletin 118 [9], with a six square-mile township grid to create polygons referred to as "basin-townships." Townships were downloaded from the Public Land Survey System.[10] Each basin-township serves as an approximated boundary for summarizing localized water quality. Figure 3 and 4 illustrate Bulletin 118 groundwater basins and how they are combined with the township grid to create basin-township boundaries.

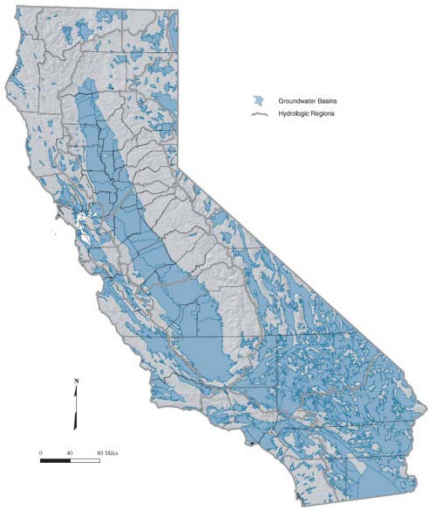

Figure 20 Groundwater basins and subbasins

Figure 3: Bulletin 118 Hydrological Regions and Basins.

[9] DWR Bulletin 118. http://www.water.ca.gov/iwris/
[10] Public Land Survey System (PLSS). http://nationalatlas.gov/articles/boundaries/a_plss.html

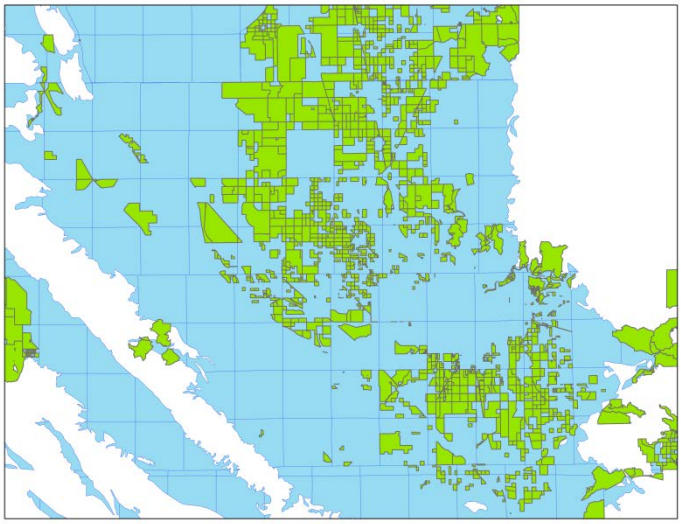

Figure 4: Detail of six square mile township grid and groundwater basins (basin-townships in blue) in the San Joaquin Valley. Populated census blocks left over after reported and approximated public water system allocations layered were removed.

Assumptions:

- People outside of reported and approximated water system service areas, but in groundwater basins, drink groundwater (wells).
- The basin-township boundary accurately represents likely water quality available in that area.

Data Gaps and Limitations:

- Uncertainty whether these areas are served by small water systems not in state databases, or if they have groundwater wells.

D. Summary

Figure 5 shows the percentage of Californians served by public water systems (including systems with reported boundaries and systems with approximated boundaries) and Californians who use groundwater. The population-served numbers for public water systems, reported by water providers, may result in an over-estimate because non-residential populations (such as workers who reside elsewhere) may be included. This may result in an underestimate of unassigned residents.

At this time, we do not have sufficient information to assign water quality to areas not served by public water systems or overlying groundwater basins. However, this methodology does account for about 97.5 percent of people living in California.

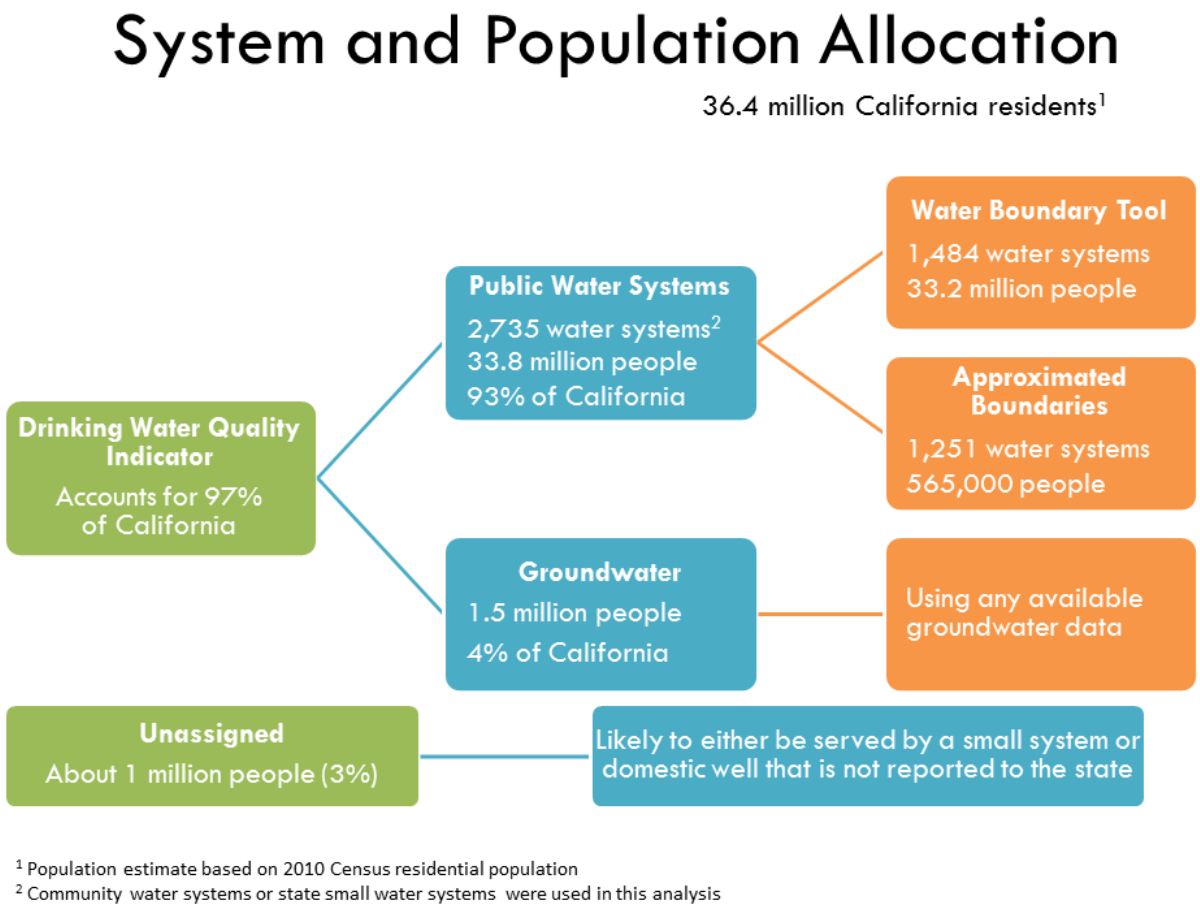

Figure 5: Allocation of population to each boundary identification system.

Figure 6 shows a map of the Bakersfield area and where water systems are identified by the different approaches (reported water systems, approximated water systems, groundwater basin areas, or unassigned).

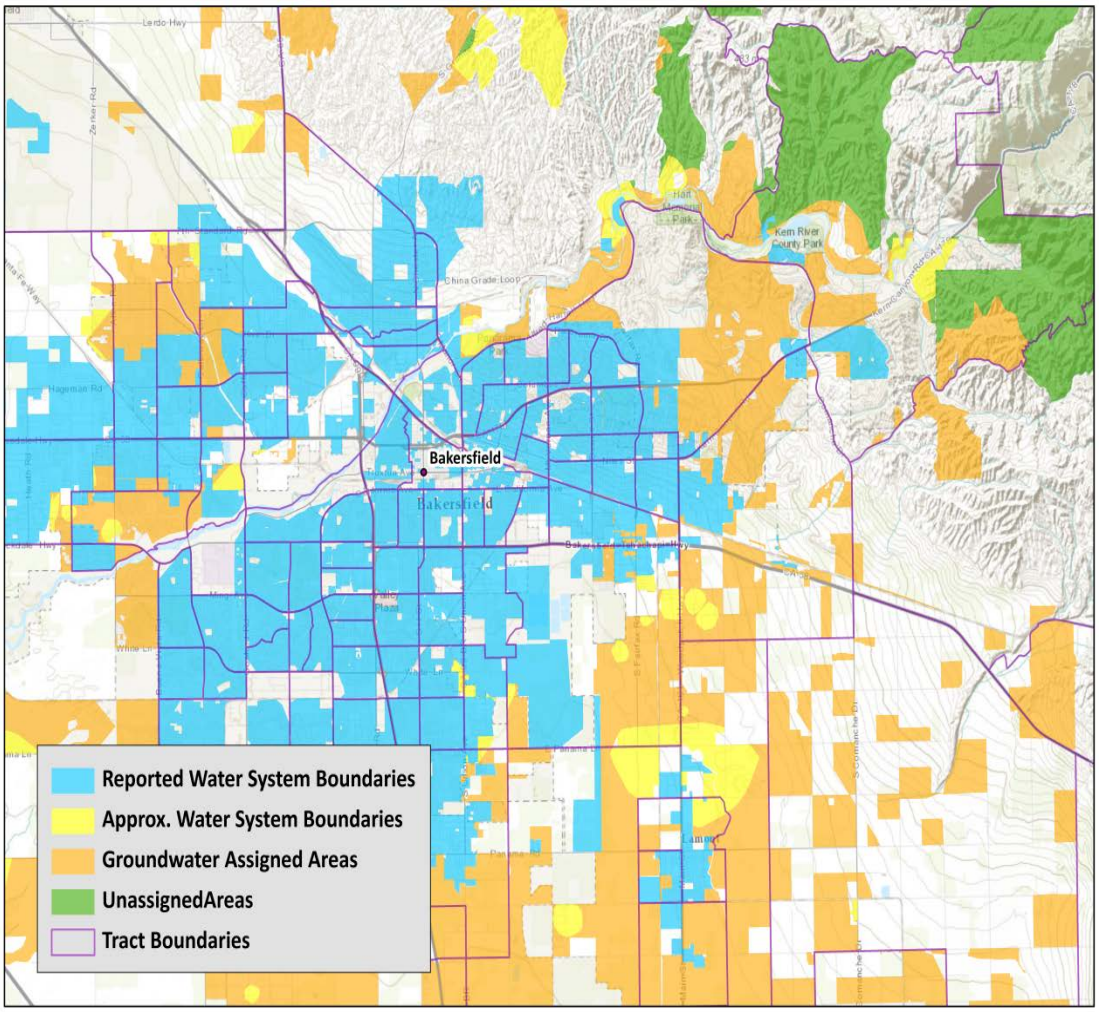

Figure 6: Geographic boundaries for water systems and groundwater assigned areas overlaid with census tracts.

III. CALCULATING DRINKING WATER QUALITY

We selected a subset of contaminants tested in drinking water across California for the analysis (Tables 1a and 1b). The contaminants were selected based on frequency of tests, detections, and toxicity concerns. Averages for these chemical concentrations were calculated for each public water system area or groundwater basin (basin-township). Each system area was then assigned a drinking water quality score based on the ratio of the average concentration to the Public Health Goal (PHG) for that chemical.

Carcinogenic Contaminants	
CHEMICAL	**PHG**
Arsenic	0.004 µg/l
Benzene	0.15 µg/l
Cadmium	0.04 µg/l
Carbon Tetrachloride	0.1 µg/l
Dibromochloropropane (DBCP)	0.0017 µg/l
Hexavalent Chromium	0.02 µg/l
Methyl-Tert-Butyl-Ether (MTBE)	13 µg/l
Radium226	0.05 µg/l
Tetrachloroethylene (PCE)	0.06 µg/l
Total Trihalomethanes (THM)	0.8 µg/l*
Trichloroethylene (TCE)	1.7 µg/l
Uranium (PCI/L)	0.43 pCi/l

*Table 1a: Contaminants used in this analysis whose primary health concern is cancer, and the adopted California Public Health Goal (PHG) or * proposed Public Health Goal.*

Non-carcinogenic Contaminants	
CHEMICAL	**PHG**
Barium	2000 µg/l
Lead	0.2 µg/l
Mercury	1.2 µg/l
Nitrate (NO3)	45 mg/l
Perchlorate	6 µg/l
Toluene	150 µg/l
Total Coliform Rule Violation	--
Xylene	1800 µg/l

Table 1b: Contaminants used in this analysis whose primary health concern is an effect or effects other than cancer, and the adopted California Public Health Goal.

California's drinking-water law requires OEHHA to develop PHGs for all regulated drinking water contaminants. A PHG is the level of a contaminant in drinking water that does not pose a health risk. PHGs are goals that California's water systems should strive to achieve if it is feasible to do so, but water systems are not required to reduce contaminants to the PHG level. Public water systems are required to comply with Maximum Contaminant Levels (MCLs), which are regulatory standards established by CDPH and that, by law, must be as close to the PHG as is economically and technically feasible. As long as contaminant levels comply with the MCLs, drinking water is considered acceptable for public consumption, even if the levels of some contaminants exceed the PHGs.

The ratio of the average concentration of a contaminant to the corresponding PHG provides an objective measure of exposure that is well suited for CalEnviroScreen's purpose of comparing such exposures in communities throughout the state. Consistent with the exposure indicators developed for CalEnviroScreen 1.0 and 1.1, the drinking water indicator screens for exposures to contaminants that contribute to a community's overall pollution burden, including exposures that are permissible under law.

A. Average Chemical Concentrations for Areas Served by Public Water Systems

Monitoring data for chemicals is available from CDPH's Water Quality Monitoring (WQM) database.[11] We downloaded reported results for water source testing locations within currently active drinking water systems. We used data from 2008-2010 and 2011-2013, the two most recent compliance periods. The goal was to identify water quality data that are most representative of water that is delivered to residents in the service area. Therefore, we primarily evaluated samples from delivered water sources. Delivered water could include sources sampled post-treatment or sampled from "untreated" sources. Water from untreated sources is delivered without ever being treated. Out of 2735 systems, about 85 percent had data from untreated or treated sources. For the few remaining systems that had no treated or untreated source water quality data, we relied on sources classified as raw.

From the PICME databases, we are able to determine which sources are connected to a wholesale water supply and are therefore part of water systems that rely either in part or completely on purchased water to distribute to their consumers. For large water systems serving more than 100,000 people that rely both on local sources of water and water purchased from wholesalers, the fraction of water that was purchased was identified from publicly available information (e.g., water quality reports). If no information was found on fraction purchased, it was assumed that the water came in equal parts from the local supply and any wholesalers listed. In other words, we assumed that 50 percent of water supplied is purchased water and the other 50 percent is from local sources of water. For all systems relying on purchased water and serving less than 100,000 people, we assumed that the water came in equal parts from the local system and listed wholesalers.

After assigning water quality data from a system's local delivered sources and from their purchased water sources, if there still were no data for a given contaminant, then water quality data from raw sources within that system were included. This process allowed us to maximize the amount of data analyzed while still prioritizing known delivered water quality.

[11] Water Quality Monitoring. http://www.cdph.ca.gov/certlic/drinkingwater/pages/EDTlibrary.aspx.

Chemical concentrations from testing are reported by sample source locations for water systems. For the purpose of this analysis, non-detects (indicated by "<" in the WQM dataset) were treated as concentrations of zero.

To calculate average concentrations of contaminants from individual sources, we first calculated time-weighted averages for each contaminant by calendar year. We then took the mean of the yearly time-weighted averages to derive a source concentration. If no test for a contaminant was reported in a given year, that year did not contribute to the multi-year average. If only a single test was reported for a contaminant in a given year, that concentration was used to represent the entire year. Subsequently, all source concentrations within a water system were averaged to calculate one concentration value for each chemical in each system (Exception: For systems with wholesaler water purchases, the average was adjusted based on the known or default fractions of the water that the wholesaler supplies that system). An example of this calculation is below.

Step 1: System Monitoring Data

System ID	Source ID	Sample Date**	Time Interval	Chemical	Finding
23456K1	23456K1-001	1/1/2010	105	Chemical A	0.0*
23456K1	23456K1-001	4/15/2010	260	Chemical A	5.0
23456K1	23456K1-001	1/1/2011	365	Chemical A	2.0
23456K1	23456K1-001	1/1/2011	365	Chemical B	6.7
23456K1	23456K1-002	1/1/2013	140	Chemical B	0.0*
23456K1	23456K1-002	5/20/2013	225	Chemical B	1.0

*Findings below the detection limit were given a value of 0.

Step 2: Calculation of Yearly Time-Weighted Average

System ID	Source ID	Chemical	Year	Calculation*	Result
23456K1	23456K1-001	Chemical A	2010	[(0.0 × 105) + (5.0 × 260)] ÷ 365	3.56
23456K1	23456K1-001	Chemical A	2011	(2.0 × 365) ÷ 365	2.00
23456K1	23456K1-001	Chemical B	2011	(6.7 × 365) ÷ 365	6.70
23456K1	23456K1-002	Chemical B	2013	[(0.0 × 140)+ (1.0 × 225)] ÷ 365	0.62

*Calculation for Time-Weighted Average = [**Σ**(Finding × Time Interval)] ÷ (Total Time Interval).

Step 3: Calculation of Average By Source

System ID	Source ID	Chemical	Result
23456K1	23456K1-001	Chemical A	(3.56 + 2.00) ÷ 2 = 2.78*
23456K1	23456K1-001	Chemical B	6.70
23456K1	23456K1-002	Chemical B	0.62

*System has multiple yearly averages for Chemical A.

Step 4: Calculation of Average by System

System ID	Chemical	Result
23456K1	Chemical A	2.78
23456K1	Chemical B	(6.70 + 0.62) ÷ 2 = 3.66*

*System has multiple source averages for Chemical B.

Step 5: Concentrations by System

System ID	Chemical A	Chemical B
23456K1	2.78	3.66
23456K2	5.00	NA*

*Raw data is used if available as described in text.

Step 6: Concentrations by System + Raw Data

System ID	Chemical A	Chemical B
23456K1	2.78	3.66
23456K2	5.00	4.00*

*Raw data is included here

Step 7: Example of Calculating Ratios to PHG

System ID	Calculation	Chemical A	Chemical B	Chemical C
23456K1	Concentration ÷ PHG	ex: 2.78 ÷ 2.5 = **1.11**	0.92	3.00
23456K2		2.00	1.00	2.00

PHG for Chemical A (Carcinogen) = 2.5
PHG for Chemical B (Carcinogen) = 4.0
PHG for Chemical C (Non-Carcinogen) = 1

Step 8: Summing Cancer and Non-Cancer Ratios Separately

System ID	Chemical A	Chemical B	Chemical C	Cancer Sum	Non-Cancer Sum
23456K1	1.12	0.92	3.00	(1.11 + 0.92) = 2.03	3.00
23456K2	2.00	1.00	2.00	(2.00 + 1.00) = 3.00	2.00

What happens next?

The cancer and non-cancer sums by system are aggregated to the census tract using population weighting. Then, the cancer and non-cancer sums for each tract receive a percentile based on their relative rank among all other census tracts. Lastly, the census tract percentiles for cancer and non-cancer contaminants are averaged to create one drinking water quality value for each census tract.

Assumptions:

- Available test data are adequate to represent delivered water quality.
- Water quality is divided equally between a system's use of purchased water from wholesalers and the system's local source. For some systems serving more than 100,000 people, more specific information was sometimes available and used to assign the relative proportions of wholesaler versus local water in delivered water.

- Contaminant concentrations represent the concentration of the water source on the day the measurement was taken until the next measurement.
- Each source within a drinking water system contributes equally to the overall water quality for that system. This may lead to overestimates of contaminant concentrations, especially if sources are mixed unequally to reduce contaminant concentrations.
- Drinking water quality is homogeneous within a water system.
- Non-detect results are treated as a zero concentration for contaminants, because test protocols may vary for different water systems. Assuming a minimum concentration for non-detects with high frequency could lead to an accumulation of high concentration when the true concentration is unknown.
- The absence of test data indicates no contaminant is present.
- If chemical concentrations are reported below the reporting limit, they are included in the analysis and are assumed to be accurately detected.
- Treatment does not affect contaminant concentrations when raw water quality data is the only available data on a contaminant.
- When no treated or untreated source locations within a system are available, the availability of a raw source suggests either an untreated source or a treated source is present, but not reported.

Data gaps and limitations:

- Use of raw water quality data may overestimate contaminant concentrations.
- Treated water quality data may be available but not reported to CDPH, especially for water systems regulated by LPA counties, state small water systems, and local small water systems.
- Sources may be misclassified as treated, untreated, or raw water.
- Reported water quality data may be an average of multiple sources within a system.
- When no treated or untreated samples were available, but raw samples were, it is possible that there was a misclassification of the water source. It is likely that this is due to errors in data entry.

B. Average Chemical Concentrations for Other Areas within Groundwater Basins

People not living in areas within a public water system boundary, but who fell within a groundwater basin, were assumed to drink groundwater. Residents of each basin-township (described earlier) were assigned water based on available groundwater testing data from three databases.

Groundwater quality data for portions of groundwater basins located outside public water system boundaries were from raw or untreated community or non-community water systems was obtained through the WQM dataset as for the reported water system boundary data from US Geological Survey Priority Basins[12] well-water quality data produced between 2004 and 2012,

[12] USGS Priority Basins.
http://www.waterboards.ca.gov/water_issues/programs/gama/priority_basin_projects.shtml

and GAMA Domestic Wells Survey data[13] produced between 2002 and 2011. Both of these datasets are publically available on the Geotracker GAMA website maintained by the State Water Resources Control Board (SWRCB). The domestic well locations are confidential and precise coordinates are not available to the public.

Groundwater quality data were assigned to basin-townships based on the associated confidential latitude/longitude coordinates of the sampling locations. We first averaged the selected contaminant concentrations for each well location by year. Then, each yearly concentration mean was averaged to create a concentration value for each sample well location. Lastly, each source concentration in the basin-township was averaged to yield one value for each contaminant. Figure 7 illustrates groundwater sample sources within basin-townships. Each basin-township grid receives the groundwater quality from the samples that are located within it.

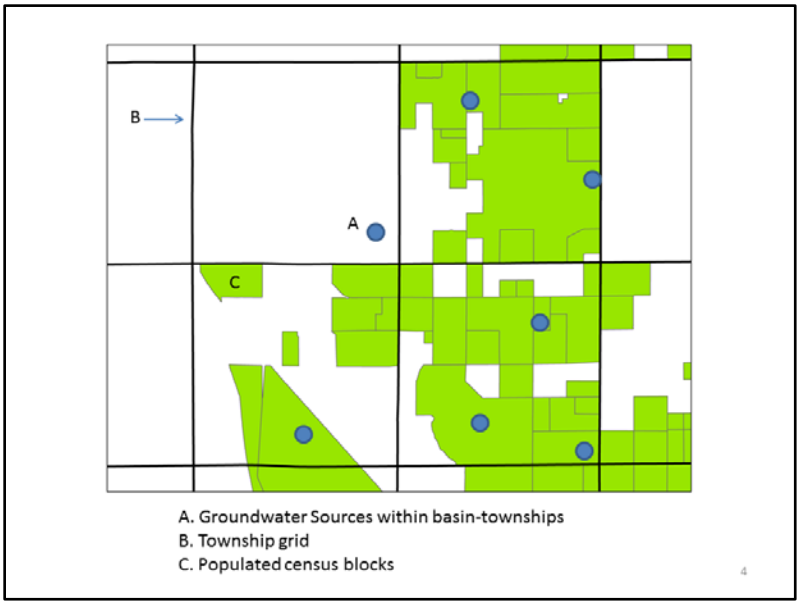

Figure 7. Groundwater sample sources within basin-townships. Note: Sample points in figure are randomly drawn and do not represent actual locations of sample wells.

Assumptions:

- People that are not on public water systems who are living within the groundwater basin boundaries are drinking from groundwater wells.
- Groundwater quality is representative of delivered water quality for people in these areas.

Data gaps and limitations:

- Small water systems that are not in the CDPH water quality database may be present in an area where groundwater is assumed to be consumed.

[13] GAMA Domestic Well Project.
http://www.waterboards.ca.gov/water_issues/programs/gama/domestic_well.shtml

IV. DRINKING WATER QUALITY INDEX

In order to achieve a statewide comparison of drinking water quality, we scored each area boundary (both census blocks within assigned drinking water systems and census blocks within basin-township boundaries relying on groundwater) based on the ratio of the area's average contaminant concentration to that contaminant's public health goal (PHG).

Chemicals known to cause cancer versus chemicals principally associated with adverse health effects other than cancer were separated into two groups because risk assessment methodologies used to establish the PHGs differ between the two types of contaminants. To account for microbial contamination, if a system had a violation of the Total Coliform Rule, a ratio of 1.5 was assigned for that system for each violation. This was included in the non-cancer group.

The ratios of contaminant concentrations to their PHG within each group (cancer and non-cancer) were summed to produce an overall toxicity-weighted drinking water index for carcinogens and for non-carcinogens for each system.

The calculation of the toxicity-weighting for the individual contaminants present in drinking water is comparable to the method by which toxic releases to air were weighted in the Toxic Releases indicator in CalEnviroScreen 1.1 and 2.0. In that case, relative toxicity was established from existing benchmarks for toxicity established for air contaminants. Here, relative toxicity was established using the values developed and adopted by OEHHA in its drinking water program.

Assumptions:

- Detectable concentrations of contaminants, even below the PHG, contribute to water quality.
- A combined score for multiple contaminants is of equal concern to the same score for a single contaminant.

Data gaps and limitations:

- Missing data for any contaminant is not part of the sum and therefore, the two indices could be an over- or under-estimation.
- Toxicological interactions between contaminants are not well understood.

V. RE-ALLOCATING WATER SYSTEM BOUNDARIES TO CENSUS TRACTS

A cancer and non-cancer toxicity index score was calculated for each system or basin-township. Census blocks were assigned the water quality associated with the system or basin-township it fell within. The two toxicity-indices for each census block were aggregated up to the census tract level using population weighting.

A census tract may have multiple water systems that contribute to its overall water quality. For example, two blocks in one tract may be from different water systems. Finally, a ratio for cancer and non-cancer categories is calculated for each census tract. Percentile scores for carcinogens and non-carcinogens were calculated for each census tract based on its relative ranking. The overall drinking water indicator score for CES is an average of the two percentiles.

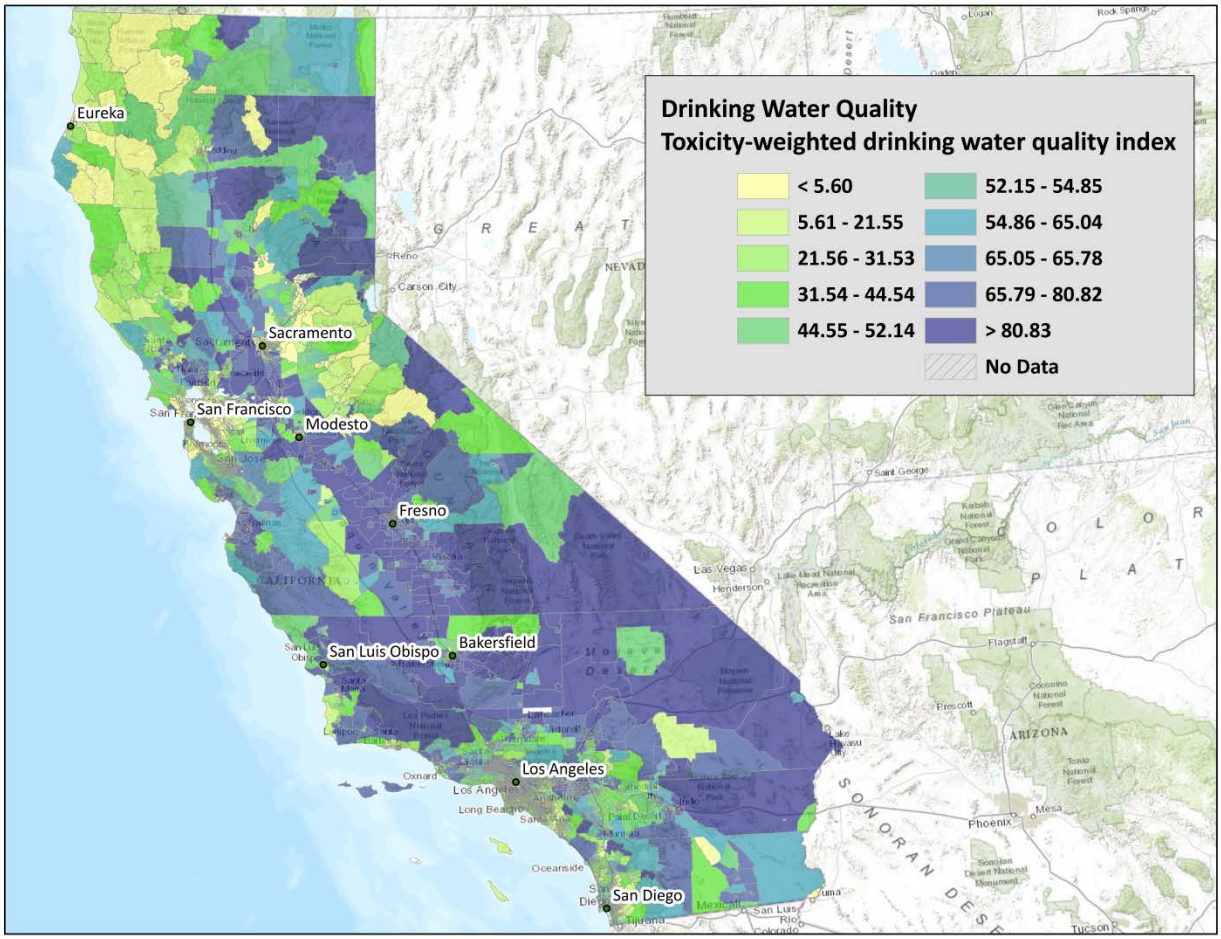

Figure 8. Statewide map of proposed drinking water quality indicator results.