

Health-Based Screening Levels to Evaluate U.S. Geological Survey Ground water Quality Data

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Federal and state drinking-water standards and guidelines do not exist for many contaminants analyzed by the U.S. Geological Survey's National Water-Quality Assessment Program, limiting the ability to evaluate the potential human-health relevance of water-quality findings. Health-based screening levels (HBSLs) were developed collaboratively to supplement existing drinking-water standards and guidelines as part of a six-year, multi-agency pilot study. The pilot study focused on ground water samples collected prior to treatment or blending in areas of New Jersey where groundwater is the principal source of drinking water. This article describes how HBSLs were developed and demonstrates the use of HBSLs as a tool for evaluating water-quality data in a human-health context. HBSLs were calculated using standard U.S. Environmental Protection Agency (USEPA) methodologies and toxicity information. New HBSLs were calculated for 12 of 32 contaminants without existing USEPA drinking-water standards or guidelines, increasing the number of unregulated contaminants (those without maximum contaminant levels (MCLs)) with human-health benchmarks. Concentrations of 70 of the 78 detected contaminants with human-health benchmarks were less than MCLs or HBSLs, including all 12 contaminants with new HBSLs, suggesting that most contaminant concentrations were not of potential human-health concern. HBSLs were applied to a state-scale groundwater data set in this study, but HBSLs also may be applied to regional and national evaluations of water-quality data. HBSLs fulfill a critical need for federal, state, and local agencies, water utilities, and others who seek tools for evaluating the occurrence of contaminants without drinking-water standards or guidelines.

KEY WORDS: HBSL; Health-based screening level; human health; unregulated contaminant; water quality

1. INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) implemented the National Water-Quality Assessment (NAWQA) Program to provide a consistent approach to describe current water-quality conditions for a large part of the nation's water resources and to de-

fine, describe, and explain, to the extent possible, long-term trends in water quality.⁽¹⁾ The NAWQA Program was not designed to assess the potential safety of the nation's water resources for drinking-water use; however, the USGS is frequently asked by a variety of stakeholders about the potential human-health relevance of the NAWQA findings. If carefully interpreted, NAWQA groundwater data can provide valuable information to state agencies, the U.S. Environmental Protection Agency (USEPA), and others interested in drinking-water quality.

To date, NAWQA has assessed groundwater-quality conditions using two approaches. The first

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approach ranks water-quality conditions among networks of groundwater wells within a study area in relation to conditions at groundwater networks in other study areas. The second approach compares contaminant concentrations with established drinking-water standards and guidelines for the protection of human health.⁽²⁾ The first approach is relative and provides no information on whether contaminant concentrations are of potential concern to human health, and the second approach is limited because drinking-water standards and guidelines do not exist for many of the contaminants analyzed by NAWQA.⁽³⁾ The USGS, therefore, began an interagency pilot study in 1998 with its cooperators, including USEPA, to develop an approach for more comprehensively evaluating the water-quality findings of the NAWQA Program in a human-health context.

The two objectives of this pilot study were to (i) develop health-based screening levels (HBSLs) for unregulated contaminants, that is, those for which drinking-water standards have not been established, using a multi-agency consensus approach,⁽⁴⁾ and (ii) demonstrate the use of HBSLs as tools for evaluating groundwater-quality data in a human-health context.⁽⁵⁾ A retrospective analysis of groundwater-quality data was conducted for areas of New Jersey where groundwater is the principal source of drinking water. USGS data on the quality of groundwater in New Jersey have been presented in numerous publications,⁽⁶⁻¹¹⁾ but these data were evaluated in a human-health context for the first time in this pilot study.

In this study, HBSLs were applied to a state-scale groundwater data set, but HBSLs also may be applied in local, regional, and national evaluations of water-quality data. For example, the USGS used HBSLs to assess the occurrence of volatile organic compounds (VOCs) in the nation's groundwater and drinking-water supply wells in the context of human health.^(12,13) HBSLs are also utilized by the USGS Source Water-Quality Assessment (SWQA) Program, which characterizes the quality of major rivers and aquifers used as a source of supply to some of the largest community drinking-water systems in the United States.

2. METHODS

2.1. Development of HBSLs

Over a three-year period, the USGS conducted a pilot study in cooperation with the USEPA, the

New Jersey Department of Environmental Protection (NJDEP), and Oregon Health & Science University (OHSU) to develop the HBSL approach for application to state- and local-scale water-quality assessments. Pilot-study participants considered multiple procedures used by federal agencies for assessing water-quality data in a human-health context. The consensus decision was to calculate HBSLs for unregulated contaminants using (i) standard USEPA Office of Water (OW) methodologies (i.e., equations) for establishing drinking-water lifetime health advisory (LHA) and risk-specific dose (RSD) values for the protection of human health^(14,15) and (ii) existing USEPA human-health toxicity information. The procedures and equations used to calculate the HBSLs used in this report differ for noncarcinogens, carcinogens, and possible carcinogens, and are described in Toccalino *et al.*⁽⁴⁾ The USGS and its cooperators are continuing to refine the HBSL methodology; any revisions to the methodology as well as HBSL values for about 440 unregulated NAWQA analytes, when available, are posted online.⁽¹⁶⁾

HBSLs are defined as estimates of benchmark concentrations (for noncarcinogens) or concentration ranges (for carcinogens) of contaminants in water that (i) may be of potential human-health concern, (ii) can be used as threshold values against which concentrations of contaminants in ambient water samples can be compared, and (iii) are consistent with USEPA OW methodologies for establishing drinking-water LHA and RSD values.⁽⁴⁾ For noncarcinogens, the HBSL represents the contaminant concentration in drinking water that is not expected to cause any adverse effects over a lifetime of exposure. For carcinogens, the HBSL range represents the contaminant concentration in drinking water that corresponds to an excess estimated lifetime cancer risk of 1 chance in 1 million to 1 chance in ten thousand. HBSL calculations adopt USEPA assumptions for establishing drinking-water guidelines, namely, lifetime ingestion of 2 L of water per day by a 70-kg adult. For noncarcinogens, it also is assumed that 20% of the total contaminant exposure comes from drinking-water sources and that 80% comes from other sources (e.g., food and air).⁽¹³⁾

Because HBSLs are calculated using standard USEPA methodologies, they are typically equivalent to existing LHA and RSD values, except for contaminants for which more recent USEPA human-health cancer classifications or toxicity information have become available. HBSLs, therefore, provide a mechanism for the incorporation of updated toxicity information for the interpretation of water-quality data.

HBSLs are not regulatory drinking-water standards and are not legally enforceable values.

2.2. Description of Study Area

The groundwater data described in this pilot study were collected as part of the USGS's NAWQA Program in New Jersey, with the exception of data from three samples that were collected in New York State. The study area included some of the most heavily urbanized and populated areas in the United States and was comprised of three groundwater sampling regions: the Kirkwood-Cohansey aquifer system in southern New Jersey, which consists of unconsolidated sedimentary deposits (sands and gravels),⁽⁶⁾ and two aquifers in the New England and Piedmont Physiographic Provinces in northern New Jersey, which consist of fractured bedrock.⁽⁷⁾ All three aquifers are vulnerable to contamination introduced at or near the land surface.^(6–11)

A total of 220 groundwater samples, one sample per well, were collected prior to any treatment or blending from three different well types during 1996–1998. Public-supply well (30) and monitoring-well (108) samples were collected from the Kirkwood-Cohansey aquifer system; domestic wells (82) were sampled in all three aquifer systems. Protocols and procedures used for sample collection are described in Koterba and others.⁽¹⁷⁾

2.3. Analytical Considerations for Using Groundwater-Quality Data

Groundwater samples were analyzed for 97 pesticides and 85 VOCs using USGS's National Water-Quality Laboratory (NWQL) methods.^(18–20) The NWQL reports nondetections as less than (<) the minimum reporting level (MRL) and assigns E codes to estimated concentrations of confirmed detections of pesticides and VOCs that are less than the MRL.⁽²¹⁾ All estimated concentrations were included in the calculation of detection frequencies in this article.

2.4. Application of HBSLs in the New Jersey Pilot Study

Three general steps were followed in this screening-level assessment for evaluating groundwater-quality data from New Jersey in a human-health context:⁽⁵⁾

I. Concentrations of regulated contaminants (contaminants that have federal or state drinking-water standards) were compared with USEPA and New Jersey State maximum contaminant levels

(MCLs) and concentrations of unregulated contaminants were compared with HBSLs, in accordance with the consensus HBSL approach for local and state-scale water-quality assessments.⁽⁴⁾

II. Contaminants of potential human-health concern were identified by calculating benchmark quotients (BQs) for individual pesticides and VOCs. BQ values are ratios of the contaminant concentrations to their respective USEPA or New Jersey MCLs (for regulated contaminants) or HBSLs (for unregulated contaminants). For regulated contaminants with New Jersey MCLs but no USEPA MCLs, the BQ values were calculated using New Jersey MCLs. Maximum BQ (BQ_{max}) values were calculated for each detected contaminant (with an MCL or HBSL) in each well type, where the BQ_{max} value represents the maximum concentration of a contaminant in a given well type divided by the contaminant's MCL or HBSL. All BQ values were rounded to one significant figure.

Contaminants of potential human-health concern were defined as pesticides and VOCs with maximum concentrations greater than or equal to MCLs or HBSLs (that is, $BQ_{max} \geq 1$) in any well type. Because comparisons between maximum concentrations and human-health benchmarks (BQ_{max}) may be conservative and represent a worst-case scenario, the distributions of all detections of frequently detected contaminants with $BQ_{max} \geq 1$ also were examined (see Section 3.2). In addition to contaminants with $BQ_{max} \geq 1$, contaminants with concentrations less than, but within a factor of 10 of, MCLs or HBSLs (that is, $1 > BQ_{max} \geq 0.1$) also were identified as contaminants that may warrant additional monitoring to analyze trends in occurrence. The selection of 0.1 as the BQ threshold for identifying contaminants that warrant further monitoring is consistent with various state and USEPA practices (e.g., see Reference 22).

III. The occurrence of the contaminants with $BQ_{max} \geq 1$ was interpreted in a human-health context by considering five primary factors:

- The magnitude of BQ values is important because contaminants with higher BQ_{max} values may have more human-health importance than contaminants with lower BQ_{max} values.
- Frequently detected contaminants are of more interest than infrequently detected contaminants. Frequently detected contaminants were defined as contaminants occurring in at least 10% of samples from any given well type, which is consistent with other USGS New Jersey publications⁽¹¹⁾ and with USEPA human-health risk assessment guidance.⁽²³⁾

- The MRL must be less than the human-health benchmark (MCL or HBSL) to ensure that the analytical methods are adequate to detect concentrations relevant to human health.
- Well type provides information about the potential for human exposure to contaminants through drinking-water consumption. Groundwater from domestic wells may be consumed with little or no treatment; however, it is used by smaller numbers of people (typically one family per well) than groundwater from public-supply wells (typically thousands of people per well). Groundwater from public-supply wells may be treated before it is consumed, potentially reducing contaminant concentrations. Groundwater data from monitoring wells are not directly relevant to human health because this water is not consumed, but contamination in monitoring wells can be both a contributor to, and a predictor of, future contamination in deeper aquifers used for drinking-water supplies.
- Contaminant sources and physicochemical properties provide information about contaminant fate (e.g., persistence) and transport (e.g., mobility), which helps assess potential human exposure.

3. RESULTS AND DISCUSSION

Ninety-eight contaminants were detected in samples from one or more wells. The numbers of pesticides and VOCs that were analyzed for and detected in the public-supply wells, domestic wells, and monitoring wells in the study area are summarized in Table I.

3.1. HBSLs Expand Human-Health Context for NAWQA Findings

Of the 98 detected contaminants, 42 are regulated contaminants, and 56 are unregulated contaminants. At present, USEPA drinking-water guidelines (LHAs or RSDs) do not exist for 32 of these 56 unregulated contaminants. New HBSLs were calculated for 12 of these 32 unregulated contaminants, increasing the number of unregulated contaminants with human-health benchmarks from 24 to 36 out of 56 (Table I). HBSLs thereby provided a basis for a more comprehensive evaluation of contaminant-occurrence data in a human-health context than can be achieved using USEPA benchmarks alone. HBSLs also were calculated for two unregulated contaminants that have USEPA LHAs (carbaryl and diuron) using updated cancer classifications and toxicity information

Table I. Numbers of (1) Pesticides and VOCs Analyzed for and Detected in Groundwater Samples and (2) Detected Unregulated Contaminants with Human-Health Benchmarks in Groundwater Samples from the New Jersey Study

Well Type	Number of Contaminants					
	All Contaminants		Detected Contaminants		Detected, Unregulated Contaminants with Human-Health Benchmarks	
	Analyzed	Detected	Regulated	Unregulated	Before HBSL Calculations ¹	After HBSL Calculations
Pesticides						
Public supply	47	15	4	11	8	10
Domestic	85	21	7	14	9	12
Monitoring	97	30	8	22	17	21
All well types	97	38	12	26	17	24
VOCs						
Public supply	85	38	24	14	4	6
Domestic	85	47	27	20	4	9
Monitoring	85	45	24	21	5	9
All well types	85	60	30	30	7	12

¹Human-health benchmarks before HBSL calculations are lifetime health advisory values from U.S. Environmental Protection Agency (USEPA) Office of Water and risk-specific dose values from either USEPA's Office of Water or their Integrated Risk Information System database.

HBSL, health-based screening level; VOC, volatile organic compound.

published by the USEPA’s Office of Pesticide Programs. HBSLs were not calculated for the remaining 20 detected unregulated contaminants because the USEPA human-health toxicity information needed to calculate HBSLs (i.e., reference dose or cancer slope factor values) was not available; the potential human-health effects of these contaminants cannot, therefore, be evaluated at this time on a comparable basis.

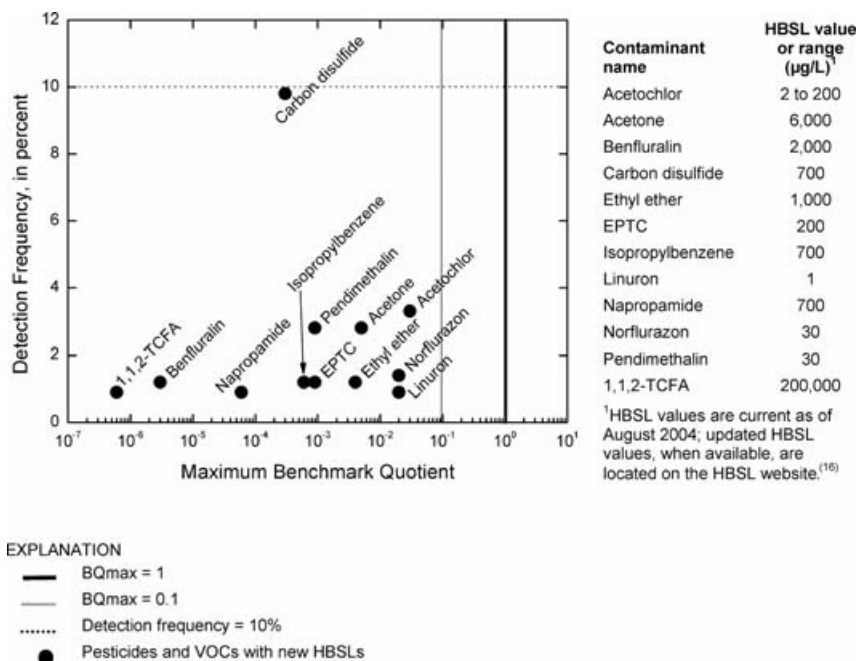
3.2. Comparing Concentrations with Benchmarks and Identifying Contaminants of Potential Human-Health Concern

Most detected contaminants with human-health benchmarks (33 of 36 pesticides and 37 of 42 VOCs) were detected at concentrations less than MCLs and HBSLs ($BQ_{max} < 1$), including all 12 contaminants with new HBSLs (Fig. 1). Indeed, more than half (41 of 70) of these contaminants with MCLs or HBSLs had a $BQ_{max} < 0.01$ (i.e., more than 100-fold less than MCLs or HBSLs). Ingesting water with concentrations less than human-health benchmarks is unlikely to result in adverse human-health effects, even if water with such concentrations were to be ingested over a lifetime.⁽¹³⁾

Seven contaminants (three pesticides and four VOCs) were identified as being of potential human-health concern because they had concentrations greater than or equal to MCLs or HBSLs (BQ_{max} range, 1–3,000) in at least one sample (Table II). When the magnitude of the BQ values, detection frequency, and well type and use of water were evaluated together, there were two patterns of occurrence for these seven contaminants.

In the first pattern, four contaminants—dieldrin, perchloroethene (PCE), trichloroethene (TCE), and ethylene dibromide (EDB)—were measured at concentrations greater than or equal to MCLs or HBSLs and were frequently detected in at least one type of drinking-water well (public-supply and (or) domestic wells). The number of individual detections of these contaminants with BQ values ≥ 1 , by well type, was 10 in public-supply wells, 4 in domestic wells, and 19 in monitoring wells (Fig. 2). In the second pattern, three contaminants—dinoseb, dibromochloropropane, and diuron—were measured at concentrations greater than or equal to MCLs or HBSLs in monitoring and (or) domestic wells, but were infrequently detected (<10% of samples) in any type of well.

Fig. 1. Detection frequencies and BQ_{max} values for unregulated pesticides and VOCs with new HBSLs (those without existing U.S. Environmental Protection Agency drinking-water standards or guidelines) detected in any well type in the New Jersey pilot study. Data points correspond to the BQ_{max} (and corresponding detection frequency) from any of the three well types.

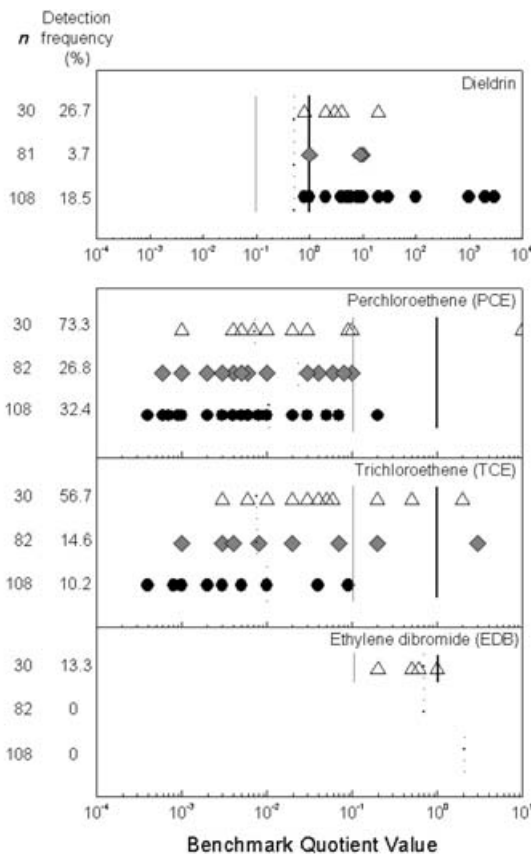


1,1,2-TCFA, 1,1,2-trichloro-1,2,2-trifluoroethane; BQ_{max} , maximum benchmark quotient = ratio of maximum-detected concentration to human-health benchmark value; EPTC, 5-ethyl dipropylthiocarbamate; HBSL, health-based screening level; VOC, volatile organic compound.

Table II. Detection Frequencies and BQ_{max} Values for Pesticides and VOCs Detected at Concentrations Within a Factor of 10 of MCLs or HBSLs in Samples from Public-Supply Wells, Domestic Wells, and (or) Monitoring Wells in the New Jersey Study

Contaminant Name	CASRN	Human-Health Benchmark (µg/L)	Type of Human-Health Benchmark	Public-Supply Wells			Domestic Wells			Monitoring Wells		
				n	Detection Frequency (%)	BQ _{max}	n	Detection Frequency (%)	BQ _{max}	n	Detection Frequency (%)	BQ _{max}
Contaminants with BQ_{max} ≥ 1 and frequently detected (>10% of samples) in at least one type of drinking-water well												
Dieldrin	60-57-1	0.002	Low end of HBSL range ¹	30	26.7	20	81	3.7	10	108	18.5	3,000
Perchloroethene (PCE)	127-18-4	5	USEPA MCL	30	73.3	10	82	26.8	0.1	108	32.4	0.2
Trichloroethene (TCE)	79-01-6	5	USEPA MCL	30	56.7	2	82	14.6	3	108	10.2	0.09
Ethylene dibromide (EDB)	106-93-4	0.05	USEPA MCL	30	13.3	1	82	ND	ND	108	ND	ND
Contaminants with BQ_{max} ≥ 1 in any well type, but infrequently detected												
Dinoseb	88-85-7	7	USEPA MCL	NA	NA	NA	60	ND	ND	72	5.6	6
Dibromochloropropane	96-12-8	0.2	USEPA MCL	30	ND	ND	82	1.2	2	108	ND	ND
Diuron	330-54-1	2	Low end of HBSL range ¹	NA	NA	NA	60	3.3	1	72	6.9	1
Contaminants with BQ_{max} ≥ 0.1, but < 1 in any well type												
Methyl <i>tert</i> -butyl ether (MTBE)	1634-04-4	70										
Heptachlor epoxide	1024-57-3	0.2	NJ MCL	30	50	0.02	82	30.5	0.4	108	38	0.6
Simazine	122-34-9	4	USEPA MCL	30	26.7	0.06	81	8.6	0.07	108	38	0.3
1,2-Dichloropropane	78-87-5	5	USEPA MCL	30	10	0.3	82	2.4	0.01	108	0.9	0.008
Benzene	71-43-2	5	USEPA MCL	30	16.7	0.04	82	3.7	0.2	108	2.8	0.07
Chloroform	67-66-3	80	USEPA MCL	30	100	0.03	82	68.3	0.2	108	81.5	0.07
Atrazine	1912-24-9	3	USEPA MCL	30	30	0.01	81	9.9	0.03	108	47.2	0.2
<i>cis</i> -1,2-Dichloroethene	156-59-2	70	USEPA MCL	30	50	0.2	82	2.4	0.04	108	2.8	0.004
Vinyl chloride	75-01-4	2	USEPA MCL	30	3.3	0.03	82	1.2	0.2	108	ND	ND
1,2-Dichloroethane	107-06-2	5	USEPA MCL	30	6.7	0.06	82	1.2	0.04	108	1.9	0.1
1,1-Dichloroethane	75-34-3	50	NJ MCL	30	43.3	0.01	82	1.2	0.04	108	8.3	0.1
1,1-Dichloroethene	75-35-4	7	USEPA MCL	30	53.3	0.1	82	7.3	0.004	108	9.3	0.01
Methylene chloride	75-09-2	5	USEPA MCL	30	ND	ND	82	2.4	0.1	108	ND	ND

¹HBSL values are current as of August 2004; updated HBSL values, when available, are located on the HBSL website.⁽¹⁶⁾ Each contaminant has a BQ_{max} greater than or equal to 0.1 in at least one well type; **Bold type** indicates benchmark quotient (BQ) ≥ 1; **Bold italic type** indicates 0.1 ≤ BQ < 1; BQ_{max}, benchmark quotient = ratio of maximum-detected concentration to MCL or HBSL; CASRN, Chemical Abstracts Service Registry Number; HBSL, health-based screening level; MCL, maximum contaminant level; n, number of samples; NA, not analyzed; ND, not detected; NJ, New Jersey; USEPA, U.S. Environmental Protection Agency; VOC, volatile organic compound.



EXPLANATION
 — BQ Value = 1
 - - - BQ Value = 0.1
 ····· Ratio of MRL to USEPA MCL or HBSL
 △ Public-supply wells
 ◇ Domestic wells
 ● Monitoring wells

BQ, benchmark quotient = ratio of detected concentration to human-health benchmark value; HBSL, health-based screening level; MCL, maximum contaminant level; MRL, minimum reporting level; *n*, number of well samples; USEPA, U.S. Environmental Protection Agency.

Fig. 2. Distributions of benchmark quotient values and detection frequencies, by well type, for four contaminants detected at concentrations greater than or equal to their human-health benchmarks and frequently detected in at least one well type in the New Jersey study.

3.3. Interpreting the Occurrence of Contaminants of Potential Human-Health Concern

Dieldrin is of particular relevance to human health because concentrations were greater than or equal to the low end of the HBSL concentration range (0.002 μg/L) in 29 of 31 public-supply, domestic, and monitoring well samples in which it was detected (Table II, Fig. 2). In the remaining two samples, dieldrin concentrations were within a factor of 10 of the HBSL. Dieldrin concentrations in four monitoring-well sam-

ples also were greater than the high end of the HBSL concentration range (0.2 μg/L), which is based on a 10⁻⁴ cancer risk. Dieldrin is an organochlorine insecticide, which is a highly persistent class of insecticides used extensively in the United States during the 1950s to 1960s; dieldrin also is a degradation product formed from aldrin. Dieldrin and aldrin are no longer registered for use in the United States.⁽²⁴⁾ Although their uses were discontinued for agriculture in the early 1970s and for termite control in the late 1980s,⁽²⁵⁾ dieldrin has been frequently detected in public-supply and monitoring well samples.

PCE concentrations were greater than USEPA’s MCL (5 μg/L) and New Jersey’s MCL (1 μg/L) in 1 of 30 public-supply well samples, and PCE was detected at concentrations within a factor of 10 of MCLs in all well types (Table II, Fig. 2). PCE is less soluble and more likely to sorb to organic matter in the subsurface than other chlorinated contaminants,⁽¹¹⁾ suggesting that it is not likely to frequently occur in groundwater. Nonetheless, PCE was frequently detected in all well types, reflecting its high-volume production and diverse industrial and commercial uses.^(11,26)

TCE concentrations were greater than USEPA’s MCL (5 μg/L) in 1 of 30 public-supply and 1 of 82 domestic well samples, and were greater than New Jersey’s MCL (1 μg/L) in two public-supply and two domestic well samples (Fig. 2). TCE also was detected at concentrations within a factor of 10 of New Jersey’s MCL in all well types (Table II, Fig. 2). TCE has been produced in large quantities since the 1960s and has a variety of industrial and commercial uses as a metal degreaser and industrial solvent.⁽²⁶⁾ TCE is likely to leach to groundwater because it is highly water soluble and has a low soil-sorption coefficient;⁽¹¹⁾ indeed, TCE was frequently detected in all well types (Table II, Fig. 2).

EDB was detected in 4 of 30 samples from public-supply wells, but was not detected in samples from any of the other well types (Table II). The maximum concentration of EDB (0.066 μg/L) in public-supply wells was greater than USEPA’s and New Jersey’s MCL of 0.05 μg/L (Table II, Fig. 2). The remaining EDB concentrations were less than, but within a factor of 10 of, the MCL value. EDB was used historically as an additive to leaded gasoline and as a turf fumigant,⁽²⁷⁾ but these uses have declined or been banned.⁽¹¹⁾ The occurrence of EDB exclusively in samples from the public-supply wells likely reflects historical use patterns, its relatively long aerobic half-life in water (180 days),⁽²⁸⁾ and the fact that public-supply wells intercept groundwater from larger contributing areas than other well types.⁽¹¹⁾

All four frequently detected contaminants with $BQ_{\max} \geq 1$ (dieldrin, PCE, TCE, EDB) had MRLs less than their MCLs or HBSLs, permitting quantitation of these contaminants at concentrations relevant to human health. The exception was EDB in monitoring well samples, where the MRL for EDB ($0.1 \mu\text{g/L}$) was twofold greater than its MCL ($0.05 \mu\text{g/L}$), resulting in the possibility that EDB was present, but not detected, in some monitoring-well samples at concentrations relevant to human health.

3.4. Potential Relevance of Concentrations Greater than MCLs or HBSLs

Water containing contaminant concentrations greater than the MCL or HBSL may be of potential human-health concern if the water were to be ingested without treatment for many years. The likelihood for adverse effects generally increases as contaminant concentrations (and BQ values) increase.⁽¹³⁾ If water containing contaminant concentrations greater than MCLs or HBSLs is ingested, it does not necessarily indicate that adverse human-health effects will occur because (i) these benchmarks are intentionally conservative (protective) and generally incorporate safety factors and conservative assumptions to account for uncertainty in toxicity information, (ii) USEPA OW models used to develop MCLs and HBSLs assume lifetime exposure, whereas actual exposure may be for less than a lifetime, (iii) water from monitoring wells is not directly consumed, and (iv) water from some wells may be treated before consumption, potentially reducing concentrations.⁽⁴⁾ Not all well types receive treatment (e.g., domestic wells), however, and the treatment methods may not be designed specifically to remove contaminants of potential human-health concern.

Identifying VOCs with concentrations less than or greater than human-health benchmarks provides useful information about what VOC occurrence may mean to human health, but screening-level assessments have limitations. For example, there are no human-health benchmarks for 20 contaminants considered in this assessment. Additionally, a limitation of MCLs and HBSLs is that they are generally based on toxicity information for single chemicals, whereas findings indicate that contaminants occur as mixtures in some samples. One or more pesticides were detected in combination with one or more VOCs in greater than 95% of the samples collected from these well types.⁽¹⁰⁾ The long-term cumulative effects of low

concentrations of multiple contaminants on human health currently are unknown.

3.5. Additional Monitoring May be Warranted for 20 Contaminants

Thirteen contaminants (3 pesticides and 10 VOCs) had concentrations less than, but within a factor of 10 of, MCLs or HBSLs in at least one well type (Table II). These 13 contaminants, in addition to the 7 contaminants with concentrations of potential human-health concern, may warrant additional monitoring to identify trends in their occurrence and to provide an early indication of concentrations approaching human-health benchmarks. Nine of these 13 contaminants were detected in more than 10% of public-supply or domestic well samples; the remaining four contaminants were not frequently detected in any well type (Table II).

Additionally, deethylatrazine is noteworthy because it was frequently detected in all well types (25% to 42% of the samples), but it has no human-health benchmarks to use for comparison against detected concentrations, making deethylatrazine a priority for toxicity testing and development of human-health benchmarks. The USEPA Office of Pesticide Programs Interim Reregistration Eligibility Decision for atrazine⁽²⁹⁾ indicates that the toxicity of atrazine and its chlorinated metabolites (including deethylatrazine) are considered to be equivalent, but the HBSL methodology does not currently permit the use of toxicity data from a parent compound to calculate an HBSL for a degradation product. Deethylatrazine forms in the environment from the degradation of the commonly used herbicides atrazine and propazine. Of the 20 detected contaminants for which HBSLs could not be calculated because of a lack of toxicity information, deethylatrazine is the only contaminant that was frequently detected in any well type.

4. CONCLUSIONS

The overall objective of the HBSL effort is to more comprehensively evaluate the water-quality findings of the USGS NAWQA Program in the context of human health. The two specific objectives of this pilot study were to develop HBSLs for unregulated contaminants using an interagency consensus approach and to demonstrate the use of HBSLs as tools for evaluating groundwater-quality data in a human-health context.

The use of HBSLs increased the number of pesticides and VOCs with human-health benchmarks from 24 to 36 out of 56 detected in this study. Because HBSLs supplement existing USEPA drinking-water standards and guidelines, they provide a basis for a more comprehensive evaluation of contaminant-occurrence data in a human-health context than by using USEPA benchmarks alone. The 12 detected contaminants with new HBSLs (but without existing USEPA drinking-water guideline values) were not identified as being contaminants of potential human-health concern because they were detected at concentrations ranging from 30- to 12-million-fold less than HBSLs ($BQ_{\max} < 0.1$) in all three well types (Fig. 1). Prior to this study and the calculation of HBSLs for these 12 contaminants, the ability to evaluate the human-health context of their occurrence on a basis consistent with USEPA benchmarks was limited. Ten of the 12 unregulated contaminants with new HBSLs were detected in public-supply and (or) domestic well samples, and because these water resources are used as drinking-water supplies, it is particularly valuable to explain the occurrence of these contaminants in a human-health context.

Seven contaminants were found to be of potential human-health concern in groundwater resources because concentrations were greater than MCLs or HBSLs. Four of these contaminants—dieldrin, PCE, TCE, and EDB—also were frequently detected in drinking-water supplies. An additional 13 contaminants had concentrations within a factor of 10 of MCLs or HBSLs in at least one type of well. Further monitoring may be warranted for these 20 contaminants to identify trends in their occurrence.

HBSLs were applied to a state-scale groundwater data set in this study, but HBSLs also may be applied to regional and national evaluations of water-quality data. HBSLs can be used as planning tools to help prioritize contaminants that may merit further study or monitoring and to provide an early indication of contaminant concentrations approaching human-health benchmarks in water resources. HBSLs potentially could aid regulatory priority-setting processes by identifying unregulated contaminants with concentrations greater than human-health benchmarks and frequently detected unregulated contaminants (such as deethylatrazine) without available human-health toxicity information.

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REFERENCES

1. Leahy, P. P. (1990). *Implementation Plan for the National Water-Quality Assessment Program* (p. 10). Reston, VA: U.S. Geological Survey. Open-File Report, 90-174. Available at <http://pubs.er.usgs.gov/usgspubs/ofr/ofr90174>.
2. Gilliom, R. J., Mueller, D. K., & Nowell, L. H. (1998). *Methods for Comparing Water-Quality Conditions Among National Water-Quality Assessment Study Units, 1992–1995* (p. 54). Sacramento, CA: U.S. Geological Survey. Open File Report, 97-589. Available at <http://ca.water.usgs.gov/pnsp/rep/ofr97589/>.
3. Toccalino, P. L., Zogorski, J. S., & Norman, J. E. (2005). *Health-Based Screening Levels and Their Application to Water-Quality Data* (p. 2). Reston, VA: U.S. Geological Survey. Fact Sheet, 2005-2059. Available at <http://water.usgs.gov/nawqa/FS.2005-3059.pdf>.
4. Toccalino, P. L., Nowell, L. H., Wilber, W. G., Zogorski, J. S., Donohue, J. M., Eiden, C. A., Krietzman, S. J., & Post, G. B. (2003). *Development of Health-Based Screening Levels for Use in State- or Local-Scale Water-Quality Assessments* (p. 22). Rapid City, SD: U.S. Geological Survey. Water-Resources Investigations Report, 03-4054. Available at <http://sd.water.usgs.gov/nawqa/pubs/wrir/wrir03.4054.pdf>.
5. Toccalino, P. L., Norman, J. E., Phillips, R. H., Kauffman, L. J., Stackelberg, P. E., Nowell, L. H., Krietzman, S. J., & Post, G. B. (2004). *Application of Health-Based Screening Levels to Ground-Water Quality Data in a State-Scale Pilot Effort* (p. 64). Reston, VA: U.S. Geological Survey. Scientific Investigations Report, 2004-5174. Available at <http://pubs.usgs.gov/sir/2004/5174/sir20045174.pdf>.
6. Ayers, M. A., Kennen, J. G., & Stackelberg, P. E. (2000). *Water Quality in the Long Island-New Jersey Coastal Drainages, New York and New Jersey, 1996–98* (p. 40). West Trenton, NJ: U.S. Geological Survey. Circular 1201. Available at <http://water.usgs.gov/pubs/circ/circ1201/>.
7. Clawges, R. M., Stackelberg, P. E., Ayers, M. A., & Vowinkel, E. F. (1999). *Nitrate, Volatile Organic Compounds, and Pesticides in Ground Water—A Summary of Selected Studies from New Jersey and Long Island, New York* (p. 32). West Trenton, NJ: U.S. Geological Survey. Water-Resources Investigations Report, 99-4027. Available at <http://pubs.er.usgs.gov/usgspubs/wri/wri994027>.
8. Kauffman, L. J., Baehr, A. L., Ayers, M. A., & Stackelberg, P. E. (2001). *Effects of Land Use and Travel Time on the Distribution of Nitrate in the Kirkwood-Cohansey Aquifer System in Southern New Jersey* (p. 49). West Trenton, NJ: U.S. Geological Survey. Water-Resources Investigations Report, 01-

4117. Available at http://nj.usgs.gov/nawqa/linj/pdf/wrir_01-4117.pdf.
9. Stackelberg, P. E., Hopple, J. A., & Kauffman, L. J. (1997). *Occurrence of Nitrate, Pesticides, and Volatile Organic Compounds in the Kirkwood-Cohansey Aquifer System, Southern New Jersey* (p. 8). West Trenton, NJ: U.S. Geological Survey. Water-Resources Investigations Report, 97-4241. Available at <http://nj.usgs.gov/nawqa/linj/pdf/wrir97-4241.pdf>.
 10. Stackelberg, P. E., Kauffman, L. J., Ayers, M. A., & Baehr, A. L. (2001). Frequently co-occurring pesticides and volatile organic compounds in public-supply and monitoring wells, southern New Jersey, USA. *Environmental Toxicology and Chemistry*, 20(4), 853–865.
 11. Stackelberg, P. E., Kauffman, L. J., Baehr, A. L., & Ayers, M. A. (2000). *Comparison of Nitrate, Pesticides, and Volatile Organic Compounds in Samples from Monitoring and Public-Supply Wells, Kirkwood-Cohansey Aquifer System, Southern New Jersey* (p. 78). West Trenton, NJ: U.S. Geological Survey. Water-Resources Investigations Report, 00-4123. Available at <http://nj.usgs.gov/nawqa/linj/wri00-4123/wri00-4123.pdf>.
 12. Zogorski, J. S., Carter, J. M., Ivahnenko, T., Lapham, W. W., Moran, M. J., Rowe, B. L., Squillace, P. J., & Toccalino, P. L. (2006). *The Quality of Our Nation's Waters-Volatile Organic Compounds in the Nation's Ground Water and Drinking-Water Supply Wells* (p. 101). Reston, VA: U.S. Geological Survey. Circular 1292. Available at http://water.usgs.gov/nawqa/vocs/national_assessment/.
 13. Toccalino, P. L., Rowe, B. L., & Norman, J. E. (2006). *Volatile Organic Compounds in the Nation's Drinking-Water Supply Wells—What Findings May Mean to Human Health* (p. 4). U.S. Geological Survey. Fact Sheet, 2006-3043. Available at <http://pubs.usgs.gov/fs/2006/3043/>.
 14. U.S. Environmental Protection Agency. (1988). *Draft Guide to Drinking Water Health Advisories*. Washington, DC: U.S. Environmental Protection Agency, Office of Drinking Water, Criteria and Standards Division, Health Effects Branch.
 15. U.S. Environmental Protection Agency. (1993). *Health Advisories for Drinking Water Contaminants* (p. 260). Boca Raton, FL: Lewis Publishers.
 16. U.S. Geological Survey. (2006). *Health-Based Screening Levels: A Tool for Evaluating What Water-Quality Data May Mean to Human Health*. U.S. Geological Survey, National Water-Quality Assessment Program. Available at <http://water.usgs.gov/nawqa/HBSL/>.
 17. Koterba, M. T., Franceska, W. D., & Lapham, W. W. (1995). *Ground-Water Data-Collection Protocols and Procedures for the National Water-Quality Assessment Program: Collection and Documentation of Water-Quality Samples and Related Data* (p. 113). Reston, VA: U.S. Geological Survey. Open-File Report, 95-399. Available at <http://water.usgs.gov/nawqa/ofr95-399/ofr95-399book.pdf>.
 18. Connor, B. F., Rose, D. L., Noriega, M. C., Murtagh, L. K., & Abney, S. R. (1998). *Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of 86 Volatile Organic Compounds in Water by Gas Chromatography/Mass Spectrometry, Including Detections Less Than Reporting Limits* (p. 78). Denver, CO: U.S. Geological Survey. Open-File Report, 97-829. Available at <http://nwql.usgs.gov/Public/pubs/OFR97-829.pdf>.
 19. Werner, S. L., Burkhardt, M. R., & DeRusseau, S. N. (1996). *Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of Pesticides in Water by Carbopak-B Solid-Phase Extraction and High-Performance Liquid Chromatography* (p. 42). Denver, CO: U.S. Geological Survey. Open-File Report, 96-216. Available at <http://nwql.usgs.gov/Public/pubs/OFR96-216/OFR96-216.html>.
 20. Zaugg, S. D., Sandstrom, M. W., Smith, S. G., & Fehlberg, K. M. (1995). *Methods of Analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of Pesticides in Water by C-18 Solid-Phase Extraction and Capillary-Column Gas Chromatography/Mass Spectrometry with Selected-Ion Monitoring* (p. 49). Denver, CO: U.S. Geological Survey. Open-File Report, 95-181. Available at <http://nwql.usgs.gov/Public/pubs/OFR95-181/OFR95-181.html>.
 21. Oblinger Childress, C. J., Foreman, W. T., Connor, B. F., & Maloney, T. J. (1999). *New Reporting Procedures Based on Long-Term Method Detection Levels and Some Considerations for Interpretations of Water-Quality Data Provided by the U.S. Geological Survey National Water Quality Laboratory* (p. 19). Reston, VA: U.S. Geological Survey. Open-File Report, 99-193. Available at <http://water.usgs.gov/owq/OFR-99-193/ofr99-193.pdf>.
 22. U.S. Environmental Protection Agency. (2003). *Code of Federal Regulations, Title 40—Protection of Environment, Chapter I—Environmental Protection Agency, Subchapter E—Pesticide Programs, Part 159—Statements of Policies and Interpretations, Subpart D—Reporting Requirements for Risk/Benefit Information*. Washington, DC: National Archives and Records Administration. Available at <http://www.gpoaccess.gov/ecfr/index.html>.
 23. U.S. Environmental Protection Agency. (1989). *Risk Assessment Guidance for Superfund. Volume I. Human Health Evaluation Manual (Part A), Interim Final*. Washington, DC: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. EPA/540/1-89/002. Available at <http://www.epa.gov/oswer/riskassessment/ragsa/pdf/preface.pdf>.
 24. Ware, G. G. (1989). *The Pesticide Book* (p. 386). New York: W. H. Freeman and Company.
 25. Nowell, L. H., Capel, P. D., & Dileanis, P. D. (1999). *Pesticides in Stream Sediment and Aquatic Biota—Distribution, Trends, and Governing Factors: Pesticides in the Hydrologic System Series* (p. 1040). Boca Raton, FL: CRC Press.
 26. Harte, J., Holdren, C., Schneider, R., & Shirley, C. (1991). *Toxics A to Z—A Guide to Everyday Pollution Hazards* (p. 479). Berkeley and Los Angeles, CA: University of California Press.
 27. U.S. Environmental Protection Agency. (2002). *Technology Transfer Network National Air Toxics Assessment*. U.S. Environmental Protection Agency, Office of Air and Radiation. Available at <http://www.epa.gov/ttn/atw/nata/pollinf2.html>.
 28. Howard, P. H., Boethling, R. S., Jarvis, W. F., Meylan, W. M., & Michalenko, E. M. (1991). *Handbook of Environmental Degradation Rates* (p. 725). Chelsea, MI: Lewis Publishers.
 29. U.S. Environmental Protection Agency. (2002). *Interim Reregistration Eligibility Decision for Atrazine* (p. 304). Washington, DC: U.S. Environmental Protection Agency, Office of Pesticide Programs. Case no. 0062. Available at http://www.epa.gov/oppsrrd1/REDS/atrazine_ired.pdf.