SOURCE WATER ASSESSMENT METHODOLOGY

For
Ground Water Sources

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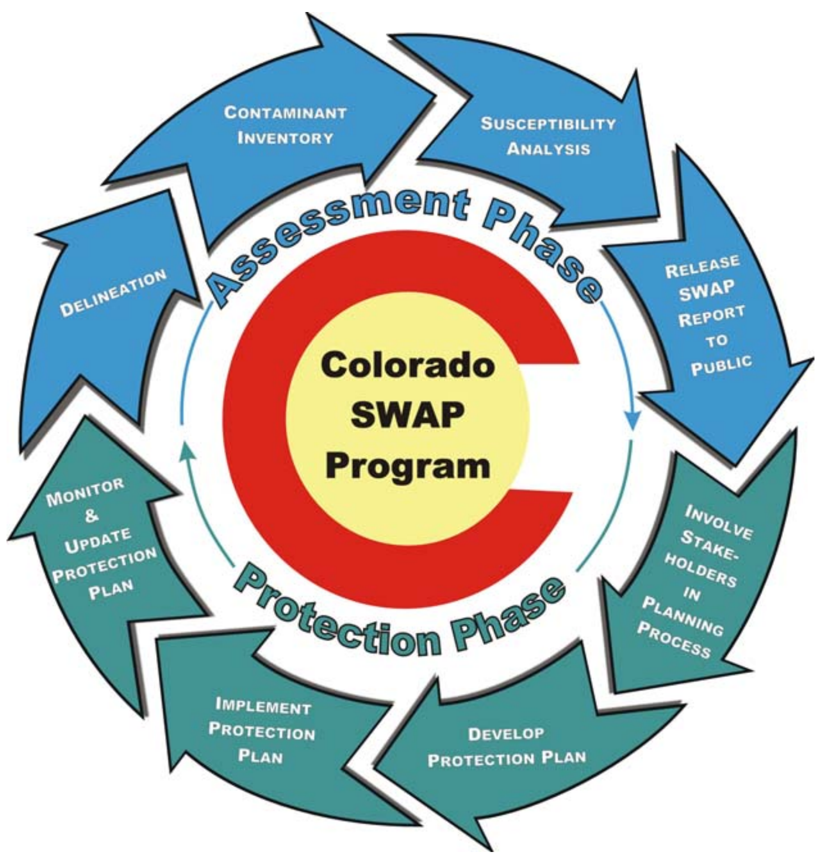
INTRODUCTION

The purpose of this document is to present an overview of the assessment methodology used by the Colorado Source Water Assessment and Protection (SWAP) Program to evaluate all public drinking water systems in Colorado that have ground water sources. Topics addressed in this document include: 1) background information on the SWAP Program; 2) an overview of the water cycle, water sources and public water systems; 3) a discussion of the source water assessment elements, methodologies and reporting requirements; and 4) local responsibility for the protection phase. A similar document presenting an overview of the assessment methodology that was used to evaluate all public drinking water systems in Colorado that have surface water sources or ground water sources under the direct influence of surface water is also available for review.

SWAP PROGRAM BACKGROUND

SWAP came into existence in 1996 as a result of Congress reauthorizing and amending the Safe Drinking Water Act. The 1996 amendments required each state to develop a source water assessment and protection program. The Water Quality Control Division, an agency of the Colorado Department of Public Health and Environment, assumed the responsibility of developing Colorado's SWAP program.

The SWAP program is designed to take a "preventive" approach to protecting a public water system from contamination, and it is a two-phased process as presented below:



The **Assessment Phase** involves understanding where each public water system's source water comes from, what contaminant sources potentially threaten the water source(s), and how susceptible each water source is to potential contamination. Since many water systems obtain their water from multiple sources, the susceptibility of a public water system is analyzed by examining the susceptibility of each of its water sources. The susceptibility of an individual water source is analyzed by examining the properties of its physical setting and potential contaminant source threats. The results of the susceptibility analysis calculations are used to report an estimate of how susceptible each water source is to potential contamination.

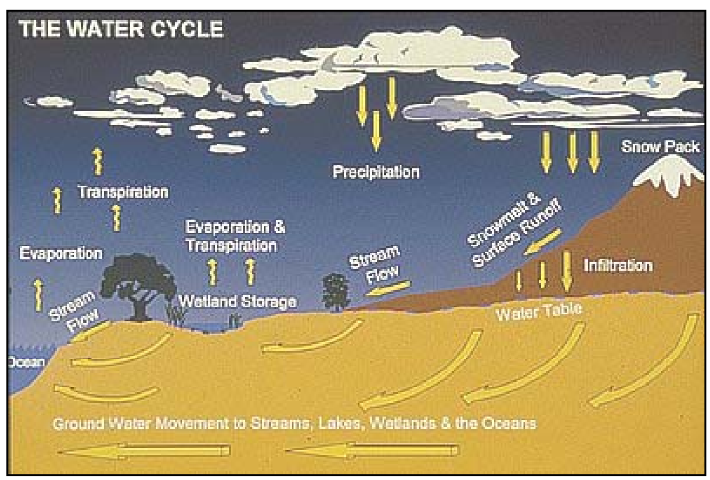
The **Protection Phase** is a voluntary, ongoing process in which the public water system and local community employ preventive measures to protect the water supply from the potential sources of contamination to which it may be most vulnerable.

This phase can be used to take action to avoid unnecessary treatment or replacement costs associated with contamination of the water supply. Source water protection begins when local decision-makers use the source water assessment results and other pertinent information to develop and implement management and response strategies to protect the water sources from potential contamination.

OVERVIEW OF THE WATER CYCLE, WATER SOURCES, AND PUBLIC WATER SYSTEMS

This section presents an overview of the water cycle, and the types of drinking water sources and the public water systems involved in the statewide source water assessment.

THE WATER CYCLE



The adjacent figure of the water cycle (or hydrologic cycle) depicts the migration pathways that a drop of water may take. Surface water and ground water are closely related. In some areas, surface water infiltrates (discharges) into the ground and therefore influences ground water. In other areas, ground water discharges to streams and lakes and therefore influences surface water. "Understanding the interaction of ground water and surface water is essential to water managers and water scientists. Management of one component of the hydrologic system, such as a stream or an aquifer, commonly is only partly effective …," per USGS Circular 1139. Contaminants can enter the water cycle through many pathways – stormwater runoff, infiltration, atmospheric deposition, discharges from man-made activities, and others.

SOURCES OF DRINKING WATER

A public water system may use one or more source water types for drinking water. These source water types include:

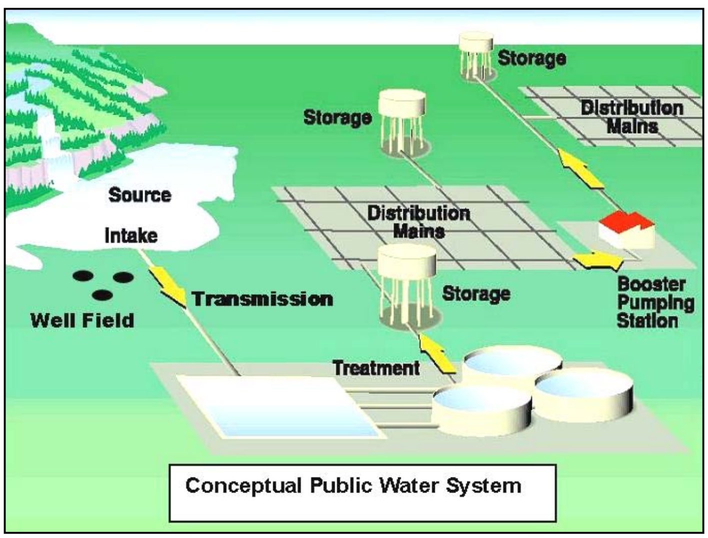
- **Ground water source** - any "untreated" water source that is diverted directly from an underground source of water (i.e., an aquifer).
- **Surface water source** - any "untreated" water source that is diverted directly from a stream, river, lake, pond or similar surface water body.
- **Ground water source under the direct influence of surface water** - any "untreated," shallow, ground water source that testing has shown to be in hydrologic connection to a nearby surface water body.

A public water system also may have purchased water sources. A purchased water source includes any "treated" water that is purchased from another public water system.

This document presents the source water assessment methodology only for ground water sources. A separate document presents an assessment methodology for surface water sources and ground water sources under the direct influence of surface water.

PUBLIC WATER SYSTEMS

There are three different categories of public water systems. The SWAP program evaluated the following types of public water systems:



1) **Community systems** which primarily serve the homes of residential customers (such as city water systems);
2) **Non-Transient Non-Community systems** which serve a relatively stable group of non-residential customers (such as schools and factories with their own water systems); and
3) **Transient Non-Community systems** which serve a changing population group (such as campgrounds, rest areas, and truck stops with their own water systems).

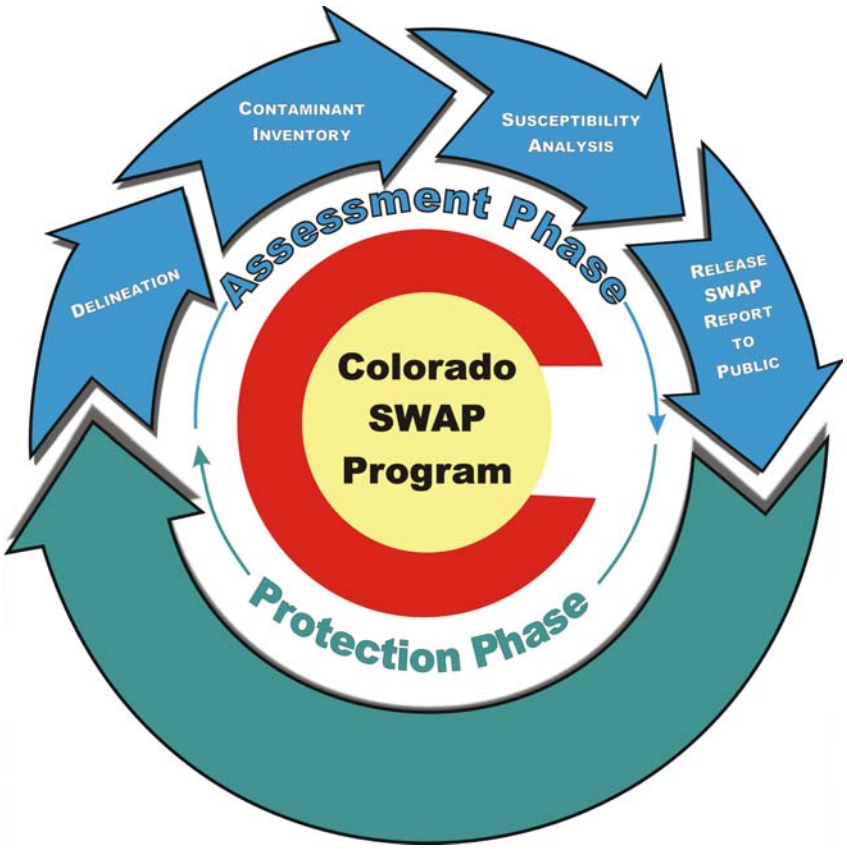
The SWAP program evaluates the untreated water component of the public water system, *before water enters the transmission, treatment, and distribution part of the system*. **The source water assessment is NOT a reflection of the quality of the water being provided to drinking water consumers.** The accompanying figure shows the major components of a public water system. *The source water area is the primary concern of the SWAP program, and is depicted in the far left portion of the figure (in the vicinity of the well field).*

SOURCE WATER ASSESSMENT ELEMENTS

This section presents details of the source water assessment process that was conducted by the Water Quality Control Division and its subcontractors between 2000 and 2004. A source water assessment consists of the following elements:

1) **Delineation** of source water assessment areas for each water source;
2) **Inventory** of potential sources of contamination within the source water assessment areas;
3) **Susceptibility Analysis** of each water source to the potential contaminant sources; and
4) **Reporting** the assessment results to the public.

These elements are discussed below.

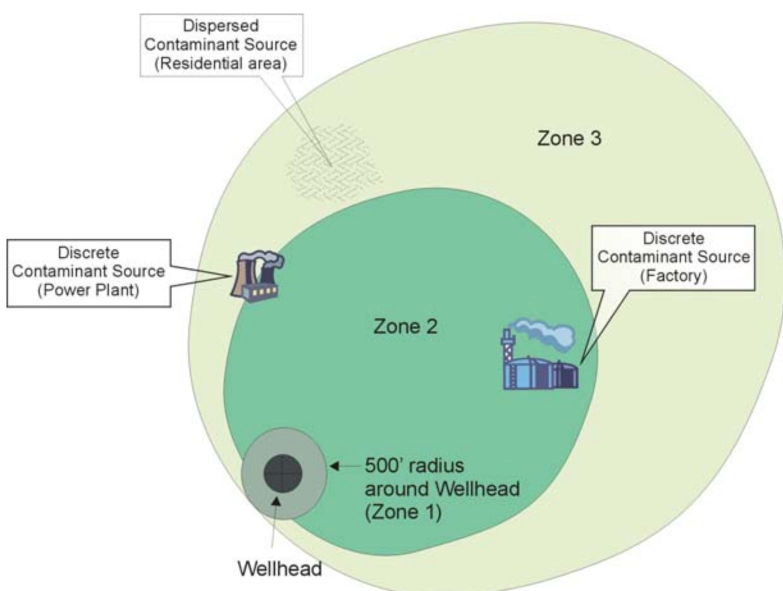


Delineation of Source Water Assessment Areas

The first step in conducting the source water assessment for a public water system is to delineate the source water assessment area to evaluate where the drinking water comes from. This was done for each active water source on record when the assessment phase began in 2000. Inactive water sources were not considered in this assessment. With feedback from the participating public water systems, the Water Quality Control Division identified and verified the location of each active water source intake for each public water system in the state.

The source water assessment area approximates the area or region of the watershed or aquifer contributing untreated water to the public water system's water intake, and the area or region where potential contamination of this water supply could occur. An intake is defined as any structure used to divert the source water from a surface water body (stream, lake, etc.) or an aquifer directly to the water treatment plant. For ground water systems, the source water assessment area essentially includes the area of the aquifer drained by the source water intake. In the case of ground water systems, the intake most commonly would include wells, and to a lesser extent include spring boxes and infiltration galleries. Sensitivity zones were delineated for each source water assessment area. These sensitivity zones, as well as other characteristics of the source water area, are important in the susceptibility analysis. They are discussed in further detail in the Susceptibility Analysis section of this document.

Each public water system was provided an electronically generated map(s) showing the source water assessment area associated with each of their water sources. Corrections to the intake locations and the source water assessment areas were made based on comments received from the public water systems. The following figure presents a conceptual example of a source water assessment area delineation, the sensitivity zones within the area, and the potential contaminant sources within the area.

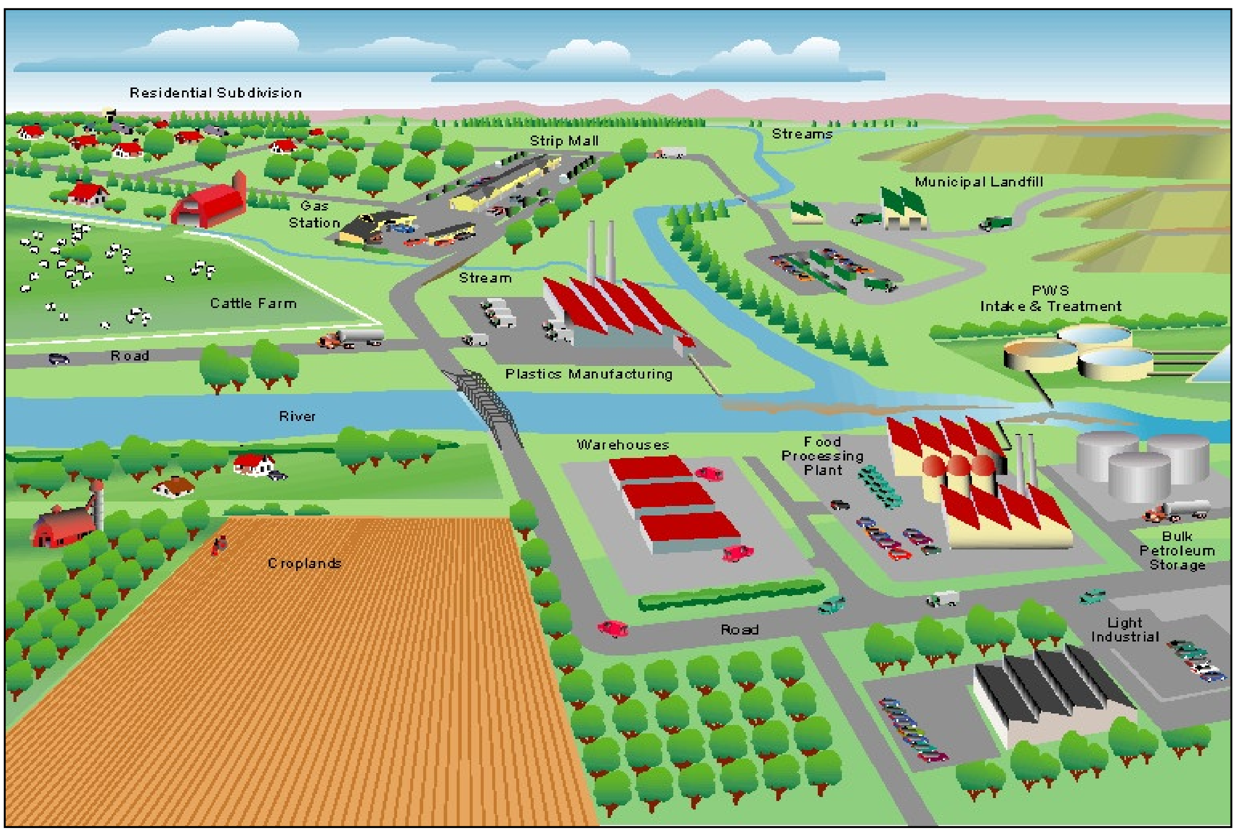


INVENTORY OF POTENTIAL CONTAMINANT SOURCES

After the source water areas have been delineated, the second step of conducting a source water assessment is to inventory potential sources of contamination located within each of the defined source water assessment areas. Potential contaminant sources include any activity likely to manufacture, produce, use, store, dispose, or transport regulated or unregulated contaminants. Colorado's SWAP program identified the most significant or serious potential sources of contamination that were evaluated in this initial assessment phase. Significant potential sources of contamination were divided into two groups:

- **Discrete contaminant sources –** generally include facility-related operations from which the potential release of contamination would originate from a relatively small area. Examples shown on the figure below include bulk petroleum storage, a gas station, plastics manufacturing, a municipal landfill, and a food processing plant.

- **Dispersed contaminant sources –** generally include broad based land uses and miscellaneous sources from which the potential release of contamination would be spread widely over a relatively large area. Examples shown on the figure below include a residential subdivision, croplands, a cattle farm, and roads.



Discrete Contaminant Sources

Discrete contaminant sources generally can be viewed as facilities that have a fixed location and can be mapped as a point. Sources of information about these discrete contaminant sources were assembled in 2001 and 2002 primarily from environmental databases maintained by federal and state environmental regulatory agencies. Additional discrete contaminant sources were assembled in 2002 from a publicly available Standard Industrial Classification database of businesses throughout Colorado. This database was filtered to identify the larger business facilities that were expected to conduct similar activities to those facilities contained in the regulated databases. The following table summarizes the various data sources used for the assessment and the approximate number of discrete contaminant sources associated with each.

Description of Discrete Potential Contaminant Sources	Number of Facilities in Colorado (approximate)
Storage Tanks (above ground and underground)	15,000
Mines	13,000
Standard Industrial Classification (SIC) Facilities	11,000
Oil & Gas Facilities (excluding wells)	10,000
Hazardous Waste Facilities	5,400
Superfund Amendments and Reauthorization Act (SARA) Facilities	1,500
Permit Compliance System (PCS) Dischargers	1,500
Toxic Release Inventory (TRI) Facilities	421
Confined Animal Feeding Operations (CAFO)	377
Solid Waste Facilities	282
Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) Facilities	61
Superfund Facilities	20

It is possible that a discrete contaminant source may be inventoried more than once. This occurs when the facility is contained in more than one of the databases that were used. In many cases, a facility may be regulated under two or more programs and therefore may present different potential contaminant threats to the water source.

Dispersed Contaminant Sources

Dispersed potential contaminant sources generally can be viewed as potential non-point sources of pollution, where contamination originates over a large area. Land use coverages were obtained from the most recently available United States Geological Survey land use map for Colorado. Other dispersed contaminant sources included septic systems, oil and gas wells, and primary roads. The septic system locations were estimated using statewide domestic water well records obtained from the State Engineer’s Office. The assumption was made that the vast majority of septic systems can be associated with domestic water wells, especially in rural areas. As a result, the locations of domestic water wells in the state were mapped and a one to one correlation between domestic water wells and septic systems was assumed in order to estimate the locations of septic systems.

The following table summarizes the dispersed potential sources of contamination of most concern that were inventoried and the contaminant-related activities associated with each.

DISPERSED CONTAMINANT SOURCES	CONTAMINANT-RELATED ACTIVITIES
Urban Land Uses:	
Commercial/Industrial/Transportation	• Manufacture, production, or use of regulated/ unregulated contaminants • Improper storage, disposal, or transport of regulated / unregulated contaminants • Stormwater and wastewater discharges
Residential (high-density / low-density)	• Over-use of household pesticides, herbicides and fertilizers • Improper disposal of common household chemicals • Stormwater discharges
Recreational Grasses	• Large-scale use of pesticides, herbicides and fertilizers • Improper disposal of pet wastes • Stormwater discharges
Rural Land Uses:	
Quarries/Mines/Gravel Pits	• Use of regulated / unregulated contaminants • Improper storage, disposal, or transport of regulated / unregulated contaminants • Storm runoff and mine adit discharges
Agricultural (cropland, pasture, fallow, orchards)	• Large-scale use of pesticides, herbicides and fertilizers • Improper storage or disposal of regulated/ unregulated contaminants • Storm runoff discharges
Forest (evergreen, deciduous, and mixed forests)	• Erosion runoff from fire-burn areas • Large-scale use of pesticides and herbicides (managed forests) • Improper storage or disposal of regulated/ unregulated contaminants and human/pet wastes (related to recreational uses) • Animal wastes and erosion (related to grazing livestock and natural wildlife)
Miscellaneous	
Septic Systems (estimate of 63,000 in Colorado)	• Improper disposal of human waste due to improperly designed / maintained septic system • Improper disposal of common household chemicals to the septic system
Oil & Gas Wells (estimate of 57,000 in Colorado)	• Production of regulated / unregulated contaminants • Improper storage / disposal of regulated/unregulated contaminants and production wastes (brine)
Primary Roads	• Accidental spill of regulated / unregulated contaminants • Runoff from road sanding/salting operations

Public Water System Feedback on the Contaminant Inventory Results

The Water Quality Control Division and its contractors assembled the discrete and dispersed contaminant source information obtained from the various data sources into an electronic mapping library (i.e., a Geographic Information System or GIS) along with the source water area delineation information. Contaminant source inventory maps and tabular summaries of the discrete and dispersed contaminant sources were generated for each public water system's source water assessment area(s). The public water systems were asked to:

1) Review the locations of the intake structures and the source water assessment areas for accuracy one last time;
2) Review the locations of the discrete potential contaminant sources on the map for accuracy and add information on previously unidentified discrete contaminant sources that were not shown on the draft map; and
3) Provide corrections and additional information about the discrete and dispersed potential contaminant sources to the Water Quality Control Division, if necessary.

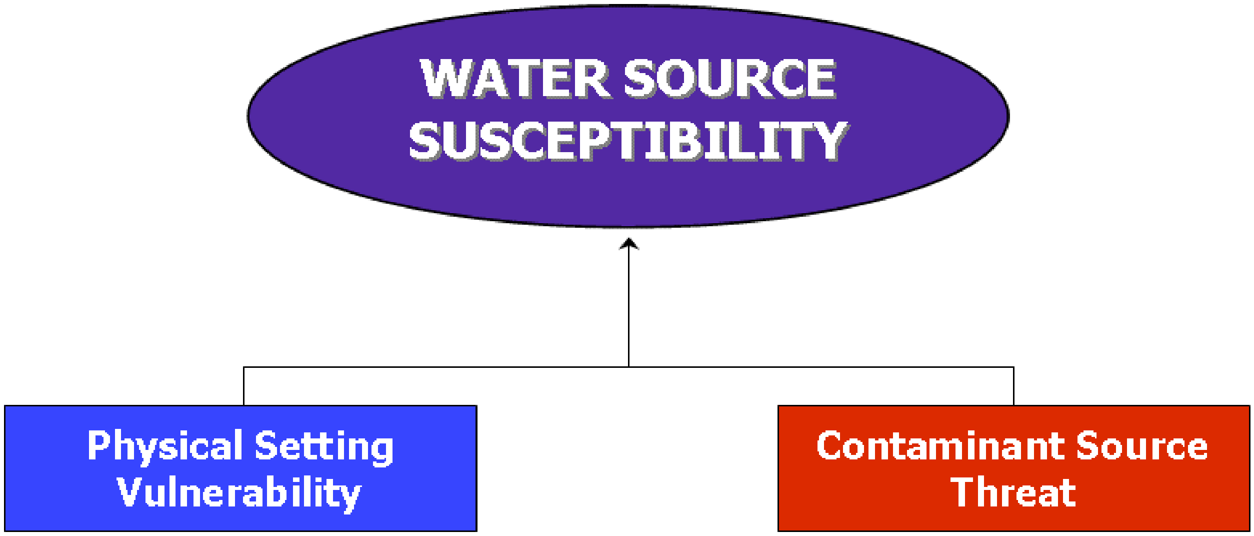
Nearly 400 public water systems provided responses, and their responses were incorporated into the source water assessments accordingly.

SUSCEPTIBILITY ANALYSIS

After the delineation and contaminant inventories have been completed, the third step in conducting a source water assessment is to perform a susceptibility analysis of each water source. The susceptibility analysis evaluates the potential for the raw untreated water source to become contaminated at concentrations that may pose a health concern to consumers of the water. It should be noted that the analysis does not attempt to predict what these potential contaminant concentrations would be, nor does it provide an indication that a potential contamination problem has or will occur. The process for conducting the susceptibility analysis and reporting the results was automated because the analysis was performed on more than 3,300 water sources throughout the state.

The two primary components of the susceptibility analysis model are:

1) **Physical Setting Vulnerability** of the water source, and
2) **Contaminant Source Threat** posed by a potential source of contamination.

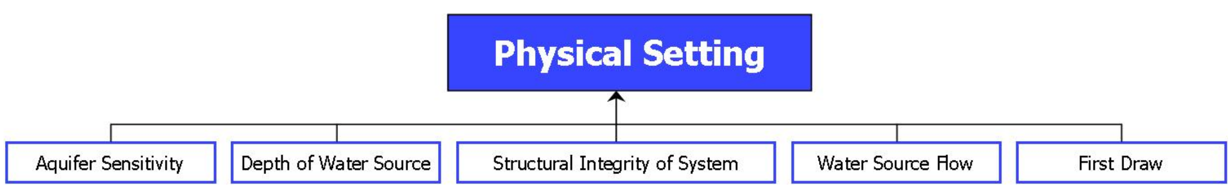


Physical Setting Vulnerability

The first component of the susceptibility analysis model involves an examination of the vulnerability of the water source's physical setting. The physical setting for a water source has a strong buffering influence on the potential contaminant concentrations in the source water. The more vulnerable the physical setting, the more susceptible a water source will be to potential contamination.

The key hydrologic, geologic, geographic, and source characteristics analyzed in the model include:

1) Aquifer sensitivity at the water source intake location;
2) Depth of the water source;
3) Structural integrity of the water system at the withdrawal point;
4) Flow of the water source (i.e., permitted pumping rate in gallons per minute); and
5) First draw of the water source (i.e., the uppermost depth at which water enters the well).

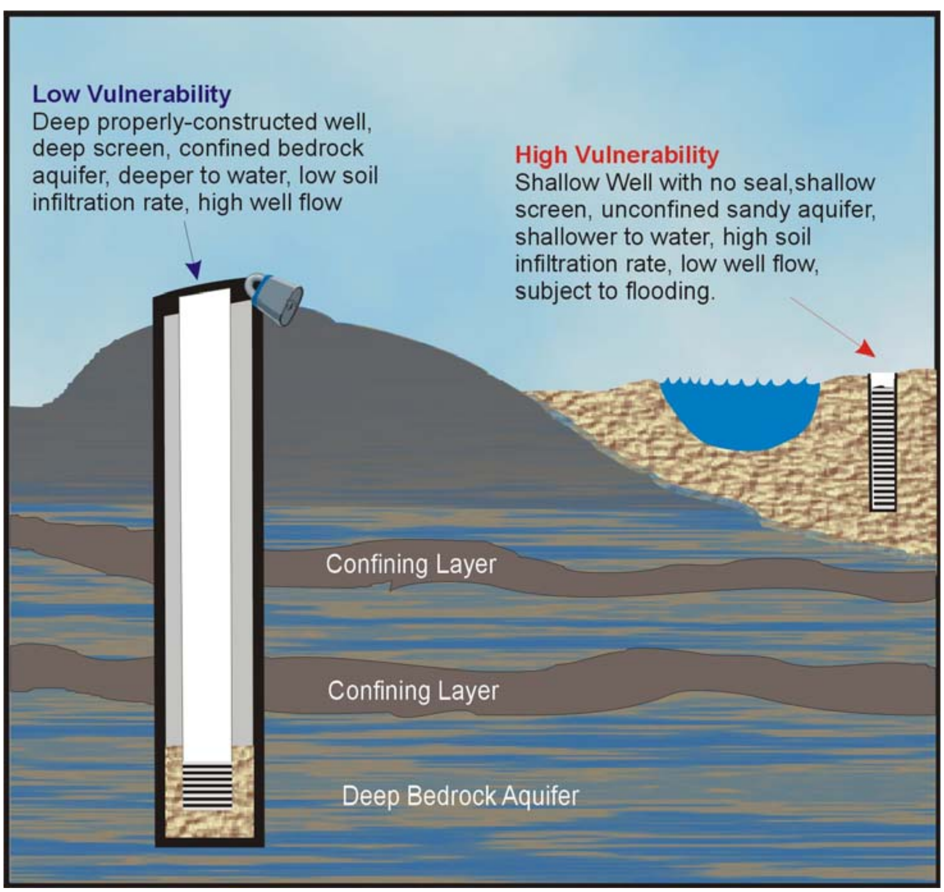


The variables Aquifer Sensitivity, Depth of Water Source, Water Source Flow, and First Draw act together to affect the ability of the physical setting within a source water area to buffer potential contaminant concentrations. The buffering capacity of the physical setting helps to mitigate potential contaminant concentrations and is affected largely by the type of aquifer, depth of well, and first draw associated with the water source, and, to a lesser extent, by the structural integrity of the system and flow rate of the water source. The buffering capacities of source water areas can be highly variable given the numerous possible combinations of how these factors act together with one another.

Aquifer sensitivity is derived from an evaluation of selected characteristics of the aquifer from which the water source originates, including: 1) depth to first water (contaminants normally migrate laterally once they reach the first water bearing zone), 2) soil infiltration rate (higher infiltration rates allow contaminants to migrate downward to impact the aquifer faster), 3) assigned aquifer (primarily based on type and permeability of the aquifer), and 4) whether the aquifer is confined (confined aquifers generally are more protected from contaminant impacts than unconfined aquifers).

Depth of the water source and first draw are evaluated based on the water source's construction details. Water source flow is derived from the average permitted pumping/flow rate of the source. Finally, the variable Structural Integrity of System examines the structural soundness and maintenance of the intake structure, and whether the water system has an emergency plan is in place to address possible disruption of the water supply operation. A higher level of intake integrity will reduce the likelihood of potential contaminants entering the water supply.

In general, the shallower the intake, first draw, aquifer and depth to first water, the lower the flow rate, and the poorer the structural integrity characteristics, the greater the likelihood that the water source would have a high Physical Setting Vulnerability score. Conversely, the deeper the intake, first draw, aquifer and depth to first water, the higher the flow rate, and the better the structural integrity characteristics, the greater the likelihood that the water source would have a low Physical Setting Vulnerability score. The following figure illustrates a comparison of a highly vulnerable physical setting to a less vulnerable physical setting.

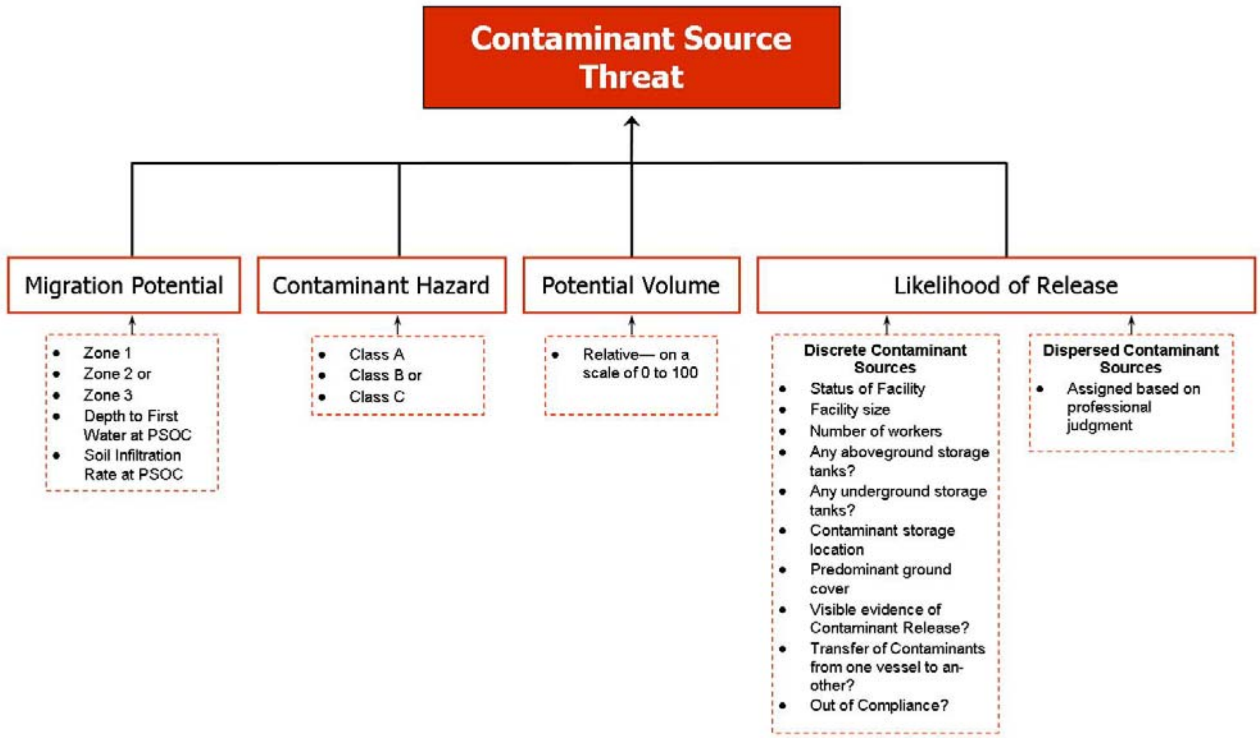


Contaminant Source Threat

The second component of the susceptibility analysis model involves an examination of the contaminant threat that a potential contaminant source (discrete or dispersed) poses to the water source. The greater the contaminant source threat, the more susceptible a water supply will be to potential contamination.

Determining the contaminant source threat involves examining the:

1) **Potential for contaminants to migrate** from the contaminant source to the intake in the event of a release;
2) **Contaminant hazard** posed by the contaminant source;
3) **Volume** of contaminants in use or storage at the contaminant source; and
4) **Likelihood that contaminants might be released** from the contaminant source.



Migration Potential

The migration potential generally has the greatest influence on whether a contaminant source could provide contaminants in amounts sufficient for the source water to become contaminated at concentrations that may pose a health concern to consumers of the water. Shorter migration paths and times of travel for contaminants mean less chance for dilution or degradation of the contaminant before it reaches the intake. The proximity of the potential contaminant source to the intake, as well as the depth to first water at the contaminant source site (contaminants normally migrate laterally once they reach the first water bearing zone, therefore increasing the migration path) and the soil infiltration rate at the contaminant source site (higher infiltration rates allow contaminants to migrate downward to impact the aquifer faster) determines both the relative migration path and time that a contaminant must travel to enter the source water and then flow to the intake.

The proximity of a potential contaminant source to the intake was evaluated using Geographic Information System (GIS) technology to determine its location relative to three “sensitivity zones” defined as:

1) **Zone 1** was a 500-foot radius around the water source intake.
2) **Zone 2** was defined by estimating the distance it takes a parcel of water to travel to the water source intake over a two-year time period. In cases where this zone could not be determined through analytic calculations, Zone 2 was defined as a 1.5-mile radius around the intake.
3) **Zone 3** was defined by estimating the distance it takes a parcel of water to travel to the water source intake over a five-year time period. In cases where this zone could not be determined through analytic calculations, Zone 3 was defined as a 2.5-mile radius around the intake.

The depth to first water at the contaminant source site and the soil infiltration rate at the contaminant source site also were evaluated using GIS technology. Statewide GIS map coverages of depth to first water and soil infiltration rates were used to generate input data for these variables for most of the contaminant source sites.

Contaminant Hazard

The contaminant hazard is an indication of the potential human health danger posed by contaminants likely or known to be present at the contaminant source. Default values were assigned for the various discrete and dispersed contaminant sources based on the professional judgment of the Water Quality Control Division and its contractors. Each contaminant source was assigned an overall contaminant hazard class rating of A, B or C:

- Class A contaminants include primary drinking water standard contaminants that pose the most serious and immediate (i.e., acute) health threats or are classified as potential cancer-causing agents.
- Class B contaminants include the remainder of the primary drinking water standard contaminants that pose longer-term (i.e., chronic) health threats.
- Class C contaminants include the secondary drinking water standard contaminants that do not have serious health threats, but cause “nuisance” problems like bad taste or odor.

Potential Volume

The volume of contaminants at the contaminant source is important in evaluating whether the source water could become contaminated at concentrations that may pose a health concern to consumers of the water in the event these contaminants are released to the source water. Large volumes of contaminants at a specific location pose a greater threat than small volumes.

For discrete contaminant sources, information was available from a limited number of the databases to evaluate the volume of contaminants at particular facilities. Where this information was unavailable, the Water Quality Control Division and its contractors used professional judgment to assign a default value for volume based on the type of discrete contaminant source.

For dispersed contaminant sources, the volume of contaminants was estimated by either the percent coverage (land uses) or the relative density (septic systems, oil and gas wells, and road miles) of the particular dispersed contaminant source within the various sensitivity zones (*see Migration Potential section for description*) identified for the source water assessment area.

Likelihood of Release

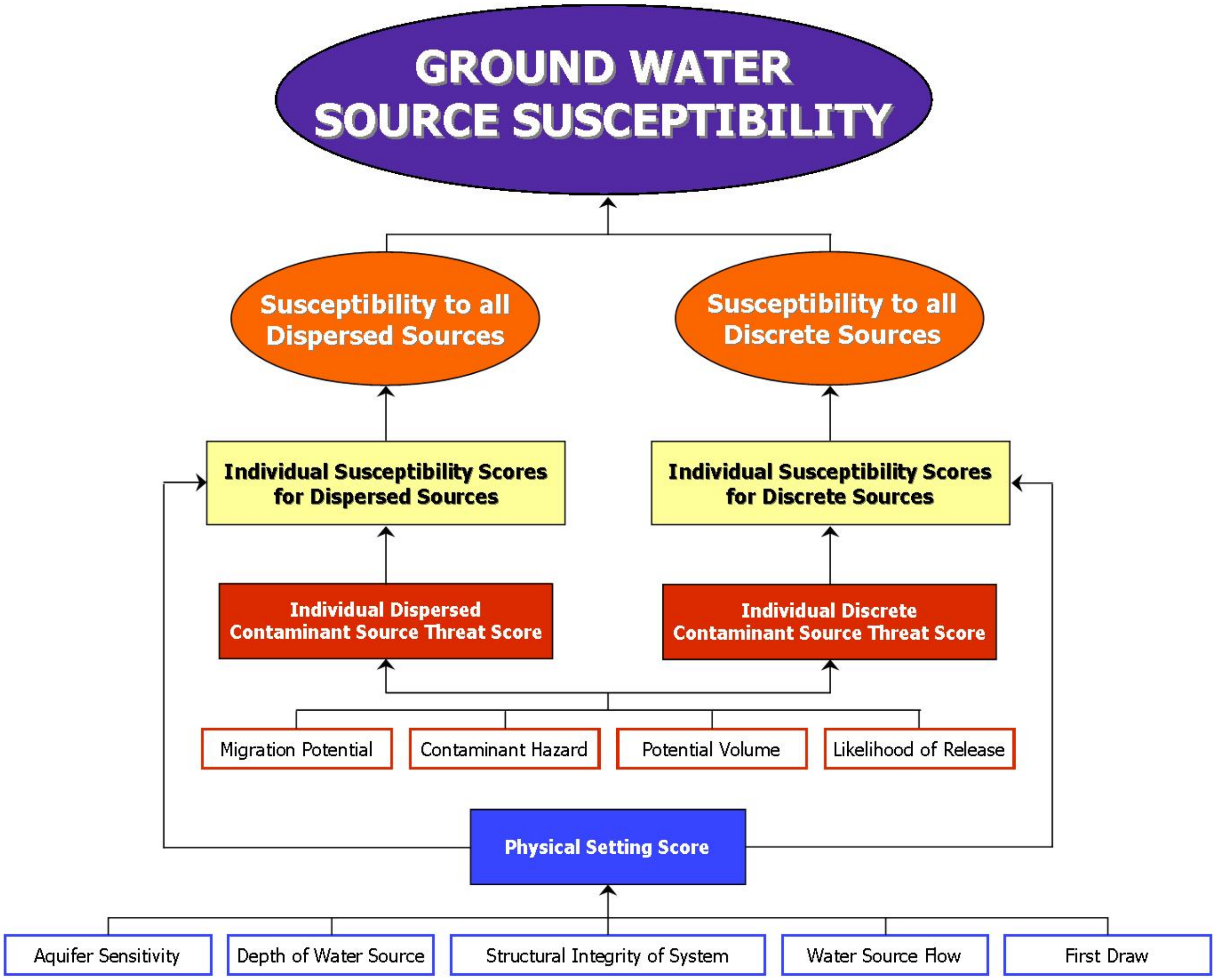
The more likely that a potential source of contamination is to release contaminants, the greater the contaminant threat posed. The regulatory compliance history for regulated facilities and operational practices for handling, storage, and use of contaminants were utilized where available to evaluate the likelihood of release.

For discrete contaminant locations, the likelihood of release variables that were evaluated include: 1) active vs. inactive facility; 2) size (area) of the facility; 3) number of workers; 4) presence of above ground storage tanks or drums; 5) presence of underground storage tanks; 6) location of contaminant storage (inside or outside); 7) predominant ground cover at the facility (mostly paved vs. mostly unpaved); 8) visible evidence of release; 9) transfer of contaminants from one vessel to another; and 10) regulatory compliance status.

For dispersed contaminant locations, the Water Quality Control Division and its contractors used professional judgment to assign a relative value for likelihood of release based on the type of dispersed contaminant source.

Methodology for Estimating Potential Susceptibility

The Water Quality Control Division and its contractors designed an automated susceptibility analysis model to evaluate the susceptibility of each water source to contamination and to summarize the results in a report. The process for estimating susceptibility involves a matrix scoring system for the independent and dependent variables in the susceptibility analysis model. Independent variables are the building blocks of the model and their characteristics are independent of any other factor. Independent variables can contribute directly or indirectly to overlying dependent factors. Independent variables require actual or default data to initiate the scoring process. Dependent variables are variables whose characteristics are dependent on the characteristics of other variables. Dependent variables also can contribute directly or indirectly to other dependent factors. As a result, dependent variables indirectly rely on actual or default data. These independent and dependent variables are arranged in progressive levels of importance in the model. These levels of importance are reflected in the following figure showing the primary model components.



Deriving Scores for Independent Variables

In this scoring system, scores are derived initially for the various independent variables in the model based on actual and/or default data associated with each variable. Independent variables shown in the figure above include Depth of Water Source, Water Source Flow, First Draw, Contaminant Hazard and Potential Volume. This figure does not reflect all of the independent variables in the model. Several other independent variables are associated with the lower-level dependent variables but are not shown in the figure above. Examples of contaminant source threat independent variables were provided in the flow chart figure previously presented in the discussion on Contaminant Source Threat.

Scores for most independent variables are derived using look-up tables. A look-up table assigns a derived score based on a comparison of the actual or default data value with a range of probable data values for the independent variable. In the event there is no actual data value, the derived score is based on the assigned default value for that variable. An example of a look-up table for the independent variable Depth of Water Source is presented below. For instance, a water source with a depth of 270 feet would receive a derived score of 50 since the actual data value falls in the range of greater than 250 feet, but less than or equal to 350 feet.

Depth of Water Source (feet)	Derived Factor Score
> 750	10
> 600 but < or = 750	20
> 450 but < or = 600	30
> 350 but < or = 450	40
> 250 but < or = 350	50
> 150 but < or = 250	60
> 50 but < or = 150	70
> 10 but < or = 50	80
> 5 but < or = 10	90
< or = 5	100
Default = 380 feet	***40***

In a few cases, scores for independent variables are derived by assigning default scores directly to the independent variable. This case usually applies where actual data did not exist for the variable. As a result, best professional judgment was used in assigning these default scores directly to the independent variable.

Deriving Scores for Dependent Variables

Once scores have been derived for the independent variables, derived scores are generated for the various lower-level and higher-level dependent variables. Lower-level dependent variables presented in the previous figure showing the model components include Aquifer Sensitivity, Structural Integrity of System, Migration Potential, and Likelihood of Release. Progressively higher-level dependent variables in the model include Physical Setting Vulnerability, Individual Dispersed Contaminant Source Threat, Individual Discrete Contaminant Source Threat, Individual Susceptibility to Dispersed Contaminant Sources, Individual Susceptibility to Discrete Contaminant Sources, Susceptibility to All Dispersed Contaminant Sources and Susceptibility to All Discrete Contaminant Sources. The highest-level dependent variable is Ground Water Source Susceptibility.

Based on its relative importance, the derived score for each independent variable associated with an overlying dependent variable is weighted relative to the other independent variable scores by multiplying the derived score by a pre-determined weight or percentage. This results in weighted scores that are percentages of the previously derived independent variable scores. The weighted scores of each independent variable are summed to produce the derived score of the overlying dependent variable. For instance, the derived score for the lower-level dependent variable Migration Potential for a discrete contaminant source is calculated from the underlying independent variables Zone 1, 2 or 3 at Contaminant Source, Depth to First Water at Contaminant Source, and Soil Infiltration Rate at Contaminant Source in the following manner:

	Migration Potential Variables (Discrete Contaminant Source)			
	Zone 1, 2 or 3 at Contaminant Source	Depth of First Water at Contaminant Source	Soil Infiltration Rate at Contaminant Source	**Derived Migration Potential Score**
Derived Score	50	70	60	---
x Weight	0.60	0.20	0.20	---
= Weighted Score	30	14	12	**56**

Scores for higher-level dependent variables that may be composed of both independent and lower-level dependent variables are derived in a similar fashion. *In these cases, the derived scores for the independent factors and the lower-level dependent factors are weighted relative to each other, based on their relative importance to one another.* In the case of a higher-level dependent variable, it is not uncommon for a contributing lower-level dependent variable to be weighted lower than a contributing independent variable, and then have this condition reversed for another higher-level dependent factor. This is demonstrated in the example calculation tables below for the Physical Setting Vulnerability variable and the Discrete Contaminant Source Threat variable.

Again, this calculation results in weighted scores that are percentages of the derived scores. The weighted scores of each independent variable and each lower-level dependent variable are summed to produce the derived score of the overlying, higher-level dependent variable. Examples of this type of calculation for the next higher level of dependent factors in the model (see previous figure showing the model components) are included below for the Physical Setting Vulnerability variable and the Discrete Contaminant Source Threat variable.

Physical Setting Vulnerability Score

The derived score for the higher-level dependent variable Physical Setting Vulnerability is calculated from the underlying independent variables Aquifer Sensitivity, Depth of Water Source, First Draw and Water Source Flow, and the underlying lower-level dependent variable Structural Integrity of System in the following manner:

	PHYSICAL SETTING VULNERABILITY VARIABLES					
	Aquifer Sensitivity	Depth of Water Source	First Draw	Water Source Flow	Structural Integrity of System	**Derived Physical Setting Vulnerability Score**
Derived Score	50	60	60	70	50	---
x Weight	0.30	0.25	0.25	0.10	0.10	---
= Weighted Score	15	15	15	7	5	**57**

The Physical Setting Vulnerability score calculation is made only once for each water source. In deriving the Physical Setting Vulnerability score, the lower-level dependent variable Structural Integrity of System was weighted lower than the associated independent variables since it was deemed to be less important than the other variables in determining the Physical Setting Vulnerability for the water source.

Contaminant Source Threat Scores

The derived score for the higher-level dependent variable Individual Discrete Contaminant Source Threat is generated in a similar fashion by summing the weighted scores for the underlying independent variables Contaminant Hazard and Potential Volume, and the underlying lower-level dependent variables Migration Potential and Likelihood of Release. An example of how the score is calculated for the higher-level dependent variable Individual Discrete Contaminant Source Threat is presented in the table below.

	DISCRETE CONTAMINANT SOURCE THREAT VARIABLES				
	Migration Potential	Contaminant Hazard	Potential Volume	Likelihood of Release	**Derived Contaminant Threat Score**
Derived Score	56	90	40	40	---
x Weight	0.40	0.25	0.25	0.10	---
= Weighted Score	22.4	22.5	10	4	**58.9**

This calculation is repeated for all other discrete contaminant sources inventoried within the source water area. In deriving the Individual Discrete Contaminant Source Threat score, the lower-level dependent variable Migration Potential was weighted higher than the other associated variables since it was deemed to be more important than the other variables. Conversely, the lower-level dependent variable Likelihood of Release was weighted lower than the other associated variables since it was deemed to be less important than the other variables.

Deriving the score for the higher-level dependent variable Individual Dispersed Contaminant Source Threat is similar to, yet slightly more complicated than deriving the score for a discrete contaminant source. The Contaminant Source Threat calculation for dispersed contaminant sources is slightly different from the Contaminant Source Threat calculation for discrete contaminant sources. In the case of dispersed contaminant sources, the variables Migration Potential, Contaminant Hazard and Likelihood of Release form the basis for the calculation, and the variable Potential Volume is now used as a multiplier in the calculation. For the dispersed land uses of concern, the percentage of each land use that occurs in a particular sensitivity zone is used to approximate the relative volume of contaminants that one might associate with the land use. Similarly, in the case of the other dispersed contaminant sources of concern (i.e., septic systems, oil and gas wells, and total road miles) the relative density of these contaminant sources in a particular sensitivity zone is used to approximate the associated volume of contaminants that one might associate with these other dispersed contaminant sources.

The calculation starts by deriving Contaminant Source Threat scores for each sensitivity zone in which the dispersed contaminant source occurs. The calculation involves summing the weighted scores for the underlying independent variable Contaminant Hazard, and the underlying lower-level dependent variables Migration Potential and Likelihood of Release. The sum of these weighted scores is then multiplied by the Potential Volume value to obtain the Contaminant Source Threat score for that sensitivity zone. An example of how the Contaminant Source Threat score is calculated for a dispersed land use of concern occurring in a given sensitivity zone is presented in the table below. In the example, approximately 65% of the sensitivity zone was covered by the particular land use, which is reflected by the multiplier value of 0.65 for Potential Volume.

	DISPERSED CONTAMINANT SOURCE THREAT VARIABLES				
	Migration Potential	Contaminant Hazard	Likelihood of Release	Potential Volume	**Derived Contaminant Threat Score**
Derived Score	80	90	50	---	---
x Weight	0.50	0.25	0.25	---	---
= Weighted Score	40.0	22.5	12.5	0.65	**48.8**

The Contaminant Source Threat scores for each sensitivity zone in which the dispersed contaminant source occurs are calculated in a similar fashion. In turn, the Contaminant Source Threat scores for each sensitivity zone are summed and divided by the total number of sensitivity zones present within the source water assessment area to produce an individual Contaminant Source Threat score for the dispersed contaminant source. This calculation essentially averages the contaminant threat over the whole source water assessment area. This calculation is repeated for all other dispersed contaminant sources inventoried within the source water area.

An example of how these contaminant threat scores are averaged over the source water assessment area for a dispersed land use is presented in the table below. In the example, three sensitivity zones were assumed to be present (Zone 1, Zone 2, and Zone 3) within the source water assessment area for the ground water source, and the dispersed land use is assumed to cover a certain percentage of the total area of each sensitivity zone (see Potential Volume values in the table).

	DISPERSED CONTAMINANT SOURCE THREAT WEIGHTED VARIABLE SCORES				
Sensitivity Zone	Migration Potential	Contaminant Hazard	Likelihood of Release	Potential Volume	**Contaminant Threat Score for Zone**
Zone 1	40	22.5	12.5	0.65	48.8
Zone 2	28	22.5	12.5	0.41	25.8
Zone 3	16	22.5	12.5	0.19	9.7
Individual Contaminant Threat Score	---	---	---	---	**28.1**

In the example above, if the dispersed contaminant source had only occurred in two of the three sensitivity zones, the calculation still would divide the summed Contaminant Source Threat scores for the two sensitivity zones by the total number of sensitivity zones present in the source water assessment area. Since the calculation averages the potential contaminant threat over the whole source water assessment area, the relative Contaminant Source Threat contribution from each sensitivity zone is factored into the averaging calculation, irregardless of whether or not a dispersed contaminant source occurs in a given sensitivity zone.

Individual Susceptibility Scores for Water Source

The scoring system proceeds to the next higher level (see previous figure showing the model components) by deriving the susceptibility of the water source to individual contaminant sources (discrete and/or dispersed). The score for the next higher-level dependent variable Individual Susceptibility to Discrete Contaminant Sources is generated in a similar fashion by summing the water source's weighted Physical Setting Vulnerability score and the discrete contaminant source's weighted Contaminant Source Threat score. This calculation is repeated for all other discrete contaminant sources inventoried within the source water area. An example of how the individual susceptibility score for a discrete contaminant source is calculated is presented below.

	INDIVIDUAL SUSCEPTIBILITY VARIABLES		
	Physical Setting Vulnerability	Discrete Contaminant Source Threat	**Susceptibility Score for Discrete Source**
Derived Score	57	58.9	---
x Weight	0.60	0.40	---
= Weighted Score	34.2	23.56	**57.76**

With respect to the companion higher-level dependent variable Individual Susceptibility to Dispersed Contaminant Sources, the score is generated in the same manner by summing the water source's weighted Physical Setting Vulnerability score and the dispersed contaminant source's weighted Contaminant Source Threat score. This calculation is repeated for all other dispersed contaminant sources inventoried within the source water area.

In either case, the susceptibility of the water source to contamination from individual discrete or individual dispersed contaminant sources inventoried within its source water area can be evaluated in this manner.

Total Susceptibility Score for Water Source

The scoring system proceeds to the next higher level (see previous figure showing the model components) by deriving the scores for the next higher level of dependent variables: Susceptibility to All Dispersed Contaminant Sources and Susceptibility to All Discrete Contaminant Sources. These variables respectively represent the cumulative susceptibility risk posed by all of the dispersed contaminant sources and all of the discrete contaminant sources that are inventoried within a source water assessment area.

The first step in determining the cumulative susceptibility scores involves computing standardized scores for the cumulative individual susceptibility scores for the dispersed and discrete contaminant sources inventoried in each source water assessment area. Standardized scores provide the basis for comparing the cumulative susceptibilities of similar type water sources. Standardized scores for dispersed contaminant sources are derived by summing the individual susceptibility scores for the dispersed contaminant sources inventoried in each source water assessment area. Standardized scores for discrete contaminant sources are derived by summing the individual susceptibility scores for the discrete contaminant sources inventoried in each source water assessment area and dividing this total by the area of the source water assessment area.

The next step in determining the cumulative susceptibility scores involves converting the standardized scores to percentile ranking scores. Percentile ranking scores allow one to be able to statistically compare the standardized cumulative susceptibility scores for similar types of water sources to determine their relative position within both populations of standardized cumulative susceptibility scores. The standardized scores are converted to percentile ranking scores through standard statistical analysis using z-scores. The derived percentile ranking scores are then used to represent the Susceptibility to All Dispersed Contaminant Sources score and the Susceptibility to All Discrete Contaminant Sources score for each water source.

The scoring system proceeds to the highest level by deriving the score for the highest-level dependent variable, Ground Water Source Susceptibility (i.e., Total Susceptibility).   As with previous dependent variables, the weighted scores for the variable Susceptibility to All Dispersed Contaminant Sources and the variable Susceptibility to All Discrete Contaminant Sources for each water source are summed to arrive at a total susceptibility score for each water source. A water source's total potential susceptibility to contamination from all discrete and/or all dispersed contaminant sources inventoried within its source water area can be evaluated in this manner. An example of how the total susceptibility score of a water source is calculated from the Susceptibility to All Dispersed Contaminant Sources score and the Susceptibility to All Discrete Contaminant Sources score is presented below.

	TOTAL SUSCEPTIBILITY VARIABLES		
	Susceptibility to all Discrete Contaminant Sources	Susceptibility to all Dispersed Contaminant Sources	**Total Susceptibility Score for Water Source**
Derived Score (percentile ranking score)	48.2	33.8	---
x Weight	0.50	0.50	---
= Weighted Score	24.1	16.9	**41.0**

The physical setting vulnerability, individual susceptibility and total susceptibility scores are assigned a qualitative rating of Low, Moderately Low, Moderate, Moderately High, or High to provide the reader a general sense of the potential risk to a water source. The higher the physical setting vulnerability rating and/or the susceptibility rating, the greater the risk for potential contamination of the water source.

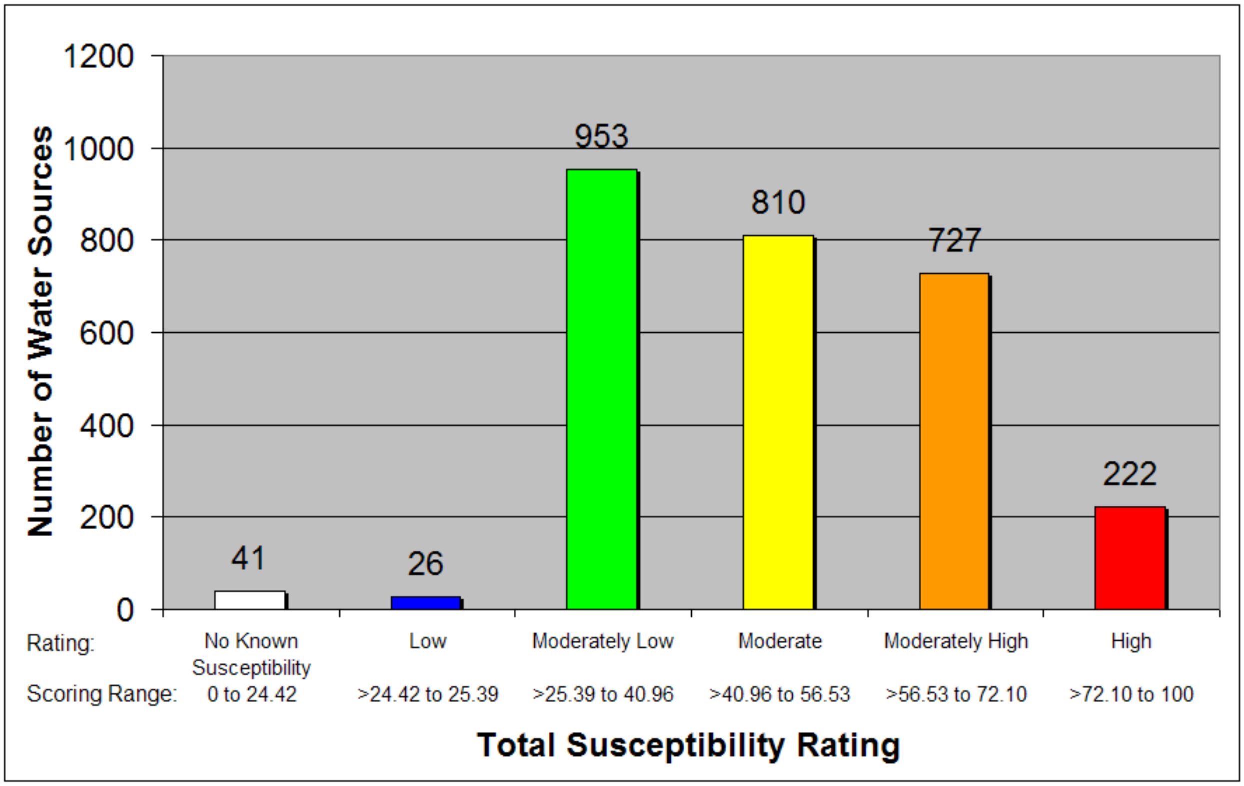
These qualitative rating categories are based on a statistical evaluation of the statewide population of physical setting vulnerability scores, individual susceptibility scores and total susceptibility scores for similar types of water sources.   This evaluation involves determining the average [also referred to as the mean (μ)] and the standard deviation (σ) of each population of scores. The standard deviation (σ) is a measure of how all of the scores in the population are centered around the mean of the population. This measure provides an indication of whether there is a narrow or wide range of variability in the scores, as indicated by a lower or higher standard deviation value, respectively. The upper and lower bounds for the three intermediate qualitative rating categories were set based on a pre-determined number of standard deviations on either side of the population mean, μ.

For the statewide populations of physical setting vulnerability scores, individual susceptibility scores and total susceptibility scores for similar types of water sources, the scoring range for the qualitative rating category of Moderate was set from $-0.5\ \sigma$ to $+0.5\ \sigma$ around the mean of the populations (i.e., the scoring range has a width of one standard deviation). Similarly, the scoring range for the qualitative rating category of Moderately Low was set at less than –0.5 σ to -1.5 σ around the mean, and the scoring range for the qualitative rating category of Moderately High was set at greater than +0.5 σ to +1.5 σ around the mean. Finally, the scoring range for the qualitative rating category of Low was set at any scores less than –1.5 σ around the mean, and the scoring range for the qualitative rating category of High was set at any scores greater than +1.5 σ around the mean.

The table below shows a hypothetical example of how the scoring ranges for each of the qualitative rating categories might be set for the variables physical setting vulnerability, individual susceptibility or total susceptibility. For this example, the population mean (μ) is 50 and the standard deviation (σ) is 16. Therefore, the lower bound of the scoring range that determines a Moderate rating would be calculated by taking the mean value (50) and subtracting 0.5 σ (or -0.5 x 16) from it, resulting in a value of 42 (i.e., 50 – 8). Similarly, the upper bound of the scoring range that determines a Moderate rating would be calculated by taking the mean value (50) and adding 0.5 σ (or +0.5 x 16) to it, resulting in a value of 58 (i.e., 50 + 8). Similar calculations would be used to set the upper and lower bounds of the scoring ranges for the other intermediate qualitative rating categories. For the variables physical setting vulnerability, individual susceptibility or total susceptibility, the population mean and standard deviation will be different from one variable to the next. Therefore, the scoring ranges for each qualitative rating category will be different from one variable to the next.

Rating:	Low	Mod. Low	Moderate	Mod. High	High
Std. Dev. Range	< –1.5 σ	< – 0.5 σ to -1.5 σ	– 0.5 σ to +0.5 σ	> +0.5 σ to +1.5 σ	> +1.5 σ
Scoring Range	< 26	26 to < 42	42 to 58	> 58 to 74	> 74

The next figure presents an example of a statewide total susceptibility distribution plot for all ground water sources. A distribution plot like this allows a person to see how the total susceptibility rating of their water source(s) compared to the total susceptibility ratings of other ground water sources throughout the state. For example, using the figure below, if your ground water source had a total susceptibility rating of High, you would know the relative number of all ground water sources in the state that received a similar total susceptibility rating.



Qualitative ratings provide an easier means for understanding the relative susceptibility of a water source to individual or a collective number of contaminant sources. Ratings on the lower end of the rating spectrum indicate a lower level of risk for the water source to become contaminated. Ratings on the higher end of the rating spectrum indicate a higher risk for the water source to become contaminated.

In some limited cases, a water source may have a total susceptibility rating of No Known Susceptibility. This special rating reflects a condition where the assessment was unable to verify the presence of known discrete and dispersed contaminant sources within the source water assessment area, based on the available data used in the analysis. Similarly, there may be cases where discrete contaminant sources are present within a source water assessment area, but dispersed contaminant sources are not, and vice versa. *In any of these cases, it is important to be aware of the water source's Physical Setting Vulnerability rating. For example, a water source currently may not have any known discrete and/or dispersed contaminant sources. However, it may have a moderately high or high Physical Setting Vulnerability rating that could cause an increased susceptibility to contamination in the future if certain discrete and/or dispersed contaminant sources were located within its source water assessment area. This potential impact ultimately will depend on the degree of contaminant threat posed by the specific potential contaminant sources.*

REPORTING THE SOURCE WATER ASSESSMENT RESULTS

After the susceptibility analysis was completed, the assessment results were reported. The primary goal of the SWAP program is to make the public aware of the potential threats to their untreated drinking water sources. This document does NOT present the assessment results for a public water system. However, the SWAP assessment results for each public water system have been reported via two separate companion documents: 1) an Assessment Summary Report which is available to both the public water system and the general public, and 2) detailed report appendices of data values used in the assessment that have been made available only to the public water system.

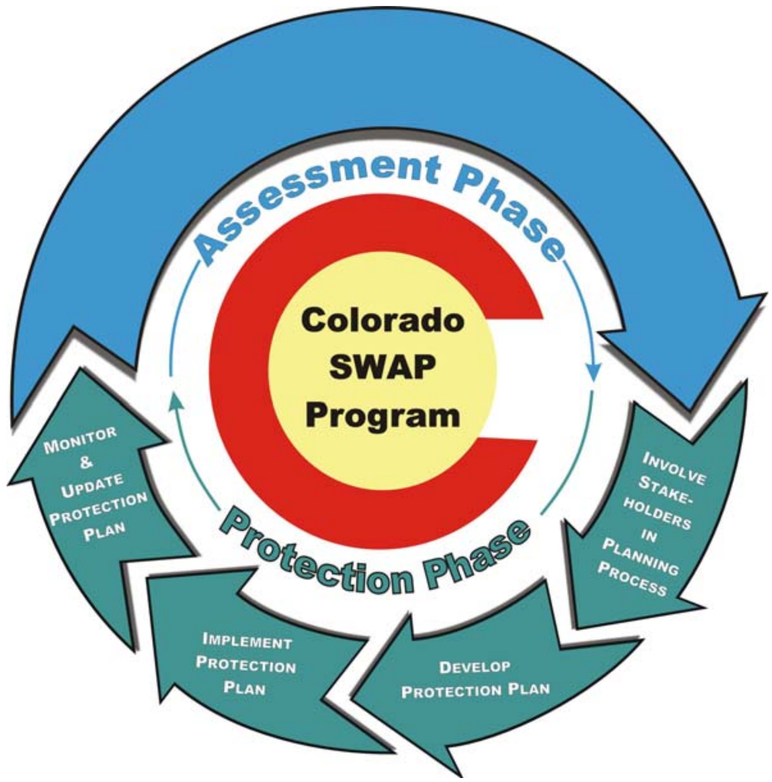
The source water assessment report provided to the public water system and to the general public is identical. The public should contact their public water system if they have any questions or concerns about the results of the source water assessment, or are interested in what protection measures the water system may be considering.

Community public water systems have a requirement to report the results of their source water assessment in their annual Consumer Confidence Report to their consumers. Consumer Confidence Reports are not required for non-community water systems. However, such water systems are encouraged to post a copy of their SWAP assessment report in their place of business.

SOURCE WATER PROTECTION PHASE

Public water systems and communities are encouraged to use this source water assessment information and voluntarily enter the protection phase of SWAP. In general, the protection phase may consist of:

1) Involving stakeholders in the planning process,
2) Developing a protection plan,
3) Implementing a protection plan, and
4) Monitoring and updating the protection plan.



The protection phase involves developing and continuously implementing a source water protection plan at the local level. Public water systems and communities interested in developing and implementing source water protection measures may be able to find limited financial assistance through the Colorado Department of Public Health and Environment.

Finally, there is no statutory requirement for any state or federal agency to enforce source water protection measures. It is up to the local interests to conduct the protection phase by developing, implementing and enforcing a source water protection plan.