METHODS FOR SEGMENTATION OF SOURCE-WATER PROTECTION AREAS AND SUSCEPTIBILITY ASSESSMENT TO CONTAMINATION FOR PUBLIC SURFACE-WATER SYSTEMS, AND THEIR APPLICATION TO AN INTAKE, AIKEN, SOUTH CAROLINA

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Abstract. Methods were determined for segmentation of source-water protection areas for South Carolina's surface-water intakes and for assessment of the relative susceptibility of these drinking-water intakes to potential contaminant sources as part of the South Carolina Source-Water Assessment Program. Flow velocities for South Carolina streams were compared with estimated velocities from an empirical method of estimating traveltime to select appropriate regression equations for calculating Piedmont and Coastal Plain stream velocities. These velocities were used to calculate 24-hour travel distances upstream from intakes on streams and upstream from the headwaters of reservoirs with intakes. The subwatersheds adjoining each 24-hour travel distance were delineated as the primary source-water protection area. Overland-flow and ground-water zones of concern were used to delineate three susceptibility zones in the source-water-protection area. Each potential contaminant source was assigned a low-, moderate-, or high-susceptibility ranking as determined by location in the susceptibility zones and associated potential contaminants. On the basis of the inventory of selected potential contaminant sources, the susceptibility determination indicated that the Aiken intake is susceptible to potential sources of volatile organic compounds, petroleum hydrocarbons, pesticides, and metals. The methods were recommended to the South Carolina Department of Health and Environmental Control for consideration as part of the South Carolina Source-Water Assessment Program.

INTRODUCTION

In response to the source-water provisions of the Safe Drinking Water Act Amendment of 1996, the U.S. Environmental Protection Agency (U.S. EPA) initiated the Source Water Assessment Program to focus attention on the susceptibility of public drinking-water supplies (U.S. Environmental Protection Agency, 1997). The U.S. EPA recommended the delineation of source-water protection areas (SWPA's) for all public drinking-water systems, the inventory of potential contaminant sources within the SWPA's, and an assessment of the susceptibility of drinking-water intakes to potential contaminant sources.

In 1998, the U.S. Geological Survey (USGS), in cooperation with the South Carolina Department of Health and Environmental Control (SCDHEC), determined methods to segment SWPA's for surface-water systems used as sources of drinking water and to assess the susceptibility of the drinking-water intake (referred to herein as intake) to potential contaminant sources. The SWPA for a surface-water system includes the entire drainage basin upstream from the intake to the hydrologic boundary of the drainage basin. Contaminants can enter a surface-water system by direct spills to streams and reservoirs, or indirectly by overland runoff and ground water derived from off-stream contaminant sources. The physical and chemical properties of a potential contaminant and the location of its source in a drainage basin determine the likely pathways and, hence, traveltime for the contaminant to reach the intake.

Three pilot-study intakes were chosen to determine source-water protection methods for surface-water drainage basins (fig. 1). These intakes include the Aiken intake on Shaw Creek (Coastal Plain stream example), the Belton-Honea Path intake on the Saluda River (Piedmont stream example), and the Greenwood intake on Lake Greenwood (reservoir example).

The purpose of this report is to document methods determined by the USGS to segment SWPA's for

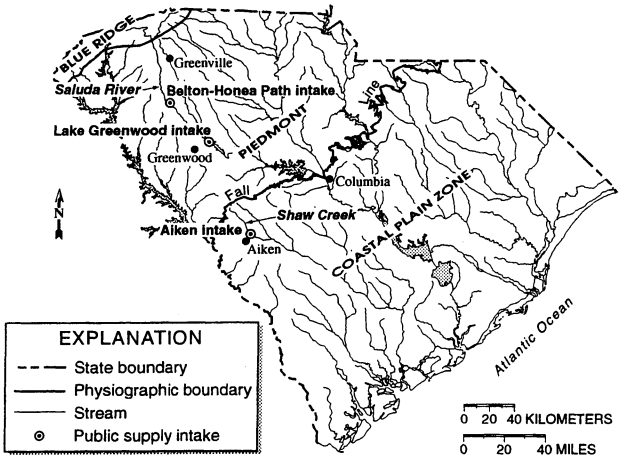

Figure 1. Location of South Carolina intakes.

streams and reservoirs in the Piedmont and Coastal Plain of South Carolina and for susceptibility assessment to contamination for public surface-water systems. As an example, a selective inventory of potential contaminant sources was used to assess the susceptibility of the Aiken intake on Shaw Creek.

SEGMENTATION AND SUSCEPTIBILITY ASSESSMENT METHODS

Methods for segmentation of a SWPA and susceptibility assessment of an intake include: (1) identification of empirical traveltime equations to estimate in-stream flow velocity; (2) use of empirically derived traveltimes to calculate in-stream flow velocities and 24-hour (hr) travel distances upstream from stream intakes and the headwaters of reservoirs with intakes; (3) use of 24-hr travel distances and subwatersheds to delineate primary and secondary SWPA's for stream and reservoir intakes; (4) delineation of overland-flow and ground-water zones of concern adjacent to the surface-water flow system; (5) delineation of susceptibility zones; and (6) determination of the susceptibility ranking of each potential contaminant source on the basis of location relative to susceptibility zones and associated potential contaminants.

Empirical in-stream traveltime methods (Jobson, 1996) provided guidance for predicting traveltimes in rivers and streams using readily attainable data. Equations including up to four variables were used to compute the mean flow velocity between two points. The use of these equations for streams in South Carolina was verified by hydrologic analysis of time-of-travel studies for South Carolina streams. Drainage area, slope, mean annual flow, and measured flow were used in the equation to calculate in-stream velocities for South Carolina Piedmont streams. Drainage area, mean annual flow, and measured flow were used in the equation to calculate in-stream velocities for South Carolina Coastal Plain streams. The streamflow velocities for high flow derived from these equations were used to determine a 24-hr travel distance upstream from the intake (fig. 2). Empirically derived velocities were used to calculate 24-hr travel distances that extend 21.9 kilometers upstream from the Aiken intake, 53.7 kilometers upstream from the Belton-Honea Path intake, and 56.5 kilometers upstream from the headwater of Lake Greenwood for the Greenwood intake.

SWPA's are divided into primary and secondary areas on the basis of the 24-hr travel distance. The primary SWPA is defined as all subwatersheds in the drainage basin that adjoin the area of the 24-hr travel distance. The secondary SWPA is defined as all

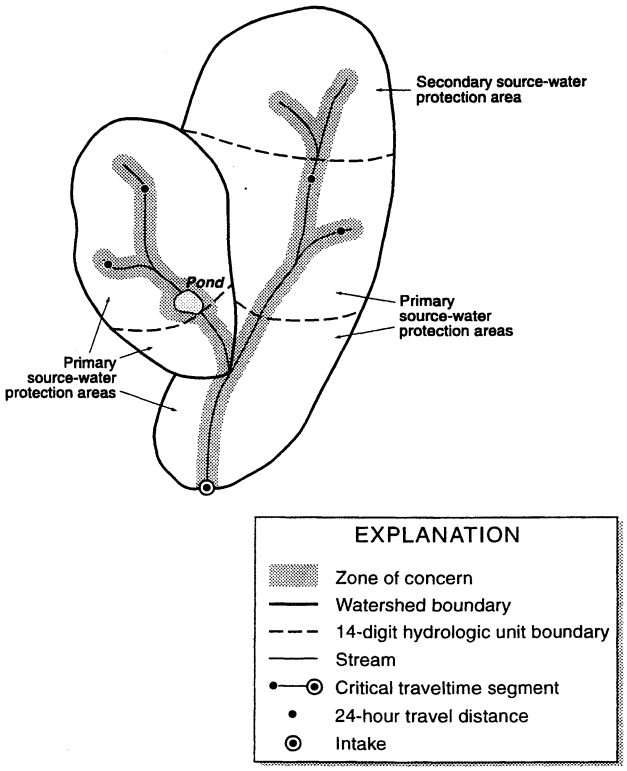

Figure 2. Generalized segmentation of source-water protection area, surface-water intake.

subwatersheds that are upstream of the primary SWPA. The effects of all upstream reservoirs are not included in determining the 24-hr travel distance for stream intakes. The entire surface area of a reservoir, the 24-hr travel distances upstream from the headwater of the reservoir, and all subwatersheds adjoining the reservoir and the 24-hr travel distances are included in the primary SWPA for a reservoir intake.

A width for an overland-flow zone of concern was computed using Natural Resources Conservation Service methods (U.S. Department of Agriculture, 1997a, b). Assuming forested conditions at a 50-percent slope, an additional 61 meters (m) adjacent to the surface-water system would be used to delineate the overland-flow zone of concern. An appropriate width for a ground-water zone of concern was determined using BIOSCREEN (Newell and others, 1996), a solute transport modeling code developed for the U.S. EPA to simulate the maximum contaminant plume lengths for dissolved gasoline and a halogenated organic solvent for a range of ground-water flow conditions and contaminant-specific properties. Based on ground-water modeling results, a ground-water zone of concern with a width of 457 m would identify most of the potential sources of petroleum hydrocarbons and volatile organic compounds that represent the greatest threat to a surface-water system in South Carolina. The overland-flow and ground-water zones of concern are applied to the edge of the surface-water flow system, which includes the main stream, tributaries, impoundments, and the geomorphic flood plain, if present (fig. 3).

The overland-flow and ground-water zones of concern are used to define three susceptibility zones adjacent to the surface-water flow system (fig. 3). Susceptibility zone 1 includes the surface-water flow system, and the area inside the 61-m overland-flow zone of concern. Zone 2 is the area outside zone 1 and inside the 457-m ground-water zone of concern. Zone 3 is the area outside zone 2, but inside the hydrologic boundaries of the drainage basin. Any potential contaminant source located within these zones will be identified without regard to their primary mode of travel.

Each potential contaminant source is assigned a low-, moderate-, or high-susceptibility ranking as determined by location in the susceptibility zones and associated contaminants (table 1). Seven general categories of contaminants are considered: volatile organic

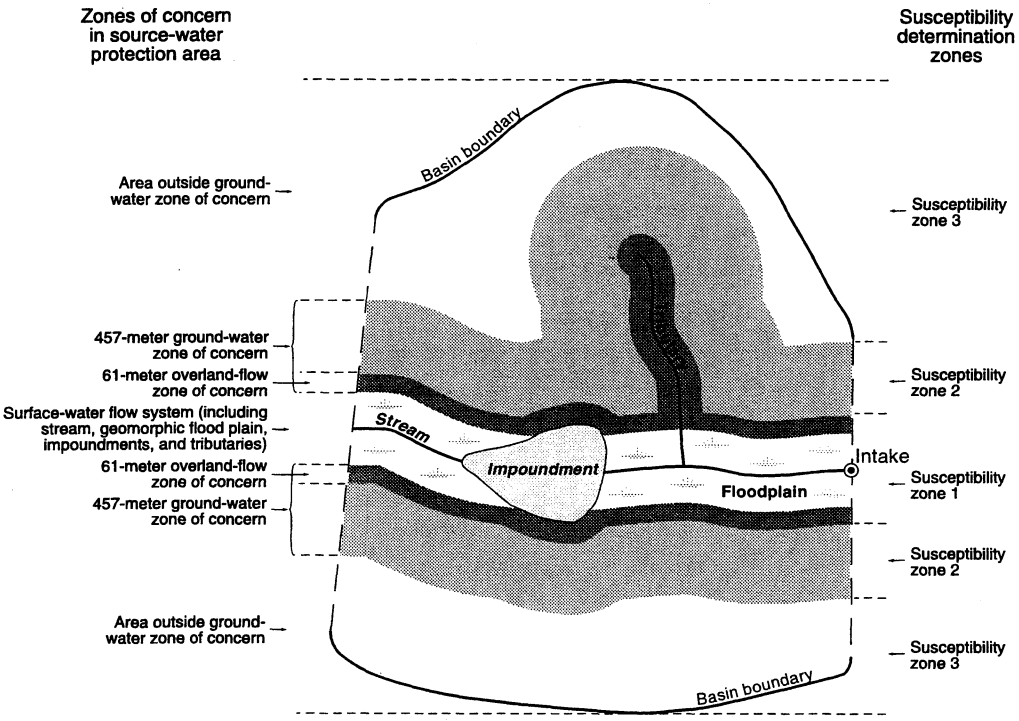

Figure 3. Zonation of source-water protection area for susceptibility assessment.

compounds (halogenated solvents), radionuclides, undetermined, petroleum hydrocarbons, pesticides, metals, and pathogens. Potential sources for all seven categories of contaminants are assigned high-susceptibility rankings for zone 1 in the primary SWPA's. Potential sources of volatile organic compounds, radionuclides, and undetermined contaminants are assigned high- and moderate-susceptibility rankings in zones 2 and 3, respectively. Potential sources of petroleum hydrocarbons, pesticides, metals, and pathogens are assigned moderate- and low-susceptibility rankings in zones 2 and 3, respectively. Potential contaminant sources, that would be assigned high- and moderate- susceptibility rankings in the primary SWPA's, are assigned moderate- and low-susceptibility rankings, respectively, in the secondary SWPA's.

SUSCEPTIBILITY ASSESSMENT OF THE AIKEN INTAKE

An inventory of selected potential contaminant sources was completed for the Aiken SWPA by the Earth Sciences Resource Institute at the University of South Carolina (Jim Rine, Earth Sciences Resource Institute, oral commun., July 1998). The inventory included the location of 54 selected potential sources (fig. 4) and a list of potential contaminants for each source compiled from electronic databases, maps, and field trips through the SWPA. The data from this inventory were used by the USGS to determine the susceptibility to contamination for the Aiken intake.

Volatile organic compounds are inventoried at 39 potential sources in the Aiken SWPA. The 16 potential sources in zone 2 and the 23 potential sources in zone 3 are assigned high- and moderate- susceptibility rankings, respectively.

The undetermined contaminant category are assigned to three of the inventoried potential sources in the Aiken SWPA because information about specific contaminants are not inventoried at these sites. Two of the potential sources are located in zone 2 and are assigned high-susceptibility rankings for the undetermined contaminant category. A potential source is located in zone 3 and is assigned a moderate-susceptibility ranking. All road and railroad bridges over Shaw Creek and its tributaries are located in zone 1 and are assigned high-susceptibility rankings for undetermined contaminants.

Petroleum hydrocarbons are listed as a potential contaminant at 42 potential sources. One of the potential sources is located in zone 1 and is assigned a

Table 1. Susceptibility assessment matrix for South Carolina surface-water intakes.

General contaminant categories	Susceptibility zone 1	Susceptibility zone 2	Susceptibility zone 3
Primary Source-Water Protection Area			
Volatile organic compounds	High	High	Moderate
Radionuclides	High	High	Moderate
Undetermined	High	High	Moderate
Petroleum hydrocarbons (BTEX)	High	Moderate	Low
Pesticides	High	Moderate	Low
Metals	High	Moderate	Low
Pathogens	High	Moderate	Low
Secondary Source-Water Protection Area			
Volatile organic compounds	Moderate	Moderate	Low
Radionuclides	Moderate	Moderate	Low
Undetermined	Moderate	Moderate	Low
Petroleum hydrocarbons (BTEX)	Moderate	Low	Low
Pesticides	Moderate	Low	Low
Metals	Moderate	Low	Low
Pathogens	Moderate	Low	Low

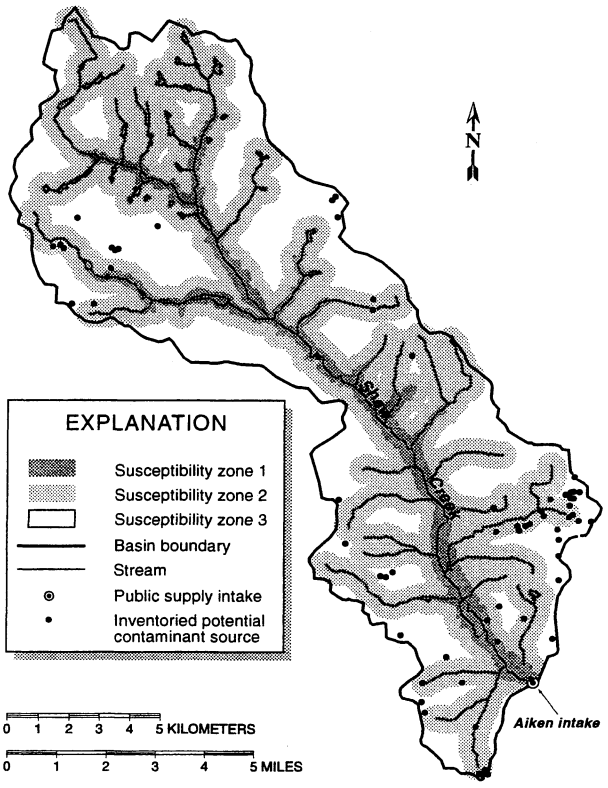

Figure 4. Potential contaminant sources plotted relative to susceptibility zones for Aiken source-water protection area.

high-susceptibility ranking. The 17 potential sources in zone 2 and the 24 potential sources in zone 3 are assigned moderate- and low-susceptibility rankings, respectively, for petroleum hydrocarbons. Petroleum pipelines also crossed the stream system in zone 1 and are assigned high-susceptibility rankings for petroleum hydrocarbons.

Pesticides are listed as potential contaminants at seven potential sources. The two potential sources in zone 2 and the five potential sources in zone 3 are assigned moderate- and low- susceptibility rankings, respectively. Several row-crop farms are located in the SWPA, but only one is included in the selected inventory for this assessment example.

Metals are listed as potential contaminants at 15 potential sources. Two of the potential sources are located in zone 1 and are assigned high- susceptibility rankings. The nine potential sources in zone 2 and the four potential sources in zone 3 are assigned moderate- and low- susceptibility rankings, respectively, for metals.

Radionuclides and pathogens are not identified as potential contaminants for any of the selected potential sources in the inventory for the Aiken SWPA. However, radionuclides and pathogens could be included at potential sources where the potential contaminants are undetermined.

SUMMARY AND CONCLUSIONS

These described methods for segmentation of source-water protection areas for South Carolina's surface-water intakes and for assessment of the relative susceptibility of these drinking-water intakes to potential contaminant sources are recommended to the South Carolina Department of Health and Environmental Control for consideration as part of the South Carolina Source-Water Assessment Program. The location of selected potential sources in the susceptibility zones and the list of potential contaminants at each source indicated that the Aiken intake on Shaw Creek is susceptible to halogenated organic compounds, petroleum hydrocarbons, pesticides, and metals. The results of a susceptibility assessment can be used by the public, the intake operator, and the South Carolina Department of Health and Environmental Control to: (1) identify the relative threat posed to an intake by each existing potential source; (2) evaluate existing water-quality monitoring efforts for raw source water; (3) prioritize the potential sources for implementation of best-management practices or abatement efforts; (4) plan emergency responses to contaminant releases; and (5) manage future development practices in the source-water protection area.

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