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COMPARATIVE ANALYSES OF LOCAL WELLHEAD PROTECTION PROGRAMS*

J. E. CONNICK

LARRY W. CANTER

University of Oklahoma, Norman

ABSTRACT

An analysis of the implementation of local wellhead protection programs (LWHPPs) focused on preventing contamination of public ground water supplies is presented herein. From over 300 such programs in varying stages of development in the United States, the analysis presented is based on twenty-nine LWHPPs found in twenty-five different states. Delineation of wellhead protection areas (WHPAs) involved the use of using one or more of up to six methods as specified by the U.S. Environmental Protection Agency; the most frequently used method was hydrogeologic mapping. Approximately 150 potential types of sources of contamination were inventoried; however, prioritization of these sources was accomplished in only ten of the twenty-nine case study communities. Prioritization was typically based on rating source types or characteristics and local hydrogeological factors. A total of thirty-one different wellhead protection measures were identified, with all twenty-nine communities using a mixture of such approaches. New source evaluations were considered in eighteen case studies, with the most popular method for control being via the adoption of land use-related ordinances. The following observations and lessons can be drawn from this comparative analysis study: 1) the twenty-nine LWHPPs were unique and reflected local needs, hydrogeological conditions, and land uses; 2) several

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methods are available for delineating WHPAs and identifying potential sources of ground water contamination within the defined areas; 3) methods are needed for facilitating consistent source/contaminant prioritization for different levels of available information; 4) research is needed on the implementation and effectiveness of pollution prevention measures, particularly as related to specific source types; and 5) systematic approaches are also needed for evaluating potential land use changes which may occur within defined WHPAs, or for evaluating proposed wells co-located within existing WHPAs.

INTRODUCTION

The 1986 Amendments to the Safe Drinking Water Act (SDWA) in the United States included provisions for wellhead protection. Specifically, Section 1428 established state-focused programs for protecting the wellhead areas of all public water systems from contaminants that may have adverse human health effects. The term wellhead protection area (WHPA) means the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield [1]. A national wellhead protection program is important in that the focus is on protection of ground water resources as opposed to remediation of existing contamination resulting from historically inappropriate waste disposal practices and other inadvertent activities of man.

Over forty state wellhead protection programs have been implemented as a result of the SDWA requirements. However, specific applications of the concepts occur at the local city/municipality/town/community level. Due to the relative newness of such programs, there is a need to explore current practices and then use this information in further program planning and implementation. Accordingly, this article presents an analysis of the planning and implementation of local wellhead protection programs (LWHPPs). It is estimated that over 300 such programs are in varying stages of development in the United States. The analysis presented herein is based on twenty-nine LWHPPs; and comparative information is included on the WHPA delineation methods used, potential sources of contamination, contaminant/source prioritization methods used (if any), features of included ground water protection measures, and approaches for new source evaluations in WHPAs.

DESCRIPTION OF STUDY SAMPLE

The twenty-nine LWHPPs included in the study sample were identified through normal literature searching, contacts with regional offices of the U.S. Environmental Protection Agency (USEPA), and discussions with ground water professionals. Information on over forty identified LWHPPs was requested, with useable information procured from twenty-nine in twenty-five different states. The twenty-nine case studies and brief program descriptions are included in Table 1; they are listed in alphabetical order by state of origin, then community. The provided information was fairly complete for some implemented LWHPPs, while it was more sparse for others. More extensive information on the study sample and the comparative review is contained elsewhere [2].

There are four typical components in a WHPP: WHPA delineation, contaminant source inventory, management plan, and implementation. For comparison of the LWHPPs, the following components and related issues were considered: delineation of WHPAs, contaminant source inventory, volunteers used for the inventory, a management plan, a contingency plan, and public participation. A summary of the comparisons is in Table 2. The component included most often (20 case studies) was a contaminant source inventory; the second most included were contingency plans and the delineation of WHPAs (19 communities each). The case studies were also examined for use of geographic information systems (GISs). Eight communities used GISs, in some form, to assist in mapping potential sources of contamination, ground water vulnerability, and management strategies. Two reports received were proposals for WHPPs, and while some information was given about the community, not enough was provided to be considered a complete program. Three communities sent reports that consisted of relevant ordinances. These reports gave insight as to the composition of the community's program, but likewise, they did not reflect complete programs.

WHPA DELINEATION

The technical method (or methods) used to delineate WHPAs in the case studies was examined. As shown in Table 3, WHPA delineation methods were based on six types specified by the USEPA; they include arbitrary fixed radius, calculated fixed radius, simplified variable shapes, analytical methods, hydrogeologic mapping, and numerical flow and transport modeling [1]. A time-of-travel (TOT) method is also included in Table 3. Since all of the twenty-nine communities were unique, any single WHPA method cannot be universally applied. For the case studies analyzed herein, more than one method of delineation was commonly used. This can be beneficial to a community because it enables the delineation of a WHPA for their unique conditions, and possibly, at a more affordable cost.

Nine of the twenty-nine case studies used either the arbitrary or calculated fixed radius method alone, or in combination with another method. Eleven LWHPPs used a form of hydrogeologic mapping to define their WHPA. TOT boundaries were used in six of the case studies, and analytical methods were used by eight of the communities. Five communities listed no WHPA delineation method: Central Connecticut Planning Region; Rathdrum Prairie Aquifer, Idaho/ Washington; Portland, Oregon; East Dakota Water Development District, South Dakota; and Williamstown, West Virginia. Two communities used a special

Table 1. Description of Local Wellhead Protection Programs in Study Sample

Case Study	Description
Madison, AL	WHPP for City has three steps: (1) Collect well data; define local geology; define hydrogeology (2) Evaluate delineation methods; define WHPA boundaries (3) Inventory contamination sources; prepare management plan
Prattville, AL	Delination of WHPAs only
Gila River Indian Reservation, AZ	WHPP proposal
Santa Clara County, CA	Pilot WHPP and GIS study; goals of project were: (1) Demonstrate the usefulness of GIS technology in day-to-day WHP activities (2) Demonstrate the usefulness of GIS technology in long-range planning and decision making Program components: (1) WHPA delineation (2) Source inventory for hazardous material storage sites
West San Bernardino County, CA	WHPP Master Plan (proposal)
Eads, CO	WHPP for Town consisting of: (1) Delineation of WHPA (2) Contamination source inventory (3) Management approaches (4) Contingency plan (5) Siting of new wells

Central Connecticut Planning Region	Wellhead Demonstration Program consisting of four main components: (1) Map aquifers from local water system maps and data to establish a GIS map and database (2) Assist in the implementation of the Aquifer Protection Act (3) Coordinate with the Connecticut Department of Environmental Protection during the implementation of aquifer protection (4) Analyze current land uses and evaluate local interim protection measures so that aquifer protection can start before implementation of regulations (land use ranking)
Broward and Dade Counties, FL	Ordinances only; no description of program available
Moloka'i, HI	Demonstration project for Ground-Water Hydrology, Contamination, and Management on Moloka'i, HI. Consisted of three parts: (1) Hydrology, legal, and institutional framework for island were researched and a training program prepared and conducted (2) Inspections of areas around wellfields by Federal, State agencies and local groups (3) Public workshop held Report separated into four sections: (1) Basic Hawaiian hydrology (2) Overview of ground water contamination threats (3) WHPAs and APAs results (4) Overview of ground water related legislation for Moloka'i (5) Protection tools available, including a draft overlay zoning district ordinance
Rathdrum Prairie Aquifer, ID/WA	Wellhead demonstration project for RPA. The program follows the seven elements of WHPP established by USEPA. Project is broken down into three categories: (1) Managing pollution sources (2) Promoting public awareness (3) Interagency coordination and cooperation

Table 1. (Cont'd.)

Case Study	Description
Pekin, IL	Pilot Groundwater Protection Needs Assessment for Pekin; demonstration project The Illinois Groundwater Protection Act requires a minimum of six steps for an assessment: (1) Determination of the adequacy of ground water protection by setback zones (2) Delineation of the recharge area outside setback zones, if any, within the study area (3) Inventory of potential primary and secondary sources of contamination within the recharge area of a well (4) Hazard assessment of potential sources with respect to geologic and hydrogeologic conditions (5) Evaluation of local protection measures to determine if ground water protection is provided, whether directly or indirectly (6) Contingency measures
Winnsboro, LA	WHPP was conducted for Town, report received consisted of the following parts: (1) Delineation of WHPAs (2) Potential contaminant source inventory (3) Public water system characteristics (4) Contingency plan
Norway, Oxford, Paris Water Districts, ME	Wellhead and Aquifer Protection Plan for Norway, Oxford, and Paris Water Districts Wellhead protection process includes: (1) Conducting a pumping test on the production well at maximum pumping stress, with adequate monitoring around the well (2) Determination of primary, secondary, and tertiary zones of protection from ZOC, and smaller TOT zones taken from pumping tests and ground water flow model (3) Inventory of potential contamination threats in each zone and recommendations on how to minimize them

Hollister, MO	Demonstration project to determine: (1) How to use a GIS to protect community ground water supplies (2) How to determine a wellhead protection program for the community Components of the program consisted of: (1) A door-to-door survey within a half mile of city perimeter (2) Application of GIS (3) Delineation of WHPAs (4) Recommendations made for implementing project (management techniques)
Sante Fe, NM	Ordinances only; no description of a WHPP
Dutchess County, NY	Water Supply Protection Program Project approach consists of three components: (1) Delineate protection areas (2) Evaluate contamination threats (3) Develop strategies to protect the water supplies These components were broken into seven tasks: (1) Delineation of aquifer protection areas (2) Evaluation of delineation methodologies (3) WHPA delineation (4) Land-use—identification of contaminant sources (5) Nitrogen loading analysis (6) Safe yield analysis (7) Protection strategies Emergency response to be developed as part of ordinance, but no contingency plan was specifically described

Table 1. (Cont'd.)

Case Study	Description
Rolla, ND	Pilot Project included: (1) Contaminant source inventory (2) At time of report, developing a management plan to implement a WHPP (3) WHPAs drawn by ND State Health Department (4) After identification of potential contaminants, a "Risk Ranking and Screening System" developed by the EPA Office of Ground-Water was used
Towner, ND	(1) Delineation of WHPA (2) Contingency plan (3) Copy of the city ordinance for wellhead protection districts
Dayton, OH	Multi-jurisdictional Wellfield Protection Program (WFPP), considered a comprehensive program The overall purpose of the program is geared for risk management Program consists of the following components: (1) WFPA designation (2) Potential contaminant inventory (3) Land use control zoning (prevent new risk—cornerstone) (4) Types and quantities of regulated substances are controlled (5) Contingency plan (6) Ground water monitoring (7) Program funded through a Well Field Protection Fund—special tax on water consumption

Enid, OK	Wellhead Protection Demonstration Project which is part of an overall comprehensive ground water management program Program made up of five parts: (1) WHPA delineation (2) Contaminant source inventory database development (3) Determination of aquifer vulnerability through DRASTIC (4) Creation of a GIS-based data management system including a Wellfield Risk Assessment (5) Development and incorporation of contingency plan into GIS
Portland, OR	Preventive containment program for protecting ground water in Columbia South Shore area from hazardous materials spills Approach is part of ground water quality protection plan A ground water risk study was done using a model to examine on a risk/probability basis the relationship of existing and projected development in the study area to hydrogeology and surface hydrology. The program contains the following main components: (1) Development and implementation of Columbia South Shore Water Quality Protection Plan (2) Submission of hazardous materials list by project site which city must approve (3) Land use control components consist of: monitoring, management and response; preventative containment of the transportation systems; and development site containment

Table 1. (Cont'd.)

Case Study	Description
Lehigh-Northampton Counties, PA	Lehigh-Northampton County Wellhead Protection Project—demonstration project Report is (divided) into twelve chapters based on discrete work efforts under the project covering the areas of: (1) Determination of contaminants to be controlled and corresponding containment sources (2) Assessment of current regulation of identified contaminant sources to identify needed supplemental local regulations (3) GIS application (4) Ground water contamination vulnerability assessments and WHPA delineation (5) Available WHP techniques (6) Evaluation of targeted wells (delineation of WHPAs) (7) Education of residents on wellhead protection
North Kingstown, RI	North Kingstown Groundwater Protection Plan Ground Water Committee recommended actions that should be given priority for implementation (10 in all) (1) Wellhead delineation (2) Land use ordinances/regulations (3) USTs (4) Septic systems/wastewater management (5) Public education (6) Commercial/industrial discharges to ground water (7) Monitoring program (8) Regional involvement (9) Hazardous materials planning (10) Land acquisition

East Dakota Water Development District (South Dakota)	Comprehensive local ground water protection project Work plan for project consists of fifteen tasks: (1) Overall project task force (2) Data gathering around wells (3) County shallow aquifer maps (4) WHPA procedure/delineation (5) Model county/city GWP ordinances (6) Protection measures for deep (confined) PWS wellfields (7) Promote county/city ordinances (8) Water supply contingency plan (9) Identify/resolve sources of contamination (5 “supplemental” projects) (10) Reducing domestic well contamination (11) Land conversion of critical areas (12) WHPA delineation and early contaminant detection monitoring wells (13) Highway educational signs (14) GWP educational (video, pamphlets, water festival) (15) GIS demonstration
El Paso, TX	Main components of strategy: (1) Potential contaminant source inventory *survey conducted using organized volunteers (2) Delineation of WHPAs (3) Contingency planning (4) Recommended BMPs (best management practices)
Houston, TX	Same components as El Paso, except no recommended BMPs, per se, but “strategy recommendations”

Table 1. (Cont'd.)

Case Study	Description
Thurston County, WA	Thurston County Ground Water Management Plan developed and ground water management areas (GWMAs) established by the Department of Ecology (1) Northern Thurston County GWMA designated in 1987 extending horizontally and vertically (2) Aquifers in area categorized using three methods: Aquifer sensitivity, DRASTIC, and a modification of the Aquifer Sensitive Map The Aquifer Sensitive Areas (ASAs) were mapped out according to four categories: extreme, high, moderate, low (3) Source contaminants of concern were mapped for the county (4) Land use categories and contaminants were rated for their contamination potential in local area and region according to low, moderate, high scale (5) Contaminant sources and activities "critical" to area were described in more detail. Plan seeks to protect area from contamination now and in the future by preventing ground water contamination and providing protection measures—goal of non-degradation of ground water (6) To do this, three levels of protection areas were designated for the GWMA: protection measures able to be applied to entire GWMA designation of "special protection" measures for "Aquifer Sensitive Areas" designation of "special protection" measures for "Wellhead Protection Areas" (7) Ground water protection recommendations discussed related to: (a) WHPA delineations (b) Sites inventoried (c) Management approaches recommended (d) Ground water monitoring (e) Contingency planning (f) Educating public (g) Implementation framework and cost estimates for issues

Williamstown, WV	Local Wellhead Protection Plan (1) Contingency plan (2) Background information on wells (3) Contaminant source inventory conducted by community volunteers (4) WHPA identified, but no delineation method given (5) Ordinances restricting land use activities enacted (6) Public education planned for future

Table 2. Comparison of Program Components and Related Issues for 29 LWHPPs

Program Component/Issue	MA	PA	GA	SC	WC	EC	CC	BF	DF	MH	RP	PI	WL	NM	HM	SN	DN	RN	TN	DO	EO	PO	LP	NR	BS	ET	HT	TW	WW
Delineation of WHPAs	X	X		X		X				X		X	X	X	X		X		X	X	X		X	X	X	X	X	X	
Contaminant source inventory	X			X		X	X			X		X	X	X	X		X	X		X	X		X	X	X	X	X	X	X
Volunteers used for inventory																										X	X		X
Management plan	X						X			X	X	X					X	X		X	X	X	X	X	X			X	
Contingency plan	X					X				X		X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Public participation										X	X															X	X		X
Utilized GIS				X			X								X						X		X	X	X			X	
Proposal only			X		X																								
Ordinances only								X	X							X													

Abbreviations:
Madison, Alabama = MA
Prattville, Alabama = PA
Gila River Indian Reservation, Arizona = GA
Santa Clara Valley, California = SC
West San Bernardino County, California = WC
Eads, Colorado = EC
Central Connecticut Planning Region = CC
Broward County, Florida = BF
Dade County, Florida = DF
Moloka'i, Hawaii = MH
Rathdrum Prairie Aquifer, Idaho/Washington = RP
Pekin, Illinois = PI
Winnsboro, Louisiana = WL
Norway, Oxford, Paris Water Districts, Maine = NM
Hollister, Missouri = HM
Santa Fe, New Mexico = SN
Dutchess County, New York = DN
Rolla, North Dakota, RN
Towner, North Dakota = TN
Dayton, Ohio = DO
Enid, Oklahoma = EO
Portland, Oregon = PO
Lehigh-Northampton Counties, Pennsylvania = LP
North Kingstown, Rhode Island = NR
East Dakota Water Development District = BS
El Paso, Texas = ET
Houston, Texas = HT
Thurston County, Washington = TW
Williamstown, West Virginia = WW

Table 3. WHPA Delineation Methods Used in Twenty-Nine LWHPPs

	Delineation Method[a]						
Case Study	1	2	3	4	5	6	7
Madison, AL	X				X		
Prattville, AL				X	X		
Gila River Indian Reservation, AZ					X		
Santa Clara Valley, CA		X					
West San Bernardino County, CA				X	X		
Eads, CO		X		X			X
Central Connecticut	—	—	—	—	—	—	—
Broward/Dade Counties, FL					X		X
Moloka'i, HI						X	
Rathdrum Prairie Aquifer, ID/WA	—	—	—	—	—	—	—
Pekin, IL					X		
Winnsboro, LA	X						
Norway, Oxford, Paris Water District, ME						X	
Hollister, MO					X		X
Santa Fe, NM		X					
Dutchess County, NY				X	X		
Rolla, ND	X						X
Towner, ND				X	X		
Dayton, OH							X
Enid, OK				X			
Portland, OR	—	—	—	—	—	—	—
Lehigh-Northampton Counties, PA		X		X	X		
North Kingstown, RI					X		
East Dakota Water Development District (SD)	—	—	—	—	—	—	—
El Paso, TX		X					
Houston, TX		X					
Thurston County, WA							X
Williamstown, WV	—	—	—	—	—	—	—

[a]1 = arbitrary fixed radius, 2 = calculated fixed radius, 3 = simplified variable shapes, 4 = analytical methods, 5 = hydrogeological mapping, 6 = numerical flow and transport models, 7 = time-of-travel (TOT), — = no information available.

WHPA model created by the USEPA, including Enid, Oklahoma, and West San Bernardino County, California. Some WHPA delineations were taken directly from state WHPPs such as Louisiana and New Mexico. Others utilized an original method such as Moloka'i, Hawaii.

POTENTIAL SOURCES OF CONTAMINATION

There are numerous potential sources of ground water contamination in communities, and the twenty-nine case studies were examined for such identified source categories. There were approximately 150 different contaminant sources/activities identified. The most frequently cited threats were underground and above ground storage tanks (USTs and ASTs), septic tank systems, and solid waste disposal facilities. Twenty communities cited USTs and ASTs, septic tank systems were listed by seventeen, and solid waste disposal facilities were noted by sixteen communities. The case studies varied in the number of potential contaminant sources cited. At one extreme, the LWHPP documents for Prattville, Alabama, and Santa Fe, New Mexico, included no lists of contaminant sources; this probably reflects their development stage. In contrast, the LWHPP for Madison, Alabama, listed the most potential source types with sixty-two. There were six communities with single digit listings, eleven included ten to nineteen potential source types, and six listed from twenty to twenty-nine source types; the next highest was the Central Connecticut Regional Planning Agency with forty-eight.

An attempt was made to group the contaminant source categories as appropriate. However, many contaminant inventories provided no explanation of source types per se; also, there was no uniformity in terminology and categories. For example, land run-off for the Towner, North Dakota, LWHPP included run-off from applied herbicides, pesticides, and fertilizers; and the land use listing addressed agricultural, residential, industrial, and commercial uses. Liquid waste was cited as a source category by Dade County, Florida, and it included the following: waste treatment works; air pollution control facilities; domestic, commercial, mining, institutional, agricultural, or governmental operations; septic tank grease traps; sediment traps; portable toilets; solvents; sewage; industrial waste; hazardous waste; semisolid waste; or potentially infectious waste. Other LWHPPs included separate listings of one or more of the components of the Dade County liquid waste category. Finally, manufacturing as a source type was used in several LWHPPs as a broad category which encompasses different types of manufacturing. For example, manufacturing in the Pekin, Illinois, LWHPP means paper and cardboard manufacturing; for other communities there were different meanings.

CONTAMINANT/SOURCE PRIORITIZATION

The majority of the twenty-nine case studies did not prioritize potential contaminants, sources, or source types. Instead, they delineated WHPAs, conducted an inventory with respect to potentially contaminating activities and sources, and implemented a pollution prevention management plan. However, as shown in Table 4, ten of the local communities applied some type of analysis. This approach is desirable since not all land-use activities pose the same pollution hazards for ground water resources [3]. The simplest contamination prioritization method involved rating land uses according to their risk to ground water quality. For example, the Central Connecticut Planning District LWHPP qualitatively identified potentially contaminating activities with high risks. The Central Connecticut Regional Planning Agency (CCRPA) utilized a GIS to pinpoint high risk land uses in the area (Central Connecticut Regional Planning Agency, undated). Additionally, the Connecticut Department of Environmental Protection (DEP) has developed a rating system for land uses according to their potential risk to ground water quality. The qualitative ratings of the land uses with the highest risk to ground water are displayed in Table 5 (Central Connecticut Regional Planning Agency, undated); these ratings were used in the Central Connecticut Planning District LWHPP.

The next method (in increasing complexity) listed in Table 4 involved the rating of potential contaminants based on a determined risk factor. This method was used by Eads, Colorado, and the Norway, Oxford, and Paris Water Districts in Maine. Each potential contaminant source/activity was assigned a number based on increasing risk; the higher the number, the higher the risk. The Eads, Colorado, LWHPP utilized a simplified contamination prioritization system (1 = lowest risk to 5 = highest risk). The goal was to protect WHPAs that were assigned a risk factor of 3 or above. The methodology used to create the prioritization system was not described in the information received; however, the results for seven sources are shown in Table 6 (Colorado Department of Health, undated).

The next category included the rating of contamination potential based on a high, moderate, or low scale. For Thurston County, Washington, this rating approach was accomplished for both the regional and local level. The LWHPP for Lehigh-Northampton County, Pennsylvania, incorporated a rating approach to assess the vulnerability of the ground water and soils in the area. The rating was based on the vulnerability of the soils in relation to their ability to transport potential contaminants to ground water. All soils in the LWHPP area were rated and mapped according to one of the following categories: low, low to moderate, moderate, moderate to high, high, and low to high [4]. Finally, the Dayton, Ohio, LWHPP used a potential contaminants "intensity" rating for prioritization.

The next most complex contaminant/source prioritization method used was the DRASTIC vulnerability analysis. Three of the communities categorized the vulnerability of their local ground water using DRASTIC: 1) Santa Clara Valley, California; 2) Enid, Oklahoma; and 3) Thurston County, Washington. The GIS-based DRASTIC method was used in the Thurston County, Washington, LWHPP. Activities considered to be threats to ground water were delineated based on the

Table 4. Contamination Prioritization Methods Used in the Study Sample

Case Study[a]	Categories (Increasing from Simplest to Most Complex)						
	Rating of land uses according to risk to ground water quality	Rating of potential contaminants based on risk	Rating of contamination potential (high, moderate, low)	Potential contaminants "intensity" rating	DRASTIC Vulnerability Analysis	Ground Water Risk Assessment Model	USEPA Priority Setting Approach
Santa Clara Valley, CA					X		
Eads, CO		X					
Central Connecticut Planning District	X						
Pekin, IL							X
Norway, Oxford, Paris Water District, ME		X					
Dayton, OH				X			
Enid, OK					X		
Portland, OR						X	
Lehigh-Northampton Counties, PA			X				
Thurston County, WA			X		X		

[a]Pertinent references for each case study, in order, are as follows: [5-12, 4, 13].

Table 5. Rating of Potentially Hazardous Land Uses by Connecticut Department of Environmental Protection [7]

Land Use Category	Higher Risk Uses
Open Space	Golf courses; cemeteries
Residential	Unsewered high and moderate density residential; certain home occupations
Agricultural	Commercial nurseries and greenhouses
Commercial	All automotive sales and services; general repair shops; body shops; machine shops; junk or salvage yards; fuel oil distributors; lumber yards; hardware stores; auto and home supply stores; garden centers; heavy construction businesses; personal and repair services including laundromats, beauty shops, photo processors, pharmacies, funeral parlors, and printers; medical, dental, and veterinary offices; furniture strippers; appliance repair; exterminators; research labs; underground fuel and/or chemical storage
Institutional	Garages and vehicle service areas; fuel storage and dispensing; salt storage; hospitals; secondary schools; colleges; prisons; nursing homes
Industrial	All manufacturing and processing except simple assembly and warehousing of durable goods (no chemicals); warehousing distribution and storage of chemicals, fertilizers, pesticides, petroleum, coal, other fuels, and hazardous materials; mining and quarries
Utilities	Electric power generation; oil or chemical pipelines
Transportation	Airports; highway maintenance facilities; truck, rail, or bus terminals and maintenance facilitites
Waste Disposal	All waste disposal sites and businesses

Table 6. Rating of Potential Sources of Contamination for Eads, Colorado [6]

Site	Source Description	PotentialSource(s)	Risk Factor (1-5)
1	Pig Breeding Units	Anaerobic Lagoon	4
2	Pig Breeding Units	Water Wells	2
3	Pig Breeding Units	Irrigation Circles	5
4	Residence	Water Well, Septic Tank	1
5	Residence	Water Well, Septic Tank	1
6	NE Wellfield	Water Wells	1
7	Homestead	Water Well	1

following criteria: 1) known problem activities; 2) known instances of contamination in Thurston County; and 3) the professional experience of the Ground Water Management Plan (GWMP) committee members [13]. The land uses were rated according to their contamination potential based on a high, moderate, and low scale. The results are shown in Table 7 [13].

The LWHPP for Portland, Oregon, used a complex risk assessment model to determine risk to the ground water supply; the model was primarily based on containment of hazardous materials in the Columbia South Shore area. The model, called the Airport Way Water Quality Risk Assessment Model (AWWQRAM), was designed to examine the relationship between existing and potential area development and effects on hydrogeology and surface hydrology based on a "risk/probability" approach. AWWQRAM simulates a hazardous material release, migration, and interception by selected target locations chosen to represent single or multiple supply wells. Generally the model can predict the effects of future development by 1) estimating the release rates of three hazardous material types from a variety of sources; 2) calculating the hazardous material concentrations in the ground water directly below the points of release; 3) calculating the resulting ground water concentrations at the targets; and 4) comparing the predicted concentrations with water quality criteria [12].

Finally, the USEPA Priority Setting Approach was used by Pekin, Illinois, to prioritize potential contaminants in the WHPA [14]. The approach consisting of a three phase potential hazard screening system was utilized. Phase I determines whether or not potential primary or secondary sources, potential routes, or other possible sources meet certain minimal hazard and Illinois Responsible Property Transfer Act (RPTA) criteria. If a site fails to meet the requirements then it is considered a potential threat. Phase II consists of an analysis of the Phase I screening results in conjunction with geologic susceptibility, soil attenuative properties, and depth to the water table. A GIS was used to relate the variables, and to evaluate potential hazards to ground water in the study area. Phase III consisted of applying the USEPA Priority Setting Approach document to screen for potential hazards [8]. One GIS-based package Pekin used was GRASS (Geographic Resource Analysis Support System); it was used to relate recharge areas for wells to zoning districts. By combining zoning, geologic susceptibility, and zones of capture, existing local controls were evaluated. GRASS was also used to identify areas in which certain activities were most likely to contaminate ground water, such as in commercial and industrial zoning districts [8].

GROUND WATER PROTECTION MEASURES

A variety of protection measures were identified in the twenty-nine case studies to guard against potential contamination of ground water supplies. Comparisons of the protection measures are displayed in Table 8. There were thirty-one categories of measures identified. Contingency plans and ordinances/legislation/regulations were the measures most often used (19 communities). Zoning, public education, and water quality monitoring were also frequently used by communities. A few communities used measures that were unique, such as a "grassy swale" for stormwater or land application for treated effluent. The Dutchess County, New York, LWHPP listed the most protection measures with seventeen. No protection measures were listed in the LWHPPs for three communities: Prattville, Alabama; Gila River Indian Reservation, Arizona; and West San Bernardino County, California. It should be noted that the key issue is not listing measures, it is to implement such measures. No information was available from the twenty case studies on the actual effectiveness of the measures in protecting local ground water resources.

NEW SOURCE EVALUATION

New source evaluation refers to how a LWHPP will manage new sources of potential contamination proposed for location in the WHPA. The sources could come from new land use activities or as a result of an accident, such as a spill on a road passing through the community. Most of the twenty-nine case studies examined herein concentrated on addressing new sources before they became a problem. The focus was on the implementation of ordinances or permitting procedures. Many communities also highlighted the siting of new water wells and the prevention of their contamination from current and future land use activities. New source evaluation considerations are tabulated in Table 9; and six main

Table 7. Thurston County, Washington, Contamination Potential Rating of Land Use [13]

Land Use Category	Contaminant Source	Typical Contaminants	Contamination Potential: Local	Contamination Potential: Regional
Agriculture	Agricultural chemical use	Pesticides, herbicides, fertilizers	High	High
	Storage tanks	Petroleum products	High	Low
	Materials stockpiles	Pesticides, fertilizers	Moderate	Low
Animal husbandry	Animal feeding operations	Biological, nitrates	Moderate	Low
Gravel mining	Excavation	Biological, organic, and inorganic chemicals	Moderate	Moderate
Medium density residential on septic systems (up to 1 home per 3.5 acres)	On-site sewage disposal	Biological, nitrates	Moderate	Moderate
	Storage tanks	Heating oil	High	Moderate
	Urban run-off	Various contaminants	Moderate	Low
High density residential on sewer (greater than 3.5 homes per acre)	Sanitary sewers	Biological, nitrates	High	Moderate
	Storage tanks	Heating oil	High	Low
	Urban run-off	Wide variety of potential contaminants	High	High
Commercial	Sanitary sewers	Biological, nitrates	High	Moderate
	Storage tanks	Organic chemicals	High	Low
	Urban run-off	Organic and inorganic chemicals	High	High
Industrial	On-site sewage disposal	Organic and inorganic chemicals, biological,	High	Mod-High
		nitrates	High	Low
	Sanitary sewers	Organic and inorganic chemicals	High	Low-Mod
	Land application of waste water	Biological, nitrates, heavy metals, organic chemicals	High	Low

Industrial	Illegal dumps	Wide variety of organic and inorganic chemicals	High	Mod-High
	Surface impoundments		High	Low-Mod
	Waste piles		High	Low-Mod
	Materials stockpiles		High	Low-Mod
	Above-ground storage tanks		High	Low-Mod
	Storage tanks		High	Low-Mod
	Containers		High	Low-Mod
	Hazardous materials pipelines		High	Low
	Contaminant transport		High	Low
	Urban run-off		High	Low-Mod
Landfills	Landfills	Biological, organic and inorganic chemicals, methane	High	High
Sources not associated with specific land uses	Illegal dumps	Organic and inorganic chemicals, metals	High	High
	Hazardous materials pipelines	Petroleum	High	Low
	Contaminant transport via trucking, railroad, or shipping	Organic and inorganic chemicals	High	Low
	Ground water monitoring or supply wells	Surface water or contaminated ground water	High	Moderate
	Excavations	Surface water run-off	High	Moderate

Table 8. Pollution Prevention Measures Identified in the Twenty-Nine LWHPPs

Measure	MA	PA	GA	SC	WC	EC	CC	BF	DF	MH	RP	PI	WL	NM	HM	SN	DN	RN	TN	DO	EO	PO	LP	NR	BS	ET	HT	TW	WW
"buildout analysis"										X				X			X					X							
Best Management Practices (BMPs)							X					X					X		X	X				X	X	X	X	X	
central sewer system											X				X			X				X							
contingency plans	X					X				X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
environmental easements						X											X												
"grassy swales" for stormwater											X												X						
household hazardous waste collection											X						X											X	
inspection								X																			X		
Integrated Pest Management (IPM)																								X				X	
inventory all potential sources within a 1/4 mile of proposed well																											X		

land acquisition						X	X									X	X												
land application of treated effluent											X																		
land banks																X													
land conversion of "critical" areas																								X			X		
land use restrictions	X					X	X	X	X	X	X					X	X	X			X	X					X		
mitigation							X														X						X		
ordinances, legis-lation, regulations	X			X		X	X	X	X	X	X	X			X		X	X	X	X			X	X	X		X	X	
permits	X						X	X		X	X						X	X									X		
preventive contain-ment in the trans-portation systems																						X							
public education	X					X	X			X	X	X				X	X	X	X				X	X	X	X	X	X	X
purchase of development rights																											X		
restricting of land										X																			
reporting inventory									X						X					X									

Table 8. (Cont'd.)

	MA	PA	GA	SC	WC	EC	CC	BF	DF	MH	RP	PI	WL	NM	HM	SN	DN	RN	TN	DO	EO	PO	LP	NR	BS	ET	HT	TW	WW
road signs													X					X		X					X				
school visitations																									X				
sealing wells				X											X												X		
UST requirements																X			X										
video																									X	X			
water conservation									X																				
water quality monitoring	X					X	X		X	X						X	X	X		X		X	X	X	X			X	
zoning (overlay and traditional)	X					X	X		X	X		X			X		X	X	X	X		X		X	X			X	

Abbreviations:
Madison, Alabama = MA
Prattville, Alabama = PA
Gila River Indian Reservation, Arizona = GA
Santa Clara Valley, California = SC
West San Bernardino County, California = WC
Eads, Colorado = EC
Central Connecticut Planning Region = CC
Broward County, Florida = BF
Dade County, Florida = DF
Moloka'i, Hawaii = MH
Rathdrum Prairie Aquifer, Idaho/Washington = RP
Pekin, Illinois = PI
Winnsboro, Louisiana = WL
Norway, Oxford, Paris Water Districts, Maine = NM
Hollister, Missouri = HM
Santa Fe, New Mexico = SN
Dutchess County, New York = DN
Rolla, North Dakota, RN
Towner, North Dakota = TN
Dayton, Ohio = DO
Enid, Oklahoma = EO
Portland, Oregon = PO
Lehigh-Northampton Counties, Pennsylvania = LP
North Kingstown, Rhode Island = NR
East Dakota Water Development District = BS
El Paso, Texas = ET
Houston, Texas = HT
Thurston County, Washington = TW
Williamstown, West Virginia = WW

Table 9. Comparison of New Source Evaluation Methods in the Study Sample

Case Study	Buildout Analysis	Computer Model for New Well Sites	Land Use and Source Controls	Ordinances	Permits	Upgrading of Facilities
Madison, AL				X	X	
Santa Clara County, CA				X		
West San Bernardino County, CA			X	X		
Dade and Broward Counties, FL				X	X	
Moloka'i, HI	X			X	X	
Pekin, IL					X	
Norway, *Oxford*, Paris Water Districts, ME	X					X
Hollister, MO				X		
Santa Fe, NM				X		
Dutchess County, NY	X			X	X	
Towner, ND				X	X	
Dayton, OH	X			X		
Enid, OK					X	
Portland, OR	X			X		
Lehigh-Northampton Countries, PA				X		
North Kingstown, RI		X		X		
Eastern Dakota Water Development District (South Dakota)				X		
Houston, TX					X	

approaches were identified: build-out analysis, computer modeling for siting new wells, land use and sources controls, ordinances, permits, and upgrading of facilities. Ordinances were the most popular approach as fourteen case studies used them for preventing and/or controlling new and existing sources of contamination. Permitting of facilities and new wells were typically a part of these ordinances; however, they are listed separately in Table 9.

Five LWHPPs included a "build-out analysis" to deal with any new pollution that may enter the WHPA, or possibly into the drinking water wells. Build-out analysis basically identifies future land uses based on applying current zoning laws. The zones are expanded to their boundaries and "inventoried" for potentially contaminating activities and sources. In this way, a community can forecast what the potential contaminants might be and how to prevent them. For example, BCI Geonetics, Inc., conducted a build-out analysis for three water districts (Norway, Oxford, and Paris) in Maine. Surface and ground water samples were collected and analyzed for contamination. A time-lapse analysis of aerial photographs was then used to detect any historical changes in land-use and the presence of any previous, but currently unknown, contaminant threats. Further, the effect the "building-out" of the land area would have in the zone of contribution (ZOC) in relation to current land use ordinances and regulations was also considered [9]. The Dutchess County, New York, LWHPP also included a similar analysis by examining existing and potential development and correlating that with the potential contribution of contamination to the water supply based on local zoning regulations [15].

The siting of new wells was mentioned in the LWHPPs of several case studies, including: Santa Clara Valley, California; Moloka'i, Hawaii; Pekin, Illinois; Enid, Oklahoma; and North Kingstown, Rhode Island. Regulations and ordinances that govern existing wells were considered to apply to new wells, including WHPA delineation, and management options. For example, in Pekin, Illinois, the establishment (e.g., siting and developing) of new well sites is part of the state permitting process. The Illinois Environmental Protection Agency may issue permits for new community water wells on the condition that an evaluation of a WHPA within 1,000 feet around the proposed well be conducted. The area must be examined for contaminants and routes of contamination. Such an evaluation would assist in the determination of the maximum setback zones for a new well [8]. Similarly, the Houston, Texas, LWHPP, in anticipation of new contamination sources, calls for the conduction of an inventory of wells within a quarter-mile radius of any proposed well. A computer model for locating new well sites was employed by the North Kingstown, Rhode Island, LWHPP.

SUMMARY

An analysis of current practices related to different components (issues) of LWHPPs has been presented based on twenty-nine case studies. Delineations of

WHPAs were typically achieved using one or more methods as specified by the U.S. Environmental Protection Agency; the most frequently used method was hydrogeologic mapping. Approximately 150 potential types of contamination sources were inventoried in the twenty-nine LWHPPs; however, prioritization of these sources was accomplished in only ten case study communities. The most popular method of prioritization involved a GIS application of DRASTIC, a hydrogeologically-based vulnerability scoring method. Several different measures were delineated for preventing ground water contamination; in all, thirty-one different measures were identified, with all twenty-nine communities using a mixture of such approaches. New source evaluations were considered in eighteen case studies. The most popular method for preventing new contaminant sources in WHPAs was via the adoption of land use-related ordinances.

Based upon this comparative analysis of twenty-nine LWHPPs in the United States, and recognizing that the amount of information on each program differed depending upon program status and response to the information request, the following lessons can be delineated:

1. The twenty-nine LWHPPs were each appropriately unique in that they reflected the needs of local communities and existing local hydrogeological features and land uses in the WHPAs. While similar principles were used, the specific features of individual programs differed.
2. Program components most frequently addressed included WHPA delineation and surveys to identify potential ground water contamination sources. This is understandable since the initial emphasis in the national wellhead protection program, based upon guidance from the USEPA, was to delineate WHPAs. Considerable information is available on the relative features of different bases for delineating WHPAs. A second emphasis area has been on identifying potential sources of ground water contamination within the defined areas, and approaches for identifying such sources are also well-developed.
3. An emerging issue of importance in LWHPPs is the prioritization of potential types of contamination sources and resultant contaminants. Approximately one-third of the twenty-nine case studies incorporated such a prioritization, with the techniques used ranging from qualitative comparisons of source types to the application of a developed numerical scoring method (the USEPA Priority Setting Approach). Additional guidance is needed on appropriate techniques for prioritization, including the development of methods of varying complexity which would provide consistency in approaches used for prioritization.
4. The most extensive information in the twenty-nine case studies was related to measures that could be used to prevent ground water pollution. While this is admirable and responsive to the general program thrust toward pollution prevention, added emphasis needs to be given to relating specific

measures to prioritized sources, and to evaluating the effectiveness of such measures over time. Said differently, it is relatively easy to identify measures which might be used to prevent ground water pollution, the real need is to evaluate actual implemented measures.

5. Methods are needed for the evaluation of potential land use changes which may occur within defined WHPAs, or for the evaluation of proposed wells co-located within existing WHPAs. In this context, such proposed land-use changes or new wells need to be evaluated from the perspective of their potential impact on the subsurface environment, and the impact of the existing conditions on such proposed developments. A focused environmental impact assessment process needs to be developed to facilitate these evaluations.

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Direct reprint requests to:

Professor L. W. Canter
Director, Environmental and Ground Water Institute
University of Oklahoma
200 Felgar Street
Room 127
Norman, OK 73019