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STRATEGY FOR CONDUCTING ENVIRONMENTAL SURVEILLANCE OF GROUNDWATER TO COMPLY WITH DOE ORDERS

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EXECUTIVE SUMMARY

This document defines the strategy for conducting environmental surveillance of groundwater quality at Department of Energy (DOE) installations as it will be implemented by Martin Marietta Energy Systems, Inc. The primary objectives of defining this generic strategy prior to developing site-specific plans are to:

1. Clearly differentiate between effluent monitoring and environmental surveillance as they apply to groundwater. (Together they comprise environmental monitoring.)

2. Describe the principles and concepts of groundwater flow that must be considered when establishing a groundwater surveillance program.

3. Provide for a consistent approach to developing plant-specific groundwater surveillance plans.

Groundwater surveillance is defined herein as monitoring that is conducted to determine the effects, if any, of the installation as a whole on groundwater and/or surface water quality outside the plant boundaries. Groundwater surveillance generally takes place at the plant perimeter and off-site. In contrast, groundwater effluent monitoring is defined as monitoring that is conducted to comply with permit conditions or to investigate and characterize contamination associated with particular units or facilities. Groundwater effluent monitoring generally takes place within the plant boundaries.

The groundwater surveillance strategy described in this document consists of a two-pronged approach: plant perimeter surveillance and off-site water well surveillance. Plant perimeter surveillance provides for monitoring of the exit pathways from a plant through which contaminated groundwater would have to travel to reach the accessible environment. It is conducted to monitor any effects the plant has on local groundwater and/or surface water quality. Perimeter sampling locations, parameters, and frequencies are determined through evaluation of the best technical information available regarding the hydrogeologic setting of the plant.

Off-site water well surveillance is conducted to satisfy DOE Order requirements to monitor drinking water sources and address areas of public interest or concern. Off-site water well sampling locations, parameters, and frequencies are determined primarily by availability of suitable existing wells, public interest, and legal and economic constraints, and secondarily by the technical criteria applied to plant perimeter surveillance.

Development of plant-specific groundwater surveillance plans according to the strategy defined within this document will provide consistency in the approach to meeting DOE Order requirements while maintaining the flexibility necessary to address plant-specific circumstances.

1. INTRODUCTION

DOE Orders in the 5400 series define the Department's policies and objectives regarding compliance with environmental regulations and protection of the public and the environment from releases of hazardous or radioactive materials (DOE 1988, 1989a, 1989b, 1989c, 1990a, 1990b). DOE order 5400.1 mandates the preparation and implementation of environmental monitoring plans, including groundwater monitoring, by November 9, 1991. The same Order specifies that environmental monitoring consists of two distinct components, effluent monitoring and environmental surveillance.

To paraphrase DOE Order 5400.1, effluent monitoring is conducted to characterize and quantify contaminants to demonstrate compliance with regulations or permits. Environmental surveillance, on the other hand, is conducted to verify compliance and to determine the effects, if any, of effluent releases on the local environment. Table 1 presents the definitions and specific program objectives of environmental monitoring, effluent monitoring, and environmental surveillance, as provided in DOE Order 5400.1. This report will be concerned primarily with environmental surveillance of a single medium--groundwater--including its potential effects on surface water.[*]

The purpose of this report is to set forth the strategy for environmental surveillance of groundwater at DOE installations managed by Martin Marietta Energy Systems, Inc. (Energy Systems). These sites include: the Oak Ridge National Laboratory (ORNL), the K-25 Site, and the Oak Ridge Y-12 Plant on the 14,260-ha (35,250-acre) DOE Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee; the Paducah Gaseous Diffusion Plant (PGDP) on the 544-ha (1345-acre) PGDP reservation in McCracken County, Kentucky; and the Portsmouth Gaseous Diffusion Plant (PORTS) on the 1620-ha (4000-acre) PORTS reservation in Pike County, Ohio.

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[*]Inasmuch as the groundwater and surface water systems are closely interrelated in humid environments, so too should groundwater surveillance and surface water surveillance be closely interrelated at Energy Systems installations. Therefore, this document will discuss the complementary aspects of surface water surveillance, even though its focus is groundwater surveillance.

Table 1. Definitions and program objectives of environmental monitoring, effluent monitoring, and environmental surveillance.

<u>Environmental Monitoring</u> is the collection and analysis of samples or direct measurements of environmental media. Environmental monitoring consists of two major activities: effluent monitoring and environmental surveillance

<u>Effluent monitoring</u> is the collection and analysis of samples or measurements of liquid and gaseous effluents for the purpose of characterizing and quantifying contaminants, assessing radiation exposures of members of the public, providing a means to control effluents at or near the point of discharge, and demonstrating compliance with applicable standards and permit requirements

(1) Effluent monitoring shall be conducted at all DOE sites to satisfy the following program objectives:

(a) verify compliance with applicable federal, state, and local effluent regulations and DOE Orders

(b) determine compliance with commitments made in environmental impact statements, environmental assessments, or other official documents

(c) evaluate the effectiveness of effluent treatment and control

(d) identify potential environmental problems and evaluate the need for remedial actions or mitigation measures

(e) support permit revision and/or reissuance

(f) detect, characterize, and report unplanned releases

<u>Environmental surveillance</u> is the collection and analysis of samples or direct measurements of air, water, soil, foodstuff, biota, and other media from DOE sites and their environs for the purpose of determining compliance with applicable standards and permit requirements, assessing radiation exposures of members of the public assessing the effects, if any, on the local environment

(1) Environmental surveillance shall be conducted to monitor the effects, if any, of DOE activities on-site and offsite environmental and natural resources. An environmental surveillance screening program shall be undertaken at DOE sites to determine the need for a permanent surveillance program. Environmental surveillance shall be designed to satisfy one or more of the following program objectives

(a) verify compliance with applicable environmental laws and regulations

(b) verify compliance with environmental commitments made in environmental impact statements, environmental assessments, safety analysis reports, or other official DOE documents

(c) characterize and define trends in the physical, chemical and biological condition of environmental media

(d) establish baselines of environmental quality

(e) provide a continuing assessment of pollution abatement programs

(2) Effluent monitoring shall comply with applicable regulations and shall be conducted to provide representative measurements of the quantities and concentrations of pollutants in liquid and airborne discharges, and solid wastes

(a) Monitoring Stations. Effluents from on-site waste treatment or disposal systems shall be monitored in accordance with applicable regulations. Influents to on-site waste treatment or disposal systems should be monitored as needed.

(b) Sampling. Sample-collection programs shall reflect specific facility needs. Type and frequency of sampling shall be adequate to characterize effluent streams

(c) Sample Analysis. Standard analyses shall be used to analyze samples wherever such methods are required by regulatory programs. Exemptions due to analytical problems or for non-routine analyses may be employed after receiving approval from the appropriate regulatory agency. Analyses not required by regulations may be conducted as determined by site-specific conditions

(d) Monitoring Data Record Keeping. Auditable records shall be established in accordance with the requirements of DOE Order 5700.68

(f) identify and quantify new or existing environmental quality problems

(2) Environmental surveillance programs and components should be determined on a site-specific basis by the field organization. Programs should reflect facility characteristics, applicable regulations, hazard potential, quantities and concentrations of materials released, the extent and use of affected air, land, and water, and specific local public interest or concern. Surveillance programs are likely to include one or more of the following:

(a) monitoring stations

(b) sampling and analysis

(c) monitoring data recordkeeping

The primary objectives of defining a generic strategy within this document, prior to developing site-specific plans, are to:

1. Clearly differentiate between effluent monitoring and environmental surveillance as they apply to groundwater. The DOE Orders state that effluent monitoring and environmental surveillance together comprise environmental monitoring. However, the orders are not clear as to what groundwater activities satisfy which category of environmental monitoring requirements. Section 2 of this report interprets the general definitions provided in the Orders to arrive at definitions for groundwater effluent monitoring and groundwater surveillance.

2. Describe the principles and concepts of groundwater flow that must be considered when establishing a groundwater surveillance program. These principles and concepts provide the technical basis for the program. They are described in Sect. 3.

3. Provide for a consistent approach to developing plant-specific groundwater surveillance plans. Consistency is provided through the definition of a generic strategy in Sect. 4.

The strategy presented within this document was generated through an integration of the program objectives for environmental surveillance, as they have been interpreted to apply to groundwater, and the scientific principles (and associated concepts) governing groundwater flow. It is the ultimate goal of this document to define a generic strategy at a sufficient level of detail to allow its easy application at each Energy Systems plant, while maintaining a nonprescriptive posture to allow flexibility for addressing site-specific circumstances and adjustments over time.

The ultimate objective of developing groundwater surveillance programs, besides merely complying with DOE order requirements, is to establish mechanisms which ensure that any discharge of contaminated groundwater across plant perimeters is detected in time to institute control measures that prevent exposure of off-site groundwater users.

2. INTERPRETATION OF DOE ORDER DEFINITIONS

DOE Orders in the 5400 series contain the requirements for environmental monitoring programs, including effluent monitoring and environmental surveillance. These orders describe the need for groundwater monitoring as part of the overall environmental monitoring program, but they do not clearly differentiate between "effluent monitoring" and "environmental surveillance" as they apply to groundwater. Thus, interpretation of the order definitions is needed.

For the purposes of developing a groundwater surveillance strategy, the following interpretive definitions have been derived from the definitions and program objectives listed in Table 1:

Groundwater effluent monitoring - Groundwater monitoring activities conducted at a unit or facility to (1) comply with regulations, permit conditions, or environmental commitments made in environmental impact statements, environmental assessments, or other official documents; or (2) investigate, characterize, quantify, or otherwise define groundwater contamination associated with waste treatment, storage, disposal, or spill sites, or groupings thereof (waste area groupings) or monitor the effectiveness of environmental restoration activities at such sites.

Groundwater surveillance - Groundwater surveillance activities conducted to (1) monitor the effects, if any, of the plant as a whole on local groundwater and/or surface water quality, thus providing verification of compliance with regulatory requirements and environmental commitments, as well as providing a means of detecting previously unidentified on-site groundwater quality problems (plant perimeter surveillance); and (2) monitor drinking water sources to address the public interest in or concern about potential contamination of off-site wells (off-site water well surveillance).

Table 2 lists the generalized characteristics of groundwater effluent monitoring and groundwater surveillance that are compatible with the preceding definitions. These definitions and characteristics were developed to clearly distinguish the different scopes and objectives of the two programs.

Despite their differences, a number of groundwater monitoring activities can satisfy the needs of both programs, when properly integrated. There is also a synergistic relationship between the two programs. Information generated through groundwater effluent monitoring is needed to establish and update the groundwater surveillance program; by the same token, groundwater surveillance can help identify on-site problems that may otherwise go undetected, thus providing a safety net to groundwater effluent monitoring. There is a definite need for interaction between the two programs if groundwater surveillance is to be successful.

All five Energy Systems plants currently have established programs to conduct what is defined as "groundwater effluent monitoring" (Douthitt 1990, Forstrom 1990, Geraghty & Miller 1990, King and Haase 1990, McMaster 1990). In addition, all five Energy Systems plants currently conduct or participate to some extent in the surveillance of off-site water wells. However, no Energy Systems plant currently conducts a well-defined perimeter surveillance program to monitor any effects of the plant on the local groundwater and/or surface water quality.

Table 2. Generalized characteristics of groundwater effluent monitoring vs groundwater surveillance

Groundwater effluent monitoring	Groundwater surveillance
Regulation, permit, or investigation driven	DOE Order driven
Monitors individual units, facilities, or waste area groupings	Monitors plant as a whole
Monitoring locations are generally on-site	Monitoring locations are at the plant perimeter and off-sit
Temporary--short, intermediate, and/or long-term monitoring	Permanent
Constantly changing--new sites, added wells, deleted wells, changed parameters, changed frequencies	Rarely changes after full implementation

3. APPLICABLE SCIENTIFIC PRINCIPLES AND CONCEPTS

This section contains a brief discussion of the scientific principles and concepts that were applied in developing the generic groundwater surveillance strategy. The discussion is purposely simplistic to facilitate comprehension by the layperson. Trained groundwater professionals will recognize the ramifications that the actual complexities of groundwater systems impose on groundwater surveillance. However, to avoid giving the impression to the layperson that groundwater surveillance is simple to accomplish, some of the factors that may complicate implementation of a groundwater surveillance program are discussed briefly.

Note that the definition for groundwater surveillance in Sect. 2 provides for a two-pronged approach, plant perimeter surveillance and off-site water well surveillance. Plant perimeter surveillance complies with DOE order requirements to monitor plant effects on the surrounding environs. It is plant perimeter surveillance to which the following discussion of principles and concepts most directly applies. The same principles and concepts are applied, in varying degrees, to off-site water well surveillance. However, the primary factors influencing off-site water well surveillance tend to be nontechnical and are discussed separately in Sect. 4.2.

3.1 HYDROLOGIC CYCLE

The principles and concepts of groundwater flow are rooted in the hydrological cycle (Fig. 1). Simply put, precipitation that does not runoff or evapotranspire infiltrates into the groundwater system. Groundwater flows through the system and, after residence times ranging from minutes to millennia, is either evapotranspired or discharged to surface water. Evaporation from surface water and evapotranspiration from other sources combine to recharge atmospheric moisture, leading to precipitation and thus completing the hydrologic cycle.

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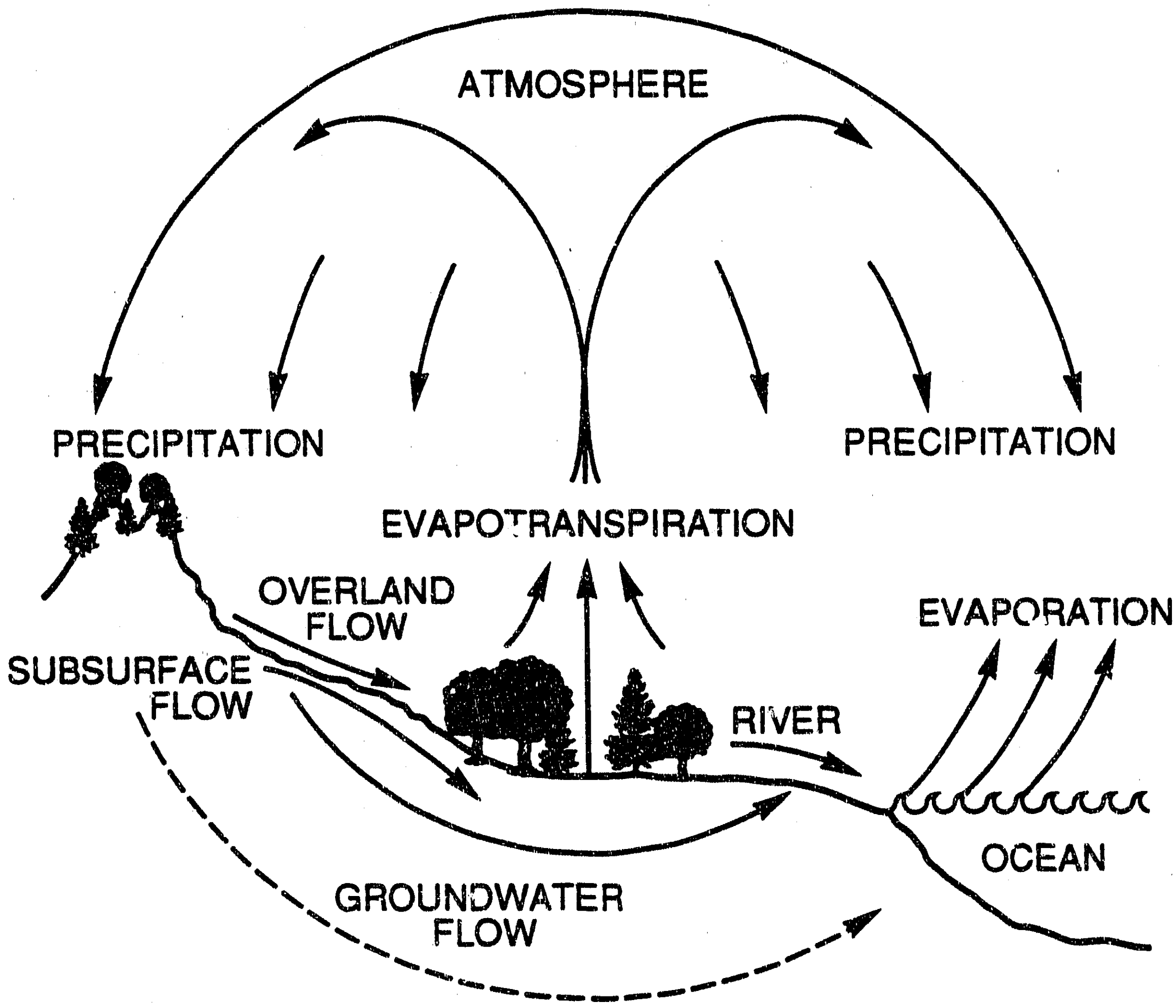

Fig. 1. Hydrologic cycle [modified from Hewlett and Nutter (1969)].

3.2 GROUNDWATER FLOW PATHS

Groundwater flows from areas of recharge, which are generally topographic highs, to areas of discharge, which are topographic lows usually occupied by surface water features such as streams and rivers in humid environments. In areas of pronounced local relief, groundwater flow paths from recharge areas to discharge areas tend to be short and define a local groundwater system. In areas where local relief is negligible, flow paths tend to be long and define a regional groundwater system (Freeze and Cherry 1979). In many cases both local flow systems and a regional flow system are present, with perhaps an intermediate flow system in between (Fig. 2). To establish a groundwater surveillance program, all levels of flow systems present at an installation must be evaluated as to their potential for becoming contaminated and transmitting that contamination off-site to the accessible environment. All flow systems having transport potential should be monitored as part of both the plant perimeter and off-site residential well portions of the groundwater surveillance program.

3.3 CONVERGENT FLOW

Large numbers of monitoring wells are employed for groundwater effluent monitoring at the Energy Systems plants, which cover many acres and include numerous potential sources of contamination. It obviously would be redundant to include all the same wells in a groundwater surveillance program. Likewise, the plant perimeters are quite extensive. Attempting to establish surveillance locations at regularly spaced intervals around the perimeter would be technically meaningless for very large intervals and economically untenable because the sheer number of wells required for smaller intervals. As a result, each perimeter groundwater surveillance well location must be selected to monitor as large an area of the plant as possible, thereby minimizing the total number of wells and samples needed.

The principle of convergent flow can be applied in designing monitoring systems to ensure that only the minimal number of perimeter groundwater surveillance wells necessary to monitor an installation are used. This principle is based on the analysis of flow nets, which demonstrates the convergence of groundwater flow lines at discharge points such as streams

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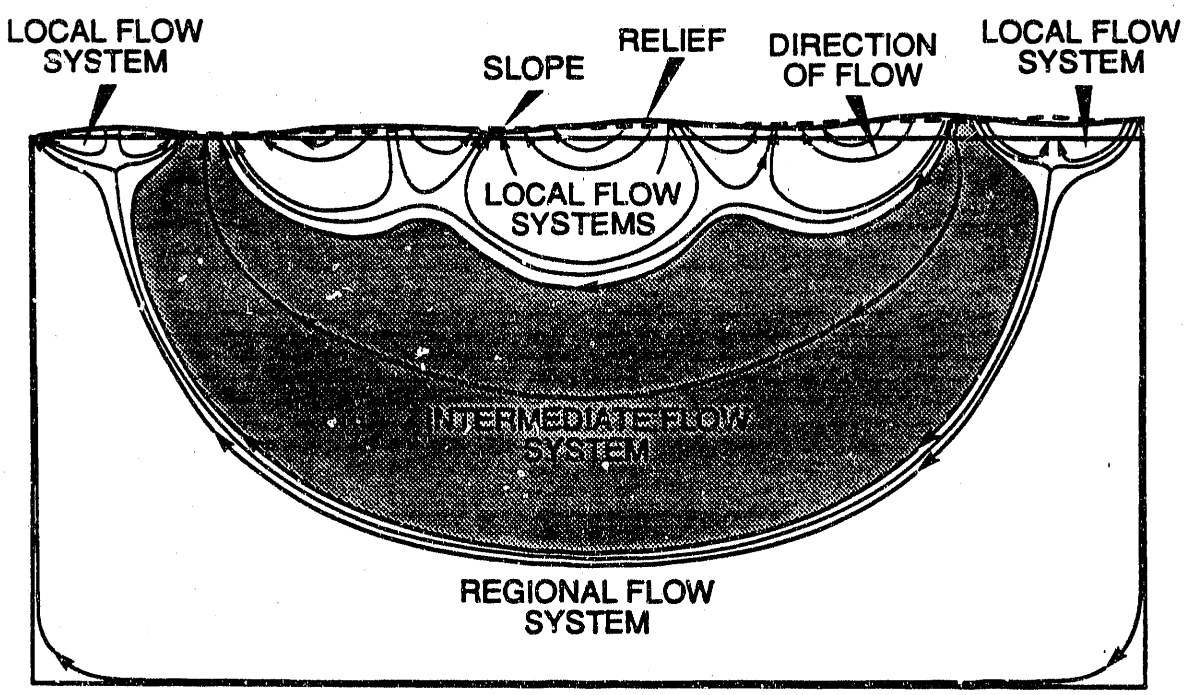

Fig. 2. Local, intermediate, and regional groundwater flow systems [after Fetter (1980) and Hubbert (1940)].

(Fetter 1980). Figure 3 is a cross-section through a four-well groundwater effluent monitoring network in which three of the wells are downgradient of three different waste units. Note how potential groundwater contamination from all three sources in Fig. 3 can be monitored by the single well GW3 [or by monitoring the stream (see Sect. 3.4)], eliminating the need to include wells GW1 and GW2 in the groundwater surveillance network. It follows, therefore, that the most efficient locations for perimeter groundwater surveillance wells are in discharge areas, where groundwater flow paths are converging. (The examples in Fig. 3 and previously in Fig. 2 illustrate the importance of developing cross-sectional drawings depicting groundwater flow and waste source configurations.)

3.4 EXIT PATHWAYS

Figure 3 illustrates convergent groundwater flow discharging to a stream in a cross section perpendicular to the axis of the stream valley. Figure 4 illustrates the concept of exit pathways on a map view of the same valley; it displays a groundwater effluent monitoring network consisting of twelve wells, nine of which are downgradient of waste units. All nine of these wells could be included in a groundwater surveillance network (the need to include background wells in groundwater surveillance is discussed in Sect. 3.5). Alternatively, eight perimeter surveillance wells could be installed at equally spaced intervals around the boundary, at the seven locations marked X and the one marked Z.

Note that wells GW3, GW6, and GW9 all monitor converging groundwater flow in the discharge area near the stream. It would, therefore, appear that these three wells could constitute a groundwater surveillance network for the plant. This network would obviously be more cost-effective and technically justified than a groundwater surveillance program that includes all nine groundwater effluent monitoring wells or all eight equally spaced perimeter wells.

However, the exit pathways for the potentially contaminated groundwater have yet to be considered. In the simple case depicted by Figs. 3 and 4, all potentially contaminated groundwater from within the plant would either discharge to the stream before it crosses the plant boundary at stream location Y or flow through the groundwater system parallel and very

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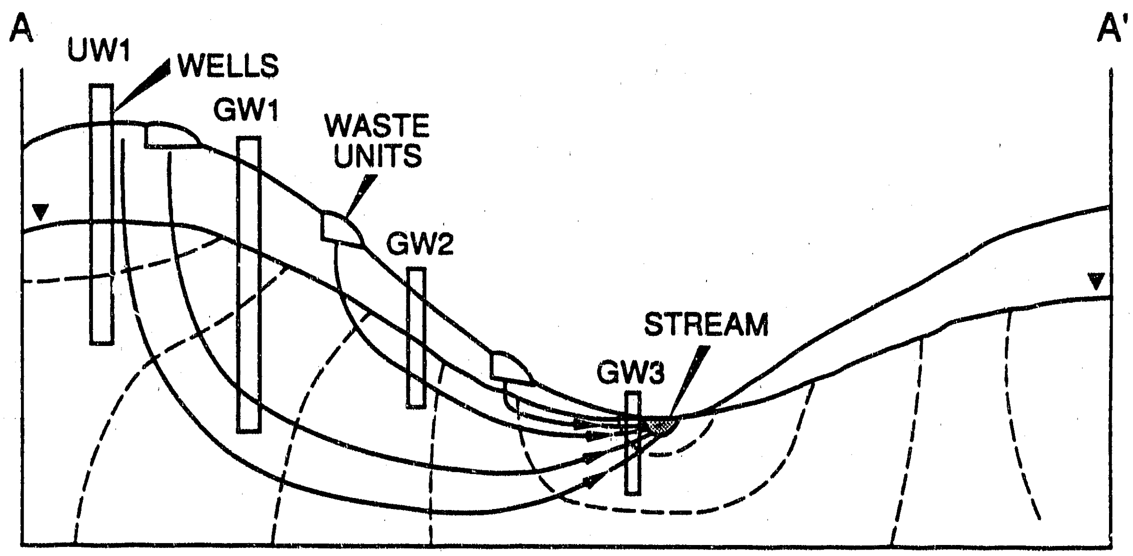

Fig. 3. Principle of convergent flow.

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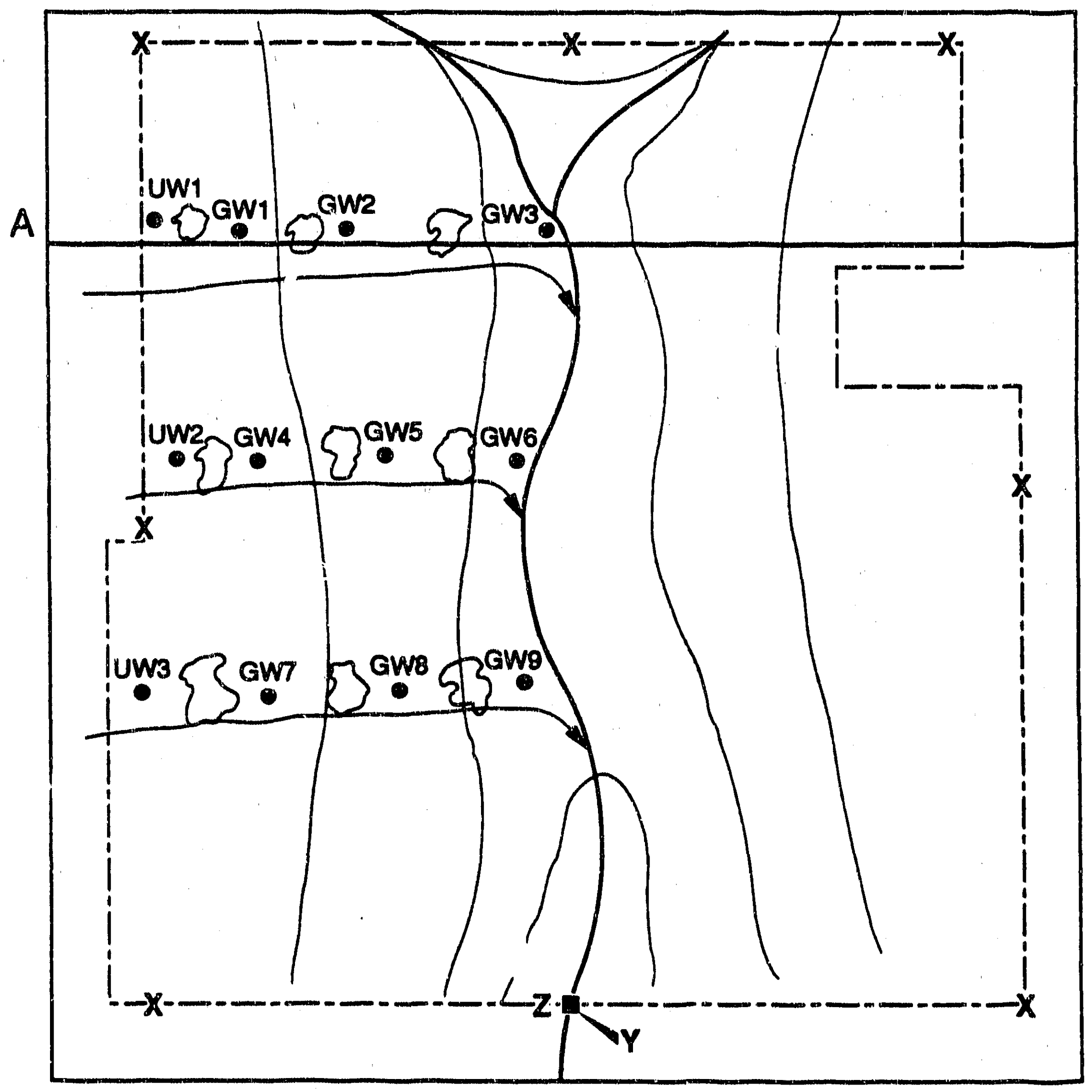

Fig. 4. Concept of exit pathways.

close to the stream, past perimeter well location Z. The exit pathways for potentially contaminated groundwater to leave the plant and reach the accessible environment have thus been identified.[**]

As a result, it is clear that the most efficient and cost-effective perimeter groundwater surveillance network for the plant includes only a single perimeter well at location Z and a single stream monitoring station at location Y. None of the other groundwater effluent monitoring wells or wells at perimeter locations would provide any additional information regarding the plant's effects on local groundwater or surface water quality [unless used to determine background water quality (see Sect. 3.5)]. The preceding discussion points out the complementary nature of groundwater and surface water surveillance and the need for coordination of the two programs.

Surveillance of groundwater so far downgradient of potential sources or after discharge to a stream may not seem to be a valid means of detecting the existence of on-site contamination because of the dilution that takes place before the groundwater reaches the sampling point. This is true, but it is a moot point. Perimeter surveillance of exit pathways is conducted to monitor the effect of the plant as a whole on groundwater or surface water quality in the surrounding environs. If existing on-site contamination is diluted to levels below detection before exiting the plant, the contamination obviously is not affecting the surrounding environs. It is the objective of groundwater surveillance to monitor contamination at the plant perimeter and the objective of groundwater effluent monitoring to characterize the extent of groundwater contamination.

[**]The example given is extremely simple and assumes that the underlying geology is a homogeneous isotropic porous medium. In actuality, a thorough understanding of site hydrogeology, including all the complicating factors discussed in Sect. 3.7, is required before exit pathways can be definitively identified.

3.5 BACKGROUND GROUNDWATER QUALITY

The DOE Orders require that environmental surveillance results be compared with background conditions. For groundwater surveillance purposes, background groundwater quality is defined here as the quality of groundwater that is completely unaffected by the plant or its operations. Suitable background wells may be located upgradient of any potentially contaminating units or facilities within the plant, upgradient of the entire plant, or they may be located off-site.

Information should be available from the groundwater effluent monitoring program to fulfill the groundwater surveillance need for background data. For instance, each of the wells (UW1, UW2, and UW3) in Fig. 4 serves as the background well for three waste units. The monitoring results from all three of these wells could be combined to establish the background groundwater quality for the plant as a whole. This example underscores the need for interaction between groundwater effluent monitoring and surveillance programs.

It is expected that plant groundwater effluent monitoring programs have generated sufficient data to allow a determination of background groundwater quality for surveillance purposes. Therefore, the need to incorporate background wells into the groundwater surveillance program is not anticipated at this time. However, should insufficient background data be available, actions would be initiated to establish background groundwater quality.

3.6 FREQUENCY OF SAMPLING

Although plant perimeter groundwater surveillance locations are determined through the identification of exit pathways, the frequency of perimeter surveillance sampling must be based on an evaluation of contaminant migration rates and distance to potential off-site groundwater users. Contaminant migration rates are primarily influenced by groundwater velocity (advection), mechanical mixing and molecular diffusion (hydrodynamic dispersion), and adsorption of the contaminant to the geologic media (retardation).

Essentially, the faster the contaminant migration rates, the more frequently sampling is required to effectively monitor any movement of contaminants past the plant perimeter.

Also, the closer potential off-site groundwater users are to the plant perimeter, the more frequently sampling is required to ensure that any contamination migrating off-site is detected in time to institute control measures before it reaches an off-site user.

The determination of surveillance frequency from contaminant migration rates obviously requires a certain amount of knowledge about the groundwater system. Many of the factors discussed in Sect. 3.7, especially fracture flow and karst features, complicate the determination of surveillance frequency as well as surveillance locations. Interaction with the groundwater effluent monitoring program to develop an understanding of the hydrogeologic system as it affects groundwater velocity is again important. Section 4.1.2 discusses the application of establishing plant perimeter surveillance frequency from calculated (or estimated) contaminant migration rates.

3.7 COMPLICATING FACTORS

The illustrative example of the process of identifying exit pathways and perimeter surveillance locations presented in Sect. 3.4 is very simplistic. This section briefly discusses some of the factors that complicate the process. Some of these factors also affect the determination of surveillance frequency and influence the selection of off-site water well surveillance locations. The presence of these complicating factors reiterates the need for a thorough understanding of the hydrogeology of each site and for coordination and interaction among the site-specific groundwater effluent monitoring program.

3.7.1 Heterogeneity

In the hydrogeologic sense, a homogeneous unit is one that has the same physical and hydraulic properties at all locations. A heterogenous unit, on the other hand, is one in which the physical and hydraulic properties change spatially (Fetter 1980). Heterogeneity complicates the groundwater flow system, thereby complicating the identification of exit pathways. Heterogeneity may lead to the development of preferred pathways for groundwater flow and contaminant transport, such as highly permeable sand channels within clay deposits. Where preferred pathways exist because of heterogeneity, they may comprise the principal groundwater exit pathways from an installation. As such, they must be identified and monitored as part of the perimeter groundwater surveillance network. Heterogeneity commonly causes spatial variability of groundwater velocity, which may also complicate the determination of surveillance frequency.

3.7.2 Anisotropy

An isotropic unit is one in which the hydraulic conductivity is the same in all directions of measurement from a point in the unit. An anisotropic unit is one in which the hydraulic conductivity varies according to the direction of measurement from a point in the unit (Freeze and Cherry 1979). Figure 5 helps explain the difference between heterogeneity and anisotropy. Examples of anisotropy include (1) a shale unit where hydraulic conductivity parallel to the orientation of the book-shaped grains is much greater than hydraulic conductivity perpendicular to grain orientation and (2) a fractured rock unit in which hydraulic conductivity is much greater in the direction of the fractures than perpendicular to the fractures (Fetter 1980).

The complicating nature of anisotropic systems is that groundwater flow lines do not cross equipotential lines (such as water table contours) at right angles, but rather are slanted in the direction of greatest hydraulic conductivity (Freeze and Cherry 1979). If the groundwater system at an installation is anisotropic, the determination of groundwater exit pathways must take the anisotropy into consideration to ensure that surveillance locations are actually along the flow lines, not just apparently downgradient, of the plant.

3.7.3 Fracture Flow

Fracture flow can be doubly complicating because it not only implies anisotropy, but also because the only significant groundwater flow and contaminant transport in the system

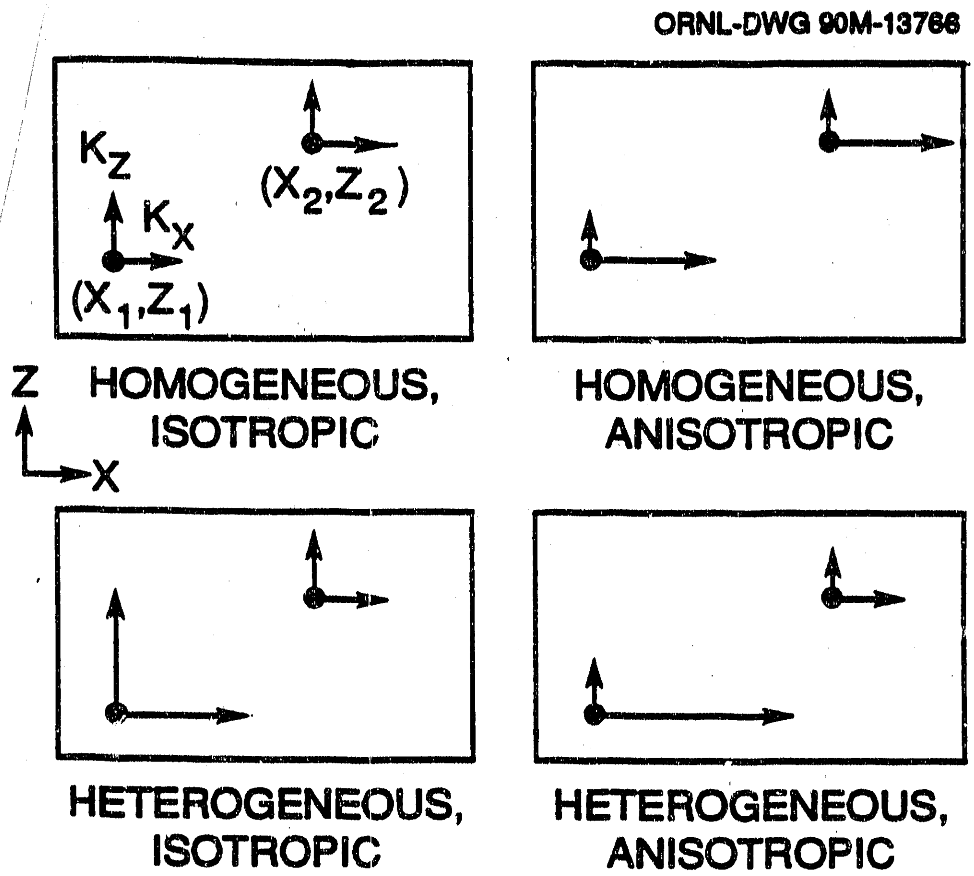

Fig. 5. Heterogeneity and anisotropy [after Freeze and Cherry (1979)]. Arrows indicate the direction and magnitude of the vector components of hydraulic conductivity.

may take place within the fractures, not in the rock matrix. As a result, determination of perimeter surveillance locations may be made by considering the effects of fracture flow, but the actual success of the wells depends on their encountering the specific fractures through which groundwater flow and contaminant transport may take place. In addition, groundwater flow velocities in fracture systems can be highly variable both spatially and temporally, significantly complicating the determination of surveillance frequency. For these reasons, adequate characterization of hydrogeologic systems influenced or dominated by fracture flow is of paramount importance to the success of the groundwater surveillance program.

3.7.4 Karst Features

Karst features such as solutionally enlarged joints and fractures, caves, caverns, and sinkholes commonly form in carbonate rocks. These features can impose much the same complications on determining perimeter groundwater surveillance locations as fractures do (i.e., to be successful, a well has to encounter the actual feature through which groundwater flow and contaminant transport would take place).

However, karst features may be even more complicating to the groundwater surveillance process. For instance, dye trace studies at the Weldon Spring site in Missouri have demonstrated that the influence of solution features can result in groundwater flowpaths that are completely unrelated to the surface water drainage system or the water table configuration as determined from a limited number of monitoring wells (Meier 1989). Karst features can also complicate the selection of groundwater surveillance frequencies as a result of the potentially extreme spatial and temporal variability of groundwater velocity.

Groundwater surveillance programs must be carefully constructed at installations where the groundwater system is influenced or dominated by karst features. Helpful guidance in this regard is provided in Quinlan (1989). Again, adequate characterization of hydrogeologic systems is of paramount importance to the success of the groundwater surveillance program.

3.7.5 Intermediate and Regional Flow Systems

Intermediate and regional flow systems, as depicted in Fig. 2, can complicate the selection of perimeter groundwater surveillance locations. This complication arises because the principle of convergent flow and/or the concept of exit pathways may not apply unless the plant happens to be located near the discharge area of the system. As a result, methods of selecting perimeter surveillance locations must rely on the identification of preferred pathways or the simple placement of perimeter wells along the most likely flow path downgradient of suspected sources. Depending on the saturated thickness of the flow system and the characteristics of the potential contaminants of concern (i.e., "floaters" or "sinkers"), there may be a need for perimeter monitoring to be conducted at multiple depths in the system.

Intermediate and regional flow systems only require perimeter surveillance if there is a potential for them to become contaminated and serve as transport pathways. For example, a well-confined, artesian regional aquifer that is monitored on-site and has exhibited no contamination would not require perimeter groundwater surveillance. (If it serves as a source of domestic drinking water, it would require surveillance at off-site residential wells as such or in response to public concern. See Sect. 4.2.) Review of data generated by the groundwater effluent monitoring program is necessary to determine the need and locations for perimeter surveillance of intermediate and regional groundwater flow systems.

3.7.6 Areal (Spatial) Distribution of Sources

In addition to all of the complicating factors described in the preceding sections, there may be individual facilities that are spatially distributed such that they do not share the same perimeters and/or exit pathways as the rest of the installation with which they are associated. If these facilities are potential sources of groundwater contamination, they would have to be treated as "mini-installations" and separate perimeter groundwater surveillance networks would have to be established for them.

4. GENERIC STRATEGY FOR GROUNDWATER SURVEILLANCE

The generic strategy for conducting groundwater surveillance to be implemented at DOE plants managed by Energy Systems is defined in this section. The purpose of defining a generic strategy is to promote the consistency in the approach to groundwater surveillance at the different Energy Systems installations. The goal is to define the generic strategy at a sufficient level of detail to allow its easy application at each Energy Systems plant, while maintaining a nonprescriptive posture to allow flexibility for addressing site-specific circumstances and adjustments over time. This strategy was developed through an integration of the program objectives for environmental surveillance, as they have been interpreted to apply to groundwater, and the scientific principles (and associated concepts) governing groundwater flow.

The groundwater surveillance strategy consists of two parts, plant perimeter surveillance and off-site water well surveillance. Each part fulfills what has been interpreted by Energy Systems to be the applicable requirements for environmental surveillance of groundwater, as provided for by the 5400 series of DOE Orders. Because the requirements for each part differ, so do the rationales that govern how each is developed and implemented. Plant perimeter surveillance and off-site water well surveillance are therefore discussed separately within this section. Table 3 provides a summary and comparison of the components of the two.

Note that the strategy defined below is limited to a discussion of the rationales to be used in establishing groundwater surveillance locations, parameters, and frequencies for each plant because the specific requirements for these program components are not defined in the DOE Orders. The requirements for other program components, such as procedures, quality assurance/quality control, and analytical methods are far better defined in the orders and are therefore omitted from the following discussion. The plant-specific groundwater surveillance plans will document that these program components meet or exceed order requirements, Energy Systems standards, and other applicable guidelines.

Table 3. Summary and comparison of the components of plant perimeter surveillance and off-site water well surveillance

	Program basis	Locations	Parameters	Frequency
Plant Perimeter Surveillance	Monitor effects of plant on local GW[a] and/or surface water quality	Plant perimeter using existing effluent monitoring wells or new WQ[b] wells, based on exit pathways, discharge areas, preferred pathways, and downgradient	Based on plant GW contaminants and key indicator contaminants	Based on contaminant migration rates and distance to off-site groundwater users
Off-site Water Well Surveillance	Monitor drinking water and address area if public interest or concern	Off-site using existing drinking water or other wells, based on availability, direction and distance, public concern, and economics	Based on plant GW contaminants, economics, legal implications, and level of public concern	Based on regional GW flow rate, level of public concern, and economics

[a]GW = groundwater
[b]WQ = water quality.

4.1 PLANT PERIMETER SURVEILLANCE

The purpose of plant perimeter surveillance of groundwater is to fulfill the order requirements to monitor any effects of a plant on groundwater and/or surface water quality in the surrounding environs. As a result, the locations, parameters, and frequency of plant perimeter groundwater surveillance are to be determined primarily through the evaluation of available information on the site-specific hydrogeologic system.

All five plants currently have extensive programs that conduct what has been defined as groundwater effluent monitoring. None of them has a plant perimeter surveillance program as defined in this strategy. However, there probably are a number of existing monitoring well locations or other activities that would fulfill the objectives of both programs. It is therefore implicit in this strategy that the plant perimeter portion of the groundwater surveillance program be closely coordinated and, where possible, integrated with the existing groundwater effluent monitoring programs.

4.1.1 Locations

DOE Orders in the 5400 series provide little guidance concerning groundwater surveillance locations except that site-specific characteristics should determine monitoring needs (DOE Order 5400.1) and that surveillance locations should be related to the nature of groundwater use, location of contaminant sources, and pollutant pathways (DOE Order 5400.6).

Under this generic strategy, plant perimeter groundwater surveillance locations will be determined through an identification of exit pathways, as described in Sect. 3.4. Sampling stations will be established at the plant perimeter, property boundary, or other control point along the exit pathway between the plant and the accessible (uncontrolled) environment. Isolated facilities or units will be considered on an individual basis if their exit pathways do not coincide with the plant exit pathways as a result of spatial separation.

Identification of exit pathways will be based on an evaluation of the hydrogeological system and its complexities, including consideration of intermediate and regional flow systems, when present. Should the exit pathway concept not be applicable at a plant, perimeter groundwater surveillance locations should be established in areas of convergent flow (discharge areas) and/or along preferred pathway migration routes. Only when no better method can be applied should perimeter groundwater surveillance locations be established simply because they are downgradient of the suspected source(s).

There is no generic minimum or maximum number of groundwater surveillance locations required at an installation. A single sampling location may be adequate to monitor an entire plant if there is only one exit pathway. On the other hand, it may require numerous sampling locations to monitor an installation having numerous exit pathways or one at which the concept of exit pathways are not applicable, such as where intermediate or regional flow systems dominate.

It is anticipated that sufficient upgradient or background wells exist at each plant to establish background conditions for the plant as a whole. Identification of wells to represent background for comparison to perimeter surveillance results should be made in coordination with the effluent monitoring program. Because the identification of perimeter groundwater surveillance locations and, especially, the exit pathway concept, are so closely related to the surface water system, groundwater surveillance locations will be coordinated closely with surface water surveillance locations.

4.1.2 Parameters

DOE Orders in the 5400 series provide little guidance concerning groundwater surveillance parameters except that they should be both radiological and nonradiological and that site-specific characteristics should determine monitoring needs (DOE Order 5400.1). DOE Order 5400.6 requires that gross radioactivity analyses be used only as trend indicators unless they can be directly related to specific radionuclides. It is therefore likely that analyses for specific radionuclides will be necessary.

Under this generic strategy, the appropriate parameters for plant perimeter groundwater surveillance will be determined through a review of existing groundwater monitoring data, waste disposal records, radionuclide inventories, and other records of potential contaminants at the plant. This review should produce a list of plant groundwater contaminants, including those previously detected in the groundwater and those known to be at the plant but not previously detected.

Perimeter groundwater surveillance will include sampling for plant groundwater contaminants and/or key indicator contaminants, depending on the degree to which groundwater effluent monitoring has defined the extent and severity of existing groundwater contamination at the installation. If existing groundwater contamination at a plant is well defined, perimeter surveillance can be limited to sampling for key indicator contaminants i.e., plant groundwater contaminants that, because of their mobility in the hydrogeological environment and the proximity of their sources to surveillance locations, would be expected to reach the plant perimeter first, thus serving as key indicators of contaminant migration.

At an installation where existing contamination is not completely defined, perimeter surveillance may require that sampling for key indicator contaminants be supplemented by sampling for the entire list of plant groundwater contaminants at some recurring interval (every other, every third, or every fourth, etc., sampling event), depending on the level of contamination definition. Sampling for the entire list of plant groundwater contaminants every sampling event would be justified at an installation only if a high level of uncertainty exists regarding the extent and severity of groundwater contamination.

It is anticipated that sufficient upgradient or background data exist at each plant to establish background concentrations for all of the perimeter surveillance parameters. Determination of background concentrations for comparison with perimeter surveillance results should be made in coordination with the effluent monitoring program.

Because groundwater surveillance may be accomplished in whole or part through monitoring of the surface water system, groundwater surveillance parameters will be closely coordinated with surface water surveillance parameters at dual-purpose locations.

4.1.3 Frequency

DOE Orders in the 5400 series provide little guidance regarding the required frequency of groundwater surveillance sampling. An exception is provided in DOE Order

5400 6, which states, "A good rule to follow when considering short-half-life radionuclides is that sampling and measurement intervals should not exceed twice the half-life of the radionuclide." Given that groundwater surveillance locations will generally be at some distance from individual sources and that groundwater is generally a slow-moving transport medium (relative to surface water and air), it is unlikely that small releases of radionuclides with short half-lives would reach the surveillance locations and have an effect on the surrounding environs. Any release that could have an off-site effect would be detected at the sampling frequencies determined by the methodology described below.

Under this generic strategy, determination of perimeter groundwater surveillance frequency will be based on calculated or estimated contaminant migration rates and distance to off-site groundwater users, for the reasons discussed in Sect. 3.6. Determination of contaminant migration rates will consider the combined influences of advection, hydrodynamic dispersion, and retardation. The contaminant migration rates used to establish surveillance frequencies will usually be those calculated for the key indicator contaminants. The calculated or estimated contaminant migration rates will be compared with the distance to off-site groundwater users and a surveillance frequency will be selected that ensures that any contamination migrating off-site would be detected in time to institute control measures before it reaches an off-site user. The analysis conducted to determine surveillance frequencies will be documented in the plant-specific groundwater surveillance plan.

Because groundwater surveillance may be accomplished in whole or part through monitoring of the surface water system, groundwater surveillance frequencies will be closely coordinated with surface water surveillance frequencies at dual-purpose locations.

4.2 OFF-SITE WATER WELL SURVEILLANCE

The purpose of off-site water well surveillance is to fulfill the order requirements that surveillance programs monitor drinking water sources (DOE Order 5400.6) and reflect issues of public interest or concern (DOE Order 5400.1). As a result, the locations, parameters, and frequency of off-site water well surveillance are determined primarily by availability of suitable existing wells, public interest, and legal and economic constraints, and secondarily by the technical criteria applied to plant perimeter surveillance.

All five Energy Systems plants currently conduct or participate in the surveillance of off-site water wells. As a result, the strategy for implementing the off-site water well portion of the groundwater surveillance program is to conduct a review of the existing programs to ensure that they meet order requirements and satisfy public interest or concern and that all the program elements are appropriate and consistent with their level of technical significance. Any modification of the existing programs to meet appropriate standards or perceived needs will be recommended in the plant-specific groundwater surveillance plans.

4.2.1 Locations

Sampling locations for off-site water well surveillance are largely determined through the availability of suitable existing wells downgradient of the plant and/or downgradient of the plant exit pathways. DOE Order 5400.6 recommends sampling at the nearest well used for domestic drinking water and downgradient of the potential contaminant source. If many domestic wells are used in the vicinity of the plant site, the Order recommends that "several" wells be included in the surveillance program. The same Order also recommends sampling of one or more upgradient wells for comparison. The actual number of off-site residential wells to be included in the groundwater surveillance program is generally determined by the level of public interest or concern and economic factors.

It should be noted that the off-site water well surveillance program may include both existing drinking water and nondrinking water wells if they fulfill a perceived need to conduct monitoring in a particular hydrogeologic unit or in a particular direction from the plant. Types of wells that might be included in the program include domestic drinking water, public water supply, irrigation, livestock, mine dewatering, industrial production, research, or other existing wells.

4.2.2 Parameters

The parameters to be monitored for off-site water well surveillance are determined by considering the contaminants at the plant, economics, and legal implications. Some level of radioactivity analysis will always be required because of the nature of the installations. DOE Order 5400.6 requires that gross radioactivity analyses be used only as trend indicators unless they can be directly related to specific radionuclides. It is therefore likely that analyses for specific radionuclides will be necessary. The decision to monitor specific nonradioactive parameters is complicated by the fact that numerous potential sources other than the plants exist for many of these contaminants. It therefore may be necessary to involve the legal organizations in the decision process. It is important to ensure that background concentrations have been or can be established for all off-site surveillance parameters.

4.2.3 Frequency

The frequency of off-site water well surveillance is generally determined through consideration of regional groundwater flow rates, the level of public interest or concern, and economics. Generally, because of the distance from the plants to off-site wells and the likelihood that perimeter surveillance will detect contaminants before they reach the off-site location, a semiannual or annual frequency should be sufficient. Data from an initial period of increased sampling frequency may be used to establish a baseline for the off-site surveillance wells, but this is not considered a necessity.

5. SUMMARY AND CONCLUSIONS

A generic strategy for conducting environmental surveillance of groundwater at the DOE plants managed and operated by Energy Systems has been presented. This strategy was developed through integration of the requirements of the 5400 series of DOE Orders, as they were interpreted to apply to groundwater, with the scientific principles and concepts governing groundwater flow.

The strategy is composed of two parts: plant perimeter surveillance and off-site water well surveillance. Plant perimeter surveillance complies with the technical requirements to monitor the effects of the plant on local groundwater and/or surface water quality. Perimeter surveillance locations are to be based on the exit pathways from the plant. Off-site water well surveillance complies with the requirements to monitor drinking water and address areas of public interest or concern.

The ultimate objective of developing groundwater surveillance programs, besides merely complying with DOE Order requirements, is to establish mechanisms that ensure that any discharge of contaminated groundwater across plant perimeters is detected in time to institute control measures that prevent exposure of off-site groundwater users. Successful implementation of the strategy presented will fulfill this objective.

The next step is to generate plant-specific groundwater surveillance plans for the Energy Systems installations. These plans will conform to the example table of contents provided in the Appendix. The three Oak Ridge plants will be combined into a single reservation-wide plan. By following the strategy put forth in this document, the approach taken by the groundwater surveillance programs at all the plants will be consistent.

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APPENDIX

EXAMPLE TABLE OF CONTENTS FOR PLANT-SPECIFIC GROUNDWATER SURVEILLANCE PLANS

CONTENTS

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