GROUND-WATER MONITORING AND MODELING AT THE HANFORD SITE[a]

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ABSTRACT

The ground-water monitoring program at the Hanford Site in southeastern Washington State is continually evolving in response to changing operations at the site, changes in the ground-water flow system, movement of the constituents in the aquifers, and regulatory requirements. Sampling and analysis of ground water, along with ground-water flow and solute transport modeling are used to evaluate the movement and resulting distributions of radionuclides and hazardous chemical constituents in the unconfined aquifer. Evaluation of monitoring results, modeling, and information on waste management practices are being combined to continually improve the network of ground-water monitoring wells at the site.

INTRODUCTION

Ground water beneath the Hanford Site is monitored by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE). The objective of this monitoring is to evaluate the existing and potential impacts of Hanford operations on the environment through the ground-water pathway. Radioactive and hazardous chemical constituents in Hanford ground water are monitored and the movement of these constituents in the ground water is assessed. The network of monitoring wells is designed to meet the intent of DOE orders that apply to environmental monitoring.

Activities that are a part of the Hanford Ground-Water Monitoring Project include collecting and analyzing ground-water samples for various constituents, maintaining a comprehensive ground-water monitoring network, evaluating results, estimating radiation dose-to-man attributable to radioactive constituents in the subsurface environment, and publishing an environmental monitoring report. Currently, the movement and resulting distributions of radionuclides and hazardous chemical constituents in the ground water are investigated with ground-water and geochemical modeling.

Description of the Hanford Site

The DOE's Hanford Site is located in southeastern Washington State and occupies an area of 1476 km^2 (Fig. 1). The Hanford Site is bounded by the Columbia River to the north and east, by the Yakima River to the south, and by Rattlesnake Mountain to the south and west. The climate at the Site is dry and mild; the area receives approximately 16 cm of precipitation annually (1). About 40% of the precipitation occurs during November, December, and January. The average maximum and minimum temperatures in July are 32°C and 16°C. For January, the averages are 3°C and -6°C. The major population center nearest to the Hanford Site is the Tri-Cities area (Richland, Pasco, and Kennewick), which is located on the Columbia River downstream from the Site and has a population of approximately 90,000 people.

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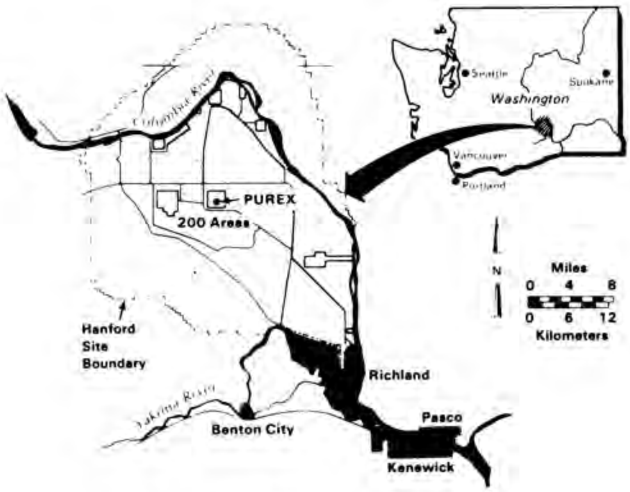

Fig. 1. DOE's Hanford Site.

The unconfined aquifer underlying the Hanford Site is located within unconsolidated to semiconsolidated gravels, sands, and silts overlying the Columbia River basalts (2). Most of the saturated thickness of the unconfined aquifer is located in the middle member of the Ringold Formation, which consists of sorted sands and gravels. On portions of the Hanford Site, the upper part of the unconfined aquifer is located in glaciofluvial sands and gravels. The bottom of the unconfined aquifer is the basalt surface or, in some areas, the clay zones of the lower member of the Ringold Formation. Confined aquifers exist within the Columbia River basalts beneath the Hanford Site. However, the unconfined aquifer is influenced by Hanford operations more than the confined aquifers are (1).

Natural recharge to the unconfined aquifer occurs primarily from rainfall and runoff from higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers (1). Artificial recharge to the unconfined aquifer occurs from offsite agricultural irrigation and from Hanford Site waste- and cooling-water disposal. Agricultural irrigation occurs to the west and enters the site through groundwater flow across the western boundary of the Hanford Site. Artificial recharge from Hanford waste-water disposal has been concentrated primarily near the center of the site in the 200 Areas (Fig. 1).

Impact of Operations at the Hanford Site

The primary DOE activities at the Site include reactor operation, fuel fabrication and reprocessing, waste management, and energy-related research and development. The DOE operations at the Hanford Site produce a large volume of waste and cooling water, which has historically been discharged to the ground through cribs, ditches, and ponds. It has been estimated that artificial recharge in the 200 Areas of the Hanford Site annually adds a volume of water to the unconfined aquifer that is ten times as great as that contributed by natural inflow to the area from precipitation and irrigation (1). The discharge water has created ground-water mounds near each of the waste-water disposal facilities (Fig. 2). These mounds affect the general flow patterns in the aquifer, which are from the recharge areas in the west to the discharge areas (primarily the Columbia River) to the east.

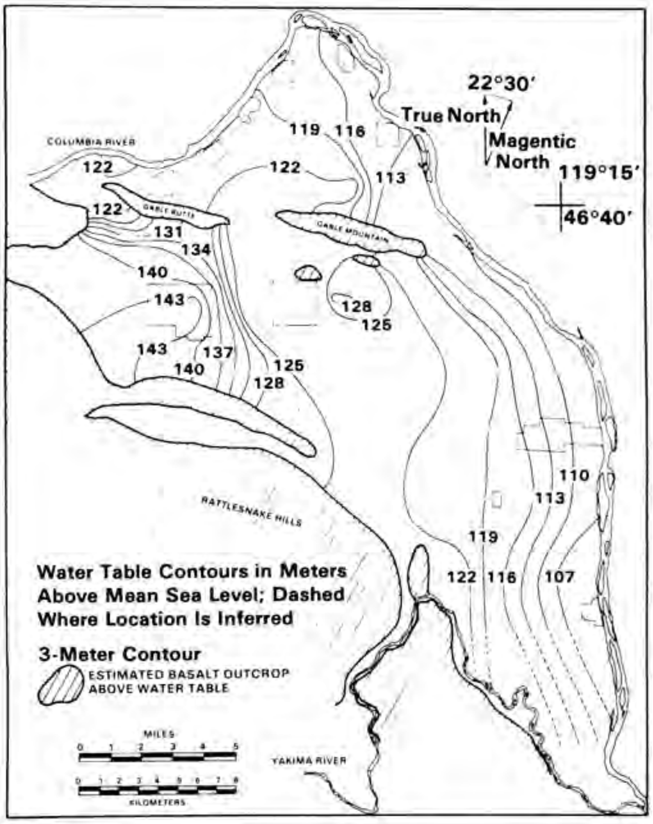

Fig. 2. Water Table Elevations (December 1985).

Ground-water levels in the unconfined aquifer have changed with time (Fig. 3) in response to changes in waste-water disposal from operations. The movement of ground water and effluents in the unconfined aquifer has also changed with time.

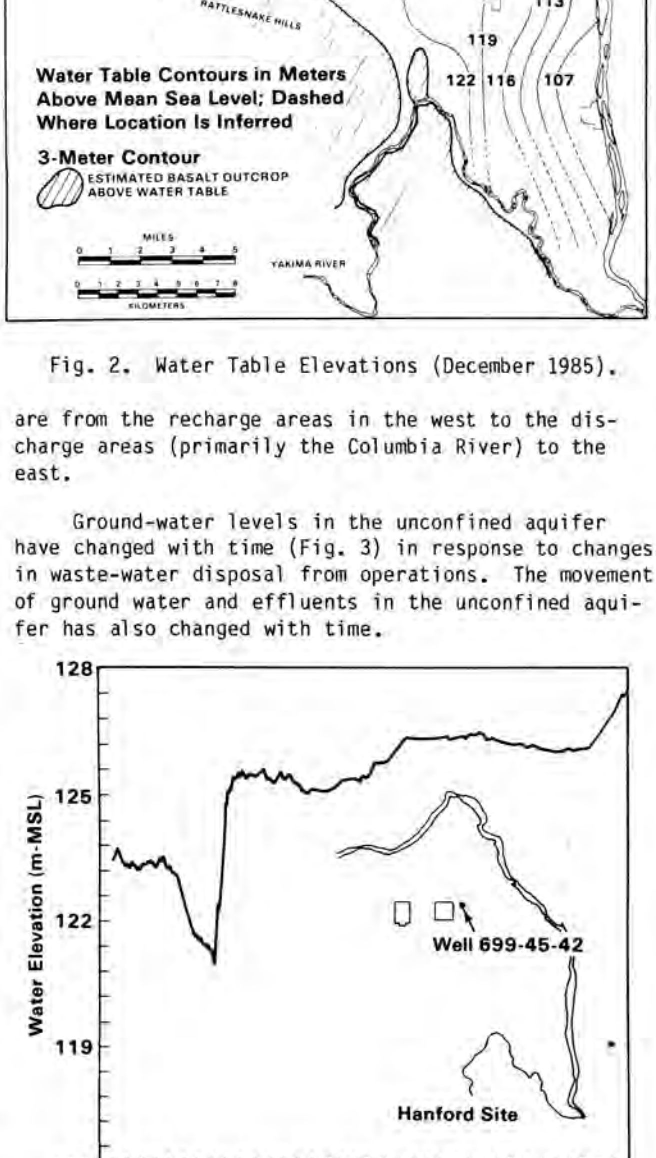

Fig. 3. Water-Level History for Well 699-45-42.

GROUND-WATER MONITORING AT THE HANFORD SITE

An environmental monitoring program to assess the impacts of nuclear and nonnuclear activities has existed at the Hanford Site since 1947 (3). Ground-water monitoring at Hanford has historically focused on the migration of tritium and nitrate in the unconfined aquifer. Tritium and nitrate are present in most of the liquid wastes and are mobile in the subsurface environment. Therefore the monitoring of these constituents has been useful in defining the movement and extent of ground-water contamination from Hanford operations. In addition to sampling the ground water, water levels are measured at least semiannually across the entire site to evaluate changes in the water table and directions of ground-water flow. The measured water levels are also used for continued calibration and testing of ground-water flow models of the unconfined aquifer.

Handling and computerized storage of Hanford ground-water data have evolved with the monitoring activities at the site. Hanford ground-water data are managed and stored on the Hanford Ground-Water Data Base, which streamlines handling the large amount of data from the ground-water monitoring project. In addition, the computerized data base provides a framework for assuring the quality of sample collection, analysis, and reporting activities. Sample scheduling and printing of sample labels are computerized. Sample collection activities and results received from the analytical laboratory on magnetic tape are tracked on the computer. Thus the data are evaluated as they are received from the field and laboratory. New data are checked for anomalies and trends with computer programs for statistical evaluation and graphic output. This allows prompt notification of operating contractors when unusual results are found. The computerized data base is also used for routine interpretations and reporting of results.

More than 2900 wells have been drilled at the Hanford Site (4). During 1986, about 1500 samples were collected from 363 of the Hanford Site wells, primarily to monitor for radionuclides in the unconfined aquifer. Over 4000 analyses were performed, most frequently for tritium, on these ground-water samples. Some of the other constituents analyzed for are ^{90}Sr, ^{60}Co, ^{106}Ru, ^{129}I, ^{137}Cs, uranium, nitrate, and various water quality parameters. Most samples are collected quarterly, while others are obtained monthly, semiannually, or annually, depending on the proximity to waste-disposal areas and on ground-water flow conditions. When elevated levels of either indicator parameters or the more mobile constituents are observed, more detailed sampling and analyses are performed. The method of sample collection varies, but most samples are obtained from wells with permanently installed submersible pumps. Samples are bailed or airlifted from a few other wells.

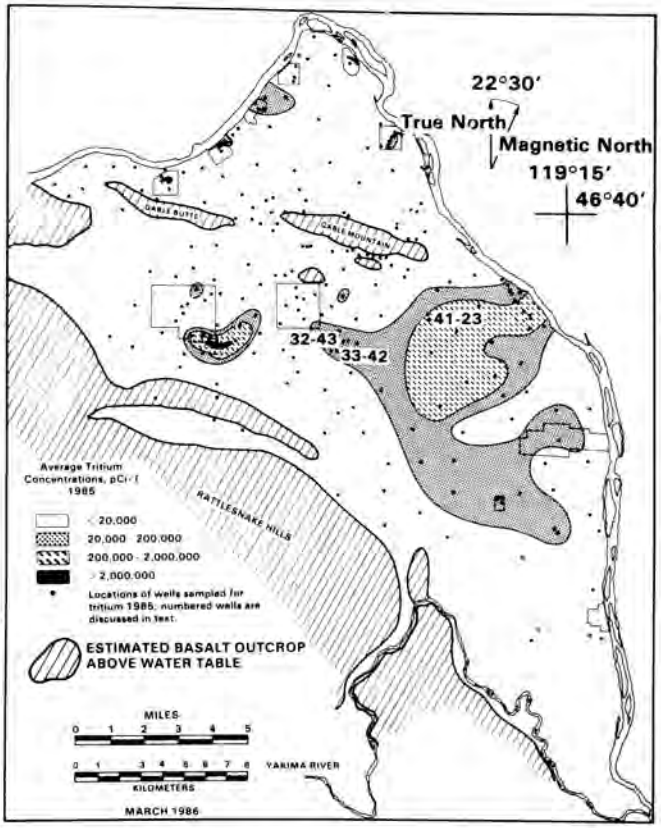

Fig. 4. Average Tritium Concentrations for 1985 [after Price (3)].

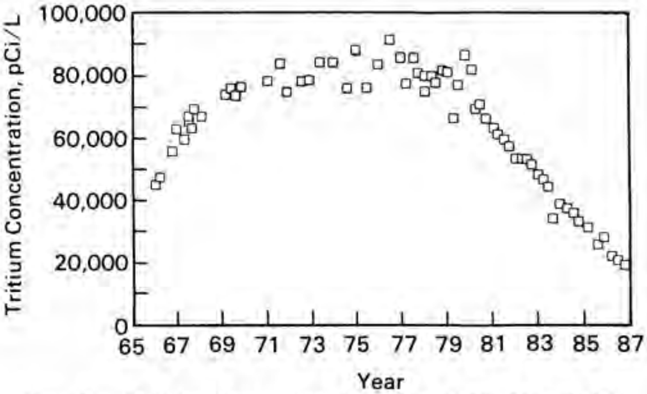

Fig. 5. Tritium Concentrations for Well 699-41-23 (location shown in Fig. 4).

The distribution of tritium in the unconfined aquifer during 1985 is shown in Fig. 4. The large plume extending from the 200 Areas to the Columbia River is a result of past disposal activities. The historical graph for well 699-41-23 (Fig. 5) shows how tritium concentrations increased and gradually decreased at the well as a result of disposal activities and ground-water flow between the 200 Areas and the Columbia River. The recent increases in tritium concentrations in wells near the 200 East Area (Fig. 6) are a result of renewed operation of the fuel reprocessing plant (PUREX).

In addition to PNL's ground-water monitoring program, the primary operating contractor at the Hanford Site monitored the ground water during 1986 near active waste facilities in the 200 Areas. Ground-water samples from more than 100 monitoring wells were analyzed for gross alpha, beta, and gamma activity, tritium, nitrate, ^{90}Sr, and uranium. The operating contractor also monitored dry wells with

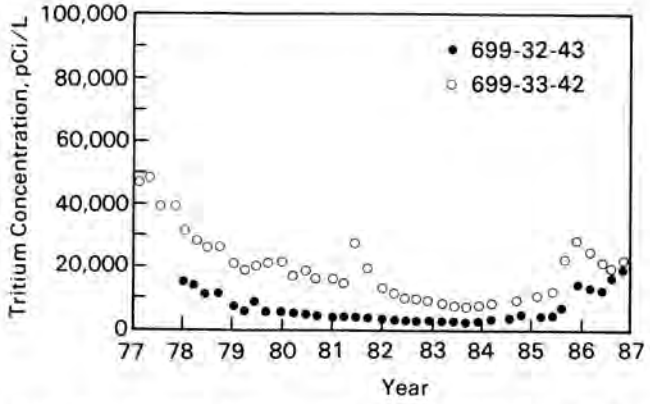

Fig. 6. Tritium Concentrations for Wells 699-32-43 (solid circles) and 699-33-42 (open circles) (locations shown in Fig. 4).

scintillation logging to detect impacts to the unsaturated zone near active and inactive waste-disposal sites.

MODELING THE UNCONFINED AQUIFER

To support waste-management and ground-water monitoring activities, a number of different ground-water flow and solute transport models have been developed for the unconfined aquifer at the Hanford Site. Most of these models have been developed on a regional scale. However, models of subregions of the unconfined aquifer have also been developed and applied.

Kipp et al. (5) used data on the aquifer bottom, water-table surface, liquid waste discharges, and aquifer properties to calibrate a two-dimensional model of ground-water flow in the unconfined aquifer that is based on the Variable Thickness Transient (VTT) code. The VTT model of the unconfined aquifer simulates steady-state or transient, two-dimensional ground-water flow. The VTT model is applied to predict pathlines and associated travel times for analyzing one-dimensional contaminant transport. One-dimensional transport of decaying radionuclides, with attenuation along pathlines predicted by VTT, are simulated with the TRANSS code (6).

The ground-water flow and solute transport models for the unconfined aquifer have been applied to evaluate waste-management practices at Hanford and to assist with waste-management decisions. The models have been applied at the Hanford Site to evaluate pumping and waste-water disposal at different locations, investigate the effects of increased agricultural development in a neighboring valley, predict the impact of leaks from waste-storage facilities, simulate the movement of contamination in the unconfined aquifer, and determine the impacts of a proposed dam on the Hanford reach of the Columbia River. The VTT ground-water flow model of the unconfined aquifer and the transport model based on the TRANSS code were also applied to assist with preparation of a recent draft environmental impact statement (7).

Ground-water flow and contaminant solute transport modeling capabilities for the unconfined aquifer at Hanford are currently being expanded and improved. A two-dimensional model of ground-water flow in the unconfined aquifer has been calibrated with an inverse method developed by Neuman (8) and modified by Jacobson (9). In the inverse procedure, past estimates of transmissivities, hydraulic heads, boundary conditions, and discharges to and withdrawals from the unconfined aquifer were used to obtain an initial calibration of the ground-water flow model.

Previous and recent geohydrologic data from the unconfined aquifer were reviewed and a three-dimensional model of ground-water flow was developed. This three-dimensional model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code (10) and has been applied on a limited basis to predict the impacts of transferring waste water from one pond to another. A two-dimensional model of tritium transport in the unconfined aquifer has also been developed based on the CFEST code. The tritium transport model has been calibrated on a limited basis to observed concentrations of tritium in the aquifer.

The ground-water flow and solute transport models were recently applied to evaluate ground-water contamination beneath an inactive waste-disposal facility. As a part of the evaluation of contamination beneath the inactive waste disposal facility, the models were applied to predict ground-water flow and contaminant transport. These predictions of flow and transport were used to evaluate the impact of the contamination, assist with placement of additional monitoring wells, and evaluate a remedial action pumping system.

The ground-water flow and solute transport models are currently being applied to assist with site characterization and monitoring activities for compliance with hazardous waste regulations outlined in the Resource Conservation and Recovery Act (RCRA). The VTT code was calibrated and applied to simulate ground-water flow in the unconfined aquifer beneath a waste facility near the Columbia River (11). Simulations were made to estimate the probable paths of any hazardous chemical transport from the facility, and as a result, locations for additional monitoring wells for regulatory compliance were recommended. The ground-water flow model and a planned solute transport model will be applied to locate and limit the number of additional monitoring wells required. Ultimately, modeling will be used to guide additional site characterization and to support the evaluation of future actions at the site.

MONITORING WELL NETWORK EVOLUTION

During 1987, the site-wide radiological monitoring well network has been changed with assistance from ground-water flow modeling and close attention to waste-disposal practices and inventories for both current and past activities. Analyses and sampling locations were selected based on knowledge of the mobility of various constituents in the subsurface environment at Hanford. Analyses for plutonium, uranium, gamma activity, and ^{90}Sr have been added to the routine monitoring program for wells near potential sources of these radionuclides. Tritium and nitrate will be monitored further from waste-disposal sites because of their mobility and association with large volume liquid waste streams.

In mid-1985, ground-water monitoring at the Hanford Site was expanded to include hazardous chemical analyses for compliance with hazardous waste regulations outlined in the RCRA. Two characterization and monitoring programs were initiated at waste facilities in 1985 and a third in 1986. The site-wide hazardous chemical survey which began in 1985 will provide input to routine site-wide monitoring for chemicals and support a technically sound approach to site-specific hazardous-waste monitoring. Although no wells have been drilled recently for routine radiological monitoring, a number of wells have been constructed for site-specific compliance with RCRA regulations. The placement and completion of these wells are influenced by regulatory compliance, site characterization requirements, and ground-water flow and solute transport modeling.

The design of a reliable monitoring network at a site requires an understanding of the ground-water flow system at the site (12). Because conditions in the unconfined aquifer are significantly influenced by operations at the Hanford Site, model predictions of how operations will affect the direction and rate of ground-water flow and contaminant movement in the unconfined aquifer can be useful in designing the monitoring well network. Planned changes in waste-management practices at the Hanford Site will continue to influence the directions of ground-water flow in the unconfined aquifer. Predictions with calibrated ground-water flow and solute transport models can be used to assess the impact of operational changes on the monitoring well network. Establishing ground-water flow and solute transport models for RCRA sites at Hanford will demonstrate the understanding of the ground-water flow system beneath each facility and assist with the design of monitoring well networks necessary for compliance with RCRA regulations.

CONCLUSIONS

The network of ground-water monitoring wells in the unconfined aquifer beneath the Hanford Site has monitored the impact of waste management practices since operations began at the site during the mid-1940s. The monitoring well network is evolving in response to changing waste-management practices, effluent movement in the ground water, and changing regulatory requirements. Ground-water flow and solute transport models are being applied to assist with the evolution of this monitoring well network.

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