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Project Summary

Investigation of Hydrogeologic Mapping to Delineate Protection Zones Around Springs

Report of Two Case Studies

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Methods commonly used to delineate protection zones for water-supply wells are often not directly applicable for springs. This investigation focuses on characterization of the hydrogeologic setting using hydrogeologic mapping methods to identify geologic and hydrologic features that control ground-water flow to springs to aid in delineating protection zones. These techniques were applied at two public-supply springs selected to represent diverse geologic settings. One spring discharges from a fractured carbonate system and one from a clastic-rock aquifer. Results of this investigation allowed development of the conceptual model for site hydrology and identification of potential constraints on ground-water flow and protective zones at each site. The report discusses results from these case studies and a general methodology for applying these techniques to delineation of protection zones around springs. The hydrogeologic conceptual model resulting from the use of these tools provides the framework for identifying significant data gaps and implementing studies to obtain any additional information required for reliable and practicable protection zone delineation.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Subsurface Protection and Remediation Division, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In the United States, over 3400 public water-supply systems obtain part or all of their drinking water from springs. These systems provide water for more than seven million people. One of the six critical elements of a wellhead protection program is delineation of a scientifically valid protection zone around public water-supply wells and springs. Hydrogeologic mapping may be used at many sites to identify geologic and hydrologic controls on ground-water flow to springs and to locate flow boundaries. Protection zones may be specified based on flow boundaries at sites where the zone of contribution to the spring is practicable to protect.

Hydrogeologic mapping, as applied in this project, refers predominantly to geologic, hydrologic, geochemical, and geophysical techniques for characterizing subsurface features using the surface expression and geophysical or geochemical signatures of such features. These techniques include:

- fracture-trace analysis,
- analysis of land surface topography,
- geologic mapping,
- potentiometric surface mapping,
- geophysical surveys,
- tracer studies,

- stable and radioactive isotope studies, and
- geochemical characterization.

Objective and Methodology

The objective of this cooperative research project was to investigate the use of hydrogeologic mapping to determine the zones of contribution to two springs and application of this information to delineation of potential protection zones at the field sites. Hydrogeologic mapping was chosen as the primary focus for this project because of its applicability as an initial characterization step in many settings that include strongly anisotropic aquifers, such as fractured bedrock. Additional considerations included the relatively low cost and low technological requirements of many of these tools.

The methodology applied in this study integrated information from multiple hydrogeologic mapping methods. An initial conceptual model for each site was developed through review of site-specific literature, principally, documents obtained from state and federal agencies and local universities. Based on this model, potential ground-water flow controls were identified. Applicable hydrogeologic mapping methods were chosen to test assumptions of the conceptual model and delineate geologic and hydrologic controls. Results from these studies were used to locate potential ground-water flow boundaries defining the zones of contribution to the springs and evaluate the effects of potential controls. The results were then evaluated for use in delineating potential protection zones. Monitoring wells were installed at each site to provide lithologic/stratigraphic information and allow limited hydraulic testing. Results of these subsurface investigations were compared with information inferred from the hydrogeologic mapping.

The objective of this report is to evaluate the utility and limitations of the hydrogeologic mapping studies performed at these sites for delineating the zones of contribution and protection zones around the springs. A general methodology for applying such basic characterization techniques is also discussed. The report is designed to aid investigators involved in planning characterization studies leading to the establishment of protection zones around springs.

Results and Discussion

Two study sites were chosen to represent different geologic settings for springs: fractured carbonate aquifers and clastic-rock aquifers. Hydrogeologic mapping methods applied at these sites included geologic mapping (stratigraphic and structural), topographic analysis, fracture-trace analysis, geochemical characterization, isotope studies, and catchment area estimation. Geologic mapping, fracture trace analysis, and topographic analysis were applied in an attempt to infer the extent of aquifers, identify lithologic units that may act as flow boundaries or pathways, map joint patterns or karst features that may act as flow paths, identify faults that may act as flow barriers or flow paths, and identify potential recharge areas. Analyses of ground-water chemistry and tritium activity were used to infer aquifer lithology, potential seasonal fluctuations in ground-water flow paths, and relative ground-water residence times. Estimates of the required catchment area were calculated from spring discharge measurements and potential recharge estimates for comparison with other estimates of the zone of contribution.

Carbonate Aquifer

Olsens Spring, located in Mantua Valley in the Wasatch Range of northern Utah, discharges about 1,700 l/min (1.0 ft^3/s) from jointed Cambrian dolomite. West Hallings Spring, which discharges about 6,400 l/min (3.8 ft^3/s) from a faulted limestone, is located approximately 275 m (900 ft) southwest of Olsens Spring within the same surface drainage basin. These springs are a source of potable water for Brigham City, which has a population of about 17,000. The area surrounding the springs is mostly hilly and mountainous, underlain by a Paleozoic-age stratigraphic section of interbedded limestone, dolomite, shale, and quartzite that has been tilted, faulted, and fractured by thrust faulting and normal faulting. This study focused on Olsens Spring. However, West Hallings Spring and other springs in Mantua Valley were considered during these investigations, as appropriate.

Geologic mapping was conducted throughout the surface drainage basin surrounding West Hallings Spring and Olsens Spring following analysis of fracture traces and lineaments visible in aerial photographs. No faults were mapped in the immediate area of Olsens Spring. However, West Hallings Spring did appear to be located on a fault. Ground-water flow to this spring may be influenced by this feature. Extensive north to northeast trending joints were observed in outcrops throughout the area indicating that ground-water flow may be predominantly controlled by secondary porosity, transmissivity may be relatively high, and that the area surrounding the spring may be vulnerable to contamination from surface sources. No karst features were observed during the geologic mapping. Based on these results, no geologic units sufficiently competent to behave as boundaries to ground-water flow could be identified.

Monthly analyses of physical/chemical parameters (i.e., temperature, pH, specific conductance, and turbidity) in water from Olsens Spring revealed no significant fluctuations and very low turbidity during a one year period. This indicates ground-water residence time was sufficient to mask any variations due to seasonal variation in recharge. Quarterly analyses of major ions were used to determine hydrochemical facies, mineral saturation indices, and calcium/magnesium molar ratios. No significant shifts in hydrochemical facies that could be related to temporal fluctuations in ground-water flow paths were observed. Calcium/magnesium molar ratios were stable and indicated ground-water flow through formations composed largely of dolomite. Calcite saturation indices were generally positive, indicating sufficient residence time for saturation to occur. A potential temporal trend in the calcite saturation index suggested a possible seasonal variation in saturation that may be related to decreases in residence time associated with increased recharge. Analyses of tritium activity indicated the average ground-water age was less than approximately 40 years and, potentially, less than 20 years.

Estimates of the catchment area required to support the combined discharge from Olsens Spring and West Hallings Spring ranged from 10 km^2 (4 mi^2) to 54 km^2 (21 mi^2). The upper limit of this range is significantly larger than the area of the surface drainage basin (approximately 17 km^2 [6.5 mi^2]), indicating that the zone of contribution to these springs may be greater than the drainage basin. However, there is significant uncertainty in estimation of the catchment area.

In order to obtain direct information concerning subsurface conditions and initial estimates of hydraulic parameters, two monitoring wells were installed topographically upgradient of Olsens Spring. Short-term, single-well pumping tests were conducted to obtain preliminary estimates of transmissivity near the wells. Transmissivity estimated from these tests ranged from 270 m^2/d (2900 ft^2/d) to 550 m^2/d (5900 ft^2/d), supporting the conceptual model of a relatively transmissive aquifer near the springs. Results of a tracer study also indicated that ground-water velocity near the springs was relatively high.

These data appear to support the hydrogeologic conceptual model of a system that may be dominated by flow through interconnected fractures. However, additional studies would be required to better define potential conduit flow components. The evidence for this model includes highly fractured bedrock units, stable field parameters, relatively stable water chemistry, very low turbidity, and relatively young ground water. As indicated by hydrogeologic mapping and in situ studies, transmissivity and ground-water velocity near the springs appear to be relatively high. Significant anisotropy may exist due to the dominant north to northeast trending fractures.

Although potential controls on ground-water flow were identified, definite flow boundaries were not located using hydrogeologic mapping techniques. The minimum zone of contribution to Olsens Spring and West Hallings Spring was estimated to be the surface drainage basin. The shallow flow system within the basin may potentially be bounded by ground-water flow divides coincident with the topographic divides. However, the zone of contribution for these springs may be larger than the surrounding surface drainage basin. These data suggest that possible protection zones around these springs should encompass the entire surface drainage basin and may extend beyond the basin boundaries. Additional studies, potentially including installation of a piezometric network and extensive aquifer testing, would be required to better define the zone of contribution and more reliable protection zones around these springs.

Clastic-Rock Aquifer

Sheep Spring is located in southwestern Utah and discharges 7.5 l/min (2 gal/min) from interbedded siltstone, sandstone, and shale. This spring is part of the Santa Clara city water system, which serves about 1520 people, and is representative of many low-flowrate springs used for drinking water in this area. Inflow to the collection tunnel appears to discharge from a sandstone layer approximately 0.5 m (1.5 ft) thick and from joints in units below this layer. The sandstone layer consists of very fine- to fine-grained silty sandstone and interbedded siltstone. Ground water discharges both from joints and pore spaces in the sandstone matrix. This layer appears to be transmitting much of the ground water to Sheep Spring. Minor seeps, other small springs, and vegetation are localized near outcrops of this unit.

Based on topography and review of previous regional studies, the zone of contribution extends north of Sheep Spring. The topographic drainage divide, which may coincide with a ground-water flow divide forming a hydrologic boundary to flow, is approximately 24 km (15 mi) north of the spring. An analysis of fracture traces from aerial photographs was conducted prior to detailed geologic mapping of an area of about 4.5 km^2 (1.75 mi^2) within the potential zone of contribution to Sheep Spring. Although significant, individual fracture traces were not observed near the spring; aerial photographs indicated a pervasive north-trending fracture system exists in this area. The bedrock is highly jointed at Sheep Spring and throughout the zone of contribution. The joints strike approximately north and dip steeply to the east and west. These data indicate that ground water may be vulnerable to surface contamination sources with fractures serving as pathways for rapid transport to the aquifer. The system may also be highly anisotropic due to the predominant north-trending joint orientation.

A seasonal variation in water temperature of approximately 4.5^o C (8.1^o F), which appears to be related to air temperature, was observed during monthly analysis of physical/chemical parameters in water from Sheep Spring. Other physical/chemical field parameters, including discharge rate, did not vary significantly. Water from the spring is a calcium-sulfate type ground water without significant seasonal variation to indicate fluctuations in ground-water flow paths. Average ground-water residence time based on analysis of tritium activity probably was greater than 40 years. Constant discharge rate, relatively constant physical and geochemical parameters, and the relatively low tritium activity are indications that ground water discharging at Sheep Spring may have a relatively long residence time.

Three monitoring wells were installed about 26 m (85 ft) north of the Sheep Spring collection tunnel. Two of the wells were cored through the sandstone layer identified during the surface mapping to provide stratigraphic control and obtain a sample for porosity measurements. Hydraulic conductivity of the formation estimated from rising head slug tests ranged from about 0.04 m/d (0.1 ft/d) to 0.2 m/d (0.6 ft/d). A study conducted by previous investigators estimated a hydraulic conductivity of 0.3 m/d (1 ft/d) based on aquifer characteristics of the same formation and the specific capacity of a well located approximately 4 km (2.5 mi) from Sheep Spring. Results from this study and the previous work indicated hydraulic conductivity in this formation may be relatively low. However, more extensive testing would be required to better define hydraulic parameters and potential anisotropy at the site.

The hydrogeologic conceptual model developed from these studies is one of a spring discharging from a fractured clastic-rock aquifer of low hydraulic conductivity with ground water moving through both primary and secondary porosity. The system may be highly anisotropic with preferential flow along the north-trending joints. Sheep Spring appears to be a local discharge point with a potentially large zone of contribution for ground water with a moderate to long residence time.

This information was evaluated for use in delineation of potential protection zones around the spring. Ground-water flow boundaries near the spring could not be inferred from these studies. Hydrogeologic mapping indicated that the distance to the hydraulically upgradient limit of the potential zone of contribution was approximately 24 km (15 mi) based on analysis of land surface topography. However, a relatively low ground-water seepage velocity may limit the zone of contribution within specified time periods to a much smaller area. Protection zones that cover the entire zone of contribution may be too large to be effectively managed by the water supplier. Other approaches (e.g., ground-water time-of-travel estimates) may be useful in refining the size of the protection zones. For example, using the limited hydraulic data that are available, ground water discharging at the spring may have traveled less than approximately 660 m (2200 ft) within a 15-year time frame. Additional studies would be required to delineate reliable protection zones based on such techniques.

Conclusions and Recommendations

Hydrogeologic mapping provided information on aquifer characteristics including aquifer lithology, vulnerability to surface sources of contamination, boundaries on average ground-water residence times, transmissivity, potential recharge area, and potential geologic/hydrologic controls on ground-water flow. Specific findings and recommendations from these studies are:

1. Hydrogeologic mapping techniques are relatively low cost characterization tools. These methods commonly will provide information essential for conceptual model development, planning subsurface investigations, and defining protection zones based on ground-water flow boundaries. It is recommended that the utility of such techniques be evaluated early in all spring protection zone delineation projects.

2. Development of a conceptual model for site hydrogeology is an essential element in the delineation process. The model serves as the focus for characterization efforts, allowing important assumptions and potential ground-water flow controls to be identified and studied.

3. Applicable hydrogeologic mapping techniques depend on site conditions and the information gaps that are identified. Available techniques include geologic, hydrologic, geophysical, and geochemical characterization tools. Mapping of the ground-water flow system using potentiometric information is an extremely powerful tool that should be used whenever data are obtainable.

4. Ground-water flow boundaries that may serve as boundaries of practicable protection zones around springs may not be definable using only hydrogeologic mapping techniques. Incorporation of additional delineation tools, such as ground-water time-of-travel estimation, and performance of detailed subsurface investigations may be required to define more reliable and manageable protection zones at some sites.

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The complete report, entitled "Investigation of Hydrogeologic Mapping to Delineate Protection Zones Around Springs Report of Two Case Studies," (Order No. XXXX-X; Cost: $X.00, subject to change) will be available only from:

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