HYDROGEOLOGY OF THE WEISER AREA,

WASHINGTON COUNTY, IDAHO

Bruce R. Otto, Allan H. Wylie and Michael J. Martin

SUMMARY

Weiser, a community of approximately 5000 residents lies near the confluence of the Weiser and Snake Rivers in Washington County, Idaho. Unacceptably high levels of nitrate influence the shallow ground water system that lies below the valleys of these two rivers near the community. The Idaho Water Resources Research Institute, Technical Assistance to Rural Ground Water Development In Idaho project team undertook this study in order to define the hydrogeological parameters of the ground water system, and to provide these data to the Weiser focus group, a consortium of organizations that works to mitigate the nitrate problem.

The community of Weiser lies at the northwestern end of the Western Snake River Plain, a regional fault-bound structural depression formed during Neogene time. Clay-rich sediments deposited from a prehistoric lake fill the

depression and form the floor of the shallow ground water system in the study area. The aquifer consists of sands and gravels that reside above the clays on the floor of the Snake and Weiser River Valleys.

Buried paleo-river channels meander through the aquifer-forming strata and describe a complicated array of high-conductivity zones. The axial, coarse-grained parts of this fluvial system could divert ground water flow along the old channels in preference to a more straightforward flow path. Surface contaminants entering this aquifer will reflect this convoluted flow path if it exists.

Most monitoring wells show elevated levels of nitrate, indicating that research should focus on locating the plume boundary. Delineating the plume footprint will help identify sources. Possible sources include agricultural fields, confined animal feeding operations, septic systems, and onion dumps.

Nitrate concentrated in canal water contributes to the total as well, as leakage recharges much of the shallow ground water system. Canal water may accumulate nitrate in either of two ways. Sheet wash during flash flood events may add a substantial quantity of nitrate-laden particulate in the areas of confined animal feeding operations. Also the constant recycling of water from canals, across fields, and back to canals probably adds nitrate to the water. The latter process may help explain nitrate concentrations in ground water on Weiser flat.

We recommend collecting geochemical samples from an array of wells distributed more broadly over the shallow ground water system in order to determine where and how nitrate is added. Samples of water from canals following intense storm events will provide an understanding of the influence from surface sheet wash events.

INTRODUCTION

The community of Weiser lies at the confluence of the Weiser and Snake Rivers in Washington County, Idaho (Figure 1). Agriculture provides the primary business in the area, and includes mostly row-crops with an increasing quantity of confined animal feeding operations. Chronically elevated levels of nitrate in ground water occur in monitoring wells throughout the area. Numerous groups, including the Idaho departments of Agriculture, Environmental Quality, and Health, and concerned individuals and businesses in the area are researching the problem. These researchers operate under the umbrella of a focus group led by the Idaho Department of Environmental Quality (IDEQ). The focus group asked the Idaho Water Resources Research Institute (IWRRI) Technical Assistance for Rural Ground Water Development in Idaho project team to assist in their effort to understand and mitigate the nitrate contamination issue. After considering the problem and research completed to date, the project team concluded that the focus group could benefit from an analysis of geologic factors that constrain ground water distribution and flow in the Weiser area. This report summarizes data and conclusions derived from the study, which focused on how the stratigraphy and structural geology of the Weiser basin influence ground water distribution and flow.

(Figure 1 near here)

Statement of Problem

The community of Weiser derives domestic water from a combination of wells and treated surface water. Most rural residents in the surrounding area derive their domestic water from wells. Nitrate levels above the maximum U.S. Environmental Protection Agency (EPA) limits occur pervasively throughout the area creating a health risk.

IDEQ ranked the Weiser basin as the number one Nitrate Priority Area in the state primarily because of progressively increasing levels of nitrate in ground water over the last several years.

Objectives

This study was undertaken in order to provide the community of Weiser and surrounding rural areas with hydrogeologic information that defines areas of ground water recharge and natural controls on flow direction. An accurate understanding of these phenomena will lead to a better understanding of how and where agricultural contaminates such as nitrate enter and flow through the ground water system.

GROUND WATER DEVELOPMENT CONCEPTS

Ground water occurs and moves through interconnected fractures and intergranular pore space in an aquifer. It moves under the force of gravity in an aquifer from higher elevation recharge areas to lower elevation discharge areas. Most recharge results from infiltration of precipitation, though some occurs from streams, lakes, canals and irrigation at elevations higher than the water table. Typical discharge areas include springs, streams and lakes. Ground water moves slowly, generally less than 10 feet per day.

Subsurface geology provides strong controls on water movement within an aquifer. Therefore, an understanding of the subsurface distribution of unconsolidated sediment, lithified rock, faults, and their physical properties generally leads to a commensurate understanding of ground water flow systems. Mapping surface rock outcrops and reviewing logs of material penetrated by wells helps interpret these features.

Ground water pumping impacts the balance between natural recharge and natural discharge within an aquifer. Well operation lowers ground water levels, which in turn reduces natural discharge. The basis for proper ground water development requires characterizing natural ground water discharge from springs and seeps, knowing the discharge of interconnected streams, and understanding the quantity and location of annual aquifer recharge. Additionally, municipal water supplies need a recharge zone protected from contamination because pollutants can mix with ground water and contaminate the municipal supply.

GEOLOGY

Regional Geology

The community of Weiser lies at the northwestern end of the Western Snake River Plain, a regional fault-bound structural depression formed during development of the basin-and-range province. Researchers debate the time basin formation initiated, but most agree that it started forming at least by late Miocene time, and it continues today. Exposures of basalt temporally correlative with the Miocene-age Columbia River Group occur along both sides of the basin, and have been intersected by deep drilling within the depression. The basin apparently subsided faster than the Snake River could carve an escape route so water pooled, forming paleo Lake Idaho (Figure 2). The lake extended from approximately Twin Falls in the southeast to Weiser in the northwest, and over much of eastern Oregon as well. Fluvial and lacustrine sediments that occupy the basin indicate the lake underwent two stages of filling and sedimentation. Erosion during a period of low lake level separates the two cycles of sedimentation. The Chalk Hills formation represents the earliest filling stage while the Glenn’s Ferry formation represents the latter. Researchers conclude that the lake lasted some 6 or more million years, and that the hiatus between these two filling stages lasted approximately one million years (Smith, et al, 1982).

(Figure 2 near here)

Clay and silt dominate the sediments in the interior of the lake while sand and conglomerate beds derived from marginal areas accumulated nearer shores. Figure 3 shows the names and time distribution of these sediments.

(Figure 3 near here)

Project Area Geology

Columbia River basalts cover much of Washington County and form a paleogeographic feature called the Weiser Embayment (Fitzgerald, 1982; Figure 3). Well-exposed basaltic lavas form the hills east of town and probably occur at depth under the Weiser area. Lacustrine sediments of the Idaho Group overlie the basalt and form the exposed strata in the study area. The base of the Idaho Group occurs unconformably above the basalt sequence in the Crane Creek area east of Weiser at an elevation of approximately 3600 feet. These exposures show a basal unit of rounded basaltic cobbles in a matrix of basaltic sand. The basal conglomerate grades up-section to medium-grained arkosic sandstone, thence to clay-rich lacustrine beds with interlayered arkosic sand lenses.

Clay- and sand-rich beds exposed at Weiser correlate with the lacustrine beds at Crane Creek and with lithologically similar strata to the southeast, throughout the Western Snake River Plain. The sediments at Weiser have not been subdivided so their formational affiliation remains unknown. Some drillholes in the Weiser Flat area penetrate over 900 feet of the sediments without encountering the underlying basaltic lavas.

Stratigraphy

Sediments of Lake Idaho

Lacustrine and fluvial sediments of the Idaho Group underlie the study area (Figure 3; Plate 1). The sediments generally show little or no lithification, except locally, where quartz was deposited from hydrothermal fluids. Sandy and gravelly fluvial sediments near Weiser occur near the top of the section, within and above clay-rich lacustrine strata. The sands and gravels were deposited in channels and deltas from streams that propagated across the lakebeds during times of low water level. The channeled sand lenses commonly show a northeast to southwest elongation. Regionally this orientation parallels pre-Tertiary fault patterns, so the fluvial beds may have been deposited in fault-controlled drainages with similar orientations.

Faulting and erosion during and since Pleistocene time modified the exposed upper surface of the Idaho Group. Isopachs of strata younger than the Idaho Group sediments reveal intricate patterns of paleo channels and meander scars carved into the Idaho Group, which were later filled by younger sediments (Plates 1, 2 and 3).

The generally clay-rich sediments of the Idaho Group form a poor aquifer because of their low hydraulic conductivity. Most wells in the Weiser basin terminate at or near the interface between these clay-rich strata and overlying unconsolidated river sediments. Subsurface contours (Plates 2 and 3) show the shape of this contact throughout the study area. Wells that penetrate the clay beds locally acquire water from interlayered sand lenses. Water quality in these lenses varies significantly. If sand lenses connect directly to external recharge then the quality of water may be better than if the lenses acquire water from surrounding clay-rich sediments or from hydrothermal fluids.

Terrace Gravels

Two discrete periods of faulting interrupted gravel deposition along the Weiser River. Elevated terraces, formed originally as stream and flood plain deposits, were later isolated from the active river channel by faulting (Plate 1). The oldest terraces reside approximately 200 feet above present river level and show strong geomorphic modification and dissection by erosion. The dissected terraces generally form grasslands with locally preserved flat areas utilized as pastures and dryland agricultural fields. The younger, lower terraces reside approximately 50 feet above present river level. The well-preserved flat morphology of these terraces provides areas for row crops.

The best example of the lower terrace level occurs southeast of Weiser, along the south side of the Weiser River. The active flood plain of the Weiser River borders this terrace on the north and east; an older terrace defines the southern margin, and a northwesterly trending fault marks the western side (Plate 1; Figure 4). This fault displaced strata down to the west, so the westerly extension of the terrace now occurs in the substrate beneath Weiser Flat.

(Figure 4 near here)

Ground water is scarce and locally difficult to acquire on the upper terraces due to a lack of adequate recharge and low aquifer storage capacity. The lower terraces enjoy slightly increased aquifer thickness and increased recharge via canals and irrigation. Gravel and sand beds in the correlative down-faulted strata below Weiser Flat form the primary aquifer west of Weiser. The Weiser Flat area receives greater recharge via canals, irrigation and natural stream drainages compared to correlative strata on the higher terraces.

Active River Flood Plain sediments

Deposits of unconsolidated sediments occur on the geologically active flood plains along the Snake and Weiser Rivers. The deposits include gravel, sand, silt and clay. The coarser sedimentary fraction such as gravel and sand probably accumulated in or adjacent to channels while the finer silt and clay fraction probably spilled over riverbanks during flood events and deposited further from the active channels. Migration of the river through time incised the upper surface of the Idaho group sediments and created an intricate network of anastomosing sediment-filled paleo channels. Some of these old channels form sloughs and ponds, visible in Figure 4, while correlated water-well logs indicate the locations of older channels that have no surface expression. Plate 2 shows locations of these older meander scars and Plate 3 indicates that the post-Idaho Group sediments that fill the paleo channels are generally thicker than adjacent contemporaneous flood-plain deposits.

A low-lying alluvial fan occurs at the mouth of Monroe Creek (Plate 1, Unit QTf). The feature probably formed from deposition of material carried by Monroe Creek during flash flood events. Monroe creek is presently dissecting the fan, but a flash flood event in this watershed could easily restore the depositional process within town. The fan forms a slightly higher area than the surrounding flood plains of the Weiser and Snake rivers so is somewhat less prone to river flooding induced by annual snowmelt. Dissection of the fan probably ensued after a base level change caused by down faulting along the Weiser fault.

A combination of the unconsolidated flood plain deposits and older down-faulted terrace gravels form the primary aquifers along the Snake River south of Weiser, along the Weiser River and along the lower reaches of Weiser Flat Plate 1). The water table map (Plate 4) shows that water is evenly distributed and gently inclined in the areas of the Weiser River valley and on Weiser Flat. Water table contours along the Snake River flood plain south of Weiser show a more diverse pattern, which appears to mimic the shape of the structure contours on the Idaho Group and the isopach contours of overlying sediments. The similarity of these patterns may indicate that the paleo meander scars exercise strong control on ground water flow in this area.

Structure

Structures greatly influence the topography and hydrogeology of the Weiser area. Lava flows of the Columbia River Group and the strata of the Idaho Group in this area owe their distribution to the presence of an extensive network of normal faults. The faults form two distinct populations based on strike orientation. Northwesterly trending faults form the northeastern margin of the western Snake River Plain. They generally dip and displace strata down to the southwest. Northeasterly trending faults help form the landscape near Weiser and may control the linear distribution of sand beds in the Idaho Group.

Northwest faults

Northwesterly trending faults exposed east of Weiser juxtapose the Columbia River basalt sequence and sediments of the Idaho Group. This study identified a parallel fault that forms the eastern margin of the Snake River flood plain south of Weiser. The fault drops Idaho Group sediments down to the west, exposing the lacustrine sequence along a prominent steep embankment that parallels the River (Figure 4). Fault movement over-steepened this embankment, precipitating slope failure and landslides (Figure 5). Offset gravel beds identified in well logs define the northwesterly extension of this structure. It lies beneath the city of Weiser, so is herein named the Weiser fault.

(Figure 5 near here)

The Weiser fault shows no historic activity based on geomorphic evidence. The down-faulted gravel terrace in Weiser flat and landforms such as the over-steepened embankment show geologically recent movement. The correlation of the down-faulted gravels with similar strata on the lower terrace south of the Weiser River (Plate 1; Figure 4) indicates an offset of approximately 100 feet since the gravels accumulated.

The Weiser fault forms the eastern boundary of the Snake River floodplain south of Weiser. The Snake River meandered across the floodplain many times in the past, but was unable to progress easterly past the fault scarp. Paleo Snake River channel-filling sediments, described above, lie against the fault scarp. The escarpment forms a near-perfect eastern hydrologic barrier to ground water flow in this part of the Snake River Valley.

Northeast faults

Northeasterly trending faults occur throughout much of the Rock Mountain cordillera. Stratigraphic and structural studies demonstrate that these faults were active as early as Proterozoic time, previous to 580 million years ago. Reactivation of these faults through time helped control the development of topographic surfaces and the distribution and style of sedimentary strata deposited on those landscapes. Sand beds in the Idaho Group northeast of Weiser show a northeasterly elongation that probably resulted from deposition in structurally controlled channels.

A northeasterly trending fault located at the west end of Weiser flat displaces strata down to the southeast. This fault, herein named the Indian Head fault (Plate 1) terminates the west end of the Weiser Flat aquifer. Relatively impermeable strata of the Idaho Group, including silicified sandstone and clay beds, lie west of the fault while unconsolidated fluvial sediments occur to the east. These unconsolidated sediments form the energetic aquifer beneath Weiser flat and the clay-rich strata west of the fault form the western hydrologic boundary.

HYDROGEOLOGY

Regional Hydrogeology

The Western Snake Plain contains a complex system of shallow, and deep aquifers. Shallow aquifers often supply water to domestic rural wells and some irrigation systems. Larger municipalities, industrial, and some irrigation wells generally draw water from deeper aquifers.

The shallow aquifers typically consist of unconsolidated sediments that overlie the Idaho Group (Figure 3). In the Weiser area these aquifers generally lie less than 10 ft from land surface. Ground water enters these shallow aquifers from precipitation, infiltration from canals and irrigated areas, or infiltration from river and stream channels. Shallow aquifers frequently contain localized flow systems such as from irrigated fields to the nearest drainage ditches, although some extend tens of miles. Intimate connection between shallow aquifers and surface water sources increases the likelihood that chemicals used at land surface will enter the shallow aquifers.

Surface water irrigation generally results in a net increase in ground water because some water seeps into the ground from fields and leaky canals. According to the Digital Atlas of Idaho (http://imnh.isu.edu/digitalatlas/) irrigated agriculture occupies about half of the land in the Treasure Valley, of which about 74 percent is irrigated with surface water. It follows that agricultural irrigation supplies a significant amount of the ground water in the Weiser area.

Transgressive or regressive sequences in the Idaho Group host deeper, more continuous regional aquifers that underlie the shallow aquifers. This regional system extends throughout the valley, with ground water flowing in a generally westerly direction (Digital Atlas of Idaho; http://imnh.isu.edu/digitalatlas/). Water enters the regional system at the basin margins or from downward infiltration of surface irrigation or precipitation. Water resides in these regional aquifer systems a long time, so will acquire the chemical and thermal characteristics of surrounding strata. Consequently deep aquifers in the western Snake River Plain frequently yield warmer, metal-laden water relative to their shallower counterparts.

Project Area Hydrogeology

Ground water flow systems in Idaho GROUP strata

This study provides a better understanding of where and how agricultural contaminants enter the ground water system. Clay-rich lacustrine sediments will inhibit agricultural contaminants from percolating down to the deep Idaho-Group aquifers, so contaminants will concentrate in the shallow aquifers. There are relatively few wells that derive water from Idaho Group-hosted aquifers, and hydrothermal water influences many of these wells (discussed below).

Ground water flow systems in active flood plain sediment

The shallow aquifer along the Weiser River consists of gravel and sand on the active flood plain and is generally less than 20 feet thick (Plate 3). It derives water from the Weiser River and from irrigation. This aquifer probably contains numerous local flow systems allowing water to frequently transition between the river and the gravel aquifer as it flows down gradient to the Snake River.

Aquifers in the two terrace levels reside above where they could acquire water directly from the river. The thickness and distribution of these aquifers is highly variable. Water must come exclusively from canals, irrigation, precipitation, and by infiltration from natural drainages such as Scott and Jenkins creeks. Local residents claim that water levels in wells rise quickly after the canals begin to flow in the spring indicating that irrigation plays a large role in the water budget for these aquifers. Such an intimate connection with surface water leaves the ground water flow systems vulnerable to contamination from agricultural practices as well as other activities.

Hydrothermal water flow systems

Ground water in local flow systems generally approximates the mean annual air temperature while ground water in regional flow systems shows affects of the geothermal gradient (Fetter, 1994). Weiser maintains an annual average temperature of 50.2° F (NWS; http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?idweis). Wells that show temperatures greater than 60° F are therefore probably influenced by the geothermal gradient.

Logs from a total of 257 wells in the study area record accurate temperature and lithologic data. Table 1 shows the number of wells that contain hydrothermally influenced water in each aquifer. These statistics, based on an arbitrarily chosen temperature threshold of 60° F, show an affinity of hot water to the Idaho Group aquifers; however, no apparent correlation exists between drill hole depth below the top of the Idaho Group and temperature. This probably results from low vertical conductivity in clay-rich strata combined with a weak hydrothermal system.

(Table 1 near here)

Widespread occurrences of silicified arkosic sandstone of the upper Idaho Group attest to the former widespread presence of hydrothermal activity in the Weiser Basin, and some hot springs still occur in the area. Weiser hot springs, one of the better-known hydrothermal systems, lies in the northwestern part of Weiser Flat, and St. Marie et al (2002) describe other nearby areas with hydrothermal resource potential.

Broken rock concentrated along the intersections of faults commonly provides the plumbing necessary to allow deep hydrothermal fluids to migrate upward. Weiser hot springs lies near the intersection of the Indian Head and the Weiser faults. The intersection of these faults may explain the location of the thermal system, and other occurrences of thermal water in the Weiser basin may utilize similar plumbing systems along unmapped faults. Strata, bleached and altered from the flow of thermal water, occur to the east and northeast of Weiser. Alignment of the altered zones suggests that northeasterly faults play a crucial role in locating both ancient and modern hydrothermal systems.

Analysis of water quality data

Many administrative agencies collect water quality samples in the Weiser area, including the Idaho departments of Agriculture, Environmental Quality, and Water Resources. Compiled data from these agencies indicate growing nitrate concentrations. Figure 6 shows the nitrate concentrations observed in 1996. The larger bubbles in these plots indicate nitrate concentrations at or above minimum EPA drinking water limits. Figure 7 shows the nitrate concentrations observed in 2002. The maximum observed concentration increased from 23 μg/L to 30 μg/L between 1996 and 2002. The concentration increased markedly on Weiser Flat, in the western part of the study area.

(Figures 6 and 7 near here)

The state agencies also sampled for pesticides including Simazine. Sevin, Metoachl, Diazinon, Atrazine, and Alachlor. Figure 8 presents the results for Alachlor. The other pesticides show a similar distribution, with the same two wells receiving pesticide hits just above detection limits. Perhaps these results indicate well construction problems. In any case, they do not indicate that pesticide use represents a general threat to the aquifer.

(Figure 8 near here)

DISCUSSION OF RESULTS

Three types of aquifers occur in the Weiser area; terrace gravels disconnected from major waterways, shallow unconsolidated sediments above strata of the Idaho Group, and sedimentary beds within the Idaho Group (Plate 1). Problematic nitrate concentrations occur primarily in the shallow unconsolidated-sediment aquifer, on which this discussion will focus.

Paleo channels occur buried along the Snake River flood plain. Similar to the Snake River today, these old channels meander back and forth across the flood plain, describing a complicated substratal geometry. Gravel and sand filled the channels while fine-grained sand, silt, and clay accumulated along the over-bank reaches of the old channels. The axial, coarse-grained parts of this fluvial system probably have higher hydraulic conductivity, so could divert ground water flow along the old channels. If these flow patterns exist surface contaminants entering this aquifer will reflect this potentially convoluted flow path.

A combination of precipitation, irrigation, leakage from canals, and infiltration from rivers and streams recharges the shallow aquifer. Though the influence from each is unknown, the quick response time between when the canals are filled in the spring and static water level rise in wells indicates that the canal system is a primary recharge component. Infiltration from irrigation likely contributes a substantial quantity as well.

Most monitoring wells show elevated nitrate levels. This indicates that plume boundaries have not been adequately explored, so delineating these boundaries should become a priority. Delineating the boundary will help identify possible sources and focus abetment efforts on critical areas. Several possible sources exist, including agricultural fields, septic systems, confined animal feuding operations, and onion dumping grounds.

Several potential mechanisms may explain how the nitrate enters the ground water system. Shepherd and Lord (1996) indicate that nitrate leaching from agricultural fields can be significant. Poor well design could allow contaminated surface water to flow directly into the aquifer. Fertilizer applied to farmlands, effluent from agricultural facilities, or nitrate from buried degrading vegetation such as onions, could percolate downward into the ground water system.

Nitrate concentrations in leaky canal water would add to the total as well. Canal water starts its journey from relatively clean river water, though land and water usage along the system will progressively degrade its quality. Sheet wash during flash flood events, to which this area is prone, will add a substantial quantity of particulate to the canal. The particulate could locally contain high concentrations of nitrate if the source were from confined animal feeding operations such as along the Galloway Canal. Constant recycling of water from canals, across fields, and back to canals will add nitrate to the water. This process may help explain elevated nitrate concentrations in ground water on Weiser flat.

CONCLUSIONS AND RECOMMENDATIONS

Most nitrate contamination in the Weiser area occurs in the shallow aquifer that resides in fluvial strata directly above lacustrine Idaho Group sediments. This aquifer derives its water primarily from canals and irrigation and subordinately from streams and direct precipitation.

Agricultural practices probably provide the largest supply of nitrate to the shallow ground water system. The nitrate probably enters the ground water through a combination of mechanisms, including poorly sealed wells, leaky canals, infiltration from fields and confined animal feeding operations, degrading buried vegetation, and domestic septic systems. The relative contribution from each is not known. Shepherd and Lord (1996) found that the growth of cover crops before spring crops were the single most effective technique at reducing nitrate leaching from agricultural fields.

Continued water sampling in the same monitoring wells, though probably necessary, will only confirm what is already known. A sampling program strategically designed to define whether nitrate-loading results from point or non-point sources would foster a better interpretation of contamination in the ground water. This could be accomplished by simultaneously sampling an array of wells covering a large area such as Sunnyside that tests both thick and thin zones in the shallow aquifer (See Plates 2 and 3).

Water leaking from Canals could contribute nitrate to the ground water from particulate loading during flash-flood sheet-wash events. Sampling of canal water below potential sources of contamination after flash flood events would address this possibility.

If additional onion dumps are constructed, they should be built out of the flood plain in clay-rich strata of the Idaho Group. The uppermost terrace shown on Plate 1 as unit Tg1 would be a good location.

ACKNOWLEDGEMENTS

The authors accept responsibility for the interpretations expressed in this document. These views do not necessarily reflect those of the University of Idaho, IWRRI, the United States Environmental Protection Agency (USEPA), or any other institution. Rather, they reflect our opinions as shaped by our observations and experiences in the field, interpretation of the scientific and technical literature and our understanding of input provided by our colleagues and representatives from the community of Weiser, Idaho.

This work was funded through grant number X97008601 from USEPA region 10 to the University of Idaho Water Resources Research Institute and the Idaho Geologic Survey. We thank representatives from Weiser for their contributions, the Idaho departments of Environmental Quality and Agriculture for their assistance during the study, and the Idaho Geologic Survey for providing peer reviews and publishing this work.

REFERENCES CITED

Fetter, C.W., 1994, Applied Hydrogeology. Prentice Hall, Upper Saddle River, New Jersey.

Fitzgerald, J. F., 1982, Geology and basalt stratigraphy of the Weiser embayment, west-central Idaho, in Bonnichsen, B. and Breckenridge, R. M. editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 103-128.

Shepherd, M.A. and Lord, E.I., 1996, Nitrate leaching from a sandy soil: the effect of previous crop and post-harvest soil management in an arable rotation. Journal of Agricultural Science, Cambridge University Press v 127, p 215-229

Smith, G. R., Swirydczuk, K., Kimmel,P.G. and Wilkinson, B.H., 1982, Fish biostratigraphy of late Miocene to

Pliocene sediments of the western Snake River Plain, Idaho, in Bonnichsen, B. and Breckenridge, R. M. editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 519-541.

St. Marie, J. L. Mink, Neely, K., 2002, Examination and evaluation of geothermal sites in the State of Idaho with emphasis given to potential for electrical generation or direct use: Idaho Water Resources Research Institute project report.

LIST OF FIGURES

Figure 4: Aerial photograph of the area immediately south of Weiser. The northwesterly trending light colored linear embankment that bisects the photograph is the escarpment of the Weiser fault.

Figure 5: Photograph showing the headwall of a landslide block. The slide occurs along the escarpment of the Weiser fault, located a few miles south of Weiser. This feature and others are visible from Highway 95.

Figure 6: Concentrations of nitrate in samples collected in Year 1996.

Figure 7: Concentrations of nitrate in samples collected in Year 2002.

Figure 8: Wells sampled for Alachlor.

LIST OF TABLES

LIST OF PLATES