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THE POTENTIAL FOR GROUNDWATER CONTAMINATION ALONG BASIN MARGINS IN THE ARID WEST: ALLUVIAL FANS AND LAKE FEATURES

by

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ABSTRACT

Many towns of the arid west were built upon alluvial fans and upon sites underlain by Pleistocene lake deposits. The objective of this study was to assess the potential impact of the activities of man upon groundwater quality within these geological features. Emphasis was placed on shallow groundwater quality after it was determined that deep groundwater is rarely contaminated at such sites.

A reconnaissance of Utah and Nevada was made and four sites underlain by alluvial fans (Willard, Manti, Elsinore, and Spring City) and four sites underlain by lake shore deposits (Hyde Park, Fielding, Providence, and Richmond) were selected in Utah for more detailed geologic, hydrologic, and water quality studies. Samples for water quality analyses were taken from existing wells and springs where available. At Hyde Park a shallow, small diameter well was constructed. Three groundwater sampling wells were constructed on the Willard Creek fan. Sites were selected to represent various degrees and types of land use.

It was concluded that septic effluents, agricultural wastes, and other sources of man-made contamination can be hazards to shallow groundwater quality in alluvial fans and lake shore sediments. Mercury was found in concentrations exceeding the EPA drinking water standards at a few of the sites, but its source was probably natural. Nitrates and phosphates usually were the observable indicators of shallow groundwater contamination at the sites investigated, while coliform bacteria evidently are not transported appreciable distances underground and made poor indicators. The conclusions reached in this report are believed to be applicable to other areas of the arid west where similar geologic features and basin margin sediments occur.

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INTRODUCTION

Problem Statement

Growing population increases the demand for water and produces more waste materials. In the arid intermountain area, the growth has concentrated on the basin margins below the steep mountain slopes which generate most of the runoff and above the flat valley bottoms generally characterized by impervious fine-grained soil layers and, particularly in closed basins, by accumulated soil salinity.

Where surface streams and reservoirs are lacking, increasing the water supply to accommodate growth requires fuller utilization of groundwater storage. Development of this resource requires wells to pump from the underlying aquifer, recharge where the aquifers are exposed to the surface at the basin margins, and protection of the recharge water from pollution loadings from sewage and runoff from urbanized areas. Thus groundwater development requires particularly careful management because the growth which increases water demand tends simultaneously to lead to paving over recharge areas and exposing those remaining to contaminated water.

Careful management requires a good understanding of underground conditions. Basin margin areas in Utah are characterized by two distinct geomorphic regimes: 1) areas underlain by alluvial fans; and 2) areas formed or altered as a result of Pleistocene Lake activity, most notably the activity of Lake Bonneville. Consequently, this research project was divided into two phases in order to study shallow groundwater contamination in each regime.

Alluvial fan deposits

Many towns in Utah have been built upon alluvial fans. Municipal, domestic, and some farm wastes are being generated on those fans; and increased amounts of groundwater are being used from aquifers recharged by these fans. An appraisal of this potentially hazardous situation is urgently needed before the public health becomes endangered. A study of this problem for making recommendations for minimizing groundwater contamination is one of the chief purposes of this investigation.

Alluvial fans are unique geologic structures but they are fairly common in the arid west. Unpublished research by members of the Department of Geology at Utah State University has shown that alluvial fans formed by different depositional processes should have distinctly different characteristics of groundwater flow. Therefore, in this study, different types of alluvial fans were examined in an attempt to determine the primary depositional process involved in their origin as well as the potential and actual amounts and sources of groundwater contamination in each.

Lake features

Features related to Lake Bonneville and other Pleistocene lakes of the arid west are either erosional or depositional. Many of the valley bottoms in northern and central Utah as well as other arid states are underlain by lake sediments of fine-grained silt and clay. Peripheral areas of many of the valleys show the extensive influence of the lakes in the form of deltas, bars, spits, beaches, and other shoreline deposits. An excellent example of a large, elongated sand bar, produced through the action of longshore currents, is located a few miles south of Tooele, Utah. Similar geologic and climatologic features are found in other nearby arid basin states. Although this study was conducted mostly in Utah, the results apply also to those areas.

Project Objectives

The general objective of this investigation is to gain a better understanding of the relationships between overlying land use on recharge areas of alluvial fan or lake deposits, underground water movement, groundwater use, and contamination. Specifically, the objectives of the project are as follows:

A. Alluvial fan aquifers

1. To determine from the published literature and from information on other research in progress what is currently known about the contamination of groundwater in arid basins with emphasis on alluvial fan aquifers.

2. To select specific sites for study using the following guidelines:

a. Type and degree of development on fans by man. In order to determine the influence of different types and degrees of development, the following categories were used:

1) Undeveloped, natural areas with no apparent sources of contamination;

2) Some agriculture and/or feedlots;

3) Scattered housing with septic tanks and private wells;

4) Extensive urban development with city water systems and septic tanks or city sewer systems; and

5) Industralized.

b. Geographic location. Sites chosen for detailed study were located in Utah within a reasonable distance of the Utah Water Research Laboratory (UWRL) in Logan for accessibility and for the sake of getting water samples to the laboratory for analysis the same day of collection.

c. Type of fan. Because the depositional processes which form alluvial fans have a large influence on their internal structures and, therefore, on their hydraulic characteristics, fans were classified as follows:

1) Fans built chiefly by mudflows;

2) Fans built chiefly by braided-flow streams; and

3) Fans built by both braided-flow streams and mudflows.

3. To study groundwater flow in alluvial fan aquifers at selected sites.

4. To identify and characterize the water recharging the alluvial fan aquifers; to identify natural water sources (e.g., snowpack, direct rainfall and infiltration, intermittent and perennial streams), and determine the water quality. This provides a standard with which to compare down-gradient water quality.

5. If groundwater contamination exists, or could develop, in any of the study areas, to identify the problem and the type of contamination.

6. To experiment with simplified drilling and well-construction techniques and to sample the completed wells in order to arrive at practical specifications for test wells and sampling.

B. Lake feature aquifers

1. To determine from the published literature and from other research what is currently known about the contamination of groundwater in lacustrine deposit aquifers of arid basins.

2. To select specific sites for study based on the following criteria:

a. Geographic location. Sites chosen for detailed study were located in Utah, within a reasonable distance of the UWRL, Logan, for accessibility and for the sake of getting water samples to the laboratory for analysis the same day of collection.

b. Location with respect to type of lake features, i.e., beach or shoreline deposit, or lake-bottom deposit.

3. To determine the quality of water recharging the shallow aquifers, so as to have a standard against which down-gradient water quality could be compared.

4. To determine the water quality in shallow aquifers to see if a contamination problem exists. If a problem does exist, to identify the problem area and the type of contamination.

RESEARCH PROCEDURE

Literature Search

Very few references were found which directly addressed groundwater contamination in alluvial fan aquifers, although the investigation included two computer searches, which scanned tens of thousands of technical reports. The best results were obtained by use of the "Selected Water Resources Abstracts" published by the Water Resources Scientific Information Center, Office of Water Research and Technology, U.S. Department of the Interior.

While few references dealt directly with the subject of this report, numerous technical references were found that were related to the various facets of this investigation. These references generally fit into three principal disciplines; namely, geology, groundwater hydrology, and water quality. More specifically, the geologic publications included the general geology of alluvial fans and arid basins of the western United States, as well as groundwater movement in such geologic structures and their associated geologic formations. The hydrologic publications included the quantitative aspects of groundwater hydrology and the design, distribution, and use of test wells. Water quality publications covered all phases of the origin, transport, detection, and impact of contaminants in groundwater. These latter two broad categories were studied and applied in this investigation to the specific environments of arid basins in Utah. Publications used as background material for this investigation are listed alphabetically by authors in the Selected Bibliography included as Appendix D, wherein they are separated into the three broad headings mentioned above.

Particularly noteworthy among the geologic publications (see Appendix D) were the works of Denny (1965), Hooke (1967), Price (1974), and Wooley (1946). Denny and Hooke have presented excellent summaries of alluvial fan formation, sedimentation processes, dimensions and other fan characteristics. Price (1974) dealt especially with the internal fabric of alluvial fans. Wooley (1946) gave valuable information on the nature of mudflows and how they are related to cloudbursts and described historic mudflows at Manti and Willard, Utah.

A wide range of related topics were covered in the section on groundwater hydrology of Appendix D. Tolman (1937) presented excellent sections on the geology and hydrology of alluvial fans that provided much of the background information needed for this study. Two publications, one by Diefendorf and Ausburn (1977) and the other by Spaulding et al. (1976), contributed useful principles related to groundwater monitoring wells and well sampling. Fryberger and Bellis (1976) presented a model of natural flushout of alluvial aquifers which was helpful in understanding groundwater flow in alluvial fans. Basak and Murty (1978) described diffusion in groundwater and its relationship to contaminant concentrations.

A wide variety of material related to water quality (see Appendix D) was found, the majority of which were U.S. Environmental Protection Agency (EPA) publications. Among the more useful EPA publications was the series "Monitoring Groundwater Quality," which included publications titled "Monitoring Methodology," "Methods and Costs," "Data Management," and "Economic Framework and Principles." Dunlap et al. (1977) proved helpful in the selection of materials for use in well and sampling apparatus construction to insure representative, uncontaminated groundwater samples. The reference by Lehr et al. (1976) was informative as to the laws, regulations, and institutions that are concerned with the control of groundwater pollution. Warner (1975) provided several monitoring well system principles, which were incorporated into this study. Karubian (1974) estimated the effects of man's activity on groundwater pollution.

Outside of EPA publications, Fried (1975) gave excellent coverage to all aspects of groundwater pollution, and was particularly good with respect to theory. The American Public Health Association's guidelines for water sample analysis "Standard Methods for the Examination of Water and Wastewater, 14th Edition" (1975) were followed for all samples tested.

Alluvial Fans Reconnaissance

Alluvial fans are formed by two principal depositional processes; i.e., by braided-streamflow and by mudflow/debrisflow/sieveflow deposition. Deposits of these processes may be interspersed in various proportions at a given fan. Fans built dominantly of braided-flow and sieveflow deposits are generally steeper and are more permeable than fans constructed of mudflows and debrisflows. Accordingly, alluvial fans formed by different depositional processes or the same processes in different proportions range widely in groundwater flow characteristics.

In examining a given fan, information was sought on 1) the relative proportions of the various deposits, 2) the kinds of human development and surface contamination present on the different kinds of fans, and 3) the effectiveness of different deposits in restricting downward flow of surface contaminants or in reducing their effects through physico-chemical reactions or dilution.

A reconnaissance was planned to inventory the origins of large fans within one day's driving distance of Logan, Utah. U.S. Geological Survey topographic maps and Landsat (EROS) photographs were used to select fans with different degrees of human development and potential surface contamination. The reconnaissance was conducted for the purpose of selecting several representative sites for pilot studies. A total of 6 days of intensive field work was required to complete the reconnaissance. Ten fans were selected for further investigation from the preliminary reconnaissance. Visits to these fans reduced the number to four selected as most suitable for detailed studies.

Field Studies

After selecting four suitable alluvial fans in the reconnaissance, the objectives of the more detailed field studies were:

1. To examine the structure of each selected alluvial fan in as much detail as possible, short of drilling exploratory holes.

2. To determine the location and depth of wells on each fan and the availability of each well for obtaining water samples. Drilling records obtained from the State Engineer's Office contained subsurface information about the internal structure of each alluvial fan and the distribution of aquifers within each fan.

3. To determine surface features on the alluvial fans that would affect existing groundwater quality and recharge. Of prime importance were the identification and location of features such as waste settling ponds, dumps, septic tanks, feed lots, agricultural activity, etc. All these features are considered to be potential sources of groundwater contamination. Septic tanks and agricultural activity are probably the most common of these possible sources of contamination.

4. To outline, carefully examine, and describe the recharge areas and internal fabric of each selected fan. It is essential for a thorough study of groundwater contamination in a fan to have accurate information as to quality and quantity of the recharge water.

5. To obtain groundwater samples for chemical and bacteriological analyses. Samples from the recharge areas were needed as standards against which down-gradient samples can be compared.

6. To construct and monitor a few test wells as a pilot study.

Water Quality

All chemical, physical, and bacteriological analyses of groundwater samples collected for this investigation were done at the Utah Water Research Laboratory. The following sampling and analytic techniques were used in this study.

Bottles used for sample collection were prepared at the UWRL and taken to the sample site for collection. One 3.8 liter (1-gallon) polyethylene bottle (rinsed with dilute HCl followed by three rinses of distilled water) was used at each sampling station. The bottles were rinsed thoroughly with sample water on site prior to filling. Specially manufactured and sealed, sterile, plastic bags were used to collect the bacteriological samples and small vials with screw caps were used for the samples to be analyzed for trihalomethanes. No on-site rinsing was required for these specific sample containers. Water samples were packed on ice in the field and returned as quickly as possible to the UWRL where the analyses or adequate preservation were immediately begun.

Following sample coding and pretreatment (filtration through 0.45 μm membrane filter and/or preservation), analyses were performed on the bag samples for coliforms and on the other samples for orthophosphates, total alkalinity, nitrate, nitrite, pH, mercury, and ammonia. On some occasions the analyses of nitrates and nitrites were postponed until the following day. When this was necessary, the samples were preserved with chloroform. The analyses for calcium, chloride, iron, magnesium, potassium, sodium, sulfate, total hardness, and total dissolved solids were completed within 7 days using the methods listed in Table 1.

Table 1. Analytical methods used.

Analysis	Method
Total hardness	EDTA Titrimetric. S. M.[a] p. 202
pH	pH electrode. S. M. p. 460
Total alkalinity	Potentiometric. S. M. p. 278
Total dissolved solids	Gravimetric. S. M. p. 82
Chloride, dissolved	Titrimetric $(HgNO_3)_2$. S. M. p. 304
Sulfate, dissolved	Turbidimetric $(BaCl_2)$. S. M. p. 496
Phosphate, ortho-	Ascorbic acid. S. M. p. 481
Ammonia	Indophenol. S. M. p. 416
Nitrate	Cadmium reduction, diazotization (automated). S. M. p. 620
Nitrite	Diazotization (automated). S. M. p. 620, p. 634
Calcium	Titrimetric (EDTA). S. M. p. 189
Magnesium, dissolved	Calculated from calcium and total hardness
Iron, dissolved	Atomic absorption. S. M. p. 148
Mercury, dissolved	Atomic absorption. (cold vapor). S. M. p. 56
Potassium, dissolved	Atomic absorption,[b] direct aspiration. Method 258.1
Sodium, dissolved	Atomic absorption,[b] direct aspiration. Method 273.1
Coliforms	Membrane filter. S. M. p. 928

[a]S. M. = Standard Methods for Examination of Water and Wastewater, 14th Edition. APHA (1975).

[b]Methods for Chemical Analysis of Water and Wastes. USEPA, March 1979.

CHARACTERISTICS OF ALLUVIAL FANS

Structural Framework

An alluvial fan is a landform built over a long period of time by the deposition of alluvium where a stream emerges from a mountain canyon onto a broad valley floor. The typical fan is shaped like a flattened cone with its apex at the canyon mouth and a curved surface which radiates outward and downward from the apex to form a distinctive fan shape as seen in plan view. A profile of the land surface across an alluvial fan and parallel to the mountain range is always convex upward, while a radial profile is typically concave upward and is usually divided into three distinguishable slope segments. The steepest segment is at the apex, where the stream often incises its channel into this uppermost sector of the fan. The next segment represents a broader area of intermediate slope where much alluvial deposition occurs. Finally, the flattest slopes are found in a very broad, curved area approaching the toe or periphery of the fan. Often these three areas grade imperceptibly into one another as well as into the broad valley floor surrounding the toe of the fan.

Alluvial fans are usually very thin over the areas they encompass, but many attain sizable thickness as they are built up in unison with interfingering thicknesses of valley alluvium surrounding their toes. The largest fan observed in this study covered an area of 342 km^2 (132 mi^2), whereas the average fan covered only about 26 km^2 (10 mi^2).

When several closely spaced streams emerge from a mountain range, their fans coalesce laterally to form an undulating alluvial slope, flanking the mountains, called a bahada. Alluvial fans and bahadas are found mainly in arid and semiarid regions because of the infrequent but highly intense storms, which characterize those regions. The most favorable settings for alluvial fans appear to be along active fault-line escarpments. Alluvial fans are most common in the mountainous, arid west for these reasons. Alluvial fans also form at sharp decreases in slope and reduction of confinement in arctic climates and, less often, in humid-temperate climates.

Streamflow onto alluvial fans varies from almost clear-water, braided-streamflow carrying small amounts of suspended sediment to viscous mudflow and debrisflow. The resulting deposits vary from lenticular beds of well sorted sand and gravel to poorly sorted mud and alluvial debris that can include boulders weighing many tons. These two extremes in depositional characteristics provide a range that can be used in the classification of alluvial fan deposits.

At a given site, some flood flows, usually larger ones occurring after a long dry period providing sufficient time for large amounts of detritus to accumulate in the tributary catchment, can be characterized at the mudflow end of the spectrum, while other storm events carry much smaller sediment loads. Some fans, however, are characterized by events principally at one end of the spectrum, whereas the opposite conditions tend to prevail at the other sites. The mixture of events, the processes of fan development, and the resultant characteristics of the deposits depend largely on the source rocks and climate. Various geologic and climatic factors determine the composition and grain sizes of sediments available, the types of chemical weathering and disaggregation, and the processes of transportation and deposition.

As a stream passes from a steep, narrow canyon onto a broad valley, the abrupt change in lateral confinement and gradient allow the flow to spread out and slow down, which causes deposition of sediment. Also deposition will occur when a stream, passing over permeable materials, loses water by infiltration underground. This is called sieveflow deposition. In both of these cases, coarser-grained sediments are normally deposited near the apex and progressively finer materials are deposited downstream as the slope of the stream bed and the sediment carrying capability of the flow diminish.

In contrast to the above situation in which the water transporting the sediment deposits large sediments first as it loses its transporting power, the water in a mudflow provides the lubrication which permits viscous flow of a soil-water mass. On the fan, additional solid material is entrained while some water is lost from the mass until the whole becomes too stiff for further flow and movement stops. The mixed material contrasts with the segregation by grain-size found in braided-flow deposits. Nevertheless both types of deposits in the apex area generally have coarser-grained sediments, that provide better conditions for the infiltration of water.

As a fan grows by some combination of the two processes, each big flood usually results in a change in course for the stream and a subsequent build-up of sediments in yet another sector of the fan. As the fan grows the older stream beds are repeatedly covered and new channels are formed. Beyond the active channels sheet-flood and mudflow deposits may be interspersed laterally over the fan, all of which generally radiate outward and downward from the apex. On inactive parts of many fans, radial, branching, commonly braided, relict distributary channels remain. Also, channels that head on the fan gather runoff that falls directly on the fan or adjacent mountain slopes. Such channels dissect the inactive portions of the fan and may form subsidiary fans.

Braided-flow fans generally are steeper than adjacent mudflow/debrisflow fans associated with similar areas of drainage, reliefs of drainage, and types and amounts of precipitation. Braided-flow fans themselves tend to be steeper for larger grain size, lower peak discharge, lower suspended sediment concentration, higher relief of drainage area, and smaller drainage area. The largest boulder size, the average pebble size, and average overall grain size decrease downfan on braided-flow fans. Particle sizes greater than 0.3 m (1 ft) are seldom transported. Distinct layers 0.02 m to 0.5 m (1 in to 1.5 ft) thick are often laterally discontinuous, and exhibit channel scours, distinct sorting, grading, and parallelism of elongate clasts or upstream imbrication.

Mudflow/debrisflow/sieveflow fans locally exhibit individual lobes that can be convex upward with steep toes, margins, and natural levees. Grain sizes can show little statistical change downfan through distances of 8 to 10 km (5 to 6 mi) in part because larger flows carry larger particles and tend to go farther than smaller flows. Maximum boulder sizes larger than 9 m (30 ft) in diameter are reported. Deposits are distinctly layered, 0.05 to 5 m (2 in to 15 ft) thick, locally are continuous through more than 200 m (600 ft) downfan, and show little or no sorting or graded bedding. Open pores, from air bubbles and decayed plant material, and ephemeral clay-formed bonds retard compaction in the shallow layers of mudflow/debrisflow fans. These open structures enhance differential subsidence (hydrocompaction) during prolonged surface wetting. Mudflow deposits are typically chaotic in grain-size distribution, whereas braided-stream deposits exhibit various degrees of sorting. Because of this, mudflow/debrisflow deposits normally are much less permeable to water.

In arid or semiarid regions, mudflow is a much more effective means of sediment transport than the usual stream flow. Mudflow has been recognized more widely in recent years for its major role in the formation of alluvial fans.

Groundwater Regimen

The natural flow patterns of groundwater within an alluvial fan are determined by the structural makeup and internal geometry of the fan, the recharge situation, and the infiltration into underlying materials. Groundwater movement is controlled by the detailed nature of the framework through which it moves as well as the imposed hydraulic gradients. The groundwater regimen is also controlled by the varying amounts and distribution of water available for recharge and the conditions under which water may escape from the lower reaches of the fan. It is difficult to generalize as the flow of groundwater differs so widely from one fan to another. Each fan requires a separate study to determine its individual regimen of groundwater flow. Even then the understanding of the subsurface flow can be no better than the scientific data obtained for a particular investigation.

Infiltration and recharge

Alluvial fan recharge is largely supplied by the stream which formed the fan. This stream normally provides continuing (but fluctuating or intermittent) deposition of alluvial materials which build the fan and furnishes water for recharge. Because of this continual recharge, fans often contain higher quality groundwater than surrounding alluvial formations. Recharge by the principal stream of the fan is accomplished through infiltration of water from the main channel, from the channels of any distributaries, and from infiltration from flooding on the general surface of the fan when streams overflow their banks. Also there is often a significant underflow in the alluvium beneath the principal stream bed as it emerges from the mountains at the apex of the fan. Other natural sources of recharge to alluvial fans include direct infiltration of precipitation on the fans and infiltration of runoff from minor drainages and hillsides flanking the fans.

The works of man often contribute considerable amounts of recharge to alluvial fans through irrigation systems, canal seepage, pond leakage, and municipal water supply and sewerage systems. Whether or not these systems use imported water, the end result is greater recharge to the aquifers of the alluvial fans than would have occurred naturally.

Natural recharge takes place mainly by infiltration near the apex areas of a fan, where the alluvium is generally coarser-grained and, therefore, more permeable. For this reason the uppermost portions of fans or apex areas are also called the intake areas. Additional infiltration of water from the principal stream and from any of its distributaries may take place downstream from the intake area as long as water flows in those channels. Recharge from man-made systems occurs wherever those systems permit infiltration of water.

Coarser-grained alluvium, however, may occur anywhere on a fan. Occurrences away from the apex often represent former stream channels or coarser materials deposited on the surface of the fan in times of extreme flooding. Such deposits may be found at any depth in the fan, where they have been covered by subsequent deposition. Coarser-grained materials do not always have higher permeabilities, such as in the case of mudflow deposits which contain a very large portion of fines mixed with the coarse materials.

Percolation

The internal fabric or hydraulic framework of alluvial fans is typically heterogeneous and lenticular in cross section, but because of the general flow of streams and floods depositing sediments down the fan surfaces radiating from the apex area, there is more radial continuity in both the water-bearing formations (aquifers) and in the non-water-bearing formations (confining members). Often buried stream beds form highly permeable conduits through which the groundwater moves rapidly. Many times these conduits and other more permeable formations are confined within relatively impermeable formations. Generally in the intake area the infiltrating water is unconfined. Then, as water percolates downward and radially outward beneath the main body of the fan, it passes into aquifers between confining members. Usually the land surface slopes downward and outward more rapidly than the hydraulic gradient of the confined groundwater. This situation gives rise to artesian conditions in water wells which tap those confined aquifers in the intermediate portions of a fan, called the conduit zone. Above the confining layers, there is often an unconfined shallow aquifer which receives recharge directly from the land surface (and from septic tanks if present). This water percolates toward the toe of the fan in higher conduit zones as does the deeper, confined water below it.

Discharge

As these unconfined and confined groundwaters approach the toe of the fan (called the discharge zone), the aquifers which transmit them may outcrop allowing the waters to escape freely from the ground, forming springs. When the aquifers do not outcrop, confined groundwaters may find their way to the land surface through zones of weakness or through discontinuation of the confining beds. Accordingly, it is characteristic for fans to have springs or seeps in the areas of their discharge zones. The tendency for groundwater to rise to the surface in the discharge zone of a fan is often augmented by impervious subsurface structure or saturated groundwater conditions in adjoining alluvial formations. Where the opposite conditions prevail, alluvial fans act as sources of groundwater recharge to the surrounding arid-basin alluvial or lacustrine deposits.

Groundwater Contamination

Natural sources of groundwater contamination in alluvial fans are presumed to be rare for they would have to be caused by abnormally high concentrations of deleterious substances in the discharge of the principal stream or in the mineral composition of the fan itself.

By far the greater potential for groundwater contamination is from man-made sources. These can be located almost any place on the surface of the fan can contribute any of a number of contaminants. Sources are particularly serious if they introduce contaminants into the principal stream of the fan either within or upstream from the intake area (for instance, by mining or agricultural activities). Contaminants which infiltrate in the intake area are much more likely to penetrate the deeper, confined aquifers and thus become more widely distributed within a fan. Fortunately, the intake areas of fans are relatively small and often have not been attractive areas for the activites of man (partly because of the hazard of flash floods and mudflows). Accordingly, extensive, deep-seated contamination is not common in alluvial fans, although the apex areas are particularly vulnerable.

Contamination introduced below the apex areas is less likely to penetrate to the deeper strata. However, these areas are large and provide desirable sites for a wide range of man's activities. Thus, contamination can become a very serious problem where fans are heavily populated or used in any way where contaminants are permitted to go underground. Most often the contamination reaches only the shallow, unconfined aquifers and then percolates toward the toe of the fan without going appreciably deeper because of the presence of confining strata. The phenomena of dispersion and diffusion cause the plume of contamination to spread and enlarge as it moves radially down-gradient toward the toe of the fan. Whether the groundwater is confined or not, the shape of the plume can become highly irregular due to local variations in permeability and hydraulic gradient. If contamination enters a buried, permeable stream bed, the plume of contaminated water can become highly elongated within this virtual conduit of fast moving water and emerge below in springs.

In the upper reaches of fans, contaminated water can enter deeper strata through improperly constructed or improperly abandoned water wells. Contaminated waters can be forced deeper by recharge (of either contaminated or uncontaminated water) on top of the original contamination. Altogether, a wide variety of situations involving contamination can arise in the groundwater regimen of alluvial fans. Furthermore, contaminated water can escape from fans in the artesian discharge areas of fans and threaten downstream water supplies.

Underground dilution increases the volume of contaminated water. Except for waters reduced by dilution to concentrations considered to be below contamination levels, the groundwater becomes unfit for use. In closed basins the contamination can never leave the basin in which it is generated. In fact, it can be concentrated by evaporation in playas or wherever it may be discharged to the land surface by natural or man-made means. In well-drained basins, it is undesirable to have contaminated groundwater discharging into surface streams or entering the underflow of such streams to contaminate downstream water supplies.

Some contaminants may be filtered out of groundwater by the fine-grained constituents of alluvial fan aquifers or removed by adhesion, adsorption, and related physicochemical phenomena. Factors which affect filtration ability include length of travel, elapsed time, concentration of contaminants, and amount and duration of contaminants previously passed through the same aquifer. Due to the heterogeneous grain-size distribution in most fans, it is very difficult to predict filtering or adsorptive effects.

The capacity of alluvial aquifers to remove contaminants is limited by the fact that most of the permeability occurs in pockets of coarse grained material. Once contamination reaches the groundwater reservoir, the a hazard remains for a very long time and removal is costly. The phenomena of dispersion and diffusion make it difficult to remove contaminants totally because of the volumes of water required for dilution and the fact that any displacing waters also become partially contaminated. Groundwater contamination is better removed by interception and disposal than by dilution and flushing. Better yet, preventive measures are far less expensive than remedial measures.

RECONNAISSANCE AND CLASSIFICATION OF ALLUVIAL FANS

In the selection of alluvial fan sites for more detailed study, possible sites were identifed from maps of promising regions of Utah and Nevada. Reconnaissance field trips were then made to gather sufficient information to define the important features of the observed alluvial fans and to make possible a preliminary classification of them.

Reconnaissance

U.S. Geological Survey topographic maps of Utah and Nevada at a scale of 1:250,000 and EROS black-and-white IR photos were obtained for preliminary fan identification. From the maps, 76 large, promising, alluvial fan study sites were located--48 in Nevada and 28 in Utah. These potential study sites were screened to conform to certain criteria. They were to be within one day's driving time of Logan, Utah, and near major paved roads and settled communities, for access, supplies, lodging, and communication. The surface morphology needed to be well-formed cover of a sufficiently large area to justify study. The sites should show little effect of Lake Bonneville, i.e., the fan toe should be near or above 1580 m (5200 ft) in altitude, or there should be evidence of considerable, recent, rapid fan development. Varied apparent uses should be visible such as undeveloped, farming, towns, and industry.

Three reconnaissance trips, totaling 6 field days, resulted in descriptions of 28 potential sites for further study (see Figure 1). Sufficient detail was collected for evaluation and is included in Appendix A.

Evaluation and Classification

For the reconnaissance trips, a fan classification matrix (Table 2) was established, based on: 1) whether the fan

Table 2. Matrix used to classify fan-like features identified in the reconnaissance study. Numbers represent fans located in Figure 1.

TYPE AND DEGREE OF DEVELOPMENT	ESSENTIALLY UNDEVELOPED	MINOR ALTERATION (e.g., RANCHES, HOMES WITH SEPTIC TANKS)	CULTIVATION/FEED LOTS/ORCHARDS/ OTHER CHEMICAL	HOMES WITH SEWERS/OTHER NONINDUSTRIAL	INDUSTRIAL AND OTHER URBAN
COMPOSITION OF FAN[a] MF >> BF	14	6 12 25 26 28	11 18 (toe)	18 (midfan) 20	
MF ≈ BF	7 8	5 15 (head) 27	15 (SW toe)		
MF << BF	1 2 3 21	4 23			
THIN FAN OVER DELTA OR LAKE SEDIMENTS	9			13 22 24	
DELTA OR OTHER SHORELINE	16	9 10 17		19 (LANDSLIDE)	
PEDIMENT AS A MAJOR COMPONENT	1 3				

[a]MF = mudflows, debrisflows, and sieveflows; BF = braided-stream flow. Some fans exhibit dual features and appear twice in the matrix.

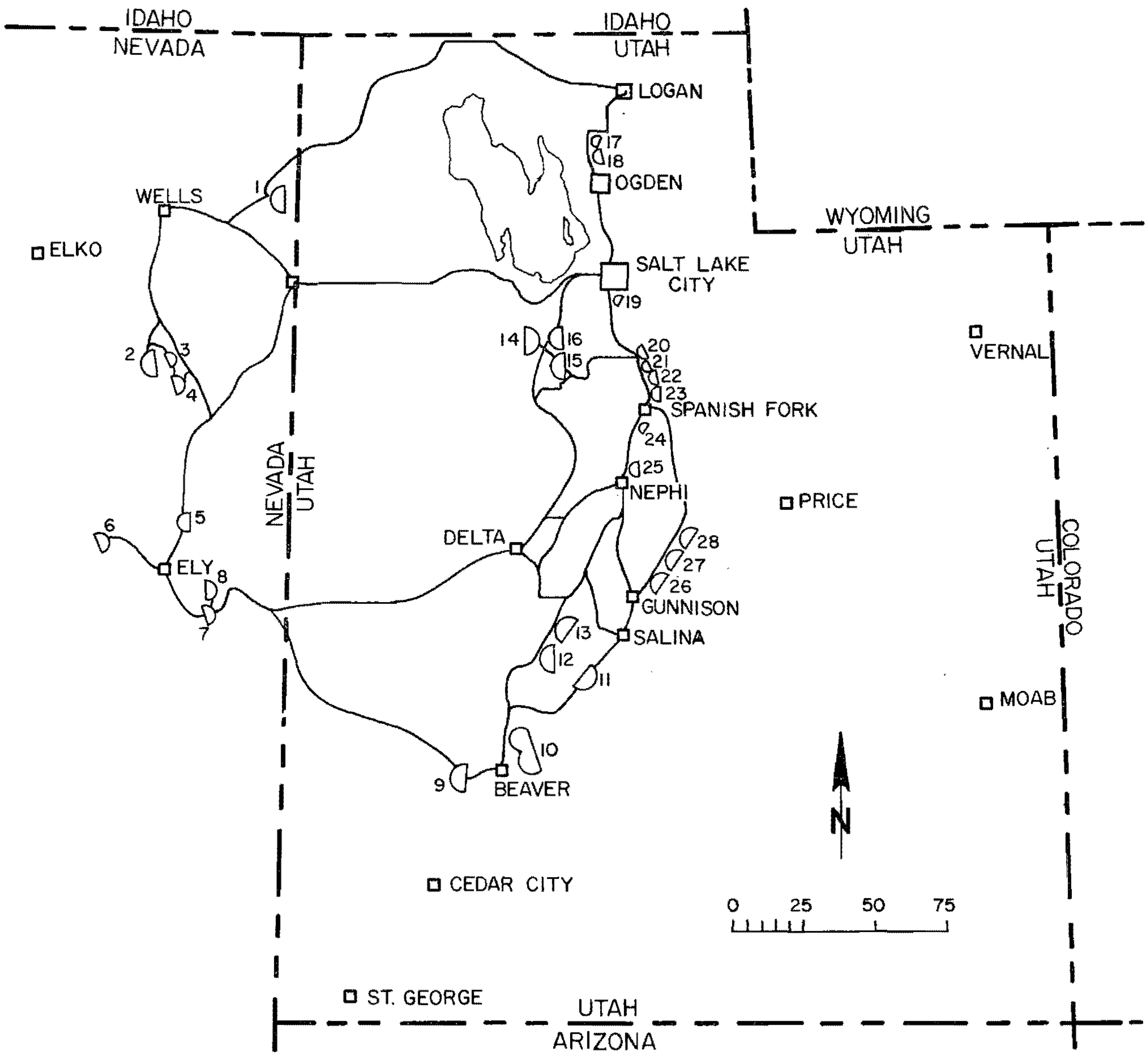

Figure 1. Sites of fan-like features identified for reconnaissance study and described in the field notes. (See Appendix A.) (Solid lines are major roads of access to these features.)

consists dominantly of mudflow/debrisflow (MF) deposits, braided-flow (BF) deposits, or approximate equality of both; and 2) degree of man-made developments, i.e., essentially undeveloped, farming, towns, and industry.

Evaluation led to the rejection of sites 9, 10, 16, 17, 22, and 24 as lake deltas, although 9 had a small fan on its north flank. Fan 13 is badly dissected and affected by Lake Bonneville; fans 21 and 23 are too small and, respectively, too steep or too dissected; fan 19 is completely developed (access difficulties), small, and located in part on a landslide. The double fan 20 is dissected, strongly modified at the two canyon mouths, and is partly affected by Lake Bonneville. Most types of fans are present in Utah in a convenient circuit, so fans in Nevada were given lower priorities for convenience, economy, and total travel time.

The reduced matrix of study sites in Table 3 shows few fans that are dominantly braided-flow (BF) and only a modest number that are about equally mudflow (MF) and BF. No suitable fans were located with major industrial development. It is surmised that the railroads have avoided the steeper sloping fan surfaces and used the valley bottoms instead, and that subsequent industrial development to date has been along the railroads.

The final selection of fans for more complete study is shown in Table 3. Because of the few fans in Utah with dominance of braided-flow deposits and the distance from Logan to the more remote Nevada braided-flow sites, it was decided to concentrate this study on fans consisting primarily of mudflow deposits and to select six or seven fans to study representing a variety of land use. Preference was given to those larger fans with minor erosional dissection. Seven Utah fans were selected but further examination led to exclusion of one (No. 22) that was only a thin veneer over deltaic and lake deposits (Table 3).

The most thorough study with sampling of water from wells was made of fans 11 (Flat Canyon), 18 (Willard Creek), and 26 (Manti Canyon). Water samples also were obtained from fan 28 (Spring City). Ten field days were required. Results of these more detailed studies and analyses of the water samples are reported in a later section.

Additional Search for Suitable Study Sites

Topographic maps of adjacent states were studied to locate other potential sites for study, partly in the hope of locating fans with industrial developments. In western Colorado, northern Arizona, southwestern Wyoming, southern Idaho, and southwestern Montana, 41 alluvial fans were located for possible future evaluation.

Conclusions

No fans were located with major industrial development in Utah. Maps of the semiarid states show that alluvial fans are grouped along one or both sides of certain mountain ranges and poorly developed or absent throughout large areas elsewhere. It is surmised, from the sharp topographic breaks along mountain fronts where fans and coalesced fans (bahadas) are abundant, that active fan development is mostly restricted to areas of rather recent tectonic activity.

Table 3. Fans selected for more detailed study and sampling of water. Numbers represent fan located in Figure 1.

TYPE AND DEGREE OF DEVELOPMENT	ESSENTIALLY UNDEVELOPED	MINOR ALTERATION (e.g., RANCHES, HOMES WITH SEPTIC TANKS)	CULTIVATION/FEED LOTS/ORCHARDS/ OTHER CHEMICAL	HOMES WITH SEWERS/OTHER NONINDUSTRIAL
COMPOSITION OF FAN[a] MF >> BF	14[b]	6 (Nev.) 12 25[b] 26[b] 28 (?)	11[b] 18[b] (toe)	18[b] (midfan) 20
MF ≅ BF	7 (Nev.) 8 (Nev.)	5 (Nev.) 15[b] (head) 27	15[b] (SW toe)	
MF << BF	2 (Nev.)	4 (Nev.)		

[a]MF = mudflows, debrisflows, and sieveflows; BF = braided-stream flow.

[b]Denotes 6 fans selected for more detailed study; fan 22 was also originally selected but proved, upon further examination, to be a thin veneer over deltaic and lake sediments, and therefore was excluded.

LAKE FEATURES

Introduction

During much of Pleistocene time, and probably earlier, northern and western Utah was occupied by large lakes. The last, Lake Bonneville, occupied the Bonneville Basin during the last major glacial stage of the Pleistocene Epoch, known as the Wisconsin, which began about 75,000 years ago. At its maximum, the lake occupied approximately 52,000 km^2 (20,000 sq mi), and was almost 305 m (1,000 ft) deep. Today, relics of ancient Lake Bonneville are the Great Salt Lake, Utah Lake, and Sevier Lake.

History of Lake Levels

The level of Lake Bonneville fluctuated through time with changes in climate. These changes in lake level are etched in the topography and sediments of the Bonneville Basin area. G. K. Gilbert (1890) set up a chronology of Lake Bonneville which was modified by Hunt et al. (1953) and by Feth et al. (1966). A summary of the chronology is given below.

The first significant stage of Lake Bonneville, known as the Alpine stand, was at an elevation of about 1,550 m (5,100 ft). That lake level or stand evidently was constant for a considerable length of time, during which the deposition of gravel and sand as beaches, deltas, spits, and other shoreline and offshore deposits took place. In deeper water throughout most of the basin, silt and clay were deposited. Wave and current action was also responsible for large-scale erosion of pre-existing alluvial or lake deposits. The littoral and offshore currents eroded away large volumes of sediment and carved the bedrock mountain fronts. Thus, when the lake level subsided, the Bonneville Basin was covered by a thick deposit of gravel, sand, silt, and clay, called the Alpine Formation. In other areas, bedrock was exposed, or only a thin veneer of Alpine deposits was present.

With a change in climate, the basin again filled, this time 30 m (100 feet) above the Alpine level, to its highest level, known as the Bonneville stand. Red Rock Pass at the north end of Cache Valley then became Lake Bonneville's only outlet and the reason the lake couldn't rise higher. The Bonneville stand was short lived and its principal deposits are shoreline and near-shore gravels and sands near the Bonneville level at 1,580 m (5,200 ft).

The rock which initially dammed Lake Bonneville at Red Rock Pass eroded away. When the rim collapsed, the less resistant, underlying material quickly washed away, creating one of the largest prehistoric floods known. The lake level dropped 120 m (400 ft). Gilbert (1890) estimated that the lake dropped to the Provo level of 1,460 m (4,800 ft) in less than 25 years. It is not known how long the lake remained at the Provo level, but extensive shoreline, near-shore, and deep-water deposits blanket much of the basin area.

Between 90 and 170 m (300 and 350 ft) below the Provo level, another conspicuous shoreline is recognized. Because it is especially well developed on Stansbury Island, this stand is known as the Stansbury level. It is thought that this shoreline represents a still-stand as the waters receded from the Provo level.

Deposits of the Lake Bonneville Group

The Lake Bonneville Group of lacustrine deposits is comprised of the Alpine, Bonneville, and Provo members. The Alpine member has three characteristic lithofacies: 1) gravel, 2) sand, and 3) clay, silt, and fine sand. Sand and gravel of the Alpine member are exposed principally in areas close to the mountain fronts, and some of the water in the streams that flow from the Wasatch and Bear River Ranges enters the groundwater reservoir through these deposits.

The Bonneville member forms a series of sand and gravel deposits at altitudes ranging from 1,550 to 1,580 m (5,100 to 5,200 ft), adjacent to the consolidated rock of the Wasatch and Bear River Ranges. As with the Alpine sediments, the well-sorted and uncemented sediments of the Bonneville member are exceptionally receptive to recharge.

The Provo member has three recognized lithofacies: 1) gravel, 2) gravel and sand, and 3) sand. Considerable areas adjacent to the mountain fronts are underlain by gravel and sand of the Provo member. This member is most receptive to recharge.

Sediments of the Provo member form broad benches along the mountain fronts at about 1,460 m (4,800 ft). The coarse material of the Provo formation absorbs water that falls on, or runs across, its surface, such as precipitation or irrigation of farmland, lawns, and gardens. Such recharge percolates downward until it reaches the finer materials in the underlying Alpine member (which had been deposited in deep water during the Alpine stand and later covered with coarse material during the Provo level) and then it moves laterally toward the valley bottoms.

Lake Bonneville with Respect to Cache Valley

The Bonneville shoreline in Cache Valley is etched high on the mountain fronts at an elevation of 1,570 m (5,140 ft). This lower elevation for the Bonneville shoreline in this area as compared with the Salt Lake Valley is the result of less isostatic rebound; that is, less recovery of elevation due to the unloading of the earth's crust by the receding waters. At 1,460 m (4,800 ft), the Provo level creates a broad bench along the eastern mountain front of Cache Valley. Several terraces are present below the Provo level. These have been attributed to short still-stands of the lake. The littoral and offshore currents formed deltas and spits at the southern end of the valley and spits in the area of Bear River Narrows, where the major portion of the lake connected to Cache Valley.

Most of the groundwater in the Utah portion of Cache Valley is recharged by infiltration of water from precipitation, streams, canals, and irrigated fields. Recharge occurs mainly along the margins of the valley where thick, unconsolidated, Bonneville group sediments are exposed and are partially dissected, such as at the Logan River delta.

Possible Areas of Study

The objective of this phase of the project was to study possible contamination of shallow aquifers along the basin margins where recharge and man-made development is greatest. To accomplish this, communities whose locations were within a reasonable distance of Logan and which met the following requirements were sought: 1) well-preserved basin margins structures, 2) a shallow water table, and 3) a possible contamination problem.

Twenty-five communities were selected as possible study sites. These sites were located using topographic maps, air photos, geologic maps, groundwater data, water level maps, and the criteria listed above. After data were compiled on these communities, a series of reconnaissance trips was made to the more promising locations. A list of possible study areas, along with the more promising locations, is given in Table 4.

The most extensive basin margin structures with possible sources of contamination are situated in northern Utah. Shorelines of ancient Lake Bonneville are well-preserved in this area which provides a variety of basin margin deposits for study. For the most part, the communities are small and, although most have water distribution systems, the majority do not have sewerage systems.

Table 4. Preliminary list of possible study sites on lake features.

	Alpine		North Ogden
	Beaver Dam		Oak City
*	Clarkston		Orem
	Deweyville		Penrose
	Edgemont		Plain City
**	Fielding	*	Plymouth
	Garden City	*	Portage
	Garland	**	Providence-Millville
*	Honeyville	**	Richmond
**	Hyde Park	*	Riverside
	Lake Town		Thatcher
	Lynndyl		Tremonton
*	Newton		

* Locations chosen for field reconnaissance.
** Locations chosen for further study.

Another factor considered in site selection was the occurrence of springs in close proximity down-gradient from the towns. These springs provided convenient and valuable sampling points from the shallow groundwater flowing under the town. Contamination produced by the town should be picked up at such springs.

Several areas in the central portion of the state were considered, but were rejected because of the lack of well-developed basin margin features, or because the water table was too far below the land surface and out of reach of the simple drilling methods used in this investigation.

Study Sites Selected

From the 25 possible study sites (Table 4), 10 were found to fit the requirements for this study. Additional study, combined with reconnaissance trips, were used to select four communities for detailed study: Fielding, Hyde Park, Providence-Millville, and Richmond, Utah.

These locations encompass a variety of situations for this study. At the community of Fielding a shallow water table and a lack of a sewerage system in a geologic setting of fine-grained lake bottom sediments permitted the study of groundwater movement and contamination in an area some distance from the basin margin recharge region. Hyde Park and Richmond are both situated on moderately developed basin margin shoreline deposits and both are very similar with respect to areal size, population density, depth to groundwater, and man-made developments. The major difference between them is that Richmond has a sewerage system and Hyde Park does not. The Providence-Millville area was chosen because of its high concentration of homes on well developed shoreline deposits.

From the study of these four locations some insight was gained into the special groundwater contamination problems encountered by Utah communities along the basin margins.

DESCRIPTION OF STUDY SITES

The Willard Creek Fan

General description

Location. The small town of Willard, (in the southeast extremity of Box Elder County and with a present population of nearly 2,000) has been built completely upon the Willard Creek alluvial fan. Figure 2 shows the town, the fan, and the Willard Creek catchment draining onto the fan. U.S. Highway 89-91 passes north-south directly through the center of the town. Interstate Highway 15 and the Union Pacific Railroad cross through the western-most extremity of the fan. Willard Reservoir and the Willard Bay State Park are located west of the interstate highway. Immediately east of the fan is the Wasatch Range and the Cache National Forest. The Ogden-Brigham Canal passes along the foot of the Wasatch Range and crosses the apex of the Willard fan through an inverted siphon.

Elevation. On the west, the margin or toe of the fan is at an elevation of about 1,295 m (4,250 ft) above mean sea level. The average elevation of Willard and the center of the fan is about 1,325 m (4,350 ft) above mean sea level. At its apex, the fan rises to about 1,430 m (4,700 ft) in elevation. Mountain peaks surrounding Willard Canyon average approximately 2,590 m (8,500 ft) and reach as high as 2,960 m (9,700 ft). Accordingly, Willard Creek has an extremely steep gradient for its short total length of about 6.8 km (4.2 mi) above the apex of the fan. Willard Creek heads at a spring at an elevation above 2,650 m (8,700 ft) near the southern extremity of its drainage area.

Geology. The Willard Creek fan is an elliptically shaped, undissected, alluvial fan covering an area of about 4.1 km^2 (1.6 mi^2). The fan has been built by the deposition of sediments from Willard Creek since the recession of Lake Bonneville at the beginning of Recent or Holocene time. These sediments have been washed from the approximately 13 km^2 (5 mi^2) of rugged mountainous terrain, just east of Willard, that comprise the drainage basin of Willard Creek. This perennial stream has transported a wide variety of sediments produced from the weathering and erosion of the several types of bedrock and alluvium found in that small basin. From a study of the deposits on the land surface, it is evident that the primary mechanism of transport and deposition of the fan deposits has been by mudflow. Lesser deposition of water-borne, braided-stream sediments has taken place intermittently in the process of fan development.

Although the fan is rather undisturbed, its formation was is complicated by the fact that it is situated upon a dissected lake delta obviously formed by the same stream during the Pleistocene Epoch when Lake Bonneville was at its Provo level and possibly at earlier levels. This ancient delta was dissected upon recession of the lake. Thus some of the earlier fan deposits are composed of reworked delta deposits. Segregation of these delta and early fan deposits is virtually impossible. This is especially evident along the western toe of the fan where the stratigraphy is further complicated by interrelated lake deposits.

On the land surface, a prominent remnant of the delta exists on the northeast flank of the fan just north of its apex, and a small remnant persists just south of the apex. The Willard fan is further complicated by a small alluvial fan at its southeast extremity, evidently built primarily of mudflow deposits by the intermittent Cook Creek.

The abrupt, steep face of the mountains immediately east of Willard is attributable to a profound zone of normal faults which extends many miles both north and south of Willard. Vertical displacement on this Wasatch fault zone has to be in excess of 2,700 m (9,000 ft) as the bedrock to the east of the fault rises at least 1,500 m (5,000 ft) above Willard Bay and the basin sediments are known to extend to at least 1,200 m (4,000 ft) beneath the land surface near Brigham City about 3.7 km (6 mi) to the north. This fault has been largely responsible for the formation of the Willard Creek fan and delta as well as many other fans, deltas, and other basin-margin deposits along its escarpment by the gradual up-thrust of the mountain compared to the valley floor.

Other significant faults occur eastward within the drainage area of Willard Creek. These are ancient thrust faults which have brought great sections of bedrock up from the west to override the bedrock formations seen in the mountain face at Willard. Practically all of the Willard Creek drainage area is underlain by the over-thrust sections of bedrock. These thrusts have caused repetition of bedrock formations in the Willard Creek watershed. The principal thrust fault is called the Willard thrust.

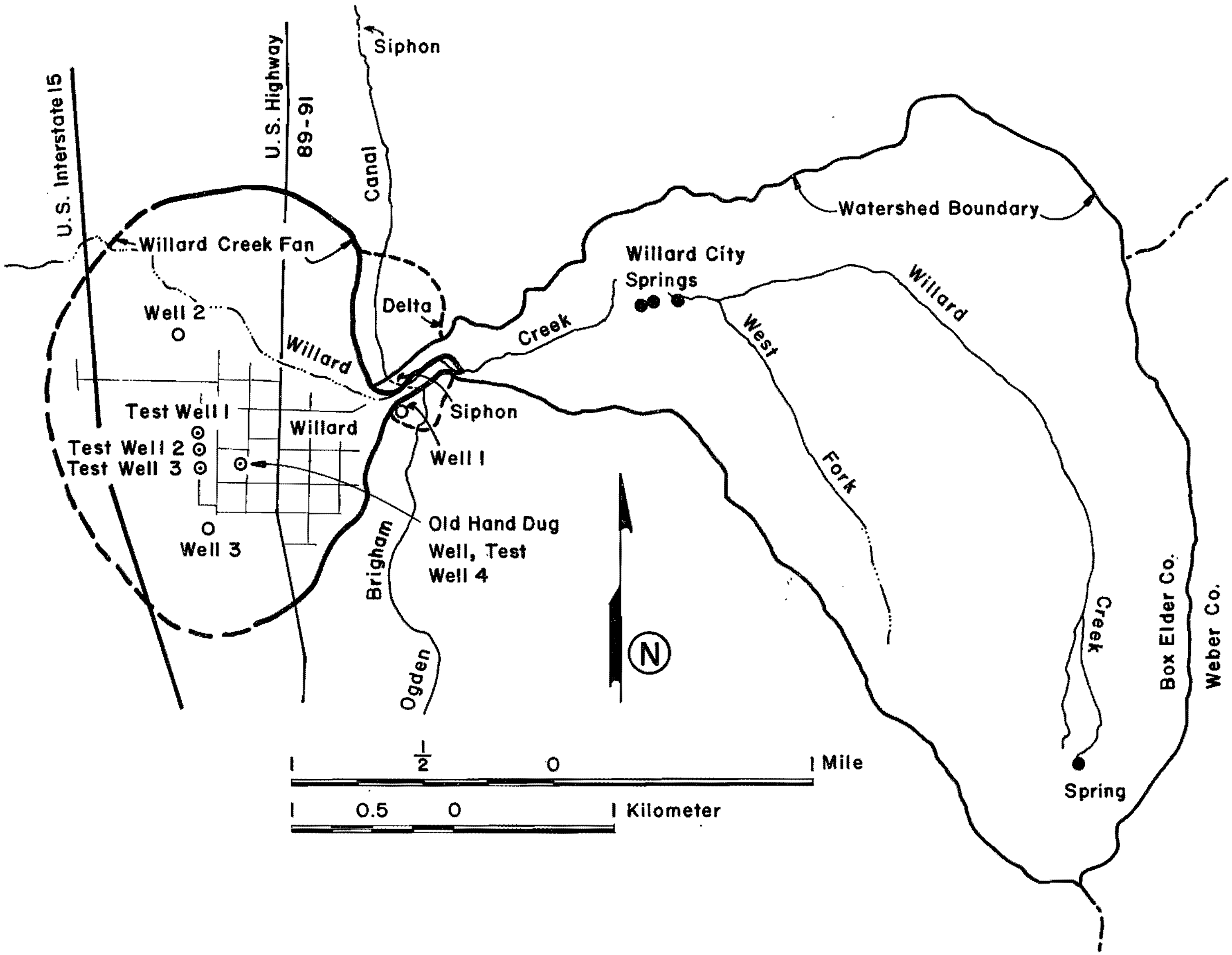

Figure 2. Willard Creek fan and tributary area.

The various types of bedrock and alluvium exposed in Willard Canyon determine the types of alluvial deposits found in the Willard Creek fan. These formations also determine to some degree the quality of groundwater extracted from the Willard Creek fan and the springs which feed Willard Creek. A portion of the precipitation falling into this small watershed infiltrates the bedrock and alluvium and thus derives its mineral content in the process.

Bedrock formations exposed in Willard Canyon consist mainly of Precambrian quartzites, micaceous-quartzitic schists, slates, siltstones, sandstones, and mudstones. The area is underlain to a small degree by Cambrian dolomites, limestones, and quartzites. Many other rock types occur in lesser proportions.

A large, centrally located area of Willard Canyon is covered with alluvium. A few scattered patches of alluvium exist in other areas of the watershed, some at higher elevations. Much of this alluvium is perched upon steep slopes which could be conducive to the formation of mudflows in severe storms.

Willard Creek. This perennial stream drains the small watershed of Willard Canyon. It is sustained by springs and runoff rising in the watershed area. However, there is a possibility that some of the springs could be fed in part by underground water from adjoining areas in this rugged terrain. Practically all the runoff of Willard Creek, once it reaches the apex of the fan infiltrates into the alluvium and joins the groundwater reservoir within the fan. The stream bed presently runs northwesterly across the fan, but, of course, it has played across the fan in all westerly directions in the process of building this symmetrical fan.

In August 1923 Willard Creek overflowed its banks in the form of a devastating mudflow (Wooley 1946). Several buildings were destroyed or damaged. Enormous boulders and a thick coating of mud covering 62.78 hectares (155 acres) were left in its wake. A large debris basin was then constructed to contain subsequent mudflows. Now, this basin is practically full of sediments, and offers little protection from future large mudflows. The severity of the 1923 mudflow was intensified by the fact that the Willard Creek watershed had been overgrazed and most of the timber removed. The area was closed to grazing in 1951. Subsequent cloudbursts in the watershed have not yielded such destructive mudflows.

Groundwater regimen

The entrance of groundwater into the Willard Creek fan is controlled by the infiltration rate while its flow patterns are determined by the geometric configurations of the formations composing the fan and associated lake deposits. The amount, duration, and distribution of infiltrating water determine the volume of water entering the fan. Both micro- and macroscopic features of the geometry of the formations affect groundwater movement within this fan and adjoining sediments. Hydraulic conditions at the points of discharge to the west affect groundwater movement to a much lesser degree.

Before Willard Creek emerges from the mountains, it passes over rather impervious rock formations, for the alluvium was removed by the mudflow of 1923. In that reach almost all of the flow must be above ground level. Accordingly, the prime sources of recharge to the Willard Creek fan are by direct infiltration from Willard Creek into the intake area of the fan and in diminishing amounts by infiltration along the present stream bed as it crosses the northern sector of the fan.

A small amount of runoff from the adjoining mountains and a small amount of underflow may infiltrate the fan from the east. Direct infiltration from precipitation is probably extremely small, as the general vegetation cover would consume practically all of it within the root zone. The Ogden-Brigham canal is lined throughout the area and should have very little leakage into the groundwater reservoir.

There are about 35 acres of orchards and irrigated land bordering Willard Creek on the north and extending eastward from Highway 89-91. Water is evidently supplied to this land from Willard Creek, thus any recharge from excess irrigation would be virtually indistinguishable chemically from stream recharge unless agricultural wastes contaminate the water. A great deal more irrigated land surrounds the fan on its north, west, and south flanks. The irrigation water is supplied from Willard Creek, private wells, and the Ogden-Brigham canal. Cattle and horses range in this agricultural area and are particularly concentrated in a number of dairies and feedlots in the southwest corner of Willard. The combined effect could contaminate the groundwater in that area.

Because there is no central sewerage system, the greatest threat of groundwater contamination is from the approximately 500 septic tanks distributed throughout the town. Historically the town has grown very slowly, but there has been an acceleration of home construction in the past few years. The danger of contamination becomes greater as the density of septic tanks continues to increase. So far, there appears to be no industrial waste nor other non-residential wastes being generated in Willard.

Willard is fortunate in having a central water distribution system, which derives its water from three springs about one mile up Willard Canyon and a well in the apex of the Willard Creek fan (see Figure 2). All but one of the old, shallow, private wells in the water table aquifer have been abandoned or are no longer used. The watershed area upstream from these sites has been barred for grazing and other uses which might contaminate the municipal water supply.

Wells along the western extremities of the fan are artesian flowing, whereas those in the central and apex areas of the fan must be pumped. There are a few small springs along the western toe of the fan and some large boggy areas in the northwest near the present stream bed. These are all indications that the regimen of groundwater flow within the fan is typical of alluvial fans.

Drillers' logs from wells in and around Willard are difficult to analyze because they lack technical accuracy. Many beds contain the mixtures of clay and gravel, which are indicative of mudflow deposits. Some of the wells to the west have clay layers which may be interconnecting lake sediments. A considerable number of formations containing clays have been reported and probably form the confining layers in the Willard fan. A few highly prolific water-bearing gravels have been reported. These are most likely conduits of braided-stream deposits. Unless new sources of contamination enter the intake area or contamination occurs through improperly constructed wells, the deeper, confined aquifers of the Willard fan should be safe from contamination. Water from the very shallow water-table aquifer, which is locally contaminated by the hundreds of septic tanks, must not be allowed to mix with the water from other aquifers or surface streams. This objective places a limit on how great a pumping rate can be allowed from the deeper aquifer since a favorable gradient should be maintained from the deeper towards the shallower aquifers.

Almost half of the municipal water supply is pumped from Well 1. Two other irrigation wells are available to the town for emergency use, but they have not yet been needed. Three springs in Willard Canyon once furnished all and now supply over half the water for the town. These springs have been covered for sanitary reasons and are piped to the town's reservoirs at Well 1, where the spring and well waters are chlorinated and mixed before distribution. Mixing of the waters is not constant in time for the well is only pumped during hours of peak water usage.

Water quality

On 8 November 1978 water samples were collected from three widely spaced wells on the Willard fan. These samples were chemically analyzed at the Utah Water Research Laboratory in Logan and the results are presented in Table 5. The locations of these wells are shown on Figure 2. Well 1 belongs to the town of Willard and is located in the intake area of the fan. Well 2 belongs to David Kunzler and is located in a pasture in the northwest sector of the fan. Well 3 belongs to Roy G. Lemmon and is located in the southwest sector beside the owner's residence.

Table 5. Analysis of water samples taken from the Willard Creek fan.

Constituent[a]	Municipal Well 1 8 Nov. 78	Kunzler Well 2 8 Nov. 78	Lemmons Well 3 8 Nov. 78	Municipal Springs 27 Nov. 78	Municipal System,[b] 13 April 60	Municipal System,[c] 9 Aug. 79
Bicarbonate	111	115	82	178	134	
Chloride	10	12	9	4	8.5	2
Sulfate	15	3	7	26	15	40
Nitrate (as N)	0.66	0.04	0.49	0.24	1.0	1.31
Nitrite (as N)	0.02	0.02	0.03	0.001		
Ammonia (as N)	0.107	0.582	0.082	0.030		
Calcium	35	5	7	54	38	
Magnesium	6	3	3	15	8.3	
Sodium	7	38	22	4	3.5	
Potassium	<3	5	5	2		
Iron	<0.03	0.63	<0.03	<0.03	0.03	
Mercury	0.002	0.001	0.001	<0.001		
Orthophosphate (as P)	0.016	1.227	0.166	<0.001		
pH	7.74	7.88	7.62	7.92	8.05	7.86
Alkalinity (as $CaCO_3$)	91	94	67	146	111	
Total Hardness (as $CaCO_3$)	113	25	28	197	129	
Total Dissolved Solids, by Evaporation	136	140	102	228	148	163

[a]All constituents are expressed in milligrams/liter, except pH.

[b]Sample taken from the distribution system in the center of town (chemical analysis taken from the files of the Utah Department of Health).

[c]Sample taken from the distribution system from the public drinking fountain in the park by the City Hall.

A sample of the city spring water was collected on 27 November from the 4-inch pipeline above the location where treatment take place. The results of the analysis of this spring water are also presented in Table 5. For comparison, an analysis of Willard's municipal water sampled 13 April 1960 by the Utah Department of Health and one sampled 9 August 1979 are included in Table 5. The 1960 sample was taken from the distribution system in the center of town. It is presumably all spring water as the well was not completed until December 1962. The 1979 sample was taken from the public drinking fountain in the park by the City Hall and was analyzed at the Utah Water Research Laboratory.

Table 6 lists of the State of Utah and EPA water quality standards for drinking water for comparison.

The municipal well 1 was drilled to 140 m (460 ft). It produces from perforations in the casings between the depths of 88 m (290 ft) and 101 m (330 ft) and between 111 m (365 ft) and 134 m (440 ft). After completion, the well was pumped at 104 l/s (1,650 gpm) for 3 days with a total drawdown of 21.3 m (70 feet).

Table 6. Drinking water standards.

	Utah[a] and EPA[b] Limits
	μg/l
I. Metals	
a) Arsenic	50.0
b) Barium	1000.0
c) Cadmium	10.0
d) Chromium	50.0
e) Copper	1000.0
f) Iron	300.0
g) Lead	50.0
h) Manganese	50.0
i) Mercury	2.0
j) Selenium	10.0
k) Silver	50.0
l) Zinc	5000.0
	mg/l
II. Non-metals	
a) Chloride	250.0
b) Cyanide	0.2
c) Fluoride	1.4-2.4 (Temp. dependent)
d) Nitrate as N	10.0
e) Sulfate	250.0[b]-500[a]
f) Total Dissolved Solids	500.0[b]-2000[a]
III. Other	
g) Turbidity (TU)	1.0-5
h) pH	6.5-8.5

[a]Utah Department of Health (1979).

[b]U.S. Environmental Protection Agency (1976).

Well 2, the Kunzler well, was drilled to 40.5 m (133 ft), and produces from perforations in the casing between the depths of 17.4 m (57 ft) and 39.3 m (129 ft). When it was completed in December 1960, it flowed 12.6 l/s (200 gpm). The well still flows but has not been tested recently. Well 3, the Roy G. Lemmon well, also continues to flow. It was drilled to 100 m (327 ft) and produces through perforations in the interval from 85.3 m (280 ft) to 91.4 m (300 ft). It was pump tested upon completion in February 1961 at 63.1 l/s (1,000 gpm) for 19 hours with a maximum drawdown of 15 m (50 ft). The well presently flows about 6.3 l/s (100 gpm).

When the three wells and the spring were sampled in November, bacteriological samples were also collected. None of these samples produced positive results upon analysis for fecal coliform bacteria. One negative sample from each well may not be conclusive, but the results suggest that the bacteriological pollution of the deeper aquifers and the springs is not a problem. Nevertheless, Utah Department of Health often finds coliform bacteria in the Willard municipal distribution system on their routine monthly sampling. According to Health Department records, coliform bacteria were found in 5 of 12 months during 1978. Infection in the distribution system may be the explanation, but further sampling should be done on the municipal well and springs to prove conclusively that they are not sources of infection.

The chemical quality of the well and spring waters reported in Table 5 is quite good. Concentrations of all constituents determined are easily within the maximum allowable limits set by the State of Utah and EPA.

The bicarbonate concentrations of the five analyses of Table 5 are all modest amounts of a nondeleterious constituent for drinking water. The municipal springs have a significantly higher concentration of bicarbonate ions than the water wells. These springs issue from a dolomitic limestone and evidently derive bicarbonate from underground contact with this slightly soluble rock formation. Likewise, the calcium and magnesium concentrations of the spring water are higher than those of the well waters, because these elements are also chemically a part of the dolomitic-limestone rock formation. Any carbon dioxide that the water may obtain from the atmosphere and from bacterial oxidization of organic matter in the soil before going underground to contribute to the spring flow would greatly intensify this natural process of solution. The carbon dioxide forms carbonic acid in solution with the water and this weak acid slowly attacks the calcium carbonate and magnesium carbonate of the rock to form calcium, magnesium, bicarbonate, and possibly some carbonate ions, which subsequently issue from the springs.

As there are no other rock formations in the catchment containing appreciable amounts of these slightly soluble minerals, it is anticipated that the water of Willard Creek upstream from the municipal springs has relatively little calcium, magnesium, or bicarbonate ion concentrations. Supporting evidence is found in the fact that municipal well receives recharge mainly from Willard Creek (including the spring waters) and has significantly lower concentrations of these three ionic species.

In addition, the concentrations of calcium and to a lesser degree magnesium are significantly lower in the two wells to the west than they are in the municipal well. This trend, which is not true with respect to the bicarbonate concentrations, may be explained by a natural adsorption or ionic exchange in the underground formations which bicarbonate does not experience. It is to be noted that the concentration of sodium is significantly higher in the two westerly wells than it is in the municipal well and spring. The exchange of sodium for calcium and magnesium occurs in nature and is the basic principle used in the zeolite water softening process. Thus the reversal of proportions of these constituents in those groundwaters may be explained by either natural ionic exchange or by water softening zeolites used by Willard residents or both. Inasmuch as less than 10 percent of the population have water softeners in their homes, it is concluded that this apparent ionic exchange is mainly a natural phenomenon. A more thorough geochemical study of the Willard Creek fan would provide additional insight into the patterns of variation observed in these chemical analyses.

The concentrations of sulfate ions appear to have the same proportional relationships as calcium does, except not so pronounced. Sulfate ion does not adsorb nor exchange with other ions in nature. However, it is reduced by bacteria under anaerobic conditions, which often exist in individual septic tanks such as are prevalent in Willard and sometimes exist in water wells. This is one possible explanation for the low sulfate ion concentrations found in the two westerly wells.

Orthophosphate concentrations are significantly higher in the westerly wells. This might represent a low degree of pollution from the use of household detergents in Willard. Phosphates rarely occur in nature, but they are sometimes found in lake sediments. Further study should be made at Willard to determine the source of the phosphorus.

The rather even distribution of chloride ions in the wells and springs would tend to disprove the lacustrine origin of the phosphates, but the disparity in their solubilities makes further proof necessary. On the whole, the chloride content of the waters is very low as could be expected from water emerging from a small watershed with the rock types present in Willard Canyon. This is also true of the small, even distribution of potassium ions in the waters tested.

The concentrations of nitrogen compounds (nitrate, nitrite, and ammonia) vary among the wells, but are generally higher than those found in the springs. None are of high enough concentrations to suggest present danger from pollution except possibly the ammonia concentration in the Kunzler well. This level is high enough to begin to be toxic to a few types of fish, and could possibly represent a diluted source of anaerobic pollution from septic tanks.

The distribution of iron content of the various water sources appears low in all cases except the Kunzler well, where it is in excess of the EPA recommended limit of 0.3 mg/l. Indeed the ground around the well-head is stained with iron oxides where the water has spilled over.

Mercury concentrations are at or below the EPA standard of 0.002 mg/l, and do not appear to represent any source of contamination.

The range of pH of the various waters is normal and is such that we know all of the alkalinity is due to the rather harmless bicarbonate-ion concentration. As total hardness is due to the calcium and magnesium concentrations of the waters represented, all that was concluded about those individual ions applies to the hardness of the waters. Waters of the two westerly wells are considered very soft, while water of the municipal well is considered to be moderately hard. The spring water is hard. The mixture of municipal waters would be classified as hard, which has probably led some Willard residents to the use of water softeners.

The total dissolved solids reported were obtained after filtering and evaporating to dryness. They are all well below the EPA recommended limit of 500 mg/l for municipal drinking waters. If one were to add the concentrations of the individual constituents, the total would be somewhat higher than the reported TDS by evaporation. This is due to the fact that upon evaporation, some of the bicarbonate constituent is lost to the atmosphere in the form of carbon dioxide and water vapor. Nevertheless, the Willard municipal water supply is of high quality as is the Lemmons well.

The Manti Canyon Fan

General description

Location. The Manti Canyon alluvial fan is located in central Utah at the town of Manti in Sanpete County as shown in Figure 3. The town has been built upon the topographically higher portions of the fan, whereas the lower areas have been devoted to agriculture.

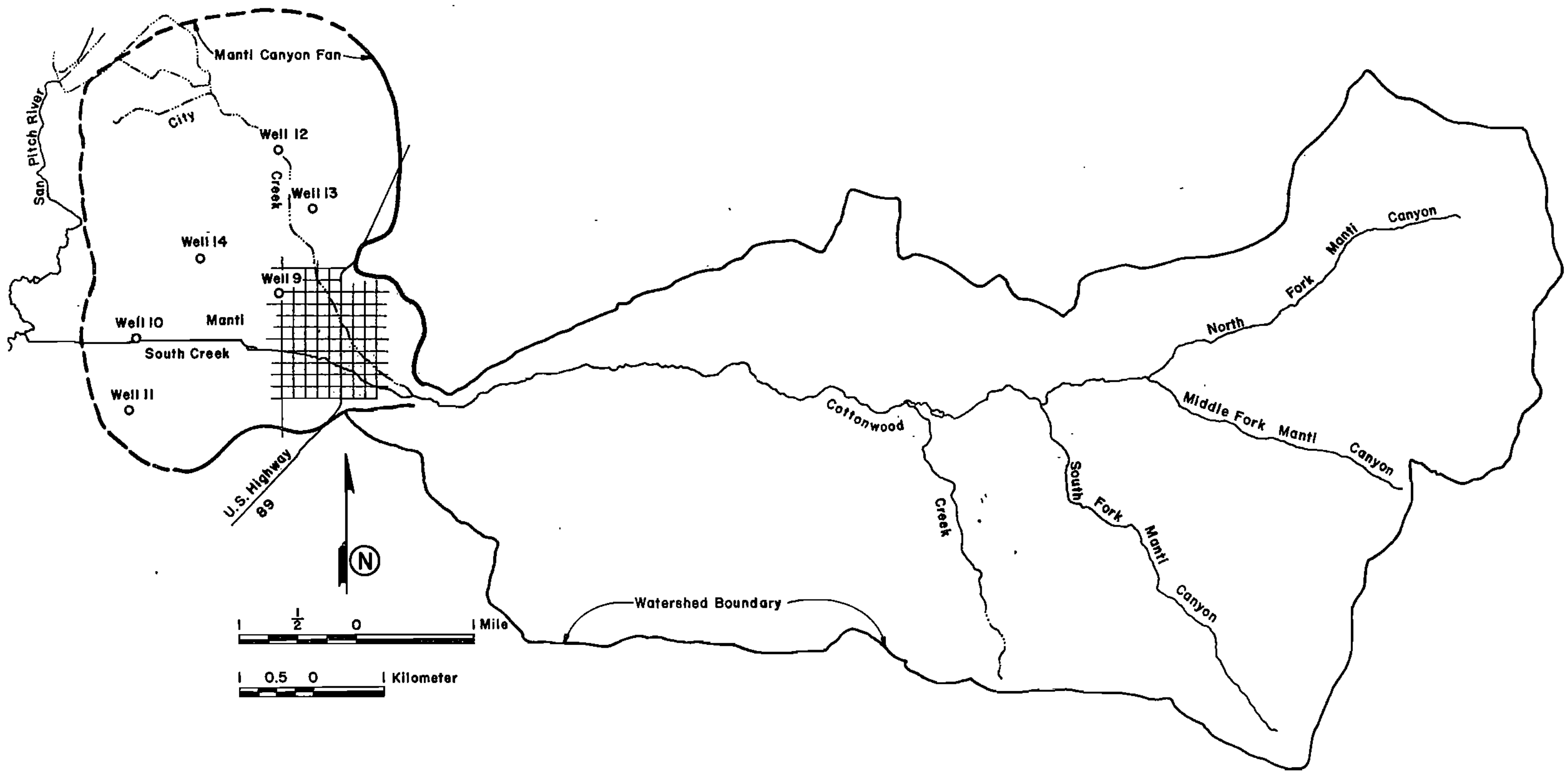

Figure 3. Manti Canyon fan and tributary area.

Figure 3 shows the outline of the fan, the town of Manti, the catchment area tributary to the fan, and the well locations. U.S. Highway 89 passes through the center of Manti in a north-south direction. Many paved and gravelled roads in and around Manti provide easy access to all portions of the fan. The Denver and Rio Grande Western Railroad crosses the middle of the fan in a northeast-southwest direction.

The west flank of the Wasatch Plateau rises abruptly on the east side of the town. Manti Creek, the principal stream of Manti Canyon, drains a portion of that plateau. This stream has formed the Manti Canyon alluvial fan where it leaves the Wasatch Mountains and enters Sanpete Valley. At the western flank of the fan the distributaries of Manti Creek, City Creek, and South Creek join the San Pitch River, which then flows into the Gunnison Reservoir about 3 miles southwest of Manti.

Elevation. The geographic center of the fan surface is about 1,680 m (5,520 ft) above mean sea level. All of the town lies just above this elevation at an average elevation of 1,720 m (5,640 ft). The topography steepens through the town toward its southeast corner near the apex of the fan. Elevation of the fan's apex is approximately 1,810 m (5,950 ft). The toe of the fan averages about 1,655 m (5,430 ft) in elevation. Considering the horizontal distances involved, the upper portion of the fan, upon which the town lies, is more than four times steeper than the broad portion outside of the town.

Mountain peaks at the eastern end of the drainage basin of Manti Creek average 3,170 m (10,400 ft) in elevation. It is approximately 16 km (10 mi) from the eastern rim of the basin to the apex of the fan. Manti Creek has a total fall of 1,130 m (3,700 ft) between its headwaters and the fan's apex.

Geology. The Manti Canyon fan is a large elliptically-shaped alluvial fan covering an area of about 23 km^2 (9 mi^2). It grades into the alluvium of the valley floor on the north, west, and southern portions of its perimeter and interfingers with this alluvium below the land surface. Evidently both were deposited contemporaneously during Quaternary time as fluviatile and valley-bottom deposits. Thickness of the fan is not known, but it is thickest at Manti and becomes thinner around the toe where it interfingers with the valley alluvium.

In the apex area of the fan on the south side of the canyon, the remnants of alluvial deposits are situated about 15 m (50 ft) above the present fan surface. Within the apex area the present stream is intrenched 4 to 6 m (15 to 20 ft) below the general fan level. This intrenchment decreases to the west. The present stream has not yet begun to widen out this latest cut.

Mudflow deposits exposed at the land surface in the upper portions of the fan indicate that mudflow has been the predominant mode of deposition in very recent time. Driller's logs from the middle areas of the fan indicate that few fine materials were encountered in drilling wells to about 90 m (300 ft), which suggests that earlier deposition may have been largely by braided-streamflow. Wells nearer the toe of the fan encountered appreciably more fine-grained sediments. This is to be expected as the distance of sediment transport increases. In this case, however, the transition is so rapid that the fine-grained formations are valley bottom sediments and/or mudflows that have deposited their coarser-grained particles upstream. Both soft and relatively hard types of sedimentary rocks are found in Manti Canyon. These can be expected to yield both coarse-grained and fine-grained sediments at the same time when eroded.

At the northeast corner of Manti there is a prominent ridge of Early Tertiary bedrock extending westward a short distance from the Wasatch Plateau. This ridge, called Temple Hill, has prevented alluvial deposition from taking place there, and consequently has caused a distortion of the alluvial fan as the growth of the fan was forced to take place around it.

The western margin of the Wasatch Plateau is the Wasatch Monocline, which extends as a commanding feature of the landscape north and south of Manti for more than 80 km (50 mi). The rocks at the crest of the watershed are nearly horizontal, but to the west they dip progressively more steeply westward. The freshwater Flagstaff limestone of Late Paleocene age forms a sharp ridge on both sides of the mouth of Manti Canyon and much of the sedimentary material comprising the fan has been derived from this formation. Its composition is mainly dark- to light-gray, to white and tan-colored limestone with small amounts of gray shale and sandstone (Spieker 1949). Not only the mouth of Manti Canyon, but the entire rim of the Manti Creek watershed is characterized by outcrops of this limestone formation.

The major portion of Manti Canyon is underlain by the North Horn formation, also of continental origin. It typically consists of variegated shales with associated sandstones, conglomerates, and freshwater limestones and ranges in age without interruption from Late Cretaceous to Middle Paleocene (Spieker 1949). The relatively incompetent nature of this heterogeneous formation beneath the more competent Flagstaff limestone gives rise to steep-sided canyons, many talus slopes, small landslides, a large slump-and-earthflow, and rocky soils with sparse vegetation. The watershed averages only 5 km (3 mi) in width, with Manti Creek flowing westward along the axis. Consequently its tributaries form very short, steep ravines. All of these physical characteristics of Manti Canyon are conducive to flash floods and mudflows, which occur when certain, rare meteorological events take place. Manti has suffered more than a dozen damaging flash floods during its historical record (Wooley 1946).

A large number of faults traverse Manti Canyon. These faults trend in a nearly north-south direction. Some of them extend for many miles both north and south of Manti Canyon. This system of faults has contributed to the heterogeneous characteristics of the canyon and probably has accelerated erosion.

Manti Creek. This stream drains a watershed of approximately 80 km^2 (31 mi^2). Normally Manti Creek flows year-round, however, its distributaries on the fan often cease to flow due to infiltration and low flow rates from the canyon during dry seasons. Some water is diverted from the stream by small canals on both sides of the canyon mouth. Manti Creek is sustained by many small springs and seeps, especially in the upper reaches of the watershed. The City of Manti has diverted several of these springs through a 20 cm (8-in) pipeline for municipal use. The city also uses one nearby spring which is located outside of the Manti Canyon watershed, about 1.6 km (1 mi) due east of Temple Hill. Manti Creek has several tributaries. They are of small discharge as they all drain small, steep areas.

Groundwater regimen

Principal sources of recharge to the Manti fan are by direct infiltration from City Creek, South Creek, and Manti Creek (including the underflow of Manti Creek as it emerges from the canyon). A few canals and ditches on the fan also provide some water by infiltration. Another significant source of recharge (and possible contamination) is the municipal water distribution system, which ultimately discharges into hundreds of septic tanks throughout the town and then seeps into the shallow water table aquifer. Minor sources of recharge might include runoff and infiltration of water from the hills immediately east of the fan (not including Manti Canyon) and direct infiltration from precipitation, but these sources are probably very small.

Fortunately, there are no shallow wells in Manti being used for domestic purposes as they would probably be contaminated from septic effluents. There are a few shallow wells in the agricultural sector which may be contaminated, but these are not used for human consumption. Contamination in the agricultural sector is more likely to result from livestock wastes and other agricultural sources rather than septic tank discharges. By properly developing springs up the canyon and piping that water to town for domestic and other purposes, Manti has avoided major problems of contamination in their drinking water system.

The town of Manti has access to the use of one high-capacity irrigation well located at 3rd North and 5th West streets. This well is used very rarely in the town's distribution system, because it was connected only as an emergency supply in the event the basic supply is cut off for any reason. Consequently, it is kept in operating condition at all times. It produces water from the interval between 27 m (88 ft) and 93 m (304 ft) below ground level. From the location of this main emergency well at the northwest edge of town, it is reasonable to presume this well is subject to contamination from the numerous septic tanks up-slope from the well. It is protected somewhat by the 30.5-cm (12 in) steel casing, but the driller's log shows no impervious formations above 27 m (88 ft) which might act as natural barriers to the movement of contaminated water. Bacteria may be filtered out in that vertical distance if the surface aquifer and other formations present are not exceptionally coarse grained. However, other biological and chemical contaminants possibly could reach the producing interval of that well. The town has access to one or two more wells for an additional emergency supply if needed.

Many springs, seeps, and flowing wells exist in the lower, peripheral areas of the fan. Activities of man such as irrigation and municipal distribution of water have augmented the rates of natural infiltration into the groundwater regimen of flow at Manti.

Both mudflow and braided-stream deposits are present in the Manti Canyon fan. The mudflow deposits usually tend to be the confining or semiconfining members of the fan, whereas the braided-stream deposits are normally the more permeable aquifers; however, the latter also may be composed of fine-grained materials such as clay and, therefore, restrict the flow of groundwater. Driller's logs of wells penetrating the fan indicate the most common materials comprising the fan are limestone conglomerates and clay.

Water quality

A sample of water was collected from the Manti emergency supply well (at 3rd North and 5th West) on 18 November 1978. Temperature of the water was 11.7°C (53°F). It was analyzed chemically at the Utah Water Research Laboratory by the methods described earlier. The results of this analysis are given in Table 7, wherein the well is arbitrarily given the number 9. On 27 December 1978, water samples were collected from five additional wells on the Manti Canyon fan. These samples, likewise, were analyzed at the Utah Water Research Laboratory and the results are given in Table 7.

Well 10 in Table 7 is an agricultural well located about 1 mile west of Manti. Figure 3 shows the location of this well and all the wells sampled on the Manti Canyon

Table 7. Analysis of water samples taken from Manti Canyon fan.

Constituent[a]	Manti Well 9 18 Nov. 78	Dee Well 10 27 Dec. 78	Cox Well 11 27 Dec. 78	Sorensen Well 12 27 Dec. 78	Christiansen Well 13 27 Dec. 78	Tuttle Well 14 27 Dec. 78
Bicarbonate	414	351	300	455	564	426
Chloride	11	16	22	4	10	12
Sulfate	108	75	60	85	80	55
Nitrate (as N)	8.00	2.04	2.20	2.72	2.80	8.70
Nitrite (as N)	0.001	0.001	0.001	0.002	0.001	0.001
Ammonia (as N)	0.017	0.037	0.029	0.035	0.087	0.053
Calcium	178	67	42	87	109	83
Magnesium	12	49	54	63	72	55
Sodium	19.2	16	26	16	12	13
Potassium	2.7	3.4	3.5	3.2	3.2	3.6
Iron	<0.024	<0.020	0.021	<0.020	<0.020	<0.020
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Orthophosphate (as P)	0.004	0.002	0.002	0.001	<0.001	<0.001
pH	7.43	8.28	8.08	7.97	7.93	8.03
Alkalinity (as $CaCO_3$)	340	288	246	373	462	349
Total Hardness (as $CaCO_3$)	475	371	328	480	573	438
Total Dissolved Solids, by Evaporation	520	422	354	468	571	460

[a]All constituents are expressed in milligrams/liter, except pH.

fan. This well is only about 12 m (40 ft) deep. Its standing level rises no higher than about 3 m (10 ft) below the land surface when it is not being pumped. The water is used for cattle watering and culinary supply for one nearby house.

Well 11 is another cattle-watering well, located about 0.8 km (1/2 mi) south of well 10. However, this well is artesian flowing and is probably a shallow well. The temperature of its water is 11.7°C (53°F).

Wells 12, 13, and 14 are shallow, livestock-watering wells. They all have to be pumped. The depth of well 14 is 12.5 m (41 ft) and the temperature of its water is 11.1°C (52°F). Depths and temperatures of the other wells are not known.

The municipal water supply comes entirely from a number of springs. Their waters are thoroughly mixed in the pipeline as they flow down Manti Canyon. These springs were individually sampled by the town of Manti and chemically analyzed by a private firm from Salt Lake City under the direction of the Utah State Division of Health in August 1978. Nine municipal springs were sampled at that time. Since 18 days elapsed between the time of sampling and the day the chemical analyses were started, the results of the analyses are questionable for some constituents--especially pH (which usually changes rapidly after sampling), alkalinity, sulphate, nitrate, nitrite, chloride, and TDS. Copies of these nine analyses are included in Appendix B. Concentrations of all chemical constituents of these nine samples were within the maximum allowable limits set by the State of Utah and the EPA. Only twice during 1977 and twice during 1978 were significant numbers of coliform bacteria found in the distribution system of Manti in the monthly tests made by the Utah Department of Health. The source of this contamination was probably in the distribution system rather than at the springs. As required by law, the spring water is chlorinated before distribution.

A comparison of the chemical analyses of the average Manti springs with the Manti emergency well reveals little similarity and only small evidence of groundwater contamination in the well's water. Little similarity would be expected, as the well produces from relatively deep calcareous aquifers. Any contaminated water seeping into the well from the unconfined surface aquifer would constitute a very small fraction of the well's total yield. Nevertheless, the concentration of nitrate ions (expressed in terms of nitrogen present) in the well water is relatively high (8 mg/l). Normally, nitrates are found in considerably smaller or negligible amounts in well waters. The EPA has declared a limit of 10 mg/l of nitrate nitrogen for public water supplies. When found in groundwater, apart from natural occurrences, the nitrates may originate from the decomposition of organic wastes, commercial fertilizers, or other man-made sources.

Much more thorough testing would have to be done at this site to prove conclusively the existence of groundwater contamination. Several more samples of water should be taken from this well to verify this first sample; then the groundwater in that vicinity should be extensively sampled and studied to prove the nature and extent of the possible contamination. When this well was sampled in November, it had not been pumped for a long time. Therefore, this sample is probably not representative of the average chemistry of the groundwater produced by the well. Proof would have to be established that there is hydraulic communication between this well and the unconfined surface aquifer from which the nitrate contamination could possibly come. Furthermore, nitrates are not necessarily the original contaminants, but rather, are the oxidization or decomposition products of them. The concentrations of nitrite and ammonia ions (both expressed as the nitrogen components) are very low whereas nitrates are relatively high in the town's emergency well and in all the other wells sampled. This indicates that the nitrogen compounds in the groundwaters of the fan are highly oxidized, and that sufficient time has elapsed to allow this oxidization to occur. A number of shallow, small-diameter test wells would have to be constructed and monitored to identify conclusively the source of the nitrates and any other contaminants which may be discovered in such a study.

Generally speaking the chemical quality of the groundwaters sampled is good. Only two of the wells have total dissolved solids over 500 mg/l (the EPA recommended maximum limit for drinking water). Bicarbonate ion concentrations and total hardness are high, but these are not deleterious. The only constituent which might indicate contamination is the nitrate ion. It was found in high concentrations in samples from wells 9 and 14, and in moderate concentrations in the others. A few sheep are fed and watered at well 14. Its driller's log indicates there are no impervious formations above the shallow, unconfined aquifer from which it produces. It is possible, then, that the organic wastes generated in the area immediately surrounding that well site are contributing directly to the high nitrate content of the groundwater pumped there. It is also possible that the nitrates could be moving from the town in the shallow aquifer, as well 14 is only about 0.8 km (1/2 mi) down-gradient from Manti and from well 9.

The relatively high hardness and concentrations of bicarbonates, calcium, and magnesium result from the abundance of limestones and related rock types in Manti Canyon and in the deposits of the fan, through which the groundwaters flow. Sulfates are only moderately high, and could have resulted from leaching of gypsiferous formations in the area. Other constituents are of such low concentrations that they are of no serious consequence as indicators of contamination.

The Flat Canyon Fan

General description

Location. The Flat Canyon alluvial fan is located near the center of Utah in Sevier County just a few miles south-southwest of Richfield, Utah. The small town of Elsinore is situated on the southwest extremity of the fan and the village of Central is located on the east-central toe of the fan. Figure 4 shows the location of the fan, the Flat Canyon drainage basin, and the well locations. Access to all parts of the fan is very good via the many roads which are found on the fan. U.S. Highway 89 and the Denver and Rio Grande Western Railroad both traverse the fan along its southern and eastern flanks. Four canals cross the fan, approximately following the topographic contours, on upper and lower parts of the fan. These canals stem from the Sevier River, which flows northeastward near the south and southeast flanks of the fan. The Pavant Range lies immediately west of the Flat Canyon fan.

Elevation. The average topographic elevation of the fan is about 1,640 m (5,370 ft) above mean sea level. Elevations of the apex and toe are approximately 1,690 m (5,550 ft) and 1,615 m (5,300 ft), respectively. The radial topographic profile of this fan is only slightly concave upward. Mountain peaks on the western edge of the Flat Canyon drainage basin are roughly 2,400 m (8,000 ft) in elevation, but the average of the entire rim is only about 2,100 m (7,000 ft). The streambed gradient of only 615 m (2,000 ft) decline in 10.4 km (6.5 mi) (5.8 percent) in Flat Canyon is not as steep as in most other localities studied for this report.

Geology. The Flat Canyon fan is a symmetrical, undissected alluvial fan derived from the erosion and depositon of materials from Flat Canyon. There are a few very small fans which have been built on top of the subject fan at the mouths of very small drainages in the Pavant Range both north and south of its apex. The fan covers an area of about 23 km^2 (9 mi^2). Although its topographic gradient is very low, it is a prominent feature of the Sevier Valley landscape and can be seen for some distance.

Drainage area of Flat Canyon is about 44 km^2 (17 mi^2). Flat Canyon Creek is intermittent at the present time. Mudflow deposits appear to predominate in the apex area of the fan, suggesting that mudflow is the dominant mode of sediment transportation and deposition for the fan, at least in more recent times. The general incompetent nature of the rock formations outcropping in Flat Canyon would tend to make their erosion products more susceptible to transportation by mudflow.

Geologic formations in the Flat Canyon drainage basin are all of Tertiary age, except for younger alluvium and landslide materials derived from those Tertiary formations. These rocks are a widely diverse suite of interspersed volcanics and continental sediments. The volcanics are the younger formations, which generally overlie the older fresh-water sediments.

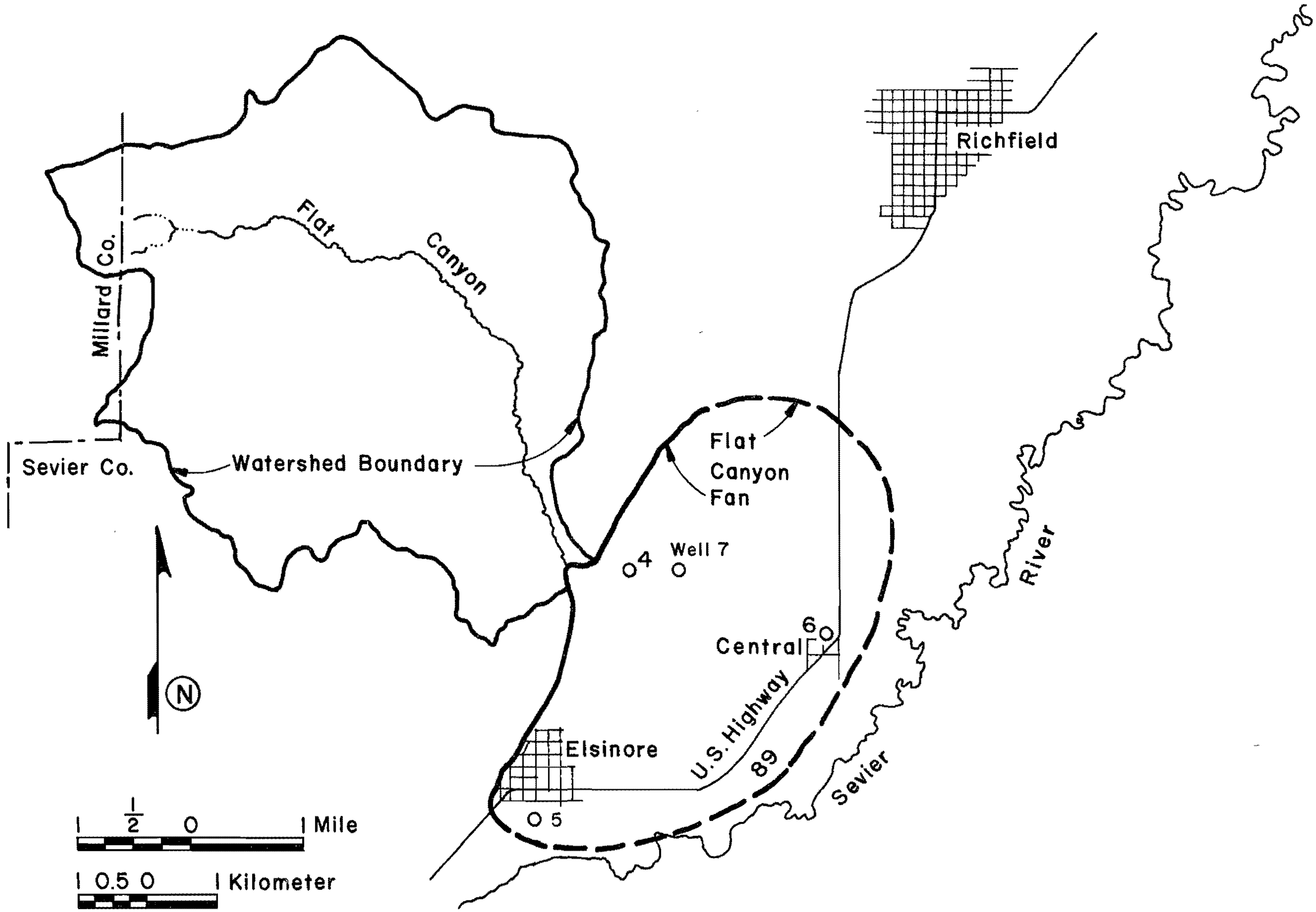

Figure 4. Flat Canyon fan and tributary area.

The Dry Hollow formation of Pliocene age is the principal formation of volcanic origin. It consists of dark-gray to dark brownish-gray basaltic andesite flows, which are locally vesicular. It also contains white to pale brownish-gray crystalline tuff, mostly of quartz-latite and other related compositions. The associated Gray Gulch formation in Flat Canyon is a complex aggregation of pyroclastic rocks with contemporaneous sandstones, limestones, and shales of various colors. There are a few older, non-volcanic formations in Flat Canyon that represent a wide variety of fresh-water, sedimentary deposits. They consist of brightly colored sandstones, sandy conglomerates, siltstones, bentonite, gypsum, shales, limestones, argillaceous limestones, mottled calcareous sandstones, pebble and cobble conglomerates, and many gradational facies of the foregoing. The abundance of relatively soft formations and their weathering products tends to be more conducive to mudflow occurrence. Boulder-lined streambeds do not develop and the soft materials of the canyon are more readily swept away by flash floods.

Faulting is of very minor consequence within Flat Canyon. However, the profound Elsinore fault crosses the apex of the fan at the mouth of Flat Canyon. This fault delineates the southeast flank of the Pavant Range and its vertical displacement is in large part represented by the towering height of the Pavant Range above the Sevier River valley in this region. The fault terminates a few kilometers south of Elsinore, but it does extend for many kilometers to the northeast. Displacement on this fault has been a principal factor in the development of the Flat Canyon fan as well as many lesser fans along the southeast face of the Pavant Range.

A reconnaissance of the entire fan reveals that mudflow deposition has predominated braided-flow deposition. An inspection of several water well logs of wells drilled upon the fan revealed that fines and poorly sorted materials predominate and thus confirmed that most of the fan is of mudflow origin. Clay is the most abundant material logged by the drillers of local wells. Relatively few water-bearing sands or gravels are reported. These subsurface conditions are readily understood when the geology of the source area in Flat Canyon is considered.

<u>Flat Canyon Creek</u>. As noted above, the stream of Flat Canyon flows only intermittently. At neither time when this fan was visited for study (September 1977 and November 1978) was there any water flowing from the canyon. However, when it was visited in September 1977 the fresh remnants of a small mudflow were observed. This mudflow left a trail of light-pink colored sand and mud as it flowed out of the canyon's mouth northeastward before dissipating. It was interesting to note that its momentum at one point near the mouth of the canyon forced it upward and out of the shallow stream channel. This is a characteristic of mudflows which does not occur in normal stream flow.

<u>Groundwater regimen</u>

It is evident from the data collected for this study that the groundwater regimen of flow in this fan is not typical of alluvial fans. There are no flowing wells nor springs around the toe of the fan. Average depth to water in 12 wells located around the toe of the fan is about 7.6 m (25 ft) according to the well drillers' reports. Insufficient data are available to determine hydraulic gradients in the interior areas of the fan, but it appears there are no strong radial hydraulic gradients in the deeper aquifers.

Thick layers of clay are logged in all of the wells including one well near the apex of the fan. It is probable that these thick clay beds prevent the downward infiltration of groundwater in the apex area. Since the periods of stream flow are of relatively short duration and the flash floods are mainly of mudflow nature and the streambed is not highly permeable, there is naturally a paucity of recharge in the apex area. The four canals provide water for recharge at various levels on the fan but the clayey nature of the surficial subsoils and the thick clays beneath them evidently hold this to a minimum.

A few tiny fans are superimposed upon the Flat Canyon fan where very small drainages are located along the front of the Pavant Range, bordering the fan along its northwest flank both north and south of its apex. These drainages apparently contribute very little recharge to the fan. Direct infiltration by rainfall is also very small due to the clayey nature of the subsoil. Significant portions of the fan are irrigated from the canals and this could be the largest source of recharge to the groundwater of the fan, at least to the shallow unconfined materials.

In consideration of the geologic characteristics of this fan, it appears this fan is susceptible to contamination only in the discontinuous shallow horizons near possible sources of contamination. There is one large turkey farm close to the apex of the fan at well 4. There are a few locations on the fan where cattle are fed and watered. One of these sites is at well 7. The small town of Elsinore (population about 400), has no sewerage system and thus is a possible source of contamination. It is situated on a tiny fan at the mouth of Raphaelsen Canyon which, in turn, is situated upon the southernmost toe of the Flat Canyon fan. The smaller town of Central, located on the eastern toe of the fan, also could be contributing a small measure of contamination to the shallow groundwater in that vicinity from septic tank seepage. The water supply of the towns of Elsinore and Central are rather safe from contamination because they obtain their water from deep wells which tap the confined aquifers beneath the thick clay formations of the fan. The wells are located within the townsites, thus failure of the sanitary seal is always a remote hazard. The rest of the fan is farmed in traditional ways and much of that area is irrigated by canal water.

Water quality

Water samples were taken for analysis from four wells on the Flat Canyon fan on 18 November 1978 and were analyzed at the Utah Water Research Laboratory. The results are presented in Table 8.

Well 4 furnishes the water supply for the large turkey farm near the apex of the fan. It is believed to be producing from an aquifer between 72.5 m (238 ft) and 84.7 m (278 ft) below the land surface. The water of this well is of unusually poor quality, but it is virtually impossible to claim it is due to contamination by man, unless there is a casing failure or it is, in fact, a shallow well. While it was not unusual to find a natural groundwater with such a high concentration of nitrate ions, it was unexpected in view of the lower concentration in nearby wells. Several other constituents were found in high concentrations, but they could have been derived from the native earth materials of Flat Canyon. Similarly, the nitrates could also occur naturally. Other wells sampled on the fan likewise have appreciable, but lower nitrate-ion concentrations. Detailed testing would have to be done at this area of the fan to prove the existence of possible contamination. Mercury concentration is in excess of the EPA standard of 0.002 mg/l for municipal use.

Well 5 is the main water supply for the town of Elsinore. The quality of its water is satisfactory for municipal use, except it is very hard. Temperature of the water as it is pumped from the well is 12.2°C (54°F). The nitrate-ion concentration is 2 mg/l (expressed as nitrogen) which is not high enough to demonstrate contamination. The well produces from an aquifer between 51.2 m (168 ft) and 57.3 m (188 ft) beneath the land surface. This aquifer is overlain by red clay and other confining beds. This precludes the possibility of contamination from seepage from the many septic tanks of the town which partly surround the well. Only in the event of a casing failure or breakdown of the sanitary seal could there be contamination of the well water. There is a possibility that this could happen as the well is about 30 years old at this time. Based upon what is known of the subsurface geology and its geographical position, recharge to this well is probably coming from the general underflow of the Sevier River valley rather than from the Flat Canyon drainage. This is also probably true of well 6 at the town of Central.

Well 6 supplies Central with its municipal water. It is producing water from aquifers between 115 m (378 ft) and 141 m (462 ft) below the land surface. It was constructed only about 5 years ago, and the top 30 m (100 ft) of casing were grouted for a sanitary seal. Contamination from septic tank seepage or other causes is virtually impossible, yet this well's water has a nitrate-ion concentration of about 6 mg/l (expressed as nitrogen). The relatively high nitrate-ion concentrations of groundwaters in this region are most likely from natural

Table 8. Analyses of water samples taken from the Flat Canyon fan.

Constituent[a]	Turkey Farm Well 4 18 Nov. 78	Elsinore Well 5 18 Nov. 78	Central Well 6 18 Nov. 78	Ogden Well 7 18 Nov. 78
Bicarbonate	384	303	311	409
Chloride	70	27	27	17
Sulfate	959	40	47	440
Nitrate (as N)	15	2	6	5
Nitrite (as N)	0.003	0.001	0.027	0.003
Ammonia (as N)	0.058	0.038	0.048	0.017
Calcium	405	105	129	251
Magnesium	109	46	27	46
Sodium	147	28	11	48
Potassium	19	5	4	10
Iron	<0.024	<0.024	<0.024	<0.024
Mercury	0.0103	0.0008	0.0003	0.0004
Orthophosphate (as P)	0.017	0.017	0.007	0.013
pH	7.28	7.76	7.58	7.48
Alkalinity (as $CaCO_3$)	315	249	255	336
Total Hardness (as $CaCO_3$)	1464	455	434	818
Total Dissolved Solids, by Evaporation	2349	403	412	1178

[a]All constituents are expressed in milligrams/liter, except pH.

sources. All ionic species in the water of Well 6 are below EPA maximum permissible limits for drinking water but the water is very hard.

Water from well 7 (Ogden) is of poor quality. The depth and other construction details of well 7 are not known. Even though many cattle are kept and fed in corrals by the well, there is no conclusive evidence from this study that contamination from the cattle reaches the water of this well. Some dissolved constituents of the water exceed the EPA standards for human consumption. Temperature of the water is 11.1°C (52°F).

The Spring City Fan

General description

Location. The Spring City fan is located at the town of Spring City (population about 500) near the center of Utah in Sanpete County. Figure 5 shows the fan, the tributary drainage area, and the location of the town of Spring City. State Highway 117 passes across the western extremity of the fan as well as the center of Spring City. U.S. Highway 89 and the Denver and Rio Grande Western Railroad pass near the toe of the fan at a distance of approximately 1.6 km (1 mi) to the northwest. The fan is bounded on the east by the Wasatch Plateau from which the materials composing the fan have been derived.

Elevation. The toe of the fan is rather difficult to delineate as it merges rather imperceptibly with the general valley floor. It has been dashed on Figure 5 because of this uncertainty. The toe is at an elevation of 1,760 m (5760 ft) and the apex of the fan is about 2,070 m (6800 ft) in elevation. Thus the total relief on the fan is at least 300 m (1000 ft). This is a relatively steep-surfaced fan, because its length from apex to toe is roughly 6 km (4 mi).

The upper rim of the drainage basin averages about 3,140 m (10,300 ft) in elevation. Between this high rim at the southeast portion of the basin and the apex of the fan a 1,070 m (3500 ft) drop in elevation occurs. Several springs are found in the mountains at the extreme southeast rim of the drainage basin. Some are outside of the basin. Spring City uses the water from a few of these springs for its municipal supply in addition to a water well in town. One new well for the town has been placed into service recently. It is located 2.4 km (1.5 mi) east of town.

Geology. The Spring City fan does not have the typical alluvial-fan shape because it is confined between other fans that form a series of coalesced fans or a bahada. It has been formed by the accumulation of erosional products transported by Oak Creek from its drainage basin. The fan covers an area of about 18 km^2 (7 mi^2), which includes all of Spring City. Oak Creek drains an area of approximately 31 km^2 (12 mi^2) but the face of the plateau bordering the fan contributes some sediments to the fan. The total drainage area tributary to the fan is 37 km^2 (14.2 mi^2). Nevertheless, practically all of the fan has been built of sediments of Oak Creek.

Oak Creek has only two or three distributaries on the fan which may flow following storms. Oak Creek is classified as a perennial stream, but there are times when it is fully diverted for beneficial use. During times of heavy rain, its natural channels bear the load of runoff and sediments. Canal Creek drains the adjoining basin to the south and has built the adjoining fan. Presently Canal Creek flows northward from the apex of its fan until it reaches the south flank of the Spring City fan, whereupon it then flows northwesterly along the boundary common to both fans. The Spring City fan is only lightly dissected despite the presence of the several streams mentioned above and the steep gradients of their channels.

It is believed that the Spring City fan is largely of mudflow origin, but not entirely so. Insufficient well records are available, and more field work would have to be done to ascertain more precisely the subsurface nature of the fan. The rock formations and general geology in the canyon of Oak Creek are quite similar to those of Manti Canyon, previously described in this report. As the geologic and hydraulic characteristics of a fan are determined to a significant extent by the geology and hydrology of its parent drainage basin, it is reasonable to expect the subsurface characteristics of the Spring City fan to be quite similar to those of the Manti fan, especially since they are also comparable in location, aspect, climate, elevation, and many other ways.

Groundwater regimen

Little is known about the subsurface geology and hydrology of the Spring City fan. It does receive significant recharge, however, in its apex area. There are flowing wells, springs, and seeps in the toe area of the fan. These are indications that the groundwater regimen of the fan is near that of the typical fan.

The town of Spring City is situated in the artesian flow portion of the fan. Therefore, deeper aquifers of the fan are not subject to contamination from septic tank seepage as long as the artesian head persists. Nevertheless, the shallow, unconfined aquifer at the town site is probably contaminated locally due to septic effluents. A few flowing springs occur within the town. This additional flow from below could aid the spread of septic contamination.

Spring City uses its well in town only for peak-load periods and to have a

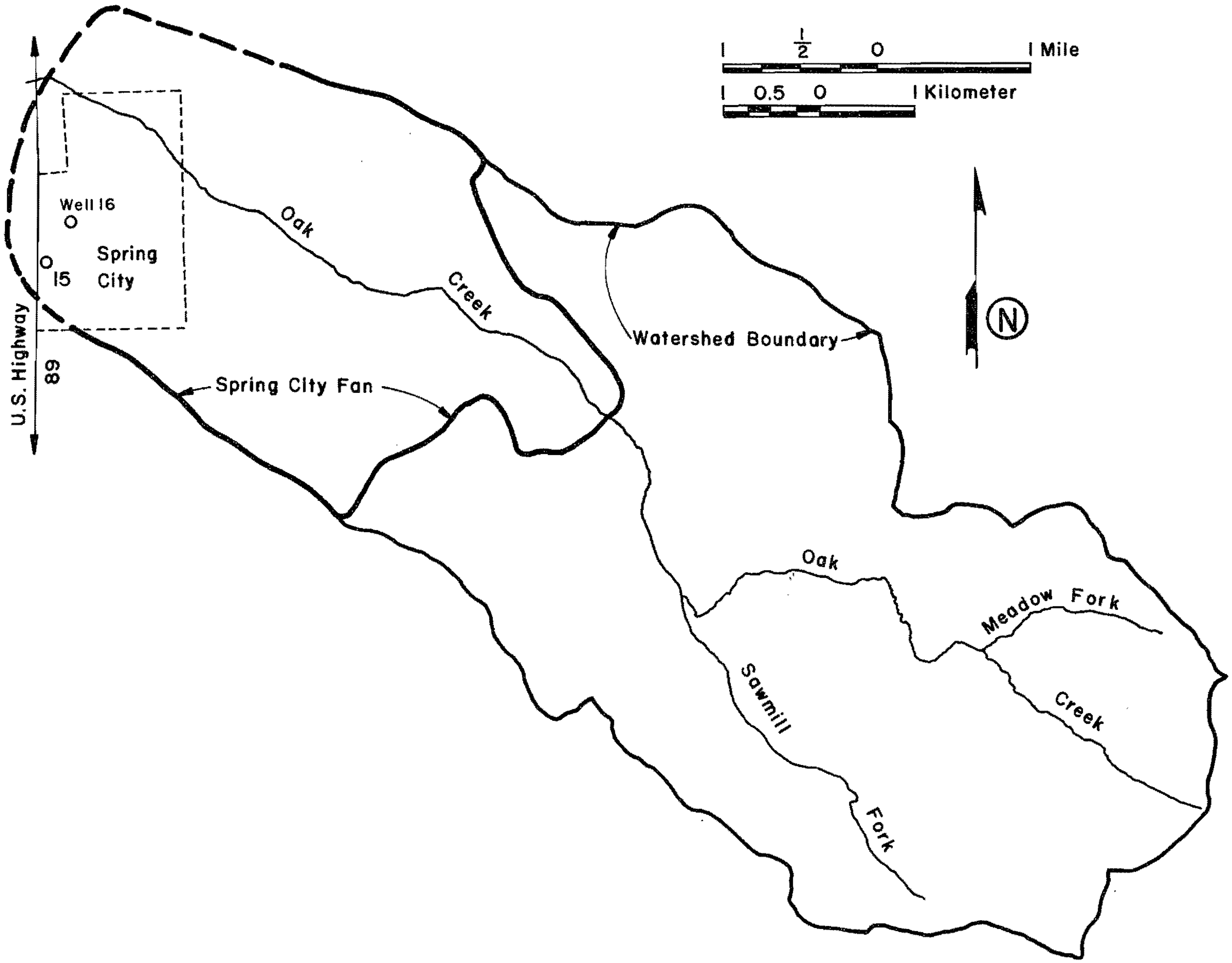

Figure 5. Spring City fan and tributary area.

dependable emergency supply should the spring supply fail. It is presumed the well has an effective sanitary seal to prevent contamination from septic effluents.

Water quality

On 27 December 1978 water samples were collected from the active municipal well (15) in Spring City and from the flowing spring (16) at First North and Main streets. Water temperature was 10.6°C (51°F) at both of these sources at the time of collection. Figure 5 gives the locations of the well and the spring. The samples were analyzed at the Utah Water Research Laboratory and the results are presented in Table 9.

As could be expected, the quality of these waters of the Spring City fan is quite similar to that of the Manti Canyon fan. No indication of contamination is evident from these analyses and all constituents are within recommended limits for drinking water.

Table 9. Analyses of water samples taken from the Spring City fan.

Constituent[a]	Municipal Well 15 27 Dec. 78	Spring 16 27 Dec. 78
Bicarbonate	394	494
Chloride	4	6
Sulfate	8	16
Nitrate (as N)	1.73	2.90
Nitrite (as N)	0.001	0.001
Ammonia (as N)	0.034	0.031
Calcium	58	61
Magnesium	44	34
Sodium	17	17
Potassium	3.2	4.3
Iron	<0.020	<0.020
Mercury	<0.0002	<0.0002
Orthophosphate (as P)	0.002	0.005
pH	8.02	8.14
Alkalinity (as $CaCO_3$)	323	405
Total Hardness (as $CaCO_3$)	328	295
Total Dissolved Solids, by Evaporation	332	333

[a]All constituents are expressed in milligrams/liter, except pH.

Fielding

Fielding, a small farming community 12.8 km (8 mi) northeast of Tremonton in Box Elder County, was chosen for study because it is situated on fine-grained lake sediments which represent offshore deposition close to the valley center (Figure 6). The intention was to study groundwater movement and contamination in these fine-grained sediments. The sampling location was a large spring just southwest of the center of town. The spring flows from a tile pipe which extends toward the general direction of the town's center.

The spring was sampled twice (see Table 10). The first sample, taken February 14, 1980, was for a complete set of analyses. The second sample, taken February 21, 1980, was taken for coliform bacteria analysis only. When coliform tests were run on the first sample, the lab technicians were expecting normal spring water. They filtered a 100 ml sample and a 10 ml sample for the coliform tests, both of which produced coliforms too numerous to count. A second sample was obtained, and this time the sample was treated like a sewage sample, using a 1 ml sample aliquot. Total and fecal coliforms were estimated at 1.2×10^4 and 2.6×10^3 coliforms/100 ml respectively. These estimates are almost as high as one would expect of effluent from a sewage disposal facility.

The sample was also extremely high in ammonia (380 μg/l), nitrite (47 μg/l), orthophosphate (198 μg/l), total phosphorus (202 μg/l), arsenic (30 μg/l), and mercury (6 μg/l).

Table 10. Analyses of water samples taken from spring at Fielding, Utah.

Constituent[a]	14 Feb. 80
Total Coliforms/100 ml	1.3×10^4
Fecal Coliforms/100 ml	2.6×10^3
BOD	2
Dissolved Oxygen	3.00
Total Dissolved Solids	
Alkalinity (as $CaCO_3$)	421
Calcium	52
Magnesium	68
Total Hardness (as $CaCO_3$)	406
Fluoride	0.69
Ammonia (as N)	0.38
Nitrate (as N)	4.70
Nitrite (as N)	0.047
Total Kjeldahl Nitrogen	<1
Orthophosphate (as P)	0.198
Total Phosphorus	0.202
Total Organic Carbon	4.2
Arsenic	30
Cadmium	<2
Chromium	<29
Copper	<7
Iron	<20
Mercury	5.7
Manganese	25
Lead	2.5
Selenium	<1
Silver	<8
Zinc	4
pH	8.52

[a]All metals are expressed in micrograms/liter. All non-metals are expressed in milligrams/liter except pH and coliforms.

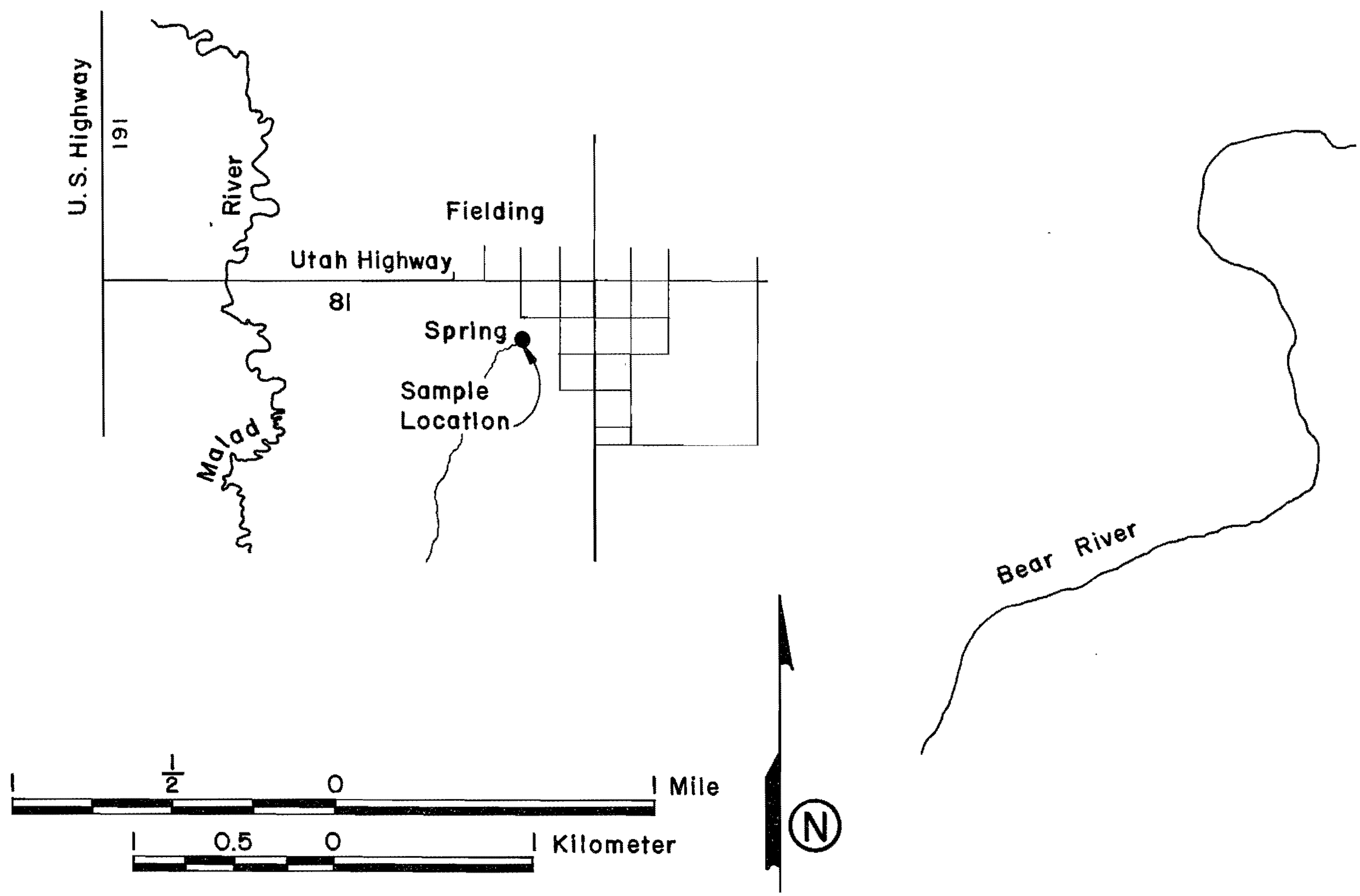

Figure 6. Fielding, Utah.

Because it appeared that septic tank effluents and/or animal wastes were directly entering the spring, no further samples were taken at Fielding. The goals of this study (to investigate contaminated groundwater rather than direct connections to sources) could not be accomplished at Fielding without establishing other sampling points.

Hyde Park

General description

Hyde Park is located at the foot of the Bear River Range in the southern portion of Cache Valley, Cache County, northern Utah, about 6.4 km (4 mi) north of the City of Logan. Figure 7 shows the location of the town, the topography, the location of springs and the sampling well, and the drainages which recharge the shallow aquifer. U.S. Highway 91, which passes north-south through Cache Valley, passes 0.8 km west of Hyde Park. Three irrigation canals pass through the town. The Logan and Hyde Park Canal passes directly through the center of town, the Logan Northern Canal passes through the upper, or eastern, portion of the town, and the Logan-Hyde Park and Smithfield Canal passes between the town and the mountain front.

The present population is 1,300 (August 1978), with a projected growth to 3,500 by the year 2000. Most of the residents work elsewhere in Cache Valley, with only a small percentage of self-employed individuals running small businesses or farming. The only industry located in town is a small meat packing plant.

Hyde Park is situated on an elevated, lobate, alluvial slope formed by deposition of sediments eroded from Hyde Park Canyon and Dry Hollow directly to the east. At the western end of town the alluvial slope meets the valley floor.

Elevation. The center of Hyde Park is located at an elevation of 1,390 m (4,560 ft) above mean sea level, with the lower, western end of the town at 1,366 m (4,480 ft), and the upper limit of the town at an elevation of 1,460 (4,800 ft). The topography gradually steepens to the east and then rises abruptly at the western flank of the Bear River Range to peaks over 2,700 m (9,000 ft) high. The intermittent streams of the Hyde Park watershed head in the Bear River Range at an elevation of 2,800 m (9,200 ft).

Geology. The topographically high landform upon which Hyde Park is situated was formed by complex interaction of several geomorphic processes. The fluctuation of the ancient lakes created a constantly changing base level which produced sediments representing a range from subaqueous near-shore lake deposits to subaerial alluvial deposits.

The dramatic changes in mode of sedimentation is best observed in the stratigraphic cross-section of Hyde Park (Figure 8). Although the cross-section was produced from well logs of water wells drilled by several different drillers, the changes in deposition are well recorded. See Appendix C for summaries of these drillers logs used in construction of Figure 8. The thick sequences of coarse sand and gravel, which thicken toward the mountain front to the east, represent alluvial deposits which were laid down during periods of low lake stands. To the west, the clay layers become more abundant and thicken westward. During low lake levels, or during complete absence of the lake, the pre-existing deposits were partially dissected by the intermittent mountain streams. The existence of streams can be observed as gravels found in ancient channels, now incorporated in fine-grained lake sediments which outcrop at the upper end of Hyde Park.

During the Pleistocene Epoch, as now, the streams of the Hyde Park drainage flowed intermittently. The sediments which represent periods of high lake levels are not those of a delta, but are more likely the deposits of mud or debris flows which lost energy rapidly upon entering the lake. With the loss of energy, the coarser material was deposited rapidly and the progressively finer material was deposited outward into the lake.

The Bonneville stand of Lake Bonneville is etched along the mountain front at the 1,567-m (5,140-ft) level, forming a sharp break at the base of the steeply faulted mountain front of the Bear River Range. It is in this area that a large amount of recharge for the shallow aquifer occurs. At 1,460 m (4,800 ft) the shoreline of the Provo stand cuts across the unconsolidated material east of Hyde Park. The Provo shoreline cuts fine-grained silt and clay lake sediments and forms a steep slope, which separates the Bonneville bench from the Provo bench.

The deposits related to Lake Bonneville and earlier lakes form a thin but areally extensive hydrologic unit. The major aquifers are composed of sand and gravel in fans, bench deposits, and the delta deposits produced during intermittent flow of nearby streams. The interbedded layers of lake-bottom clays and silts confine the aquifers and cause artesian conditions.

The shallow observation well drilled for this project is located 15 m (50 ft) east of a spring at the lower, west, end of town. The well was augered to a depth of 3.2 m (10.4 ft), and jet drilled from that point to 4.1 m (13.3 ft). The earth materials sampled during the drilling were a mixture of fine sand, silt, and clay. During drilling with the jet rig, circulation of the drilling water was partial or was lost completely.

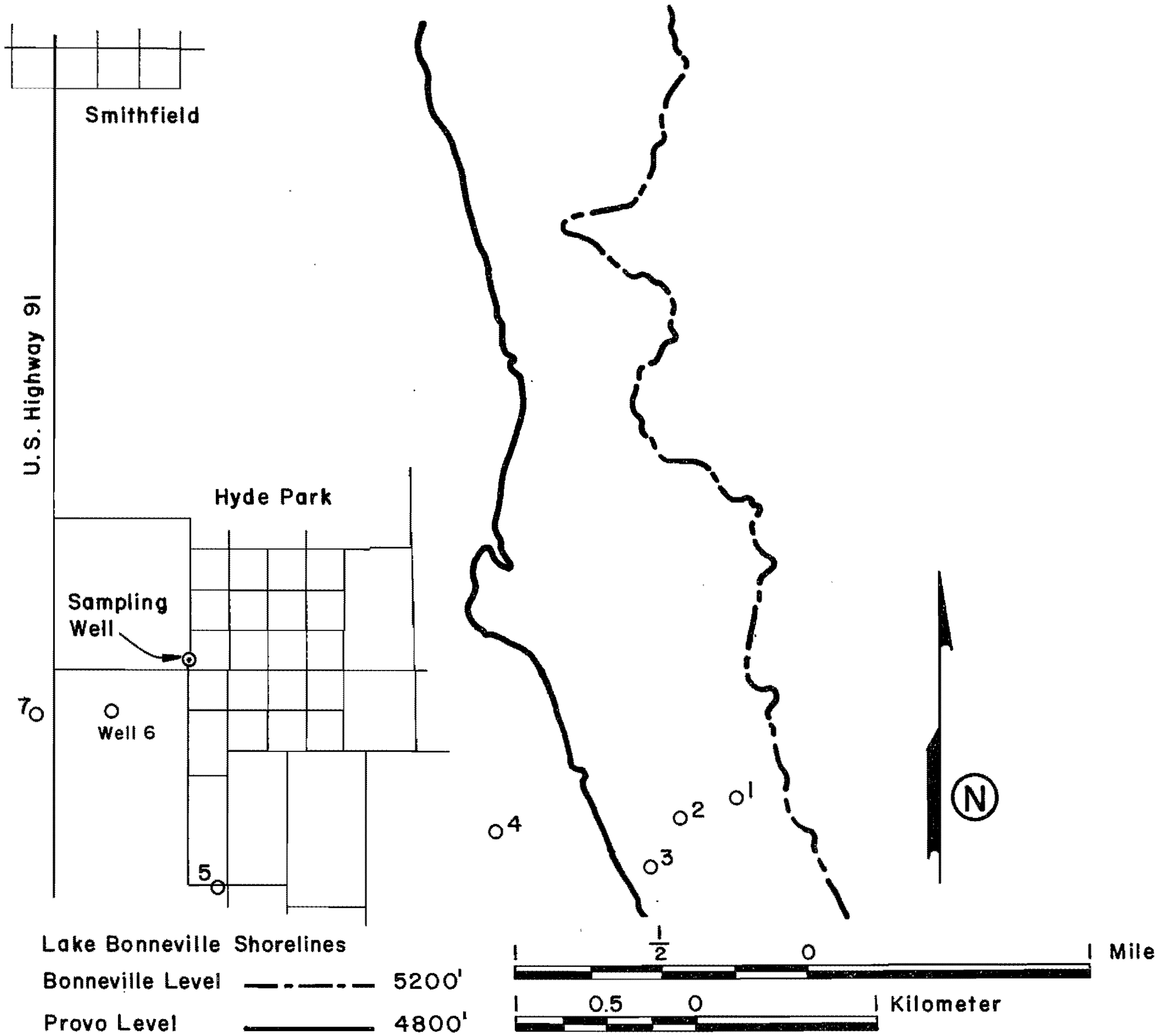

Figure 7. Hyde Park, Utah.

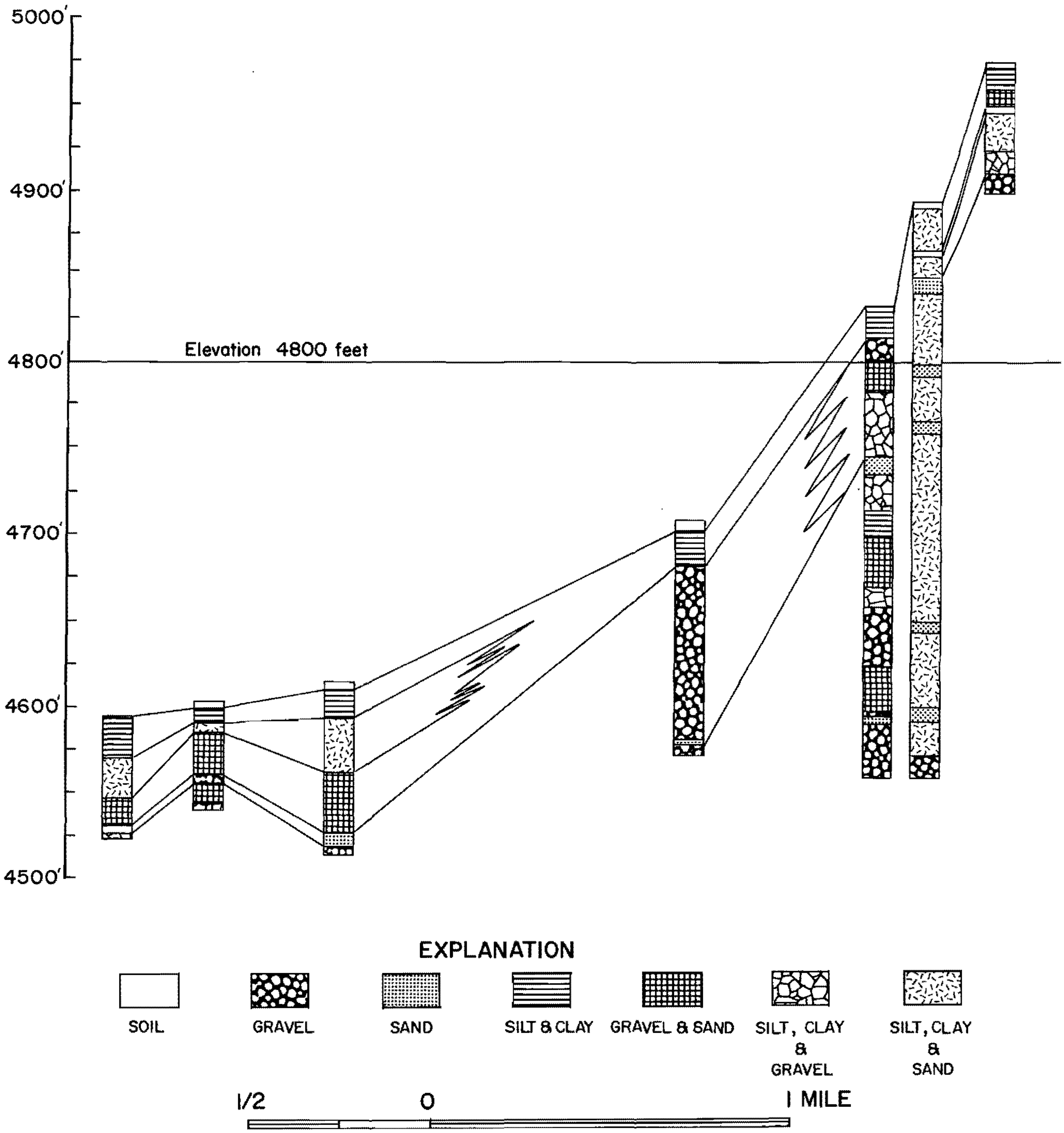

Figure 8. Generalized logs of seven water wells in Hyde Park, Utah.

The fine-grained sediments, at least in the vicinity of the well, are very permeable.

Water use

The main source of drinking water for the residents of Hyde Park is a spring located in Birch Canyon, 6 miles to the northeast. A well, located east of town, supplements the spring water when demand is high. There are 400 family dwellings connected to the public water system, and although each has a water meter used for billing, there are no records of total water used. In 1971 the State Engineer's office estimated that 450,000 m^3 (365 ac-ft) of water were used in 1968. Since that time the population has increased from 1,000 to 1,300, with an increase of 175 new service outlets.

Disposal of wastewater is handled by individual septic tanks. The septic tanks and drain fields are located in the fine-grained lake sediments which cover most of the area. Although fine-grained, this material is quite permeable, as was determined at the location of the observation well drilled for this project. Hyde Park has plans for a sewerage system, but construction of the system is not planned in the near future. The town has recently completed the installation of a new water distribution system intended to increase pressure and rate of flow to individual users. Because of the new water system and the inflation, the town probably will not be financially able to construct the sewerage system for at least 5 years.

In addition to water used for human consumption, water is also used for irrigation and livestock. Water for irrigation is supplied by the three canals located in or above town. None of these canals is lined completely, thus canal leakage can cause additional recharge to the shallow aquifer.

Sampling location

The spring located at the western edge of town was originally chosen as the sampling site, but due to the possibility of contamination from surface runoff, an alternate location was used. The observation well was drilled 15 m (50 ft) to the east and up-gradient from the spring to insure the aquisition of a representative shallow groundwater sample.

The observation well was drilled to a depth of 4.1 m (13.3 ft) using a soil auger and hand operated jet-drill rig. The well was cased with 2.5 cm (1 in) schedule 40 PVC pipe, with fine perforations from 2.4 m (8 ft) to 4.1 m (13.3 ft). The well was cased at the land surface with a 3.8 cm (1.5 in) galvanized pipe, 0.75 m (2.5 ft) in length, cemented in place, and fitted with a threaded cap to provide a sanitary seal.

The most heavily populated section of Hyde Park is up-gradient from the well with the nearest house less than 30 m (100 ft) away. No forms of industry are located near the sampling location, so any contamination found would be domestic wastes generated by the residents.

Water quality

To identify a possible increase in groundwater contamination caused by discharge of septic wastes into the shallow aquifer, the water quality of the observation well was compared with water from the springs above town which serve as the municipal water supply. The municipal water supply was chemically analyzed by the Utah Department of Health, and water from the observation well drilled for this project was analyzed by the Utah Water Research Laboratory.

The observation well was sampled twice, once on January 31, 1980, and again on April 10, 1980. When the chemical analysis data from the observation well were compared with those of the spring water from above the town, all constituents showed a marked increase (Table 11). Although the water quality of the observation well was within the Utah and EPA drinking water limits (Table 11), it was close to those limits in total dissolved solids and nitrates.

Concentrations of calcium and magnesium are relatively high, as is total alkalinity. This should be expected, as the source rocks for the sediments are predominantly limestones and dolostones, carbonate rocks which are slightly soluble in groundwater.

The concentration of nitrate ions in the well water is relatively high (6.4 mg/l compared with 0.4 mg/l in the background sample). Normally, nitrates are found in smaller or negligible amounts in well waters and the EPA has declared a limit of 10 mg/l of nitrate nitrogen for public water supplies. When found in groundwater, the source may be natural deposits of nitrates, or may originate from the decomposition of organic wastes, commercial fertilizers, or other man-made sources. More investigation is needed to determine the source of nitrates in this well water.

Phosphorus, which is another indicator of contamination, is also high in the well water. Commonly, phosphorus is found in fertilizers and domestic detergents. Phosphorus may reach the groundwater from domestic septic tank effluents.

In addition, the amount of mercury in the sample collected from the observation well (6 μg/l) was three times the limit specified by the Utah and EPA drinking water limits. The source of mercury is not known at this time.

The shallow groundwater in the vicinity of Hyde Park probably is being contaminated by man-made wastes. Although the level of contamination is low, increased growth of the

Table 11. Analyses of water samples taken from Hyde Park, Utah.

Constituent[a]	Hyde Park Public Water Supply		Observation Well	
	9-1-41	7-20-60	1-31-80	4-10-80
Total Coliforms/100 ml			<1	<1
Fecal Coliforms/100 ml			<1	<1
Fecal Strep/100 ml				15
BOD			<1	<1
Dissolved Oxygen			4.8	4
Total Dissolved Solids	202	184	437	481
Alkalinity (as $CaCO_3$)			255	357
Calcium	48	49	83	
Magnesium	14	13	36	
Total Hardness (as $CaCO_3$)	178	177	352	
Fluoride	0.1	0	0.12	
Ammonia (as N)			<0.010	0.028
Nitrate (as N)		0.4	6.44	1.10
Nitrite (as N)			0.002	<0.002
Total Kjeldahl Nitrogen			<1	1
Orthophosphate (as P)			0.101	0.129
Total Phosphorus			0.239	0.129
Total Organic Carbon			1.9	2.5
Arsenic			<2	
Barium			22	
Cadmium			<9	
Chromium			<50	
Copper			<7	
Iron	1.5	2	<20	
Mercury			6.3	
Manganese			<5	
Lead			<1	
Selenium			<1	
Silver			<46	
Zinc			4	
pH	7.8	7.9	8.20	8.45

[a]All metals are expressed in micrograms/liter. All non-metals are expressed in milligrams/liter except pH and coliforms.

town could intensify the problem. Because the town draws its water from a spring located several miles northeast of the town, it appears that there will be no contamination of the town water supply. However, shallow wells for stock watering or irrigation may be contaminated down-gradient from Hyde Park.

Richmond

General description

Location. Richmond, a community with a population of about 1,650, is located 5 miles south of the Utah-Idaho border in Cache Valley. Directly to the east, the mountain front of the Bear River Range rises abruptly from the valley floor. Logan is located 32 km (20 mi) to the south. Figure 9 shows the location of the city, the general topography, and the drainages which recharge the shallow aquifer. State Highway 170 intersects U.S. Highway 91 at the western end of the city, and the Union Pacific Railroad passes through the western city limits in a north-south direction.

The local economy is supported mainly by dairy-related industry and numerous small businesses. A large portion of the residents are employed locally, and the remainder commute to work throughout Cache Valley and beyond.

Richmond is situated on an elevated alluvial slope formed by sediments deposited by Cherry Creek and City Creek, which head in the Bear River Range directly east of the city. At the western end of the city the alluvial slope meets the valley floor.

Elevation. A bench mark located at the intersection of Utah 170 and U.S. 91 at the western end of Richmond is situated at an elevation of 1,404 m (4,607 ft). The eastern city limit is along the mountain front at 1,460 m (4,800 ft) above mean sea level. From there the topography abruptly rises to over 2,700 m (9,000 ft) in the peaks of the Bear River Range. The intermittent streams of the Richmond watershed head in the Bear River Range at an elevation of 3,000 m (9,980 ft).

Geology. The City of Richmond is situated on a topographically high land form built by the complex interaction of ancient lakes and intermittent mountain streams. The constantly changing base level created by fluctuation of ancient lake levels caused a repeated depositional change from subaerial alluvial deposits to subaqueous delta and near-shore lacustrine deposits. Well logs from water wells in the area show the depositional changes. Gravel layers gradually thin toward the valley as interfingered clay layers thicken toward the valley (see Figure 10). The thick sequences of gravel and coarse sand represent the alluvial deposits, which were laid down during periods of low lake stands. The fine-grained deposits represent lake bottom and near-shore deposits laid down during the times when the ancient lakes occupied those levels of the valley. The lake deposits are partially dissected and the erosional cuts are filled with stream gravels. This dissection occurred during low lake levels, when intermittent mountain streams flowed over the recently deposited lake sediments. These ancient filled stream channels are very permeable and provide easy passage for groundwater.

The Bonneville stand of Lake Bonneville is etched along the mountain front behind Richmond at an elevation of 1,567 m (5,140 ft). Little or no deposition of sediments is associated with this shoreline. The sharp break at the base of the mountain front at 1,460 m (4,800 ft) formed as a result of extensive deposition during the Provo stand of Lake Bonneville.

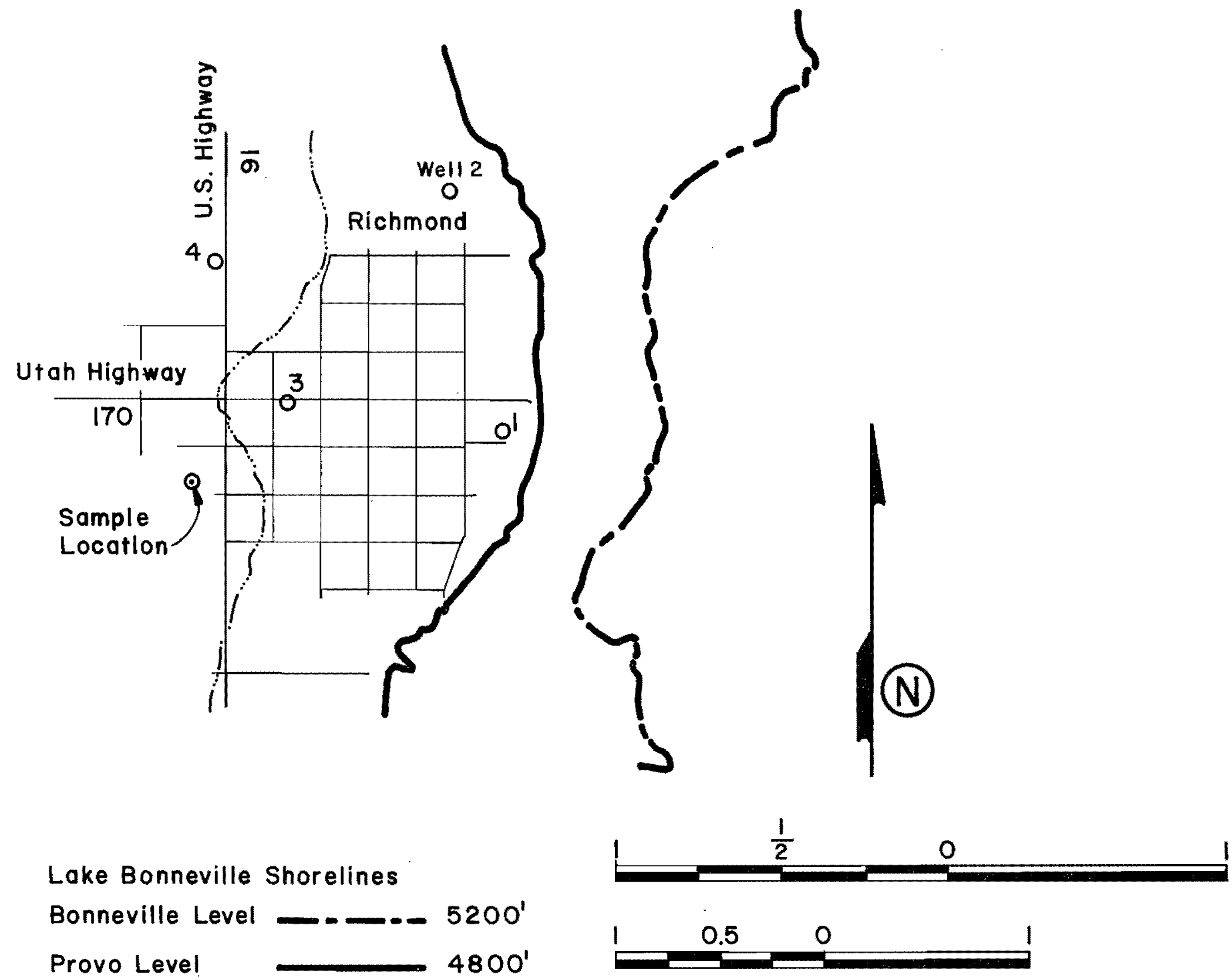

Figure 9. Richmond, Utah.

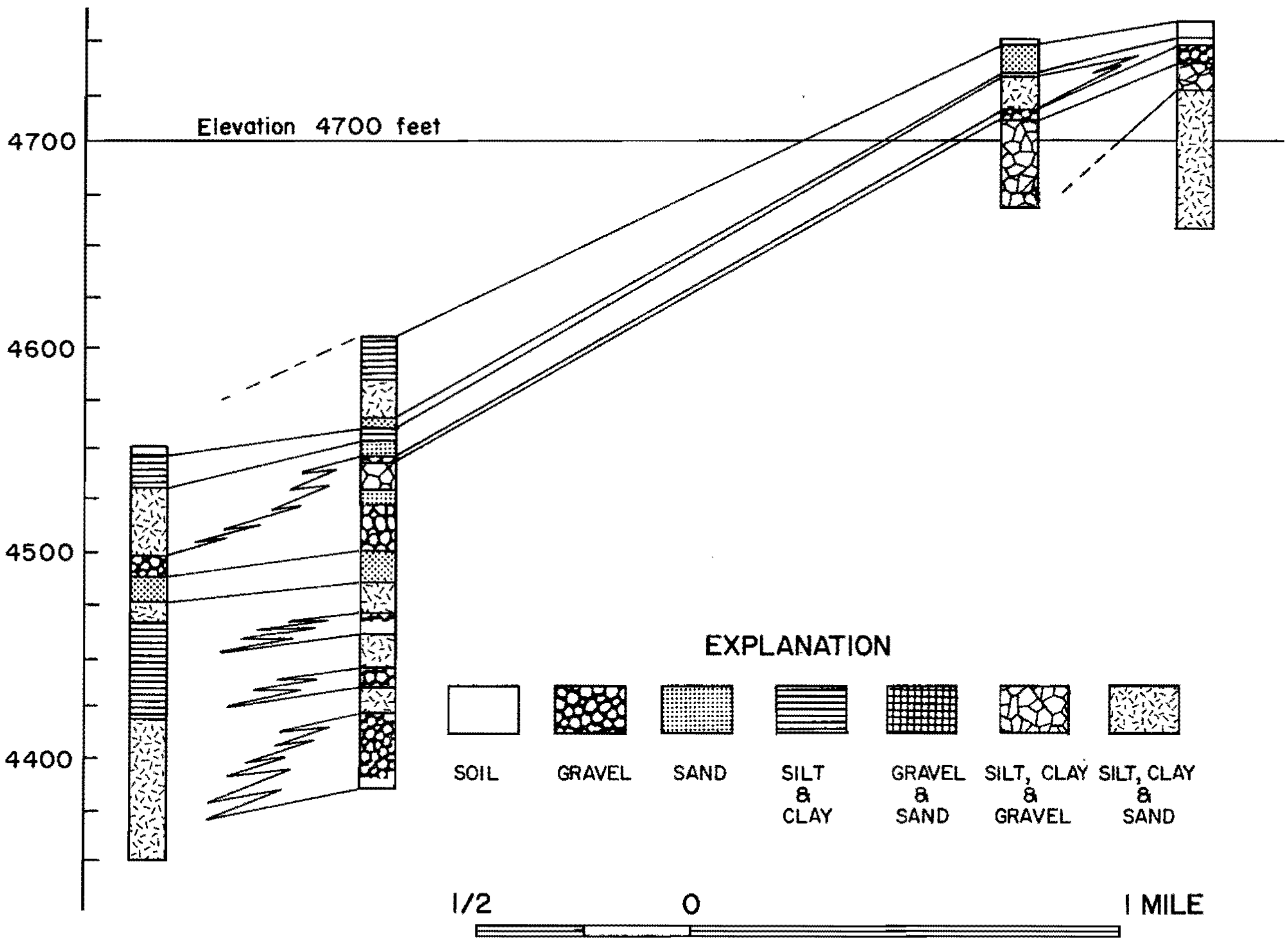

Figure 10. Generalized logs of four water wells in Richmond, Utah.

The Lake Bonneville deposits form a thin but extensive hydrologic unit. The major aquifers are composed of sand and gravel of beach, delta, and alluvial fan deposits with interbedded silt and clay lake-bottom sediments, which form confining layers.

Water use

Four springs located in the canyons east of Richmond are the main source of drinking water for the residents. The public water distribution system has 460 individual connections, with an average of 473 m^3 (125,000 gal.) of water used per connection per year. In addition to the public water system, which is primarily for domestic use and small scale irrigation, there are several large irrigation wells nearby, and an industrial well used at the local cheese plant.

Wastewater disposal is handled by a sewer system which was installed in 1972. Prior to the sewer installation, each household utilized its own septic tank. With the installation of the sewer system the amount of liquid waste now entering the groundwater system has been drastically reduced.

Sampling location

Robinson Spring, located at the western edge of town, was the sampling location. This spring taps the shallow groundwater that flows beneath the town. Any contamination produced by the town should be detected in the spring water.

The Richmond location provided the greatest amount of development encountered during this study. Up-gradient from the sampling location are two gas stations, a car wash, and a fast-food restaurant. The spring is also in the vicinity of one of the most heavily populated sections of Richmond.

A sampling tube was placed several meters into the cavity from which the spring waters emerge to reduce possible contamination from surface runoff in the area around the spring. The tube was then connected to the sampling pump and pumped for at least 30 minutes in order to obtain a representative groundwater sample.

Water quality

Richmond was chosen as a study location primarily because of its recently installed sewer system. An attempt was made to compare the groundwater quality before and after installation of the waste disposal system. The samples taken for this study from Robinson Spring were compared to a well-water sample taken by the U.S. Geological Survey near Robinson Spring in 1968 (see Table 12). The main difference is the marked decrease in the amount of nitrate in the spring water when compared to the well water. The well had a nitrate nitrogen level of 24 mg/l, which is more than twice the 10 mg/l limit for nitrate set by the U.S. Environmental Protection Agency and the State of Utah (see Table 6). The spring had nitrate levels of 9.29 mg/l and 1.04 mg/l on the two occasions it was sampled and analyzed by the Utah Water Research Laboratory for this study. Note also that the mercury content of water from the spring is three times the acceptable limit as defined by the State of Utah. The source of the mercury is not known.

Table 12. Analyses of water samples taken from Richmond, Utah.

Constituent[a]	Cherry Creek Spring 5-8-68	Well SE of Town 4-17-68	Robinson Spring 2-14-80	Robinson Spring 4-10-80
Total Coliforms/100 ml			<1	<1
Fecal Coliforms/100 ml			<1	<1
Fecal Strep/100 ml				41
BOD			<1	1
Dissolved Oxygen			3.55	2
Total Dissolved Solids	118	353		535
Alkalinity (as $CaCO_3$)			464	451
Calcium	30	81	76	
Magnesium	7.3	26	67	
Total Hardness (as $CaCO_3$)	106	308	472	
Fluoride			0.28	
Ammonia (as N)			<0.01	0.015
Nitrate (as N)	1.5	24	9.29	1.04
Nitrite (as N)			0.010	0.002
Total Kjeldahl Nitrogen			<1	1
Orthophosphate (as P)			0.065	0.079
Total Phosphorus			0.065	0.079
Total Organic Carbon			2.0	4.0
Arsenic			15	
Barium			101	
Cadmium			<2	
Chromium			<29	
Copper			<7	
Iron			<20	
Mercury			6.0	
Manganese			<5	
Lead			1	
Selenium			<1	
Silver			11	
Zinc			3	
pH	7.9	7.6	8.47	7.69

[a]All metals are expressed in micrograms/liter. All non-metals are expressed in milligrams/liter except pH and coliforms.

Due to the similarity in location, size, geology, and background water quality, a comparison was made between the groundwater quality of Richmond and Hyde Park. The background samples of the two towns' public water supplies compare quite closely, but when the shallow groundwater samples are compared, the Richmond samples are of superior quality in some respects. The nitrate levels are similar, but lower values were recorded for orthophosphate and total phosphorus in the Richmond groundwater.

Richmond is an example of the difference a wastewater disposal system makes with respect to groundwater quality. The groundwater beneath the town evidently shows an improvement since the installation of the sewer system. Some constituents are still high, such as nitrates, but as long as agriculture and the dairy industry play a major role in the area, some contamination is to be expected.

Providence and Millville, Utah

General description

Location. The neighboring communities of Providence and Millville are situated on prominent benches (shoreline deposits) along the mountain front on the eastern side of Cache Valley just south of Logan. The location of the two communities, the sampling location and the recharge areas are shown in Figure 11. Millville, population 500, has grown little in the past 10 years. In contrast, Providence is a rapidly growing community of approximately 2,500. Both communities lack major industry. Horse and cattle ranches, together with farming, make up most of the local economy. Most of the residents work in the City of Logan 1.6 km (1 mi) to the north, or elsewhere in Cache Valley. As the population grows, more and more development is taking place along the mountain front where much of the recharge to the groundwater takes place. Neither community has a sewer system; most of the wastewater disposal is handled by individual septic tanks.

Elevation. The 1,400-m (4,600-ft) contour passes through the center of both Providence and Millville. Both communities are situated between elevations of 1,390 m (1,390 ft) and 1,460 m (4,800 ft). From the upper limits of the towns the topography rises abruptly to peaks over 2,700 m (9,000 ft) in the Bear River Range. The Providence Canyon drainage basin heads at an elevation of 2,960 m (9,710 ft) at Logan Peak.

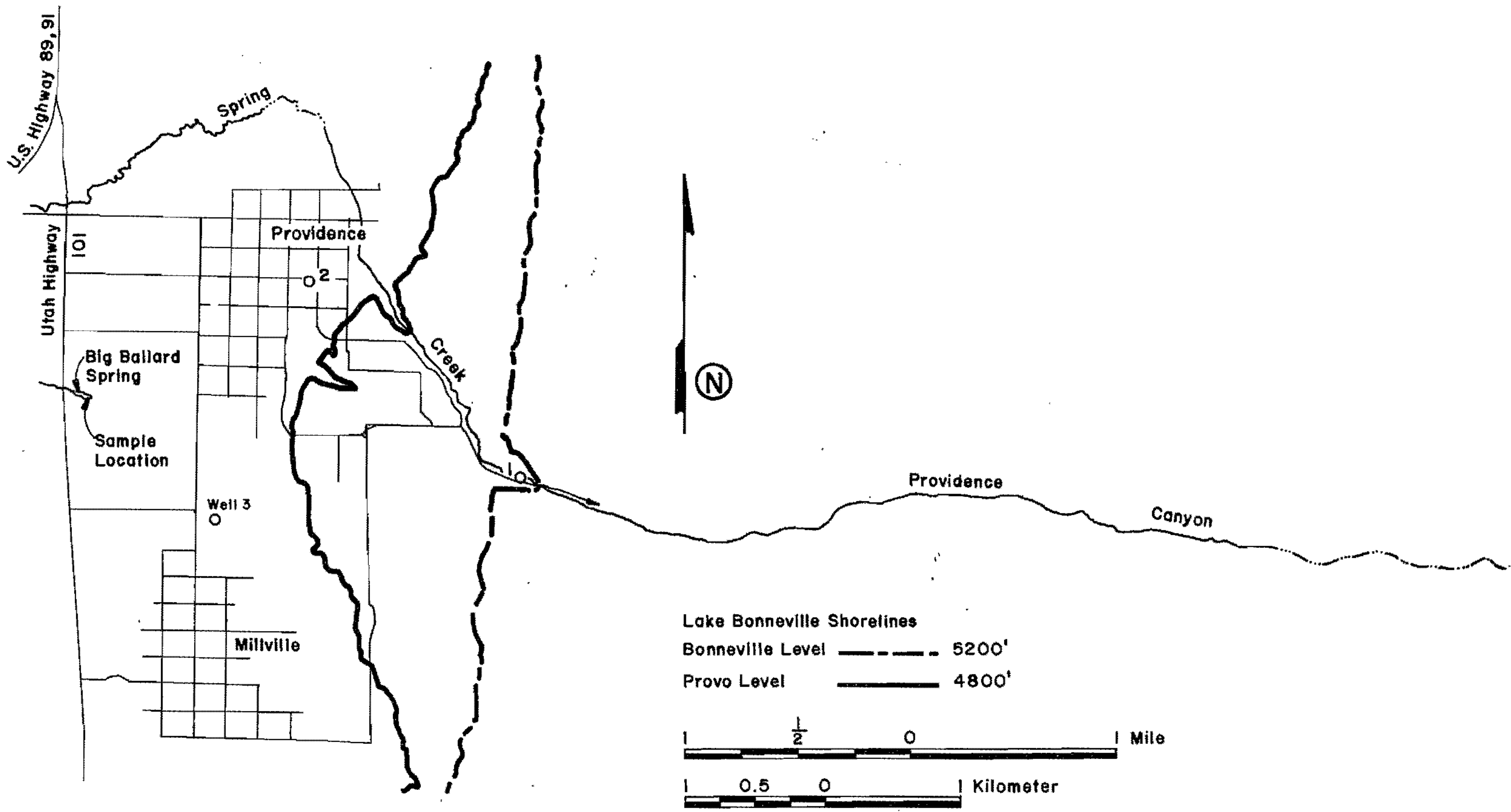

Figure 11. Providence and Millville, Utah.

Geology. Providence and Millville are situated on well-developed shoreline deposits of ancient Lake Bonneville. The Bonneville lake level is etched along the mountain front at an elevation of 1,567 m (5,140 ft) above mean sea level with much more extensive deposits than are normally associated with the Bonneville stand of the ancient lake. The Bonneville deposits grade to the west into deposits of the Provo stand of the lake. Extensive deposition along the mountain front during Provo time has produced a broad plain which gently slopes toward the valley. The majority of municipal development in the Providence-Millville area is on the Provo-level deposits. Several short-term lake stands are recognized below the Provo level. These deposits represent short periods when the lake level held constant during its most recent withdrawal from Cache Valley.

The main reason for the well-developed lake deposits in the Providence-Millville area is a complex interaction of fluvial deposition, littoral and offshore currents, lake level fluctuation, and mudflow deposition. Sediments carried by the Logan River formed large deltaic deposits during the times the ancient lakes occupied the valley. The prevailing winds from the northwest created generally north-south littoral and offshore currents which swept a portion of the sediment carried in suspension by the Logan River to the south into the Providence-Millville area. Another source of the extensive deposits is the intermittent stream which flows from Providence Canyon. Figure 11 shows the lobate landform built by deposition of sediments from Providence Canyon. The generalized driller's logs of wells in the vicinity also support the idea that Providence Canyon played a significant role in the development of the surficial deposits of the area. See Appendix C for these logs. The well-logs bear record of thick sequences of gravel, cobbles, and boulders. These coarser-grained sediments could not have traveled any great distance by stream action or offshore currents. It is thought the mode of transport for the majority of these sediments is by mudflow and/or debris flow from Providence Canyon.

The coarse-grained sediments form the major aquifers of the area. These permeable aquifers receive infiltration in the recharge area along the mountain front. The thin layers of lake bottom clays and silts interbedded with the coarse sediments form confining layers which are responsible for the artesian condition encountered locally, as well as the springs at the western end of the two towns.

Water use

Providence and Millville each have their own water distribution systems. Millville relies on springs, which flow from canyons along the mountain front. Providence uses a combination of wells and a spring. In 1971 it was reported that Millville used 800,000 m^3 (650 ac-ft) per year, while the much larger city of Providence used only 260,000 m^3 (210 ac-ft) during the same year. The large difference in the amount of water used reflects the different mode of life of the two communities. Millville is a rural town which uses a large amount of water for irrigation and livestock purposes, whereas Providence is primarily residential. It uses water mostly for domestic purposes.

Disposal of wastewater in both communities is handled by individual septic tanks. Providence is one of the largest unsewered communities in Utah. The septic tanks and drain fields are located in the coarse-grained surface sediments. These coarse-grained sediments are very permeable and allow easy movement of the wastewater into the groundwater system.

Sampling location

Big Ballard Spring, located 0.4 km (1/4 mi) west of the two towns was the sampling location. A metal pipe 3.2 cm (1 1/4 in) in diameter has been driven into the hillside at the spring head. The pipe enabled sampling of the groundwater without contamination from the standing surface water in the small pond formed by the spring. A steady flow of approximately 0.3 l/s (5 gal.) per minute (0.3 l/s) flowed from the pipe in late January 1980 when the spring was first sampled, but on two subsequent sampling attempts in March and April no water was flowing from the pipe. Consequently, no additional samples were taken.

Water quality

Table 13 contains the chemical analysis of the sample of water taken from Big Ballard Spring in January 1980. Also for comparison Table 13 contains water quality data of a May 1968 sample taken from the same spring by the U.S. Geological Survey. A sample taken by the U.S. Geological Survey at a spring located in Providence Canyon was added to help infer what, if any, changes might occur down-gradient from the primary recharge area.

The results show little change in water quality except the normal increase in hardness and dissolved solids that one would expect as the groundwater moves towards the valley center. The May 1968 sample of Big Ballard Spring shows a nitrate level of 14 mg/l. Big Ballard Spring is located in the middle of cultivated land, and the increase in nitrate may have been due to fertilizers applied nearby. The January sample shows a low nitrate level which supports this idea. All other constituents are low and well within the Utah and EPA drinking water limits, except for mercury which is equal to the limit of 2 μg/l. The source of the mercury is unknown, but its level should be monitored.

Table 13. Analyses of water samples taken from Providence and Millville, Utah.

Constituent[a]	Providence Canyon Spring 5-10-68	Big Ballard Spring 5-8-68	Big Ballard Spring 1-31-80
Total Coliforms/100 ml			4
Fecal Coliforms/100 ml			4
BOD			2
Dissolved Oxygen			5.0
Total Dissolved Solids	187	345	350
Alkalinity (as $CaCO_3$)			316
Calcium	44	74	67
Magnesium	17	35	38
Total Hardness (as $CaCO_3$)	180	326	324
Fluoride	0.3	0.3	0.12
Ammonia (as N)			0.030
Nitrate (as N)	2.8	14	2.3
Nitrite (as N)			0.003
Total Kjeldahl Nitrogen			<1
Orthophosphate (as P)			0.023
Total Phosphorus			0.031
Total Organic Carbon			2.4
Arsenic			<2
Barium			13
Cadmium			<9
Chromium			<50
Copper			<7
Iron			<20
Mercury			1.8
Manganese			<5
Lead			<1
Selenium			<1
Silver			<46
Zinc			6
pH	8.1	8.3	8.25

[a]All metals are expressed in micrograms/liter. All non-metals are expressed in milligrams/liter except pH and coliforms.

The groundwater aquifer tapped by Big Ballard Spring shows little contamination from the waste disposal practices of Providence and Millville. The mercury level should be monitored. If it increases to hazardous levels, an attempt to locate its source should be made.

The water table is well below the communities of Providence and Millville. It is perhaps due to this factor that the groundwater shows little indication of contamination. The other possibility is that Big Ballard Spring taps a deeper aquifer than is recharged by flow from the mountain and not from septic wastes from the two towns.

PILOT STUDY AT WILLARD

To gather additional data on one alluvial fan aquifer and to further develop the necessary field procedures, a pilot study was done at Willard.

Well Construction

During the months of June and July 1979, three test wells and two piezometers were constructed at Willard using the auger and jetting methods. Many test wells were started but had to be abandoned because of the large quantities of boulders and other coarse-grained sediments encountered in drilling. Lost circulation was also an insurmountable problem in two of the wells.

Locations of the three test wells are shown in Figure 2. An old hand-dug well, number 4, is also shown on the figure. Evidently this is the last of the old domestic wells in town which still remains accessible. A water sample from this old well was analyzed for evidences of groundwater contamination and future use could be made of this well for monitoring purposes. The two piezometers are located near the site of Test Well 2.

The test holes and piezometers were constructed in June but the water table rose so much that the casings and screens had to be reset at shallower depths in the first part of July. As the casings and screens were withdrawn to higher levels, the boreholes filled with sand and gravel but hydraulic communication with the deeper levels of the aquifer still remains. All measurements of casings and screens were taken from ground level. The tops of all pipes are terminated at ground level or within a few inches of ground level.

Test Well 1 was drilled to a total depth of 5.5 m (18 ft). A 64-mm (2 1/2-in) nominal diameter casing was cemented about 0.6 m (2 ft) deep and a 38-mm (1 1/2-in) nominal diameter galvanized casing was suspended from the top of the 64-mm (2 1/2-in) casing to a depth of 3.0 m (10 ft). Finally, a saw-slotted, all teflon screen of 25-mm (1-in) internal diameter by 32-mm (1 1/4-in) outside diameter was suspended between the depths of 3.7 m (12 ft) and 5.5 m (18 ft) at the bottom of a 25 mm (1-in) nominal, galvanized pipe, which in turn was suspended from the top of the well. When Test Well 1 was initially completed on 19 June 1979, the static water level was 4.39 m (14.41 ft) below the top of the well. On 9 July it had risen to 3.81 m (12.50 ft) and was still rising in response to nearby irrigation activities.

Test Wells 2 and 3 were drilled to total depths of 7.56 m (24.8 ft) and 4.9 m (16 ft), respectively. Surface casings of 64 mm (2 1/2-in) nominal diameter were cemented in both wells to about 0.6 m (2 ft) depth, and 38 mm (1 1/2-in) casings were suspended from the tops of those casings to depths of 2.7 m (9 ft) and 0.6 m (2 ft), respectively. Teflon screens connected to 25 mm (1-in) pipe were suspended in Test Well 2 between the depths of 2.4 m (8 ft) and 4.3 m (14 ft) and in Test Well 3 between 0.6 m (2 ft) and 2.4 (8 ft), all in the same general manner and pipe sizes as for Test Well 1.

When Test Well 2 was initially completed on 11 June 1979, the static water level was 3.95 m (12.96 ft) below the top of the well. By 9 July it had risen to 2.69 m (8.83 ft) because of adjacent irrigation activities. Water levels in the two piezometers constructed at the site rose in unison with that of Test Well 2. An average of six sets of measurements during this initial month indicated that the direction of groundwater flow at Test Well 2 was practically due west and the average hydraulic gradient was 0.011.

When Test Well 3 was completed on 14 June, the static water level in that well was 1.58 m (5.17 ft) below the top of the well. By 5 July it had risen to 0.84 m (2.75 ft) and then receded to 0.98 m (3.21 ft) on 9 July in response to irrigation activities nearby. During the period from 20 June to 9 July the water level rose in the hand-dug Well 4 from 7.57 m (24.83 ft) to 7.40 m (24.27 ft) as measured from the top of the ceramic casing pipe.

The north piezometer at the site of Test Well 2 was drilled to a depth of 6.86 m (22.5 ft), 64-mm (2 1/2-in) casing was cemented at 0.6 m (2 ft) and 38 mm (1 1/2-in) casing was suspended from the surface to 4.72 m (15.5 ft). The south piezometer was drilled to a depth of 6.4 m (21 ft), 64 mm (2 1/2-in) casing was cemented at 0.6 m (2 ft), and 38 mm (1 1/2-in) casing was suspended to 4.57 m (15 ft). All wells and piezometers were cleaned out insofar as practical by pumping with the jetting pump and finally with the small sampling pump.

Casing top elevations of the test wells and piezometers were determined using an engineers level to an accuracy of about

± 15.24 cm (0.05 ft). A Coast and Geodetic Survey benchmark, number P 171, located at the northeast corner of the intersection of Highway 89, 91 (Main Street) and Center Street in Willard, was used as the reference datum from which the elevations of the top (head) of each well casing were determined. The benchmark elevation is 1324.593 m (4345.779 ft) above mean sea level. The elevations of the well heads of the test wells and piezometers are as follows:

Test Well 1	1312.13 m (4304.88 ft)
Test Well 2	1310.75 m (4300.35 ft)
Test Well 3	1308.66 m (4293.52 ft)
Hand-dug Well 4	1317.01 m (4320.90 ft)
North Piezometer	1310.92 m (4300.92 ft)
South Piezometer	1311.00 m (4301.17 ft)

The reference point on the hand-dug well is on top of the ceramic casing pipe on the west side of the well, which is about 0.6 m (2 ft) above ground level. The datum points of all the other well heads are taken at the west rims of the uppermost pipe and are approximately at ground level.

Test Well 1 is located about (82.3 m (270 ft) west of the west line of 200 West Street and about 143.3 m (470 ft) north of the south line of Center Street in Willard. Test Well 2 is located on a public alley-way about the same distance west of 200 West Street and about 13.7 m (45 ft) south of the south line of Center Street. Test Well 3 is located on the same alley-way about the same distance west of 200 West Street and about 152 m (500 ft) south of the south line of Center Street. Hand-dug Well 4 is located in the back yard of the residence on the west side of 100 West Street at its intersection with South Center Street.

At the site of Test Well 2, both piezometers are located on private property. The north piezometer is located at a distance of 10.93 m (35.87 ft) on a bearing of north 16° east while the south piezometer is 10.95 m (35.93 ft) north 76° east from Test Well 2. The piezometers are 10.91 m (35.81 ft) apart.

Water Quality

On 11 July 1979 and again on 9 August 1979, four water samples were collected for analysis from the three test wells constructed on this pilot project and from hand-dug Well 4, located closer to the center of town. The results of these analyses are presented in Table 14. Not all the same chemical constituents that were analyzed for

Table 14. Analysis of water samples taken during Willard Creek fan pilot study.

Constituents[a]	Test Well 1		Test Well 2		Test Well 3		Dug Well 4		Municipal Supply[b]
	11 July 1979	9 Aug. 1979	11 July 1979	9 Aug. 1979	11 July 1979	9 Aug. 1979	11 July 1979	9 Aug. 1979	9 Aug. 1979
Metals									
Arsenic	<0.6	<0.6	<0.6	0.65	<0.6	<0.6	<0.6	<0.6	<0.6
Barium	<60	<60	130	212	<60	149	<60	132	<60
Cadmium	<3	<3	<3	<3	<3	<3	<3	<3	<3
Chromium	<10	<13	<10	<13	<10	<13	<10	<13	<13
Copper	<11	<10	<11	20	<11	25	<11	<10	<10
Iron	33	42	140	219	230	103	85	389	60
Mercury	<0.2	0.9	0.5	4.5	1.3	4.0	2.0	1.3	2.7
Manganese	24	23	166	36	84	<6	<10	29	<6
Lead	<5	<5	<5	<5	<5	<5	<5	5	<5
Selenium	1.3	<0.7	1.10	<0.70	0.80	<0.7	<0.7	<0.7	<0.7
Silver	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	224	35	2180	6870	350	158	18	17	10
Non-metals									
Chloride	2	2	26	23	3	3	8	8	2
Cyanide	0.03	0.14	0.03	0.10	0.03	0.12	0.03	0.11	0.09
Fluoride	0.05	0.04	0.07	0.06	0.08	0.05	0.06	0.04	0.03
Nitrate (as N)	0.53	0.77	20.8	26.3	5.08	2.26	1.33	0.99	1.31
Sulfate	31	21	69	37	69	24	48	48	40
Total Dissolved Solids, by Evaporation	221	153	443	482	321	204	302	342	163
Turbidity	2.8	1.3	140	7.3	72	8.4	1.4	3.9	2
pH	6.94	7.06	6.70	6.81	7.17	7.04	7.07	7.12	7.86
Water Temperature at Well Site	13.9°C		15.0°C		16.7°C		11.1°C		

[a]All metals are expressed in concentrations of micrograms/liter. All non-metals are expressed in milligrams/liter except turbidity, pH and trihalomethanes, which are expressed in nephelometric turbidity units, dimensionless pH scale values and micrograms/liter, respectively.

[b]Sample taken from the distribution system from the public drinking fountain in the park by the City Hall.

Table 4 were determined in these more recent analyses. Several trace metals and other more specific indicators of contamination were determined instead.

A study of Table 14 reveals that no positive indication of groundwater contamination is to be found in Test Well 1. Well 4 has only slight indications, in that the mercury content of its water is approximately equal to the maximum concentration allowed by the State of Utah. Sulfate and nitrate concentrations in the water of Well 4 are somewhat higher than normal for uncontaminated waters such as the Willard springs and the municipal water well.

Test Wells 2 and 3 definitely show some evidences of groundwater contamination. It should be noted, however, the waters of both of these wells are highly turbid due to fine-grained aquifer materials which are not screened out of the wells. These naturally occurring materials could be contributing somewhat to the unusually high concentrations of some contaminating constituents in these analyses.

Water of Test Well 2 appears to be the most highly contaminated of all the waters sampled at Willard. Test Well 2 is located not only down-gradient from several homes having septic tanks in the vicinity of West Center Street, but it is located immediately down-gradient from a small backyard corral where two horses are kept and fed a few months during the winter. It is probable that the horses are responsible for some of the evidences of contamination, but they probably are not responsible for all of it because of the numerous septic tank systems in the vicinity.

The concentration of nitrate nitrogen is unusually high in the water of Test Well 2, being about double the allowable limit. Other constituents which appear high for the Willard area are manganese, zinc, chloride, sulfate, and total dissolved solids. All of these relatively high concentrations combined are good supporting evidence of contamination at that site.

Concentration levels of certain constituents of water from Test Well 3 are also indicative of contamination, but at a lower level than that of Test Well 2. Constituents which are considered to be of high concentrations in the water of Test Well 3 when compared to other well waters at Willard are: iron, mercury, manganese, nitrate, sulfate, and total dissolved solids. Test Well 3 is situated immediately down-gradient from a very small back-yard alfalfa field and relatively few homes are situated up-gradient from it. The water levels in this well are close to the surface and, consequently, contamination can take place more readily.

Groundwater Flow Velocity

One important aspect examined was the rate at which groundwater moves through the aquifer. This gives some idea of the rate at which possible pollutants may be transported by the groundwater.

In order to determine the rate of groundwater flow, an experiment was performed using fluorescein dye, the south piezometer, and Test Well 2. Approximately 340 g. (3/4 lb) of fluorescein dye powder was mixed with 8 l (2.1 gal.) of water. The resulting dye solution was injected as a single slug into the south piezometer, which is about 11.0 m (35.9 ft) up-gradient from Test Well 2, and about 20 l (5.3 gal.) of water were added to the well. Water samples were taken at approximately 24-hour intervals and were examined at the Utah Water Research Laboratory using a spectrofluorometer. Unfortunately the water table was declining at the time of the test at the end of the irrigation season. The dye appeared in Test Well 2 12 days later, but the well went dry in 14 days as the water table receded below the bottom of the wellscreen. It was impossible to detect a peak in the dye concentration and the results were rather inconclusive. As these wells are not exactly up- and down-gradient with each other, it's possible the head of the plume of dye passed Test Well 2 a little before its lateral expansion encompassed the well and its presence was detected. The wells were only between 5° and 10° off the hydraulic flow line. At least it is known that some dye traversed the distance underground at an average rate of roughly 0.92 m (3 ft) per day.

SUMMARY AND CONCLUSIONS

Alluvial Fan Aquifers

Willard Creek fan

Study of the Willard Creek fan suggested two separate groundwater regimens: 1) A deep confined regimen, separated and protected from the surface by impervious layers interbedded with the more permeable aquifers; and 2) a shallow unconfined groundwater system.

Recharge in the deep-seated system is primarily along Willard Creek in the apex area of the fan and up-gradient from the town of Willard. There appears to be little or no vertical movement or exchange of groundwater between the shallow water-table aquifer and this deep aquifer system. Water quality in these deep aquifers is in conformance with EPA and Utah standards for drinking water, and there appears to be no problem of contamination or pollution.

The shallow groundwater system receives recharge from the land surface through processes such as precipitation, septic tank discharge, and percolation of excess irrigation waters. Depth to the shallow water table was quite variable and greatly dependent on the rate and time of local irrigation schedules. An average hydraulic gradient of 0.011 was determined during June of 1979, with the direction of flow being essentially due west at the site of Test Well 2. Analysis of water samples taken from test wells drilled down-gradient from the center of Willard indicates that the shallow aquifer is probably contaminated by septic tank effluents and other wastes.

Manti Canyon fan

The Manti Canyon fan study showed that the water in the alluvial fan is generally of good quality. Samples studied came primarily from relatively shallow (probably less than 15 m (50 ft)) wells, used mainly on the lower areas of the fan for stock watering, and the emergency supply well for the town of Manti. In all cases the water quality met EPA and Utah standards for drinking water.

Although there are exposures of mudflow deposits on the surface of the fan, braided-flow deposition is believed to predominate in at least the first 30 m (100 ft) of sediments composing the fan. However, mudflow deposition probably predominates below 30 m (100 ft). Due to the lack of shallow confining beds in the fan, contamination could reach deeper within this fan than in some of the others studied. There are slight indications that mild contamination could be present in the unconfined aquifers of the fan from septic tank effluents, livestock wastes, and possibly other sources. The relatively deep water table beneath the town of Manti does allow for considerable filtration and adsorption of contaminants in the unsaturated vadose zone.

Flat Canyon fan

The Flat Canyon fan appears to have been formed dominantly of mudflow deposits, with large amounts of fine-grain-sized, poorly-sorted material. Aquifers deep within the fan are thus isolated from downward percolating surface waters. Recharge of the deeper aquifers is probably from the general underflow of the Sevier River Valley.

Shallow horizons may be subject to some pollution, possibly from the turkey farm or livestock or from septic tank discharge. Much of the recharge for the shallow, poorly defined aquifers probably comes from the canals crossing the fan and from irrigation.

Spring City fan

The Spring City fan appears to be typical of a fan which has coalesced with adjacent fans to form a bahada. Although it appears to have been formed predominantly by mudflows, its steep slopes suggest a large component of braided-flow deposits may be present. Waters of wells and springs, which were sampled, were all within the recommended limits for drinking water. Since the town is on the lower portion of the fan, there is little danger of groundwater contamination under the present circumstances.

Conclusions

In general there appears to be little or no contamination of groundwater supplies in deep aquifers of alluvial fans. Generally these aquifers are separated and protected from the downward percolation of shallow groundwater and contaminants by layers of impermeable clay except in the apex areas where the probability of contamination is small. These clay layers were present mainly because most of the fans studied had been formed by the process of aggrading mudflows with only minor amounts of typical stream flow deposition. As a result, the internal stuctures of the fans consisted of large amounts of fine-grain-sized, poorly sorted, relatively impermeable materials, with occasional coarser-grained, better-sorted layers or channels, which function as the aquifers. Fans built of practically all braided-stream deposition would have few confining layers and hence, would not have the usual protection from contamination for their deeper aquifers. The deeper aquifers of any type of alluvial fan have a natural immunity to man-made contamination because of their deep burial and the processes of filtration, adsorption, and dilution, which would take place as contaminants percolate to appreciable depths in the fan.

The situation with respect to the unconfined, shallow aquifers of alluvial fans is not so promising. In these aquifers the recharge occurs over much of the fan's surface area. This greatly increases the potential for contamination from septic tanks, from fertilizers and pesticides, and from numerous other sources. Results from the test wells drilled on the Willard Creek fan suggest that there is a contamination problem in the shallow aquifer of that fan. It is likely that most alluvial fans, which have been used for residential or agricultural purposes, will show evidence of shallow groundwater contamination.

Lake Features

Fielding

Study of the Fielding site was begun in an attempt to assess the groundwater movement and water quality in aquifers located within lake bottom deposits. As such, the sediments are generally fine-grained, well-sorted, well-bedded, and laminated.

Water samples were taken from a flowing spring below the center of town. Unfortunately, it appears that septic tank effluent and/or animal wastes are directly entering the spring, if indeed it is a spring at all. This conclusion is based on the extremely high total and fecal coliform counts (1.2×10^4 and 2.6×10^3 coliforms/100 ml, respectively) and the very high ammonia (380 μg/l), nitrite (47 μg/l), orthophosphate (198 μg/l), and total phosphorus (202 μg/l) content of the water. Because of the high readings indicated a possible direct connection to a contaminant source, study of this particular area was discontinued.

Hyde Park

The study site at Hyde Park was selected to give a representation of the groundwater regime in an area characterized by an intermixing of shoreline, near-shore, and alluvial environments. The town of Hyde Park is located between the Provo and Stansbury levels of Lake Bonneville. A test well was constructed on the topographically low end of the town.

Water quality of the area is within most of the limits recommended for public water supplies in Utah. However, the total dissolved solids and nitrate content are close to the recommended limits, and the amount of mercury exceeds the limit by three times. At the present time the source of the mercury is unknown.

The high concentration of nitrate and a relatively high concentration of phosphorus in the water suggest that some contamination of the shallow groundwater aquifers may be occurring. The contamination may be coming either from septic tank effluent or from irrigation water that has percolated through fertilized fields. Determination of the actual degree and source of contamination requires additional study.

Richmond

The study at Richmond was begun as an attempt to compare groundwater quality in two geologically similar areas: one that has only individual home septic tanks and one that has a city sewerage system. Hyde Park was the study area with septic tanks and Richmond the area with a sewerage system.

Water quality in the Richmond area is comparable to that of Hyde Park. However, the amounts of phosphorus, nitrate, and nitrite found in the shallow groundwater below Richmond are lower than amounts of those constituents found at Hyde Park. This suggests that one of the sources of contamination in Hyde Park could be septic tank effluents. This source of contamination in Richmond has been mostly removed by installation of the city sewage collection and treatment system.

The amount of mercury in the water sample exceeded the recommended Utah limit by three times, as did the sample from Hyde Park. It is possible that both samples are tapping a natural source of mercury, especially since the two areas are so similar geologically.

Providence and Millville

The towns of Providence and Millville were chosen as a study site because they represent dominantly shoreline deposits of the Provo level of Lake Bonneville with some additional alluvial deposits. The water sample was taken from a flowing spring west of the two towns. It was assumed that the spring tapped the shallow, unconfined aquifer, but it is possible that the spring actually taps a deeper, confined aquifer and thus, the results were inconclusive.

Water quality is within the limits set by the State of Utah for drinking water, with the exception of mercury, which is right at the recommended limit. The source of the mercury is unknown.

Conclusions

In general, groundwater from shallow, unconfined lacustrine and alluvial aquifers in the areas studied is of reasonably good quality, usually within drinking water limits specified by both the EPA and the State of Utah. The exception to this is mercury, which exceeds the recommended limit by a factor of three in three of the areas and is at the limit in the fourth. The source of mercury in all cases is unknown, but probably is of natural origin.

Although water quality is within recommended limits, concentrations of nitrate and phosphorus in the water at Hyde Park suggest that some contamination of the shallow, unconfined aquifers is occurring. A comparison of the Hyde Park data, in which the city uses septic tank disposal, with the data from Richmond, in which a city sewage treatment system is used, suggests that at least some of the phosphorus and nitrate in Hyde Park may come from septic tank outflow.

The municipal water systems of the areas studied appear not to be in danger of contamination from the shallow groundwater. However, the shallow, unconfined groundwater aquifers are in danger of contamination, not only from septic tank discharges, but also from man's activity in terms of agriculture and animal husbandry. Much of the potential for contamination can be controlled by installation of sewage treatment systems.

REFERENCES CITED

Feth, J. H., D. A. Barker, L. G. Moore, R. J. Brown, and C. E. Veirs. 1966. Lake Bonneville: Geology and hydrology of the Weber Delta district, including Ogden, Utah. U.S. Geol. Survey Prof. Paper 518. 76 p.

Gilbert, G. K. 1890. Lake Bonneville. U.S. Geol. Survey Monograph 1. 438 p.

Hunt, C. B., H. D. Varnes, and H. E. Thomas. 1953. Lake Bonneville: Geology of northern Utah Valley, Utah. U.S. Geol. Survey Prof. Paper 257A. 99 p.

Spieker, E. M. 1949. Guidebook to the geology of Utah; No. 4. Utah Geological Society. Utah Geological and Mineral Survey, Salt Lake City, Utah.

U.S. Environmental Protection Agency. 1976. National interim primary drinking water regulations. U.S. Environmental Protection Agency, Office of Water Supply, Washington, D.C. EPA-570/9-76-003.

Utah Department of Health. 1979. State of Utah public drinking water regulations. State of Utah, Department of Health, Division of Environmental Health, Bureau of Public Water Supplies, Salt Lake City, Utah.

Wooley, R. R. 1946. Cloudburst floods in Utah 1850-1938. U.S. Geol. Survey Water-Supply Paper 994.

APPENDIX A

SUMMARY OF FIELD RECONNAISSANCE NOTES

1. Name	MONTELLO
2. State/County	Nevada/Elko
3. Number(Category)	1 (Alluvial Fan/Bahada; older part in N truncated by Pediment)
4. Location	T 38/39 N, R 69/70 E, center approx. 6 mi. SE of Montello on Nevada State Highway 30; unnamed valley.
5. Drainage	
a. Range	Pilot Rg. (predominantly in Utah)
b. Canyon(s)	4 unnamed mountain-front drainages and 1 unnamed major drainage.
c. Area	25.8 sq. mi.
d. Altitude/Relief	8000-6000 = 2000 ft.
e. Bedrock	Cambrian quartzite, Paleozoic carbonates with minor sandstone, quartzite, shale, and chert, Tertiary tuffaceous lake deposits, Early Tertiary granitic rocks.
6. Aspect	West
7. Altitude/Relief	6000-5000 = 1000 ft.
8. Area/radius/average slope/designation	44.5 sq.mi./5½ mi./3.4%/steep
9. Morphology, esp. at head of Fan	NE/4 is a pediment (with gravel cap, desert pavement, and desert varnish) that truncates W-dipping beds in high-standing alluvial-fan deposits; NW/4 and S/2 are low-standing coalesced alluvial-fan deposits (bahada); Bonneville shoreline along toe, near 5000 ft.
10. Dissection of Fan Surface	Pediment area dissected by wide (200-300 ft.), flat-bottomed, steep-sided, W-trending gullies approx. 20-30 ft. deep; steep scarp approx. 50 ft. high along S margin of pediment, at major drainage; fan portions gently rolling (undulant) with narrow, vertical-walled gullies 4 to 10 ft. deep.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Sagebrush; junipers on undissected pediment remnants near head, in NE/4.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment, and direct precipitation on fan with runoff into dissected channels.
14. Springs/Wells	None shown; two defunct wells with windmills along toe, at W margin and at SW margin.
15. Present Uses	Grazing for cattle
16. Contamination Sources	None major.
17. Other alterations	Abandoned small mines along mountain face and two small ranches near base of mountain face, both in NE; other small mines along N side of major canyon in mountains.
18. Access	Good, unpaved.
19. Ownership	Drainage unknown; Fan probably private; Playa probably private.
20. Classification	BF > MF (Braided-flow deposits dominate over mudflow deposits), at least in NE/4 where deep cuts expose highly variable proportions of each: probably the result of the numerous drainages that formed this older bahada; S/2 may have MF > BF, based on cuts in two gullies.
21. Other	

1. Name	TAYLOR
2. State/County	Nevada/Elko
3. Number(Category)	2 (Alluvial Fan)
4. Location	T 27/28 N, R 6^2 E, center approx. 16 mi. SSE of U. S. 93 & 14 mi. W of Currie; Butte Valley.
5. Drainage	
a. Range	Cherry Creek Rg.
b. Canyon(s)	Taylor on S (about 3/4 of total) & 2 smaller, unnamed canyons on N.
c. Area	16.1 sq. mi.
d. Altitude/Relief	9200-6800 = 2400 ft.
e. Bedrock	Late Paleozoic carbonates with minor sandstone, quartzite, and shale.
6. Aspect	West
7. Altitude/Relief	6800-6100 = 700 ft.
8. Area/radius/average slope/designation	13.4 sq.mi/4 mi./3.3%/steep
9. Morphology, esp. at head of Fan	Paired remnants at head (cyn. mouth) 50' high, decreasing within 0.5 mi. to present (inset) level of fan; one soil at surface and one paleosol visible.
10. Dissection of Fan Surface	Few surface gullies, all of low relief; lack of major surface channel
11. Complications, esp. Tectonics	Probable fault with fairly recent offset across head of fan
12. Natural Vegetation	Sagebrush
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; fault across head may be important.
14. Springs/Wells	At least 4 along toe, in playa-lake sediments; strong flow in September, 1977, a drought year.
15. Present Uses	Grazing for horses
16. Contamination Sources	None major
17. Other alterations	E-W Fence on N side of Taylor Canyon at head.
18. Access	Good, unpaved.
19. Ownership	Drainage unknown; Fan probably BLM; Playa Ruby Valley Indian Reservation
20. Classification	BF (Braided-flow deposits dominate, based on cuts in remnants with few large clasts, on deep entrenchment at head, on steep slopes, on lack of surface channels despite large catchment, and on numerous springs at base)
21. Other	

1. Name	COTTONWOOD
2. State/County	Nevada/Elko
3. Number(Category)	2 (Alluvial Fan)
4. Location	T 28/29 N, R 63/64 E, center approx. 5 mi. NW of Currie on U.S. 93; S end of northern Steptoe Valley.
5. Drainage	
a. Range	Cherry Creek Rg.
b. Canyon(s)	Cottonwood and unnamed canyon on N, onto pediment; two small unnamed drainages onto fan in S.
c. Area	12.5 sq. mi. (10.1 sq. mi. for pediment)
d. Altitude/Relief	8400 (fan) - 6600 (fan) = 1800; 9200 (pediment) - 6600 (pediment) = 2600 ft.
e. Bedrock	Late Paleozoic carbonates with minor sandstone, quartzite, and shale; Tertiary tuffaceous lake deposits; Early Tertiary acidic volcanics
6. Aspect	East

7. Altitude/Relief	6600-5900 = 700 ft.
8. Area/radius/average slope/designation	7.0 sq. mi./5 mi./2.7%/medium (all for fan) (22.2 sq. mi. for pediment)
9. Morphology, esp. at head of Fan	Main (Cottonwood) channel, near center of pediment, approx. 100 ft. deep, decreases in depth E-ward, exposes truncated, W-dipping reddish sandstone through 2 mi. E of mountain front; small fans overlie pediment along mountain front S of main channel; along N margin pediment truncates probable Salt Lake Formation, dipping W; truncates older fan deposits along S margin.
10. Dissection of Fan Surface	Fan undulant with many small, shallow gullies; fan surface separated from pediment surface by steep, S-facing scarp approx. 25 ft. high.
11. Complications, esp. Tectonics	None noticed
12. Natural Vegetation	Sagebrush; junipers on high(undissected) headward parts of pediment.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment into pediment along main channel and onto fan; direct precipitation onto fan.
14. Springs/Wells	At least 2 along toe of pediment and one in small, S-facing scarp that forms N margin of pediment.
15. Present Uses	Grazing.
16. Contamination Sources	None major.
17. Other Alterations	None noticed.
18. Access	Good, unpaved.
19. Ownership	Drainage unknown; Fan unknown; Playa unknown.
20. Classification	BF >> MF (exposed in cut along N margin of fan.)
21. Other	

1. Name	MCDERMITT
2. State/County	Nevada/Elko
3. Number(Category)	4 (Alluvial Fan)
4. Location	T 26/27 N, R 64 E, center approx. 5 mi. SW of Currie on U.S. 93; Goshute playa lake on E; middle Steptoe Valley
5. Drainage	
a. Range	Cherry Creek Rg.
b. Canyon(s)	McDermitt and Corral (coalesced) in center (about)
c. Area	21.7 sq. mi.
d. Altitude/Relief	10,200-6600 = 3600 ft.
e. Bedrock	Late Paleozoic carbonates with minor sandstone, quartzite, and shale.
6. Aspect	East
7. Altitude/Relief	6600-5900 = 700 ft.
8. Area/radius/average slope/designation	21.4 sq.mi./5½ mi./2.4%/moderate
9. Morphology, esp. at head of Fan	Paired remnants at head (cyn. mouth) 110' high decreasing downfan through at least 3 mi.; 30' of chiefly BF deposits over E-dipping carbonate bedrock w/minor N-S folds; Upper surface of bedrock slopes beneath present fan surface E-ward.
10. Dissection of Fan Surface	Moderate surface dissection
11. Complications, esp. Tectonics	May be fault approx. E-W in bedrock, along McDermitt Canyon.
12. Natural Vegetation	Sagebrush; shade trees and orchard at old homestead ranch in valley at head of fan.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment.

14. Springs/Wells	At least 7 along toe chiefly in NE; 2 cfs in September at source for Currie water supply (permission required).
15. Present Uses	Irrigation farming along main channel, confined to mid-fan and head of fan, with old homestead ranch buildings.
16. Contamination Sources	Cultivated fields along main channel; barnyards at old homestead.
17. Other Alterations	Dam across McDermitt Canyon just upstream from canyon mouth, with spring upstream.
18. Access	Good, unpaved, potential problems with washouts at gullies.
19. Ownership	Drainage, partly private; Fan private; Playa unknown.
20. Classification	BF >> MF (Braided-flow deposits dominate, based on cuts in remnants with few large clasts, on deep entrenchment at head, on moderate slopes, and on numerous springs at base).
21. Other	

1. Name	DUCK CREEK
2. State/County	Nevada/White Pine
3. Number(Category)	5 (Alluvial Fan)
4. Location	T 18/19 N, R 64 E, center approx. 5½ mi. N or McGill, 17 mi. NNE of Ely, crossed by U.S. 93; middle Steptoe Valley.
5. Drainage	
a. Range	Schell Creek Rg. (incl. Duck Creek Rg.)
b. Canyon(s)	Duck Creek in S (about 4/5 of total); N, Middle & E creeks in N (about 1/5 of total).
c. Area	132 sq. mi.
d. Altitude/Relief	11,900-6600 = 5300 ft.
e. Bedrock	Late Precambrian quartzite, sandstone and shale with minor carbonate; Paleozoic carbonates with minor sandstone, quartzite, and shale; Tertiary tuffaceous lake deposits; Early Tertiary acidic volcanics; Late Cenozoic alluvium.
6. Aspect	West
7. Altitude/Relief	6600-6100 = 500 ft.
8. Area/radius/average slope/designation	33.2 sq.mi./7½ mi./1.3%/low
9. Morphology, esp. at Head of Fan	Undulose; fairly steep near the head; profile downfan prob. segmented; abundant recent mudflow deposits on surface; both MF & BF exposed in natural and artificial cuts, respectively; landslide blocks along mountain front on S side at head of fan.
10. Dissection of Fan Surface	Main channel entrenched approx. 25 ft. at head, swings abruptly to S; minor dissection elsewhere.
11. Complications, esp. Tectonics	Probable fault across head of fan; no evidence of recent offset.
12. Natural Vegetation	Sagebrush; shade trees near springs at ranch.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment, previously; springs at head and direct snowfall
14. Springs/Wells	None shown along toe; one present along fault scarp at head, on N side at Pescio Ranch.
15. Present Uses	Homestead ranch buildings on N side at head, still occupied; range cattle; several small gravel pits; mostly undeveloped.
16. Contamination Sources	Cattle and irrigated fields upstream in major drainage near dam.
17. Other Alterations	Dam about 2 mi. up Duck Creek: all flow diverted by pipeline to McGill; tailings pond against SSW toe of fan.
18. Access	Good, mostly unpaved; U.S. 93 N-S across upper 1/3 of fan.
19. Ownership	Drainage partly U.S.F.S., partly private; Fan private; Playa unknown (perennial stream, prob. private).
20. Classification	MF ≅ BF (recent MF deposits on surface, exposed in natural cuts; local gravel pits in BF deposits).
21. Other	

1. Name	ILLAPAH
2. State/County	Nevada/White Pine
3. Number(Category)	6 (Alluvial Fan)
4. Location	T 17/18 N, R 59 E, center approx. 24 mi. WNW of Ely, crossed by U.S. 50; Jakes Valley.
5. Drainage	
a. Range	White Pine Rg. (incl. Moorman Ridge)
b. Canyon(s)	Illapah Cr. & Harris Cyn. in S (about 2/3 of total); unnamed creeks in N.
c. Area	77.8 sq. mi.
d. Altitude/Relief	9350-6600 = 2750 ft.
e. Bedrock	Late Paleozoic carbonates with minor sandstone, quartzite, and shale; Tertiary tuffaceous lake deposits; Early Tertiary acidic volcanics
6. Aspect	East
7. Altitude/Relief	6600-6400 = 200 ft.
8. Area/radius/average slope/designation	7.1 sq. mi./3mi./1.3%/low
9. Morphology, esp. at Head of Fan	Small scarp approx. 12 ft. high on N side at head only, dies out downfan within 1/4 mi.
10. Dissection of Fan Surface	Main channel entrenched with gully 6 to 8 ft. deep; slight dissection elsewhere.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Sagebrush NW of road and below irrigated fields.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff and numerous springs in mountain catchment.
14. Springs/Wells	None on map; full dug pond approx. 1/2 way down fan SE of highway may be from seepage (spring) or piped in; defunct windmill near head.
15. Present Uses	Ranch with irrigated alfalfa fields at head; range cattle on rest of fan; highway maintenance area with mixing batching NW of highway near head; also, wind sock for cleared landing strip.
16. Contamination Sources	Cultivated fields at head.
17. Other Alterations	Fences along U.S. 50.
18. Access	Good, mostly unpaved; U.S. 50 across fan, NE from head.
19. Ownership	Drainage partly U.S.F.S., partly private; Fan private; Playa probably private.
20. Classification	MF >> BF (Cuts at head, dug pond, no springs at toe, low gradient).
21. Other	

1. Name	MAJORS PLACE
2. State/County	Nevada/White Pine
3. Number(Category)	7 (Alluvial Fan/Bahada)
4. Location	T 13/14 N, R 66/67 E, center approx. 20 mi. SE of Ely; Spring Valley
5. Drainage	
a. Range	Schell Creek Rg.
b. Canyon(s)	Unnamed canyons.
c. Area	19.1 sq. mi.
d. Altitude/Relief	9000-6600 = 2400 ft.
e. Bedrock	Dark Shales: Late Precambrian shale, sandstone, and quartzite with minor carbonate; Paleozoic carbonates with minor sandstone, quartzite, and shale.
6. Aspect	East
7. Altitude/Relief	6600-5800 = 800 ft.

8. Area/radius/average slope/designation — 23.0 sq. mi./6 mi./2.5%/moderate

9. Morphology, esp. at Head of Fan — Main channel and adjacent channel to S inset approx. 40 ft. near head of fan, with downfan, truncated shale outcrops at head that are progressively burried to E; depths of cuts decrease local surface cementation by caliche across remnants (exposed in channel walls).

10. Dissection of Fan Surface — Slight dissection, gently rolling S of major channels, moderately dissected to N.

11. Complications, esp. Tectonics — None noticed.

12. Natural Vegetation — Sagebrush near toe, junipers near head.

13. Sources of Water /Annual Ppt. — Snowmelt and other runoff from mountain catchment.

14. Springs/Wells — None shown along toe; windmill just E of toe of fan.

15. Present Uses — Grazing for cattle.

16. Contamination Sources — None major.

17. Other Alterations — Two power lines down fan; store with gas pumps at head near highway bifurcation.

18. Access — Excellent. Unpaved roads and U.S. 93 and U.S. 6/50 and state highway.

19. Ownership — Drainage U.S.F.S., Fan unknown, Playa unknown.

20. Classification — MF $\geqq$ BF (seen in deep cuts near head).

21. Other

1. Name — COOPER CANYON

2. State/County — Nevada/White Pine

3. Number (Category) — 8 (Alluvial Fan)

4. Location — T 14/15 N, R 66/67 E, center approx. 18 mi. ESE of Ely; Spring Valley.

5. Drainage
   a. Range — Schell Creek Rg.
   b. Canyon(s) — Cooper on S (about 9/10 of total) & 1 small, unnamed canyon on N.
   c. Area — 33.0 sq. mi.
   d. Altitude/Relief — 10,750-6600 = 4150 ft.
   e. Bedrock — Wide variety of acid volcanics, minor chert and dark carbonate: Late Precambrian sandstone, quartzite, and shale, with minor carbonate; Paleozoic carbonates with minor sandstone, quartzite, and shale; Early Tertiary or Mesozoic granitic rocks; Early Tertiary acid volcanics.

6. Aspect — East

7. Altitude/Relief — 6600-5800 = 800 ft.

8. Area/radius/average slope/designation — 24.3 sq. mi./6 mi./2.5%/moderate (fairly steep on S).

9. Morphology, esp. at Head of Fan — Main channel inset approx. 30 ft. near head of fan, with wide, flat bottom; depth decreases downfan to meet present fan surface approx. ½ mi. W of State highway; two small hills project above fan surface in NW/4 with channel along base on E side, abundant recent mudflow deposits on surface.

10. Dissection of Fan Surface — Upper part of fan moderately dissected and rolling, lower part only slightly dissected.

11. Complications, esp. Tectonics — None noticed.

12. Natural Vegetation — Scattered junipers in main channel and uplands at the head, sagebrush elsewhere.

13. Sources of Water /Annual Ppt. — Snowmelt and other runoff from mountain catchment.

14. Springs/Wells — None shown along toe; wet area at S toe of fan where State highway drains from both N and S.

15. Present Uses — Grazing for cattle.

16. Contamination Sources — None major.

17. Other Alterations	Large, inactive borrow pit in SE/4 of fan just E of State highway, two E-W power lines down axis of fan, small dug pond with dam in main channel, N-S telephone line (E) and N-S embankment for mudflow diversion along State highway.
18. Access	Good, paved State highway N-S across middle of fan, and unpaved roads.
19. Ownership	Drainage partly U.S.F.S., Fan unknown (upper part U.S.F.S.), Playa unknown.
20. Classification	MF ≷ BF (seen in large borrow pit and walls of entrenched main channel).
21. Other	

1. Name	MINERSVILLE (Lincoln Wash)
2. State/County	Utah/Beaver
3. Number(Category)	9 (Alluvial Fan)
4. Location	T 29/30 S, R 9/10 W, center approx. 4 mi. N. of Minersville; crossed by State highway 21; Escalante Valley.
5. Drainage	
a. Range	Mineral Mts.
b. Canyon(s)	Lincoln Wash on SE (about ½ of total) & unnamed canyon on NW.
c. Area	8.0 sq. mi.
d. Altitude/Relief	8000-6200 = 1800 ft.
e. Bedrock	Late Paleozoic carbonates and sandstone; Mesozoic sandstone and shale with minor carbonate; Tertiary granitic rocks; Early Tertiary acidic volcanics.
6. Aspect	Southwest
7. Altitude/Relief	6200-5200 = 1000 ft.
8. Area/radius/average slope/designation	10.6 sq. mi./3½ mi./5.4%/very steep
9. Morphology, esp. at Head of Fan	Fan is backed up behind low hills that block SE/4 of fan near toe.
10. Dissection of Fan Surface	No data
11. Complications, esp. Tectonics	No data
12. Natural Vegetation	Sagebrush
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment and perhaps direct precipitation on fan.
14. Springs/Wells	None shown along toe.
15. Present Uses	No data
16. Contamination Sources	Old mine along SE edge of catchment.
17. Other Alterations	Rocky Ford Irrigation Co. canal along toe of fan; embankment along upfan side of State highway 21 for flood control.
18. Access	Good, radiating unpaved roads from apex, paved State highway 21 along contour near toe.
19. Ownership	Drainage unknown; Fan unknown; Valley private.
20. Classification	No data
21. Other	Note: low, fan-shaped area at Minersville, original objective, probably is a small delta built into Lake Bonneville at the Bonneville level; the Lincoln Wash fan lies above this delta, and age relationships are unknown.

1. Name	NORTH CREEK
2. State/County	Utah/Beaver
3. Number(Category)	10 (Delta)
4. Location	T 28/29 S, R 6/7 W, center approx. 5 mi. NE or Beaver, unnamed (?Beaver) valley.
5. Drainage	
a. Range	Tushar Mts.
b. Canyon(s)	North Creek: N Fork and S Fork (glaciated)
c. Area	39.3 sq. mi.
d. Altitude/Relief	12,150-6800 = 5450 ft.
e. Bedrock	Late Tertiary acidic volcanics; minor Tertiary granitic rocks, Late Tertiary basalts, and Late Tertiary volcanic conglomerates.
6. Aspect	West-Southwest
7. Altitude/Relief	6800-6200 (crest of Scarp on W approx. 6400) = 400 ft.
8. Area/radius/average slope/designation	17.1 sq. mi./4½ mi./1.7%/gentle from apex to marginal scarp.
9. Morphology, esp. at Head of Fan	Nearly planar upper surface slopes gently to WSW, bounded on W by steep scarp approx. 110 ft. high; hills block SW toe.
10. Dissection of Fan Surface	Deep incision along North Creek, rest of delta dissected by E-W gullies up to 15 ft. deep that head on the delta.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Junipers
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment and direct precipitation.
14. Springs/Wells	None shown along toe; city water tank in hills along S toe.
15. Present Uses	Grazing for cattle in N/4, subdivisions on scarp crest just NW of North Creek and along toe in S, irrigation farming along toe of scarp near North Creek.
16. Contamination Sources	Septic tanks (probably minor).
17. Other Alterations	Some fences; small irrigation canal along crest of scarp NW of North Creek.
18. Access	Good, partly paved.
19. Ownership	Drainage, U.S.F.S.; Delta, Private; Valley, private.
20. Classification	BF >> MF, probably mostly topset and foreset delta beds.
21. Other	Note: this feature probably is a dissected delta, built into a lake near 6400 ft., approx. 1200 ft. above recognized high stand of Lake Bonneville.

1. Name	FLAT CANYON
2. State/County	Utah/Sevier
3. Number(Category)	11 (Alluvial Fan)
4. Location	T 24 S, R 3 W, Elsinore is at SW edge and Central is at E edge, along toe, center approx. 5 mi. SW of Richfield; southern Juab Valley.
5. Drainage	
a. Range	Pavant Range
b. Canyon(s)	Flat canyon
c. Area	18.7 sq. mi.
d. Altitude/Relief	8000-5600 = 2400 ft.
e. Bedrock	Late Tertiary acidic volcanics; minor Early Tertiary limestone, sandstone, siltstone, and conglomerate.
6. Aspect	East-Southeast
7. Altitude/Relief	5600-5200 = 400 ft.

8. Area/radius/average slope/designation	6.6 sq. mi./3 mi./2.5%/moderate
9. Morphology, esp. at Head of Fan	Main channel entrenched 3-5 ft. at head, dies out on fan; recent pink mudflow spread over NE/4 of fan.
10. Dissection of Fan Surface	Undulant, minor dissection.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Not recorded; cleared and farmed below canals.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; unlined canals and irrigation.
14. Springs/Wells	None shown along toe; wells probable for culinary water supplies for Elsinor and Central.
15. Present Uses	Turkey farm, small stock yard, extensive farming (corn, alfalfa, wheat); small borrow pit near head, on SW.
16. Contamination Sources	Numerous: canals, turkeys, stock, farming, cemetary, solid waste.
17. Other Alterations	Unlined irrigation canals follow contours: 1 near head, 1 near toe, 1 at toe; Elsinore covers old city dump; new dump near canyon mouth; cemetary on S near toe; power line NNE-SSW across head of fan; dike to divert floods just E of road along power line, with concrete funnel and ramp across canal in N.
18. Access	Excellent, unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, private; Valley, private.
20. Classification	MF >> BF (based on cuts in borrow pit and head of fan, plus recent pink mudflow).
21. Other	

1. Name	MEDOW CREEK
2. State/County	Utah/Millard
3. Number(Category)	12 (Alluvial Fan)
4. Location	T 22 S, R 4/5 W, center approx. 5 mi. SSW of Fillmore, Black Rock Desert
5. Drainage	
a. Range	Pavant Range
b. Canyon(s)	Medow Creek
c. Area	12.2 sq. mi.
d. Altitude/Relief	10,300-6000 = 4300 ft.
e. Bedrock	Tintic Qzt & N. Horn Cgl.;Navajo Ss. outcrop at head on S side of main channel near fan head; minor Early Paleozoic shale and carbonates and Early Tertiary sandstone and lake limestone.
6. Aspect	West-Northwest
7. Altitude/Relief	6000-5000 = 1000
8. Area/radius/average slope/designation	6.9 sq. mi./4 mi./4.7%/steep to very steep
9. Morphology, esp. at Head of Fan	Main channel follows SW side of fan, entrenched 24 ft. below earth-filled flood-control dam across head of fan, but only 10 ft. above dam; entrenchment dies out downfan.
10. Dissection of Fan Surface	Few surface
11. Complications, esp. Tectonics	Bonneville shoreline escarpment, 10 ft. high, follows 5200 ft. contour across lower part of fan; large sandstone clasts that characterize surface to the E are not exposed to the W; small hill along N side just below fan head.
12. Natural Vegetation	Junipers in upper 2/3 of fan, sagebrush below.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; dam at head supplies 2 lined irrigation canals down axis of fan (approx. ½ cfs during drought year, 9 September, 1977).
14. Springs/Wells	None shown.

15. Present Uses	Grazing for cattle.
16. Contamination Sources	None major.
17. Other Alterations	Telephone relay station on axis at midfan; 1955 diversion dam within canyon mouth (?upstream from flood-control dam?).
18. Access	Moderate, unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, head U.S.F.S., remainder unknown; Valley, private.
20. Classification	MF > BF (based on boulders, cobbles and fines in slope wash covering scarps along main channel, and sandstone boulders and cobbles across fan surface down to Bonneville shoreline).
21. Other	

1. Name	CHALK CREEK
2. State/County	Utah/Millard
3. Number(Category)	13 (Dissected Alluvial Fan modified along shoreline of Lake Bonneville)
4. Location	T 21 S, R 4 W, Fillmore near toe in center with U.S. highway 91 and State highway 100; Black Rock Desert.
5. Drainage	
a. Range	Pavant Range
b. Canyon(s)	N and S forks of Chalk Creek and tributaries, especially Dry Creek in S.
c. Area	53.6 sq. mi.
d. Altitude/Relief	10,300-5900 = 4400 ft.
e. Bedrock	Cambrian quartzite with minor shale and carbonate; Late Cretaceous and Early Tertiary sandstone and conglomerate; Mesozoic sandstone with minor conglomerate and siltstone; Tertiary volcanic conglomerate.
6. Aspect	Northwest
7. Altitude/Relief	5900-5000 = 900 ft.
8. Area/radius/average slope/designation	8.8 sq. mi./6 mi./2.8%/moderate
9. Morphology, esp. at Head of Fan	Large fan remnants on N and S, 70-80 Ft. high; inset area between fan remnants, along Chalk Creek, widens to W and is nearly flat.
10. Dissection of Fan Surface	Remnants dissected; little relief in inset area except along Chalk Creek, which lies below the Bonneville level and has been modified by nearshore lake processes.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Not recorded.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment.
14. Springs/Wells	None shown along toe; wells probable for culinary uses in Fillmore.
15. Present Uses	Not recorded.
16. Contamination Sources	City of Fillmore, near toe.
17. Other Alterations	Not recorded.
18. Access	Moderate, unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, dissected remnants at head, U.S.F.S., remainder private; Valley, private.
20. Classification	MF ≈ BF (based on cuts along high-standing fan remnants)
21. Other	

1. Name	HICKMAN CREEK
2. State/County	Utah/Tooele
3. Number(Category)	14 (Alluvial Fan)
4. Location	T 4 S, R 5/6 W, center approx. 11 mi. SW of Tooele and 11 mi. S of Grantsville at U.S. highway 40; Rush Valley.
5. Drainage	
a. Range	Stansbury Mts.
b. Canyon(s)	Hickman Creek
c. Area	11.6 sq. mi.
d. Altitude/Relief	9950-6200 = 3750 ft.
e. Bedrock	Sandstone and limestone: Late Paleozoic sandstone, shale, carbonates, and quartzite.
6. Aspect	East
7. Altitude/Relief	6200-5200 = 1000 ft.
8. Area/radius/average slope/designation	8.9 sq. mi./4½mi./4.2%/steep
9. Morphology, esp. at Head of Fan	Toe of fan, blocked by South Mtn. in NE, splits there into a small lobe to N and a larger lobe to E, other small hills lie along N side; main channel lies along N side of fan, inset approx. 50 ft. near head, 30 ft. downfan, with incised channel 5 ft. deep along flat bottom; caliche layers approx. 15 ft. and 25 ft. below fan surface near head.
10. Dissection of Fan	N/2 undulant but essentially undissected; S/2 deeply dissected and regraded; 3 levels seen in SE/4 of fan; cobbles at E to SE-facing scarps, mud and small pebbles between; large, theater-shaped drainages head to NW against N/2 of fan.
11. Complications, esp. Tectonics	Abrupt step up to S, 20-30 ft. high, across ESE-trending drainage near head, may be a fault; E to SE-facing scarps may be faults.
12. Natural Vegetation	Junipers in headward/4 of fan and in dissected lowlands in S/2; sagebrush elsewhere.
13. Sources of Water /Annual Ppt.	Direct precipitation onto fan; minor contribution from snow-melt and other runoff from mountain catchment, confined to N margin of fan.
14. Springs/Wells	At least 3 on playa, below toe of fan in SE, near irrigated fields at Morgan Ranch; windmill near S toe.
15. Present Uses	Wheat fields near head.
16. Contamination Sources	None major; small area of agriculture near head.
17. Other Alterations	Fenced in SE/4; SE/4 also burned over several years ago.
18. Access	Good in N, moderate in S, both unpaved.
19. Ownership	Drainage, mostly U.S.F.S., partly private; Fan, at least partly private; Valley, private.
20. Classification	MF > BF (based on cuts along main channel; braided-flow deposits)
21. Other	

1. Name	OPHIR CANYON
2. State/County	Utah/Tooele
3. Number(Category)	15 (Alluvial Fan)
4. Location	T 5/6 S, R 4/5 W, center approx. 13 mi. SSW of Tooele; crossed diagonally NW-SE by State highway 73; Rush Valley.
5. Drainage	
a. Range	Oquirrh Mts.
b. Canyon(s)	Ophir Creek
c. Area	18.1 sq. mi.
d. Altitude/Relief	10,600-6000 = 4600 ft.
e. Bedrock	Late Paleozoic carbonates, sandstone, and shale with minor quartzite; minor Early Paleozoic carbonates and shale; minor Tertiary granitic rocks.

6. Aspect	West
7. Altitude/Relief	6000-5200 = 800 ft.
8. Area/radius/average slope/designation	12.9 sq. mi./5½ mi./2.8%/moderate
9. Morphology, esp. at Head of Fan	Main channel turns S, follows SE margin of fan, inset approx. 100 ft. deep with wide, flat bottom of irrigated farmland and one set of paired terraces above that level.
10. Dissection of Fan Surface	Minor dissection
11. Complications, esp. Tectonics	Bonneville shoreline along toe in W.
12. Natural Vegetation	Sagebrush
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment.
14. Springs/Wells	None shown.
15. Present Uses	Irrigated fields along inset valley of Ophir Creek; U.S. Army Deseret Chemical Corps Depot on S/4 of fan.
16. Contamination Sources	Agriculture, chemical storage, and old mine tailings.
17. Other Alterations	Two small, earth-filled diversion dams and an abandoned gold mine in Ophir Canyon; old railroad grade to NW down axis of fan.
18. Access	Good, State highway 73 paved, several unpaved; permission required for access to Deseret Chemical Corps Depot.
19. Ownership	Drainage, unknown; Fan, partly private, partly U.S. Army, perhaps partly B.L.M.; Valley, probably private.
20. Classification	MF $\geq$ BF (based on cuts along Ophir Creek; braided-flow deposits cemented locally).
21. Other	

1. Name	SOLDIER CREEK
2. State/County	Utah/Tooele
3. Number(Category)	16 (Delta)
4. Location	T 4/5 S, R 4/5 W, center approx. 8 mi. SSW of Tooele, State highway 36 is just below the toe; Rush Valley.
5. Drainage	
a. Range	Oquirrh Mts.
b. Canyon(s)	Soldier Creek
c. Area	9.8 sq. mi.
d. Altitude/Relief	10,200-5600 = 4800 ft.
e. Bedrock	Late Paleozoic sandstone, shale, and limestone with minor quartzite; minor Tertiary granitic rocks.
6. Aspect	West
7. Altitude/Relief	5600-5200 = 400 ft.
8. Area/radius/average slope/designation	4.5 sq. mi./3½ mi./2.2%/moderate
9. Morphology, esp. at Head of Fan	Two scarps follow contours around W side of dissected, fan-shaped delta; inner scarp is approx. 50-70 ft. high, crest lies approx. 100 ft. above crest of lower scarp.
10. Dissection of Fan Surface	Deep, radiating dissection with contributaries; surface morphology confusing.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Sagebrush
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment.
14. Spring/Wells	None shown.
15. Present Uses	None noticed.
16. Contamination Sources	None major.

17. Other Alterations	Considerable gravel removed from borrow pits in lower, outer parts of delta in W, near State highway 36.
18. Access	Moderate, unpaved.
19. Ownership	Drainage, unknown; Delta, unknown; Valley, partly private.
20. Classification	Lake muds and braided-flow deposits dip E (sic) and are capped by nearly horizontal braided-flow deposits.
21. Other	

1. Name	PERRY CANYON
2. State/County	Utah/Box Elder
3. Number(Category)	17 (3 Deltas, 2 inset)
4. Location	T 8 N, R 2 W; center approx. 3 mi. SSW of Brigham City; U.S. 89 & 91 cross middle.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Three-mile creek, in Perry Canyon
c. Area	4.9 sq. mi.
d. Altitude/Relief	8725-4750 = 3975 ft.
e. Bedrock	Late Precambrian quartzites and argillites; minor basalt and carbonates.
6. Aspect	West
7. Altitude/Relief	4750-4275 = 475 ft.
8. Area/radius/average slope/designation	1.1 sq. mi./1.25 mi./7.2%/low gradient (fan)
9. Morphology, esp. at Head of Fan	3 levels, dissected deltas corresponding with Bonneville, Provo, and Stansbury levels of Lake Bonneville, 2 younger are successively inset between paired remnants of the next-older delta. Possible thin fan over lake-bottom deposits, farther to W.
10. Dissection of Fan Surface	Fan itself is undissected.
11. Complications, esp. Tectonics	Head of highest delta probably offset by faulting.
12. Natural Vegetation	Sagebrush.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment
14. Springs/Wells	None noted.
15. Present Uses	Farms and farmhouses on thin fan.
16. Contamination Sources	Septic tanks, fertilizers & pesticides (on fan).
17. Other Alterations	Borrow pits in delta.
18. Access	Moderate.
19. Ownership	Drainage, U.S.F.S.; Delta/fan, private; Valley, U.S. wildlife service.
20. Classification	Delta (foreset gravels) and lake-bottom; fan unknown.
21. Other	

1. Name	MT. OLYMPUS COVE
2. State/County	Utah/Utah
3. Number(Category)	19 (Alluvial Fan and Rockslide)
4. Location	T ½ S, R ½ E; center approx. 9 mi. SE of State Capitol & 5 Mi. E of U.S. 89 & 91; Salt Lake Valley.

5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Neffs Canyon
c. Area	3.9 sq. mi.
d. Altitude/Relief	9400-5700 = 3700 ft.
e. Bedrock	Late Precambrian and Cambrian quartzites and argillites; minor shales and carbonates.
6. Aspect	Northwest.
7. Altitude/Relief	5700-5000 = 700 ft.
8. Area/radius/average slope/designation	0.7 sq. mi./1 mi./13.2%/extremely steep.
9. Morphology, esp. at Head of Fan	Typical semi-conical fan shape; delta just to NE, at mouth of Mill Creek; smaller fan along N side of Neffs Canyon.
10. Dissection of Fan Surface	Undissected.
11. Complications, esp. Tectonics	Rockslide (or rockfall), perhaps onto fan (typical fan shape).
12. Natural Vegetation	Scrub oak, brushy vegetation.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; much recharge currently decreased by paving, roofs, and storm sewers.
14. Springs/Wells	None shown.
15. Present Uses	Subdivision.
16. Contamination Sources	None major.
17. Other Alterations	Underground utilities, sewage lines, storm sewers.
18. Access	Excellent, paved, but permission unlikely because of high-density development of homes and landscaping.
19. Ownership	Drainage, U.S.F.S.; Fan, private; Valley, private.
20. Classification	MF and/or rockslide (grading cuts near head, for subdivision, show boulders and fines).
21. Other	

1. Name	PLEASANT GROVE (N) - LINDON (S)
2. State/County	Utah/Utah
3. Number(Category)	20 (Alluvial Fans)
4. Location	T 5 S, R 2 E; center approx. 9 mi. NNW of Provo, city of Pleasant Grove and U.S. 89 & 91 at toe; Utah Valley.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Two unnamed canyons
c. Area	11.7 sq. mi.
d. Altitude/Relief	11,800-5000 = 6700 ft.
e. Bedrock	Late Paleozoic sandstone, quartzite, carbonates, and shale.
6. Aspect	Southwest.
7. Altitude/Relief	5000-4600 = 400 ft.
8. Area/radius/average slope/designation	2.7 sq. mi./2 mi./3.8%/steep (lower part moderate to gentle).
9. Morphology, esp. at Head of Fan	Coalescing fans.
10. Dissection of Fan Surface	Minor dissection.
11. Complications, esp. Tectonics	Wave-built sand embankments at Provo shoreline level, entrenched, with inset younger fans; fine-grained lake-bottom deposits exposed locally in cuts farther W.
12. Natural Vegetation	Oak brush and other trees at heads of fans.

13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; debris dams with overflow water diversion at heads of both fans (2 in N, 1 in S); water running onto N fan in October of drought year; water tank at head of S fan.
14. Springs/Wells	One drainage canal near S toe of N fan.
15. Present Uses	Subdivisions on S fan, Pleasant Grove on toe of N fan, both with sewer lines; extensive orchards; high school and swimming pool near toe of N fan.
16. Contamination Sources	Unlined irrigation canal follows contour near middle of fans; fertilizers and pesticides in orchards; 2 corrals near head of S fan, pasture for horses along N side of N fan.
17. Other Alterations	Small borrow pit on N flank of S fan.
18. Access	Good, paved and unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, head U.S.F.S., toes private; Valley, private.
20. Classification	MF >> BF (based on a few roadcuts and generally gentle slope).
21. Other	

1. Name	BRIDAL VEIL FALLS
2. State/County	Utah/Utah
3. Number(Category)	21 (Alluvial Fan)
4. Location	T 5/6 S, R 2 E; center approx. 7 mi. N of Provo; Utah Valley.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Unnamed canyons
c. Area	2.8 sq. mi.
d. Altitude/Relief	11,400-5300 = 6100 ft.
e. Bedrock	Late Paleozoic sandstone, quartzite, carbonates, and shale.
6. Aspect	Southwest.
7. Altitude/Relief	5300-4900 = 400 ft.
8. Area/radius/average slope/designation	0.8 sq. mi./1 mi./7.6%/extremely steep.
9. Morphology, esp. at Head of Fan	Symmetrical, typical semi-conical fan shape.
10. Dissection of Fan Surface	Undissected.
11. Complications, esp. Tectonics	Lower part modified by shoreline at Provo level.
12. Natural Vegetation	Not noted.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from watershed.
14. Springs/Wells	None shown.
15. Present Uses	Undeveloped.
16. Contamination Sources	None major.
17. Other Alterations	Unlined irrigation canal along toe.
18. Access	Poor, unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, unknown; Valley, private.
20. Classification	Unknown; steep slope suggests BF dominates.
21. Other	

1. Name	ROCK CANYON
2. State/County	Utah/Utah
3. Number (Category)	22 (Alluvial Fan over delta remnants and lake beds)
4. Location	T 6 S, R 3 E; entirely in Provo, Utah (L.D.S. Temple at mid fan, B.Y.U. campus at SW toe); Utah Valley.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Rock Canyon
c. Area	10.0 sq. mi.
d. Altitude/Relief	11,000-5200 = 5800 ft.
e. Bedrock	Late Precambrian and Cambrian quartzite and argillite; minor shale and carbonates; Late Paleozoic sandstone, quartzite, carbonates, and shale.
6. Aspect	West
7. Altitude/Relief	5200-4800 = 400 ft.
8. Area/radius/average slope/designation	2.1 sq. mi./2 mi./3.8%/steep
9. Morphology, esp. at Head of Fan	Fan surface inset between remnants, approx. 60 ft. high, of delta built at Bonneville level of Lake Bonneville; debris dam with spillway and water tank at head.
10. Dissection of Fan	Undissected, although delta remnants on both N & S are dissected.
11. Complications, esp. Tectonics	May be fault offset across head of fan.
12. Natural Vegetation	Unknown.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; infiltration at debris dam.
14. Springs/Wells	Two wells at midfan, just SW of L.D.S. Temple.
15. Present Uses	Homes (subdivisions).
16. Contamination Sources	None major except associated with installation of utilities.
17. Other Alterations	Considerable present excavation for installation of utilities.
18. Access	Excellent, paved and unpaved, but permission unlikely because of high density of houses and landscaping.
19. Ownership	Drainage, U.S.F.S.; Fan, private; Valley, private.
20. Classification	MF (exposed in numerous exposures); deposits only 5 to 10 ft. thick over deltaic and lake deposits.
21. Other	

1. Name	SLATE CANYON
2. State/County	Utah/Utah
3. Number (Category)	23 (Alluvial Fan)
4. Location	T 7 S, R 3 E; SW margin of Provo, U.S. 89 & 91 along toe; Utah Valley
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Slate Canyon
c. Area	5.9 sq. mi.
d. Altitude/Relief	11,100-5200 = 5900 ft.
e. Bedrock	Late Precambrian and Cambrian quartzite and argillite; minor shale and carbonates; Late Paleozoic sandstone, quartzite, carbonates, and shale.
6. Aspect	West
7. Altitude/Relief	5200-4700 = 500 ft.
8. Area/radius/average slope/designation	0.6 sq. mi./1 mi./9.5%/extremely steep.

9. Morphology, esp. at Head of Fan	Typical semi-conical fan shape.
10. Dissection of Fan Surface	Undissected.
11. Complications, esp. Tectonics	Not noted.
12. Natural Vegetation	Not noted.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from watershed.
14. Springs/Wells	Springs observed along toe; 2 irrigation canals follow toe of fan.
15. Present Uses	Upper part undeveloped; several homes on lower part.
16. Contamination Sources	None major.
17. Other Alterations	Old iron works at toe in SW.
18. Access	Good; paved in lower part.
19. Ownership	Drainage, U.S.F.S.; Fan, Head U.S.F.S., remainder private; Valley, private.
20. Classification	Unknown; steep slope suggests BF dominates, although field notes record speculation that MF dominates.
21. Other	

1. Name	PAYSON CREEK
2. State/County	Utah/Utah
3. Number(Category)	24 (Alluvial Fan over Delta)
4. Location	T 9 S, R 2 E; city of Payson covers lower part of fan, U.S. 6, 40, & 91 cross fan.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Payson Creek
c. Area	27.0 sq. mi.
d. Altitude/Relief	10,700-4800 = 5900 ft.
e. Bedrock	Minor Cambrian shale and carbonate; Late Paleozoic carbonates, sandstone, quartzite, and shale; Late Mesozoic and Early Tertiary sandstone, limestone, and shale; Early Tertiary acidic volcanics.
6. Aspect	North
7. Altitude/Relief	4800-4600 = 2 mi.
8. Area/radius/average slope/designation	2.2 sq. mi./2½ mi./1.9%/gentle
9. Morphology, esp. at Head of Fan	Head confined by two ridges, probably paired remnants of a delta at the Bonneville shoreline level.
10. Dissection of Fan Surface	Moderately dissected by at least 2 radial channels 5 to 10 ft. deep.
11. Complications, esp. Tectonics	Fan probably is a thin venear over a delta.
12. Natural Vegetation	Sagebrush.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; irrigation canal across head of fan.
14. Springs/Wells	Intermittent lake and marshy area along NE toe of fan.
15. Present Uses	Payson on lower part; orchards.
16. Contamination Sources	Irrigation canal across head of fan; also, rodeo grounds and stables; fertilizer and pesticides at orchards.
17. Other Alterations	Small borrow pit for delta gravels.
18. Access	Good, paved.
19. Ownership	Drainage, chiefly U.S.F.S., lower part private; Fan-delta, private; Valley, private.
20. Classification	MF (based on exposures along channels) over deltaic washed gravels with parallel bedding.
21. Other	

1. Name	MONA
2. State/County	Utah/Juab
3. Number(Category)	25 (Alluvial Fan)
4. Location	T 11/12 S, R 1 E, center approx. 7 mi. N of Nephi; community of Mona on toe of fan; center of fan crossed N-S by U.S. 91 and I-15; Juab Valley.
5. Drainage	
a. Range	Wasatch Range
b. Canyon(s)	Willow Creek
c. Area	6.7 sq. mi.
d. Altitude/Relief	11,900-5800 = 6100 ft.
e. Bedrock	Late Paleozoic sandstone, quartzite, carbonates, and shale.
6. Aspect	West
7. Altitude/Relief	5800-5000 = 800 ft.
8. Area/radius/average slope/designation	3.9 sq. mi./2½ mi./6.1%/very steep (moderate near toe).
9. Morphology, esp. at Head of Fan	Fault across head offsets original fan surface approx. 50 ft.; main channel upstream, in uplifted section, has eroded to grade with fan surface W of fault.
10. Dissection of Fan Surface	Minor dissection, gently undulant, but unusual, high-standing remnants are present in upper part of fan--origin is uncertain (?upfaulted block?)
11. Complications, esp. Tectonics	Fault across head of fan, remnants in upper part of fan.
12. Natural Vegetation	Sagebrush.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from watershed; fault at head probably promotes deep infiltration.
14. Springs/Wells	One well near midfan, in progress, October, 1977; probably another at Mona; marshy areas along toe of fan.
15. Present Uses	Borrow pit and garbage dump in upper fan; 3 or 4 mobile homes in upper fan; a few homes in midfan; Mona at toe in NW; cattle grazing.
16. Contamination Sources	Garbage dump and septic tanks (probably minor); fluorspar-lead-zinc mines (?abandoned?) in drainage; chickens, barnyard, and dairy in Mona.
17. Other Alterations	Power substation and cemetary on north side of upper part of fan; Interstate I-15 N-S across midfan; U.S. 91 along toe; abandoned borrow pit used as rifle range; 3 stock ponds in midfan.
18. Access	Good paved and unpaved.
19. Ownership	Drainage, U.S.F.S.; Fan, private; Valley, private.
20. Classification	MF (based on exposures in borrow pit and boulders at surface of fan.
21. Other	

1. Name	CANAL CANYON
2. State/County	Utah/Sanpete
3. Number(Category)	27 (Alluvial Fan)
4. Location	T 16 S, R 4 E, center approx. 3 mi. S of Spring City, 8 mi. SSW of Mount Pleasant, 14 mi. NW of Manti; U.S. highway 89 along toe; San Pete Valley.
5. Drainage	
a. Range	Wasatch Plateau
b. Canyon(s)	Canal Canyon and its southern tributaries
c. Area	15.9 sq. mi.
d. Altitude/Relief	11,000-7000 = 4000 ft.
e. Bedrock	Late Mesozoic and Early Tertiary sandstone, limestone, and shale; minor conglomerate.
6. Aspect	Northwest
7. Altitude/Relief	7000-6000 = 1000 ft.

8. Area/radius/average slope/designation	7.6 sq. mi./3½ mi./5.4%/very steep (noticeably flatter toward toe)
9. Morphology, esp. at Head of Fan	Main channel turns N.
10. Dissection of Fan Surface	Minor dissection near toe with several radiating channels approx. 5 ft. deep; main channel approx. 6 ft. deep near head.
11. Complications, esp. Tectonics	None noticed.
12. Natural Vegetation	Junipers in upper 2/3 of fan; sagebrush below; head of fan covered by (?oak) trees.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from mountain catchment; direct precipitation onto fan.
14. Springs/Wells	None shown.
15. Present Uses	Irrigated fields in NE/4; grazing for sheep elsewhere.
16. Contamination Sources	Minor: irrigated fields.
17. Other Alterations	Cement-lined irrigation ditches to W and to N near head; fences and farm on N flank.
18. Access	Moderate, unpaved except for U.S. highway 89 along toe; small city dump and fence near toe.
19. Ownership	Drainage, U.S.F.S.; Fan, probably BLM except NE/4 private; Valley, private.
20. Classification	MF ≥ BF (based on several cuts near the toe and main channel at head, and on distribution of large boulders on surface from head to toe of fan).
21. Other	

1. Name	SPRING CITY
2. State/County	Utah/Sanpete
3. Number(Category)	28 (Alluvial Fan)
4. Location	T 15/16 S, R 4 E; center approx. 5 mi. S of Mount Pleasant & 17 mi. NNE of Manti; San Pete Valley.
5. Drainage	
a. Range	Wasatch Plateau
b. Canyon(s)	Two Unnamed canyons
c. Area	11.3 sq. mi.
d. Altitude/Relief	11,000-7000 = 4000 ft.
e. Bedrock	Late Mesozoic and Early Tertiary sandstone, limestone, and shale; minor conglomerate.
6. Aspect	West-northwest.
7. Altitude/Relief	7000-6000 = 1000 ft.
8. Area/radius/average slope/designation	6.1 sq. mi./4 mi./4.7%/very steep (moderate near toe).
9. Morphology, esp. at Head of Fan	Bedrock buttress on S side at head, main channel is approx. 300 ft. wide and 15-20 ft. deep with a narrow entrenched channel 8-10 ft. deep along its WNW axis.
10. Dissection of Fan Surface	Minor dissection, gently undulant.
11. Complications, esp. Tectonics	None noted.
12. Natural Vegetation	Oaks and juniper at head; sagebrush elsewhere.
13. Sources of Water /Annual Ppt.	Snowmelt and other runoff from watershed; flowing water in small channel down axis of fan; several diversion channels at head, with 8-10 in. diam. cement pipe newly laid along main road down fan.
14. Springs/Wells	Cable-tool water well in progress, October, 1977; spring likely along toe of fan at Spring City.
15. Present Uses	Two homes at head of fan (1 on bedrock on S side); pumping station and small generating plant at head; Spring City at toe.

16. Contamination Sources — Turkey farm near middle; minor septic tanks at head; dump near toe in NW.

17. Other Alterations — Small generating plant at head.

18. Access — Moderate, unpaved.

19. Ownership — Drainage, U.S.F.S.; Fan, head U.S.F.S., middle unknown, toe private; Valley, private.

20. Classification — (?) MF (based on medium-sized boulders on surface of fan).

21. Other

APPENDIX B

ANALYSES OF WATER SAMPLES FROM SPRINGS NEAR MANTI, UTAH, TAKEN IN AUGUST 1978

Constituent[a]	Deer Trail Spring	Dry Spring	Big Spring	North Slope Spring	Hogard Spring	Milk Creek Spring	Sister Spring	Middle Fork Spring	Cold Spring
Bicarbonate	268	249	249	249	229	281	242	290	251
Chloride	2	<1	<1	<1	<1	<1	<1	<1	<1
Sulfate	64	54	54	53	60	44	56	87	44
Nitrate (as N)	0.35	0.42	0.29	0.34	0.28	0.32	0.32	0.29	0.39
Nitrite (as N)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01
Calcium	52	47	49	47	56	56	49	59	46
Magnesium	37	29	29	29	26	32	28	34	31
Sodium	5	8	8	8	4	4	8	14	11
Potassium	1	1	1	1	1	1	1	1	1
Iron	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
pH	8.2	7.9	8.0	7.9	8.1	8.1	8.0	8.0	8.2
Total Alkalinity (as $CaCO_3$)	220	204	204	204	188	230	198	238	206
Total Hardness (as $CaCO_3$)	284	240	242	240	248	274	238	288	236
Total Dissolved Solids	290	265	263	262	260	278	259	335	259

[a]All constituents are expressed in milligrams/liter, except pH.

APPENDIX C

SELECTED WELL LOGS

Hyde Park

Well 1 (A-12-1)12 cac — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Soil	2	2
Clay, brown	24	26
Clay, gray	13	39
Sand, fine	6	45
Clay, blue	38	83
Silt and Sand, blue	23	106
Sand and Gravel	17	123

Well 2 (A-12-1)12 cca — Log by J.V. Stoddard Drillers Inc.

Material	Thickness in ft	Depth in ft
Topsoil	2	2
Clay	44	46
Sand	4	50
Clay	22	72
Sand	12	84
Clay	66	150
Sand	12	162
Clay	43	205
Sand	10	215
Clay	177	392
Sand	6	400
Clay	72	472
Sand	12	484
Clay	30	514
Gravel	26	540

Well 3 (A-12-1)12 ccc — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Clay	30	30
Gravel, fine	20	50
Clay and Gravel	30	80
Gravel w/red Clay	60	140
Cobbles	15	155
Clay, brown w/Gravel	35	190
Clay, brown	25	215
Clay, Sand and Gravel	47	262
Sand and Gravel, gray	18	280
Gravel w/Clay lens	55	335
Sand and Gravel, layered	43	378
Gravel	3	381
Sand	7	388
Gravel	52	440

Hyde Park (Continued)

Well 4 (A-12-1)11 dcd — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Soil	8	8
Clay, brown	34	42
Gravel	158	200
Sand	3	203
Boulders	2	205

Well 5 (A-12-1)10 dcc — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Soil	2	2
Clay, gray w/silt	29	31
Clay, blue w/silt	49	80
Clay, gray w/silt	57	137
Sand, fine to coarse	13	150
Sand and Gravel	5	155

Well 6 (A-12-1)10 bca — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Soil	2	2
Clay, brown	16	18
Clay, blue	8	26
Clay, black	40	66
Gravel	10	76
Clay, gray to black	13	89
Gravel	1	90
Clay, brown	4	94
Gravel, coarse	6	100

Well 7 (A-12-1)9 aad — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Clay, brown	36	36
Clay, blue	38	74
Clay, gray	27	101
Sand, medium	8	109
Sand, coarse w/Gravel	4	113

Providence-Millville

Well 1 (A-11-1)14 daa — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Cobbles and Boulders	25	25
Sand and Gravel	11	36
Boulders	22	58
Gravel	2	60
Boulders	10	70
Gravel	12	82
Boulders	4	86
Bedrock (Laketown Fm.)	24	110

Well 2 (A-11-1)11 cbb — Log by Cache Valley Drilling Company

Material	Thickness in ft	Depth in ft
Cobbles	3	3
Sand, Silty	6	9
Cobbles	3	12
Clay, brown	16	28
Cobbles	19	47
Clay, brown	2	49
Cobbles	20	69
Clay w/Cobbles	7	76
Gravel and Cobbles	13	89
Clay, gray	1	90
Gravel	20	110
Clay, gray	3	113
Gravel and Cobbles	13	126
Sand	9	135
Boulder	2	137
Clay, Top of the Salt Lake Fm.	2	139
Sand	33	172
Gravel	58	230
Clay, brown w/Gravel	13	243
Sand	18	261
Clay, gray	4	265
Gravel, coarse	1	266
Gravel, conglomerate	58	324
Sand and Gravel	13	337
Sand and Gravel	9	346
Gravel	31	377

Well 3 (A-11-1)15 dbc — Log by J.S. Lee & Sons

Material	Thickness in ft	Depth in ft
Clay, Gravel and Boulders	57	57
Clay, tan	29	76
Clay and Gravel	157	233
Clay	2	235
Clay and Gravel	28	263
Gravel	9	272
Clay and Gravel	34	306
Gravel	6	312
Clay, tan	18	330
Gravel	21	351

Willard Test Wells

Test Well 1

Material	Thickness in ft	Depth in ft
Clay, sand and gravel, up to cobble size	9	9
Clay, sand and gravel (more gravel sizes)	6	15
Medium to fine sand	2	17

Test Well 2

Material	Thickness in ft	Depth in ft
Coarse to fine gravel, sandy	6	6
Medium size gravel, sandy	3	9
Fine size gravel, sandy	5	14
Sand, trace of gravel	9	23

Test Well 3

Material	Thickness in ft	Depth in ft
Boulders, old wall foundation	3	3
Sand, coarse to fine, few pebbles	6	9
Sand, coarse to fine	6	15
Clay	1	16

North Piezometer

Material	Thickness in ft	Depth in ft
Gravel, coarse to fine, and sand	15	15
Sand, silt	3	18
Sand, silt and clay, yellowish-brown to olive green	4	22

South Piezometer

Material	Thickness in ft	Depth in ft
Sand, silt, and clay, trace gravel	10	10
Fine gravel, silt, sand and clay	11	21

APPENDIX D

SELECTED BIBLIOGRAPHY RELATED TO ALLUVIAL FANS

Geology

Blackwelder, E. 1928. Mudflow as a geologic agent in semi arid mountains. Geologic Society of America Bulletin 39:465-480.

Blissenbach, E. 1952. Surface angle and particle size distribution on alluvial fans. Journal of Sedimentary Petrology 22:25-28.

Blissenbach, E. 1954. Geology of alluvial fans in semi arid regions. Geologic Society of America Bulletin 65:175-189.

Bluck, B. J. 1964. Sedimentation of an alluvial fan in southern Nevada. Journal of Sedimentary Petrology 34:359-400.

Bull, W. B. 1964. Alluvial fans and near-surface subsidence in western Fresno County, California. U.S. Geological Survey Professional Paper 437-A. 71 p.

Bull, W. B. 1968. Alluvial fans. Journal of Geologic Education 16(3):101-106.

Croft, A. R. 1962. Some sedimentation phenomena along the Wasatch Mountain front. Journal of Geophysical Research 64:1511-1524.

Denny, C. S. 1965. Alluvial fans of the Death Valley region of California and Nevada. U.S. Geological Survey Professional Paper 466. 62 p.

Denny, C. S. 1967. Fans and pediments. American Journal of Science 265:81-105.

Hooke, R. L. 1967. Processes on arid-region alluvial fans. Journal of Geology 75(4):438-460.

Hooke, R. L. 1968. Steady-state relationships on arid-region alluvial fans in closed basins. American Journal of Science 266:609-629.

Lindsay, J. F. 1968. The development of clast fabric in mudflows. Journal of Sedimentary Petrology 38:1242-1254.

Lustig, L. K. 1962. Competence of transport on alluvial fans. U.S. Geological Survey Professional Paper 475 C. p. c126-c129.

Price, W. E., Jr. 1974. Simulation of alluvial fan deposition by a random-walk model. Water Resources Research 10(2):263-274.

Rich, J. L. 1935. Origin and evolution of rock fans and pediments. Geological Society of America Bulletin 46:999-1024.

Sorensen, M. L., and M. D. Crittenden, Jr. 1976. Preliminary geologic map of the Mantua Quandrangle and part of the Willard Quandrangle, Box Elder, Weber, and Cache Counties, Utah. U.S. Geological Survey Miscellaneous Field Studies Maps.

Spieker, E. M. 1949. Guidebook to the geology of Utah; No. 4. Utah Geological Society. The Utah Geological and Mineral Survey, Salt Lake City, Utah.

Wooley, R. R. 1946. Cloudburst floods in Utah 1850-1938. U.S. Geological Survey Water-Supply Paper 994.

Groundwater Hydrology

Appel, C. A., and J. D. Bredehoeft. 1976. Status of groundwater modeling in the U.S.G.S. U.S. Geological Survey Circular 737.

Bachmat, Y., B. Andrews, D. Holtz, and S. Sebastion. 1978. Utilization of numerical groundwater models for water resources management. Robert S. Kerr Environmental Research Laboratory. U.S. EPA. (EPA 600/8-78-012)

Basak, P., and V. V. N. Murty. 1978. Concentration-dependent diffusion applied to groundwater contamination problems. Journal of Hydrology 37(3/4):333-337.

Bouwer, H., and R. C. Rice. 1976. A slug test for determining hydraulic conduct of unconfined aquifers with completely or partially penetrating wells. Water Resources Research 12(3):423-428.

Brah, W. J., and L. L. Jones. 1978. Institutional arrangements for effective groundwater management to halt land subsidence (project completion report). Technical Report No. 95. Texas Water Resources Institute. Texas A & M University.

Brustkern, R. L. 1977. The impact of land use change on the groundwater resources of the Bozeman, Montana area. Montana Joint Water Resources Research Center, Bozeman. Research Report No. 88. 38 p.

Cordova, R. M., and R. W. Mower. 1976. Fracturing and subsidence of the land surface caused by the withdrawal of groundwater in the Milford area, Utah. U.S. Geological Survey Journal of Research 4(5):505-510.

Diefendorf, A. F., and R. Ausburn. 1977. Groundwater monitoring wells. Public Works 108(7):48-50.

Fryberger, J. S., and W. H. Bellis. 1977. Quantifying the natural flushout of alluvial aquifers. Ground Water 15(1):58-65. (EPA 600/9-77-014)

Gass, T. E., J. H. Lehr, and H. W. Heiss, Jr. 1977. Impact of abandoned wells on groundwater. U.S. EPA. (EPA 600/3-77-095)

Greenkorn, R. A. 1970. Dispersion in heterogeneous non-uniform anisotropic porous media. Water Pollution Control Research Series Report No. 16060 DLL 09/70.

Groundwater development in arid basins. 1967. Symposium held at Utah State University. March 16-17.

Jones, E.E. 1974. Evaluating well construction. Journal of Environmental Health 36(6):554-561.

Keith, S. J. 1977. The impact of groundwater development in arid lands: A literature review and annotated bibliography. Arizona University, Office of Arid Land Studies. 139 p.

Khaleel, R., and D. L. Reddell. 1976. Simulation of pollutant movement in groundwater aquifers. Texas Water Resources Institute, College Station Technical Report No. 81. 248 p.

Kirkham, D., and S. B. Affleck. 1977. Solute travel times to wells. Ground Water 15(3):231-242.

Konikow, L. F. 1977. Modeling chloride movement in the alluvial aquifer at the Rocky Mountain Arsenal, Colorado. U.S. Geological Survey Water Supply Paper 2044. 48 p.

Kirshamurthi, N., D. K. Sunada, and R. A. Longenbaugh. 1977. Mathematical modeling of natural groundwater recharge. Water Resources Research 13(4):720-724.

Matlock, W. G., G. C. Morin, and J. E. Posedly. 1976. Well cuttings analysis in groundwater resources evaluation. Ground Water 14(5):272-277.

Murty, V. V. N., and V. H. Scott. 1977. Determination of transport model parameters in groundwater aquifers. Water Resources Research 13(6):941-947.

Rushton, K. R., and Y. K. Chan. 1977. Numerical pumping test analysis in unconfined aquifers. ASCE Journal of the Irrigation and Drainage Division 103(1R1):1-12.

Spaulding, R. F., M. E. Exner, and J. R. Gormly. 1976. A note on an in situ groundwater sampling procedure. Water Resources Research 12(6):1319-1321.

Tolman, C. T. 1937. Groundwater. McGraw Hill Book Company.

Utah Division of Water Resources and U.S. Geological Survey. Developing a state water plan: Groundwater conditions in Utah. Cooperative Investigations Reports 1 through 18.

Water Quality

American Public Health Association. 1975. Standard methods for the examination of water and wastewater. 14th ed.

Barica, J. 1972. Salinization of groundwater in arid zones. Water Research 6(8):925-933.

Beckers, C. V., and S. G. Chamberlain. 1974. Design of cost-effective water quality surveillance systems. U.S. EPA. (EPA 600/5-74-004)

Berk, W. J., and B. S. Yare. 1977. An integrated approach to delineating contaminated groundwater. Ground Water 15(2):138-148.

Brown, K. W., et al. 1979. The movement of fecal coliforms and coliphages below septic lines. Journal of Environmental Quality 8(1):121-125.

Crouch, R. L., R. D. Eckert, and D. D. Rugg. 1976. Monitoring groundwater quality; economic framework and principles. U.S. EPA Environmental Monitoring Series. (EPA 600/4-76-045)

Dunlap, W. J., and J. F. McNabb. 1973. Subsurface biological activity in relation to groundwater pollution. U.S. EPA. (EPA 660/2-73-014)

Dunlap, W. J., J. F. McNabb, M. R. Scalf, and R. L. Cosby. 1977. Sampling for organic chemical and microorganisms in the subsurface. Robert S. Kerr Environmental Research Laboratory. U.S. EPA. (EPA 600/2-77-176)

Everett, L. G., K. D. Schmidt, R. M. Tinlin, and D. K. Todd. 1976. Monitoring groundwater quality: Methods and costs. U.S. EPA Environmental Monitoring Series. (EPA 600/4-76-023)

Fenn, D., and E. Cocozzan. 1976. Procedures manual for monitoring solid waste disposal sites. U.S. EPA Office of Solid Waste Management Programs. 287 p.

Fetter, C. W., Jr. 1975. Use of test wells as water quality predictors. Journal of American Water Works Association 67(9):516-518.

Fried, J. J. 1975. Ground water pollution. American Elsivier Publishing Company.

Gass, T. E. 1977. Protecting groundwater from domestic wastewater effluent. Water Well Journal 31(6):34-35.

Garrett, D., F. P. Maxey, and H. Katz. 1976. The impact of intensive application of pesticides and fertilizers on underground water recharge areas which may contribute to drinking water problems. U.S. EPA. (EPA 560/3-75-006)

Gilham, R. W., and L. R. Webber. 1969. Nitrogen contamination of groundwater by barnyard leachates. Journal of Water Pollution Control Federation 41:1752-1762.

Hagedorn, C., D.T. Hansen, and G.H. Simonson. 1978. Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. Journal of Environmental Quality 7(1):55-59.

Hampton, N. F. 1976. Monitoring groundwater quality: Data management. U.S. EPA. (EPA 600/4-76-019) 63 p.

Johnson, N., and D. H. Urie. 1976. Groundwater pollution aspects of land disposal of sewage from remote recreational areas. Ground Water 14(6):403-410.

Karubian, J. F. 1974. Polluted groundwater: Estimating the effects of mans' activities. U.S. EPA. (EPA 680/4-74-002)

Kimm, V. J. Draft environmental impact statement; state underground injection control program proposed regulations (40 CFR Part 146). U.S. EPA, Office of Water Supply.

Krietler, C. W. 1975. Determining the source of nitrate in groundwater by nitrogen isotope studies. Texas University at Austin. Report of Investigations No. 83.

Law, J. P., and J. L. Witherow, eds. 1970. Water quality management problems in arid regions. Robert S. Kerr Water Research Center, Ada, Oklahoma. (NTIS PB 198 125) 105 p.

Lehr, J. H., W. A. Pettyjohn, T. W. Bennett, J. R. Hansen, and L. E. Sturtz. 1976. A manual of laws, regulations, and institutions for control of groundwater pollution. U.S. EPA. (EPA 440/9-76-006) 416 p.

Lorimor, J. C., L. N. Mielke, L. F. Elliott, and J. R. Ellis. 1972. Nitrate concentration in groundwater beneath a beef cattle feedlot. Water Research Bulletin 8:999-1005.

Mann, J. F., Jr. 1976. Wastewaters in the vadose zone of arid regions: Hydrologic interactions. Ground Water 14(6):367-373.

McNabb, J. R., W. J. Dunlap, and J. W. Keeley. 1977. Nutrient, bacterial and virus control as related to groundwater contamination. U.S. EPA. (EPA 600/8-77-010)

Metry, A. A. 1977. The fate of pollutants in subsurface environments. Journal of Environmental Sciences 20(2):27-31.

Meyer, C. F. (ed). 1973. Polluted groundwater: Some causes, effects, controls and monitoring. General Electric - TEMPO. U.S. EPA. (EPA 600/4-73-001)

Mielke, L. N., and J. R. Ellis. 1976. Nitrogen in soil cores and ground water under abandoned cattle feedlots. Journal of Environmental Quality 5(1):71-75.

Osgood, J. O. 1974. Hydrocarbon dispersion in groundwater: Significance and characteristics. Ground Water 12(6):427-438.

Page, A. L., and P. F. Pratt. 1975. Effects of sewage sludge or effluent application to soil on the movement of nitrogen, phosphorus, soluble salts and trace elements to groundwaters. Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal. August 18-20. Anaheim, California. p. 179-187.

Perez, A. K., W. C. Huber, J. P. Heaney, and E. E. Pyatt. A water quality model for a conjunctive surface-groundwater system. U.S. EPA. (EPA 600/5-74-013)

Pettyjohn, W. A. 1976. Monitoring cyclic fluctuations in groundwater quality. Ground Water 14(6):742-480.

Pfannkuch, H. O., and B. A. Labno. 1977. Design and optimization of groundwater monitoring networks for pollution studies. Proceedings of the 3rd Nat'l Groundwater Quality Symposium. Sept. 15-17. Las Vegas, Nevada. (EPA 600/9-77-014)

Pound, C. E., R. W. Crites, and J. V. Olson. 1978. Long-term effects of land application of domestic wastewater: Hollister, California, rapid infiltration site. U.S. EPA. (EPA 600/2-78-084)

Pratt, P. F. 1972. Nitrate in the unsaturated zone under agricultural lands. U.S. EPA Water Pollution Control Research Series 16060 DOE 04/72.

Robertson, J. M., C. R. Toussaint, and M. A. Torque. 1974. Organic compounds entering groundwater from a landfill. U.S. EPA. (EPA 660/2-74-077)

Romero, J. C. 1970. The movement of bacteria and viruses through porous media. Ground Water 8(2):37-48.

Runnells, D. D. 1977. Wastewaters in the vadose zone of arid regions: Geochemical interactions. Ground Water 14(6):374-385. (EPA 600/9-77-014)

Scalf, M. R., V. L. Hauser, L. G. McMillin, W. J. Dunlap, and J. W. Keeley. 1968. Fate of DDT and nitrate in groundwater. U.S. Dept. of the Interior and U.S. Dept. of Agriculture.

Scalf, M.R., W.J. Dunlap, and J.F. Kriessl. 1977. Environmental effects of septic tank systems. Ecological Research Series. U.S. EPA. (EPA 600/3-77-096)

Schmidt, K.D. 1977. Water quality variations for pumping wells. Ground Water 15(2): 130-137.

Siegrist, R., M. Witt, and W. C. Boyle. 1976. Characteristics of rural household wastewater. Journal of Environmental Engineering Division of ASCE 102(EE3):533-548.

Texas Tech. University, Dept. of Geosciences. 1971. Infiltration rates and groundwater quality beneath cattle feedlots, Texas high plains. U.S. EPA Water Pollution Control Research Series 16060 EGS 01/71.

The National Groundwater Quality Symposium. 1971. Cosponsored by EPA and NWWA. Aug. 25-27. EPA Water Pollution Control Research Series 16060 GRB 08/71.

Tihansky, D. P. 1973. Cost analysis of water pollution control: An annotated bibliography. (EPA R5-73-017)

Todd, D. K., and D. E. O. McNulty. 1975. Polluted groundwater: A review of the significant literature. Water Information Center, Inc., Hunting, New York. 179 p.

Todd, D. K., R. M. Tinlin, K. D. Schmidt, and L. G. Everett. 1976. Monitoring groundwater quality: Monitoring methodology. (EPA 600/4-76-026) June. 154 p.

United States Environmental Protection Agency. 1972. Subsurface water pollution - A selective annotated bibliography.

United States Environmental Protection Agency. 1973. Groundwater pollution for subsurface excavations. U.S. EPA. (EPA 430/9-73-012)

United States Environmental Protection Agency. 1977. The report to Congress - Waste disposal practices and their effects on groundwater. U.S. EPA Office of Water Supply and Office of Solid Waste Management Programs.

Van Der Leeden, F., L. A. Cerrillo, and D. W. Miller. 1975. Groundwater pollution problems in the northwestern United States. U.S. EPA. (EPA 660/3-75-018)

Viraraghavan, T., and R. G. Warnock. 1976. Groundwater pollution from a septic tile field. Water, Air and Soil Pollution 5(3):281-287.

Warner, D. L. 1975. Monitoring disposal-well systems. U.S. EPA. (EPA 680/4-75-008)

Weeks, M. E. 1974. The effect of land use on the chemical and physical quality of surface and groundwaters in small watersheds. NTIS Accession No. PB 251 890/OWP.

Wendt, C. W., A. B. Onkan, O. C. Wilke, and R. D. Lacewell. Effects of irrigation methods on groundwater pollution by nitrates and other solutes. U.S. EPA. (EPA 600/2-76-291)

Young, C.P., D.B. Oakes, and W.B. Wilkinson. 1976. Prediction of future nitrate concentrations in groundwater. Ground Water 14(6):426-438. (EPA 600/9-77-014)