Summary of Investigation
Upper Silver Bow Creek, Butte, Montana

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A recent investigation of the upper Silver Bow Creek drainage by the Montana Bureau of Mines and Geology has concluded that:

- the site of the Parrot Complex is the most important source of ground-water contamination in the upper Silver Bow Creek drainage,
- gaps in the water-quality and hydrogeologic data have led to underestimation of the extent of contamination by the Parrot Complex,
- hydrogeologic conditions (aquifer properties and hydraulic gradients) are favorable for the migration of contaminated ground-water toward Silver Bow Creek. Travel times of contaminates to reach Silver Bow Creek are on the order of decades, and
- the quality of ground-water can recover in a relatively short period of time (less than 100 years) if a proper removal of source material at the Parrot Complex is completed. If there is no removal, recovery will be on the order of thousands of years.

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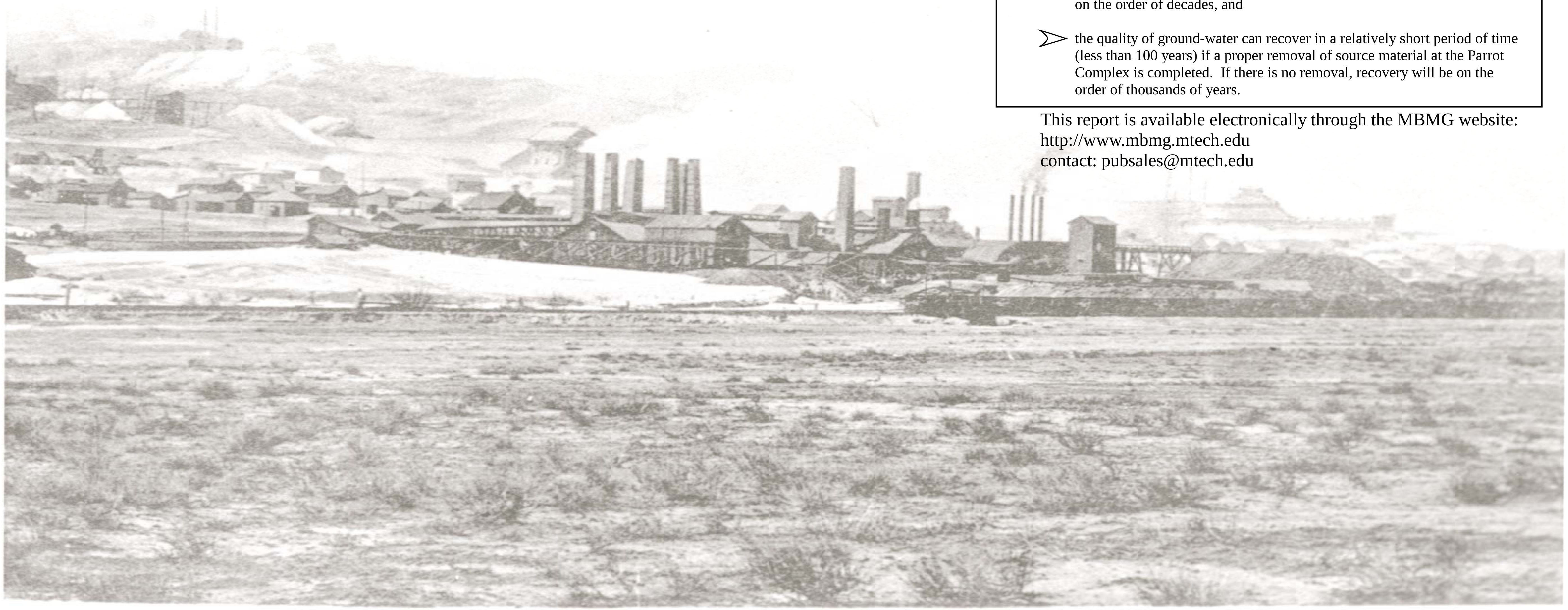

PARROT SMELTER (EMPLOY 300 MEN).

photograph from postcard: World Museum of Mining, Butte, Montana

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The area between Montana Street and Continental Drive in Butte, Montana has been identified by several names including upper Silver Bow Creek (U.S. Geological Survey, Geographic Names Information System), Metro Storm Drain, and upper Area One Operable Unit. Surface and near surface deposits of wastes associated with mining and milling have been identified as potential sources of ground-water and surface-water contamination. Prominent is a large area near the Butte Civic Center and the "county shops" that contains tailings, slag, and other waste generated by the Parrot smelter and mill; the site is herein referred to as the Parrot Complex. Construction of the smelter was completed in July 1881 and consisted of open stalls for roasting lump ore, reverberatory roasters, and matting reverberatory furnaces. In 1884, with the installation of six converters, the Parrot was the first smelter in the United States to successfully produce blister copper from copper matte using the Bessemer Process; with the installation of the converters, the Parrot was processing about 350 tons of ore per day and producing about 25,000 pounds of copper per day. In 1886, the Parrot had increased its facilities, and was the second largest copper producer in the Butte area. Besides smelting, the Parrot also had a concentrating plant to treat the second-class ore prior to smelting. The concentrating plant consisted of crushing equipment, jigs, and vanning tables, and was capable of processing 250 tons of ore per day. The Anaconda Company purchased the Parrot Smelter and closed the facility in 1899.

A recent report released by the U.S. EPA has made claims as to the rate of ground-water flow and the migration of contaminated ground-water through the alluvial aquifer in the upper Silver Bow Creek drainage. The Montana Department of Environmental Quality (MDEQ)and the Montana Department of Justice (MDOJ) solicited comments from the Montana Bureau of Mines and Geology (MBMG) as to these claims; written comments were provided to the agencies in December of 2003. These comments led to funding by the EPA and MDOJ for the MBMG to drill and sample new wells, conduct column leach tests on aquifer materials, and collect chemical data from existing wells. These new data strongly add to the body of evidence supporting the interpretations that for the aquifer underlying upper Silver Bow Creek:

1) the site of the Parrot Complex is the most important source of ground-water contamination in the upper Silver Bow Creek drainage,

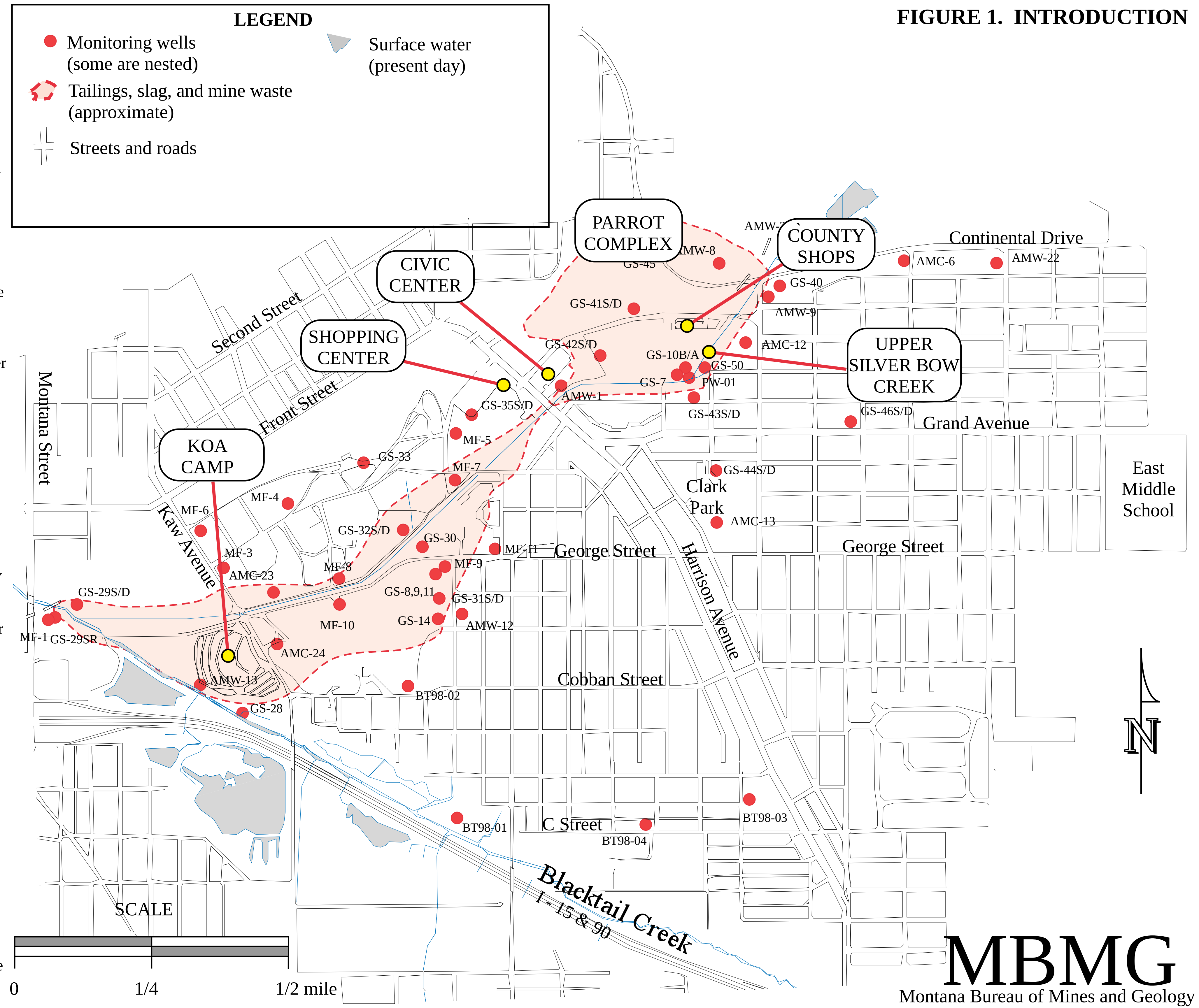
2) gaps in the water-quality and hydrogeologic data have led to underestimation of the extent of contamination by the Parrot Complex,

3) hydrogeologic conditions (aquifer properties and hydraulic gradients) are favorable for the migration of contaminated ground-water toward Silver Bow Creek. Travel times of contaminates to reach Silver Bow Creek are on the order of decades, and

4) the quality of ground-water can recover in a relatively short period of time (less than 100 years) if a proper removal of source material at the Parrot Complex is completed. If no removal occurs, recovery will be on the order of thousands of years.

Decisions will soon be made as to the remediation of contaminated ground-water in this area. Whereas many factors such as engineering, economic, and societal impacts must be considered, all good judgments must be based on good science. In a careful review of all of the available data collected over the past 20 years, this report summarizes the concepts shared by the authors as well as a good many colleagues.

FIGURE 1. INTRODUCTION



Previous Investigations

The most comprehensive study of the upper Silver Bow Creek drainage was released by the Montana Department of Environmental Health (now the MDEQ) in 1990; that study concluded that the Parrot Complex was the most significant source of contamination in the drainage. A report released by the MDOJ in 1995 identified the Parrot Complex as the most significant source (Maest and others, 1995); that report relied heavily on the 1990 report. A report released by the PRP Group in 2002 (PRP, 2002) made no statements as to source areas. A report released by the EPA in 2004 (EPA, 2004) concluded that there were multiple sources and that the Parrot Complex was not a significant source of contamination for the majority of the drainage.

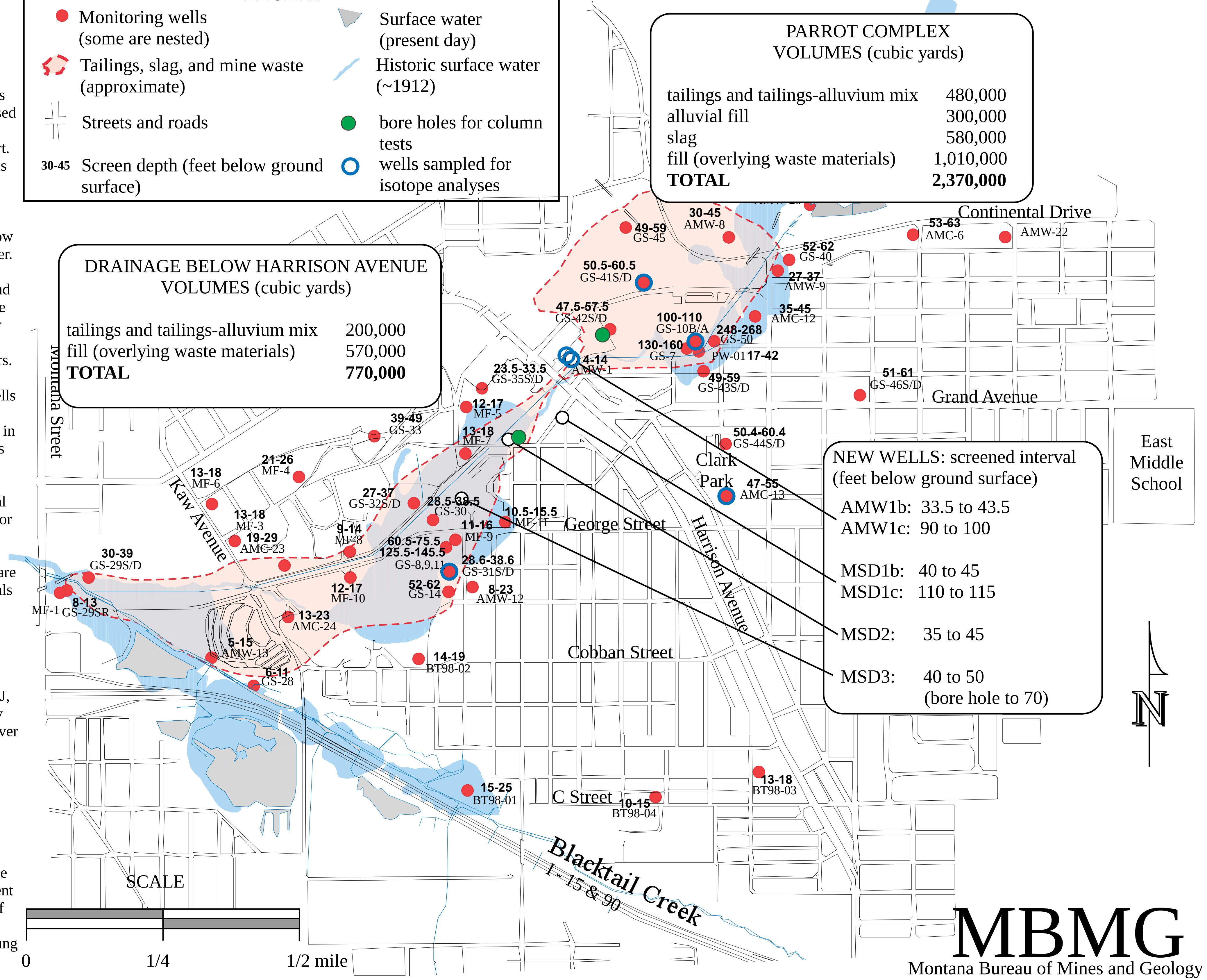
Detailed information related to ground water in the upper Silver Bow Creek area is sparse and generally limited to the shallowest part of the aquifer. Although there are about 50 monitoring wells in the area between Montana Street and Continental drive, the majority were installed in the late 1980's and a few in 1991; no wells have been installed in the last 12 years - except those installed for this investigation. All of the wells have been sampled for water quality, some wells have been sampled several times, but about 20 of the 50 wells were sampled only once in 1989 and have not been sampled in 15 years. Water levels have been collected from most of the wells at least once; continuous data sufficient for hydrographs, however, are limited to a few wells near Continental Drive. Concurrent water levels from all of the wells, sufficient to produce a potentiometric map, have only been done three times in the last 15 years - most recently for this investigation. The alluvial aquifer is over 200 feet thick in most of the area; however, the average depth of the 50 wells is less than 35 feet.

The areal extent and thickness of tailings and contaminated material in the upper Silver Bow Creek is fairly well documented by lithologic logs for wells and core samples collected over the years. Early reports suspected the presence of tailings or other contaminated material beneath the Butte Civic Center and the shopping center; most recent data shows that such materials are limited to the old stream channel. The volumes of tailings and other materials are presented in figure 2.

New Investigation

In the spring of 2004, with funding provided by the EPA and MDOJ, six monitoring wells were installed at four sites along the ground-water flow path between the Parrot tailings area and the confluence of Blacktail and Silver Bow Creeks near Montana Street. The wells were drilled deeper than most others in the area; the objective was to determine the lithology and ground-water quality in the deeper portion of the alluvial aquifer. In addition to the wells, samples of the contaminated aquifer material were collected from boreholes in the source area near the Civic Center and midway down the drainage (green dots). These materials were used to construct soil columns through which clean ground water was circulated; the data were used to evaluate whether the natural aquifer would recover if the waste material were removed. Helium and tritium isotope samples, used to determine the apparent age of ground water, were collected from six wells (blue circles). The age of the ground water might suggest whether ground water and the contaminants therein are moving very slowly (very old apparent age) or more quickly (young apparent age).

FIGURE 2: PREVIOUS AND RECENT INVESTIGATIONS



New Water-Quality Data

Previous investigations were limited to the upper 20 feet of the alluvial aquifer between the Parrot Complex and the lower portion of the drainage; as noted, the average depth of all the wells in the area is less than 35 feet. This data gap led to an underestimation of the extent of ground-water contamination caused by the tailings, slag, and other materials in the Parrot Complex. Water-quality, hydrologic, and lithologic information from the new wells fills an important gap in hydrogeologic and geochemical data in the intermediate and deeper portions of the upper Silver Bow Creek alluvial aquifer. Concentrations of dissolved constituents in upper Silver Bow Creek alluvial ground water are several orders of magnitude greater than those predicted in previous work. For example, the measured concentration of copper in well MSD-1b was 4,200 micrograms per Liter (ug/L), yet copper concentrations in ground water from this location were previously thought to be less than 100 ug/L (shown by contours on map). The concentration of zinc in well MSD-1b was about 200,000 ug/L, whereas previous studies estimated a concentration of only 10,000 ug/L. A comparison of concentrations of other constituents shows similar discrepancies and demonstrate that most pre-existing wells were too shallow to detect the migration of contaminated ground water from the Parrot Complex.

In the new wells, concentrations in ground water at intermediate depths (AMW1b, MSD1b, and MSD2) generally decreased in the down-gradient direction from the upper Silver Bow Creek area (AMW wells) to the mid-portion of the aquifer (MSD1 and MSD2). New water-quality information from the most recent investigation indicates that metals and sulfate at intermediate depths in the alluvial aquifer have migrated at least 2,000 feet down gradient in the 100 years from the source area into the lower drainage.

Concentrations of metals and sulfate in the deeper wells (AMW-1c and MSD1c) were lower than those at intermediate depths. Concentrations in MSD2, which is more down gradient and adjacent to the stream channel, were generally higher than those at MSD1. This may indicate that MSD2 is nearer the center of the contaminant plume than the other wells.

Data from the new wells cannot answer all of the questions related to ground-water flow and migration of contaminants, but they do demonstrate several things:

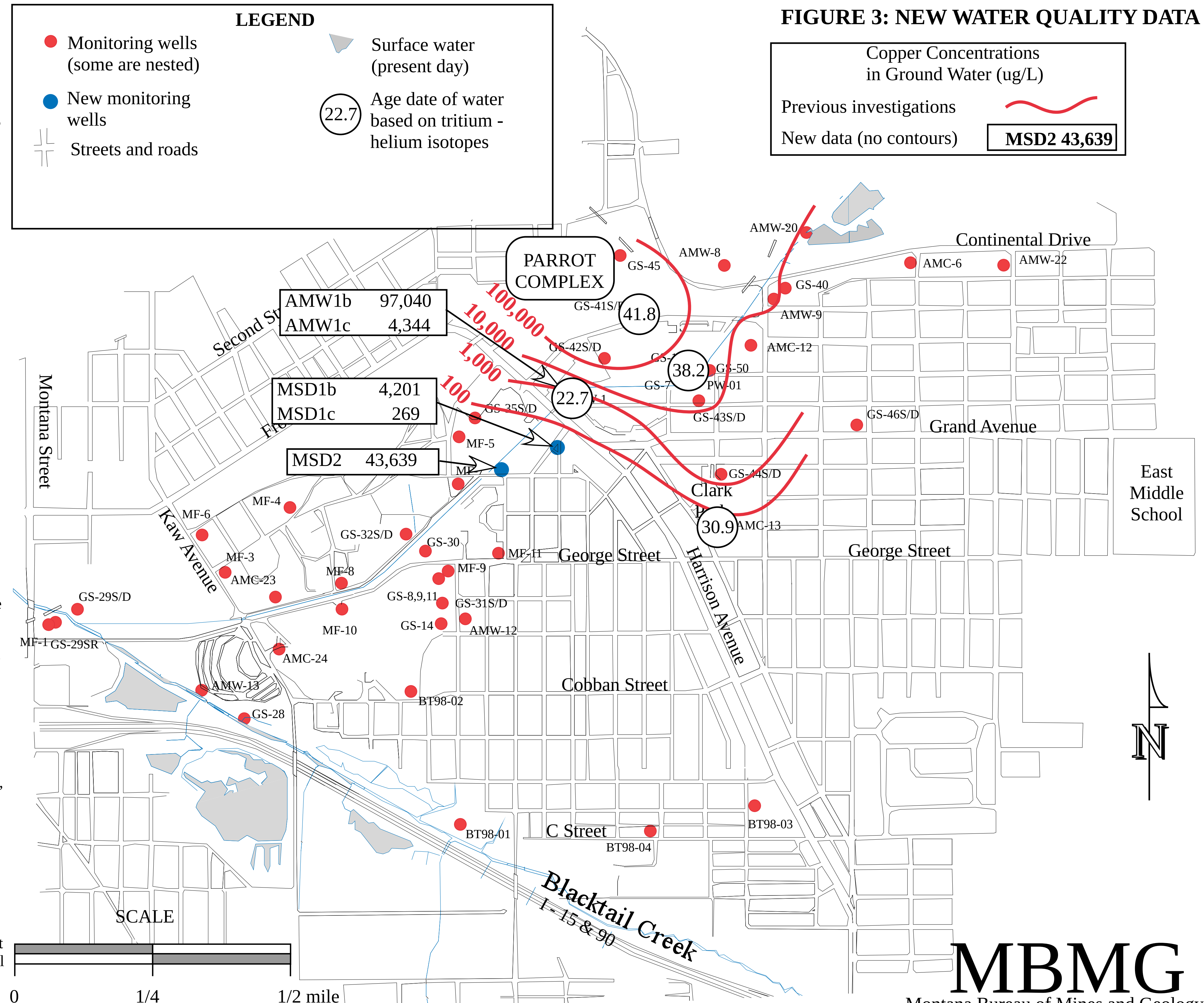
1) data gaps have led to gross underestimation of the extent of ground-water contamination originating from the Parrot Complex,

2) contamination from the Parrot Complex has migrated several thousand feet, and

3) concentrations of contaminants decrease rapidly with depth; most of the contamination occurs at 50 to 75 feet below the surface.

The concentrations of tritium and helium isotopes, used to determine the apparent age of ground water, indicate a young, dynamic flow system. Overall, there is little change in the age of the waters and the apparent, absolute age is young (less than 50 years). These data support the concept that contaminated ground water has migrated from the Parrot Complex to Blacktail Creek in a few decades.

FIGURE 3: NEW WATER QUALITY DATA



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Redefining the Ground-Water Flow System and Travel Times

Water-level elevations in wells near the Parrot Smelter have been collected by the MBMG since 1991 and in other areas since 1983. The inset shows hydrographs of water-level elevations in wells in the upper part of the drainage. The differences in water-level elevations among the wells clearly indicate that the water table in the Parrot Complex area is not flat, and that ground water readily flows though the area. The hydrographs also indicate that during the wet years of the 1990's, the hydraulic gradients in the area were greatest for the period of record. Currently, gradients are less due to several years of normal to below normal precipitation and it is not unreasonable to conclude that gradients will become steeper again when climatic conditions become wetter. The gradients may also become steeper in the future due to the rising water level in the Berkeley Pit. Overall, hydraulic gradients reflect the topographic gradient of the valley and range from .002 to .006 ft/ft.

Lithologic and hydrologic data from the new monitoring wells in conjunction with data from existing wells indicate the presence of three ground-water flow systems. The shallow system, the subject of previous investigations, is fairly well documented. Water levels in these wells are generally above the elevation of Silver Bow Creek and are the likely source of loading to the creek, especially in the upper drainage. The hydraulic conductivity of the shallow material reflects the fine-grained litholoies described in the well logs; values are on the order of a few feet per day. The concentrations of dissolved constituents in the upper 40 feet of the aquifer reflect local sources of contamination, if any, and surface recharge.

The intermediate ground-water, 40 to 60 feet below ground surface, flows through discrete layers of gravel and sand with minor silt and clay. In the upper part of the drainage, this flow system is dominated by a continuous layer of coarse gravel; in the lower part of the drainage, the coarse gravel apparently grades to a fine gravel. A layer of gravel coincident with poor quality water was recorded in lithologic logs for wells completed in the source area (e.g. GS41 and GS42) in previous investigations. The western extent of the gravel was not found during this investigation, but the concentration of dissolved constituents in these gravels tends to remain high nearly 2,000 feet from source area. When specific capacity (discharge/drawdown) is used as a rough estimate, the hydraulic conductivity of the gravel is about 150 feet per day in AMW1b and about 87 feet per day in MSD1b.

The deeper ground-water flow system in this discussion is that which is greater than 60 feet below ground surface. Lithologic information collected during the installation of the new monitoring wells indicates discrete layers of sand with minor silt and clay. Specific capacity data collected during sampling of AMW1c produces a hydraulic conductivity of about 17 feet per day for a five-foot interval of sand at a depth of 95 to 100 feet below ground surface. Concentrations of dissolved constituents in the deeper flow system are much less than those of the intermediate flow system, but still reflect migration of contaminated water from the Parrot Complex at least 1,000 feet farther than described in previous investigations. The chemistry of the deep flow system likely reflects mixing of contaminated water from the Parrot Complex with deep uncontaminated ground water. Using the appropriate hydraulic conductivity and gradient data, ground-water velocities in the Parrot Complex area are on the order of 0.5 to 0.9 feet per day.

Surface-water flow based on direct measurements and ground-water flow based on the above information yields a total of about 400,000 gallons per day discharging through the shaded area of the map (see second inset for the water balance).

FIGURE 4: REDEFINING THE GROUND-WATER FLOW SYSTEM

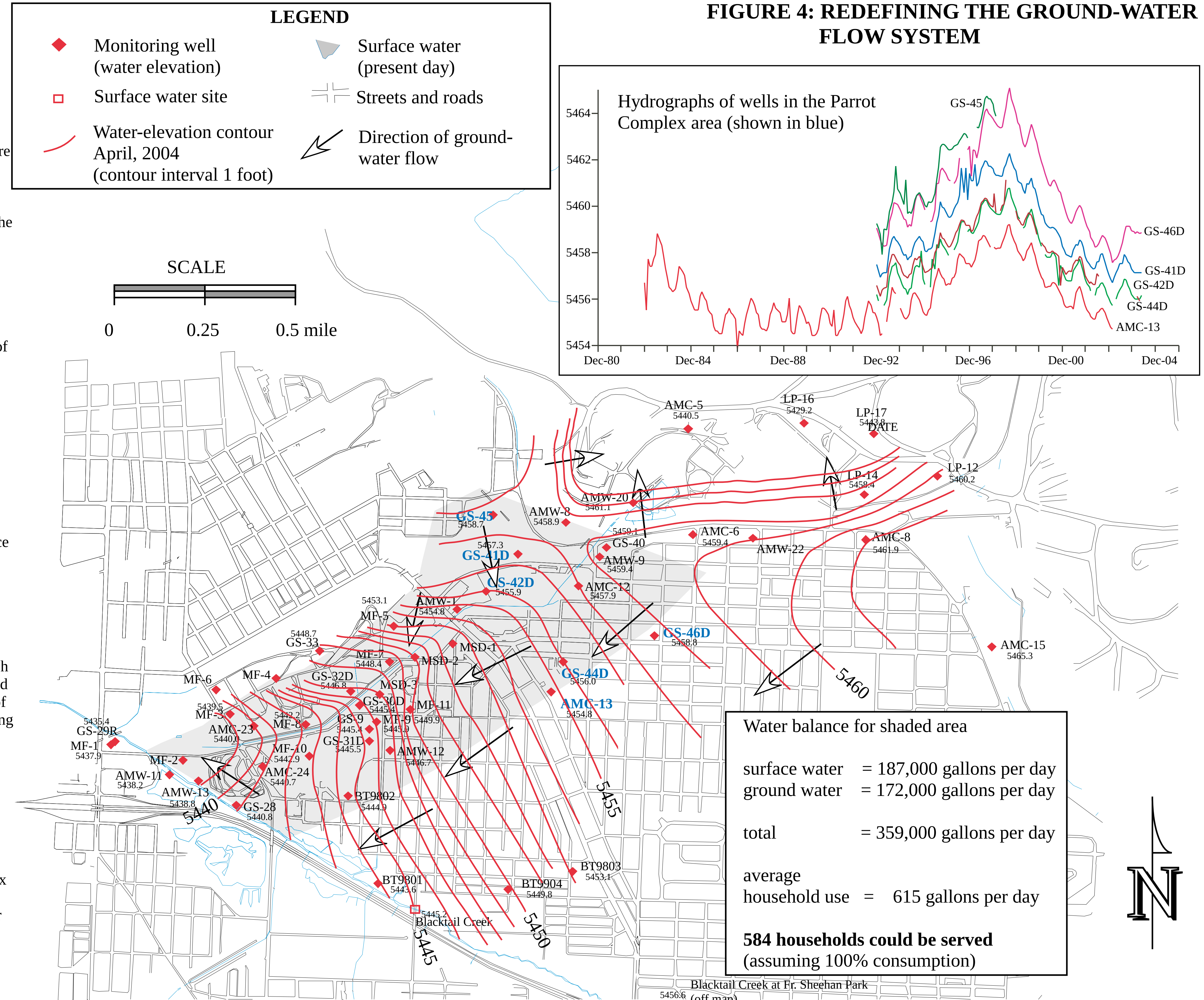
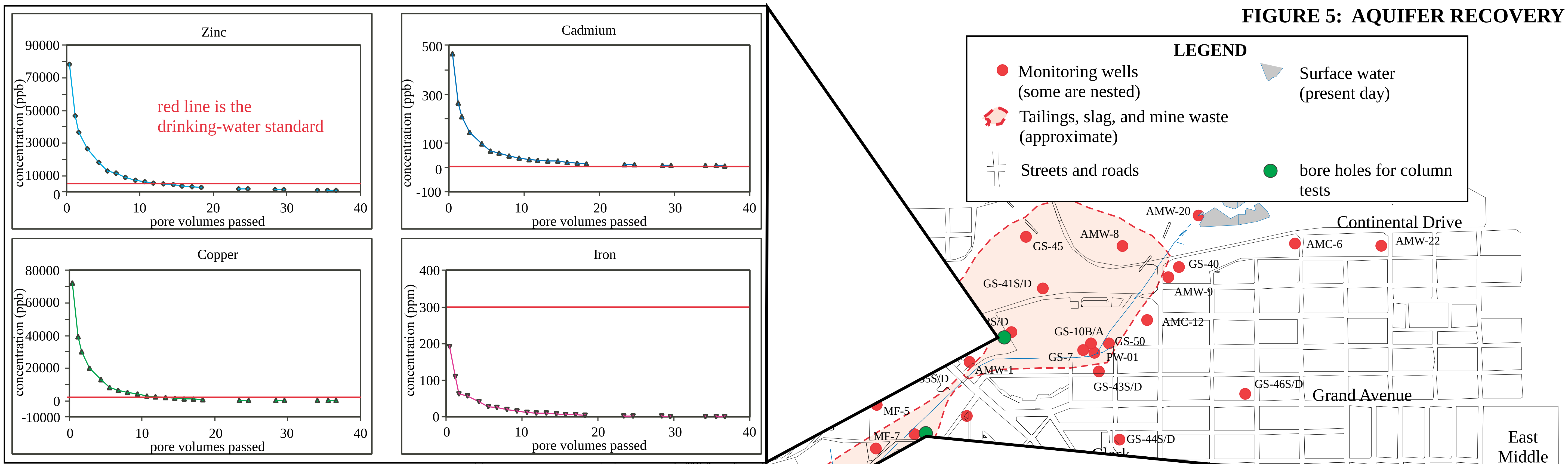
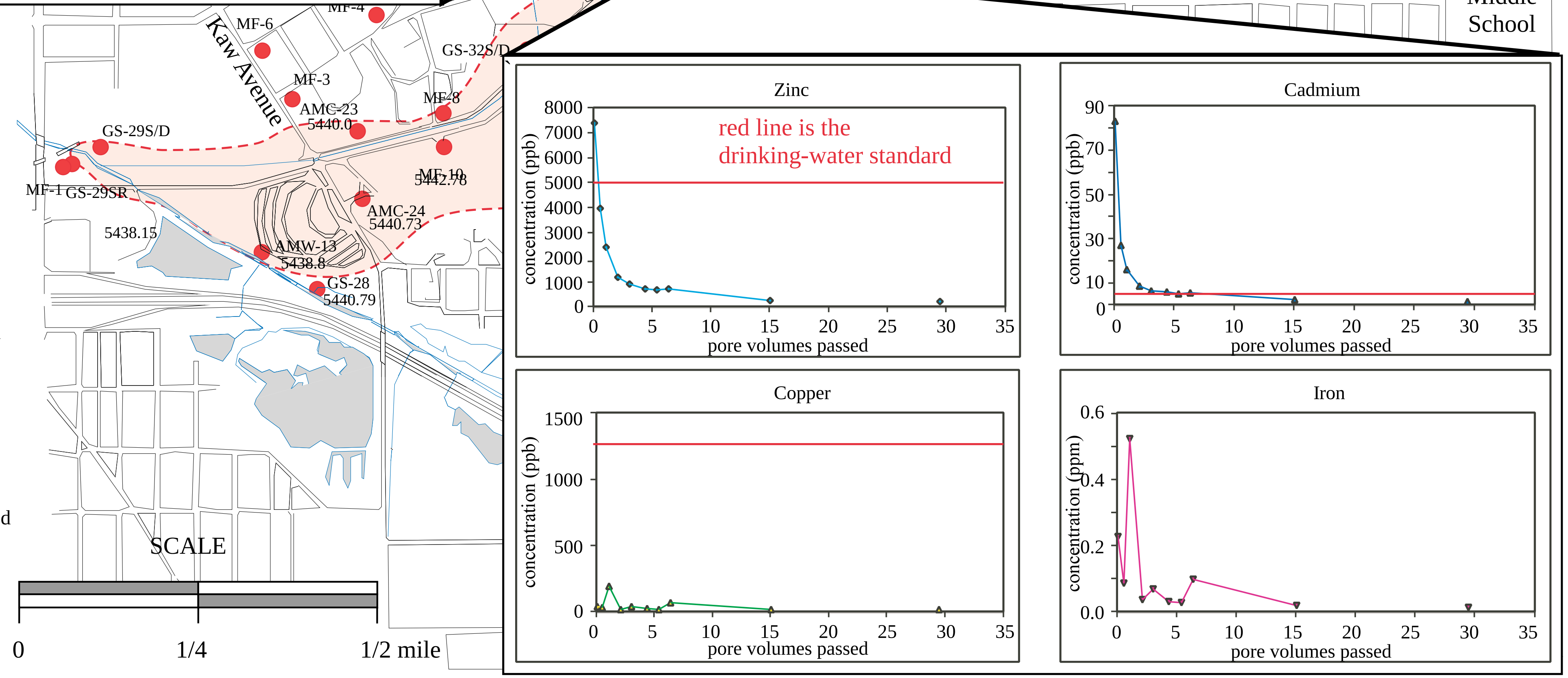


FIGURE 5: AQUIFER RECOVERY





Aquifer Recovery

Column tests using aquifer material from two contaminated areas (green dots) were conducted to test whether the water quality in the aquifer would recover if the source of contamination (tailings, slag, etc.) were removed. Uncontaminated water from the aquifer was passed through each column of contaminated material at a rate of one pore volume per day; a sample was collected and analyzed after each pore volume passed. The inset graphs show the concentrations (vertical axis) of zinc, copper, cadmium, and iron for each column. In both tests, the quality of the water improved throughout the test. With one exception, the water flowing out of the column met drinking water standards (red line) before the end of the test. The one exception is cadmium in the column for the aquifer beneath the tailings; cadmium decreased from nearly 500 to about 7 ug/L (the drinking water standard is 5 ug/L). These tests demonstrate that if the source of contamination is removed, the quality of water in the aquifer will likely recover to meet drinking water standards. The rate of recovery is simply a matter of inducing flow by pumping to pass the required number of pore volumes of clean water through the material. Thus, recovery could be induced and drinking water standards met in less than 100 years.

The two major objectives of this investigation were to 1) evaluate the rate of transport of contaminated ground water from the Parrot Complex in upper Silver Bow Creek, and 2) evaluate the recovery rate of the water quality in the aquifer if the source were removed.

Although the objectives were normally those of the remedial investigation, the data presented here demonstrate that previous investigations fell short of a complete characterization of the ground-water flow system and the geochemical conditions of the upper Silver Bow Creek. This investigation demonstrates that ground-water flow velocities are at least an order of magnitude higher than those previously reported and that contaminants have migrated much farther than presented in recent reports. It is important to note that the migration of the contaminants has probably occurred in the last 50 years. Thus, the rate of ground-water flow and rate of contaminant transport are on the order of years and decades not centuries.

Column tests, based on worst-case conditions, demonstrate a recovery rate sufficient to restore water quality to beneficial use if the source of contamination is removed. Existing hydraulic gradients, which were assumed for this evaluation, are much lower than those that would be induced during source removal or those that could be induced by short-term pumping and treating (increasing the hydraulic gradient would dramatically increase the rate of recovery).

This investigation was not intended to fully characterize the upper Silver Bow Creek drainage. Rather, it filled several gaps in the data collected over the past 15 years. Additional work should include refinement of the hydrogeologic model based on lithology and water quality in 1) the lower area near the confluence of upper Silver Bow Creek and Blacktail Creek, 2) north and west of the present stream channel, and 3) at the source area where coarse sands and gravels were identified in earlier investigations.

The MBMG gratefully acknowledges the U.S. EPA and the Montana Department of Justice for their support and cooperation in this investigation.
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FIGURE 6: SUMMARY