Design of a Monitoring Well Network for the City of Independence, Missouri, Well Field Using Simulated Ground-Water Flow Paths and Travel Times

By Brian P. Kelly

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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For addtional information write to:

District Chief
U.S. Geological Survey
1400 Independence Road
Mail Stop 100
Rolla, MO 65401

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
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ABSTRACT

The Independence, Missouri, well field supplies water from the Missouri River alluvial aquifer to about 250,000 people. Well-field expansion and commercial development near the well field have caused concerns about the potential for ground-water contamination because knowledge of the ground-water quality near the city of Independence well field is limited. Potential point and nonpoint source areas of ground-water contamination were identified. Ground-water flow simulation and particle-tracking analysis determined contributing recharge areas and ground-water travel times to the expanded well field. Contributing recharge areas defining the source area of water and time surfaces defining the outer surface of the zone of contribution were generated for 6-month and 1-, 2-, 3-, 4-, 5-, 10-, 25-, 50-, 100-, and 250-year ground-water travel times to the Independence well field. Locations of potential source areas of ground-water contamination, contributing recharge areas, time surfaces, and a geographic information system were used in combination to determine possible screened-interval altitudes and locations of 75 wells in 35 clusters around the Independence well field.

INTRODUCTION

Independence, Missouri, operates a well field (fig. 1) within the city limits of Sugar Creek, Missouri, in the Missouri River alluvial valley. About 250,000 people in several communities are supplied water from the 25 Mgal/d (million gallons per day) average daily production from the well field. Knowledge of ground-water quality near the Independence well field is limited, and concerns about potential ground-water contamination near the well field and in the vicinity of a planned well field expansion have been caused by planned commercial development and present land-use activities. Planned development includes landfill expansion south of the well field, construction of a golf course and commercial and residential areas next to the existing well field, construction of a highway bridge adjacent to the well field, and construction of a highway south of the well field. Agricultural activity, land application of municipal sludge, highway traffic, rail line traffic to the south of the well field, and operation of nearby landfills are some land-use activities that could adversely affect ground-water quality near the Independence well field.

The U.S. Geological Survey (USGS) has collected and compiled hydrogeologic data for use in a ground-water flow simulation for more than 500 km^2 (square kilometers) of the Missouri River alluvial aquifer in the Kansas City metropolitan area that includes the Independence well field (Kelly, 1996). Results from that study and an earlier study (Kelly and Blevins, 1995) were used to determine the ground-water flow directions, ground-water travel times, and zones of contribution (the volume within an aquifer that contributes water to a pumped well field) for well fields within the study area under average hydrologic and climatic conditions and pumping rates of 1994. However, the addition of a collector well on the west side of the Independence well field during 1995 and the planned expansion of the well field north of the Missouri River during 1997 will increase the size of the zone of contribution and alter local ground-water flow directions and ground-water travel times in and around the well field.

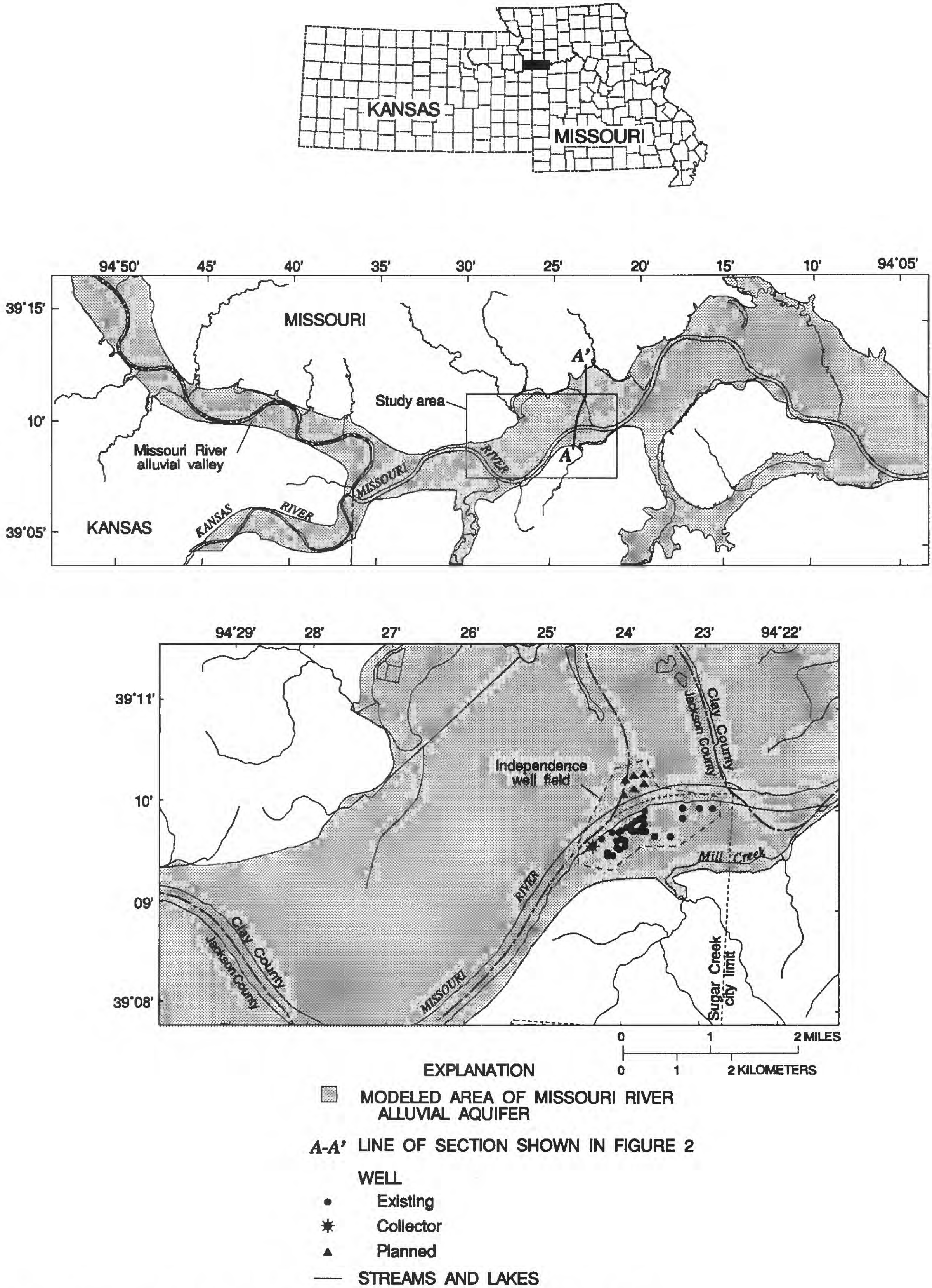


Figure 1. Location of the Independence, Missouri, well field and study area.

In 1994, the USGS, in cooperation with the city of Independence, Missouri, initiated a 2-year study to select possible well locations for a ground-water monitoring network near the expanded Independence well field based on ground-water flow paths, ground-water travel times, and particle-tracking analysis using a ground-water flow simulation (Kelly, 1996).

Purpose and Scope

The purpose of this report is to show locations of potential source areas of ground-water contamination to the alluvial aquifer, describe contributing recharge areas (CRAs) and ground-water travel times within the zone of contribution of the Independence well field, and select possible locations of wells for a ground-water monitoring network for the expanded Independence well field. This report will describe the ground-water flow simulation and particle-tracking analysis used to determine the CRAs, the outer surface of zones of contribution of ground water at various ground-water travel times, and the possible locations of monitoring wells in a ground-water monitoring network with respect to the location of potential source areas of ground-water contamination and ground-water travel time to the Independence well field. The use of ground-water flow simulation and travel-time analysis has widespread applicability to the design of monitoring networks near well fields.

Description of Study Area

The Independence well field is located within the city limits of Sugar Creek, Missouri, south of the Missouri River in the Missouri River alluvial valley. Currently (1996), 34 wells and a 10-Mgal/d-capacity collector well pump an average of 25 Mgal/d of water from the Missouri River alluvial aquifer (fig. 1). The installation of six wells north of the Missouri River in the summer of 1997 is expected to add approximately 12 Mgal/d capacity to the well field. The source of water for the Independence well field, the Missouri River alluvial aquifer, is composed of clay, silt, sand, gravel, cobbles, and boulders. Shale, limestone, and sandstone bedrock of Pennsylvanian age form the valley walls and bedrock surrounding the aquifer (Kelly and Blevins, 1995). The lithology in the aquifer at the Independence well field is shown in figure 2. Grain size generally increases with depth from the uppermost fine-grained clay, silt, and sandy silt deposits, through sand in the middle of the aquifer, to coarser sand and gravel at the base of the aquifer. The top of the bedrock in the vicinity of the Independence well field ranges from 190 to 195 m (meters) above sea level.

In general, ground water flows from the valley walls, toward the Missouri River, and down the river valley (generally west to east). However, this general pattern of ground-water flow is altered near the Independence well field by ground-water pumpage and local recharge (Kelly, 1996; Kelly and Blevins, 1995; fig. 3). Ground water supplied through the aquifer to the Independence well field comes from induced infiltration from the Missouri River, recharge to the aquifer originating as precipitation, runoff from areas adjacent to the Missouri River valley, and induced infiltration from tributaries to the Missouri River. Depth to the water table typically ranges from 4.5 to 7.5 m in areas where well pumping does not affect water-table altitude.

Previous Investigations

Detailed descriptions of the geology and aquifer characteristics of the Missouri River alluvial aquifer can be found in reports by McCourt and others (1917), K.E. Anderson and F.C. Greene (Missouri Department of Natural Resources, Division of Geology and Land Survey, written commun., 1948), Fischel (1948), Hasan and others (1988), and Gentile and others (1994). Numerous reports on the aquifer characteristics for the Missouri River alluvial aquifer (Fischel and others, 1953; Emmett and Jeffery, 1970; Nuzman, 1975; Layne-Western Company, Inc., 1978, 1979, 1980, 1981; Crabtree and Older, 1985) have been completed. Hydrogeologic data and results from recent studies of the Missouri River alluvial aquifer by the USGS (Kelly and Blevins, 1995; Kelly, 1996) provide the regional background and description of the ground-water flow simulation for the analysis presented in this report.

POTENTIAL SOURCE AREAS OF CONTAMINATION

The location of potential source areas of ground-water contamination that may affect ground-

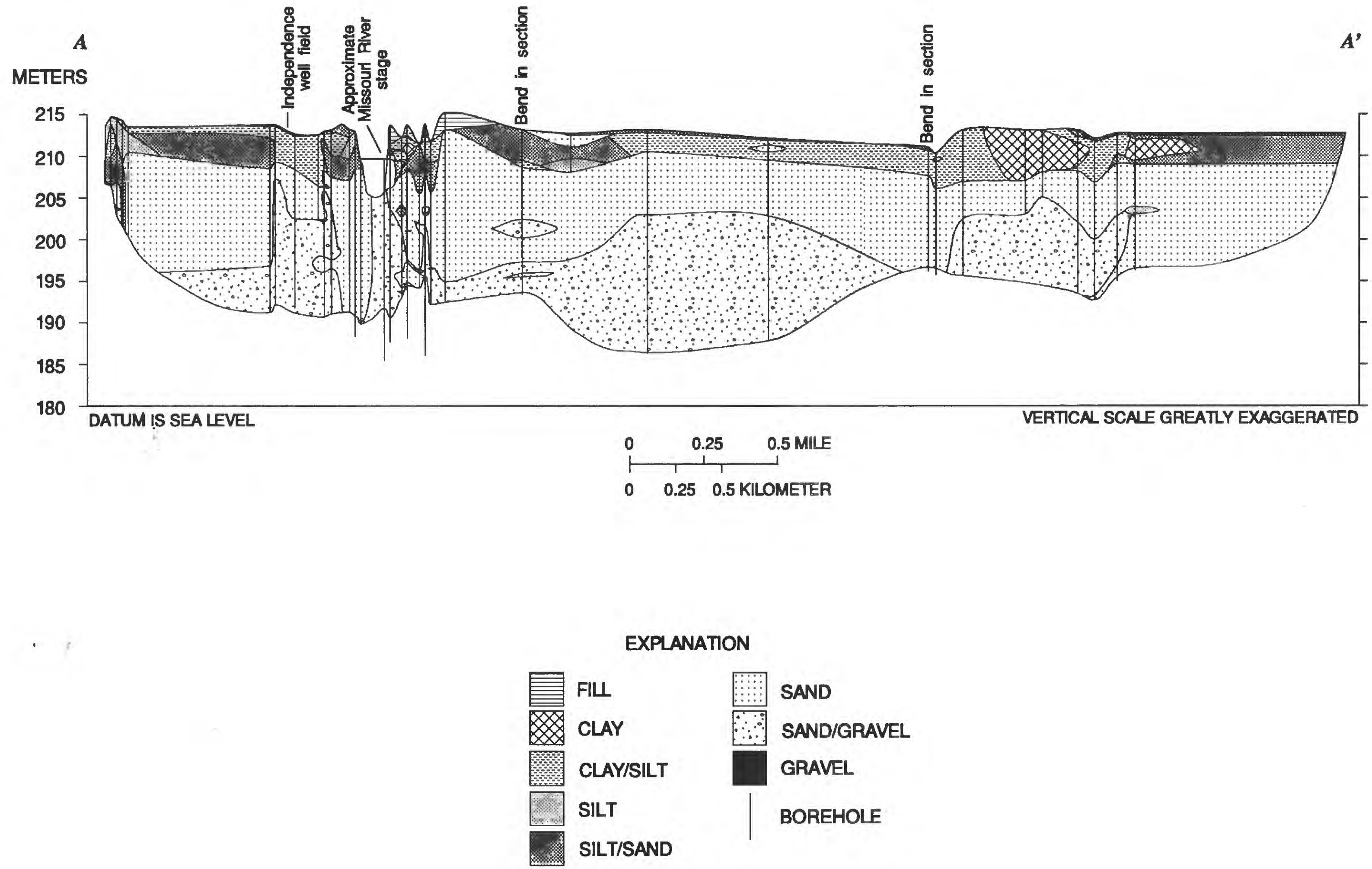
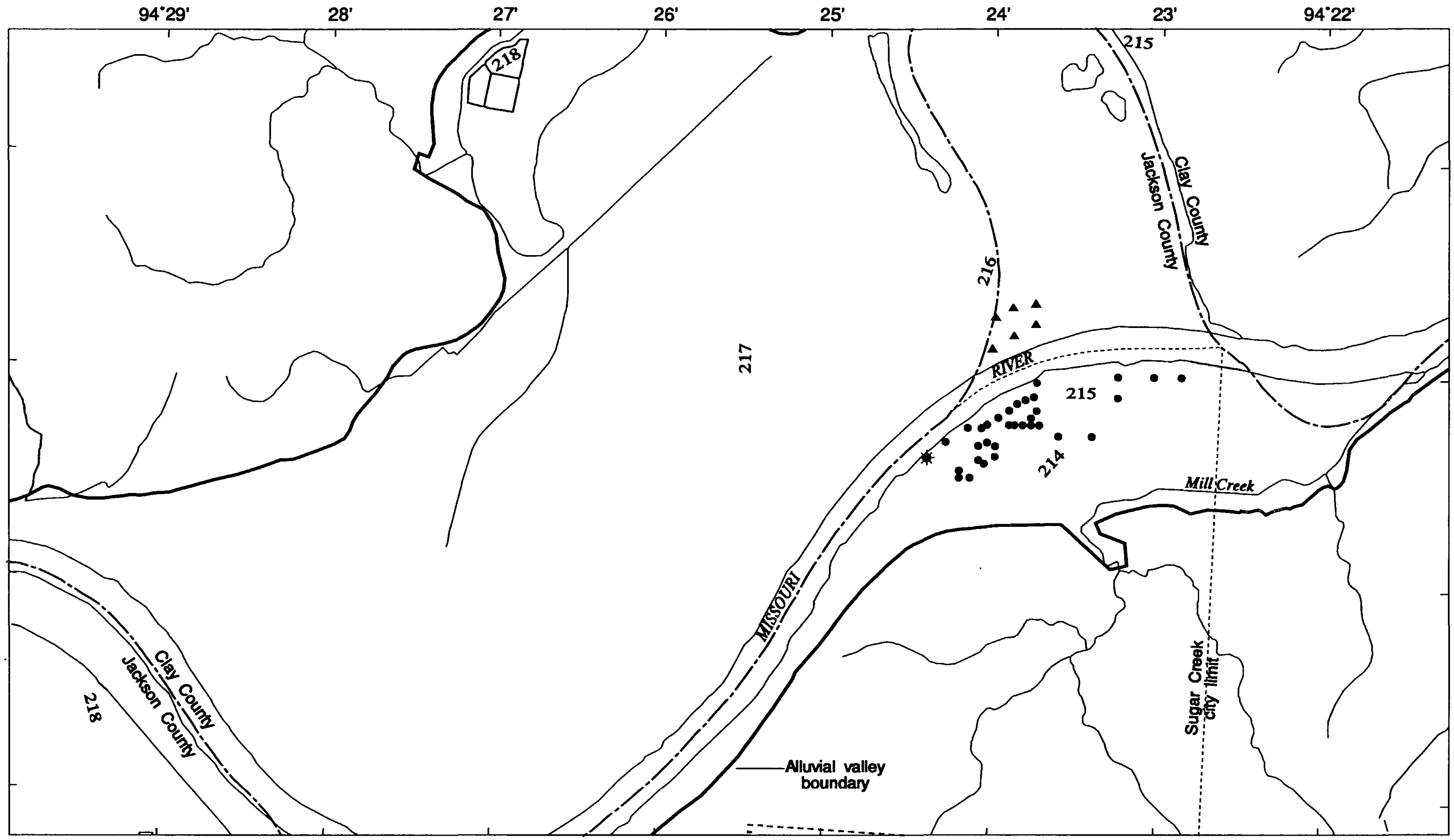


Figure 2. Lithologic section A-A' near the Independence, Missouri, well field (trace of section shown in figure 1).



EXPLANATION

216 POTENTIOMETRIC CONTOUR—Altitude to which water in a tightly cased well would have risen from hydrostatic pressure in aquifer. Contour interval 1 meter. Datum is sea level

WELL

- • Existing well
- ● Collector well
- ▲ Planned well

Figure 3. Potentiometric surface near the Independence, Missouri, well field for simulated mean annual hydrologic conditions.

water quality in the alluvial aquifer must be considered in the design of a ground-water monitoring well network. Potential source areas of ground-water contamination were identified within and in upland sources adjacent to the alluvial valley. Potential source areas near the Independence well field include crop production areas, municipal sewage sludge application areas near the well field, a rail line to the south of the well field, State Highway 291 through the middle of the well field, and nearby landfills in upland areas south of the well field. Future potential source areas of ground-water contamination include a new landfill about 2.4 km (kilometers) south of the well field near Mill Creek, which flows onto the alluvial valley; a golf course with commercial and residential areas in the alluvial valley next to the existing well field; a bridge for State Highway 291 adjacent to the well field; and a highway south of the well field.

The potential source areas of ground-water contamination (fig. 4) were identified based on the type of activity present or planned at each area. Identification as a potential source areas of ground-water contamination does not imply that this area presently is contaminating or will contaminate ground water in the Missouri River alluvial aquifer. Potential point sources of contamination near the Independence well field include (1) chemical spills adjacent to the well field along State Highway 291, along State Highway 210, along the rail lines, or along the proposed Jackson County Expressway; (2) chemical or fuel spills during construction of a bridge on State Highway 291 or the Jackson County Expressway; (3) turf management practices at the proposed golf course adjacent to the well field; (4) chemical- or petroleum-product spills in the Missouri River; (5) spills or runoff into Mill Creek from landfills; (6) leaching of contaminants into ground water from landfills in upland areas and then into the alluvial aquifer; and (7) runoff from limestone mining operations south of the well field. Potential nonpoint source areas of contamination have larger areal distribution and include infiltration of land-applied municipal sewage sludge across the Missouri River west of the well field and fertilizers and pesticides used on crops, the proposed golf course adjacent to the well field, on lawns of the proposed residential area, and on highway right-of-ways.

GROUND-WATER FLOW SIMULATION

Ground-water flow was simulated using the three-dimensional finite-difference ground-water flow model MODFLOWARC (Orzol and McGrath, 1992). MODFLOWARC is a modified version of MODFLOW (McDonald and Harbaugh, 1988) that reads and writes files using a geographic information system (GIS). The model used for this study was calibrated during a previous study of the Missouri River alluvial aquifer and was used to determine ground-water flow and the CRAs around public-water well fields in the modeled area under various pumping rates and river stages (Kelly, 1996). The area modeled (fig. 1) includes the Independence well field. A complete description of the model is given in Kelly (1996), but a brief description follows.

The model uses uniform cell areas of 150 by 150 m and contains 310,400 cells in 160 rows, 485 columns, and 4 layers. Layer 1 corresponds to the upper part of the aquifer where clay, silt, and fine-grained sand are dominant. Layers 2 and 3 correspond to the middle part of the aquifer where sand and gravelly sand are dominant. Layer 4 corresponds to the deep parts of the aquifer where gravel and sandy gravel are present. All four layers of the model are present in the study area in the vicinity of the Independence well field. Unconfined ground-water flow was simulated in layer 1, and confined ground-water flow as required by MODFLOWARC, was simulated in layers 2, 3, and 4.

The bedrock was simulated as a no-flow boundary because the hydraulic conductivity is several orders of magnitude less than values for the alluvial aquifer. The channel bottoms of the Missouri and Kansas Rivers were placed in layer 2 of the model because they intersect the sand and gravel that correspond to layer 2 of the model. The channel bottoms of the smaller rivers were placed in layer 1. Small streams and drainage ditches were simulated as drains, which do not supply water to the aquifer.

A steady-state calibration was performed using quasi-steady-state hydraulic-head data from a January 1993 synoptic water-level measurement of 155 wells. The January 1993 data were considered to represent the closest approximation of steady-state conditions where water levels, river stage, and pumped well data were readily available. Because river stage, precipitation rate, and well pumping are variable with time, true steady-state conditions probably never exist in the alluvial flow system. A transient calibration used

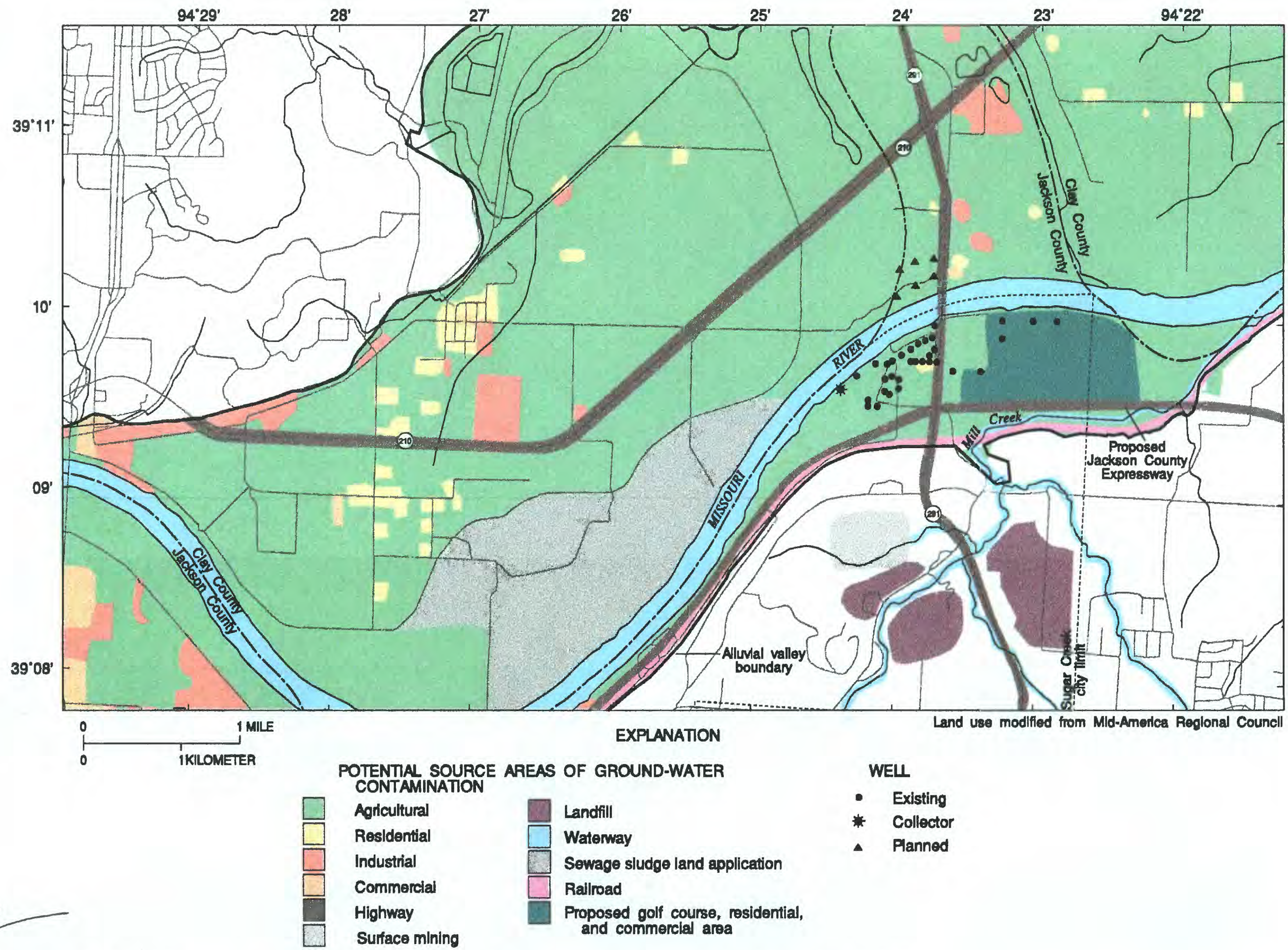


Figure 4. Potential source areas of ground-water contamination near the Independence, Missouri, well field.

hydraulic-head data from the August 1993 flood, from synoptic water-level measurements of 123 wells in October 1993, and from 98 wells in February 1994.

Available information and the steady-state calibration were used to obtain initial estimates of model parameters. The more rigorous transient calibration was used to refine the model parameters using conditions from a period of prolonged aquifer drainage from after the flood of record in August 1993 to February 1994 when river stage and ground-water levels had approached typical conditions for that time of year. The root mean square error between measured and simulated hydraulic heads was 1.15 m for the steady-state calibration, was 0.71 m for the transient calibration for October 1993, and was 0.8 m for February 1994. A sensitivity analysis indicated the model is most sensitive to changes in hydraulic conductivity values and least sensitive to decreases in vertical conductance between layers 1 and 2 and to increases in riverbed conductance.

For this study, steady-state ground-water flow was simulated using an estimated mean annual ground-water recharge rate and assumed mean annual ground-water flow conditions determined from mean annual river-stage data. Average annual recharge to the model was estimated as 20 percent of the mean annual precipitation of 0.91 m, adjusted for the vertical permeability of the soil, and ranged from 0.037 to 0.46 m/yr (meter per year). Pumping rates for all wells in the simulation other than wells in the Independence well field were set at average annual rates (Kelly, 1996). Pumping for the Independence well field was set at 2,821.45 m^3/d (cubic meters per day) or about 0.745 Mgal/d for each of the 32 existing pumped wells, 18,925 m^3/d (5 Mgal/d) for the collector well, and 3,785 m^3/d (1 Mgal/d) for each of the six wells planned to be installed north of the Missouri River during 1997 (Independence Water Department, oral commun., 1995).

Long-term discharge data are available for the Missouri River from USGS streamflow gaging stations. The gage at St. Joseph, Missouri, is 146.7 km upstream from the Independence well field and the gage at Kansas City, Missouri, is 14.6 km upstream. The gage for the Little Blue River at Lake City is about 14 km south-southeast of the Independence well field and was included as a measure of local conditions. The mean annual discharges determined between 1958 and 1994 were used to determine the mean annual river-surface altitudes at each of these gages (Reed and others, 1995). The mean annual river-surface altitude was 243.42 m at St. Joseph and 219.16 m at Kansas City for the Missouri River, and 220.02 m for the Little Blue River. These river-surface altitudes were compared to river-surface altitude data sets used in the transient calibration of the model (Kelly, 1996) to select a river-surface altitude data set that was considered to represent long-term average conditions for the modeled area. The data set chosen was from the week of January 19, 1993, with a Missouri River altitude of 242.96 m at St. Joseph and 219.09 m at Kansas City, and a Little Blue River altitude of 220.1 m.

FLOW-PATH AND TRAVEL-TIME ANALYSIS

The USGS particle-tracking program MODPATH (Pollock, 1994) was used to determine steady-state ground-water flow paths, travel times, and CRAs of the Independence well field. MODPATH uses hydraulic head and flow data from MODFLOW to calculate flow paths and travel times of imaginary particles of water moving through the simulated ground-water flow system. Knowledge of the limitations of particle-tracking analysis is necessary to correctly interpret MODPATH results and are given in detail in Pollock (1994). Particle-tracking limitations specific to this model are discussed in Kelly (1996), but the following limitation is of particular importance to the results of this study. Ground-water particle movement and ground-water travel times computed by MODPATH are based solely on ground-water flow. Because hydraulic conductivities are large in the Missouri River alluvial aquifer, ground-water flow probably is the largest component of contaminant transport. The movement of a contaminant in an aquifer by ground-water movement is known as advective contaminant transport. However, transport of contaminants in ground water also is subject to dispersion that may increase the rate of contaminant movement relative to the rate of ground-water movement and chemical or biological processes that may decrease the rate of contaminant movement relative to the rate of ground-water movement. While the rate of movement of a particular contaminant is not fully described by MODPATH results alone, a reasonable estimate is computed that can be used for planning purposes.

Areas with ground-water travel times from the water table to supply-well screens of 0 to 6 months, 6 months to 1 year, 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 10, 10 to 25, 25 to 50, 50 to 100, 100 to 250 years were grouped to create 6–month, 1–, 2–, 3–, 4–, 5–, 10–, 25–, 50–, 100–, and 250–year CRAs to the Independence well field (fig. 5). The CRAs show the source area of water and the associated ground-water travel times from the water-table surface and the major rivers to supply wells of the Independence well field. To construct the CRAs, one imaginary particle of water was placed on the water table in the center of each of the topmost active model cells and river cells and tracked to its eventual discharge point. The starting location and travel time of each particle that discharged to a simulated supply well in the Independence well field were used to determine the CRAs.

The zone of contribution around a well or well field is similar in concept to the CRA, but represents a three-dimensional volume that extends down through the aquifer rather than across a two-dimensional surface. The CRA defines the upper surface of the zone of contribution and is the intersection of the zone of contribution with the water table. Particle-tracking analysis was used to determine zones of contribution around the Independence well field for specific time periods. The ability of MODPATH to track water particles backward along ground-water flow paths facilitates determining zones of contribution by calculating the distance along a flow path a particle travels, backward from the supply well, in a specified amount of time. To determine zones of contribution, particles were placed on the outer faces of model cells that simulated the screened interval of supply wells in the Independence well field and were tracked backward through the flow system. Because ground-water flow rates are variable, the distance a particle moved for a specific travel time varied. Variations in particle travel times resulted in a three-dimensional distribution of particles that defined the zone of contribution for each selected time period. The locations of particles that traveled farthest from the Independence well field in specified periods of time were used to define the outer surfaces of the zones of contribution. The outer surface of each zone of contribution determined for a specified time is referred to in this report as the ground-water time-of-travel surface or, more simply, time surface. Each time surface represents the farthest distance ground-water particles were tracked from the well field for the specified time.

Ground-water flow velocity generally increases at depth and becomes slower near the water table because the hydraulic conductivity generally increases with depth in the Missouri River alluvial aquifer. Therefore, zones of contribution have a greater extent at greater depths within the aquifer than they do at shallower depths. The time surfaces can be represented using contour maps generated from the particle coordinates entered in the GIS. If faster ground-water flow occurred above an area of slower ground-water flow, the result would be a time surface where an imaginary vertical line would intersect the time surface at more than one point, thus precluding the use of a contour map. The relation between the zones of contribution, CRAs, and selected example time surfaces for a single supply well in an aquifer with increasing hydraulic conductivity with depth is shown in figure 6. The combination of the time surface position and extent of the corresponding CRA for 6 months and 1, 2, 3, 4, 5, and 10 years (figs. 7–13) indicates possible well-screen altitudes for monitoring wells designed to detect ground-water contamination at specific ground-water travel times to the well field.

GROUND-WATER MONITORING WELL NETWORK

Possible monitoring well cluster locations and screened-interval altitudes of wells in clusters were selected using the calibrated steady-state flow simulation, particle-tracking analysis, and GIS techniques. The well number, associated ground-water travel time, potential contamination sources monitored by the well, altitudes of land surface, bedrock surface, water table, and screened interval, and the Universal Transverse Mercator coordinates for each well in the ground-water monitoring network are listed in table 1. The locations represent only one of many possible configurations of a monitoring well network near the Independence well field. Selection of possible monitoring well cluster locations was based on locations of potential ground-water contamination, ground-water flow direction, and travel time as indicated by flow simulation results and particle-tracking analysis. The locations of possible monitoring well clusters within the monitoring well network and screened-interval altitudes of wells in clusters were selected using the following assumptions:

1. Well clusters would be located along ground-water flow paths between potential source areas of contamination (fig. 4) and the well field;

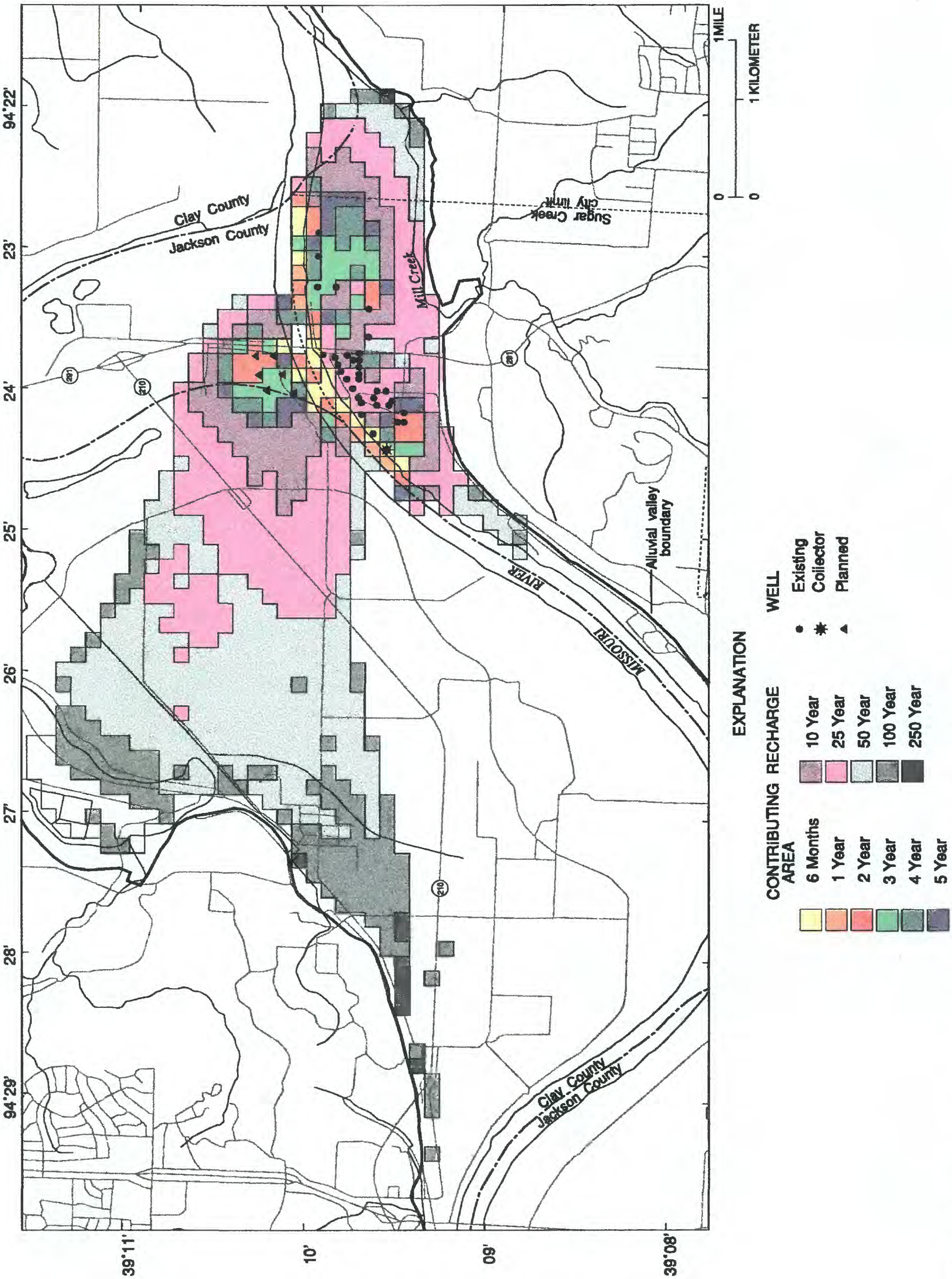


Figure 5. Contributing recharge areas for the Independence, Missouri, well field.

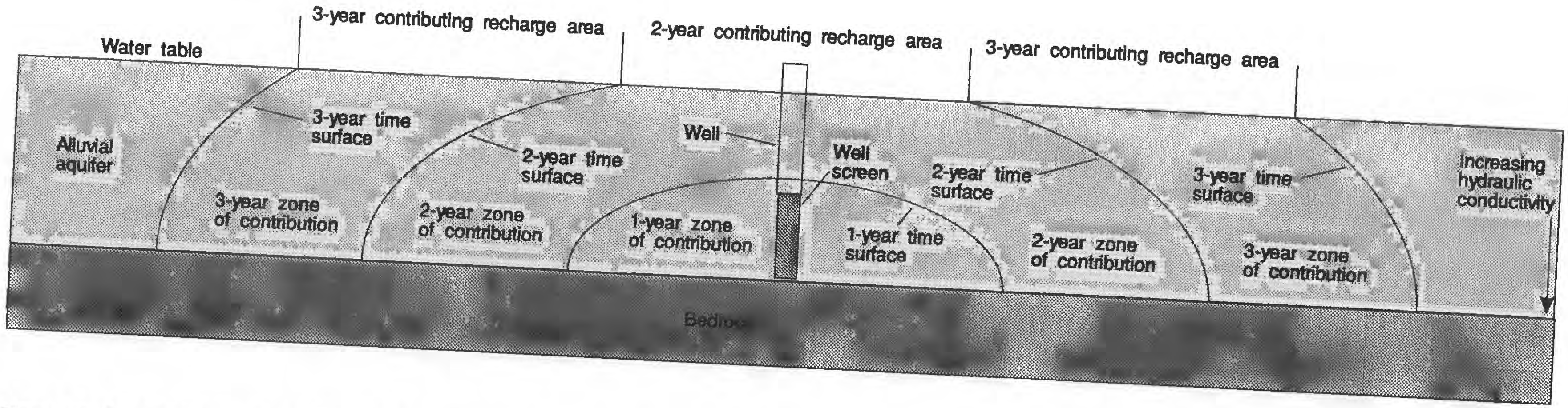


Figure 6. Schematic section showing the relation between the zone of contribution, contributing recharge area, and time surface at 1, 2, and 3 years.

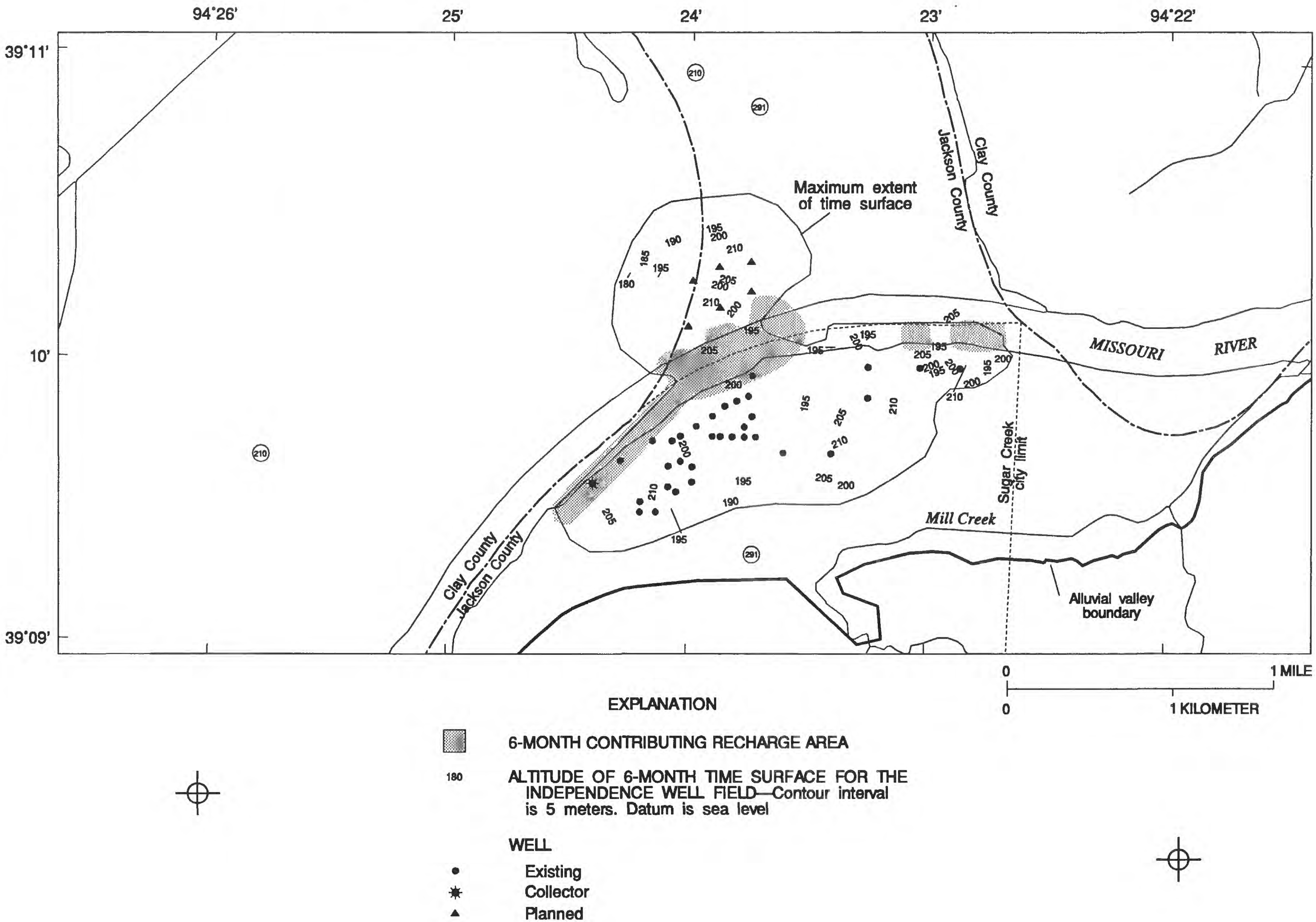


Figure 7. Altitude of the 6-month time surface for the Independence, Missouri, well field.

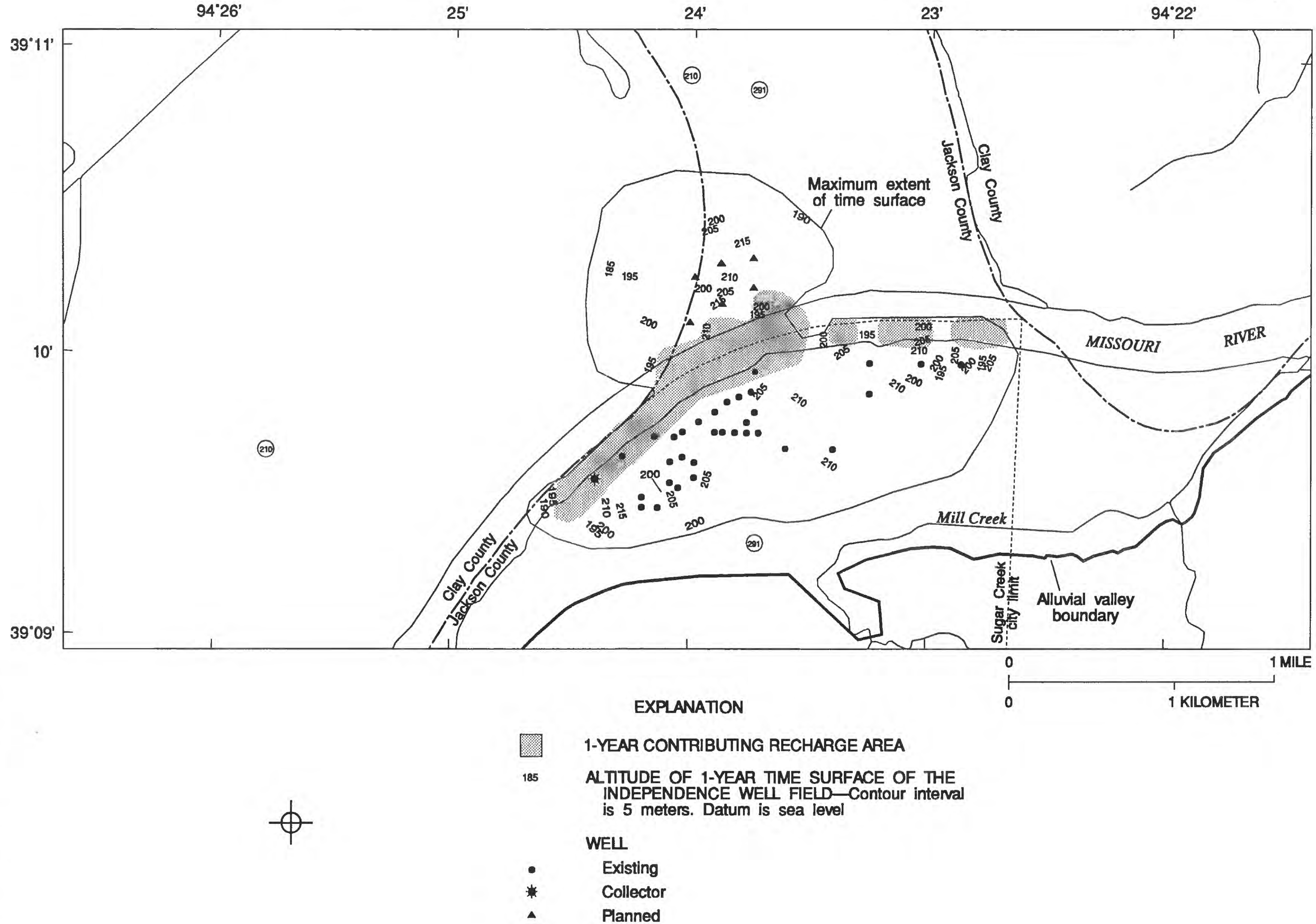


Figure 8. Altitude of the 1-year time surface for the Independence, Missouri, well field.

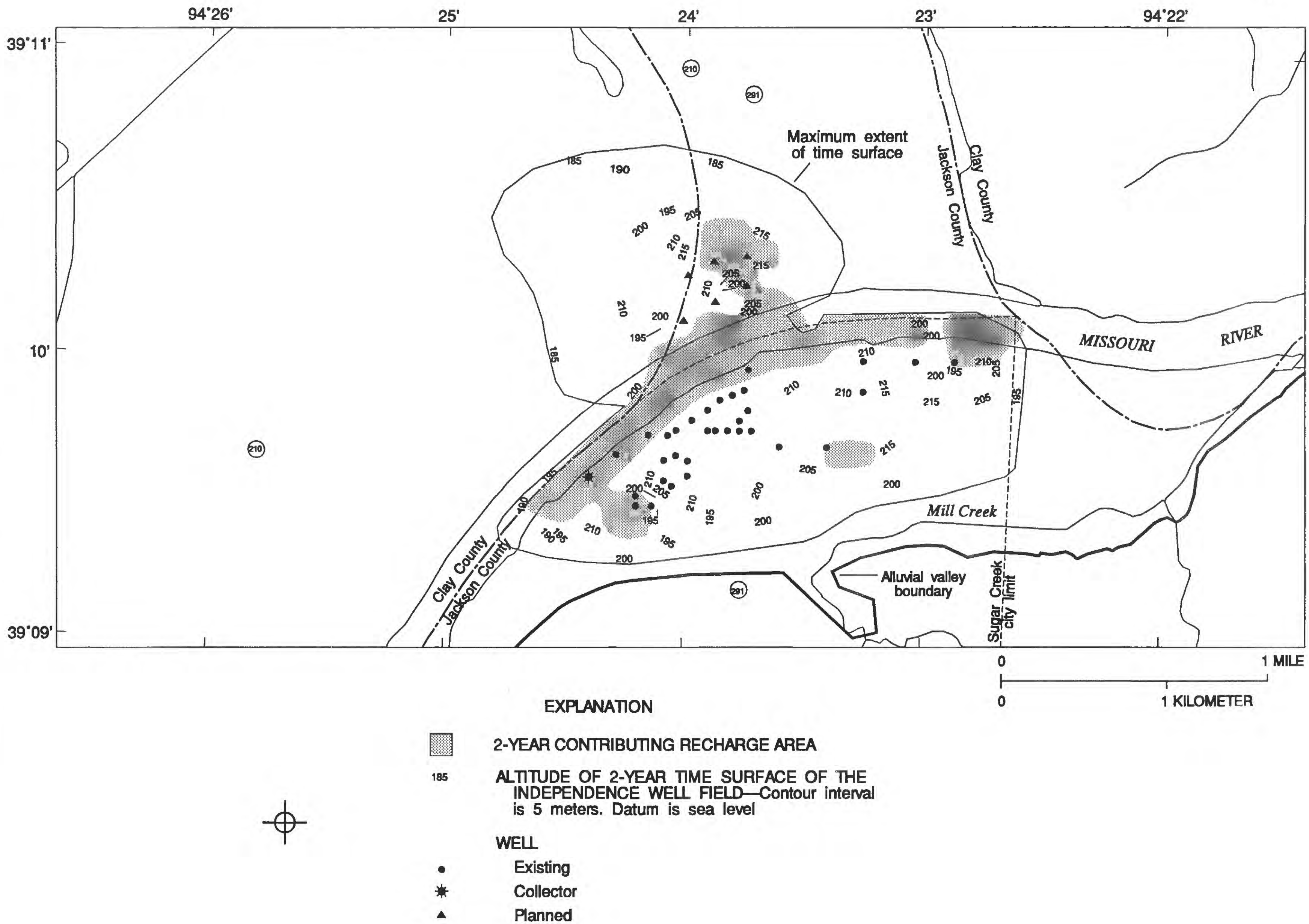


Figure 9. Altitude of the 2-year time surface for the Independence, Missouri, well field.

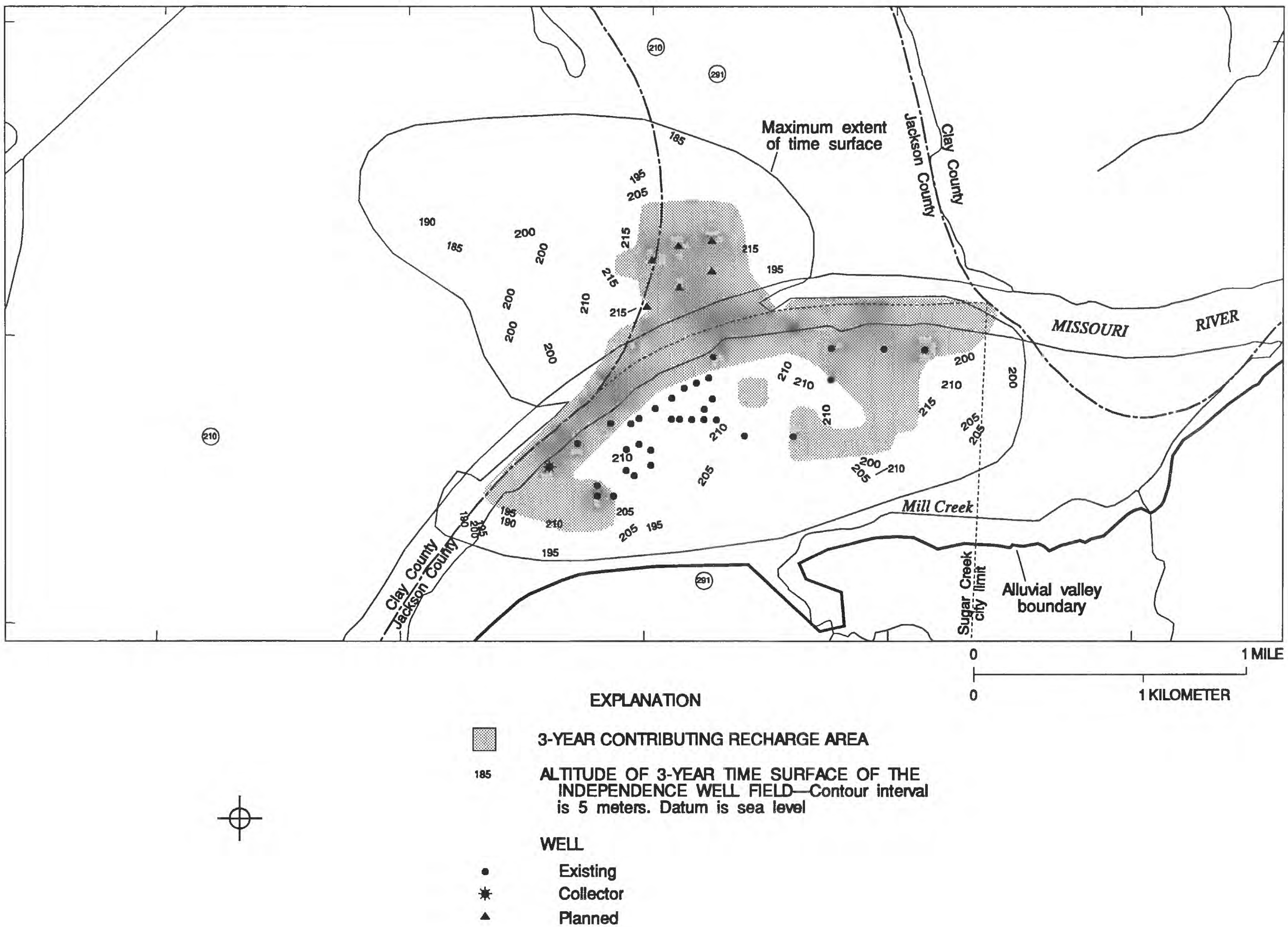


Figure 10. Altitude of the 3-year time surface for the Independence, Missouri, well field.

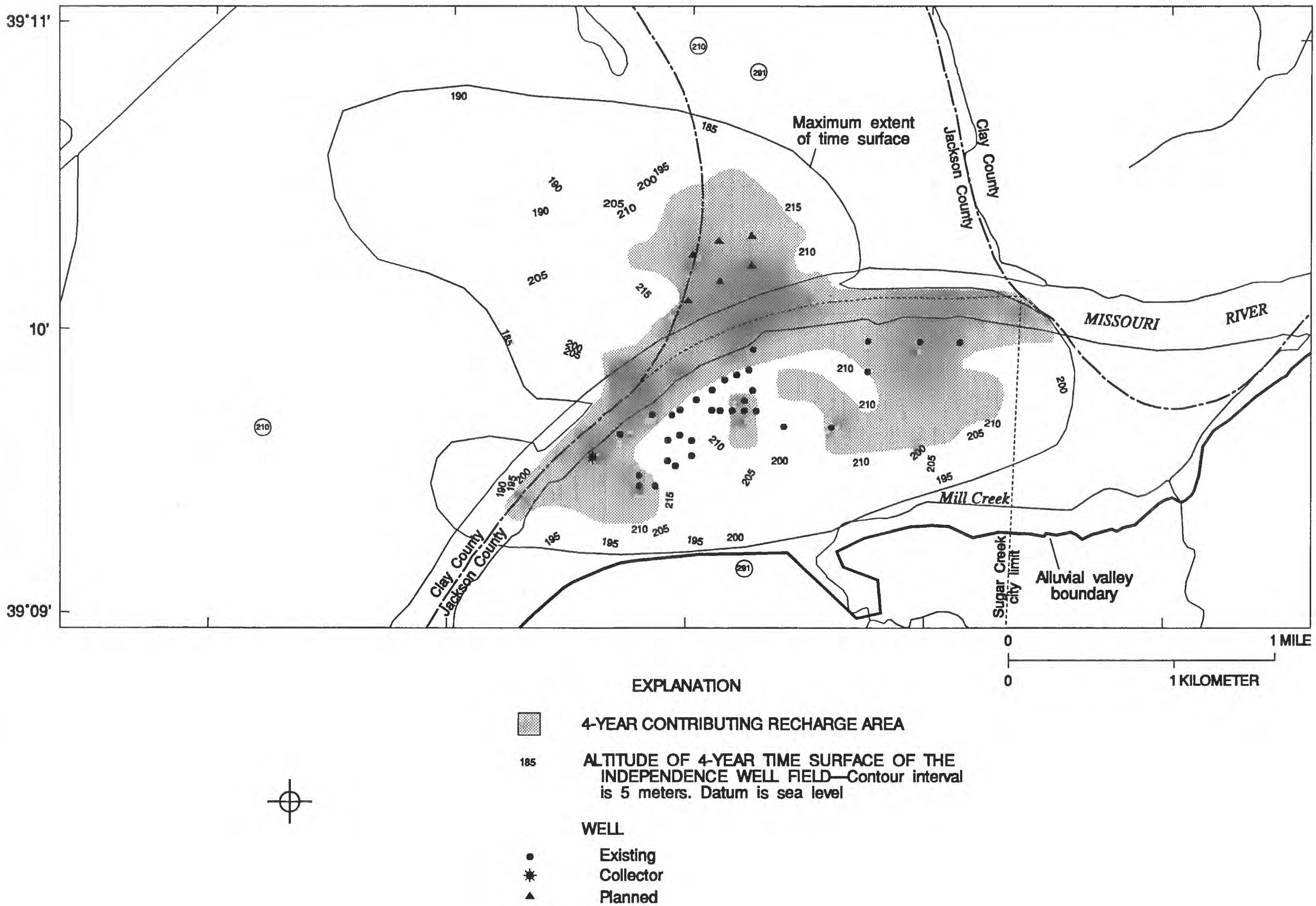


Figure 11. Altitude of the 4-year time surface for the Independence, Missouri, well field.

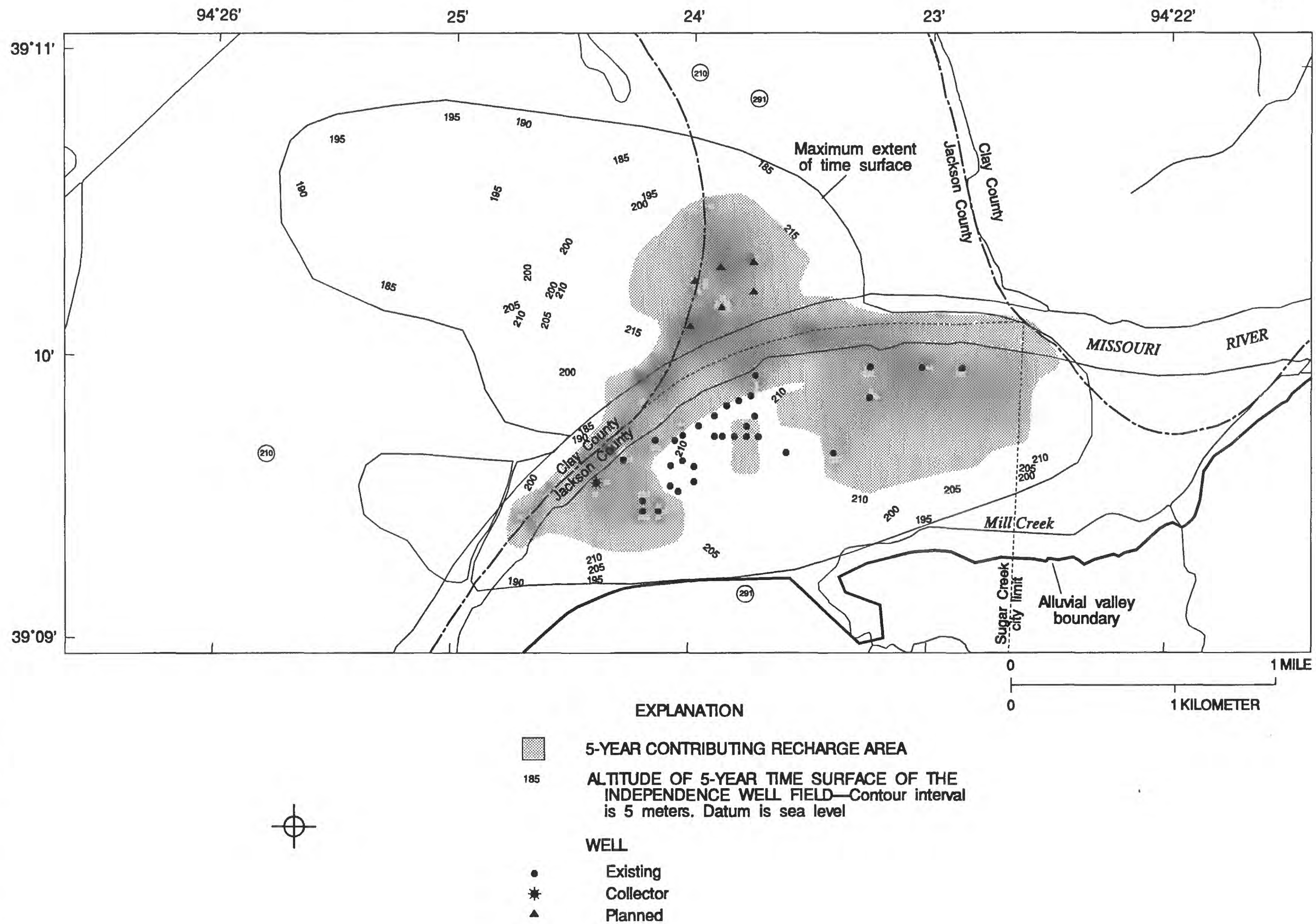


Figure 12. Altitude of the 5-year time surface for the Independence, Missouri, well field.

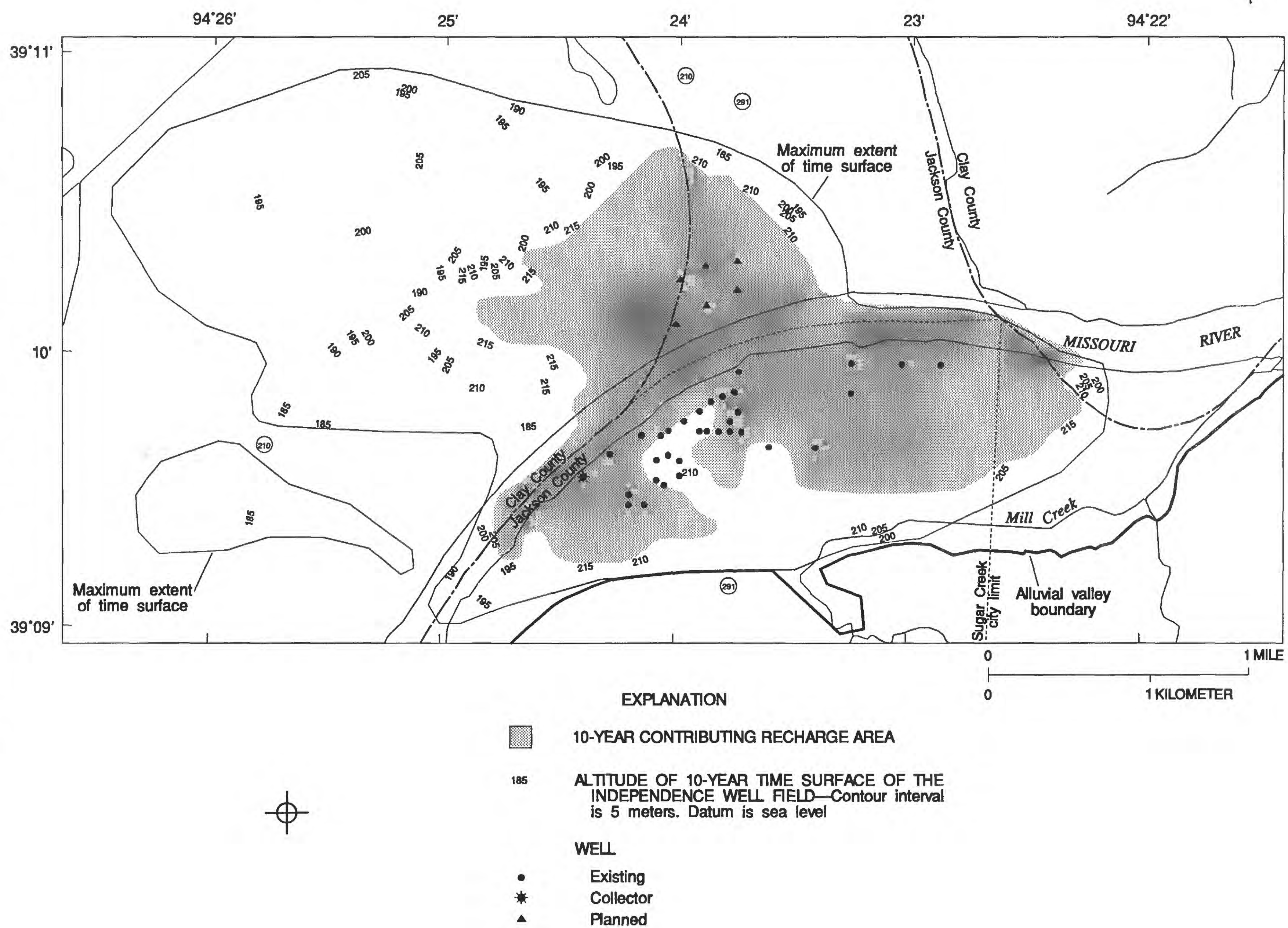


Figure 13. Altitude of the 10-year time surface for the Independence, Missouri, well field.

Table 1. Information pertaining to possible monitoring well cluster locations near the Independence, Missouri, well field

[Potential contamination sources: AG, agricultural; I, industrial; H, highway; RR, railroad; SM, surface mining; L, landfill; W, waterway; G, golf course; SS, sewage sludge; R, residential; C, commercial; Universal Transverse Mercator Coordinates for zone 15]

Well cluster or well (fig. 14)	Ground-water travel time to well field, in years	Potential contamination sources (figs. 4 and 14)	Land-surface altitude, in meters above sea level	Bedrock altitude, in meters above sea level	Steady-state simulated water-table altitude, in meters above sea level	Altitude of mid-point of 1.5-meter screened interval, in meters above sea level	East-west Universal Transverse Mercator coordinate, in meters	North-south Universal Transverse Mercator coordinate, in meters
1a	5	AG, I, H, RR	222.49	194.76	216.39	201.11	378,189	4,334,787
1b	10	AG, H, RR	222.49	194.76	216.39	211.48	378,189	4,334,787
2a	5	AG, H, SM, L, RR	223.27	195.52	214.80	199.86	378,810	4,334,757
2b	10	AG, H, SM, L, RR	223.27	195.52	214.80	209.80	378,810	4,334,757
3a	3	AG, H, SM, L, RR	230.96	197.70	214.12	201.13	379,310	4,334,874
3b	5	AG, H, SM, L, RR	230.96	197.70	214.12	207.93	379,310	4,334,874
3c	10	AG, H, SM, L, RR	230.96	197.70	214.12	210.49	379,310	4,334,874
4a	2	AG, H, SM, L, W, RR	226.97	197.16	214.23	197.41	379,758	4,334,915
4b	5	AG, H, SM, L, W, RR	226.97	197.16	214.23	206.05	379,758	4,334,915
4c	10	AG, H, SM, L, W, RR	226.97	197.16	214.23	208.85	379,758	4,334,915
5a	2	AG, H, L, W, RR, G	220.65	196.93	215.06	197.35	380,391	4,335,160
5b	10	AG, H, L, W, RR, G	220.65	196.93	215.06	211.23	380,391	4,335,160
6a	10	AG, H, W, RR, G	220.00	196.82	215.70	200.93	381,309	4,335,359
7a	2	AG, W, SS	223.22	182.36	216.47	183.28	378,294	4,335,849
7b	5	AG, W, SS	223.22	182.36	216.47	203.49	378,294	4,335,849
7c	10	AG, W, SS	223.22	182.36	216.47	212.10	378,294	4,335,849

Table 1. Information pertaining to possible monitoring well cluster locations near the Independence, Missouri, well field—Continued

Well cluster or well (fig. 14)	Ground-water travel time to well field, in years	Potential contamination sources (figs. 4 and 14)	Land-surface altitude, in meters above sea level	Bedrock altitude, in meters above sea level	Steady-state simulated water-table altitude, in meters above sea level	Altitude of mid-point of 1.5-meter screened interval, in meters above sea level	East-west Universal Transverse Mercator coordinate, in meters	North-south Universal Transverse Mercator coordinate, in meters
8a	5	AG	222.57	181.98	216.66	186.74	377,763	4,336,379
8b	10	AG, H	222.57	181.98	216.66	196.86	377,763	4,336,379
9a	2	AG	220.99	182.73	216.33	190.69	378,399	4,336,895
9b	5	AG	220.99	182.73	216.33	194.09	378,399	4,336,895
9c	10	AG, H	220.99	182.73	216.33	212.23	378,399	4,336,895
10a	10	AG	220.03	184.98	216.02	190.28	379,084	4,337,339
11a	5	AG, I, H	225.18	192.60	215.88	199.36	379,777	4,336,771
11b	10	AG, I, H	225.18	192.60	215.88	210.33	379,777	4,336,771
12a	1	AG, H, SM, L, W, RR	224.42	192.24	214.07	199.66	379,081	4,335,092
12b	2	AG, H	224.42	192.24	214.07	208.65	379,081	4,335,092
12c	4	AG, H	224.42	192.24	214.07	210.40	379,081	4,335,092
13a	1	AG, H, SM, L, W, RR	224.39	189.46	213.93	200.83	379,303	4,335,243
13b	2	AG, H	224.39	189.46	213.93	206.17	379,303	4,335,243
13c	5	AG, H	224.39	189.46	213.93	210.57	379,303	4,335,243
14a	3	AG, H, SM, L, W, RR, G	223.99	192.17	214.11	205.48	379,743	4,335,276
14b	10	AG, H, G	223.99	192.17	214.11	211.46	379,743	4,335,276

Table 1. Information pertaining to possible monitoring well cluster locations near the Independence, Missouri, well field—Continued

Well cluster or well (fig. 14)	Ground-water travel time to well field, in years	Potential contamination sources (figs. 4 and 14)	Land-surface altitude, in meters above sea level	Bedrock altitude, in meters above sea level	Steady-state simulated water-table altitude, in meters above sea level	Altitude of mid-point of 1.5-meter screened interval, in meters above sea level	East-west Universal Transverse Mercator coordinate, in meters	North-south Universal Transverse Mercator coordinate, in meters
15a	2	AG, H, W, RR, G	221.24	194.43	215.48	199.41	380,842	4,335,382
15b	5	AG, R, G	221.24	194.43	215.48	203.96	380,842	4,335,382
16a	3	AG, R, W, G	220.29	195.76	215.84	196.99	381,241	4,335,860
16b	5	AG, R, G	220.29	195.76	215.84	202.13	381,241	4,335,860
17a	1	AG, H	221.15	180.99	216.24	190.24	378,633	4,336,406
17b	3	AG	221.15	180.99	216.24	211.14	378,633	4,336,406
17c	5	AG	221.15	180.99	216.24	214.95	378,633	4,336,406
18a	2	AG, H	220.44	181.55	216.08	193.28	378,840	4,336,902
18b	5	AG	220.44	181.55	216.08	210.67	378,840	4,336,902
19a	1	AG, H	222.09	180.98	215.92	185.99	379,231	4,337,042
19b	3	AG, H	222.09	180.98	215.92	198.47	379,231	4,337,042
19c	5	AG	222.09	180.98	215.92	213.59	379,231	4,337,042
20a	2	AG, I, H, SM, L, RR	225.03	193.46	215.65	206.89	378,546	4,334,866
20b	5	AG, H	225.03	193.46	215.65	211.49	378,546	4,334,866
21a	2	AG, H	221.04	188.79	214.33	208.72	379,412	4,335,717
21b	5	H	221.04	188.79	214.33	212.13	379,412	4,335,717

Table 1. Information pertaining to possible monitoring well cluster locations near the Independence, Missouri, well field—Continued

Well cluster or well (fig. 14)	Ground-water travel time to well field, in years	Potential contamination sources (figs. 4 and 14)	Land-surface altitude, in meters above sea level	Bedrock altitude, in meters above sea level	Steady-state simulated water-table altitude, in meters above sea level	Altitude of mid-point of 1.5-meter screened interval, in meters above sea level	East-west Universal Transverse Mercator coordinate, in meters	North-south Universal Transverse Mercator coordinate, in meters
22a	1	AG	221.23	189.57	214.32	207.34	379,559	4,335,653
22b	2	AG, H	221.23	189.57	214.32	211.28	379,559	4,335,653
23a	1	AG, R, C, G	220.75	196.92	215.48	200.42	380,782	4,335,781
23b	3	AG, R, C, G	220.75	196.92	215.48	209.45	380,782	4,335,781
24a	1	AG, W	220.02	183.76	216.21	190.76	378,908	4,336,172
24b	3	AG	220.02	183.76	216.21	208.26	378,908	4,336,172
25a	1	AG, H	220.24	180.68	216.01	203.22	378,911	4,336,673
25b	3	AG	220.24	180.68	216.01	211.16	378,911	4,336,673
26a	1	AG, I, H	223.02	185.47	215.86	193.61	379,431	4,336,891
26b	3	AG, I, H	223.02	185.47	215.86	213.55	379,431	4,336,891
27a	1	AG, R, H	222.87	190.92	215.86	200.30	379,638	4,336,680
27b	3	AG, R, H	222.87	190.92	215.86	214.27	379,638	4,336,680
28a	2	AG, R, C, G	221.15	197.62	215.08	214.65	380,334	4,335,713
29a	.5	AG, R, C, W, G	220.14	190.62	215.52	199.10	380,609	4,336,033

Table 1. Information pertaining to possible monitoring well cluster locations near the Independence, Missouri, well field—Continued

Well cluster or well (fig. 14)	Ground-water travel time to well field, in years	Potential contamination sources (figs. 4 and 14)	Land-surface altitude, in meters above sea level	Bedrock altitude, in meters above sea level	Steady-state simulated water-table altitude, in meters above sea level	Altitude of mid-point of 1.5-meter screened interval, in meters above sea level	East-west Universal Transverse Mercator coordinate, in meters	North-south Universal Transverse Mercator coordinate, in meters
30a	0.5	AG, R, C, W, H, RR, G	220.52	193.59	215.19	208.54	380,078	4,335,939
30b	2	AG, R, C, W, G	220.52	193.59	215.19	214.19	380,078	4,335,939
31a	.5	AG, R, I, C, H	222.27	190.59	215.79	206.42	379,438	4,336,545
31b	1	AG, R, I, C, H	222.27	190.59	215.79	214.81	379,438	4,336,545
32a	.5	AG, H	221.54	184.85	215.77	209.68	379,258	4,336,692
32b	1	AG	221.54	184.85	215.77	214.15	379,258	4,336,692
33a	.5	AG, H	220.00	183.16	215.98	200.73	379,002	4,336,398
33b	1	AG	220.00	183.16	215.98	208.90	379,002	4,336,398
33c	2	AG	220.00	183.16	215.98	214.03	379,002	4,336,398
34a	.5	AG, H, W, RR, G	221.90	196.70	214.74	208.58	380,131	4,335,408
34b	1	AG, G	221.90	196.70	214.74	213.00	380,131	4,335,408
35a	.5	AG, R, H, RR, G	223.35	188.17	213.79	205.51	379,386	4,335,438
35b	3	AG, R, H, G	223.35	188.17	213.79	211.70	379,386	4,335,438

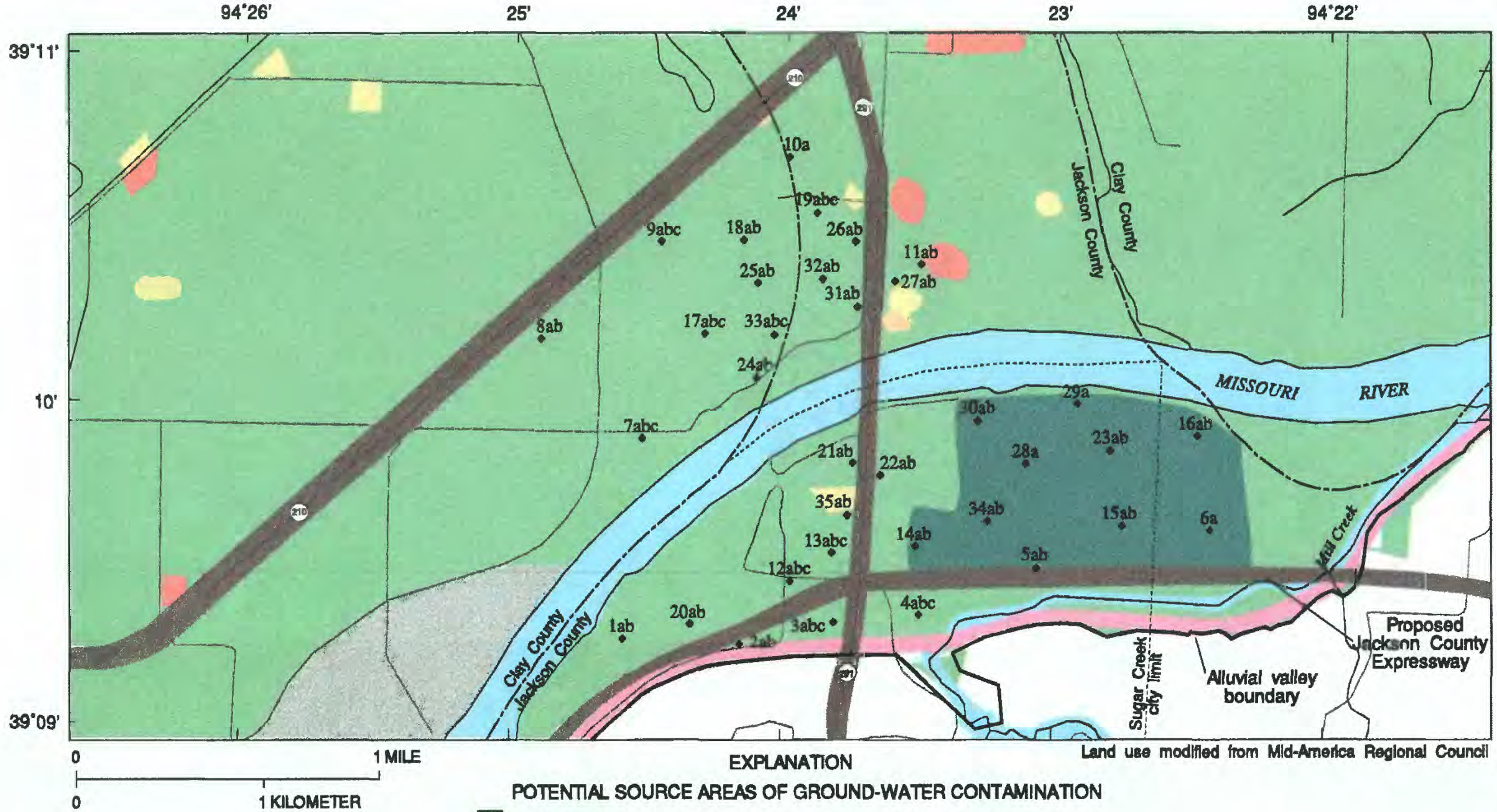
2. Analyses of samples from wells in each cluster would provide the maximum warning time possible (as much as 10 years) prior to potential contamination reaching the well field;
3. At most locations, screened-interval altitudes of well clusters would intersect potential contamination moving along intermediate or deep ground-water flow paths within the aquifer. However, all well cluster locations would include a shallow well because most potential contamination in the Missouri River alluvial aquifer is from surface sources;
4. A short well screen length of 1.5 m would ensure that initial contaminant detection corresponds to a specific ground-water travel time to the well field, precludes sample dilution, and is approximately twice the range of the model error of between 0.7 and 0.8 m; and
5. To help prevent dry wells, the top of the screened interval would be at least 1 m below the water-table altitude at that location as indicated by the ground-water flow simulation results.

Possible locations of monitoring well clusters (fig. 14) were selected based on ground-water flow paths and potential sources of contamination. As previously discussed, potential contamination that would be the most areally extensive is nonpoint source in nature. Therefore, possible well cluster locations in the monitoring well network were chosen primarily to detect nonpoint source contamination. After possible well-cluster locations were selected, the coordinates were entered into the GIS. The altitude of the midpoint of the 1.5 m screened interval was determined by intersecting the coordinates of the well-cluster location with the 6–month, and 1–, 2–, 3–, 4–, 5–, and 10–year time surfaces generated using the GIS. The coordinates also were intersected with GIS-generated surfaces of land-surface altitude, bedrock surface altitude (Kelly, 1996), and simulated water-table altitude for assumed long-term average conditions (fig. 3) to provide distance to the well screen from land surface and above the bedrock and to result in the well screen being 1 m below the average water-table altitude.

Possible screened-interval altitudes for wells in each cluster were chosen based on the previously discussed criteria combined with the results of the intersections of the cluster locations with the time surfaces. The screened-interval altitude of one well at each cluster location was selected to intersect the water table because that altitude corresponds to the maximum ground-water travel time to the Independence well field (as much as 10 years). Screened-interval altitudes of any additional wells in the cluster were selected to intersect deeper ground-water flow paths between the well field and potential contamination sources.

The number of wells designed to intercept specific potential sources of ground-water contaminants are 74 wells for agricultural sources, 15 wells for residential sources, 8 wells for industrial sources, 8 wells for commercial sources, 48 wells for highway sources, 12 wells for surface mining sources, 14 wells for landfill sources, 19 wells for waterway sources, 21 wells for railroad sources, 19 wells for the proposed golf course sources, and 3 wells for sewage sludge sources. In some instances, the location of a well with respect to the potential contamination source it is designed to intercept is not readily apparent. This is especially true for wells located next to a potential source of contamination but with a screened-interval altitude set to intercept contamination moving along intermediate or deeper ground-water flow paths. For example, several well clusters are located next to highways but only the shallow well in each of these clusters can intercept a potential surface spill from a highway accident. This is illustrated with well clusters 8 and 9. Also, the potential for overland flow of any potential surface spill required that shallow wells in clusters located close to a potential surface contamination source, but upgradient with respect to ground-water flow, be designated to intercept contamination from that source. This is illustrated with well clusters 11 and 27.

Several well clusters are designed to intercept potential contamination from source areas located in the uplands adjacent to the alluvial aquifer. These potential source areas (fig. 4) include surface mining, landfills, and spills or runoff in Mill Creek. Potential contamination may move from the uplands either in surface runoff entering Mill Creek with subsequent flow onto the alluvial plain or through infiltration (landfill leachate or precipitation) into fractures or bedding planes in the limestones and shales with subsequent movement into the aquifer. Well clusters or wells designed to intercept potential contamination from Mill Creek are 4abc, 5ab, 6a, 12a, 13a, 14a, 15a, and 34a. Well clusters or wells designed to intercept potential contamination in ground-water flow from upland areas are 2ab, 3abc, 4abc, 12a, 13a, and 20a.



EXPLANATION

POTENTIAL SOURCE AREAS OF GROUND-WATER CONTAMINATION

- Agricultural
- Residential
- Industrial
- Commercial
- Highways
- Waterway
- Sewage sludge land application
- Railroad
- Proposed golf course, residential, and commercial area

7abc • MONITORING WELL CLUSTERS—Letters indicate individual wells (table 1)

Figure 14. Monitoring well cluster locations and potential ground-water contamination source areas near the Independence, Missouri, well field.

SUMMARY

The Independence, Missouri, well field supplies water from the Missouri River alluvial aquifer to about 250,000 people. Knowledge of ground-water quality near the Independence well field is limited. However, future expansion of the well field, planned commercial development adjacent to the well field, and present land-use activities near the well field have caused concerns about potential ground-water contamination. Numerous potential point and nonpoint sources of ground-water contamination exist within and adjacent to the Missouri River alluvial aquifer, but potential nonpoint sources of contamination are the most widespread. In 1994, the U.S. Geological Survey, in cooperation with the city of Independence, Missouri, began a 2-year study to select possible well locations and screened-interval altitudes for wells in a ground-water monitoring network around the expanded Independence well field. The well locations and screened-interval altitudes were based on potential ground-water contamination source areas, ground-water flow paths, and ground-water travel times.

The U.S. Geological Survey has developed a three-dimensional finite-difference ground-water flow model calibrated during a previous study of the Missouri River alluvial aquifer that includes the Independence well field. Steady-state ground-water flow was simulated using assumed long-term average hydrologic conditions determined with mean annual river-stage data and mean annual recharge rate. Particle-tracking analysis of model results determined ground-water flow paths and ground-water travel times around the Independence well field and were entered into a geographic information system. Contributing recharge areas defining the source area of water, and time surfaces that define the outer surface of the zone of contribution were generated from model results, particle-tracking analysis, and geographic information system techniques for 6–month and 1–, 2–, 3–, 4–, 5–, 10–, 25–, 50–, 100–, and 250–year ground-water travel times to the Independence well field. The combination of the time surface and corresponding contributing recharge areas indicate optimal well-screen altitudes to detect ground-water contamination at specific ground-water travel times away from the well field.

The location of 75 monitoring wells in 35 clusters and screened-interval altitudes of wells in each cluster were based on the calibrated steady-state flow simulation, particle-tracking analysis, and geographic information system techniques. Analyses of samples from wells, located along ground-water flow paths between potential source areas of contamination and the well field, would provide the maximum warning time possible (as much as 10 years) between the potential contamination source areas and the well field. It was assumed that each cluster would include a shallow well because most potential contamination in the Missouri River alluvial aquifer comes from surface sources. Most locations contained multiple wells to intersect potential contaminants moving along intermediate or deep ground-water flow paths. A screened interval of 1.5 meters would ensure that initial contaminant detection corresponds to a specific ground-water travel time to the well field. The top of the screened interval was assumed to be at least 1 meter below the water-table altitude to help prevent dry wells.

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