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Hydrogeologic Conditions Around Deep Aeration Lagoons at the Bardstown Wastewater Treatment Plant

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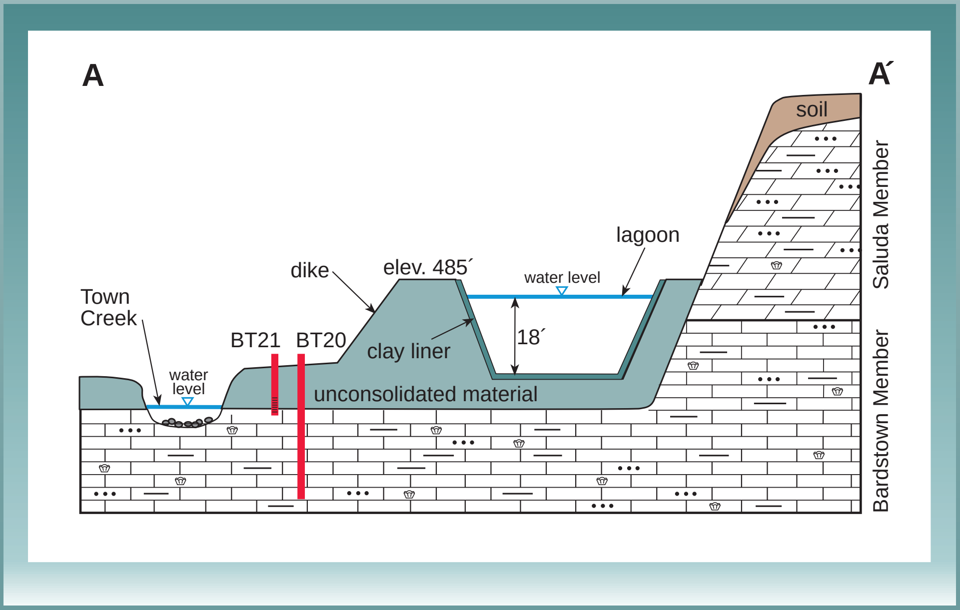

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Hydrologic Conditions Around Deep Aeration Lagoons at the Bardstown Wastewater Treatment Plant

David R. Wunsch[1], Gregory L. Secrist[1], and Lyle V.A. Sendlein[2]

Abstract

The hydrogeologic conditions around the Bardstown Sewage Treatment Plant were studied from August 1996 through December 1997. Hydraulic and geochemical data were collected from eight monitoring wells and four surface-water monitoring sites on the plant property.

There is a large hydraulic gradient between the lagoons at the plant and the surrounding stream, Town Creek. Initial water-level measurements in wells surrounding the site suggest no major leakage from the lagoons, however. Neither flowing artesian conditions nor unusually high water levels were observed in any of the wells. Water-level measurements collected by data loggers showed that shallow wells responded quickly to recharge, whereas bedrock wells were relatively unresponsive throughout most of the observation period. Slug tests indicate that the hydraulic conductivities of the unconsolidated material monitored by the shallow wells are several orders of magnitude greater than for the underlying bedrock.

Surface-water flow measurements indicate that Town Creek is a losing stream adjacent to the lagoons. This conclusion is supported by hydraulic data from the monitoring wells. These data suggest that it is unlikely the lagoons are leaking significantly into Town Creek. Town Creek appears to become a gaining stream along its lowest reaches on the northwestern side of the plant property.

Interpretation of chloride, bromide, fluoride, and major-ion chemistry data indicates that the water chemistry in the shallow wells is not affected significantly by the lagoons. Well-water chemistry is influenced by Town Creek, which recharges the shallow alluvial sediments during high flow. All metal concentrations appear to be below primary and secondary maximum contaminant levels (MCL's) in both the lagoons and the stream water. The only metals for which the MCL was exceeded at the site are iron and manganese; concentrations were relatively high in the shallow ground-water monitoring wells. Concentrations of these metals are commonly elevated in ground water derived from shallow, alluvial sediments in this physiographic region, however. These data suggest that the lagoons are having a minimal impact, if any, on the quality of ground water around the lagoons.

The results from a one-time sampling for bacteria indicate that the total coliform in the monitoring wells ranged from 10 to 1,920 colonies per 100 ml (col/100 ml). Analysis for *E. coli* bacteria showed that only one well, BT30, contained measurable counts (10 col/100 ml). The presence of *E. coli* in this well is inconsistent with other parameters that would indicate contamination from the lagoons, however; their presence may represent contamination during sampling.

The data from this investigation, as well as previous studies, indicate that the lagoons provide efficient primary water treatment without causing significant ground-water contamination. Moreover, the design and engineering used for the Bardstown plant may provide a model for cost-effective, efficient primary water-treatment systems capable of long-term operation without affecting the local ground-water system. Lagoons in other physiographic and geologic settings should be studied to determine the effect of large lagoons throughout the state. This is especially pertinent now, because public and regulatory agencies have expressed great interest in lagoon technology for managing wastes from large-scale livestock operations.

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Introduction

Deep-cell aerated lagoons have been used for decades and are recognized as an efficient primary treatment process for sewage and wastewater. These lagoons have proven to be effective in lowering the suspended solids content, while minimizing the accumulation of sludge. Interest in the use of large primary treatment lagoons diminished in recent years because of their large area requirements and limited denitrification capabilities. Aerated lagoons, in conjunction with improved secondary treatment technology, are again being considered in the design for new wastewater treatment plants. An important consideration in using lagoons for wastewater treatment is their impact on the quality and movement of subsurface water.

The Bardstown wastewater treatment plant was chosen for study because it has produced a minimum amount of residual sludge while successfully meeting its Kentucky Pollution Discharge Elimination System specifications. A limited amount of ground-water research has been conducted around active lagoons in various parts of the United States (Foster, 1983; Murphy and others, 1992), but no previous appreciable research has been conducted in Kentucky.

Site Location

Bardstown is a small city of approximately 6,200 residents in Nelson County, Ky. The city is located in the Outer Bluegrass physiographic region (Fig. 1). The plant is located approximately 1 mi south of the center of Bardstown on a small floodplain near the confluence of Town Creek and Beech Fork (Fig. 2). Town Creek is reported to be a "flashy" stream, meaning that it does not sustain flow during dry periods, but substantial overbank flooding occurs several times throughout the year during prolonged precipitation. The flooding potential has been increased because the floodplain has been constricted by the elevated levees that impound the lagoons (Jerry Reilly, Plant Manager, oral commun., 1996).

Plant Layout and Construction

The Bardstown Sewage Treatment Plant serves a community of approximately 11,000 residents, and also treats wastewater from several industries. The plant was modified in 1980, when two large, aerated sewage lagoons were constructed (Shaw and others, 1995). The two lagoons average 12 to 16 ft in depth (see Figure 2). The embankments for the lagoons were created by placing soil borrowed from areas around the plant site. The embankments along the north edge of the lagoons consist of compacted soil that was placed against the solid bedrock that forms the natural valley wall. All other embankments were created by compacting the soil with a sheepsfoot roller with not less than three passes at 450 lb/in^2. A 10-ft-wide cutoff trench was created in the center of each embankment, where the soil was stripped to solid bedrock, and then recompacted. The outfall slopes of the lagoons are covered with coarse, cobble-size limestone riprap to prevent erosion. The interior slopes and bottom of the lagoons have a 1- to 2-ft-thick compacted clayey soil layer that was removed from the upland area around the lagoons (Jerry Reilly, Plant Manager, oral commun., 1996). A more detailed description of construction specifications is included in the design plans prepared for the site (Parrott, Ely,

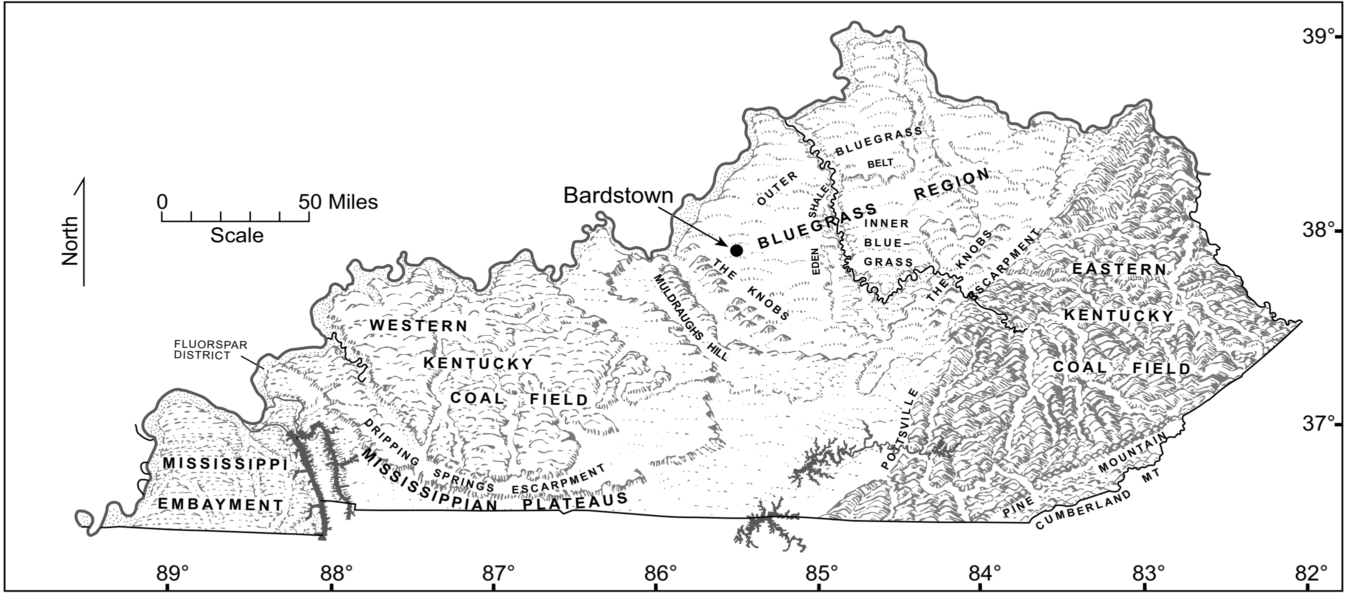


Figure 1. Physiography of Kentucky.

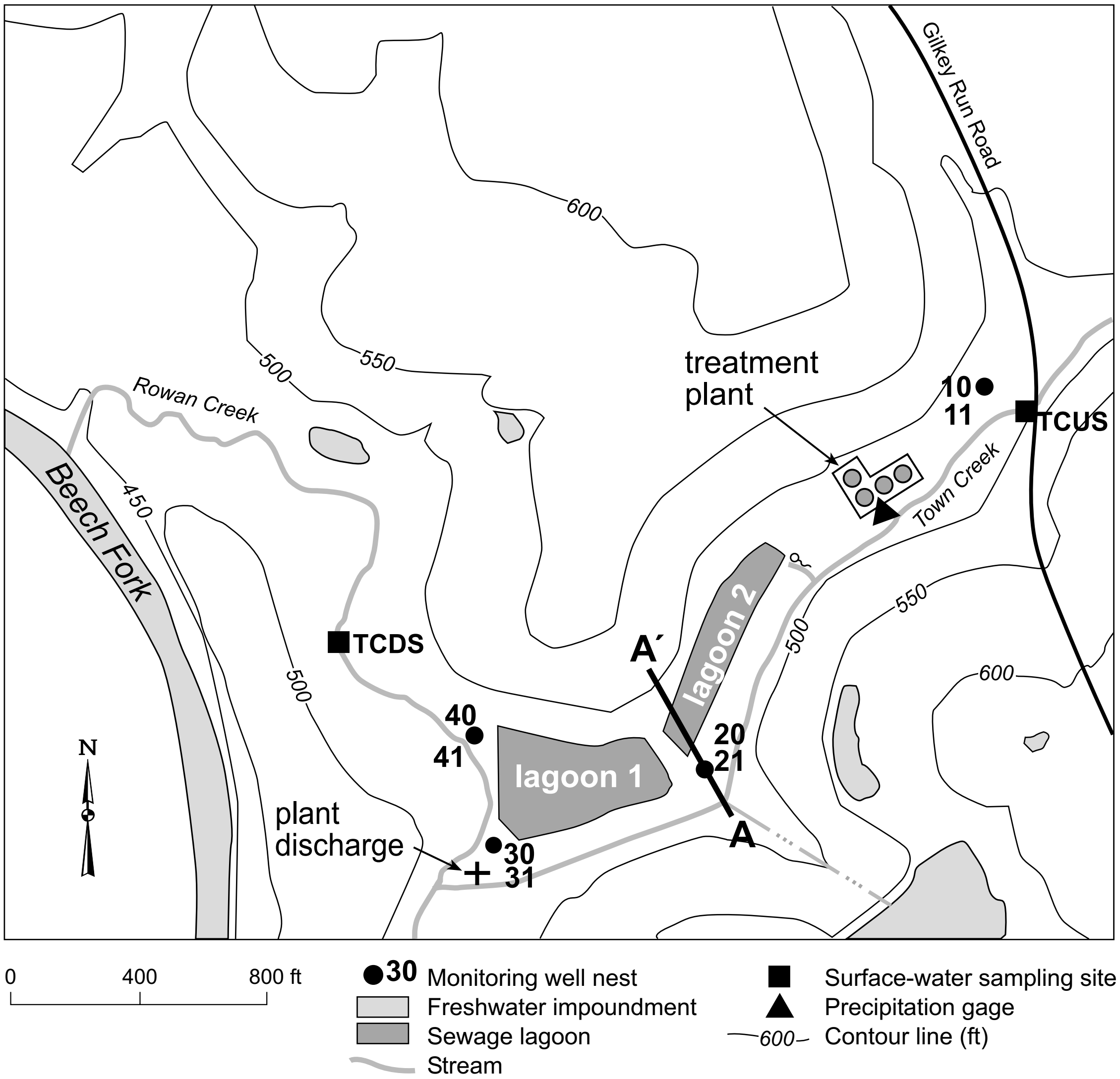


Figure 2. Location of the Bardstown Sewage Treatment Plant. The location of cross section A–A', which passes through monitoring wells 20 and 21 and lagoon 2, is also shown.

and Hurt Consulting Engineers, 1977). The banks of the lagoons have been repaired intermittently since construction in order to contain small leaks, or to mitigate erosion problems. We identified several small seeps during field reconnaissance and subsequent visits to the site. The seeps usually produced no measurable flow, but could be identified by wet soil and healthy grass and vegetation, even during dry periods.

Figure 3 is a schematic diagram of the treatment process at the plant. Sewage enters the plant through a grit chamber (1) and then is piped to the far western area of the plant into the two lagoons (2). After sludge settling and aeration, the water flows by gravity to a pumping station (3), where it is lifted into the biological reactor (4) for biochemical oxygen demand and ammonia reduction. After reaction, the water is chlorinated and dechlorinated (5), and passed through three clarifiers (6a–c). Finally, the treated water again enters the pumping station, where the water passes through a pipeline and discharges at the western edge of the plant site into Town Creek (7). Residual sludge that was not degraded during the first pass through the plant is then recycled into the system for additional treatment (8). The plant is permitted for 3 million gallons per day (Mgal/d), but normally operates below capacity at between 1 and 2 Mgal/d.

Site Geology

The plant is in a narrow valley underlain by the Saluda and Bardstown Members of the Ordovician Drakes Formation (Peterson, 1969). The Saluda Member is a dolomite, and the Bardstown Member is mainly limestone. Figure 4 is a detailed lithologic description of the Saluda and Bardstown Members. Both of these

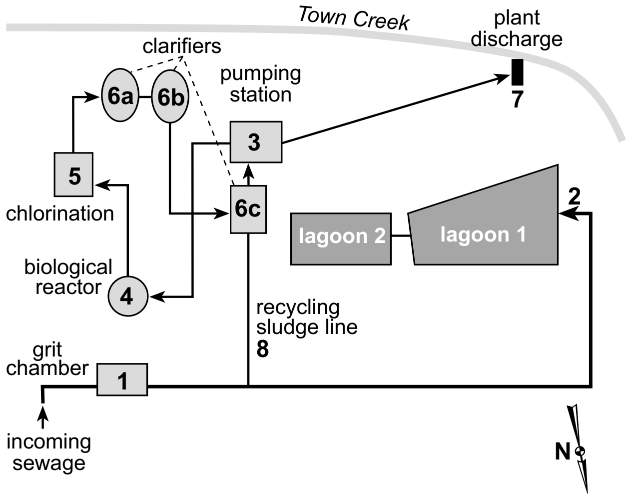


Figure 3. Schematic diagram of Bardstown Sewage Treatment Plant (not to scale).

members are argillaceous, and also contain interbedded shales, which limit their susceptibility to intense karst development. The Saluda Member crops out along the west valley wall adjacent to the lagoons. The Saluda is jointed, with a prominent set that strikes N56°E and dips 90°. Additional sets are oriented N45°E and N25°E, and also dip at nearly 90°. The fractures form tight cracks within the rock mass, and exhibit few oxidation stains or little solution enlargement, indicating that weathering is limited. The joints are regularly spaced approximately 5 ft apart.

A thin veneer of alluvium and soil partially covers the bedrock on the valley floor. Soil borings referenced on the plant's engineering plans indicate that the alluvium and soil range from 6.7 to 9.0 ft in thickness and consist mainly of clay, silt, and sand (Parrott, Ely, and Hurt Consulting Engineers, 1977). Town Creek flows directly on the bedrock surface. The channel contains lag deposits of limestone and dolomite, and abundant siliceous fossil coral heads.

Site Investigation Methods

Monitoring-Well Installation

Eight monitoring wells were installed to determine the hydraulic conditions of the soil and bedrock (see Figure 2). Well nests, each consisting of a shallow well and a relatively deeper well, were installed at four locations around the plant. The shallow wells in the alluvial sediments were drilled using a hollow-stem auger to the soil-bedrock interface, which is the primary location where water occurrence and movement are expected. Bedrock wells were drilled with an air-rotary rig equipped with a pneumatic hammer bit. The boreholes were 7 in. wide for both deep and shallow wells. The wells were installed using 2-in. interior diameter PVC riser pipe and screens with 0.01-in. slots.

One well nest (wells 10 and 11) was located northeast of the plant in an upgradient position to obtain background water-quality samples and hydraulic-head data for comparison with wells adjacent to or downgradient from the lagoons. The deep wells were drilled adjacent to the shallow wells and extended approximately 15 ft into solid bedrock. A schematic construction diagram for each well is shown in Appendix A. Each diagram also describes the soil and rock encountered when the borehole was drilled.

The drilling rig and all associated equipment were steam cleaned between drilling each hole to prevent any cross-contamination. Upon completion, each well was disinfected with a bleach and water solution according to specifications listed in the "Kentucky Water Well Construction Practices and Standards" (Kentucky Natural Resources and Environmental Protection Cabinet, 1991) to prevent bacterial contamination from the ground surface, or from aerosols created by aeration of nearby lagoons. Natural microbial populations should reestablish themselves after the initial shock caused by well installation and disinfection (Chapelle, 1993).

Well locations and elevations were determined by using a global positioning system (GPS) to establish a temporary benchmark. When used with post-processing software, this device can attain sub-centimeter accuracy in elevation. Well elevations were then surveyed by standard leveling techniques, using the benchmark as a reference.

The deeper of the two wells at each nest is identified by a number ending with "0," and the shallow well screened into the shallow alluvium by a number ending with "1." For example, well BT30 is 26.0 ft deep and set into limestone bedrock. Well BT31 is 7.0 ft deep and screened at the soil-bedrock interface.

Slug Tests

Falling-head slug tests were performed in each monitoring well to determine the spatial and vertical distribution of hydraulic conductivity. A known quantity of deionized water was injected as quickly as possible into the monitoring wells. The tests were conducted at the end of the study so the injected water would not affect water-quality samples collected during the study. The drop in head after injection was recorded by a submerged pressure transducer that stored the data on a digital data logger. The calculation of hydraulic conductivity from these data is based on methods first described by Hvorslev (1951) in the development of time-lag permeability tests. As performed here, these tests violate the assumption that instanta-

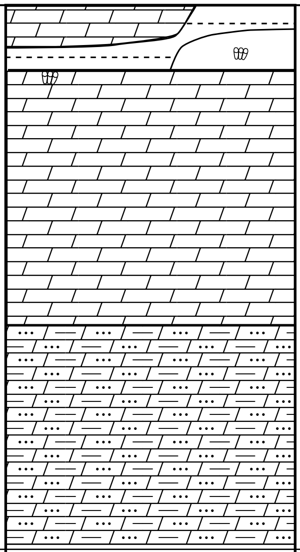
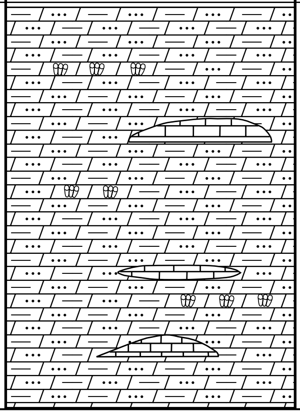
Saluda Dolomite Member		16–25	Dolomite, greenish-gray, fine-grained, calcareous, silty; in indistinct beds 1 to 3 in. thick, faintly banded parallel to bedding on some outcrops; contains thin streaks of unidentified fine-grained green mineral; weathers massive to platy. Upper part commonly crops out as smooth rounded ledge; lower part is less resistant earthy dolomite. Main mass of Saluda Member poorly fossiliferous; abundant colonial coral heads (*Tetradium*) occur in places in upper 5 ft of greenish-gray dolomite. A gray, silty, thinly laminated, resistant dolomite bed about 8 in. thick occurs near top of unit in places. It somewhat resembles the Hitz Member of the Saluda Limestone as defined by Butts (1915) in Jefferson County and has been correlated with it by Nosow (1959, Figs. 5 and 6). The gray dolomite bed is underlain by shale as much as 1.5 ft thick, which seems to be invariably present. Lithology at base of unit grades through several feet into fossiliferous rock of unit below. Contact placed at base of rock that is practically barren of fossils. Only two outcrops of Saluda Member are known along the Bardstown Monocline. Basal contact along the monocline was placed by assuming a unit thickness of 20 ft.
Bardstown Member		12–33	Limestone predominantly greenish-gray, fine- to medium-grained, very impure, silty and argillaceous, fossiliferous; in beds as much as 1 ft thick; weathers with shaly aspect. Limestone making up 5 to 25 percent of unit is medium gray, medium to very coarse grained, with abundant fossils and fossil fragments. Minor interbeds of greenish-gray calcareous shale. Fossils very abundant, include brachiopods, bryozoans, horn corals, and colonial corals. Colonial coral heads mostly in two to four layers in middle two-thirds of unit. Upper layer generally more prominent; in places it is 3 ft thick and consists of 25 to 50 percent coral heads. Basal contact arbitrarily placed within gradational zone about 3 ft thick.

Figure 4. Geologic description of the Bardstown and Saluda Members of the Ordovician Drakes Formation (modified from Peterson, 1969).

neous change in water level occurs at the initiation of a slug test. Under ideal conditions with all assumptions adequately maintained, the method on which the test above is based is not precise (Thompson, 1987). It is generally considered an appropriate means of estimating the order of magnitude of hydraulic conductivity, however. The hydraulic conductivity values determined for this study were calculated using the computer program TIMELAG (Thompson, 1987). The program allows several hydrogeologic scenarios to be selected, depending on the well configuration data provided for input into the program. Unconfined aquifer conditions were assumed for the wells in alluvium. Confined conditions were assumed for the bedrock wells. The data used for determining the hydraulic conductivities for the aquifer materials around each well are listed in Wunsch and others (2000).

Precipitation Measurements

A tipping-bucket precipitation gage was installed near the center of the treatment plant works (see Figure 2). Precipitation measurements were used to establish ground-water recharge-discharge relationships, as well as surface-water response to precipitation. This gage was capable of recording as little as 0.01 in. of precipitation.

Surface-Water Measurements

Streamflow measurements were made both upstream and downstream of the lagoons, and at sites in between where small tributaries or springs contribute to flow. Flow measurements for this study were made using a handheld magnetic flow meter. This meter can measure flow velocities from –0.05 to +19.99 ft/s with an accuracy of within 2 percent of the reading (Marsh-McBirney, Inc., 1990). Streamflow was calculated by summing the measured flow velocities within cross-sectional segments across the stream channel.

Small springs and tributaries were measured by constricting the flow and measuring the time needed to fill a vessel of known volume. Measurements for the treated wastewater discharge were obtained from the plant's daily discharge records, which were provided by the plant's manager. The locations of the upstream and downstream surface-water monitoring sites are shown on Figure 2. The site labeled "TCUS" is the upstream, or background, surface-water station, and "TCDC" is the downstream site below the point where the plant's treated discharge enters Town Creek.

Samples of lagoon water for analysis were collected from the eastern bank of each lagoon. The sampling locations are shown on Figure 2.

Water-Level Measurements

Water-level measurements were collected in monitoring wells using an electric water-level tape marked in 0.01-ft increments. Water levels were collected approximately monthly from September 1996 to August 1997 to determine temporal variation. Digital data loggers were installed in each well for approximately 4 weeks to obtain more comprehensive data on short-term water-level changes related to precipitation or stream stage. Only two data loggers were available for use, so the intervals when data were collected were staggered throughout the year. The loggers were left in each well for approximately 4 weeks to allow for one significant precipitation event (greater than 0.5 in. in a 24-hour period) while the wells were monitored.

Water-Sample Collection

Water samples were collected quarterly from October 1996 through September 1997. A dedicated PVC bailer was used for purging and sampling of the bedrock wells. The shallow wells were purged and sampled using a peristaltic pump that was connected to dedicated Teflon tubing. Wells were purged of three well volumes before sampling. Disposable latex gloves were worn when the bailers and the pump were handled to prevent contamination. All objects that were lowered into the well were placed on plastic sheeting and covered when not in use.

Specific conductance, temperature, turbidity, dissolved oxygen, and pH were recorded in the field. A flow-through meter was used to measure Eh (redox potential) values. Eh measurements were corrected for temperature using a Zobell reference solution. The flow-through cells are directly connected to the pump outlet or easily connected to a mechanical valve attached to the bailer to allow field parameters to be simultaneously monitored while the well is being purged.

The pH probe was standardized by calibrating to buffers of 4.01, 7.0, and 10.0 (standard pH units). The meters are equipped with automatic temperature compensating probes so that the pH values are automatically corrected to a temperature of 25°C. The conductance readings of water samples were corrected to conductivity standard solutions by linear regression using the actual and observed readings from 200, 2,000, and 20,000 microSiemen standards measured in the field each day.

All chemical analyses of water samples were performed by the Laboratory Services section of the Kentucky Geological Survey. Thirty-six water samples were collected during the course of this study. The analytical results are contained in Appendix B. Samples were also collected once for total coliform and *E. coli* determinations. These samples were collected in snap-seal polypropylene bottles for microbial samples and delivered to the Kentucky Health Services laboratory in Frankfort, Ky., for analysis. The bacteria results are also shown in Appendix B.

Total and dissolved metals, sulfate, chloride, bicarbonate, fluoride, nitrate, nitrite, ammonia, orthophosphate, and total organic carbon (TOC) were determined. Appendix C contains the analytical methods for each parameter determined at the KGS laboratory. The bedrock wells typically did not produce enough water to allow a full suite of samples to be collected. Therefore, any water retrieved was used for parameters most likely to be related to potential contamination from the sewage lagoons, such as nutrients (nitrogen and phosphorus species), fluoride, chloride, and sulfate.

Water samples were placed in 250-ml acid-rinsed polyethylene bottles. Samples collected for dissolved metals were filtered by pumping water, using a peristaltic pump, through a 0.45-micron cellulose-acetate membrane filter. Two milliliters of a 1:1 mixture of deionized/distilled water and double-distilled nitric acid were added to each sample for preservation and to prevent the precipitation of solutes as hydroxides (Brown and others, 1970). Samples collected for total metals analyses were acidified but not filtered. Samples collected to determine dissolved anionic species were filtered but not acidified. TOC samples were placed in a 250-ml bottle and acidified and preserved by adding 1 ml of concentrated sulfuric acid.

Quality Assurance and Quality Control

Replicate samples were collected from at least one sampling site during each sampling event to assure quality control of the collection and analytical techniques. The lack of water in the bedrock wells precluded the use of these wells for replicate sampling. Therefore, the replicate samples were usually drawn from shallow wells that produced enough water for two sets of samples. The results of analyses for replicate samples are shown in Wunsch and others (2000).

Results and Discussion

Site Hydrogeology

The head at the normal pool elevation in the lagoons is significantly greater than the water-level elevations observed in the surrounding monitoring wells. The approximate elevation of the pool in lagoon 1 is 483 ft above mean sea level (m.s.l.), and the water elevations in the adjacent wells screened in the alluvium are less than 461 ft. Well BT21 is located approximately 70 ft from the edge of lagoon 1 (see Figure 2), and the water level in this well was typically near 460 ft. Figure 5 is a schematic cross section that passes through lagoon 2 and well BT21 along line A–A', illustrating the relationship between the well and the lagoon. The difference in water levels represents a hydraulic gradient of 0.33 between the well and the lagoon. With this steep hydraulic gradient, any direct, confined leakage into the sediments adjacent to the lagoons should result in artesian conditions. Artesian conditions could increase hydrostatic pressure in the lagoon embankments, perhaps resulting in failure. Flowing wells or unusually high water levels were not observed in any of the wells. The water level in each bedrock well was much lower (by nearly 20 ft) than the elevation of water in each corresponding shallow well, indicating a downward gradient at each well nest. This indicates that the lagoons are not leaking significantly in the vicinity of the monitoring wells.

The shallow wells typically contained 1 to 3 ft of water, and would recharge quickly when purged. The deep wells screened into bedrock generally contained less than 1 ft of water, and were very slow to recharge after purging.

Results of the slug test are shown in Table 1. Each of the shallow wells behaved nearly ideally, and recovered to the original head level in a matter of hours. The recovery in the deep wells was more complicated. The limestone and dolomite bedrock must be very tight, because each of the bedrock wells recovered very slowly, on the order of a few tenths of a foot over several days. In some cases, the diurnal variation measured in water levels, caused

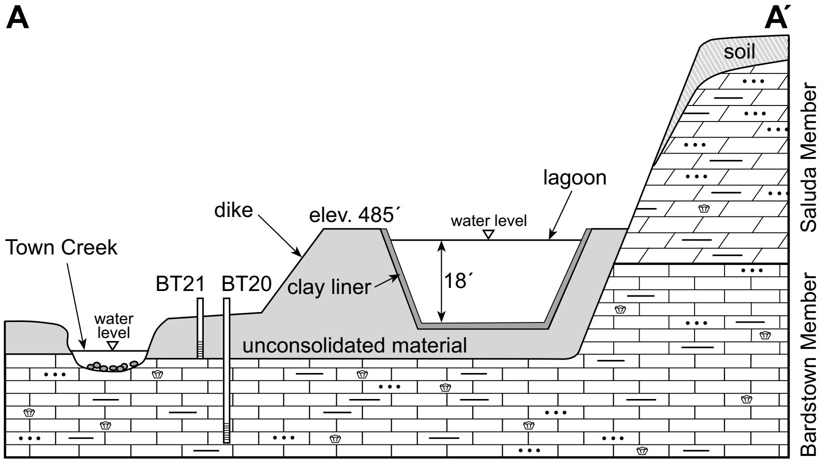


Figure 5. Schematic diagram of the Bardstown Sewage Treatment Plant along line A–A' (see Figure 2). Not to scale.

Table 1. Hydraulic conductivity measured by slug tests.

Well No.	*Geologic Material*	*Hydraulic Conductivity (cm/s)*	*Regression Coefficient Log (H/Ho) vs Time*
BT11	alluvium	2 x 10^{-4}	–0.9962
BT21	alluvium	1 x 10^{-4}	–0.9375
BT31	alluvium	3 x 10^{-4}	–0.9946
BT41	alluvium	5 x 10^{-4}	–0.9464
BT10	bedrock	1 x 10^{-8}	–0.9767
BT20	bedrock	4 x 10^{-9}	–0.9055
BT30	bedrock	3 x 10^{-9}	–0.8071
BT40	bedrock	2 x 10^{-9}	–0.6062

by solar heating of the data logger and transducer cable, would often mask the daily change in head. This behavior is reflected in the relatively lower regression coefficients for the normalized drawdown for the bedrock-well recovery curves (see Table 1).

The hydraulic conductivities of wells in alluvium ranged from 1 x 10^{-4} to 5 x 10^{-4} cm/s. These values are nearly four orders of magnitude greater than the conductivities determined for the bedrock wells, which ranged from 2 x 10^{-9} to 1 x 10^{-8}. These variations in hydraulic conductivity are consistent with the wells' water production and responses to purging described previously.

Long-term water-level data for each well are shown in Table 2. Hydrographs for the shallow wells (Fig. 6) show that the water level varies less than 2 ft for each well throughout the course of the year. The monthly water-level data are misleading, however, because monthly measurements do not provide the data resolution to show quick response in water levels.

Hydrograph and precipitation data shown on Figures 7 and 8 illustrate these relationships. The water-level data were collected over several weeks at 10-min intervals by the data loggers. Precipitation data illustrate the relationship of water level to recharge. The high-resolution hydrographs show that the water levels in the shallow wells can rise significantly (for example, over 5 ft in BT31), and recover in less than 10 days. Town Creek, which runs along the perimeter of the plant property, is very flashy, and responds quickly to precipitation. The water-level fluctuations in the shallow wells probably reflect the change in stream stage because of the wells' close proximity to the stream bank (within 100 ft of the stream channel) (see Figure 2). In addition, the wells are in the floodplain, which was

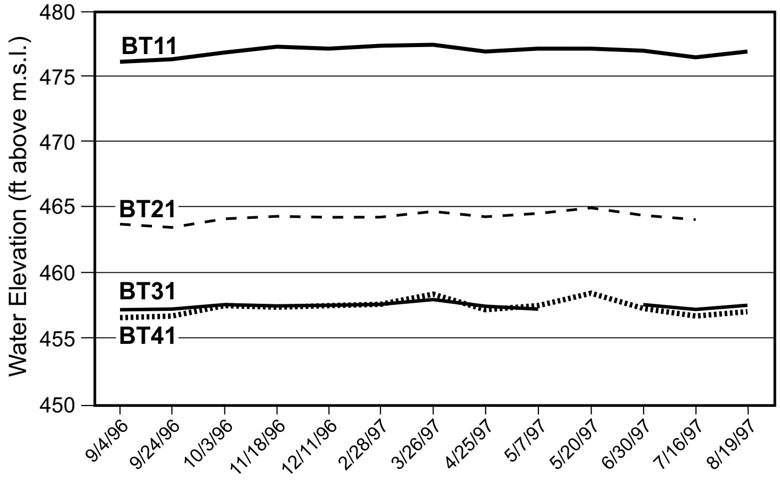


Figure 6. Long-term hydrograph for wells in alluvium.

Table 2. Long-term water-level data for monitoring wells.

Date	*BT10*	*BT11*	*BT20*	*BT21*	*BT30*	*BT31*	*BT40*	*BT41*
9/4/96	456.5	476.2	443.1	463.9	437.9	457.3	437.9	456.7
9/24/96	NM	476.5	442.8	463.7	437.1	457.4	437.5	456.9
10/3/96	454.9	476.9	442.7	464.3	437.0	457.7	437.5	457.6
11/18/96	454.9	477.3	443.1	464.4	437.5	457.6	438.7	457.5
12/11/96	454.9	477.2	442.7	464.3	437.3	457.6	437.6	457.6
2/28/97	455.0	477.4	443.3	464.3	437.9	457.7	439.3	457.6
3/26/97	455.3	477.5	443.5	464.7	438.0	458.1	439.8	458.4
4/25/97	455.1	476.9	443.0	464.3	437.3	457.5	438.6	457.2
5/7/97	455.0	477.1	443.1	464.5	437.4	457.3	437.7	457.5
5/20/97	455.0	477.1	443.1	464.9	438.7	NM	437.9	458.4
6/30/97	455.0	477.0	443.3	464.3	439.1	457.6	438.5	457.2
7/16/97	454.9	476.4	442.6	464.0	437.1	457.2	437.4	456.7
8/19/97	454.9	476.8	NM	NM	437.5	457.5	437.9	457.0

NM = no measurement

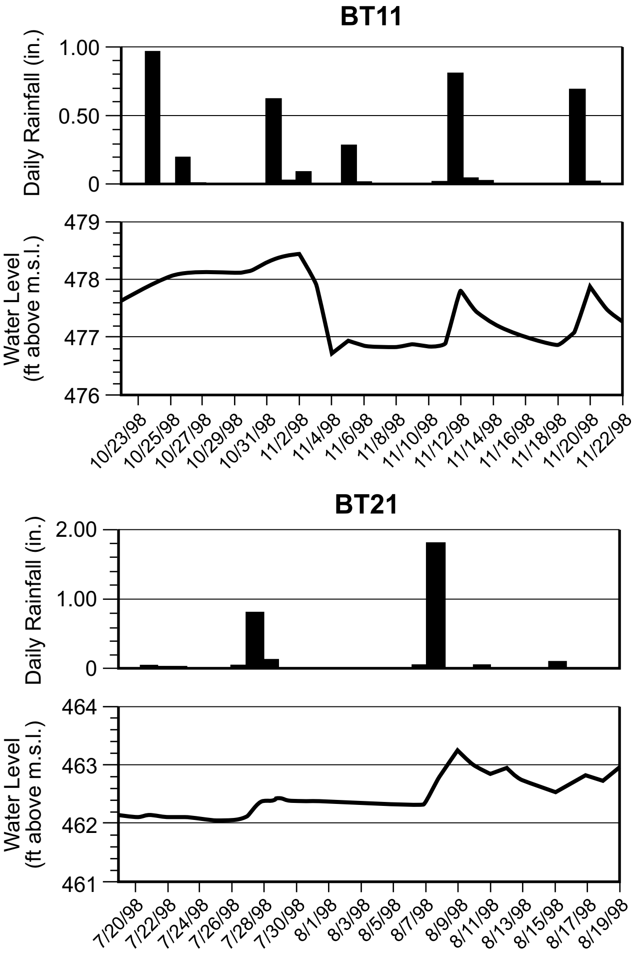


Figure 7. Short-term hydrographs and precipitation for wells BT11 and BT21.

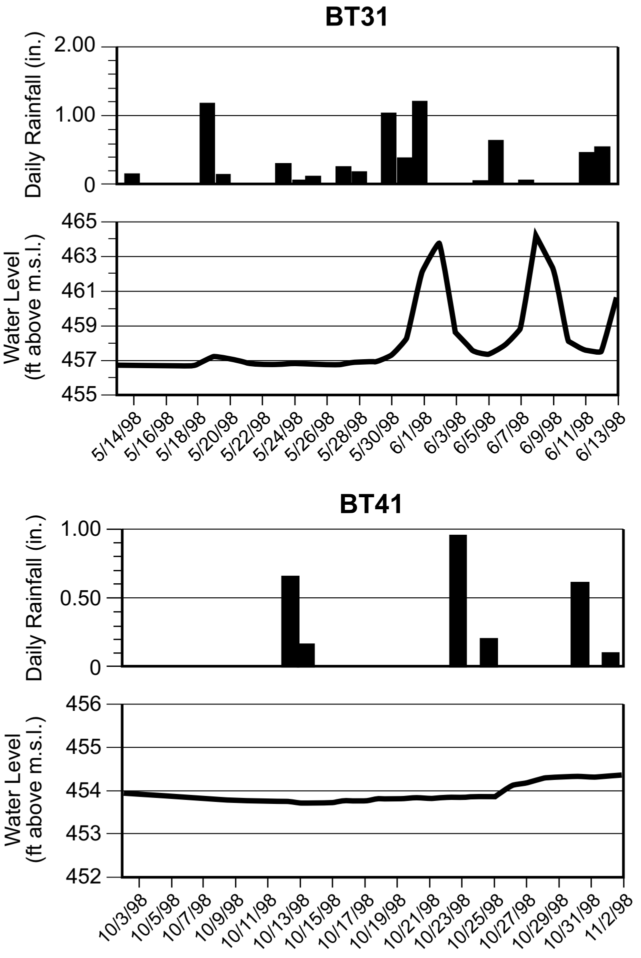


Figure 8. Short-term hydrographs and precipitation for wells BT31 and BT41.

flooded several times during the year. At least once, the floodwater may have completely submerged monitoring wells BT30, BT31, BT40, and BT41 (waterproof caps with O-rings were installed on the wells to prevent contamination by surface water in the event of flooding).

The lagoons maintain a fairly consistent pool elevation because of the constant input of wastewater. Therefore, the lagoons are at an almost constant head compared to the stream. The lack of artesian conditions in the shallow alluvial wells, and quick response to precipitation (and stream stage), suggest that the water in the alluvial deposits is strongly influenced by bank storage and recharge from the stream, and there is little or no hydraulic effect from the lagoons.

Figure 9 shows the long-term hydrographs for the bedrock wells. Wells BT10 and BT20 show relatively flat response; water level

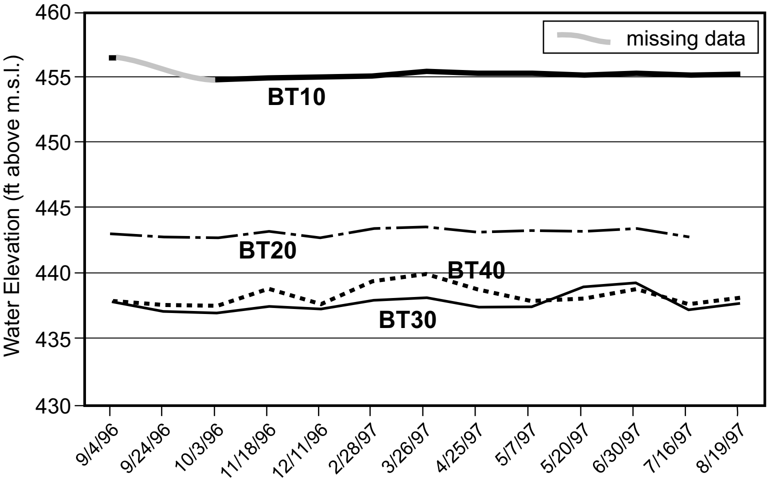


Figure 9. Long-term hydrographs for bedrock wells.

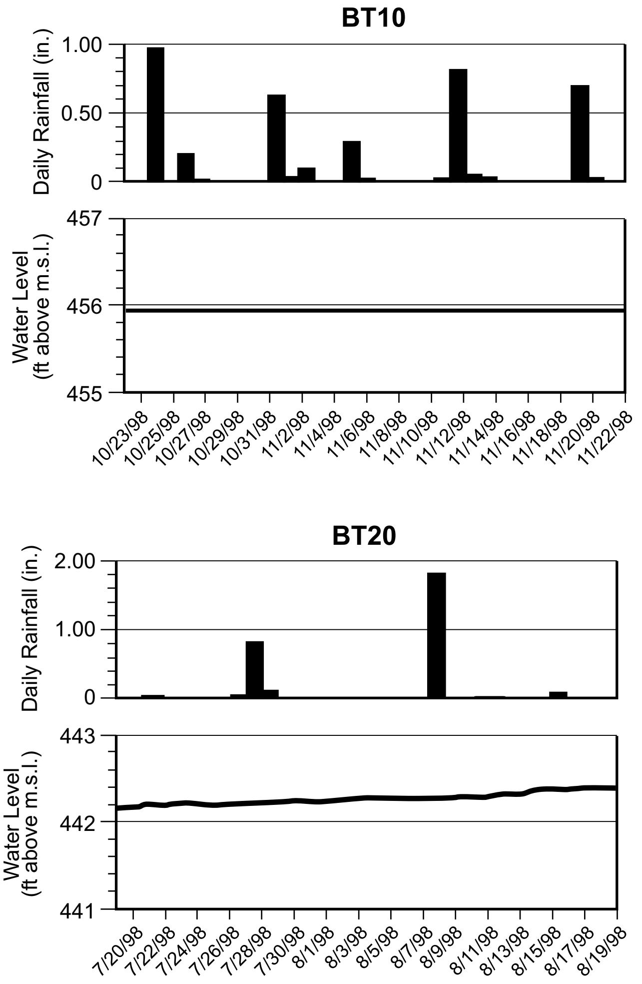


Figure 10. Short-term hydrographs and precipitation for wells BT10 and BT20.

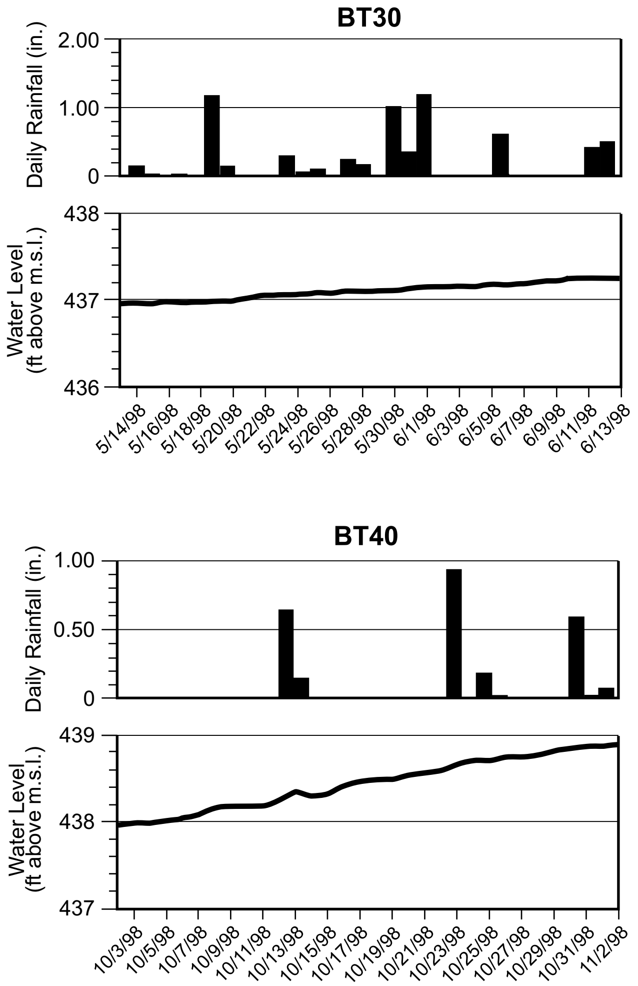


Figure 11. Short-term hydrographs and precipitation for wells BT30 and BT40.

varies generally less than 1 ft (Fig. 10). Wells BT30 and BT40 show a range of fluctuation of 2.1 and 2.4 ft, respectively (Fig. 11). Well BT10 shows an almost flat response to precipitation, even though four events occurred where more than 0.5 in. of rain fell. The remaining three bedrock wells show a slight increase in water level over their record periods. In each case, at least two precipitation events occurred where more than 0.5 in. of precipitation fell. All four wells showed less than a 1 ft rise in water level in response to these events. These hydrographs are consistent with the hydraulic test data for the bedrock wells, which indicate that the limestone and dolomite bedrock underlying the site has low hydraulic conductivity, limiting recharge rates.

Surface-Water Flow Measurements. Surface-water flow was measured at points along Town Creek on August 29, 1996, and September 30, 1997, to determine if the lagoons are leaking. If an abrupt or significant increase in streamflow was detected, it could be related to ground-water recharge from the lagoons into the creek. Measurements were taken in late summer and early fall because that is the dry part of the year for central Kentucky, and therefore flow conditions are low. The contribution of ground water to surface-water flow is normally most pronounced during low flow. Flow measurements were taken along stream segments upstream, adjacent to, and downstream from the lagoons. Figure 12 shows the results of discharge measurements collected at all sites on both dates. All of the springs measured were on the opposite bank (south) from the sewage plant, and were assumed to be unrelated to the lagoons.

The method used to determine if the lagoons were leaking in the subsurface was to determine the component of ground-water base flow (Qgw) between upstream, adjacent, and downstream segments of Town

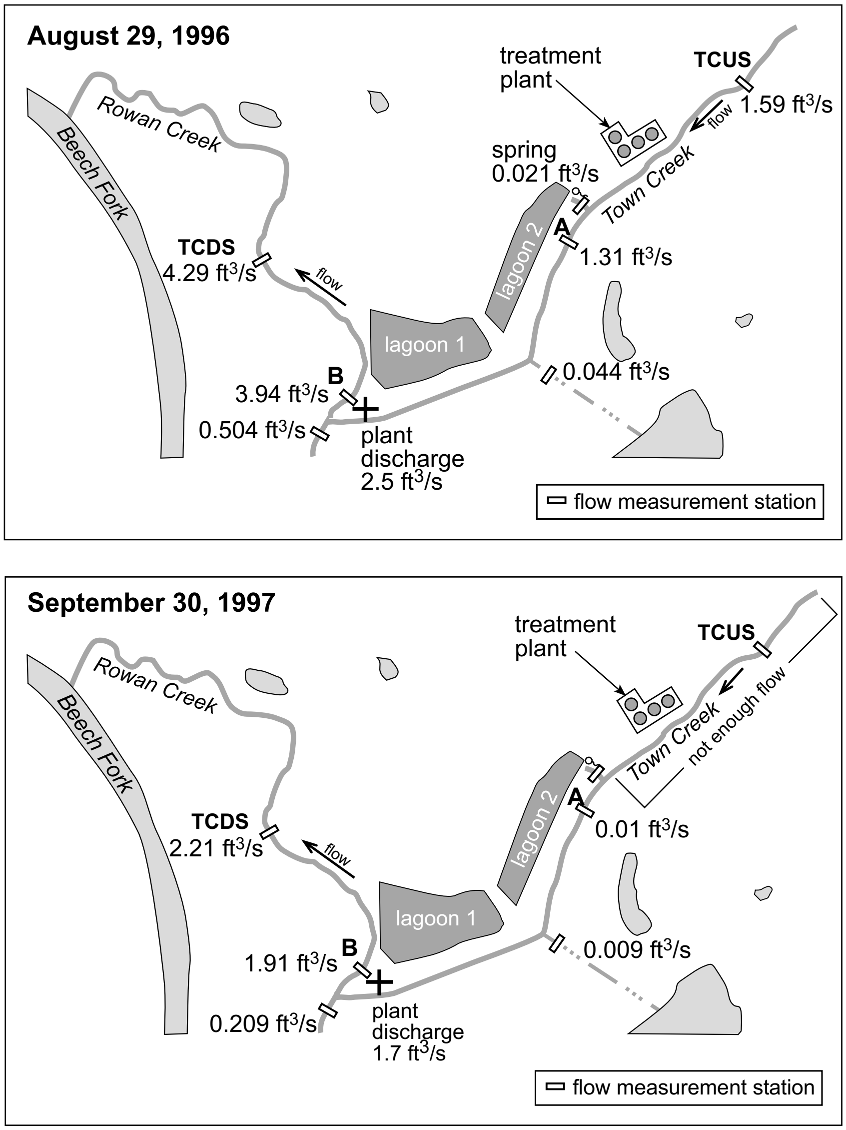


Figure 12. Discharge measurements taken along segments of Town Creek on August 29, 1996, and September 30, 1997.

Creek. The upstream flow in a segment (plus any additional surface-water inputs within the reach, such as side tributaries or springs) was subtracted from the downstream flow, or:

downstream flow – (upstream flow + tributaries) = ground-water base flow (Qgw).

The following flow measurements were collected on August 29 for the stream segment between site TCUS and site A (see Figure 12):

- downstream flow = 1.31 ft^3/s
- upstream flow = 1.59 ft^3/s
- tributary flow = 0.021 ft^3/s.

The ground-water component of base flow (Qgw) can be determined as follows:

$$\begin{aligned} Qgw &= 1.31 - (1.59 + 0.021) \\ &= -0.30 \text{ ft}^3/\text{s}. \end{aligned}$$

The negative sign indicates the downstream discharge is less than the upstream discharge, which means the stream is losing flow. The water being lost is probably being stored in the stream banks or the channel alluvium. Because this segment of stream is approximately 900 ft long, the average loss in flow per 100 ft is –0.03 ft^3/s.

The discharge measurement obtained from the plant's discharge gage, and the volumetric measurements taken where small springs enter the stream, can be considered reasonably accurate because of the accuracy and precision of the measurements for the mechanical gages used. To add confidence to the measurements obtained with the handheld flow meter, however, calculations were made using an assumed error of ± 5 percent of the field-measured value. Flow measurements made with the handheld meter used in this study are reasonably accurate, and in optimal conditions, within 2 percent of actual (Marsh-McBirney, Inc., 1990). Therefore, using an estimated error of 5 percent of measured flow seems reasonable (U.S. Geological Survey, 1980).

For example, by subtracting 5 percent from the 1.59 ft^3/s upstream flow (0.08), and adding the appropriate error to the smaller, downstream flow to minimize the difference between the two (the error value is added or subtracted from the field measurements to minimize the difference between the two values to see if they overlap; overlapping values would indicate no meaningful difference between the two), the calculated value is –0.13 ft^3/s. The Qgw calculated with an assumed error is also negative, suggesting that the field measurements are meaningful, and that the stream is probably losing flow along this stream segment.

For the segment between point A and point B, with a length of 1,750 ft:

$$\begin{aligned} Qgw &= 3.94 - (1.31 + 0.044 + 2.50 + 0.504) \\ &= -0.42\ ft^3/s. \end{aligned}$$

This segment of stream also appears to be losing flow, in the amount of 0.02 ft^3/s per 100 ft, which is a rate similar to the segment upstream from the lagoons. The flow calculated assuming the 5 percent error in measurements, using the method described above, is –0.13 ft^3/s. Once again the assumed error value is negative, supporting the field data indicating that the stream is losing flow along this segment.

For the segment between points B and TCDS:

$$\begin{aligned} Qgw &= 4.29 - 3.94 \\ &= 0.35\ ft^3/s. \end{aligned}$$

The positive Qgw (0.35 ft^3/s) indicates that the stream is apparently gaining ground water along this segment. Subtracting the 5 percent error value from the downstream (higher Q) measurement, and adding the error to the upstream (lower Q) measurement, results in a calculated discharge of –0.09 ft^3/s. This negative value indicates that the field-measurement values overlap, indicating this set of calculations is not conclusive as to whether the stream is discharging or recharging along the lower segment of Town Creek.

The results from the September 30, 1997, measurements are shown on Figure 12. The streamflow was very low on this date. The upstream segment of Town Creek did not have enough flow to measure. At site A, the flow was 0.01 ft^3/s, indicating a minute gain in flow along the segment.

The ground-water discharge between sites A and B is:

$$\begin{aligned} Qgw &= 1.91 - (0.01 + 0.009 + 0.209 + 1.70) \\ &= -0.018\ ft^3/s. \end{aligned}$$

The assumed error calculation for these data is –0.11 ft^3/s, supporting the field measurements that this segment is losing flow. Moreover, the data show that the flow from the plant (1.7 ft^3/s) and from the major tributary that flows into Town Creek near the plant discharge (0.209 ft^3/s) account for nearly 100 percent of the flow measured at point B. These results indicate that it is unlikely that the lagoons are leaking significantly in the subsurface and recharging Town Creek.

The difference between the discharge at site TCDS and site B is 0.30 ft^3/s, suggesting that the stream is gaining flow from ground water along this segment. The error calculation results in a flow of 0.09 ft^3/s, which supports the field measurements. This segment of Town Creek is in the floodplain of Beech Fork, which is a major tributary of the Rolling Fork River. Major river valleys and associated floodplains are often the area of regional ground-water discharge. Thus, the calculations indicating ground-water discharge in the lower reach of Town Creek are reasonable.

Table 3. Chemical data from replicate samples.

Date	*Sample ID*	*Calcium (mg/L)*	*Sodium (mg/L)*	*Magnesium (mg/L)*	*Potassium (mg/L)*	*Bicarbonate (mg/L)*	*Sulfate (mg/L)*	*Chloride (mg/L)*
10/3/96	BT21	122.00	24.10	41.50	4.33	437.00	122.00	28.80
10/3/96	BT21D	104.00	22.10	37.00	4.07	408.00	120.00	29.30
	% Error	7.96	4.33	5.73	3.10	3.43	0.83	0.86
12/11/96	BT41	108.00	2.91	33.70	< MDL	462.00	27.60	4.80
12/11/96	BT41D	110.00	3.03	34.40	< MDL	464.00	27.60	4.50
	% Error	0.92	2.02	1.03		0.22	0.00	3.23
3/26/97	BT31	125.00	3.74	37.50	< MDL	528.00	34.30	2.90
3/26/97	BT31D	133.00	3.54	36.20	< MDL	543.00	31.20	2.90
	% Error	3.10	2.75	1.76		1.40	4.73	0.00

Site Hydrogeochemistry

Quality-Assurance Samples. The results of analyses for quality assurance and quality control are contained in Wunsch and others (2000). Table 3 is a summary of the major cation and anion chemistry for the replicate samples drawn throughout the study. One set of replicates collected on July 1, 1997, is not included in the table or in this discussion because the samples were mislabeled in the field; thus, the field treatments and preservation measures were not the same as for the other replicate. The difference in concentration for each analyte between the original sample and the replicate (shown as percent error) was less than 8 percent. These results are less than the standard scientific experimental error of 10 percent.

The charge balance error (CBE) calculation for each sample collected in this study (n = 36) was less than 10 percent; the average for all samples was 2.69 percent (see Wunsch and others, 2000). A CBE of less than 3 percent is considered standard for research-grade laboratory analytical results (Freeze and Cherry, 1979).

Analytical results from equipment blanks showed that almost all of the parameters were below detectable limits, with the exception of fluoride, ammonia, nitrite, calcium, and silica. Each of these analytes were in trace amounts that were generally less than 0.1 mg/L, however. Bicarbonate was detected at concentrations between 6 and 7 mg/L. The deionized/distilled water used to decontaminate field equipment and sampled for the equipment blanks was in brief contact with the atmosphere during use, so the partial pressure of carbon dioxide in the atmosphere could account for the small amount of bicarbonate present. Overall, the results of the quality-control efforts are good, indicating that our sampling protocol, decontamination procedures, and laboratory analyses are adequate for meaningful data interpretation.

Water Chemistry. Halogens such as chloride and bromide are often used as ground-water tracers because of their conservative nature in aqueous systems (meaning they do not readily react chemically) (Davis and others, 1998). The chloride data for all sites sampled are listed in Table 4. Although the total number of samples is small (n = 4), the data show very little temporal variation. Therefore, the averages of the data for each site can be used for meaningful comparisons.

The deep wells produced sufficient water for us to obtain samples for a partial analysis in December 1996. Although only one sample was collected, the conductivity readings were relatively consistent during the entire study period, indicating that the chloride concentrations are representative of the water quality in these wells. The chloride concentration was approximately 1,000 mg/L in each of the bedrock wells. Also, the bedrock wells produced the only samples with detectable amounts of bromide (see Table 4). The relatively high chloride content, along with the presence

Table 4. Chloride, bromide, and fluoride data.

Chloride (mg/L)

	BT11	*BT21*	*BT31*	*BT41*	*BT10*	*BT20*	*BT30*	*BT40*	*TCUS*	*TCDS*	*LAG1*	*LAG2*
10/3/96	44.9	28.8	5.7	15.9	NE	NE	NE	NE	16.2	32.8	57.1	55.5
12/11/96	22.4	29	5.1	4.8	779	1,660	1,202	1,360	17	22.7	48.4	51.8
3/26/97	18.4	18.2	2.9	3.9	NE	NE	NE	NE	11.7	13.3	39	36.5
6/30/97	9.9	10.2	2	3.5					14.3	16.6	39	40.9
Average	23.90	21.55	3.93	7.03					14.80	21.35	45.88	46.18

Bromide (mg/L)

	BT11	*BT21*	*BT31*	*BT41*	*BT10*	*BT20*	*BT30*	*BT40*	*TCUS*	*TCDS*	*LAG1*	*LAG2*
10/3/96	< MDL	< MDL	< MDL	< MDL	NE	NE	NE	NE	< MDL	< MDL	< MDL	< MDL
12/11/96	< MDL	< MDL	< MDL	< MDL	5.6	9.8	7.8	8.2	< MDL	< MDL	< MDL	< MDL
3/26/97	< MDL	< MDL	< MDL	< MDL	NE	NE	NE	NE	< MDL	< MDL	< MDL	< MDL
6/30/97	< MDL	< MDL	< MDL	< MDL					< MDL	< MDL	< MDL	< MDL
Average												

Fluoride (mg/L)

	BT11	*BT21*	*BT31*	*BT41*	*BT10*	*BT20*	*BT30*	*BT40*	*TCUS*	*TCDS*	*LAG1*	*LAG2*
10/3/96	0.14	0.15	0.11	0.13	NE	NE	NE	NE	0.13	0.31	0.57	0.56
12/11/96	0.12	0.13	0.1	0.13	0.74	0.53	0.65	0.67	0.11	0.19	0.51	0.54
3/26/97	0.14	0.13	0.09	0.1	NE	NE	NE	NE	0.12	0.14	0.39	0.38
6/30/97	0.15	0.16	0.13	0.16					0.13	0.23	0.49	0.54
Average	0.14	0.14	0.11	0.13					0.12	0.22	0.49	0.51

of detectable bromide, suggests that residual connate water is stored in the limestone bedrock since there is no other known source of elevated chloride and bromide in and around the study site. Salty water can be encountered at shallow depths in this area (Hall and Palmquist, 1960). Additional supporting evidence is that well BT10, which is the bedrock well upgradient of any expected contamination, also contained relatively high chloride concentrations (779 mg/L). The lagoons, which are assumed to be the source of any contamination at the site, characteristically contain water with significantly lower chloride concentrations than found in well BT10. The average chloride concentrations for lagoons 1 and 2 are 45.9 and 46.2 mg/L, respectively.

Ground water from the shallow wells adjacent to and downgradient from the lagoons contains lower chloride concentrations than the lagoons, but similar concentrations as the upstream and downstream segments of Town Creek. This finding reflects the close hydraulic association of the shallow wells with the adjacent stream.

Fluoride is relatively conservative for the ground- and surface-water residence times anticipated at this study site. Moreover, the city of Bardstown fluoridates its water supply at a concentration of approximately 1.0 mg/L, so the wastewater stored in the lagoons will reflect this addition. This allows fluoride to also be used as a tracer. Fluoride concentrations are summarized in Table 4. The average fluoride concentrations from the lagoon samples are 0.49 and 0.51 mg/L for lagoons 1 and 2, respectively. These values are nearly four times the average concentrations found in the shallow alluvial wells, suggesting that the lagoons are not affecting the shallow ground water monitored by the wells. Moreover, the concentrations in the shallow wells are similar to the concentration found in samples from site TCUS, suggesting a surface-water influence. The fluoride concentration in samples from site TCDS are nearly twice the average upstream concentration, and probably reflect the addition of fluoride to the creek from the treated wastewater discharge, which is upstream from site TCDS.

The relationship between the wells, stream, and the lagoons can be explained by examining the major-ion chemistry for samples from each site. The samples were plotted on a trilinear diagram (Fig. 13) to illustrate the chemical water type as a potential signature for each hydrologic regime (stream, ground water, lagoons). The lagoon samples plot on the diamond-shaped area of the diagram, approximately in the center of the diamond field. These samples contain approximately equal percentages of calcium, magnesium, and sodium. These data also cluster apart from the majority of the other samples. The samples from the shallow wells and the creek cluster more closely together, reflecting a similar composition with a higher percentage of calcium and magnesium, and less sodium than the lagoons. Some of the shallow-well samples plot directly over the creek samples, indicating that the major-ion chemistry is nearly identical.

These data, as well as the interpretation of the chloride, bromide, fluoride, and hydrograph response, suggest that water in the alluvial sediments is related to water from the creek. We can therefore conclude that the lagoons are having a minimal impact, if any, on the shallow ground-water system.

Overall, the trace-element concentrations were higher in both the dissolved and total fractions from surface-water samples than ground-water samples. The samples from the lagoons contained the most detectable concentrations of aluminum, boron, barium, iron, copper, manganese, strontium, and silicon. The Bardstown plant treats water from industries in the area, including two small electroplating operations. Thus, the higher concentrations of heavy metals may reflect this influence. The retention and mobility of the heavy metals are probably related to the abundant organic matter in the lagoon wastewater, which will chelate or form organic-metallic complexes. All metal concentrations appear to be below the U.S. Environmental Protection Agency's primary and secondary maximum contaminant levels (MCL's) in both the lagoons and the stream water, however. The only MCL's for metals exceeded at the site were for iron and manganese, which are slightly elevated in the shallow ground-water monitoring wells (see Wunsch and others, 2000). This is common in uncontaminated ground water derived from shallow, alluvial sediments in this physiographic region (Hall and Palmquist, 1960).

Nutrients and Bacteria. Phosphorus concentration (as orthophosphate) is generally less than 0.1 mg/L in each well at the site, which is considerably less than the 0.9 to 5.0 mg/L typically observed in the lagoons. Total organic carbon content (TOC) was generally less than 5 mg/L in each shallow well, and is similar to the concentrations observed in both Town Creek monitoring sites; the concentrations in the lagoons ranged between 10.7 and 66 mg/L. Two deep wells, BT30 and BT40, provided enough water for TOC determinations. The wells contained 19 and 16 mg/L of TOC, respectively, which is more than the shallow wells and Town Creek, and within the range of values found in the lagoons. Because of the occurrence of brackish water in the deep wells, the TOC is probably related to residual fossil organic matter (Nuttall, 1996).

Well BT31 had slightly elevated concentrations of ammonia (0.8 to 1.0 mg/L compared to approximately

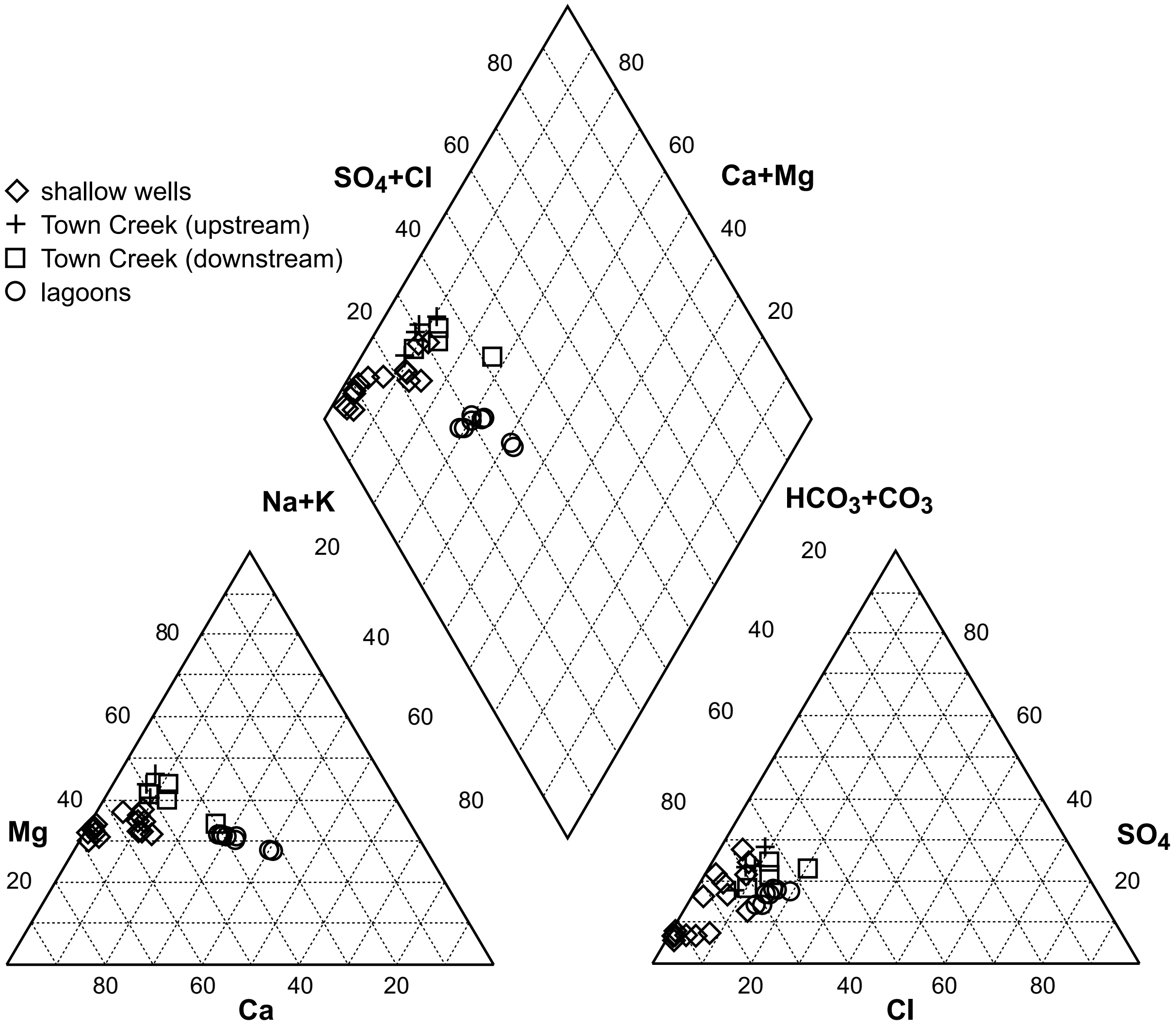


Figure 13. Major-ion water types for all samples at the Bardstown site.

0.5 mg/L or less for the other shallow wells). Other ground-water constituents in this well do not indicate contamination from the lagoons, however. Well BT31 is approximately 100 ft downstream from a seep where leakage is occurring from the levee of lagoon 1. The ammonia concentration in this well may be related to this seep.

The well nest farthest downstream from the lagoons comprises wells BT40 and BT41. Both of these wells had slightly higher concentrations of nitrogen species than the other monitoring wells at the site (see Appendix B). The concentrations of all nitrogen species, as well as of all other chemical constituents measured in these wells, were consistently below the MCL, however, with the exception of nitrite concentration in well BT40 in December 1996 (1.23 mg/L).

Along with the high nitrite, well BT40 had the highest concentration of ammonia of all the wells (6.32 mg/L). The most likely source for ammonia is the lagoons or untreated wastewater. The anomalous ammonia concentration may reflect contamination from the lagoons, which contain ammonia concentrations between 10 and 20 mg/L. Other hydraulic and hydrochemical data from well BT40 suggest, however, that the lagoons are not leaking and contaminating the ground water in the well. Another source of contamination could be surface-water recharge contaminated by surface leakage from the lagoon's levees.

Well BT40 is located the farthest downstream, and at the lowest elevation of any wells on the property. This area is submerged by Town Creek during high flows several times a year (Jerry Reilly, Plant Manager, oral commun., 1996). As demonstrated by the well hydrographs, high-stage events provide surface-water recharge into the stream-bank sediments. Leaks in the levees upstream from well BT40 could contaminate the surface water that recharges the sediments monitored by well BT40. During flooding is also when the capacity of the plant is most likely to be exceeded, which may cause untreated wastewater to overflow from the lagoons into the stream or the sediments. We observed two occasions when the water in the lagoons was at the top of the levees, making occasional overspilling a distinct possibility. Another scenario is that surface water may have entered the well from the top when floodwaters submerged the well casing. We observed two occasions when surface water was within inches of the top of BT40, and high-water marks on surrounding landmarks indicate that floodwaters did in fact totally submerge the wells. Each well had a threaded cap with a watertight rubber O-ring seal, which we installed in anticipation of high-water conditions. There is no guarantee that the caps did not leak, however.

The high nitrite concentration, in conjunction with the high ammonia, may indicate that the ammonia in well BT40 is oxidizing to nitrite by nitrifying bacteria such as *Nitrosamonas.* The lack of detectable nitrate in this well suggests that the oxidation of ammonia is occurring, and not the denitrification of nitrate (Chapelle, 1993). *Nitrosamonas* proliferate in an anaerobic environment. The redox measurements and dissolved oxygen concentrations from this well (see Appendix B) suggest slightly oxidizing conditions, so the ammonia and nitrite concentrations are problematic. In any case, well BT40 is located along the segment of Town Creek where ground water discharges into the stream during low flow. Surface-water monitoring site TCDS is approximately 570 ft downstream from well BT40, and should detect any contaminated ground-water discharge from the sediments monitored by BT40. Nitrite was consistently below the MCL at site TCDS, and ammonia was less than 0.5 mg/L, or near background levels, suggesting that any contamination from the lagoons into the ground-water system near well BT40 is being attenuated in the sediments, or diluted before discharging into the stream.

The results from a one-time sampling for bacteria (see Appendix B) indicate that the total coliform in the monitoring wells ranged from 10 colonies per 100 ml (col/100 ml) in well BT40 to 1,920 col/100 ml in well BT30. Analysis for *E. coli* bacteria showed that only one well, BT30, contained measurable counts (10 col/100 ml). The presence of *E. coli* in this well is inconsistent with other parameters that would indicate contamination from the lagoons, however; their presence may represent contamination during sampling. This well is located about 50 ft from the plant's discharge pipe, and is also directly below lagoon 1, where primary aeration of wastewater takes place. Aerosols produced by aeration may proliferate bacteria throughout the immediate area, making it difficult to collect a representative sample. The aerosols may have contaminated our sampling equipment, despite our best efforts to guard against it. Another possibility for the introduction of bacteria was during drilling. The drill bit had to pass through the alluvial sediments, which are hydraulically connected to Town Creek. Both sites TCUS and TCDS had high concentrations of coliform and *E. coli;* thus, the well could have been contaminated as a result of recharge from Town Creek.

Conclusions

Deep-cell aerated lagoons have been recognized as an efficient primary treatment process for sewage and wastewater. These lagoons have proven to be effective in lowering the suspended-solids content, while minimizing the accumulation of sludge.

Water-level data collected by data loggers showed that shallow wells responded quickly to recharge, whereas bedrock wells contained little water throughout most of the observation period. Hydraulic-conductivity data determined from slug tests performed in each well showed that the conductivity of the unconsolidated material monitored by the shallow wells is several orders of magnitude greater than for the underlying bedrock. The hydraulic conductivity values measured for the unconsolidated materials ranged from 1×10^{-4} to 5×10^{-4}, and the values for the limestone bedrock ranged from 2×10^{-9} to 1×10^{-8} cm/s.

The deep wells did not produce enough water for us to routinely obtain a complete suite of samples. Sufficient water for a partial analysis was collected in December 1996, however. This analysis showed chloride concentrations of approximately 1,000 mg/L in each of the bedrock wells. This relatively high chloride content suggests that residual connate water is stored in the limestone bedrock. Additional supporting evidence is that the upgradient well contained similar high chloride concentrations. Moreover, there is no other likely source of chloride for these wells, because the lagoons, which are assumed to be the source of any contamination at the site, characteristically contain water with significantly lower chloride concentrations (50 mg/L).

Ground water from the shallow wells adjacent to and downgradient from the lagoons contains lower chloride concentrations than the lagoons, but similar to Town Creek concentrations. This finding, in conjunction with hydrograph response data, suggests that bank storage and recharge from Town Creek is a greater influence on the shallow ground-water chemistry than the lagoons.

Wells BT40 and BT41 are the deep and shallow wells, respectively, that make up the well nest farthest downstream from the lagoons (see Figure 2). Both wells measure slightly higher in nitrogen species compared to the other monitoring wells at the site. Well BT40 had high concentrations of both ammonia and nitrite. The nitrite concentration was slightly above the MCL of 1.0 mg/L. The anomalous nitrogen species in these wells could be caused by leakage from a lagoon, surface-water recharge that has been contaminated by leaks in the lagoon's levees, or untreated overflow from the lagoons during floods. Both of these constituents are near background levels at a sampling site in Town Creek (TCDS), below the demonstrated ground-water discharge area. This indicates that natural attenuation is limiting any ground-water contamination.

The results from a one-time sampling for bacteria indicate that the total coliform ranged from 10 to 1,920 col/100 ml in ground water. Analysis for *E. coli* bacteria showed that only one well, BT30, contained measurable counts (10 col/100 ml). The presence of *E. coli* in this well is inconsistent with other parameters that would indicate contamination from the lagoons, however; their presence may represent contamination during sampling.

The data from this investigation, as well as previous studies, indicate that the lagoons provide efficient primary water treatment without causing significant ground-water contamination. Moreover, the design and engineering used for the Bardstown plant may provide a model for cost-effective, efficient primary water-treatment systems capable of long-term operation without significantly affecting the local ground-water system. Not all wastewater treatment plants in Kentucky have well-constructed lagoons that are located in favorable geologic settings. Lagoons in other physiographic and geologic settings should be studied to ascertain the effect of large lagoons throughout the state. This is especially pertinent now, since the public and regulatory agencies have expressed great interest in lagoon technology for large-scale livestock operations.

References Cited

Brown, E., Skougstad, M.W., and Fishman, M.J., 1970, Methods for the collection and analysis of water samples for dissolved minerals and gases, *in* Techniques of water-resource investigations of the United States Geological Survey: U.S. Geological Survey, book 5, chapter A1.

Butts, C., 1915, Geology and mineral resources of Jefferson County, Kentucky: Kentucky Geological Survey, ser. 4, v. 3, pt. 2, 270 p.

Chapelle, F.H., 1993, Ground-water microbiology and geochemistry: New York, John Wiley, 424 p.

Davis, S.N., Whittemore, D.O., and Fabryka-Martin, J., 1998, Uses of chloride/bromide ratios in studies of potable water: Ground Water, v. 36, no. 2, p. 338–350.

Foster, S.S.D., 1983, Potable ground water supplies and low-cost sanitary engineering—How compatible, *in* Ground water in resources planning: International Association of Hydrological Sciences Publication 142, 2 v.

Freeze, R.A., and Cherry, J.A., 1979, Ground water: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Hall, F.R., and Palmquist, W.N., Jr., 1960, Availability of ground water in Marion, Nelson, and Washington Counties, Kentucky: U.S. Geological Survey Hydrologic Atlas HA-21, scale 1:125,000.

Hvorslev, M.J., 1951, Time lag and soil permeability in ground water observations: U.S. Army Corps of Engineers, Waterways Experiment Station Bulletin 36.

Kentucky Natural Resources and Environmental Protection Cabinet, 1991, Kentucky water well construction practices and standards: Kentucky Natural Resources and Environmental Protection Cabinet–Division of Water, 25 p.

Marsh-McBirney, Inc., 1990, MMI model 2000 flo-mate portable water flowmeter instruction manual: 17 p.

Murphy, E.C., Pusc, S.W., and Blueme, J.P., 1992, The geologic and hydrogeologic conditions in the area adjacent to the Devils Lake wastewater impoundments: North Dakota Geological Survey, Report of Investigations 93, 93 p.

Nosow, E., 1959, Stratigraphy of Nelson County and adjacent areas (roadlog for Geological Society of Kentucky 1959 field excursion): Kentucky Geological Survey, ser. 10, 37 p.

Nuttall, B.C., 1996, The Middle and Upper Ordovician bioclastic carbonate ("Trenton") play in the Appalachian Basin: Kentucky Geological Survey, ser. 11, Information Circular 55, 21 p.

Parrott, Ely, and Hurt Consulting Engineers, 1977, Sewage treatment plant expansion, Bardstown, Kentucky: Construction diagrams, 39 sheets.

Peterson, W.L., 1969, Geologic map of the Bardstown quadrangle, Nelson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-825, scale 1:24,000.

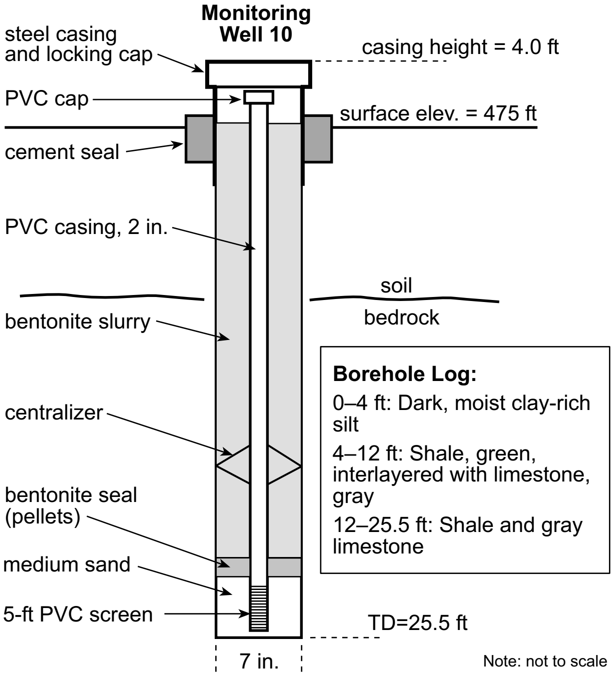
Shaw, J., Zuiderveen, J., Kercher, M., Price, D., and Birge, W.J., 1995, Use of deep water lagoons for reducing sewage toxicity prior to wastewater treatment: Second World Conference of the Society of Toxicology and Chemistry, November 1995, Vancouver, British Columbia.

Thompson, D.B., 1987, A microcomputer program for interpreting time-lag permeability tests: Ground Water, v. 25, no. 2, p. 212–218.

U.S. Geological Survey, 1980, National handbook for recommended methods for water-data acquisition; chapter 2—Ground water: U.S. Geological Survey Work Group 2, 147 p.

Wunsch, D.R., Secrist, G.L., and Sendlein, L.V.A., 2000, Data report—Hydrologic conditions around deep aeration lagoons at the Bardstown wastewater treatment plant: Kentucky Geological Survey, Open-File Report OF-00-02, 25 p.

Appendix A:
Construction Diagrams for Monitoring Wells



Monitoring Well 10

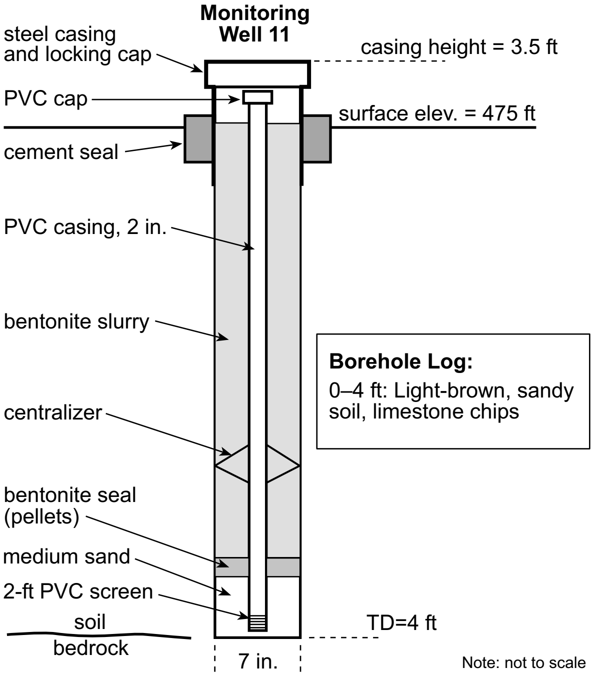
Borehole Log:

0–4 ft: Dark, moist clay-rich silt

4–12 ft: Shale, green, interlayered with limestone, gray

12–25.5 ft: Shale and gray limestone

Note: not to scale

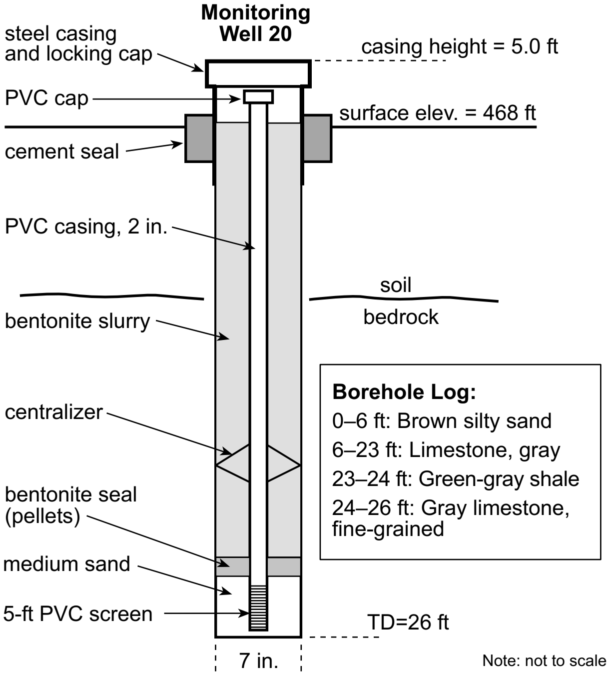


Monitoring Well 11

Borehole Log:

0–4 ft: Light-brown, sandy soil, limestone chips

Note: not to scale



Monitoring Well 20

Borehole Log:

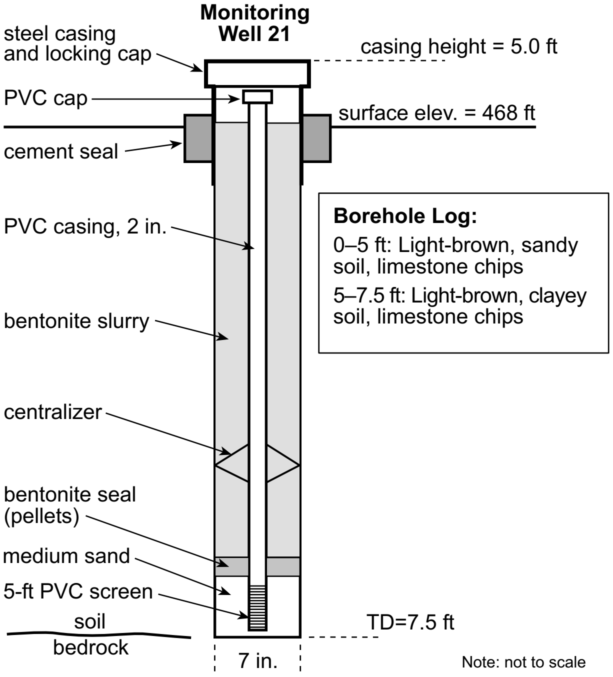
0–6 ft: Brown silty sand

6–23 ft: Limestone, gray

23–24 ft: Green-gray shale

24–26 ft: Gray limestone, fine-grained

Note: not to scale



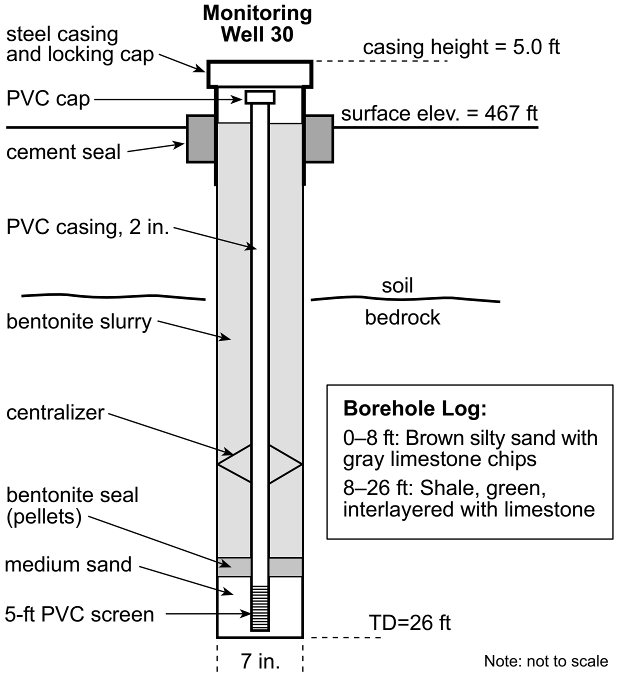
Monitoring Well 21

Borehole Log:

0–5 ft: Light-brown, sandy soil, limestone chips

5–7.5 ft: Light-brown, clayey soil, limestone chips

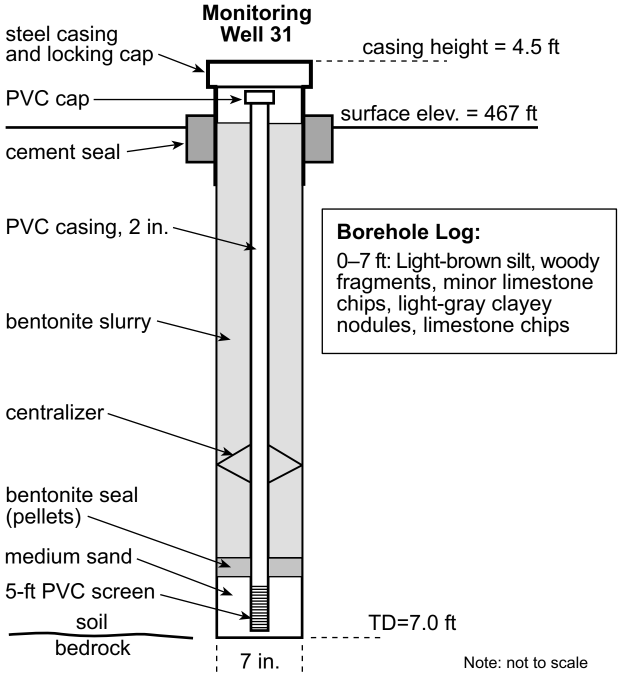
Note: not to scale



Borehole Log:

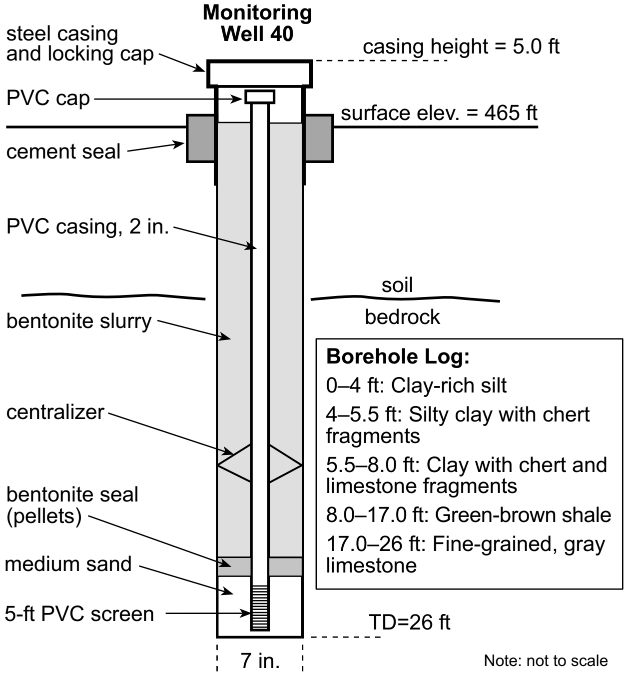
0–8 ft: Brown silty sand with gray limestone chips

8–26 ft: Shale, green, interlayered with limestone



Borehole Log:

0–7 ft: Light-brown silt, woody fragments, minor limestone chips, light-gray clayey nodules, limestone chips



Borehole Log:

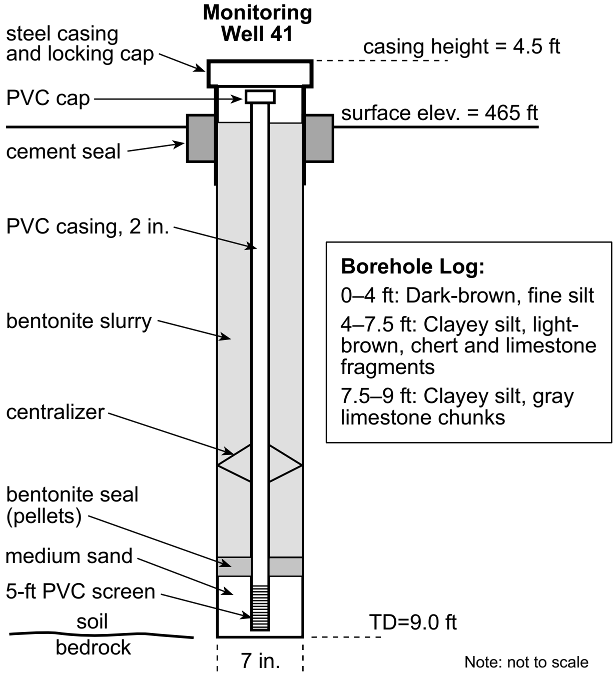
0–4 ft: Clay-rich silt

4–5.5 ft: Silty clay with chert fragments

5.5–8.0 ft: Clay with chert and limestone fragments

8.0–17.0 ft: Green-brown shale

17.0–26 ft: Fine-grained, gray limestone



Borehole Log:

0–4 ft: Dark-brown, fine silt

4–7.5 ft: Clayey silt, light-brown, chert and limestone fragments

7.5–9 ft: Clayey silt, gray limestone chunks

Appendix B:
Analytical Results

Field Parameters for Wells at the Bardstown Sewage Treatment Plant

Date	*Sample Field ID*	*pH*	*Conductivity (µS)*	*Turbidity (NTU)*	*Eh (mV)*	*Dissolved Oxygen*	*Temperature (°C)*
03-Oct-96	BT11	7.47	962	NM	133	NM	19.6
11-Dec-96	BT11	7.52	910	144	142	8.09	12.1
26-Mar-97	BT11	7.14	990	11	295	5.82	11.6
30-Jun-97	BT11	7.18	1,160	25	138	4.52	22
03-Oct-96	BT21	7	894	NM	112	NM	19.5
11-Dec-96	BT21	7.17	950	80	114	3.76	12.4
26-Mar-97	BT21	6.96	696	420	153	1.52	9.7
30-Jun-97	BT21	6.93	704	434	–15	2.66	17
03-Oct-96	BT31	6.98	687	NM	123	NM	18
11-Dec-96	BT31	7	497	10	112	3.34	13.7
26-Mar-97	BT31	6.82	663	10	142	0.78	10.7
30-Jun-97	BT31	6.9	631	31	178	0.92	16.5
03-Oct-96	BT41	7.13	690	NM	150	NM	19
11-Dec-96	BT41	7.27	541	0	97	6.81	14.3
26-Mar-97	BT41	6.97	559	25	113	1.89	10.9
30-Jun-97	BT41	6.94	567	4	117	3.62	16.6
03-Oct-96	BT10	NM	NM	NM	NM	NM	NM
11-Dec-96	BT10	7.36	3,560	972	169	8.26	12.6
26-Mar-97	BT10	7.18	5,180	> 999	205	5.19	14.3
30-Jun-97	BT10	7.28	5,400	> 999	NE	NE	NE
03-Oct-96	BT20	7.46	1,978	NM	123	NM	15.1
11-Dec-96	BT20	7.58	5,700	> 999	101	3.79	13.5
26-Mar-97	BT20	7.27	7,200	> 999	162	3	13.1
30-Jun-97	BT20	NE	NE	NE	NE	NE	NE
03-Oct-96	BT30	7.59	2,392	NM	153	NM	14.4
11-Dec-96	BT30	7.55	4,720	> 999	128	4	13.9
26-Mar-97	BT30	7.17	5,940	> 999	142	2.39	13.8
30-Jun-97	BT30	NE	NE	NE		NE	NE
03-Oct-96	BT40	7.45	4,065	NM	188	NM	14.4
11-Dec-96	BT40	7.5	4,710	> 999	127	7.17	14.4
26-Mar-97	BT40	7.27	4,800	> 999	82	4.83	14.5
01-Jul-97	BT40	7.15	4,870	750	134	6	18*
03-Oct-96	TCUS	8.17	426	NM	108	NM	17.7
11-Dec-96	TCUS	8.36	409	45	132	10.6	8.1
26-Mar-97	TCUS	8.32	337	85	163	10.68	12.2
01-Jul-97	TCUS	7.6	405	39	130	4.8	22.5
03-Oct-96	TCDS	8.07	579	NM	47	NM	18.7
11-Dec-96	TCDS	8.27	427	52	98	8.64	11.6
26-Mar-97	TCDS	8.21	370	49	–0	9.3	14.0
01-Jul-97	TCDS	7.41	445	36	176	6.73	23.3
03-Oct-96	LAG1	7.48	745	NM	40	NM	20.5
11-Dec-96	LAG1	7.54	563	238	–41	0.12	10.6
26-Mar-97	LAG1	7.33	533	42	43	1.02	13.7
01-Jul-97	LAG1	7.2	581	100	134	0.08	26.1
03-Oct-96	LAG2	7.28	738	NM	–55	NM	20.8
11-Dec-96	LAG2	7.53	571	387	–135	0.2	11.1
26-Mar-97	LAG2	7.29	530	75	28	2.3	13.4
01-Jul-97	LAG2	7.31	580	170	125	1.8	24.8

NE = not enough water to sample NM = not measured *hard to measure

Chemical Analyses of Water Samples from Wells at Bardstown Sewage Treatment Plant

Date	Sample Field ID	Bicarbonate (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Ammonia (NH_3) (mg/L)	Nitrate (NO_3) (mg/L)	Nitrate-N (NO_3-N) (mg/L)	Nitrite (NO_2) (mg/L)	Nitrite-N (NO_2-N) (mg/L)
03-Oct-96	BT11	428	44.9	< MDL	0.14	56.4	0.46	1.1	0.25	0.008	0.002
11-Dec-96	BT11	410	22.4	< MDL	0.12	69.5	0.24	1.5	0.34	0.014	0.004
26-Mar-97	BT11	463	18.4	< MDL	0.14	145	0.03	4.7	1.06	0.004	0.001
30-Jun-97	BT11	537	9.9	< MDL	0.15	118	0.12	0.1	0.02	0.024	0.007
03-Oct-96	BT21	437	28.8	< MDL	0.15	122	0.56	0.5	0.11	0.016	0.005
11-Dec-96	BT21	416	29	< MDL	0.13	98.7	0.25	1.3	0.29	0.028	0.009
26-Mar-97	BT21	455	18.2	< MDL	0.13	89.2	0.04	1	0.23	0.037	0.011
30-Jun-97	BT21	515	10.2	< MDL	0.16	79.7	0.3	0.1	0.02	0.011	0.003
03-Oct-96	BT31	458	5.7	< MDL	0.11	20.6	0.95	0.1	0.02	0.157	0.048
11-Dec-96	BT31	441	5.1	< MDL	0.1	23	0.87	0.6	0.14	0.011	0.003
26-Mar-97	BT31	528	2.9	< MDL	0.09	34.3	1	0.3	0.07	0.013	0.004
30-Jun-97	BT31	541	2	< MDL	0.13	28.8	0.87	0.2	0.04	0.008	0.002
03-Oct-96	BT41	480	15.9	< MDL	0.13	32.1	0.03	20.4	4.61	0.03	0.009
11-Dec-96	BT41	462	4.8	< MDL	0.13	27.6	0.02	10.9	2.46	0.007	0.002
26-Mar-97	BT41	424	3.9	< MDL	0.1	25.1	0.04	21.5	4.86	0.021	0.006
30-Jun-97	BT41	466	3.5	< MDL	0.16	27.1	0.25	2.6	0.59	0.035	0.011
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	779	5.6	0.74	254	NE	0.6	0.14	0.022	0.007
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10										
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	817	1,660	9.8	0.53	163	NE	0.9	0.2	0.039	0.012
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20										
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	640	1,202	7.8	0.65	205	NE	< MDL	< MDL	0.041	0.012
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30										
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
12-Dec-96	BT40	779	1,360	8.2	0.67	70.2	6.32	< MDL	< MDL	4.05	1.233
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40										
03-Oct-96	TCUS	217	16.2	< MDL	0.13	75.2	0.04	4.9	1.11	0.036	0.011
11-Dec-96	TCUS	261	17	< MDL	0.11	70	0.07	8.3	1.88	0.042	0.013
26-Mar-97	TCUS	225	11.7	< MDL	0.12	58	0.04	6.8	1.54	0.033	0.01
01-Jul-97	TCUS	252	14.3	< MDL	0.13	46.2	0.21	4.8	1.08	0.223	0.068
03-Oct-96	TCDS	217	32.8	< MDL	0.31	69.2	0.27	25.9	5.85	0.593	0.18
11-Dec-96	TCDS	260	22.7	< MDL	0.19	65.4	0.17	15.8	3.57	0.306	0.093
26-Mar-97	TCDS	219	13.3	< MDL	0.14	43.6	0.04	10.4	2.35	0.115	0.035
01-Jul-97	TCDS	227	16.6	< MDL	0.23	68.2	0.41	15	3.39	0.879	0.27
03-Oct-96	LAG1	306	57.1	< MDL	0.57	67.3	13.85	< MDL	< MDL	0.045	0.014
11-Dec-96	LAG1	327	48.4	< MDL	0.51	71	13.39	0.2	0.04	0.009	0.003
26-Mar-97	LAG1	278	39	< MDL	0.39	54.2	13.13	0.5	0.11	0.269	0.082
01-Jul-97	LAG1	323	39	< MDL	0.49	51.1	18.96	0.2	0.04	0.038	0.012
03-Oct-96	LAG2	300	55.5	< MDL	0.56	65.5	11.04	0.3	0.07	0.009	0.003
11-Dec-96	LAG2	333	51.8	< MDL	0.54	72	12.33	< MDL	< MDL	0.076	0.023
26-Mar-97	LAG2	274	36.5	< MDL	0.38	53.6	13.99	0.5	0.11	0.577	0.176
01-Jul-97	LAG2	312	40.9	< MDL	0.54	49.6	18.87	0.2	0.04	0.151	0.046
03-Oct-96	BT REP (BT21)	408	29.3	< MDL	0.16	120	0.6	0.5	0.11	0.016	0.005
11-Dec-96	BT REP (BT41)	464	4.5	< MDL	0.13	27.6	0.03	10.7	2.42	0.005	0.001
26-Mar-97	BT DP31	543	2.9	< MDL	0.09	31.2	0.96	0.2	0.04	0.012	0.004
30-Jun-97	BT31D	543	2	< MDL	0.13	26	NM	0.3	0.07	NM	NM
03-Oct-96	BT BLANK	6	< MDL	< MDL	0.04	< MDL	< MDL	< MDL	< MDL	0.003	0.001
12-Dec-96	BT BLANK	6	< MDL	< MDL	0.04	< MDL	0.03	< MDL	< MDL	0.003	0.001
27-Mar-97	BT EB	7	< MDL	< MDL	0.04	< MDL	0.03	< MDL	< MDL	0.003	0.001

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analyses of Water Samples from wells at Bardstown Sewage Treatment Plant
Dissolved Metals

Date	*Sample Field ID*	*Orthophosphate (mg/L)*	*Orthophosphate-P (PO_4-P) (mg/L)*	*Total Organic Carbon (mg/L)*	*Ammonia (NH_3-N) (mg/L)*	*Aluminum (mg/L)*	*Antimony (mg/L)*	*Arsenic (mg/L)*	*Barium (mg/L)*	*Beryllium (mg/L)*	*Boron (mg/L)*
03-Oct-96	BT11	0.022	0.007	4	0.38	< MDL	< MDL	< MDL	0.0578	< MDL	< MDL
11-Dec-96	BT11	0.012	0.004	1	0.2	< MDL	< MDL	< MDL	0.0507	< MDL	< MDL
26-Mar-97	BT11	0.016	0.005	2.4	0.03	< MDL	< MDL	< MDL	0.063	< MDL	< MDL
30-Jun-97	BT11	0.034	0.011	2	0.10	< MDL	< MDL	< MDL	0.0803	< MDL	< MDL
03-Oct-96	BT21	0.012	0.004	3	0.46	< MDL	< MDL	< MDL	0.077	< MDL	< MDL
11-Dec-96	BT21	0.014	0.005	2	0.21	< MDL	< MDL	< MDL	0.0522	< MDL	< MDL
26-Mar-97	BT21	0.011	0.004	2.1	0.03	< MDL	< MDL	< MDL	0.0327	< MDL	< MDL
30-Jun-97	BT21	0.038	0.012	3.3	0.25	< MDL	< MDL	< MDL	0.041	< MDL	< MDL
03-Oct-96	BT31	0.012	0.004	1	0.78	< MDL	< MDL	< MDL	0.0419	< MDL	< MDL
11-Dec-96	BT31	0.016	0.005	< MDL	0.72	< MDL	< MDL	< MDL	0.0257	< MDL	< MDL
26-Mar-97	BT31	< MDL	< MDL	1.3	0.82	< MDL	< MDL	< MDL	0.0585	< MDL	< MDL
30-Jun-97	BT31	0.033	0.011	1.5	0.72	< MDL	< MDL	< MDL	0.053	< MDL	0.059
03-Oct-96	BT41	0.016	0.005	2	0.03	< MDL	< MDL	< MDL	0.0388	< MDL	< MDL
11-Dec-96	BT41	0.013	0.004	1	0.02	< MDL	< MDL	< MDL	0.0335	< MDL	0.029
26-Mar-97	BT41	0.018	0.006	1.2	0.03	< MDL	< MDL	< MDL	0.0338	< MDL	< MDL
30-Jun-97	BT41	0.031	0.01	1.5	0.21	< MDL	< MDL	< MDL	0.0438	< MDL	< MDL
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	0.09	0.029	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10										
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	0.104	0.034	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20										
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	0.089	0.029	19	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30										
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT40	0.07	0.023	16	5.2	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40										
03-Oct-96	TCUS	0.07	0.023	3	0.03	< MDL	< MDL	< MDL	0.0358	< MDL	< MDL
11-Dec-96	TCUS	0.058	0.019	1	0.06	< MDL	< MDL	< MDL	0.0327	< MDL	0.028
26-Mar-97	TCUS	0.023	0.008	2.5	0.03	< MDL	< MDL	< MDL	0.0302	< MDL	< MDL
01-Jul-97	TCUS	0.036	0.012	2.1	0.17	< MDL	< MDL	< MDL	0.0393	< MDL	< MDL
03-Oct-96	TCDS	1.976	0.644	8	0.22	< MDL	< MDL	< MDL	0.0192	< MDL	< MDL
11-Dec-96	TCDS	1.119	0.365	< MDL	0.14	< MDL	< MDL	< MDL	0.0267	< MDL	0.028
26-Mar-97	TCDS	0.422	0.138	3.9	0.03	< MDL	< MDL	< MDL	0.0244	< MDL	0.032
01-Jul-97	TCDS	0.821	0.268	4.2	0.34	< MDL	< MDL	< MDL	0.0302	< MDL	< MDL
03-Oct-96	LAG1	1.802	0.588	22	11.39	< MDL	< MDL	< MDL	0.0054	< MDL	0.236
11-Dec-96	LAG1	4.241	1.383	35	11.01	< MDL	< MDL	< MDL	0.0101	< MDL	0.128
26-Mar-97	LAG1	3.345	1.091	14.8	10.8	< MDL	< MDL	< MDL	0.0093	< MDL	< MDL
01-Jul-97	LAG1	3.105	1.01	10.7	15.59	< MDL	< MDL	< MDL	0.0054	< MDL	0.184
03-Oct-96	LAG2	0.948	0.309	33	9.08	< MDL	< MDL	< MDL	0.0101	< MDL	< MDL
11-Dec-96	LAG2	4.219	1.376	66	10.14	< MDL	< MDL	< MDL	0.0172	< MDL	< MDL
26-Mar-97	LAG2	2.8	0.913	2.1	11.5	< MDL	< MDL	< MDL	0.0109	< MDL	< MDL
01-Jul-97	LAG2	2.695	0.879	15.5	15.52	< MDL	< MDL	< MDL	0.0057	< MDL	0.23
03-Oct-96	BT REP (BT21)	0.019	0.006	4	0.49	< MDL	< MDL	< MDL	0.0675	< MDL	< MDL
11-Dec-96	BT REP (BT41)	0.021	0.007	10	0.03	< MDL	< MDL	< MDL	0.0338	< MDL	< MDL
26-Mar-97	BT DP31	0.01	0.003	1.4	0.79	< MDL	< MDL	< MDL	0.0752	< MDL	< MDL
30-Jun-97	BT31D	NM	NM	NM	NM	< MDL	< MDL	< MDL	0.0453	< MDL	< MDL
03-Oct-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
11-Dec-96	BT BLANK	< MDL	< MDL	< MDL	0.03	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
26-Mar-97	BT EB	< MDL	< MDL	< MDL	0.03	< MDL	< MDL	< MDL	0.0298	< MDL	< MDL

MD = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analyses of Water Samples from Wells at Bardstown Sewage Treatment Plant
Dissolved Metals—Continued

Date	*Sample Field ID*	*Cadmium (mg/L)*	*Calcium (mg/L)*	*Chromium (mg/L)*	*Cobalt (mg/L)*	*Copper (mg/L)*	*Gold (mg/L)*	*Iron (mg/L)*	*Lead (mg/L)*	*Lithium (mg/L)*	*Magnesium (mg/L)*
03-Oct-96	BT11	< MDL	102	< MDL	< MDL	< MDL	< MDL	0.054	< MDL	< MDL	35
11-Dec-96	BT11	< MDL	91	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	38.4
26-Mar-97	BT11	< MDL	119	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	45
30-Jun-97	BT11	< MDL	125	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	42.6
03-Oct-96	BT21	< MDL	122	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	41.5
11-Dec-96	BT21	< MDL	103	< MDL	< MDL	< MDL	< MDL	0.153	< MDL	< MDL	40.6
26-Mar-97	BT21	< MDL	112	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	41.4
30-Jun-97	BT21	< MDL	122	< MDL	< MDL	< MDL	< MDL	0.12	< MDL	< MDL	46.6
03-Oct-96	BT31	< MDL	106	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	27.9
11-Dec-96	BT31	< MDL	102	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	30
26-Mar-97	BT31	< MDL	125	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	37.5
30-Jun-97	BT31	< MDL	137	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	38.9
03-Oct-96	BT41	< MDL	116	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	33.4
11-Dec-96	BT41	< MDL	108	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	33.7
26-Mar-97	BT41	< MDL	101	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	30.6
30-Jun-97	BT41	< MDL	117	< MDL	< MDL	< MDL	< MDL	0.463	< MDL	< MDL	32.8
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10										
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20										
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30										
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
12-Dec-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40										
03-Oct-96	TCUS	< MDL	54.2	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	25.9
11-Dec-96	TCUS	< MDL	62.2	< MDL	< MDL	< MDL	< MDL	0.01	< MDL	< MDL	32.4
26-Mar-97	TCUS	< MDL	51.5	< MDL	< MDL	< MDL	< MDL	0.015	< MDL	< MDL	27.1
01-Jul-97	TCUS	< MDL	53.6	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	31.7
03-Oct-96	TCDS	< MDL	50	< MDL	< MDL	< MDL	< MDL	0.011	< MDL	< MDL	25.1
11-Dec-96	TCDS	< MDL	60	< MDL	< MDL	< MDL	< MDL	0.01	< MDL	< MDL	30.3
26-Mar-97	TCDS	< MDL	50.3	< MDL	< MDL	< MDL	< MDL	0.02	< MDL	< MDL	24.7
01-Jul-97	TCDS	< MDL	53.2	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	30.7
03-Oct-96	LAG1	< MDL	45.5	< MDL	< MDL	< MDL	< MDL	0.055	< MDL	< MDL	23.5
11-Dec-96	LAG1	< MDL	55.4	< MDL	< MDL	< MDL	< MDL	0.12	< MDL	< MDL	27
26-Mar-97	LAG1	< MDL	47.7	< MDL	< MDL	0.01	< MDL	0.14	< MDL	< MDL	22.3
01-Jul-97	LAG1	< MDL	52.7	< MDL	< MDL	< MDL	< MDL	0.016	< MDL	< MDL	24.3
03-Oct-96	LAG2	< MDL	43.4	< MDL	< MDL	< MDL	< MDL	0.033	< MDL	< MDL	22.1
11-Dec-96	LAG2	< MDL	58.4	< MDL	< MDL	0.01	< MDL	0.24	< MDL	< MDL	27.4
26-Mar-97	LAG2	< MDL	47.7	< MDL	< MDL	< MDL	< MDL	0.123	< MDL	< MDL	22.4
01-Jul-97	LAG2	< MDL	53.6	< MDL	< MDL	< MDL	< MDL	0.019	< MDL	< MDL	25
03-Oct-96	BT REP (BT21)	< MDL	104	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	37
11-Dec-96	BT REP (BT41)	< MDL	110	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	34.4
26-Mar-97	BT DP31	< MDL	133	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	36.2
30-Jun-97	BT31D	< MDL	117	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	33
03-Oct-96	BT BLANK	< MDL	0.047	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
12-Dec-96	BT BLANK	< MDL	0.132	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
26-Mar-97	BT EB	< MDL	0.147	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analyses of Water Samples from Wells at Bardstown Sewage Treatment Plant
Dissolved Metals—Continued

Date	*Sample Field ID*	*Manganese (mg/L)*	*Nickel (mg/L)*	*Phosphorus (mg/L)*	*Potassium (mg/L)*	*Selenium (mg/L)*	*Silicon (mg/L)*	*Silver (mg/L)*	*Sodium (mg/L)*	*Strontium (mg/L)*
03-Oct-96	BT11	0.429	< MDL	< MDL	2.6	< MDL	6.74	< MDL	28.3	0.121
11-Dec-96	BT11	< MDL	< MDL	< MDL	2.59	< MDL	6.11	< MDL	16.2	0.104
26-Mar-97	BT11	0.014	< MDL	< MDL	1.07	< MDL	6.88	< MDL	26.1	0.146
30-Jun-97	BT11	0.491	< MDL	< MDL	2.38	< MDL	7.84	< MDL	28.2	0.141
03-Oct-96	BT21	2.83	< MDL	< MDL	4.33	< MDL	7.61	< MDL	24.1	0.104
11-Dec-96	BT21	0.977	< MDL	< MDL	3.02	< MDL	7.2	< MDL	17.6	0.088
26-Mar-97	BT21	0.033	< MDL	< MDL	2.6	< MDL	6.68	< MDL	20.6	0.091
30-Jun-97	BT21	1.39	< MDL	0.355	3.48	< MDL	7.62	< MDl	11.5	0.098
03-Oct-96	BT31	1.9	< MDL	1.4	< MDL	< MDL	6.22	< MDL	3.82	0.093
11-Dec-96	BT31	1.84	< MDL	0.348	0.948	< MDL	5.94	< MDL	2.53	0.086
26-Mar-97	BT31	1.51	< MDL	< MDL	< MDL	< MDL	6.53	< MDL	3.74	0.102
30-Jun-97	BT31	1.43	< MDL	< MDL	< MDL	< MDL	7.29	< MDL	2.64	0.112
03-Oct-96	BT41	< MDL	< MDL	< MDL	< MDL	< MDL	6.85	< MDL	5.24	0.094
11-Dec-96	BT41	< MDL	< MDL	< MDL	< MDL	< MDL	6.13	< MDL	2.91	0.083
26-Mar-97	BT41	0.009	< MDL	< MDL	< MDL	< MDL	5.43	< MDL	2.42	0.075
30-Jun-97	BT41	0.22	< MDL	< MDL	1.34	< MDL	6.43	< MDL	6.14	0.086
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10									
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20									
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30									
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40									
03-Oct-96	TCUS	< MDL	< MDL	< MDL	4.22	< MDL	4.51	< MDL	8.99	0.069
11-Dec-96	TCUS	< MDL	< MDL	< MDL	2.55	< MDL	5.11	< MDL	8.41	0.07
26-Mar-97	TCUS	0.074	< MDL	< MDL	1.97	< MDL	3.99	< MDL	7.08	0.057
01-Jul-97	TCUS	0.138	< MDL	< MDL	3.04	< MDL	3.91	< MDL	8.21	0.063
03-Oct-96	TCDS	< MDL	< MDL	0.827	6.73	< MDL	4.47	< MDL	32.9	0.111
11-Dec-96	TCDS	0.093	< MDL	0.395	3.95	< MDL	4.6	< MDL	16.2	0.092
26-Mar-97	TCDS	0.066	< MDL	< MDL	2.81	< MDL	3.96	< MDL	8.38	0.06
01-Jul-97	TCDS	< MDL	< MDL	< MDL	3.63	< MDL	3.83	< MDL	13.1	0.083
03-Oct-96	LAG1	0.089	< MDL	1.1	10.7	< MDL	4.72	< MDL	62.3	0.149
11-Dec-96	LAG1	< MDL	< MDL	1.41	8.55	< MDL	4.21	< MDL	47.9	0.177
26-Mar-97	LAG1	0.115	< MDL	1.2	6.3	< MDL	3.98	< MDL	36.1	0.137
01-Jul-97	LAG1	0.082	< MDL	1.4	7.93	< MDL	4.9	< MDL	36.6	0.136
03-Oct-96	LAG2	0.098	< MDL	0.824	9.22	< MDL	4.82	< MDL	57.1	0.142
11-Dec-96	LAG2	< MDL	< MDL	1.66	8.76	< MDL	4.98	< MDL	50	0.193
26-Mar-97	LAG2	0.129	< MDL	1.1	6.54	< MDL	4.06	< MDL	37.3	0.135
01-Jul-97	LAG2	0.037	< MDL	1.28	8.53	< MDL	4.98	< MDL	38.7	0.14
03-Oct-96	BT REP (BT21)	2.51	< MDL	0.122	4.07	< MDL	6.89	< MDL	22.1	0.093
11-Dec-96	BT REP (BT41)	< MDL	< MDL	< MDL	< MDL	< MDL	6.29	< MDL	3.03	0.085
26-Mar-97	BT DP31	1.48	< MDL	0.341	< MDL	< MDL	6.37	< MDL	3.54	0.098
30-Jun-97	BT31D	1.21	< MDL	< MDL	36	< MDL	6.36	< MDL	2.33	0.097
03-Oct-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
12-Dec-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	0.114	< MDL	< MDL	< MDL
27-Mar-97	BT EB	< MDL	< MDL	< MDL	< MDL	< MDL	0.101	< MDL	0.208	0.002

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analysis of Water Samples from Wells at Bardstown Sewage Treatment Plant
Dissolved Metals—Continued

Date	*Sample Field ID*	*Sulfur (mg/L)*	*Tin (mg/L)*	*Vanadium (mg/L)*	*Zinc (mg/L)*	*TDS (mg/L)*	*Charge-Balance Calculation (%)*
03-Oct-96	BT11	17.7	< MDL	< MDL	< MDL	487.56	1.11
11-Dec-96	BT11	18.5	< MDL	< MDL	< MDL	449.31	2.04
26-Mar-97	BT11	43.7	< MDL	< MDL	< MDL	593.82	1.82
30-Jun-97	BT11	37.4	< MDL	< MDL	< MDL	598.1	2.26
03-Oct-96	BT21	42.5	< MDL	< MDL	< MDL	565.72	0.65
11-Dec-96	BT21	28.7	< MDL	< MDL	< MDL	505.13	2.05
26-Mar-97	BT21	25.3	< MDL	< MDL	< MDL	515.41	0.57
30-Jun-97	BT21	24.9	< MDL	< MDL	< MDL	534.58	0.57
03-Oct-96	BT31	6.61	< MDL	< MDL	< MDL	395.55	2.19
11-Dec-96	BT31	5.67	< MDL	< MDL	< MDL	386.97	1.09
26-Mar-97	BT31	9.23	0.098	< MDL	< MDL	469.89	0.16
30-Jun-97	BT31	9.39	< MDL	< MDL	< MDL	482.87	3.17
03-Oct-96	BT41	10.7	< MDL	< MDL	< MDL	465.92	3.04
11-Dec-96	BT41	8.09	< MDL	< MDL	< MDL	421.22	1.02
26-Mar-97	BT41	6.97	< MDL	< MDL	< MDL	398.45	1.71
30-Jun-97	BT41	8.8	< MDL	< MDL	< MDL	426.54	2.88
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10						
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20						
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30						
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE
12-Dec-96	BT40	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40						
03-Oct-96	TCUS	22.8	< MDL	< MDL	< MDL	300.89	2.97
11-Dec-96	TCUS	19.1	< MDL	< MDL	< MDL	334.37	1.2
26-Mar-97	TCUS	16.9	< MDL	< MDL	< MDL	278.81	1.7
01-Jul-97	TCUS	15.5	< MDL	< MDL	< MDL	289.7	1.27
03-Oct-96	TCDS	21	< MDL	< MDL	< MDL	355.79	1.91
11-Dec-96	TCDS	17	< MDL	< MDL	< MDL	347.92	2.04
26-Mar-97	TCDS	14.1	< MDL	< MDL	< MDL	265.57	0.75
01-Jul-97	TCDS	21.3	< MDL	< MDL	< MDL	316.7	0.29
03-Oct-96	LAG1	21	< MDL	< MDL	< MDL	423.44	5.87
11-Dec-96	LAG1	19	< MDL	< MDL	< MDL	427.83	6.74
26-Mar-97	LAG1	16	< MDL	< MDL	< MDL	350.26	7.42
01-Jul-97	LAG1	17.8	< MDL	< MDL	< MDL	378.67	8.12
03-Oct-96	LAG2	19.2	< MDL	< MDL	< MDL	406.43	8.08
11-Dec-96	LAG2	19.8	< MDL	< MDL	< MDL	441.54	6.11
26-Mar-97	LAG2	16.4	< MDL	< MDL	< MDL	346.25	5.65
01-Jul-97	LAG2	18	< MDL	< MDL	< MDL	377.63	5.39
03-Oct-96	BT REP (BT21)	36.5	< MDL	< MDL	< MDL	524.49	3.74
11-Dec-96	BT REP (BT41)	8.23	< MDL	< MDL	< MDL	424.69	0.17
26-Mar-97	BT DP31	8.84	0.085	< MDL	< MDL	480.41	0.69
30-Jun-97	BT31D	8	< MDL	< MDL	< MDL	489.98	0.38
03-Oct-96	BT BLANK	< MDL	< MDL	< MDL	< MDL		
12-Dec-96	BT BLANK	< MDL	< MDL	< MDL	< MDL		
27-Mar-97	BT EB	< MDL	< MDL	< MDL	< MDL		

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical analyses of water samples from wells at Bardstown Sewage Treatment Plant
Total Metals

Date	*Sample Field ID*	*Aluminum (mg/L)*	*Antimony (mg/L)*	*Arsenic (mg/L)*	*Barium (mg/L)*	*Beryllium (mg/L)*	*Boron (mg/L)*	*Cadmium (mg/L)*	*Calcium (mg/L)*	*Chromium (mg/L)*	*Cobalt (mg/L)*
03-Oct-96	BT11	0.288	< MDL	< MDL	0.0593	< MDL	< MDL	< MDL	99.1	< MDL	< MDL
11-Dec-96	BT11	< MDL	< MDL	< MDL	0.0562	< MDL	< MDL	< MDL	110	< MDL	< MDL
26-Mar-97	BT11	0.059	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	148	< MDL	< MDL
30-Jun-97	BT11	< MDL	< MDL	< MDL	0.0886	< MDL	0.048	< MDL	137	< MDL	< MDL
03-Oct-96	BT21	3.6	< MDL	< MDL	0.0807	< MDL	< MDL	< MDL	122	< MDL	< MDL
11-Dec-96	BT21	4.24	< MDL	< MDL	0.0731	< MDL	< MDL	< MDL	114	< MDL	< MDL
26-Mar-97	BT21	1.98	< MDL	< MDL	0.05	< MDL	< MDL	< MDL	122	< MDL	< MDL
30-Jun-97	BT21	2.23	< MDL	< MDL	0.0702	< MDL	< MDL	< MDL	124	< MDL	< MDL
03-Oct-96	BT31	< MDL	< MDL	< MDL	0.0439	< MDL	< MDL	< MDL	105	< MDL	< MDL
11-Dec-96	BT31	0.03	< MDL	< MDL	0.0274	< MDL	0.029	< MDL	108	< MDL	< MDL
26-Mar-97	BT31	0.013	< MDL	< MDL	0.059	< MDL	< MDL	< MDL	125	< MDL	< MDL
30-Jun-97	BT31	< MDL	< MDL	< MDL	0.0595	< MDL	< MDL	< MDL	127	< MDL	< MDL
03-Oct-96	BT41	< MDL	< MDL	< MDL	0.0383	< MDL	< MDL	< MDL	112	< MDL	< MDL
11-Dec-96	BT41	< MDL	< MDL	< MDL	0.0331	< MDL	< MDL	< MDL	115	< MDL	< MDL
26-Mar-97	BT41	< MDL	< MDL	< MDL	0.0337	< MDL	0.032	< MDL	98.7	< MDL	< MDL
30-Jun-97	BT41	< MDL	< MDL	< MDL	0.0492	< MDL	< MDL	< MDL	113	< MDL	< MDL
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10										
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20										
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30										
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40										
03-Oct-96	TCUS	0.201	< MDL	< MDL	0.0387	< MDL	0.023	< MDL	53.8	< MDL	< MDL
11-Dec-96	TCUS	0.111	< MDL	< MDL	0.0348	< MDL	< MDL	< MDL	61.9	< MDL	< MDL
26-Mar-97	TCUS	0.694	< MDL	< MDL	0.036	< MDL	< MDL	< MDL	53.5	< MDL	< MDL
01-Jul-97	TCUS	0.187	< MDL	< MDL	0.0465	< MDL	< MDL	< MDL	53	< MDL	< MDL
03-Oct-96	TCDS	< MDL	< MDL	< MDL	0.0247	< MDL	< MDL	< MDL	49.3	< MDL	< MDL
11-Dec-96	TCDS	< MDL	< MDL	< MDL	0.0293	< MDL	< MDL	< MDL	59.8	< MDL	< MDL
26-Mar-97	TCDS	0.321	< MDL	< MDL	0.029	< MDL	< MDL	< MDL	51.1	< MDL	< MDL
01-Jul-97	TCDS	< MDL	< MDL	< MDL	0.0345	< MDL	< MDL	< MDL	53.2	< MDL	< MDL
03-Oct-96	LAG1	0.183	< MDL	< MDL	0.0143	< MDL	0.238	< MDL	44.5	< MDL	< MDL
11-Dec-96	LAG1	0.73	< MDL	< MDL	0.0321	< MDL	0.14	< MDL	57.8	< MDL	< MDL
26-Mar-97	LAG1	0.179	< MDL	< MDL	0.018	< MDL	0.137	<MDL	50.1	< MDL	< MDL
01-Jul-97	LAG1	< MDL	< MDL	< MDL	0.015	< MDL	0.196	< MDL	52.9	< MDL	< MDL
03-Oct-96	LAG2	0.284	< MDL	< MDL	0.0244	< MDL	0.227	< MDL	47.4	< MDL	< MDL
11-Dec-96	LAG2	0.287	< MDL	< MDL	0.027	< MDL	0.139	< MDL	59	< MDL	< MDL
26-Mar-97	LAG2	0.294	< MDL	< MDL	0.023	< MDL	0.137	< MDL	50.7	< MDL	< MDL
01-Jul-97	LAG2	0.494	< MDL	< MDL	0.0302	< MDL	0.174	< MDL	52.6	< MDL	< MDL
03-Oct-96	BT REP (BT21)	3.17	< MDL	<MDL	0.078	< MDL	<MDL	<MDL	122	<MDL	<MDL
11-Dec-96	BT REP (BT41)	< MDL	<MDL	<MDL	0.035	<MDL	<MDL	<MDL	110	< MDL	< MDL
26-Mar-97	BT DP31	0.063	< MDL	< MDL	0.059	< MDL	0.034	< MDL	120	< MDL	< MDL
30-Jun-97	BT31D	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
03-Oct-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
12-Dec-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.07	< MDL	< MDL
27-Mar-97	BT EB	< MDL	< MDL	< MDL	< MDL	< MDL	0.062	< MDL	0.133	< MDL	< MDL

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analyses of Water Samples from Wells at Bardstown Sewage Treatment Plant
Total Metals—Continued

Date	*Sample Field ID*	*Copper (mg/L)*	*Gold (mg/L)*	*Iron (mg/L)*	*Lead (mg/L)*	*Lithium (mg/L)*	*Magnesium (mg/L)*	*Manganese (mg/L)*	*Nickel (mg/L)*	*Phosphorus (mg/L)*	*Potassium (mg/L)*
03-Oct-96	BT11	< MDL	< MDL	0.799	< MDL	< MDL	36.4	0.444	< MDL	< MDL	2.5
11-Dec-96	BT11	< MDL	< MDL	0.042	< MDL	< MDL	38.3	0.297	< MDL	< MDL	< MDL
26-Mar-97	BT11	< MDL	< MDL	< MDL	< MDL	< MDL	44.2	< MDL	< MDL	< MDL	< MDL
30-Jun-97	BT11	< MDL	< MDL	0.309	< MDL	< MDL	45.6	0.463	< MDL	< MDL	1.63
03-Oct-96	BT21	< MDL	< MDL	7.410	< MDL	< MDL	43.7	2.04	0.013	< MDL	4.72
11-Dec-96	BT21	< MDL	< MDL	6.880	< MDL	0.005	42.4	1.12	< MDL	< MDL	4.23
26-Mar-97	BT21	< MDL	< MDL	3.450	< MDL	< MDL	43.0	0.416	< MDL	0.149	3.18
30-Jun-97	BT21	< MDL	< MDL	3.97	< MDL	< MDL	46.4	1.97	< MDL	0.255	3.58
03-Oct-96	BT31	< MDL	< MDL	0.088	< MDL	< MDL	28.5	1.73	< MDL	1.01	< MDL
11-Dec-96	BT31	< MDL	< MDL	0.458	< MDL	< MDL	30.6	2	< MDL	0.446	< MDL
26-Mar-97	BT31	< MDL	< MDL	0.429	< MDL	< MDL	37.7	1.58	< MDL	< MDL	< MDL
30-Jun-97	BT31	< MDL	< MDL	< MDL	< MDL	< MDL	38.7	1.4	< MDL	0.357	0.757
03-Oct-96	BT41	< MDL	< MDL	< MDL	< MDL	< MDL	32.7	< MDL	< MDL	< MDL	< MDL
11-Dec-96	BT41	< MDL	< MDL	< MDL	< MDL	< MDL	33.8	< MDL	< MDL	< MDL	< MDL
26-Mar-97	BT41	< MDL	< MDL	0.015	< MDL	< MDL	30.9	< MDL	< MDL	< MDL	< MDL
30-Jun-97	BT41	< MDL	< MDL	0.435	< MDL	< MDL	33.4	0.217	< MDL	< MDL	< MDL
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10										
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20										
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30										
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40										
03-Oct-96	TCUS	< MDL	< MDL	0.390	< MDL	< MDL	26	0.056	< MDL	< MDL	3.53
11-Dec-96	TCUS	< MDL	< MDL	0.311	< MDL	< MDL	32.4	< MDL	< MDL	< MDL	3.09
26-Mar-97	TCUS	< MDL	< MDL	1.110	< MDL	< MDL	27.8	0.122	< MDL	< MDL	2.55
01-Jul-97	TCUS	< MDL	< MDL	0.345	< MDL	< MDL	31.7	0.255	< MDL	< MDL	2.67
03-Oct-96	TCDS	< MDL	< MDL	0.223	< MDL	< MDL	25.1	0.038	0.014	1.59	6.71
11-Dec-96	TCDS	0.01	< MDL	0.265	< MDL	< MDL	30.5	< MDL	< MDL	0.657	3.89
26-Mar-97	TCDS	< MDL	< MDL	0.674	< MDL	< MDL	25.4	0.098	< MDL	< MDL	2.61
01-Jul-97	TCDS	< MDL	< MDL	0.231	< MDL	< MDL	31.5	0.057	< MDL	0.579	3.73
03-Oct-96	LAG1	0.012	< MDL	0.503	< MDL	< MDL	23.4	0.118	< MDL	3.65	10.7
11-Dec-96	LAG1	0.056	< MDL	1.230	< MDL	0.003	28	< MDL	< MDL	3.03	9.21
26-Mar-97	LAG1	0.007	< MDL	0.540	< MDL	< MDL	23.1	0.14	< MDL	1.97	6.79
01-Jul-97	LAG1	< MDL	< MDL	0.297	< MDL	< MDL	24.8	0.102	< MDL	2.23	7.6
03-Oct-96	LAG2	< MDL	< MDL	0.535	< MDL	< MDL	24.6	0.118	< MDL	3.93	10.8
11-Dec-96	LAG2	0.054	< MDL	0.642	< MDL	< MDL	27.7	0.055	< MDL	3.06	9.22
26-Mar-97	LAG2	0.018	< MDL	0.610	< MDL	< MDL	23.3	0.14	0.091	2.2	6.97
01-Jul-97	LAG2	0.025	< MDL	0.603	< MDL	< MDL	25.3	0.089	< MDL	2.73	7.92
03-Oct-96	BT REP (BT21)	< MDL	< MDL	6.080	< MDL	0.005	44.1	1.91	< MDL	< MDL	4.77
11-Dec-96	BT REP (BT41)	< MDL	< MDL	< MDL	< MDL	< MDL	34.4	< MDL	< MDL	< MDL	< MDL
26-Mar-97	BT DP31	< MDL	< MDL	0.604	< MDL	< MDL	36.5	1.52	< MDL	0.137	0.92
30-Jun-97	BT31D	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
03-Oct-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
11-Dec-96	BT BLANK	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
26-Mar-97	BT EB	< MDL	< MDL	0.013	< MDL	< MDI	< MDL	< MDL	< MDL	< MDL	< MDL

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Chemical Analyses of Water Samples from Wells at Bardstown Sewage Treatment Plant
Total Metals—Continued

Date	*Sample Field ID*	*Selenium (mg/L)*	*Silicon (mg/L)*	*Silver (mg/L)*	*Sodium (mg/L)*	*Strontium (mg/L)*	*Sulfur (mg/L)*	*Tin (mg/L)*	*Vanadium (mg/L)*	*Zinc (mg/L)*
03-Oct-96	BT11	< MDL	7.54	< MDL	31.7	0.124	17.5	< MDL	< MDL	< MDL
11-Dec-96	BT11	< MDL	6.07	< MDL	17.2	0.108	19.3	< MDL	< MDL	< MDL
26-Mar-97	BT11	< MDL	6.86	< MDL	24.4	0.144	46.2	< MDL	< MDL	< MDL
30-Jun-97	BT11	< MDL	8.46	< MDL	35.3	0.158	45.1	< MDL	< MDL	< MDL
03-Oct-96	BT21	< MDL	14.3	< MDL	23.5	0.110	34.1	< MDL	0.009	< MDL
11-Dec-96	BT21	< MDL	14.1	< MDL	17.4	0.095	28.5	< MDL	< MDL	< MDL
26-Mar-97	BT21	< MDL	10.6	< MDL	20	0.094	27.3	< MDL	< MDL	< MDL
30-Jun-97	BT21	< MDL	11.9	< MDL	14.4	0.100	22.8	< MDL	< MDL	< MDL
03-Oct-96	BT31	< MDL	6.3	< MDL	3.77	0.093	6.43	0.123	< MDL	< MDL
11-Dec-96	BT31	< MDL	6.31	< MDL	2.57	0.088	5.69	< MDL	< MDL	< MDL
26-Mar-97	BT31	< MDL	6.86	< MDL	3.63	0.101	9.92	< MDL	< MDL	< MDL
30-Jun-97	BT31	< MDL	7.03	< MDL	2.59	0.110	8.72	< MDL	< MDL	< MDL
03-Oct-96	BT41	< MDL	6.71	< MDL	4.68	0.091	9.83	< MDL	< MDL	< MDL
11-Dec-96	BT41	< MDL	6.13	< MDl	3.12	0.083	8.17	< MDL	< MDL	< MDL
26-Mar-97	BT41	< MDL	5.55	< MDL	2.29	0.075	7.70	< MDL	< MDL	< MDL
30-Jun-97	BT41	< MDL	6.43	< MDL	6.15	0.087	8.40	< MDL	< MDL	< MDL
03-Oct-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT10	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT10									
03-Oct-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT20	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT20									
03-Oct-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT30	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT30									
03-Oct-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
11-Dec-96	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
26-Mar-97	BT40	NE	NE	NE	NE	NE	NE	NE	NE	NE
30-Jun-97	BT40									
03-Oct-96	TCUS	< MDL	4.78	< MDL	8.55	0.069	21.7	< MDL	< MDL	< MDL
11-Dec-96	TCUS	< MDL	5.46	< MDL	8.35	0.068	19.1	< MDL	< MDL	< MDL
26-Mar-97	TCUS	< MDL	5.21	< MDL	6.49	0.057	18.2	< MDL	< MDL	< MDL
01-Jul-97	TCUS	< MDL	4.48	< MDL	7.99	0.063	14.5	< MDL	< MDL	< MDL
03-Oct-96	TCDS	< MDL	4.45	< MDL	30.8	0.11	20	< MDL	< MDL	< MDL
11-Dec-96	TCDS	< MDL	4.79	< MDL	16.6	0.093	17.0	< MDL	< MDL	< MDL
26-Mar-97	TCDS	< MDL	4.51	< MDL	8.65	0.062	14.1	< MDL	< MDL	< MDL
01-Jul-97	TCDS	< MDL	4.14	< MDL	14	0.086	20.7	< MDL	< MDL	< MDL
03-Oct-96	LAG1	< MDL	4.7	< MDL	57.2	0.148	19.9	< MDL	< MDL	0.133
11-Dec-96	LAG1	< MDL	5.69	< MDL	48.3	0.188	19.5	< MDL	< MDL	< MDL
26-Mar-97	LAG1	< MDL	4.59	< MDL	36.1	0.141	17.5	< MDL	< MDL	< MDL
01-Jul-97	LAG1	< MDL	5.05	< MDL	36.3	0.141	16.9	< MDL	< MDL	< MDL
03-Oct-96	LAG2	< MDL	5.23	< MDL	59	0.159	20.5	< MDL	< MDL	< MDL
11-Dec-96	LAG2	< MDL	5.54	< MDL	50	0.199	20.4	< MDL	< MDL	< MDL
26-Mar-97	LAG2	< MDL	4.78	< MDL	37.6	0.142	18.2	< MDL	< MDL	< MDL
01-Jul-97	LAG2	< MDL	5.25	< MDL	38.4	0.149	17	< MDL	< MDL	< MDL
03-Oct-96	BT REP (BT21)	< MDL	13.7	< MDL	24.1	0.112	34.1	< MDL	0.167	< MDL
11-Dec-96	BT REP (BT41)	< MDL	6.28	< MDL	3.14	0.085	8.19	< MDL	< MDL	< MDL
26-Mar-97	BT DP31	< MDL	6.79	< MDL	3.74	0.098	9.77	0.105	< MDL	0.154
30-Jun-97	BT31D	NM	NM	NM	NM	NM	NM	NM	NM	NM
03-Oct-96	BT BLANK	< MDL	0.048	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
12-Dec-96	BT BLANK	< MDL	0.068	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
27-Mar-97	BT EB	< MDL	0.113	< MDL	0.057	< MDL	0.074	< MDL	< MDL	< MDL

MDL = minimum detection limit NE = not enough water to sample REP = replicate sample NM = not measured

Bacteria Counts
(MPN / 100 ml)

01-Jul-97	*BT11*	*BT21*	*BT31*	*BT41*	*BT10*	*BT20*	*BT30*	*BT40*	*TCUS*	*TCDS*
Coliform	75	238	31	659	150	870	1,920	10	17,800	40,600
E. coli	0	0	0	0	0	0	10	0	42	164

Appendix C:
Analytical Methods

Kentucky Geological Survey
Computer and Laboratory Services

Analysis Parameters

July 2000

Inorganic—Metal

Method: EPA 200.7 and SW846-6010A, B–Inductively Coupled Plasma (ICP)

Element	*MDL (µg/L)*	*Element*	*MDL (µg/L)*
Aluminum	41	Magnesium	5
Antimony	60	Manganese	0.5
Arsenic	12	Nickel	5
Barium	3	Phosphorus	6
Beryllium	0.2	Potassium	170
Boron	2	Selenium	11
Cadmium	8	Silicon	4
Calcium	21	Silver	10
Chromium	14	Sodium	62
Cobalt	2	Strontium	14
Copper	9	Sulfur	5
Gold	2	Thallium	75
Iron	9	Tin	138
Lead	20	Vanadium	13
Lithium	6	Zinc	2

Method: EPA 200.9 and SW846-7000 series–GFAA

Element	*MDL (µg/L)*	*Element*	*MDL (µg/L)*
Arsenic	1.70	Cadmium	1.90
Chromium	1.60	Copper	1.45
Lead	1.36	Nickel	2.11
Antimony	10	Selenium	5

MDL: method detection limit

Kentucky Geological Survey
Computer and Laboratory Services
Analysis Parameters
July 2000

Inorganic—Nonmetal

Parameter	*Method*	*MDL (µg/L)*
Miscellaneous		
Acidity	EPA 305.1	8
Alkalinity	EPA 310.1	3
Bicarbonate	Calculated	3
Carbonate	Calculated	1
Conductance	SW846-9050A	1*
pH	SW846-9040	*
Oxygen (dissolved)	EPA 360.1	0.010
Specific gravity	ASTM D1429D	1.000*
Total hardness	EPA 130.2	1.00
Anions		
Bromide	SW846-9056	1.00
Bromide (low level)^R	SW846-9056	0.05
Chloride	SW846-9056	1.00
Chloride(low level)^R	SW846-9056	0.03
Fluoride	SW846-9056	0.01
Sulfate	SW846-9056	5.00
Nutrient		
Ammonia–nitrogen	SM 4500-NH_3 F	0.02
Kjeldahl–nitrogen	SM 4500-N_{org} C	0.07
Nitrate–nitrogen	SW846-9056	0.02
Nitrite–nitrogen	EPA 354.1	0.002
Orthophosphate	EPA 365.3	0.009
Total phosphorus	ASTM D 515	0.05
Residue		
Suspended solids	EPA 160.2	3
Dissolved solids	EPA 160.1	10
Demand		
TOC	SW 846-9060	1

MDL: method detection limit
SM: standard methods
^{R}: Range: 0.1–1.0 ppm
*: standard conductance, pH, and specific gravity units