UMTRA
Ground Water Project

Tuba City, Arizona, UMTRA Project Site Semi-Annual Performance Evaluation September 2002 through February 2003

September 2003

Prepared by the
U.S. Department of Energy
Grand Junction Office

Work Performed Under DOE Contract No. DE–AC13–02GJ79491 for the U.S. Department of Energy

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1.0 Introduction

This report evaluates the performance of the ground water remediation system at the Uranium Mill Tailings Remedial Action (UMTRA) project site near Tuba City, Arizona (Figure 1) for the period of September 2002 to March 2003, and cumulatively since the system became operational in March 2002. The evaluation is based primarily on a comparison of site conditions in February 2003 with baseline conditions defined by data collected between 1999 and February 2002, before startup of the remediation system (DOE 2003). This report completes the semi-annual performance evaluation requirements for the first year of treatment system operation, March 2002 to March 2003.

The ground water remediation system at the site consists of 25 ground water extraction wells completed within the contaminant plume, ion-exchange and distillation systems for water treatment, evaporation ponds for waste brine, and an infiltration trench and six injection wells to return treated water to the aquifer. To date, the injection wells have not been used; all treated ground water has been discharged into the infiltration trench or evaporated. The primary features of the site, including the remediation system and ground water monitor wells, are shown in Figure 2.

1.1 Remediation System Performance Standards

This performance assessment is based on the analysis of (1) water quality and water level data obtained from site monitoring wells, and (2) monitoring results of the volume and composition of water passing through the treatment system. Specific performance standards as established for the Tuba City ground water remediation system (DOE 2003) are summarized as follows:

- Horizontal hydraulic gradients should point in the direction of the extraction wells.
- For effective capture when the extraction wells are operating, vertical hydraulic gradients above and below the extraction well screens should be downward and upward, respectively.
- The extraction system should ultimately reduce the size of the contaminant plume.
- Approximately 30.3 million pounds of dissolved contaminants above applicable standards are in ground water beneath the Tuba City site. The extraction system should decrease contaminant mass over time.
- The design cumulative pumping rate for the extraction wells is 80 to 100 gallons per minute (gpm). The actual cumulative pumping rate should be close to this range of values.
- Drawdown in the vicinity of the extraction wells is predicted to approach 30 feet (ft). If the extraction well field is performing as expected, actual drawdown should approximate the design drawdown.
- The capture zone of the existing extraction system should bracket those portions of the plume having the greatest dissolved contaminant mass.
- The treatment system was designed to treat 100 gpm with an on-stream factor of 85 percent. The actual influent rate will be compared to the design influent rate to verify that the system is performing as expected.
- The distillation system is designed to produce effluent of less than 50 milligrams per liter (mg/L) total dissolved solids. The actual effluent dissolved solids concentration will be compared to the design effluent concentration to assess treatment effectiveness.

- The distillation system was designed to produce approximately 15 percent of the original volume of influent water as concentrated brine. Deviation from this percentage is an efficiency performance measure of the distillation process.

1.2 Contaminants of Concern and Remediation Goals

Ground water at the site is contaminated as a result of uranium milling activities between 1956 and 1966. Ground water contaminants of potential concern (COPC) at the Tuba City site include nitrate, molybdenum, uranium, sulfate, strontium, selenium, and cadmium. With the exceptions of sulfate and strontium, Safe Drinking Water Act maximum concentration limits (MCLs) apply to these constituents, and are the goals for restoring ground water quality at the site (Table 1 [DOE 1999]). The Navajo Nation proposed a cleanup level for sulfate of 250 mg/L (DOE 1998), which DOE will attempt to achieve. A remediation goal for strontium has not been formally established.

1.3 Hydrogeologic Setting

The regional aquifer in the site area is referred to as the N-Aquifer (Cooley et al. 1969; Eychaner 1983), which consists of, in descending order, the Navajo Sandstone, the Kayenta Formation (sandstone), and the Moenave Formation (Cooley et al. 1969). In the study area, an approximately 250 to 350 ft thick transitional unit, referred to as the intertonguing interval, lies between the classic Navajo Sandstone and the Kayenta Formation (Middleton and Blakey 1983; DOE 1998). The saturated portion of the classic Navajo Sandstone beneath the site is approximately 100 to 150 ft thick. The combined saturated thickness of the classic Navajo Sandstone and the intertonguing interval is the focus of ground water remediation at the Tuba City site.

The major geological units are essentially flat lying, although large-scale cross bedding is pervasive in the Navajo Sandstone and portions of the intertonguing interval. Shallow, unsaturated materials overlie the Navajo Sandstone in the vicinity of the Tuba City site; these consist mostly of loose, fine-grained eolian sands in the uppermost 10 to 20 ft below ground surface, and are underlain by alluvial sand and gravel with isolated lenses of clay. Under non-pumping conditions, depth to ground water in the Navajo Sandstone is approximately 35 to 50 ft at the site. The regional ground water flow direction is north to south toward Moenkopi Wash, approximately 2 miles south of the site. Moenkopi Wash is a regional aquifer discharge area. The site lies on the middle of three alluvial terraces associated with ancestral surface flows in Moenkopi Wash. Ground water discharge occurs locally along the steep escarpment separating the middle and lower terraces (Figure 2).

For the purpose of evaluating hydraulic behavior in the subsurface, the N-Aquifer beneath the site is divided into 50-ft intervals. Each 50-ft horizon is assigned a letter designation, beginning with the 5,000 to 5,050-ft elevation interval (Horizon A) and ending with the 4,400–4,450-ft elevation interval (Horizon M). Horizons A through C approximately comprise the classic Navajo Sandstone, Horizons D through J are approximately equivalent to the intertonguing interval, and Horizons K through M are approximately equivalent to the Kayenta Formation (see Table 2). A list of wells with the assigned horizons is provided in Table 3.

2.0 Subsurface Conditions

This section evaluates hydraulic and geochemical effects in the aquifer in response to ground water extraction and injection. Horizontal and vertical hydraulic gradients within and between designated horizons are evaluated in Sections 2.1 and 2.2 to determine flow directions and ground water capture. Water quality data are evaluated in Section 2.3 to determine the extent of contamination. In these evaluations, water quality and water level data obtained from wells 0254 (Horizon I), 0255 (Horizon M), 256 (Horizon I), and 0257 (Horizon M) are regarded as potentially biased because the integrity of these wells may be compromised.

2.1 Ground Water Gradients

2.1.1 Horizontal Hydraulic Gradients

Baseline and February 2003 horizontal hydraulic gradients and magnitudes, as calculated for the various horizons using three-point analyses, are summarized in Table 4. The gradients, calculated using the computer program V3PP (Laase et al. 2002), are graphically portrayed as vectors in Figures 3 and 4, and 6 to 10 to indicate flow direction and relative magnitude. The hachured line across the southeast quadrant of Figures 3, 4, and 6 to 10 represents the trace of the escarpment separating the middle and lower terraces.

Horizon A

Computed horizontal hydraulic gradient directions in Horizon A represent the water table at the site (Figure 3). A comparison of the gradients for baseline and February 2003 conditions suggests that, since startup of the treatment system in the spring of 2002, horizontal hydraulic gradients have shifted slightly towards the east and increased in magnitude, probably in response to recharge from the infiltration trench. The limited number of monitor wells screened in Horizon A prevents further evaluation of horizontal flow in that interval.

Horizon B

Comparison of baseline and February 2003 horizontal gradients in Horizon B (Figure 4) shows the gradient south of well 0934 has shifted approximately 180° from the baseline gradient direction, and now points northward, in the direction of nearby extraction wells (not shown). The extent of influence of the extraction well field, as depicted by the three-point analysis, compares favorably with the design capture zone predicted by a site ground water flow model (DOE 1998), as shown in Figure 5. The model indicates that capture extends to about 400–500 ft east and west of the extraction well field, and about 250 ft south of the southernmost extraction wells.

Figure 4 also suggests ground water mounding associated with the infiltration trench as evidenced by a relatively strong southeastward horizontal hydraulic gradient just south of the trench. Relatively consistent gradient directions and magnitudes south of well 0267, which is located about 1,800 ft south of the southwest corner of the disposal cell, indicate that the extraction system appears to have minimal, if any, effect on gradients in this area.

Horizon C

Computed horizontal gradient directions in Horizon C are illustrated in Figure 6. The extraction wells have caused a near reversal in flow in Horizon C north of well 932 and a change in flow directions south of extraction wells 1117 and 1118. The new flow directions point towards nearby extraction wells. Again, the extent of influence of the extraction well field, as depicted by the three-point analysis, compares favorably with the design capture zone predicted by a site ground water flow model, as shown in Figure 5. Figure 6 further indicates that the extraction wells have a minor influence on ground water flow in the vicinity of a terrace escarpment that traverses the site in a southwesterly direction about 500 to 1,500 ft south of the extraction well field.

Horizon D

Water-level measurements could not be obtained in all of the extraction wells during the period of evaluation due to obstructions within the wells. The available water levels in Horizon D wells show the influence of pumping as evidenced by the reversal in flow directions in the wells located along or near the southeast corner of the disposal cell (Figure 7; well labels omitted for clarity). February 2003 ground water flow patterns south of the escarpment are similar to baseline conditions suggesting that the extraction wells minimally influence horizontal ground water flow direction in this portion of the site. Again, the extent of influence of the extraction well field in Horizon D, as depicted by the three-point analysis, compares favorably with the design capture zone predicted by a site ground water flow model (Figure 5).

Horizon E

Figure 8 presents a single horizontal hydraulic gradient calculated for February 2003 conditions in Horizon E, utilizing hydraulic head data from the same three monitor points applied under the baseline evaluation. The February 2003 gradient direction is virtually identical to the baseline direction. Most of the extraction wells have screens extending into Horizon E. The absence of flow vectors pointing towards the extraction wells does not mean capture is not being achieved at this depth; rather, the extent of capture cannot be characterized by horizontal flow vectors due to a lack of wells having screens centered on this interval. If sufficient E Horizon wells existed to define capture extent, it is likely the extent of capture would mimic that of Horizons B through D.

The magnitude of the recent gradient vector is slightly smaller than the baseline magnitude (see Table 4). This suggests that, while the extraction wells may have minimal effect on ground water flow direction south of the capture zone created by the extraction wells, pumping might reduce the rate at which contaminants in this area migrate away from the site.

Horizons G and I

Figures 9 and 10, which contain velocity vector plots for Horizons G and I, respectively, show virtually no change in horizontal gradients between baseline and February 2003 conditions. This suggests that the extraction wells exert no noticeable influence on horizontal hydraulic gradients in these deeper horizons. A likely explanation for this observation is that none of the screened intervals in the extraction wells extends into Horizons G or I. The deepest screened interval in the extraction wells is Horizon E (DOE 2003).

2.1.2 Vertical Hydraulic Gradients

Table 5 presents a comparison of baseline and February 2003 vertical hydraulic gradients between horizons. (Erroneous vertical gradients presented in the previous performance evaluation report [DOE 2003b] have been corrected in Table 5 of this document.) In Horizons A through C, located above Horizon D where the majority of the extraction wells are centered, February 2003 vertical gradients are generally positive, indicating the potential for downward flow. Four of the five listed gradients for these upper horizons in February 2003 are larger than their baseline equivalents. The single vertical gradient that does not fit this pattern is observed at well pair 908/912. However, if measured heads in these two wells from months other than February 2003 are taken into account, the computed vertical gradients at this location are consistently downward and much larger than the comparable baseline gradient. Such observations suggest that the pumping of extraction wells increases the downward flow potential above Horizon D, particularly beneath the middle terrace where the bulk of the contaminant plume resides.

At paired wells 914 and 915, flow between Horizons C and D remained upward during the evaluation period although the vertical gradient has been reduced, presumably due to pumping. Upward flow from mid to upper horizons at this location on the middle terrace may result from seepage and evapotranspiration along the escarpment, where Horizons A, B, and C are exposed. Vertically downward flow at this location was indicated from the mid to lower horizons, as indicated by the vertical gradient between well 915 and co-located G horizon well 916. The downward potential between these wells existed prior to and during pumping. Split vertical flow within the intermediate-depth horizons at this location may result from local, shallow ground water discharge at the escarpment (upward flow) and regional discharge of the deeper horizons at Moenkopi Wash (downward flow).

Well pair 0691/1003 (Horizons C and D, respectively), located on the lower terrace, showed very slight upward or neutral vertical hydraulic gradients throughout the evaluation period. Pre-pumping (baseline) water levels differed less than about 0.2 ft from each other at these wells and indicated a slight downward flow potential.

Within the deeper horizons, water level data for the evaluation period indicate upward vertical flow gradients between the E and I horizons at middle terrace well pairs 251/252 and 268/256, which differs from the downward gradient observed at these locations under baseline conditions. The reversal in the vertical gradient between these horizons suggests that operation of the extraction system prevents further downward contaminant migration on the middle terrace. On the lower terrace, a downward vertical gradient was observed between Horizons E and I during the baseline period at wells 920 and 921. This condition persisted through the evaluation period though the magnitude of the gradient was decreased.

Consistent with baseline conditions, the vertical gradient between Horizons I and M at middle terrace well pair 254 (I) and 255 (M) remained downward during the evaluation period. At wells 256 (I horizon) and 257 (M horizon), the vertical gradient reversed from downward, as observed under the baseline condition, to upward during the evaluation period. Water level fluctuations were greater in well 256 than in well 257. The gradient reversal suggests that the deep horizons could be affected by the extraction system in the southeast portion of the millsite area.

2.2 Water Table

The estimated water table associated with baseline conditions is shown in Figure 11a. Baseline conditions indicate generally southward flow. The baseline water table gradient is relatively uniform beneath the area of the disposal cell and becomes steeper approaching the escarpment, where ground water discharge occurs. The baseline water table map was constructed with water levels measured in Horizon A, B, and C wells prior to the onset of full-scale ground water extraction in June 2002. Horizon A and B wells were used in the middle terrace area because the top of the saturated zone drops several tens of feet between the north end of the disposal cell and the escarpment and, in doing so, intersects both horizons. Water table levels below the lower terrace were estimated using Horizon C levels because the A and B horizons are absent in this area. Water levels in deeper wells were not used because relatively strong vertical gradients are observed at the site, suggesting that measured heads in Horizon D and deeper are not representative of a water table condition.

It should be noted that the baseline water table map in this report (Figure 11a) differs from baseline maps presented in earlier reports (DOE 2003a, DOE 2003b). This is because water levels in Horizon A wells 941, 686, 687, and 688 are taken into account in this evaluation, but were omitted from the previous evaluations.

Water levels from the set of baseline monitor wells shown in Figure 11a were also used to estimate the water table in February 2003 (Figure 11b). The water table at that time indicated ground water mounding along the north edge of the disposal cell. This local effect of increased hydraulic gradients in Horizons A and B was caused by infiltration of treatment system effluent placed in the infiltration trench. Mounding appears greatest toward the southwest end of the trench. This occurs either because most infiltration of treatment effluent enters the southwest end of the trench and is relatively insignificant in other portions of the trench; or, the resistance to vertical flow in Horizon A is larger below the southwestern part of the trench.

Further comparison of Figures 11a and 11b indicates that decreased water levels due to operation of the extraction wells has produced a trough-shaped depression in the water table that trends south from the southwest corner of the disposal cell. Drawdown of the water table east of the disposal cell where extraction wells are located cannot be evaluated because shallow monitor wells in this area are lacking.

2.3 Contaminant Distributions

Plume maps showing the distribution of dissolved nitrate in Horizon A during baseline conditions and February 2003, respectively, are shown in Figures 12a and 12b. Similar comparisons are provided for nitrate in Horizons B through E in Figures 13 through 16. Analogous plume maps for sulfate, uranium, selenium, and strontium contamination in Horizons A through E are given in Figures 17 through 35. (Erroneous uranium concentrations for wells 1104, 1105, 1106, and 1120 presented in the baseline report [DOE 2003a] and the previous performance evaluation report [DOE 2003b] have been corrected in this document.) Other contaminants, such as molybdenum and cadmium, have been detected in ground water, but the detections are sporadic and provide insufficient data points to construct meaningful plume maps.

Tables 6 through 10 present the contaminant concentration data used to construct the plume maps. The baseline condition maps are based primarily on water quality data from spring 2002; however, 1999–2001 contaminant data were used to augment the baseline data sets in instances where spring 2002 data were absent.

The plume concentration maps indicate that there are generally minimal differences between baseline and February 2003 conditions in Horizons A, B, and C for all constituents evaluated. However, there appears to be a significant decrease in the February 2003 ground water concentrations of contaminants from the baseline concentrations in Horizon A in the vicinity of the infiltration trench (Figures 12a, 12b, 17a, 17b, 22a, 22b, 27a, 27b, 31a, and 31b). The decreases, particularly well demonstrated at wells 0686 and 0687, are the result of dilution by inflow of treated water discharged into the trench. For example, in well 0687, the nitrate concentration has decreased from 60.6 to 12.6 mg/L and the sulfate concentration from 329 to 31 mg/L. Though it is possible that similar dilution occurs in Horizons B and C, a lack of monitor wells screened in these horizons near the infiltration trench makes it difficult to discern such effects.

Between baseline and August 2002 conditions, constituent concentrations and plume geometries in Horizons D and E appeared to change relatively dramatically. This was particularly true for extraction wells in Horizon D, where average nitrate, sulfate, and uranium concentrations were reduced by 38 percent, 41 percent, and 39 percent, respectively (DOE 2003b). Such large decreases were not observed, however, in the February 2003 samples. Rather, concentrations were closer to baseline values as average nitrate, sulfate, and uranium concentrations in the extraction wells were only 10 percent, 12 percent and 4 percent less than average baseline concentrations, respectively. The apparent concentration differences between the two sampling events probably results from differences in the time of sampling relative to the extraction rates (slower extraction or a period of non-pumping would likely result in higher concentrations) rather than persistent changes in the subsurface concentrations.

Only three locations were sampled to establish baseline concentrations for nitrate in Horizon E (Figure 16a). Prior to extraction, a single nitrate concentration (426 mg/L) at one location (well 0251) in this horizon exceeded the 44 mg/L standard. The high value of 426 mg/L was not confirmed by a second pre-extraction sampling. Two of the 3 locations in Horizon E (including 0251) were sampled in August 2002 and February 2003. Nitrate concentrations were less than the 44 mg/L standard by August 2002 (DOE 2003b) and were similarly low in February 2003 (Figure 16b). Sulfate and uranium concentrations in Horizon E had a similar pattern to that of nitrate. Well 0251 had a baseline sulfate concentration of 617 mg/L (Figure 21a), but sulfate in both Horizon E wells sampled in February 2003 was less than 19 mg/L (Figure 21b). The baseline uranium concentration in well 0251 was 0.0481 mg/L (Figure 26a) but only 0.0016 mg/L in the February 2003 sampling (Figure 26b). It appears that no contamination currently exists in Horizon E.

3.0 Extraction System Performance

3.1 Ground Water Extraction Rates

Twenty-five extraction wells operated simultaneously during the review period. Continuous ground water extraction was not possible due to treatment system malfunction. The average total discharge rate from the extraction well field from September 2002 through February 2003 was 82 gpm. The pumping rate from the extraction well field fluctuated between 0 and 125 gpm for the period (Figure 36). The fluctuations were caused by down-periods for the treatment system and are not indicative of the capacity of the wells to produce water. A rate of approximately 110 gpm was sustained during December 2002 through mid-January 2003.

Pumping rates for individual extraction wells are not available for the period of review. These rates are currently being recorded and will be analyzed in the future, in combination with measured concentrations and water levels at individual wells, to evaluate the relative ability of each well to supply water to the treatment system and to determine where the greatest reduction in plume mass can be achieved.

3.2 Contaminant Recovery

The contribution of contaminated ground water from various horizons is difficult to evaluate because of the wide variation in depths and lengths of wells screens. From uranium concentration data for the pumping wells, Horizon D appears to be highly contaminated; however, screens on the pumping wells are 100 to 150 ft long and span Horizons B through E. There are five contaminated wells that are screened only in Horizon D. These wells (0258, 0261, 0264, 0266, and 0915) had baseline uranium concentrations of 0.0018, 0.0018, 0.0033, 0.0019, and 0.0017 mg/L, respectively. These relatively low concentrations suggest that Horizon D may not be a large reservoir of contaminated ground water. However, the wells screened uniquely in Horizon D are marginal to the main plume area. Additional wells screened solely in Horizon D are needed in the plume area to fully evaluate the extent of contamination in that horizon.

Wells screened in Horizon C also exhibit relatively low uranium concentrations; for example, wells 0684, 0912, 0914, and 0932 had baseline uranium concentrations of 0.0019, 0.034, 0.0013, 0.0016 mg/L, respectively. Similar to Horizon D, however, most of the wells screened solely in Horizon C may be marginal to the main plume, and so contaminant distribution in Horizon C may not be fully characterized.

In contrast to Horizons C and D, consistently high uranium concentrations occur in wells screened solely in Horizons A and B (Figures 22a and 23a). It is possible that a large proportion of contaminated ground water is being drawn into the extraction wells from the interval that is screened in Horizon B. An evaluation should be made to determine if pumping only from Horizons A, B, and possibly C could increase contaminant recovery.

The gross performance of the extraction system for uranium recovery during the evaluation period is also illustrated in Figure 36. The total extraction rates and uranium concentrations plotted in the figure are based on weekly monitoring of the bulk feed to the treatment system. The average feed composition for the period was about 0.31 mg/L. An inverse correlation between extraction rate and bulk uranium concentration is suggested in the figure.

3.3 Water Level Mounding

Modeling performed as part of the remedial system design process (DOE 1998) predicted approximately 5 ft of mounding adjacent to the infiltration trench. This mounding was expected to occur uniformly along the length of the trench, as the treated water from the distillation system is released to the trench about halfway between its endpoints. Table 12 presents baseline and February 2003 drawdown and water elevation data. Mounding at the infiltration trench is not symmetrical; rather it is primarily confined to the western end of the infiltration trench (Figure 11b). Up to 18 ft of mounding occurs at the western end as opposed to little to none at the eastern end of the infiltration trench. Discussion of the possible causes of the mounding is included in Section 2.2.

As determined from borehole log information, the estimated elevation of the base of mill tailings in the disposal cell at the location of well 907, formerly located in what is now the southeast quadrant of the disposal cell, is 5,057 ft. The elevation of the water table at well 946, located between the disposal cell and the west end of the infiltration trench (i.e., several hundred feet northwest of the southeast corner of the disposal cell), was about 5,052 ft in February 2003 (5,054 ft in June 2003). Utilizing the injection wells or other existing drains to return some of the treated water to the aquifer would minimize the potential for the mound to intersect the tailings and mobilize contaminants to ground water.

3.4 Water Level Drawdown

Numerical modeling (DOE 1998) of the site also predicted drawdown of 20 to 30 ft within the Navajo Sandstone (approximately equivalent to Horizons A through C) in the immediate area surrounding the extraction wells (Figure 37). Observed drawdown, based on water levels measured on December 18, 2002, and February 11, 2003, are tabulated in Table 12. The December 2002 measurement data was preceded by about 2.5 weeks of continuous extraction exceeding 100 gpm. The extraction system averaged approximately 50 gpm during the month prior to the February 2003 water level measurements.

In general, the model under-predicted drawdown relative to observed values. Drawdown exceeded the predicted design range only at two wells completed in Horizon E (wells 251 and 268), as measured in December 2002. The cause of the high sensitivity to pumping of the E horizon, into which the extraction well screens extend, is unknown. As indicated in Section 2.3, contaminant concentrations in Horizon E ground water are generally low, and so excessive extraction from this horizon may be undesirable.

Significant drawdown is also observed in Horizons G, I, and M (up to 11, 21, and 4.8 ft, respectively). This is not necessarily indicative of ground water capture within theses horizons by the extraction wells, but may instead represent declining water levels due to reduced flows to the deep zones from the overlying horizons. Examples of this possibility include paired wells 254/255 and 920/921, where a downward flow potential was maintained during pumping between Horizons M and I, and E and I, respectively, despite significant drawdown. Counter-examples are well pairs 256/257 (I and M horizons) and 251/252 (E and I horizons), where drawdown was accompanied by upward flow potentials, indicating ground water capture from the deep horizons at the southeast and southwest corners of the well field, respectively.

4.0 Treatment System Performance

4.1 Operating Summary

During the reporting period, the treatment unit was in operation for 3,255 hours out of a possible 4,344 hours, resulting in an on-stream factor of about 75 percent. The unit treated a total of 22,105,398 gallons of water in that period. The average operating feed rate was 113 gpm; accounting for all down time, the effective treatment rate for the period was about 85 gpm.

4.2 Mass Removal Summary

Contaminant mass removal is summarized in Table 13 for nitrate, sulfate, and uranium. The remediation system has been in full operation since about June 2002. Assuming that future mass removal rates are equivalent to the cumulative rates as of March 2003, remediation of the nitrate, sulfate, and uranium plumes will require 58, 34, and 17 years since June 2002, respectively. This assumption is valid if volumetric extraction rates increase over time to compensate for decreasing concentrations of contaminants in the ground water. The predicted times are also conditional on the accuracy of the mass of COPCs initially present in the aquifer, as estimated in the baseline report (DOE 2003a). For example, the erroneous uranium concentration reporting noted in Section 2.3 may have resulted in underestimating the initial mass of uranium in the baseline report.

4.3 Treated Water Quality

The average total dissolved solids (TDS) concentration of the effluent of the treatment system was 91 mg/L for the review period. This compares to the design specification of 50 mg/L. The slightly elevated TDS values were the result of internal leaks within the unit, which have since been repaired to return the effluent to the design specification.

The treatment system operated to produce 5 percent brine by volume of the system feed. In addition, about 10 percent of system influent was sent to the evaporation pond as waste from the pre-treatment softener (ion exchange).

5.0 Performance Summary

Findings from the September 2002 through February 2003 performance evaluation at the Tuba City site are as follows:

- Horizontal hydraulic gradients in the vicinity of the extraction wells and the infiltration trench are influenced by the remediation system. In Horizon A, mounding associated with the infiltration trench shifts horizontal gradient directions from south to southeast. In Horizons B, C, and D operation of the remediation system causes a reversal in gradient direction, with ground water now flowing back towards the extraction well field. The observed horizontal extent of influence (capture zone) is consistent with that predicted by modeling.

- Vertical gradients in Horizons A, B, and C are downward within the plume area. This indicates vertical capture from the horizons above the mid-screen interval of the extraction wells.
- Upward vertical gradients were observed within the paired wells that are screened in Horizons E and I within the plume area on the middle terrace. This may prevent further downward migration of contaminants below Horizon D. This also indicates that some uncontaminated ground water is being extracted and treated. Downward gradients between Horizons C, E, and I at wells 903, 920, and 921, located on the lower terrace, were observed both under baseline conditions and during the evaluation period. Ground water at this location is marginally contaminated with nitrate only.
- Vertical gradients between the intertonguing interval and Kayenta Formation during pumping varied depending on location. Within the center of the extraction field, the vertical gradient was downward and equivalent in magnitude to the baseline condition (based on water levels in wells 254 [I horizon] and 255 [M horizon]). At the southeast and southwest corners of the extraction field, the vertical gradient was upward, representing a reversal in the vertical flow potential at those locations from the baseline condition (wells 256/257 [I and M horizons], and wells 251/252 [E and I horizons]).
- Observed asymmetrical mounding at the infiltration trench departs from model predictions. The observed mound may result from non-uniform distribution of influent water to the infiltration trench or hydraulic conductivity variation within the upper bedrock horizons beneath the trench. Ground water mounding at the trench will be closely monitored to prevent saturation of mill tailings in the disposal cell.
- Observed drawdown near the extraction wells (approximately 5 to 19 ft) was generally less than model-predicted values (20 to 30 ft). Much greater drawdown (52 and 40 ft, respectively) was observed at Horizon E wells 251 and 268, located within the extraction well field. Maximum drawdown at the remaining E horizon well (well 920, located on the lower terrace) was about 13 ft and exceeded the drawdown at most Horizon A, B, and C monitor wells located near and within the extraction field.
- The design cumulative pumping rate for the existing extraction well field is 80 to 100 gpm. The average total pumping rate from this evaluation period was 82 gpm. Currently, the extraction system is capable of sustaining a total pumping rate of 100 gpm.
- Comparisons of plume concentration maps prepared for both February 2003 and baseline conditions in Horizons A through C indicate that generally minimal differences occur between the two time periods. In contrast to the August 2002 data, contaminant concentrations and plume geometries in Horizon D are little changed from baseline conditions. Although concentration data in Horizon E are limited to two locations, this horizon now appears to be uncontaminated.
- The stratigraphic distribution of baseline contamination suggests that Horizons A and B are relatively highly contaminated and are important target intervals for extraction. The extent of contamination in Horizons C and D is less well defined. Most wells screened exclusively in those horizons are marginal to the main plume area.
- Observed decreases in COPC concentrations in Horizon D are largely from extraction well data, which are affected by pumping during remedial system operation.
- Current contaminant removal rates, relative to the estimated initial pre-remediation mass in ground water are approximately 2, 3, and 6 percent per year, for nitrate, sulfate, and uranium, respectively. The corresponding period required to meet remediation objectives at

current removal rates are 58, 34, and 17 years since the system became fully operational in June 2002. To maintain the current mass removal rate as contaminant concentrations decrease, the ground water extraction rate will need to increase.

6.0 Recommendations

On the basis of the preceding review, the following recommendations are provided as means to improve remedial system performance at Tuba City, or improve the ability to evaluate system performance:

- Monitor pumping rates at individual extraction wells on a weekly basis and drawdown at extraction wells monthly.
- Examine potential methods for increasing the pumping rates from Horizons A, B, and possibly C.
- Examine in greater detail the chemistry of COPCs at the site including analysis of major ion chemistry using Piper diagrams and bivariant plots (time verses concentration) of selected contaminants for selected wells. This analysis will be used to identify regions of the aquifer contributing ground water to the extraction wells.
- Return treated effluent to the ground water system using existing injection wells or the disposal cell runoff channels to mitigate mounding at the infiltration trench. Evaluate the cause of the asymmetrical ground water mound at the infiltration trench.
- Develop a global metric, based on monitoring well data only (to avoid the variation in pumping well data) that can be calculated semi-annually to evaluate contaminant concentration changes in the subsurface.
- Develop a structural cross-section of all monitoring and pumping wells showing vertical location of well screens. Consider cross-sectional plots of contaminant data.
- Eliminate some of the concentration maps to improve the clarity of presentation. Omit strontium and selenium from discussions in semi-annual reports (this would eliminate 10 maps). Consider combining Horizons A and B for contaminant plots (eliminates 5 maps).
- Prepare maps directly from the project database to minimize the possibility of transcription errors.
- Use ground water modeling to evaluate possible causes of apparent vertical gradients and to evaluate deep horizon response to ground water extraction.
- Determine if bentonite from annular seals has invaded the screens at wells 254, 255, 256, and 257. If so, consider abandoning the wells to prevent possible cross-contamination of deep horizons.

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Figures

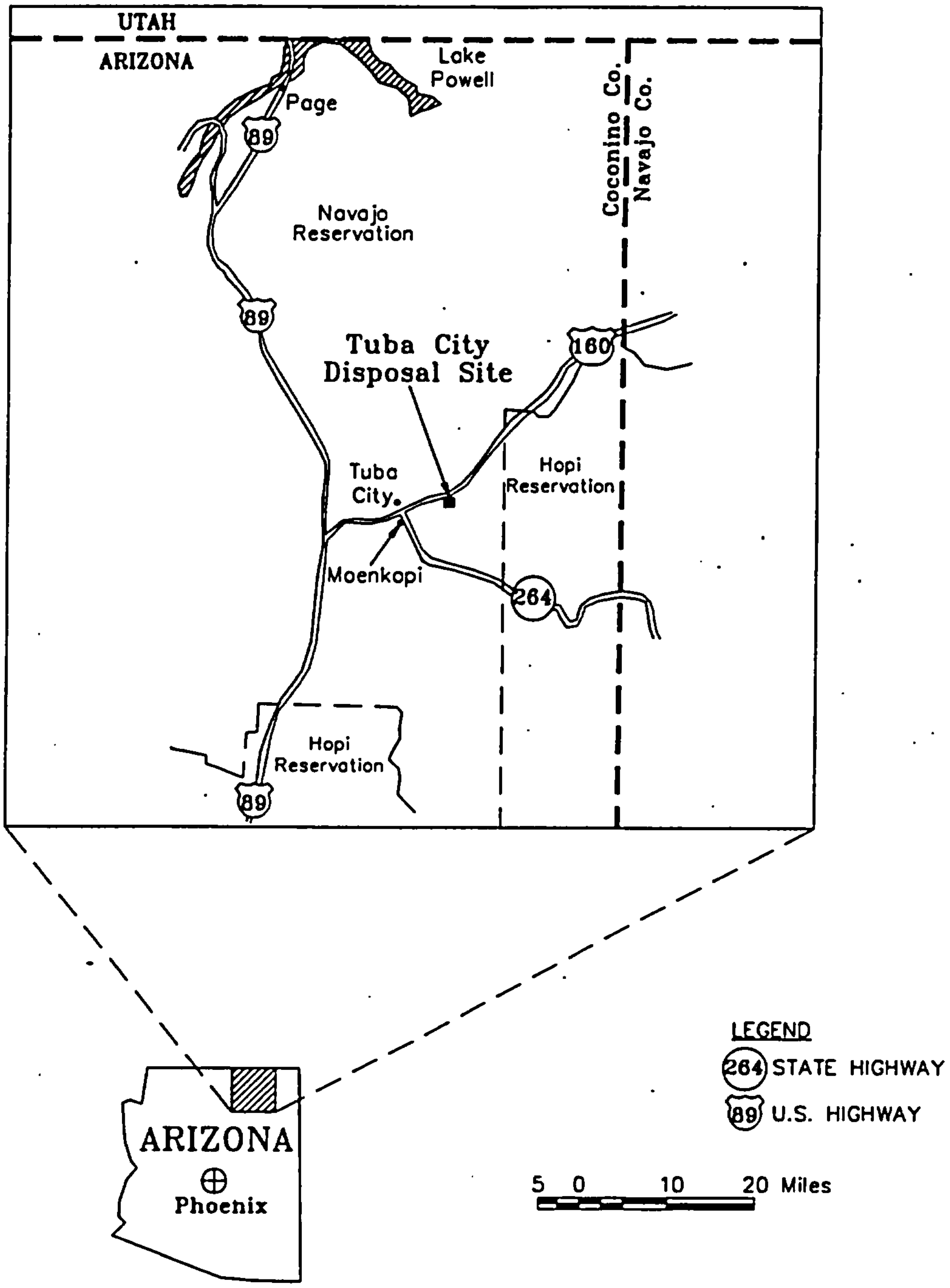

Figure 1. Tuba City UMTRA Project Site Location

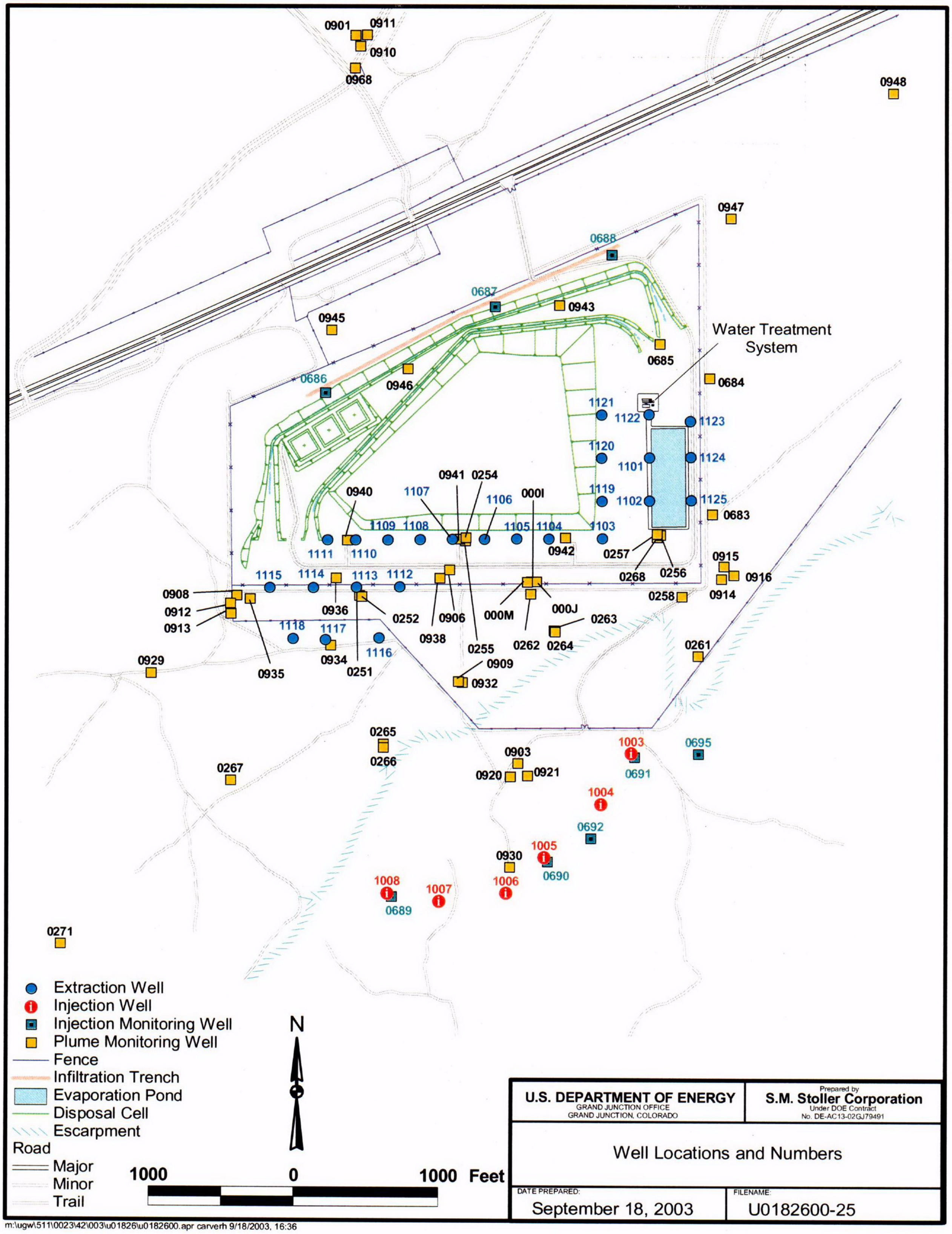

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Figure 2. Location of Extraction and Injection Wells and Infiltration Trench

C01

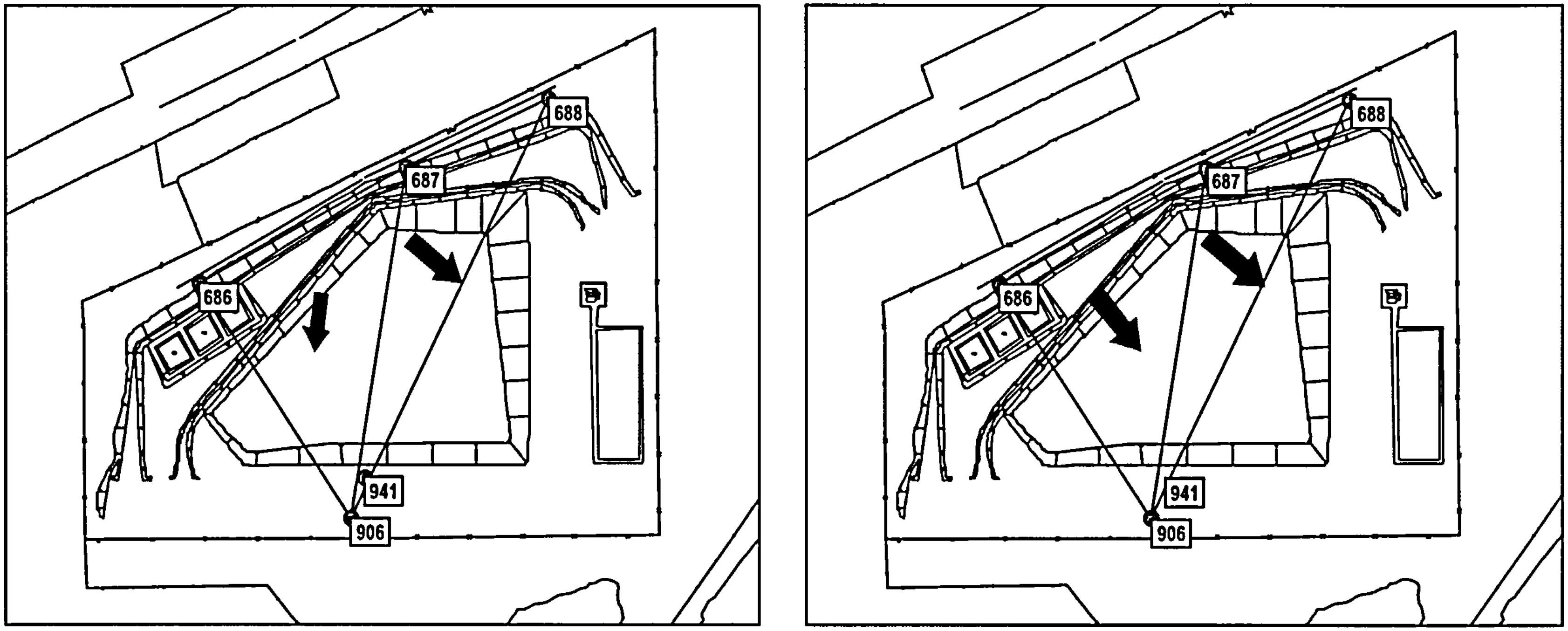

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Figure 3. Baseline and February 2003 Horizon A Horizonal Hydraulic Gradients

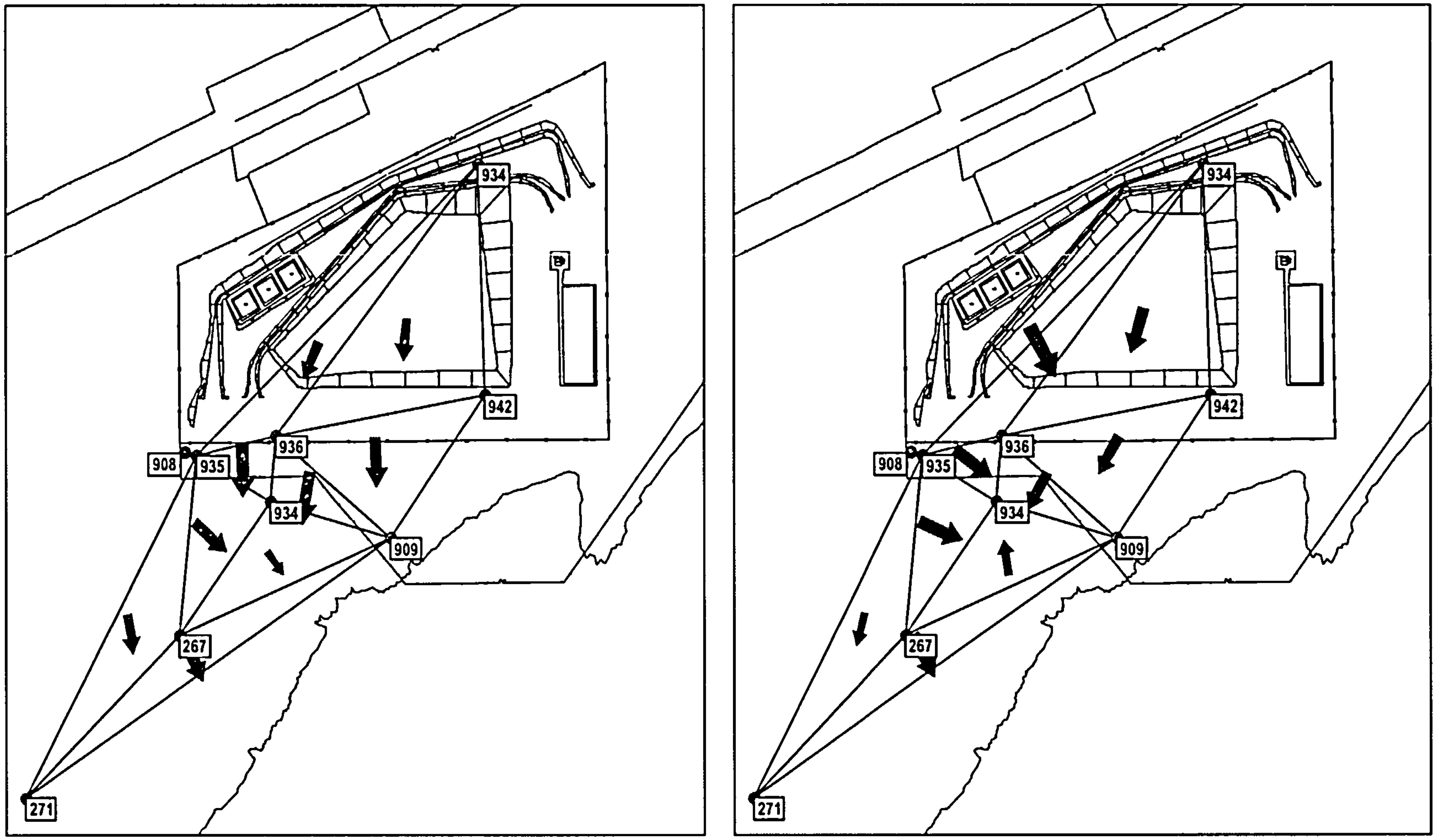

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Figure 4. Baseline and February 2003 Horizon B Horizonal Hydraulic Gradients

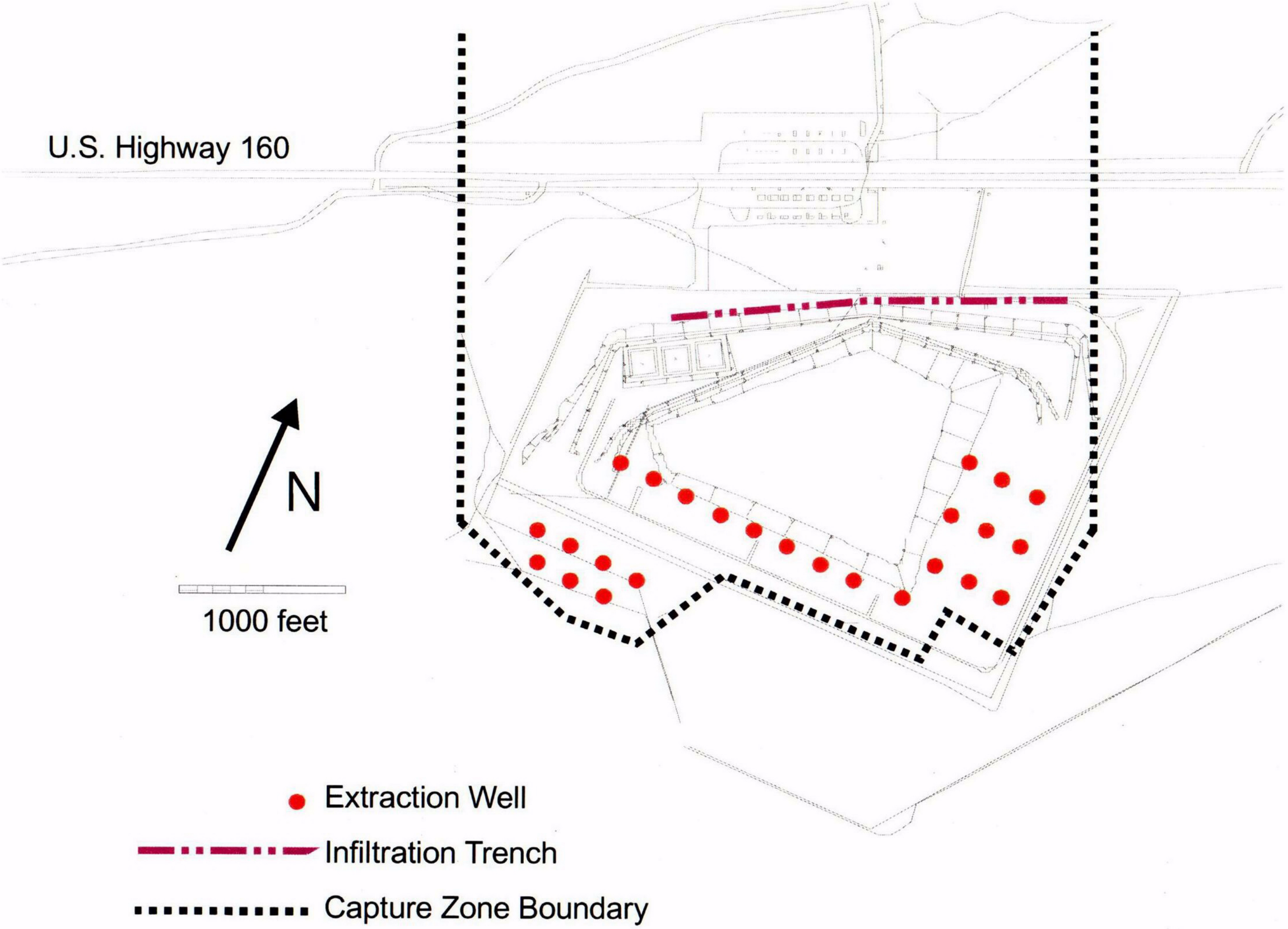
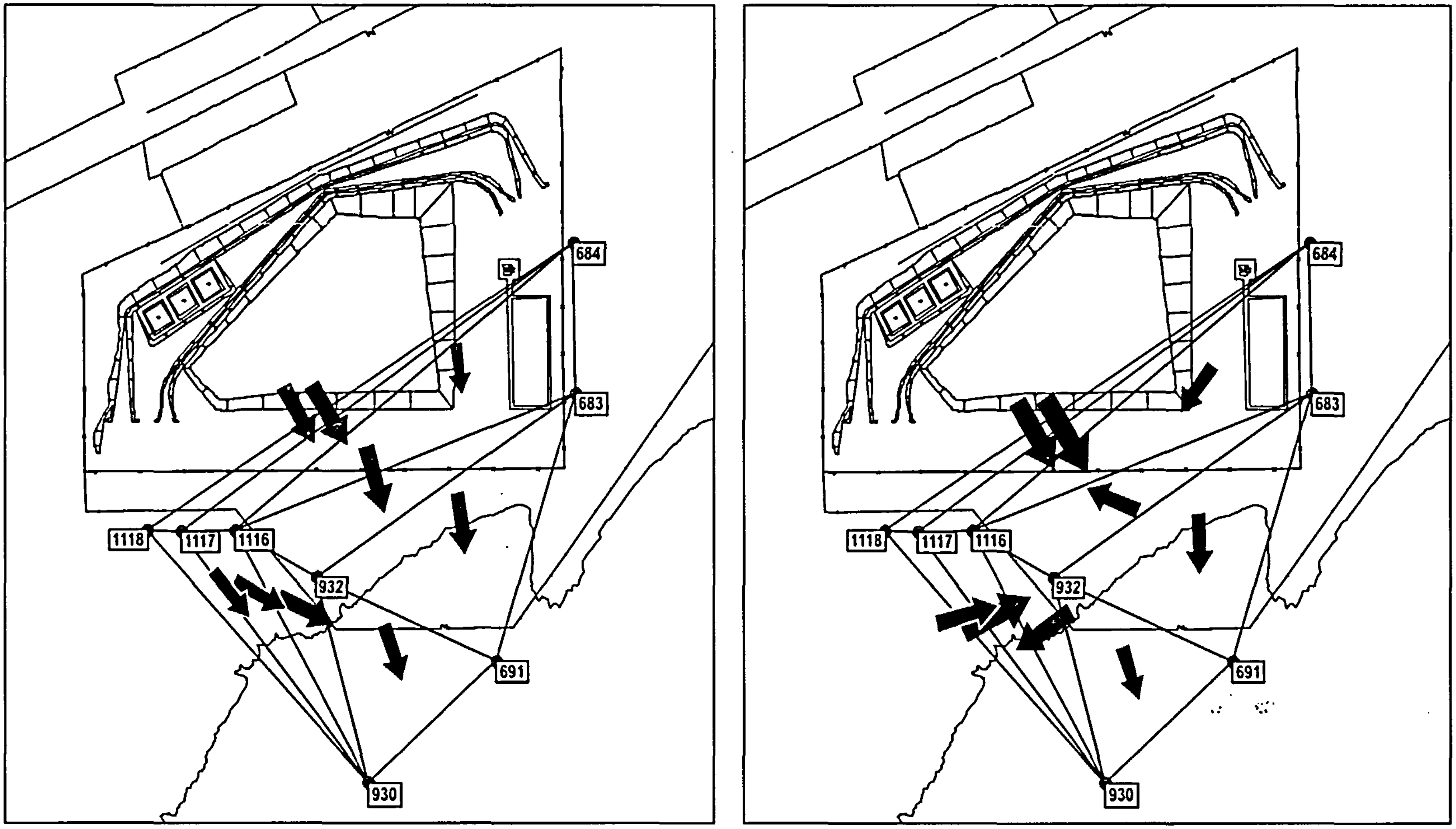


Figure 5. Capture Zone Predicted by the Site Ground Water Flow Model

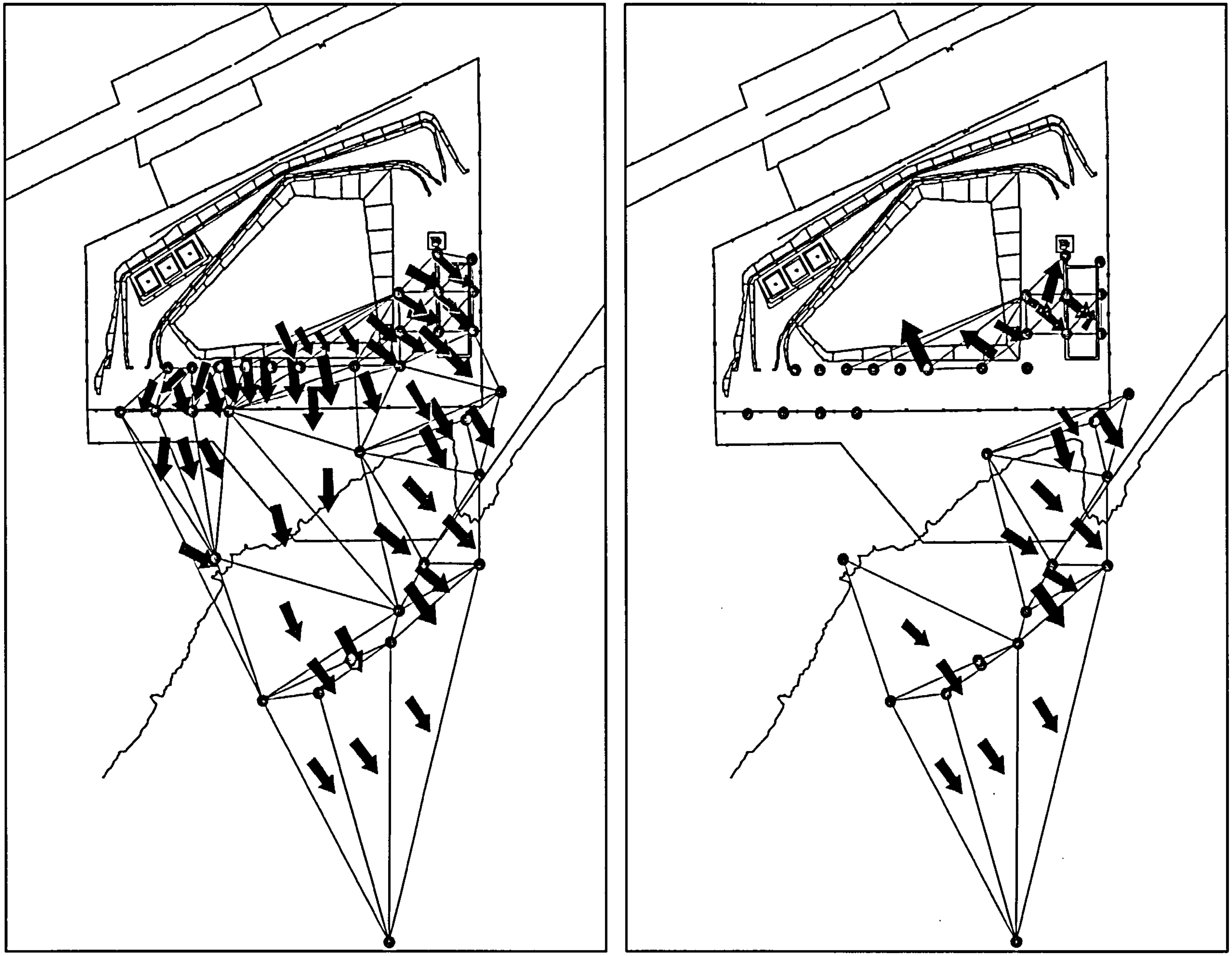
C02



September 2000

February 2003

Figure 6. Baseline and February 2003 Horizon C Horizonal Hydraulic Gradients



September 2000

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Figure 7. Baseline and February 2003 Horizon D Horizonal Hydraulic Gradients

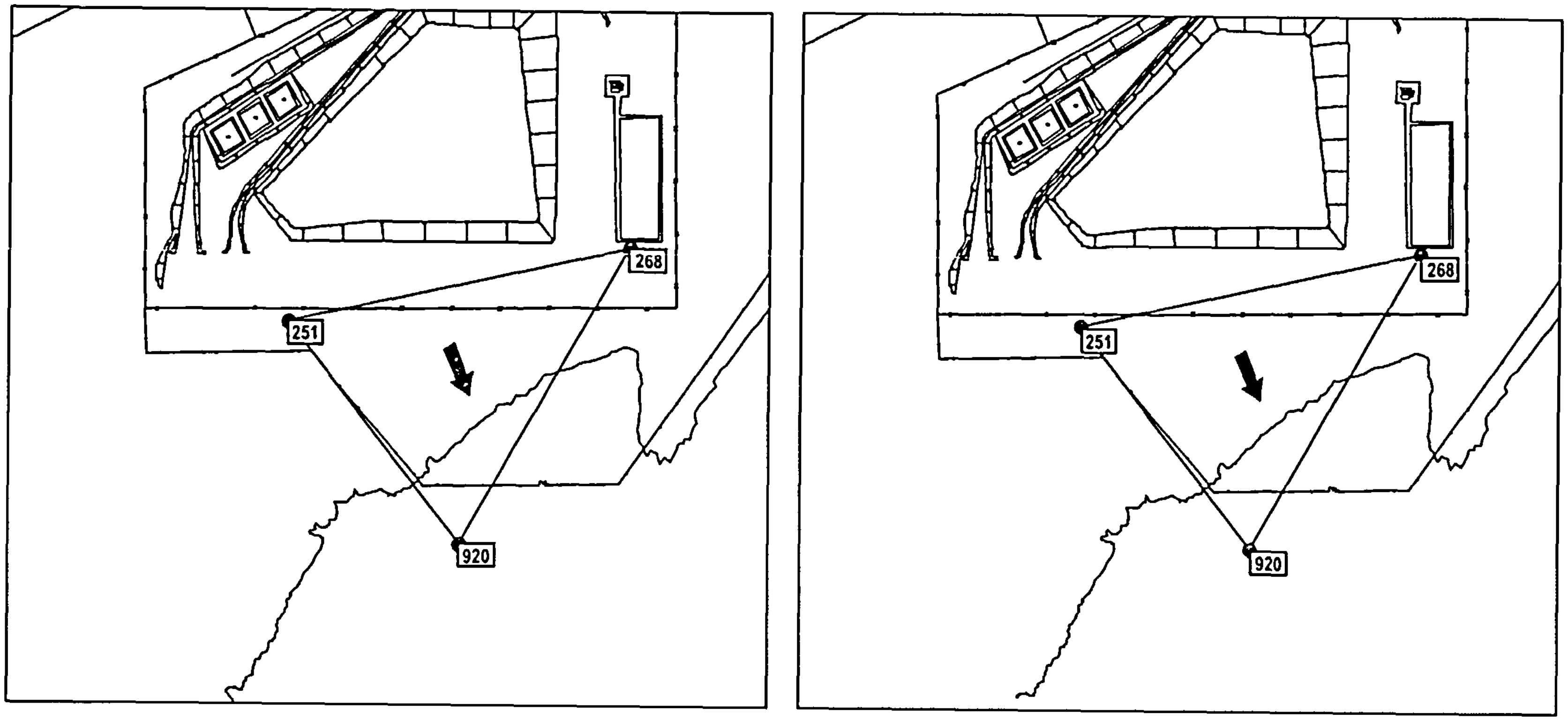

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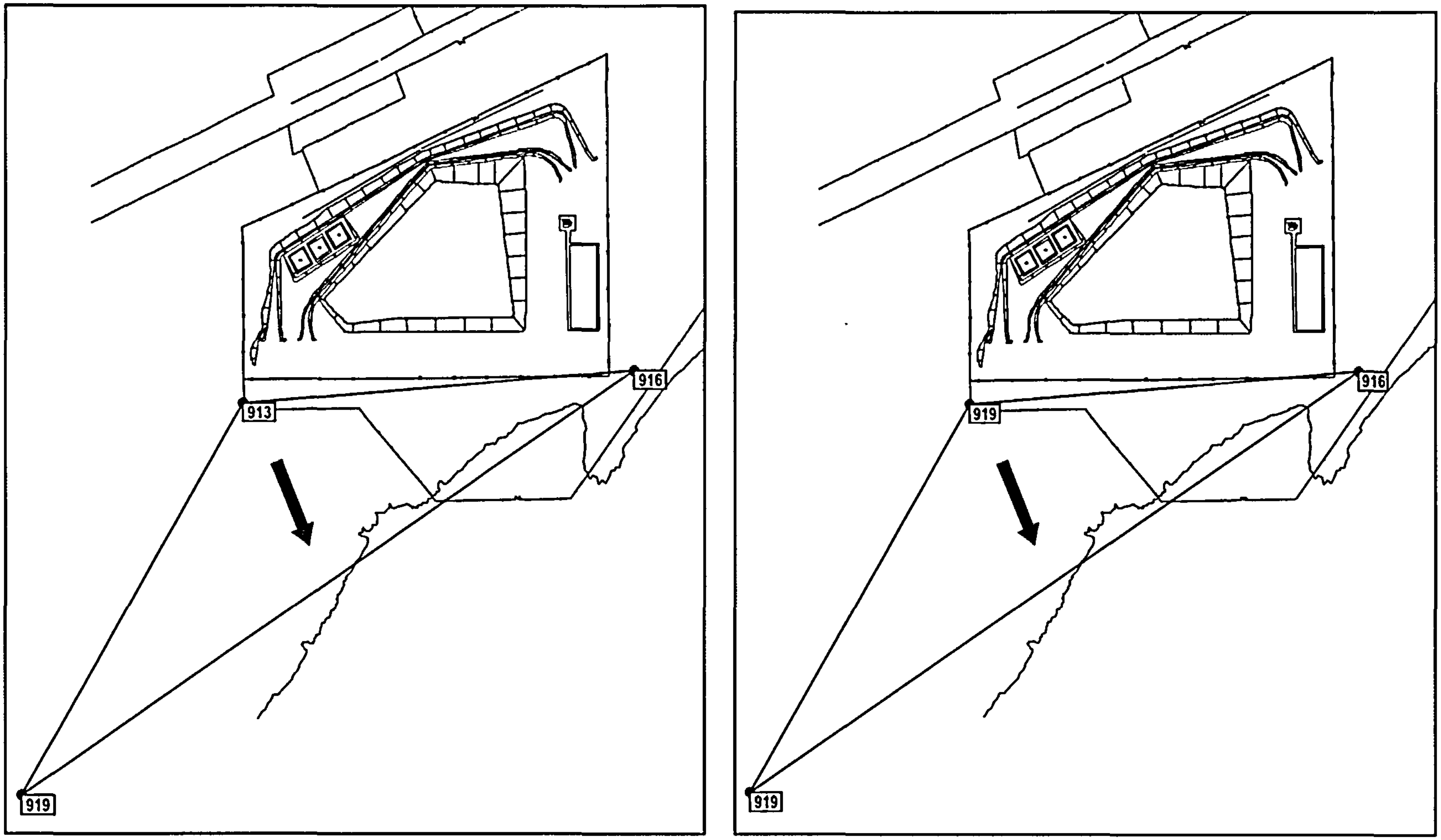
Figure 8. Baseline and February 2003 Horizon E Horizonal Hydraulic Gradients



September 2000

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Figure 9. Baseline and February 2003 Horizon G Horizonal Hydraulic Gradients

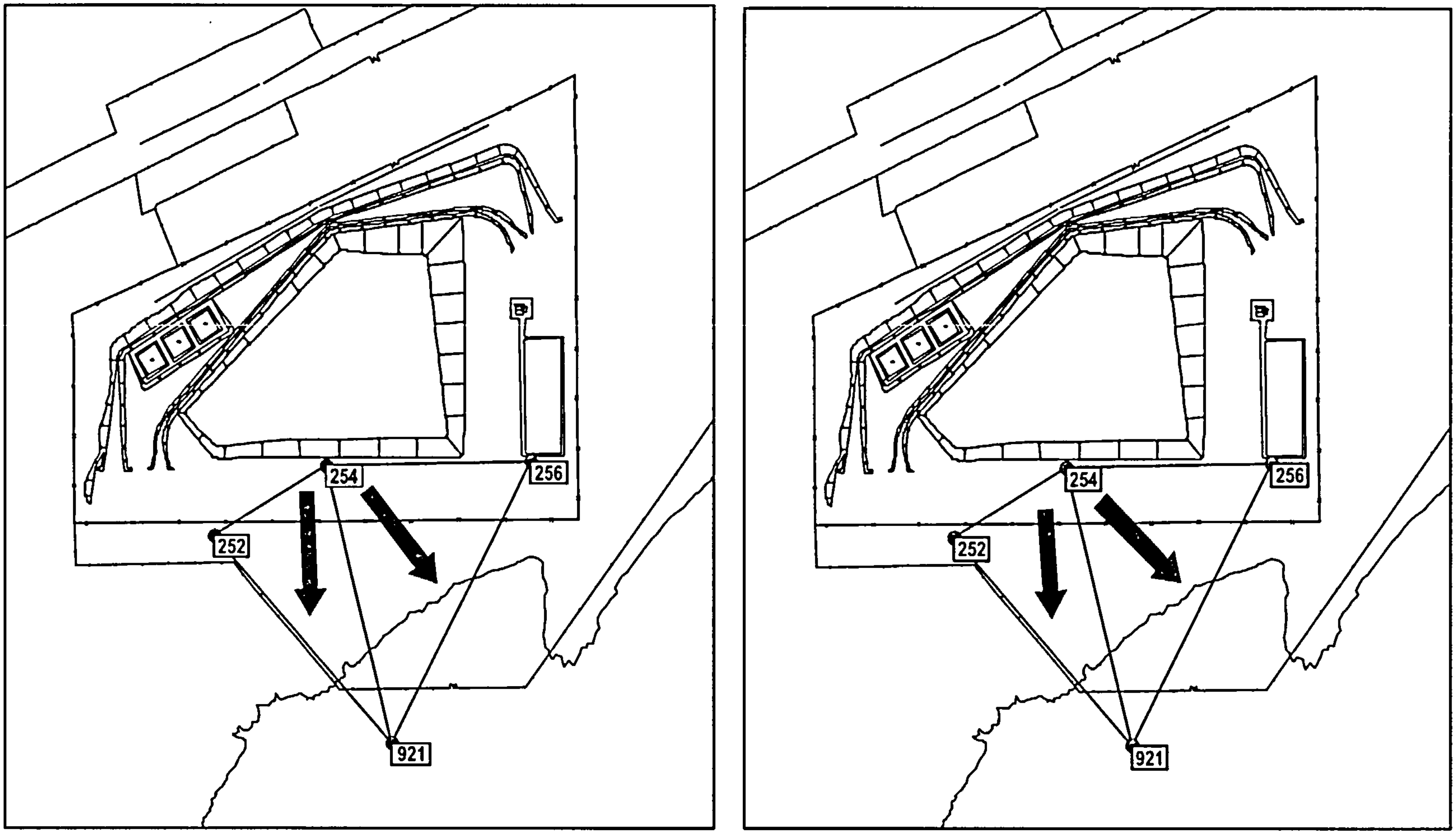

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Figure 10. Baseline and February 2003 Horizon I Horizonal Hydraulic Gradients

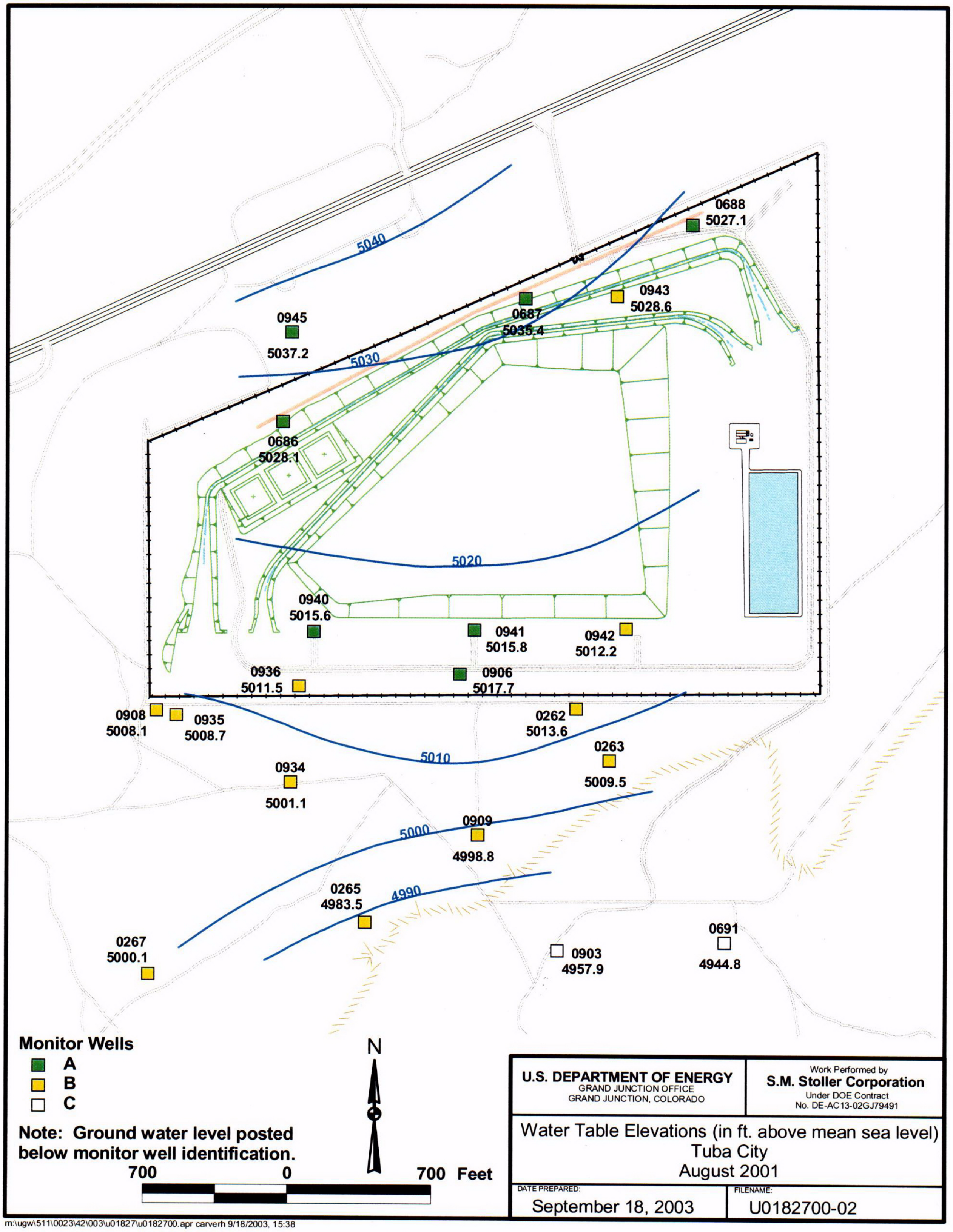

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Figure 11a. Baseline Water Table

CO3

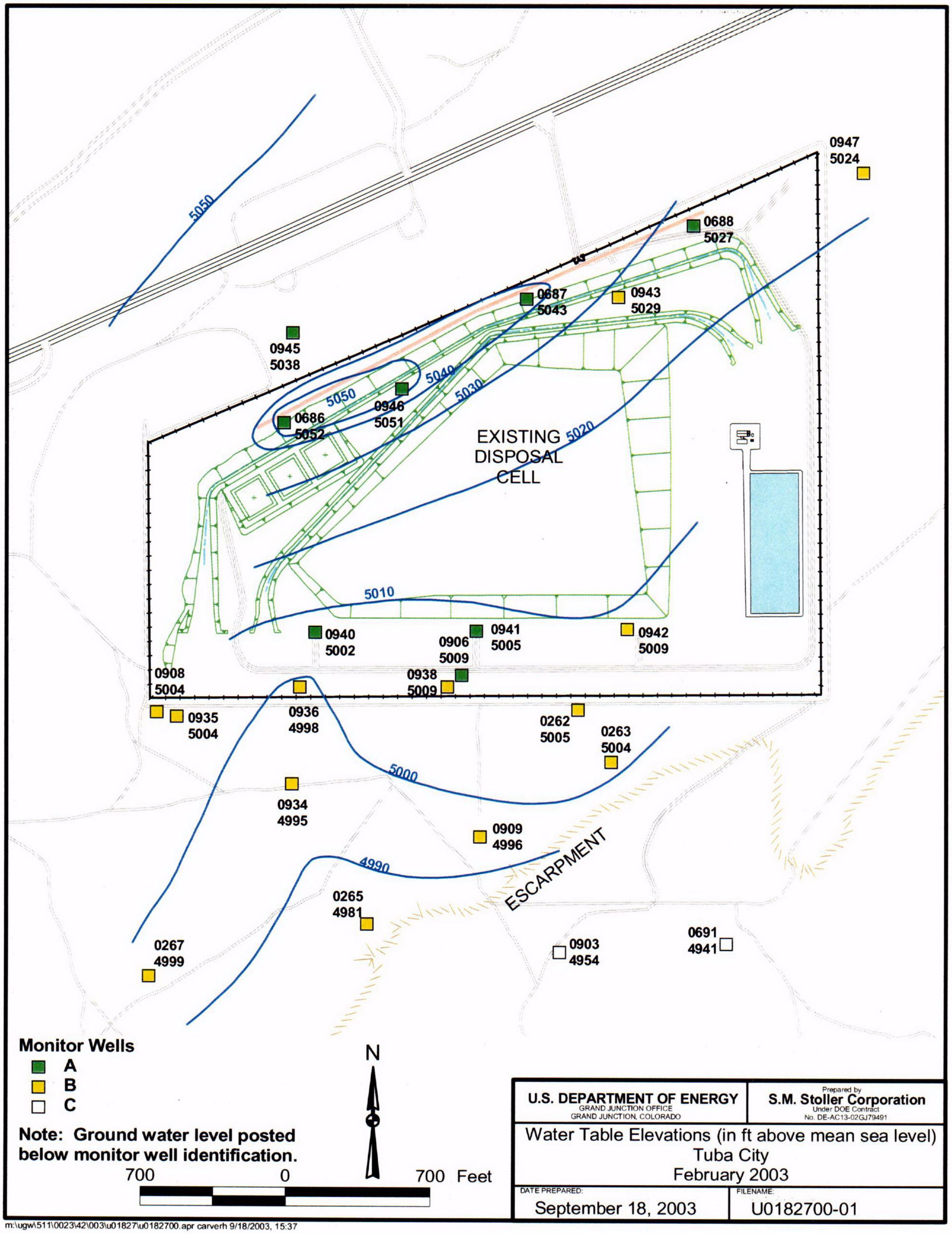

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Figure 11b. February 2003 Water Table

C04

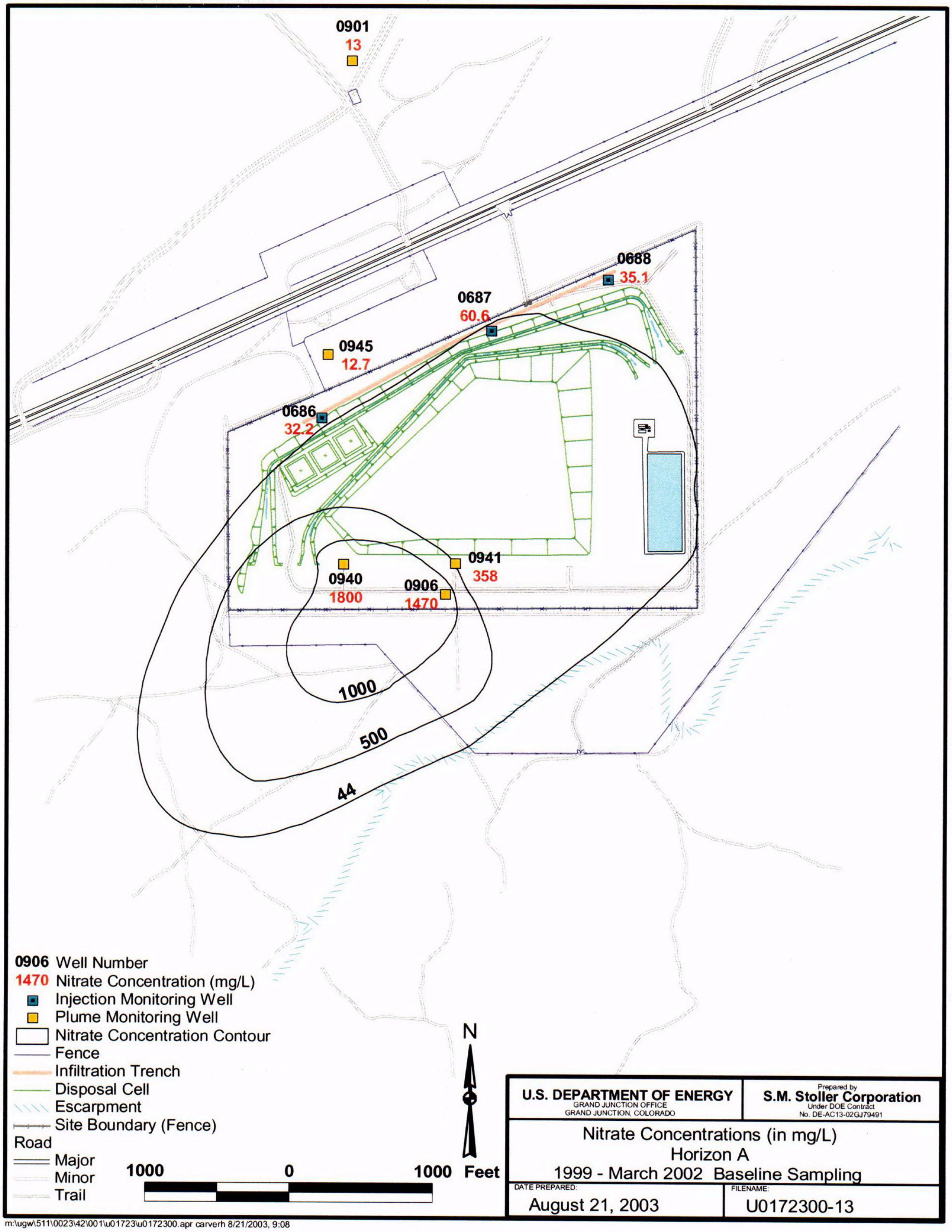

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Figure 12a. Baseline Horizon A Nitrate Ground Water Concentrations

C05

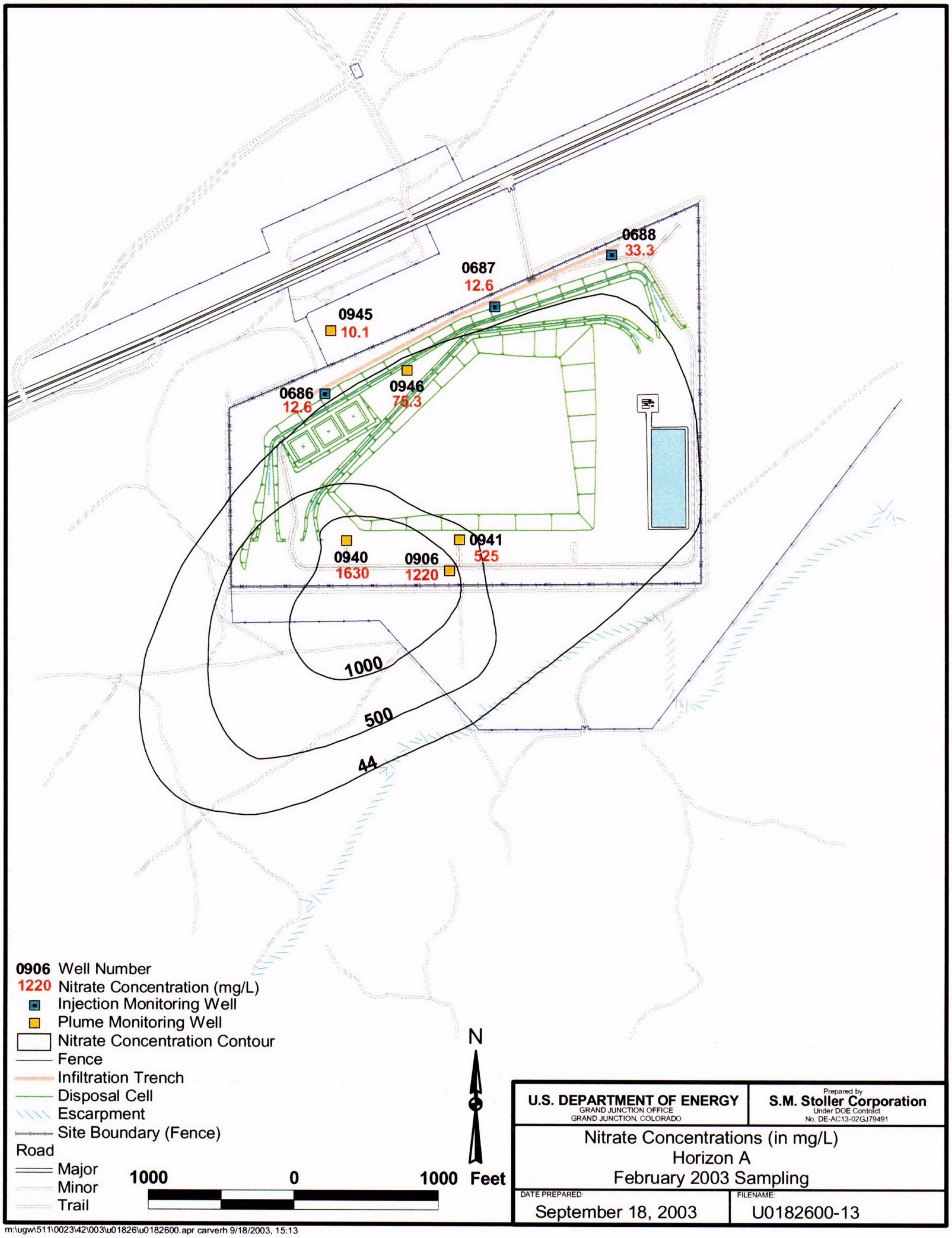

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Figure 12b. February 2003 Horizon A Nitrate Ground Water Concentrations

006

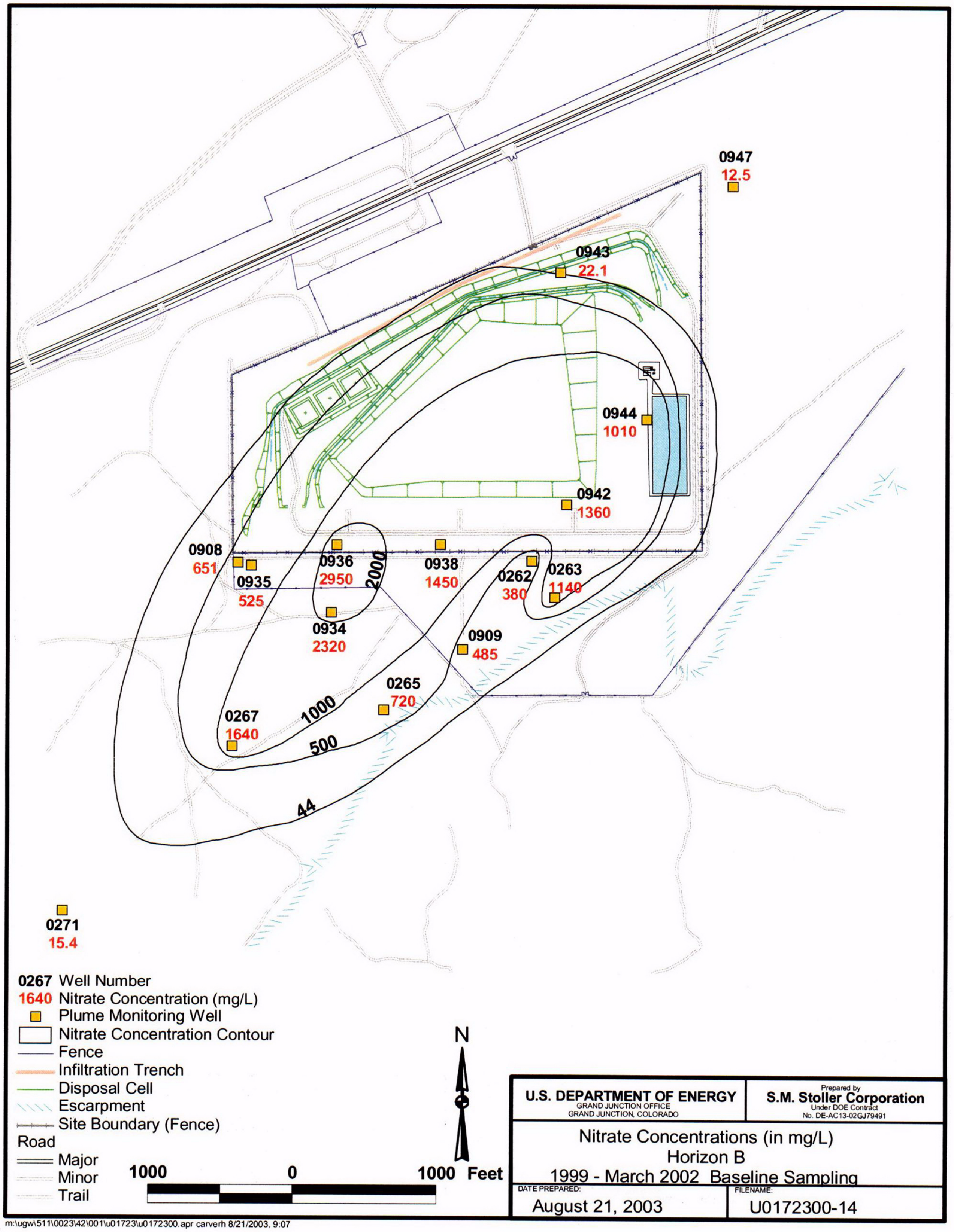

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Figure 13a. Baseline Horizon B Nitrate Ground Water Concentrations

C07

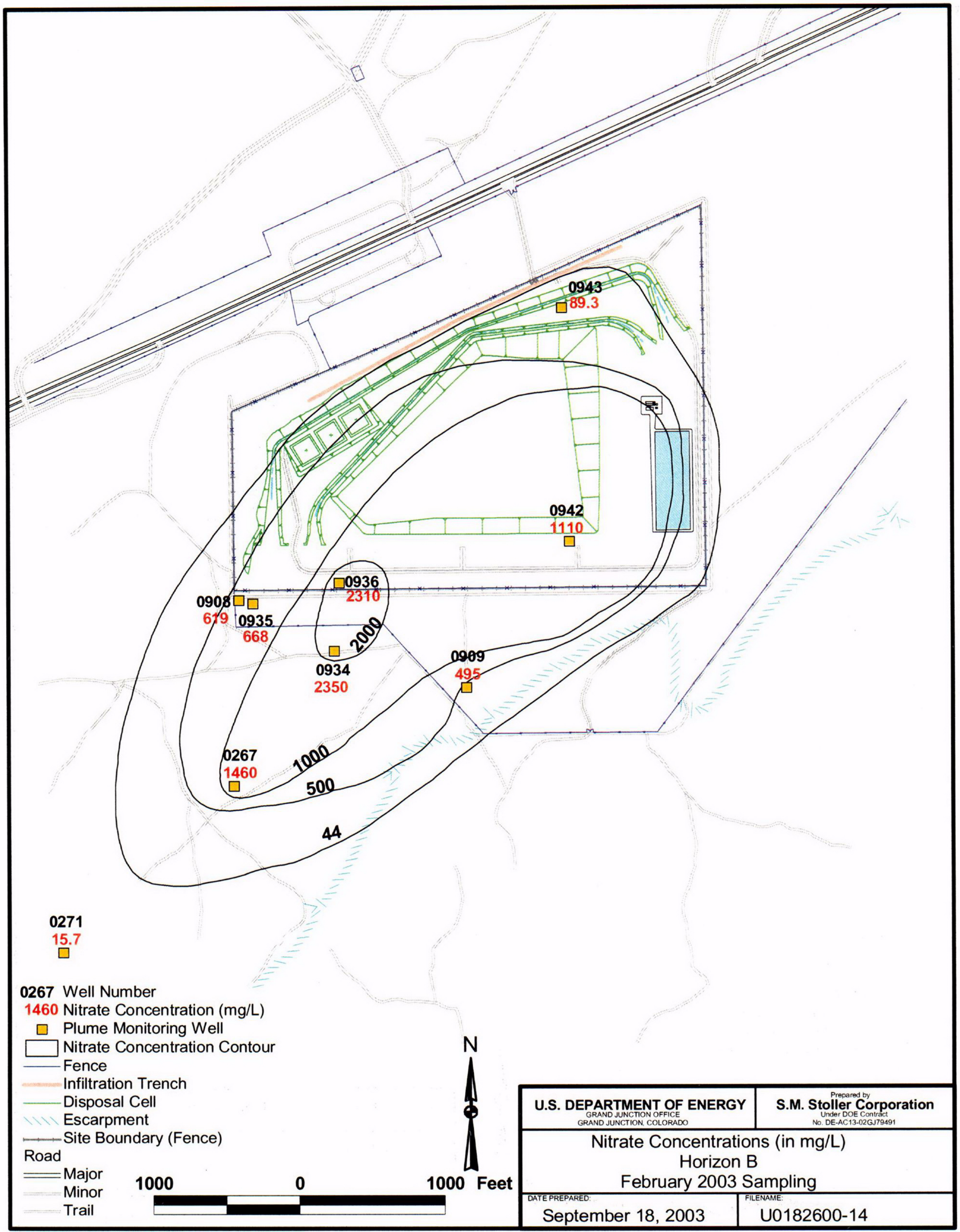

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Figure 13b. February 2003 Horizon B Nitrate Ground Water Concentrations

C08

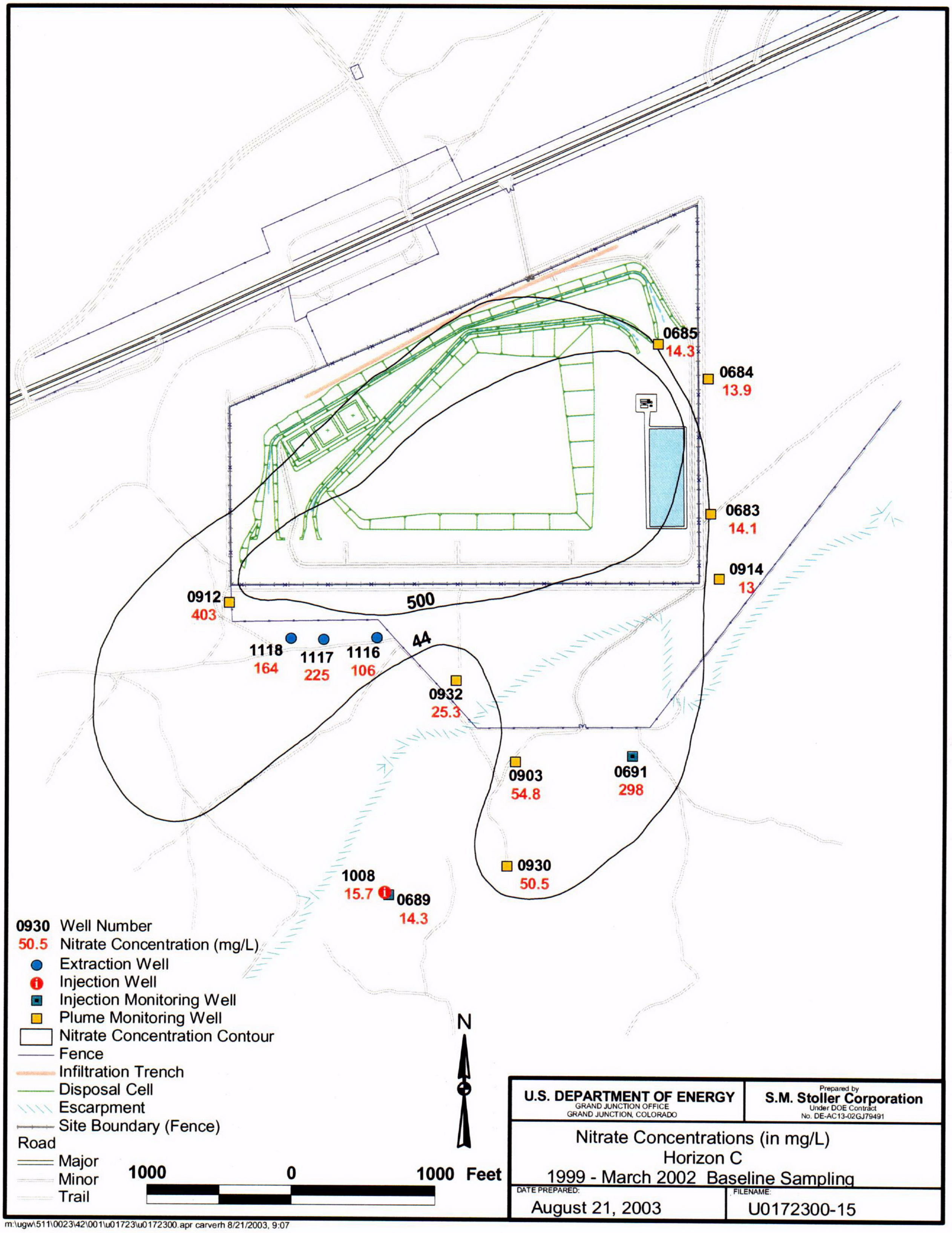

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Figure 14a. Baseline Horizon C Nitrate Ground Water Concentrations

C09

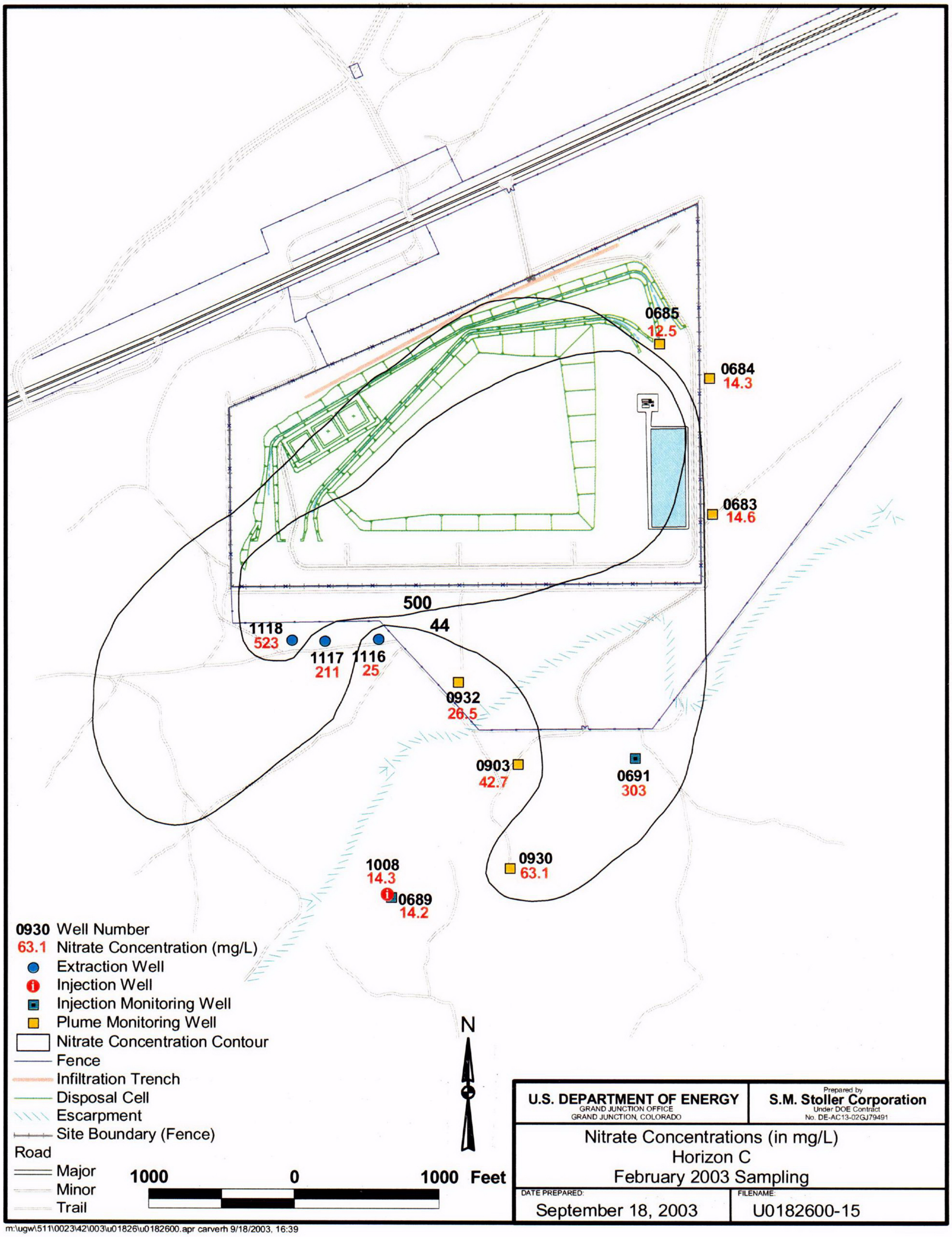

Figure 14b. February 2003 Horizon C Nitrate Ground Water Concentrations

C10

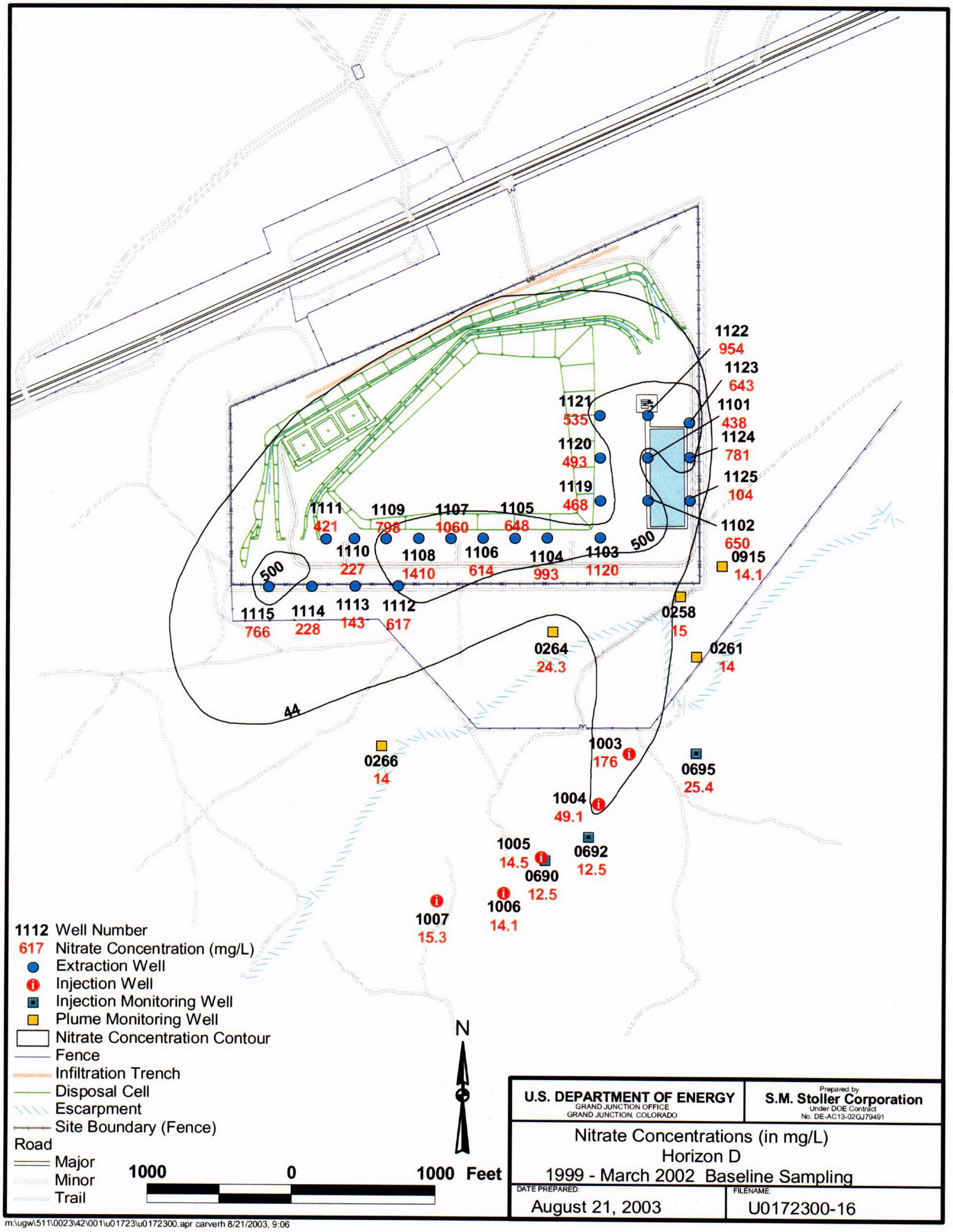

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Figure 15a. Baseline Horizon D Nitrate Ground Water Concentrations

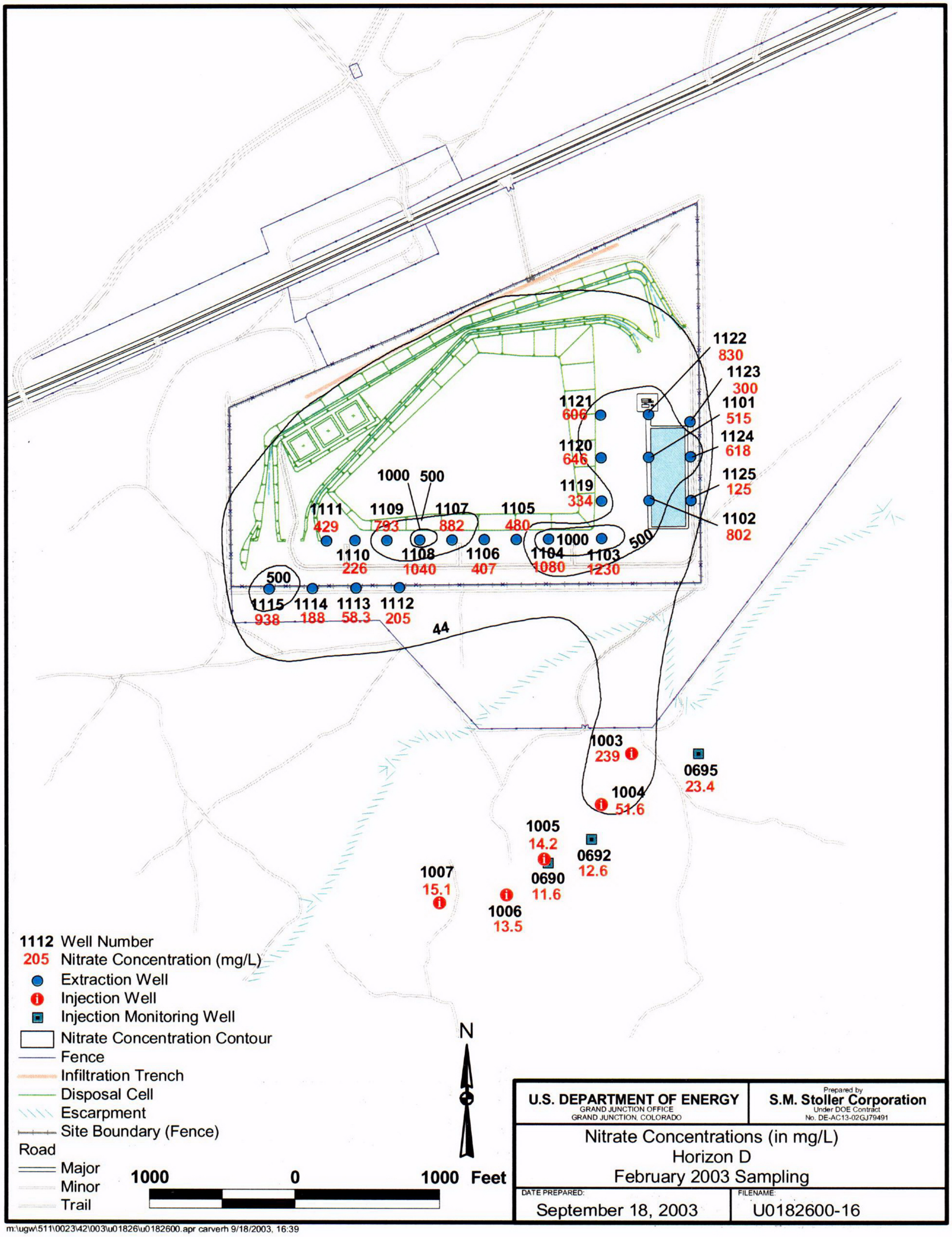

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Figure 15b. February 2003 Horizon D Nitrate Ground Water Concentrations

C12

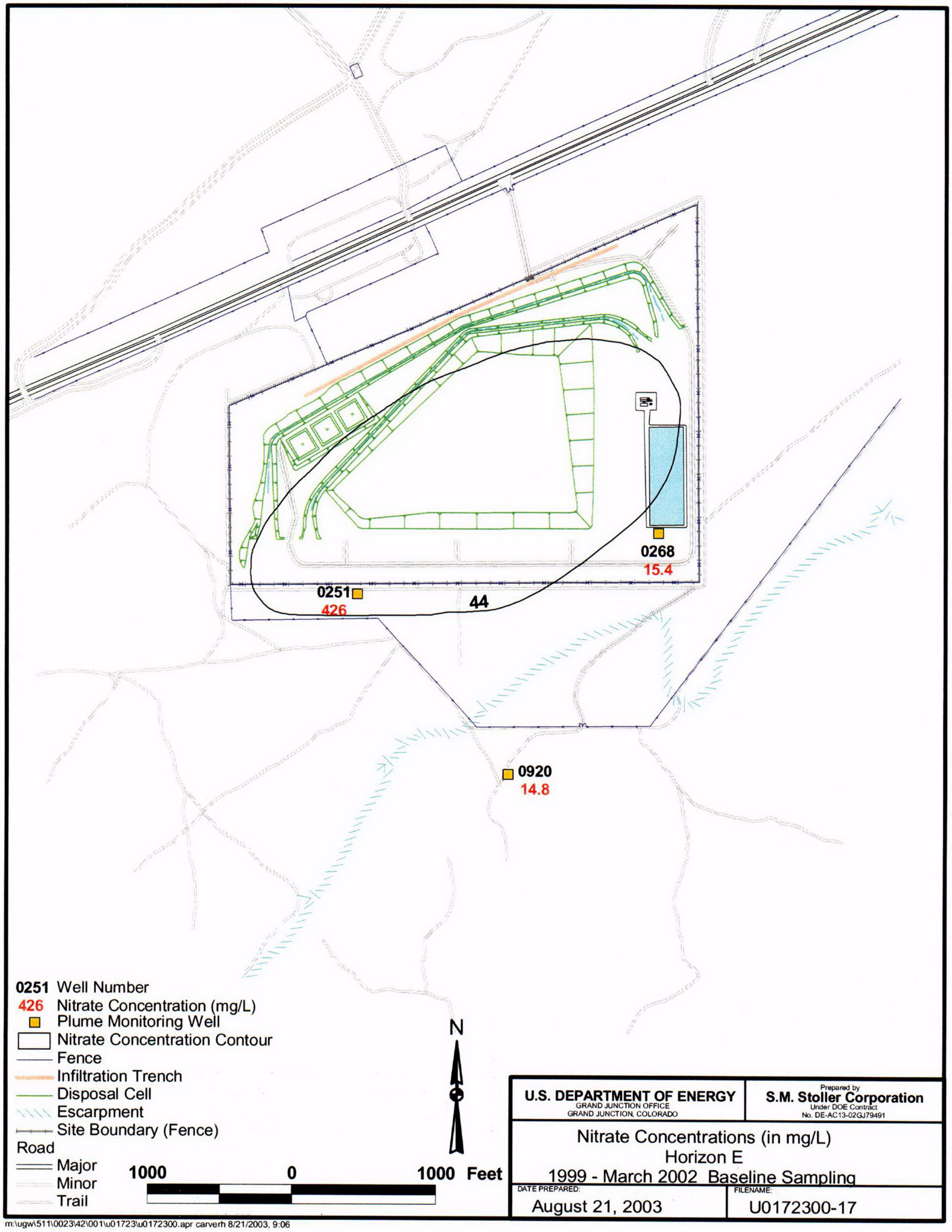

Figure 16a. Baseline Horizon E Nitrate Ground Water Concentrations

C13

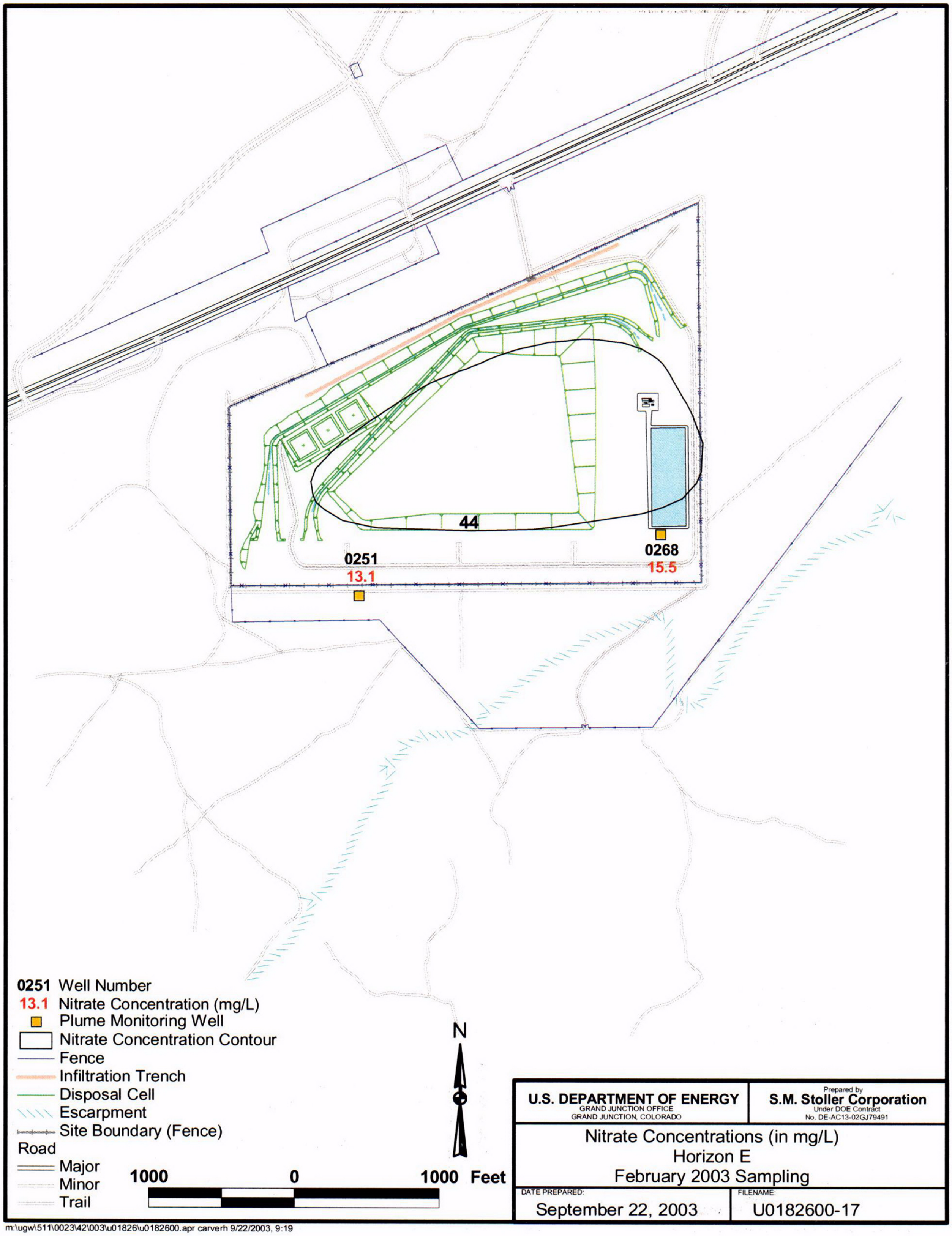

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Figure 16b. February 2003 Horizon E Nitrate Ground Water Concentrations