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DISCOVERY, INTERCEPTION, AND TREATMENT OF A GROUNDWATER PLUME: OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

A radiological groundwater plume was discovered to be discharging into a surface stream and portions of the storm drain network at Oak Ridge National Laboratory (ORNL). A CERCLA removal action was initiated to address the discharges. The plume was found to be migrating 65 degrees oblique to the overall hydraulic gradient and was identified only after historic data were analyzed and field tests were performed under the working hypothesis of stratabound flow and transport. The hypothesis states that differential lithologic/fracture conditions lead to the development of preferred flow and transport pathways of discrete vertical extent.

A detailed geologic and hydrologic analysis was performed that accurately predicted the 3-dimensional plume configuration from a single point datum where significantly elevated contaminant levels were found in a bedrock core hole. The point datum was within a 10 ft thick stratum which was suspected to be a preferred pathway. With sparse subsurface stratigraphic data from other locations at ORNL, the location of the stratum was predicted in a bordering surface stream. Subsequent sampling found that direct discharges of contamination existed in the stream only in the location of the predicted stratum. Historic contaminant data from 2 wells within the inferred plume, which previously had been unexplained, helped establish the 3-dimensional plume configuration. Similarly, the identification of plume seepage into porous storm drain catch basins explained historic storm drain outfall contaminant data.

The affected storm drain outfall discharges were suspected to be the major contributors to ^{90}Sr surface water risk from ORNL. Thus, the selected removal action focused on eliminating the known seepage to the storm drain network. The intercept system uses simple porous sumps, which locally depress the water table and transfer the collected water to a small pumping station for delivery to an existing onsite treatment plant.

Intercept system operations reduced the total surface water ^{90}Sr flux by about 90%. Ongoing investigations seek to identify the source of the plume with the hope that the intercept system may eventually be deactivated. However, the efficiency of the system exceeded expectations and demonstrated that a good understanding of the hydrodynamics is a prerequisite to success. The relatively trouble free operation of the system also indicates that simple technologies can serve as effective measures to address immediate problems.

I. BACKGROUND

During Phase I RI/FS studies at Oak Ridge National Laboratory (ORNL), a rock core drilling program was performed to accurately describe and establish geologic control and to perform subsurface hydrologic tests. Drilling of core hole 8 (CH-8) revealed radiologically contaminated conditions in the uppermost portions of the bedrock (nominally 12 ft below ground surface). Field surveillance showed that radiological contamination was increasing with depth to over 540,000 pCi/L (20 kBq/L)gross beta/gamma activity (5 orders of magnitude above background) so drilling of CH-8 was terminated at 53.5 ft. The gross beta/gamma activity was completely attributable to ^{90}Sr, a common fission product at ORNL which is relatively mobile in groundwater. Sampling of numerous downgradient wells (one as close as 20 ft from CH-8) revealed an absence of contamination, so both the source of the contamination and its migration pathway were unknown.

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II. CONCEPTUAL MODEL DESCRIPTION

Groundwater at ORNL is under water table conditions with recharge occurring in unpaved areas and discharge to surface streams bordering the site. The piezometric surface is generally coincident with the bedrock/soil weathering interface with most flow occurring along that interface. Local channelized flow occurs within underground pipeline trenches in soil and in fractures and cavities in bedrock.

Bedrock strikes northeast and dips at a relatively uniform 32 degrees southeast. CH-8 was sited in Unit E of the Middle Ordovician Chickamauga Group. The 350 ft thick Unit E is lithologically heterogeneous, generally consisting of dark-gray shaley siltstone, nodular limestone, and admixtures of both rock types at various scales. CH-8 terminated in the lower portion of Unit E, an undetermined number of feet above the contact with the subjacent Unit D, a relatively clean, cherty limestone.

The concept described in this analysis is that of the stratabound pathway (Fig. 1). The concept incorporates differential subsurface lithologic/fracture zones that operate as discrete, preferred-flow and transport pathways compared with super and subjacent lithologies. The presence of these pathways results in a preferred strike-parallel direction of flow and transport that is unaffected by the overall water table gradient. While vertical leakage out of the stratabound pathway is considered to occur, its contribution to overall ground water flow is comparatively minor, and local plumes in bedrock are envisioned to be quite narrow.

While long known as a viable concept in the mining industry to describe the dominant control of ore mineralization in certain geologic settings, the concept of stratabound, preferred flow pathways was first described and documented in environmental studies at Oak Ridge.[1] Subsequent review of other plume configurations and experimental studies at Oak Ridge indicate that stratabound flow is a prevailing transport mechanism[2-6]

III. FIELD TEST DESCRIPTION

The absence of contamination in wells downgradient from CH-8 leads to consideration of the stratabound concept. To test the concept, the most contaminated interval in CH-8 would have to be accurately located in the surface stream on the western ORNL boundary. If identified, stream sampling should show the highest levels of contamination at that location (assuming a plume was mature enough to have reached the stream). The test thus began with a geologic analysis followed by a hydrologic study. Figure 2 shows the study area.

IV. GEOLOGIC ANALYSIS

Three strike-normal cross sections were prepared from existing rock core data in the middle of ORNL and on the eastern and western ORNL boundaries. The western cross section was coincident with First Creek. Comparisons among the previously drilled core holes suggested an approximate, anticipated depth of the Unit D/E contact at the CH-8 location. With that estimate, rock core from CH-8 was correlated with known stratigraphy from two other core holes. A precise stratigraphic pick was established with a 10 ft thick silty limestone bed. The bed was of discontinuous thickness, was of apparent biohermal origin, and was present in only two of the holes. It was this limestone bed that exhibited the highest levels of contamination in CH-8 and was considered to be the stratabound preferred ground water flow pathway.

Using key stratigraphic horizons from positions higher and lower in the stratigraphic section, and assuming a constant unit stratigraphic thickness, the position of the underlying Unit D/E contact was estimated. From this estimate, the reported average angle of bedding dip (32°) was uniformly applied to perform an up-dip projection of the subsurface position of the D/E contact to its outcrop location in First Creek.

Field checking of the projected position of the D/E contact at depth to its outcrop position in the surface stream determined that the subsurface projection was accurate to within a few feet. A simple trigonometric problem was then solved to predict the outcrop location of the CH-8 contaminated limestone, an interval from about 43 to 55 ft southeast of the D/E contact in First Creek.

V. HYDROLOGIC ANALYSIS

A. Stream Sampling

The hydrologic analysis began with a seep and spring sampling program in First Creek up and downstream from the subsurface stratigraphic projection and presumed stratabound pathway. These locations included five samples obtained roughly 10 ft apart upstream and downstream of the presumed stratabound pathway. Contamination in First Creek was very nearly

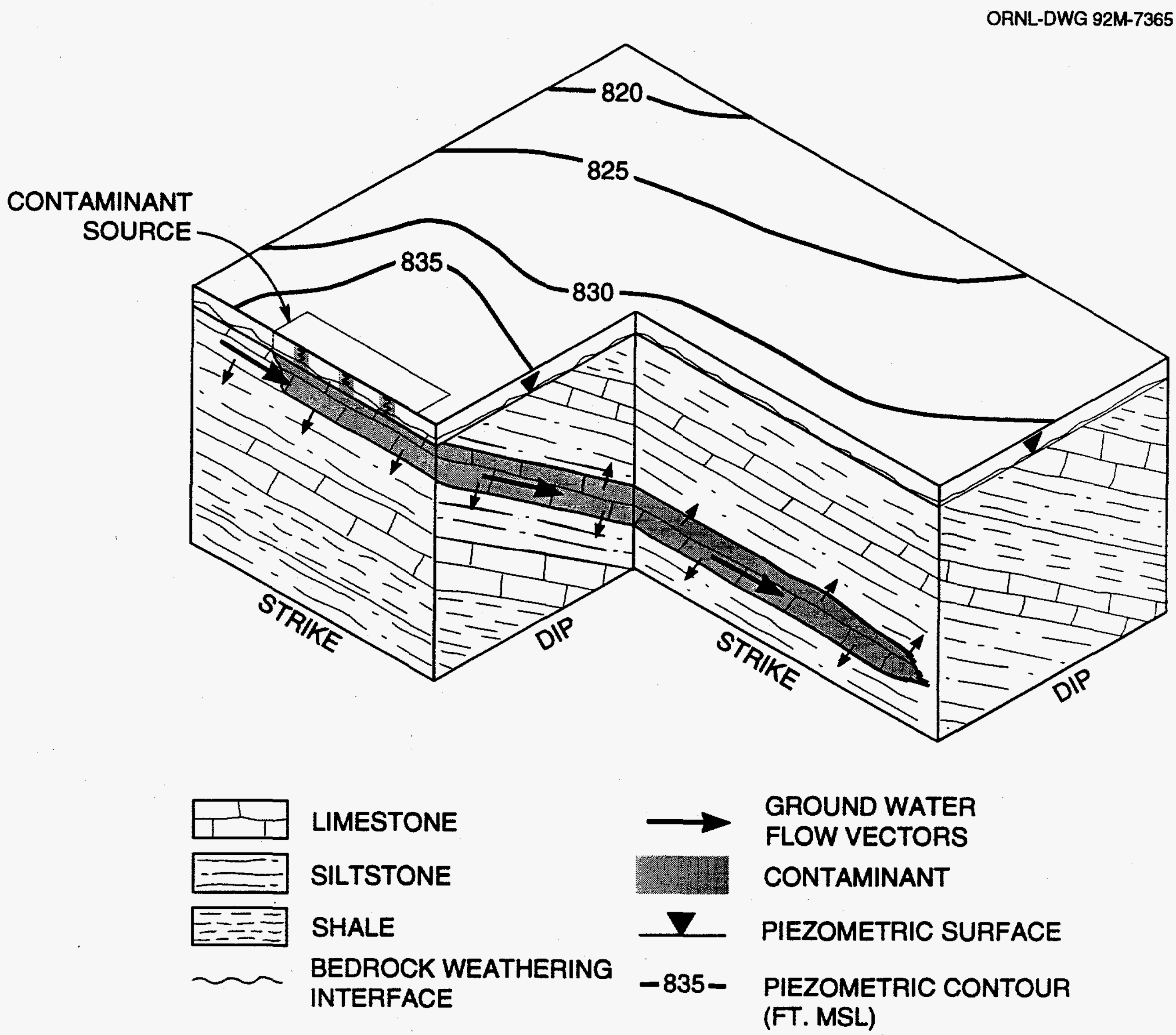

Figure 1. Idealized Block Diagram of the Stratabound Pathway Concept.

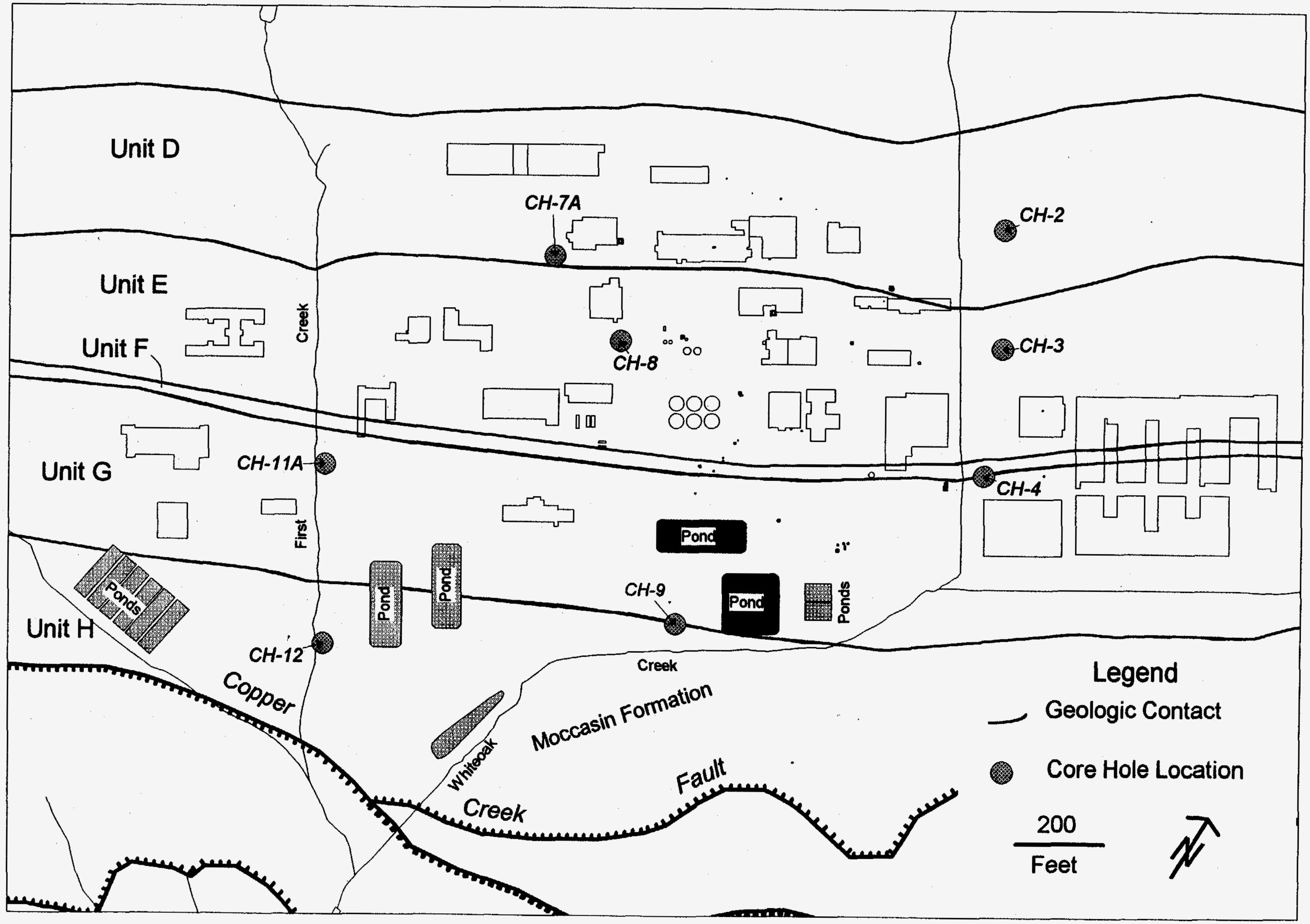

Figure 2. Geologic Map of the Oak Ridge National Laboratory.

within the interval predicted by the geologic analysis and the stratabound concept. Assuming that stream contamination and CH-8 contamination are related, migration was parallel to geologic strike and approximately 65° oblique to the hydraulic gradient.

B. Hydrogeologic study

The identification of stream contamination in the location predicted by the concept led to further investigations of ground water contamination in the western portion of ORNL. The purpose of these investigations was to describe a contaminant plume and confirm or deny a relationship between the stream contamination and CH-8.

Analysis of historic groundwater and outfall radiological data indicated that radiological contamination had been detected in ground water and storm drain discharge water from the western perimeter of ORNL since 1986. Prior to this analysis, radiological contamination at these locations had never been explained. In 1988 the storm drains feeding the outfalls were lined using the InsituForm™ process in an attempt to exclude the contaminated groundwater from discharging to First Creek via these drains. Outfall sampling results indicate that the lining job did not completely eliminate radiological discharges via the outfalls.

Figure 3 shows the results of the hydrologic analysis sampling. The analytical results and the apparent storm drain system connections indicated that the Building 2013 storm drains discharge via outfall 341, and the First Creek storm drain discharges via outfall 342. Minor vertical leakage of contaminants along the preferred, lateral-migration pathway (as shown in Fig. 1) was likely responsible for near occurrence in piezometer 539, well 812, and the piezometer 539 seep. Similar leakage to the pictured storm sewer (M-15, which discharges to First Creek via outfall 341) was responsible for high-contaminant concentrations in that outfall. Because measured groundwater elevations represented low-base conditions, the degree of connection between groundwater and the storm drain was likely greater during high-base conditions.

Unlined storm drain catch basins in the vicinity of Building 2013 and piezometer 539 were considered to be the source of radiological contaminants in storm drain outfalls 341 and 342. These storm drains appeared to capture the top of the plume, retarding its continued expansion in a westward direction.

VI. INTERCEPT SYSTEM

Sampling suggested that storm sewer outfall discharges were the major contributor to ^{90}Sr surface water risk from ORNL, while direct plume discharges to surface water were comparatively minor contributors to that risk. Thus, the selected intercept system focused on eliminating the known seepage to the storm sewer network.

Several intercept system alternatives were considered including constructing a French drain across the plume, constructing wells within the plume for use in a pump and treat system, and treating the entire stream downstream of the outfalls. In-situ treatment and transfer to the existing on-site liquid low-level waste treatment plant were the primary remediation options considered.

The authors strongly advocated interception at the known storm sewer catch basins and transfer to the on-site waste treatment plant. The rationale was that by far the bulk of the seepage was into 3 catch basins, the seepage was visible and measurable, and interception in those conditions had a much higher probability of success than in the subsurface where the plume was neither visible nor measurable. We offered a conceptual design whereby porous sumps would be installed beneath the catch basins, which would be sealed at the bottom so they could continue to be used. The sumps could gravity drain to a small lift station which could then transfer the captured liquids to the on-site treatment plant. Other benefits to the system were that 1) it would minimize disturbance of natural flow pathways thereby reducing the likelihood of seepage developing in other parts of the storm sewer system, 2) it would take advantage of existing discharging ground water conditions and would not require active pumping, 3) it would use existing on-site treatment plant capacity, 4) it would be essentially invisible to employees and visitors, 5) it would require minimal maintenance, and 6) it could be constructed and operated for relatively low cost.

Construction lasted for 4 months for a total cost of about 1.3 million dollars. Immediately upon operation, the flux of ^{90}Sr was significantly reduced to First Creek via the outfalls. Within a few days, ^{90}Sr flux from the outfalls was reduced to zero, and total ^{90}Sr flux in First Creek was reduced by 90%. Direct plume discharges to the creek and other possible discharges currently account for the remaining 10% flux. At present, the

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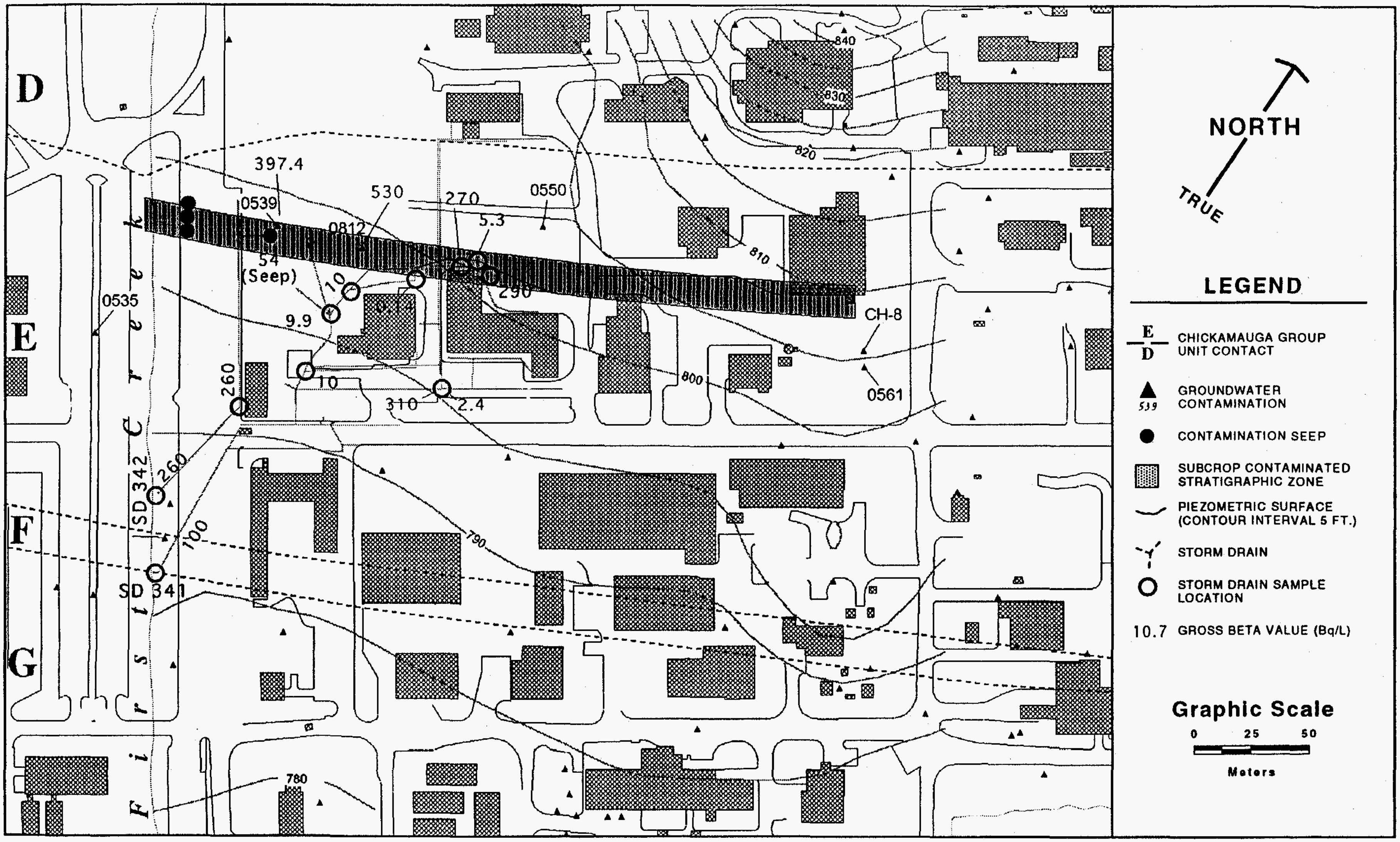

Figure 3. Hydrologic Sampling Results in the Plume, Storm Drain Catchment Basins, and Outfalls.

account for the remaining 10% flux. At present, the cost/benefit of addressing the remaining First Creek ^{90}Sr flux cannot be justified in today's fiscal environment. However, ongoing monitoring will not only assure intercept system operating efficiency but will identify changing conditions which may warrant further actions.

VII. CONCLUSIONS

The water table gradient and Darcian principles would suggest a relatively diffuse contaminant plume migrating in a southerly direction. The absence of radiological contaminants in piezometers near and down gradient from CH-8 confirms that local flow and transport are not wholly governed by the overall hydraulic gradient at ORNL. The results indicate that the stratabound concept of groundwater flow and contaminant transport at ORNL is a viable component of an overall conceptual model of the flow field. Sole reliance upon Darcian principles to predict local ground water contaminant plume migration is not always adequate at ORNL.

Detailed analyses of surface and subsurface geologic data lead to the accurate prediction of the location of groundwater contaminant discharge from CH-8 to First Creek. The development of this highly accurate predictive capability can be used to more sharply focus continued groundwater field investigations at ORNL and elsewhere at Oak Ridge. In conjunction with additional working conceptual models, numerical modeling can analyze contaminant source location scenarios and remediation options that are expected to lead to more accurate representations of the ORNL flow field and to enhanced restoration.

The relatively simple design of the intercept system effectively corrected the immediate problem of ^{90}Sr discharges via the storm sewer system to First Creek at relatively low cost. The system's effectiveness and trouble free operation demonstrates that simple technologies can serve as effective measures to address immediate problems. Activities to locate and address the source of the CH-8 plume are underway with the hope that the intercept system can eventually be deactivated.

ACKNOWLEDGMENTS

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