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Migration of a Groundwater Contaminant Plume by Stratabound Flow in Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

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EXECUTIVE SUMMARY

The discovery of radiologically contaminated groundwater in core hole CH-8 in the western portion of Waste Area Grouping (WAG) 1 at Oak Ridge National Laboratory (ORNL) prompted a detailed investigation to identify the contaminant plume. Utilizing a working hypothesis of stratabound groundwater flow and contaminant transport, investigators analyzed existing subsurface geologic data to predict the contaminant plume discharge location in First Creek and locations of contaminated groundwater seepage into storm drains. The hypothesis states that differential lithologic/fracture conditions lead to the development of preferred flow and transport pathways, of discrete vertical extent, which may not be coincident with the hydraulic gradient. Leakage out of the stratabound pathway is a minor component of the overall plume configuration.

Results of the analysis indicate that application of the stratabound pathway hypothesis accurately predicted the plume discharge location in First Creek, which was 65° oblique to the general gradient in that portion of WAG 1. Plume identification subsequently provided an explanation for historical contamination in WAG 1 piezometers and water quality wells which previously were not understood. Analysis of the subsurface storm drain in the vicinity of the plume also explained the historical contamination in storm drain outfalls to First Creek and verified the comparatively minor role of upward leakage out of the stratabound pathway to the water table as described by the hypothesis.

Characterization of a groundwater contaminant plume in the western portion of WAG 1 at ORNL will be used as input to remediation alternatives and for additional investigations to more fully describe both the three-dimensional character of the plume and its source location. The development of a highly accurate, predictive capability in groundwater contaminant migration at ORNL, demonstrated by the results of this study, will be applied to ongoing numerical groundwater analyses at ORNL and at other WAGs on the Oak Ridge Reservation.

1. INTRODUCTION

This report describes results of a study performed as part of the Martin Marietta Energy Systems, Inc., staff technical oversight in Remedial Investigation/Feasibility Studies (RI/FS) being conducted for the Environmental Restoration (ER) Program at Oak Ridge National Laboratory (ORNL). This report describes the geologic and hydrologic methods used to identify the three-dimensional nature of a groundwater contaminant plume in Waste Area Grouping (WAG) 1 from a single point datum. One element in an overall conceptual model for groundwater flow in WAG 1 is described which apparently controls and was used to predict plume migration from a source area near core hole CH-8 located south of the ORNL cafeteria, Building 2010, to the plume discharge area near First Creek. The predicted plume discharge location is compared with analytical results of radiological contamination in First Creek and the general direction of contaminant plume migration anticipated based on the water table configuration. Locations of plume discharge to the WAG 1 storm drain network are identified. Remedial measures to limit such discharge and additional field activities to more accurately describe plume configuration are recommended. Characteristics of the shallow groundwater system that are being used in flow-field conceptual model development for incorporation in numerical simulation are also described.

The technical staff from CH2M Hill [subcontractor to Bechtel National, Inc. (BNI) for the WAG 1 RI/FS] provided pertinent data and information that enabled this study to be performed. Technical exchange and peer review of this report by CH2M Hill staff are acknowledged as is peer and programmatic review by ORNL's Environmental Sciences Division and ER Program staff, respectively. In keeping with engineering survey and drilling convention, numerical values from field studies are given in British units. In keeping with laboratory analytical convention, radiological and physicochemical values are given in SI units.

2. BACKGROUND

As part of the Phase I RI/FS studies in WAG 1 at ORNL, rock core drilling has taken place to accurately describe subsurface geologic conditions and to permit the performance of subsurface hydrologic tests. In June 1991, rock core drilling of CH-8 (located immediately south of the ORNL cafeteria) revealed radiologically contaminated conditions in the uppermost portions of the bedrock (nominally 12 ft below ground surface). Radiological contamination increased with depth, so CH-8 was only drilled down to 53.5 ft. A Westbay multilevel groundwater sampling device was installed in the hole, and no down-hole geophysical data were obtained. Table 1 contains results of radiological analyses of groundwater samples obtained from the Westbay device in CH-8; these results indicate that the highest levels of gross beta/gamma contamination occur in intervals 2 and 3, 20 to 30 ft below the bedrock surface and a similar depth below the local water table.

Table 1. Interval radiological sampling results from core hole CH-8

Interval	Depth (ft BGS[a])	Water elev. (ft MSL[b])	Sample	Gross beta/gamma (pCi/L) (error)	Tritium (pCi/L) (error)	Gross alpha (pCi/L) (error)
7	11.05–12.2	804.8	2,581	32,080 (4,817)	450 (241)	597 (160)
6	16.2–21.2	804.3	2,580	118,960 (17,857)	660 (252)	1,295 (302)
5	24.2–26.2	806.52	2,493	113,545 (17,058.8)	3,170 (395)	2,516 (588.3)
4	29.2–33.2	806.12	2,494	156,799 (23,547.2)	2,670 (366)	4,263.3 (978.1)
3	36.2–38.2	806.12	2,496	487,093 (73,091.5)	3,580 (413)	3,775 (835)
2	41.2–43.2	806.12	2,482	585,497 (87,826)	3,780 (426)	5,093 (1,124.1)
1	46.2–53.9	806.02	2,483 2,497[d] (dup)	205,124 (30,796) 215,495 (32,351.8)[d]	N/A[c] 3,410 (400)[d]	950.8 (242.5) 1,461.4 (365.6)[d]

[a]Below ground surface.
[b]Mean sea level.
[c]N/A = Not applicable.
[d]Duplicate sample.

3. CONCEPTUAL MODEL DESCRIPTION

In general, groundwater occurrence and movement in WAG 1 consist of recharge in unpaved areas and outleakage from various subsurface pipes. Groundwater movement is largely along the interface of soil and bedrock with local channelized flow within pipe trenches and in fractures and cavities in bedrock. Because of large hydraulic conductivity contrasts between adjacent strata and the occurrence of discrete zones of preferred groundwater flow, flow solely along the water-table gradient is unlikely even in the general case. In areas where the top of the saturated zone occurs below the bedrock weathering interface, recharge fluxes enter fractures and flow occurs through bedrock. The interpretation presented here demonstrates how detailed geologic analyses in groundwater studies can provide a framework of predictability for contaminant plume migration which is not readily explained assuming a conventional equivalent porous medium–flow field.

The concept described in this analysis is that of the stratabound pathway, which is generally illustrated in an idealized and simplified block diagram (Fig. 1). In simplest terms, the concept incorporates differential subsurface lithologic/fracture conditions that operate as discrete, preferred-flow and transport pathways compared with superjacent and subjacent lithologies. The presence of these pathways results in a preferred strike-parallel direction of flow and transport that is generally not coincident with the overall hydraulic gradient. While vertical leakage out of the stratabound pathway is considered to occur, its contribution to overall groundwater flow is comparatively minor. This concept readily explains many solute-plume-flow paths observed in bedrock and saprolite zones on the Oak Ridge Reservation (ORR). Local plumes in bedrock tend to be quite narrow, and often solutes migrate in pathways oriented oblique to the general hydraulic gradient.

Stratabound, preferred flow has long been known as a viable concept in the mining industry to describe the dominant control of ore mineralization in certain geologic settings. Lee and Ketelle (1987) were the first to describe and document the viability of stratabound, preferred flow pathways in ORR groundwater investigations in the Knox Group underlying Chestnut Ridge. Subsequent groundwater studies on ORR (Lee and Ketelle 1988; Lee et al. 1989) indicate that the concept is also applicable in the Conasauga Group underlying Bear Creek Valley. The configuration of the S-3 Ponds contaminant plume (Geraghty and Miller 1990) is further evidence supporting the concept in the Conasauga Group in Bear Creek Valley. In the Pits and Trenches Area in Melton Valley (WAG 7), Olsen et al. (1983 and 1986) report that discrete fractures, conduits, or strata carry most of the radioactive seepage from trench 7.

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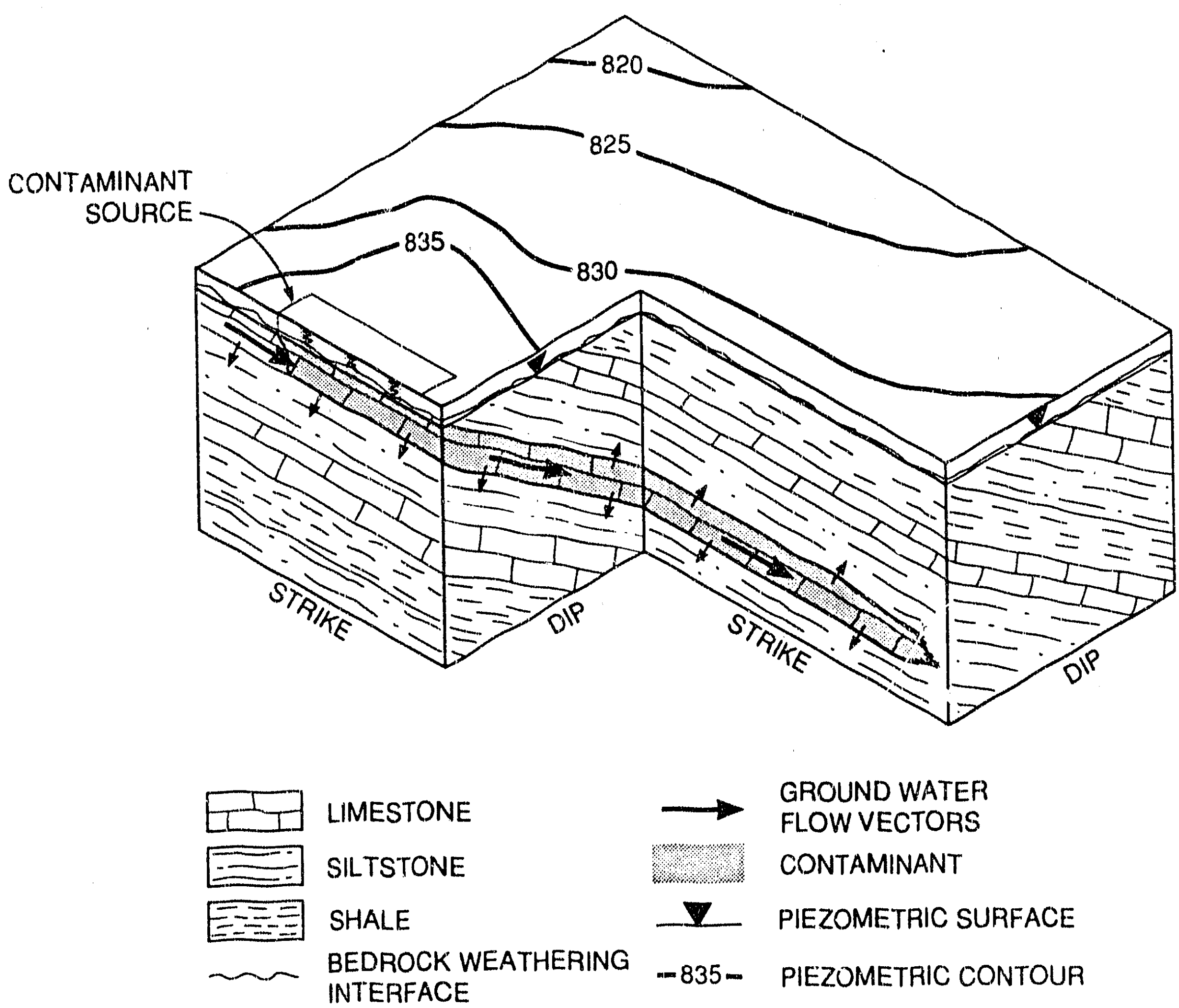

Fig. 1. Idealized block diagram of the stratabound pathway concept.

3.1 STRATIGRAPHY OF THE CONTAMINANT MIGRATION ZONE

The ground surface location of CH-8 is in Unit E of the Middle Ordovician Chickamauga Group. Unit E is lithologically heterogeneous, generally consisting of dark gray shaley siltstone, nodular limestone, and admixtures of both rock types at various scales.

The on-site geologist's core log describes a dark olive gray siltstone that is roughly 10 ft thick (approximately 19 to 30 ft below ground surface) separating two nodular limestone units. With this lithologic description, which is extremely common to much of Unit E, and with the limited amount of CH-8 rock core available for correlation with existing core (42 ft), confident placement of the CH-8 contaminated zone with respect to the stratigraphic section is difficult. However, with careful correlation of thin stratigraphic units with existing Chickamauga Group rocks, accurate stratigraphic placement can be determined.

3.2 MODEL APPLICATION

This section describes the rationale for using stratigraphy and geologic structure to apply the stratabound pathway concept for projecting contaminated subsurface bedrock units from CH-8 to their outcrop location in First Creek. The steps in applying the methology that lead to the predicted location of the bedrock units in First Creek are also described.

3.2.1 Rationale

The problem of identifying the precise location of the CH-8 contaminated strata in First Creek was readily divisible into two sequential components: (1) identifying the contaminated zone in CH-8 with respect to the stratigraphic section (establishing stratigraphic control), and (2) projecting that interval to its outcrop location in First Creek.

Because of local variations in the azimuth of bedrock strike in WAG 1, along-strike projections of subsurface stratigraphy to relatively distant locations (nominally 1000 ft) can result in considerable discrepancies between a projected datum and a known datum. Similarly, minor variations in the angle of bedding dip across WAG 1 and the presence or absence of certain discrete beds can lead to apparent differences in unit thickness. When precision is required, up- or down-dip projections through a significant thickness of the stratigraphic section can also lead to discrepancies between a projected datum and a known datum. Because high-resolution subsurface stratigraphic control is available in WAG 1, a combined triangulation method using along-strike and up-dip projections through minimal section thickness followed by field verification was considered to provide the greatest projection accuracy.

3.2.2 Methodology

The limited depth of CH-8 made identification of the precise location of the contaminated zone in the stratigraphic section somewhat complicated. Geometric and trigonometric relations were made with known stratigraphy from previously drilled core holes. Core holes used in establishing stratigraphic control are shown in Fig. 2.

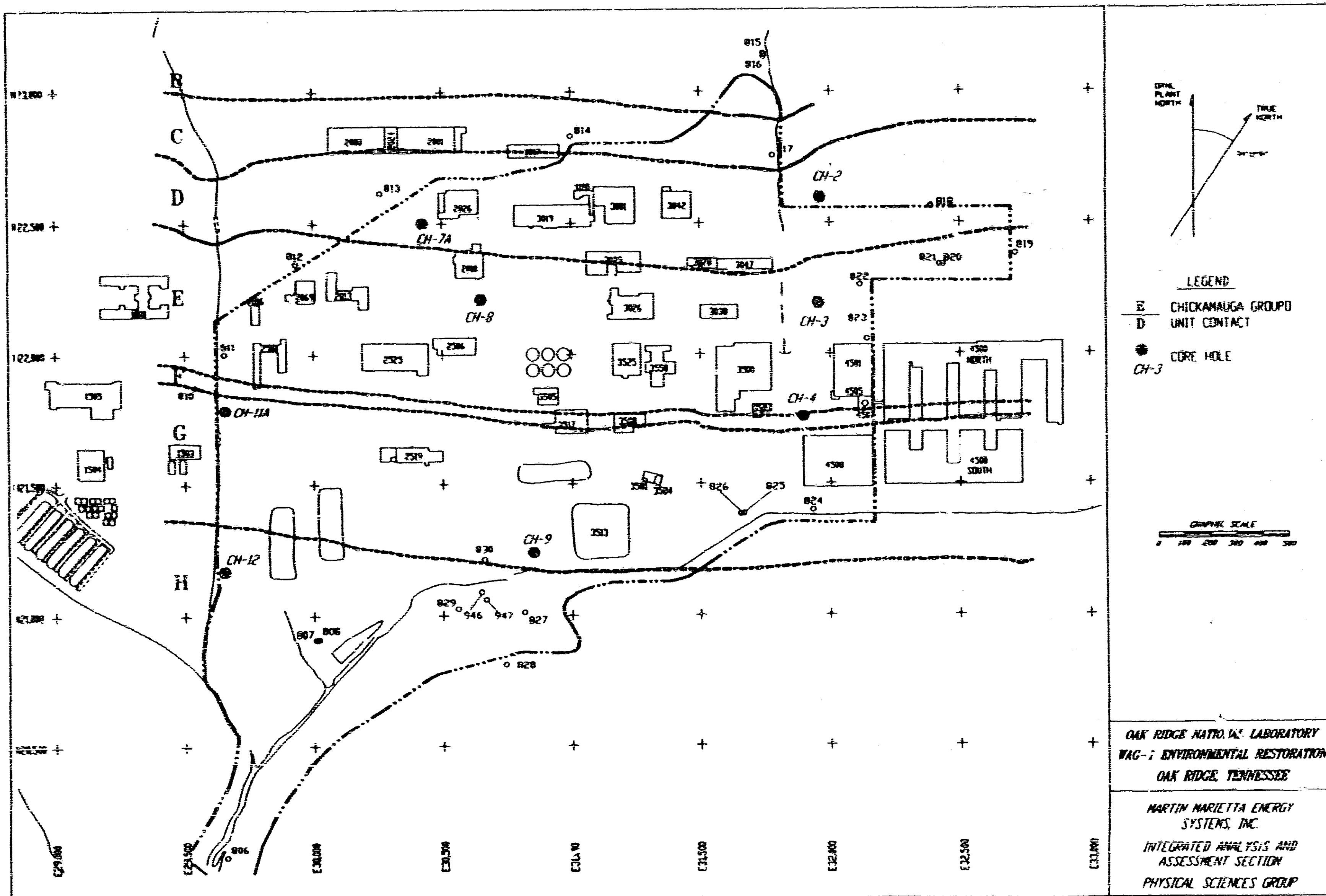

Fig. 2. WAG 1 core holes used to establish stratigraphic control with core hole CH-8.

Three strike-normal cross sections were prepared from existing rock core data approximately coincident with First, Third, and Fifth streets in WAG 1. Figure 3, a three-panel isometric perspective of those cross sections, illustrates the steps followed in problem solution. While all available WAG 1 core hole data were used in preparing each cross section, only those data pertinent to the CH-8 contamination problem are included in Fig. 3. The steps involved in projecting the CH-8 contaminated zone to First Creek are described in the following paragraphs.

Comparisons among the previously drilled core holes CH-2, CH-3, and CH-7 suggested an approximate, anticipated depth of the Chickamauga Group D/E contact at the CH-8 location. With that estimate, rock core from CH-8 was transported to Building 7042 to correlate CH-8 with known stratigraphy from core holes CH-3 and CH-4. The following stratigraphic pick was made: CH-8, 19 ft; CH-3, 52.5 ft; and CH-4, 290 ft. This horizon marks the top of the 10-ft-thick dark olive gray siltstone in CH-8 that overlies an 11-ft-thick limestone bed in CH-4. The limestone, of apparent biohermal (algal) origin, is locally thin (e.g., in CH-3) but is present in CH-8. It is this limestone bed that exhibited the highest levels of contamination in CH-8 (Table 1, intervals 2 and 3) and was considered to be the stratabound preferred groundwater flow pathway.

Using key stratigraphic horizons from positions higher in the stratigraphic section than the D/E contact (e.g., the unit E/F contact and geophysical log markers), investigators correlated CH-4 with CH-11a, which is located near First Creek. By assuming a constant unit stratigraphic thickness throughout ORNL, the positions of the unit D/E contact and the stratigraphic pick, neither of which were penetrated in CH-11a, were estimated. From these estimates, the reported average angle of bedding dip from the CH-11a drilling log (32.5°) 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 First Creek determined that the subsurface projection was accurate to within feet. A simple trigonometric problem was then solved to predict the outcrop location of the CH-8 contaminated zone, an interval from about 43 to 55 ft southeast of the D/E contact, assuming a CH-4 limestone thickness of 11 ft.

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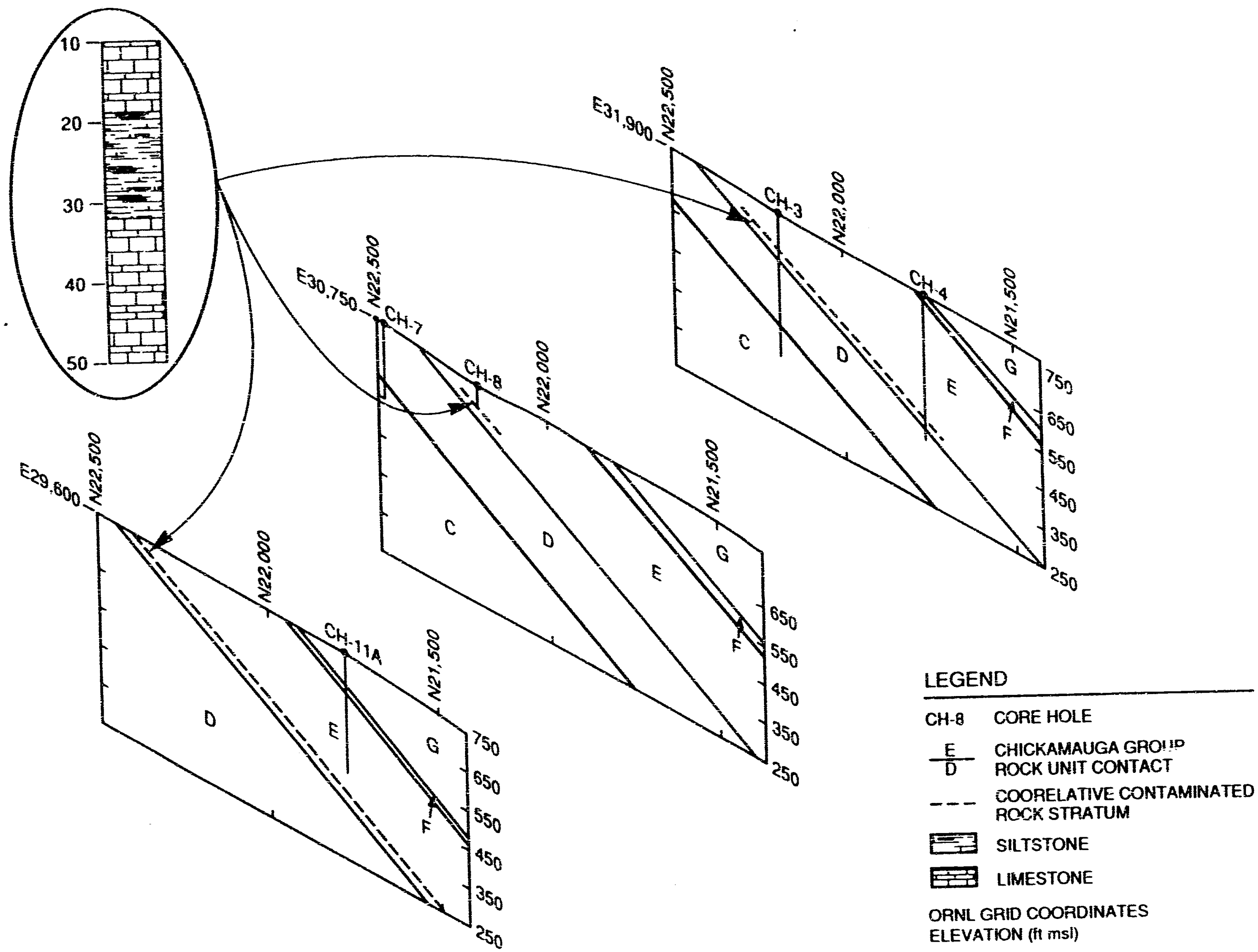

Fig. 3. Three-panel isometric perspective of core hole data used to predict the outcrop location of the contaminated stratum in First Creek.

4. RESULTS

Figure 4 shows the locations of surface water seeps in First Creek where significant radiological contamination (filtered gross beta) was found. For clarity, the more than 30 sampled surface water locations that did not exhibit radiological contamination are not shown. These locations include five samples obtained roughly 10 ft apart upstream and downstream of the locations shown in Fig. 4. The piezometric surface is based on measurements obtained on September 30 and October 1, 1991, by a team from CH2M Hill/Bechtel National, Inc.

The two northernmost seeps are 30 ft and 50 ft southeast of the D/E contact with values of 220 and 42 pCi/L gross beta (filtered), respectively. An anomalously high 4400-pCi/L gross beta (unfiltered) and <25-pCi/L gross beta (filtered) sample at 53 ft southeast of the D/E contact is not readily interpretable; however, it suggests radionuclide adsorption to seep sediments from past groundwater discharge but an absence of such discharge at the time of sampling. This was the location identified as the likely discharge location of the limestone bed before sample acquisition. Tritium is not present at any of the sample locations.

Contamination in First Creek is almost precisely within the interval predicted by the geologic analysis and the stratabound concept. If we assume that First Creek and CH-8 contamination are related, migration is parallel to geologic strike and approximately 65° oblique to the hydraulic gradient as shown by the shaded region in Fig. 4. Migration is also outside the western boundary of WAG 1.

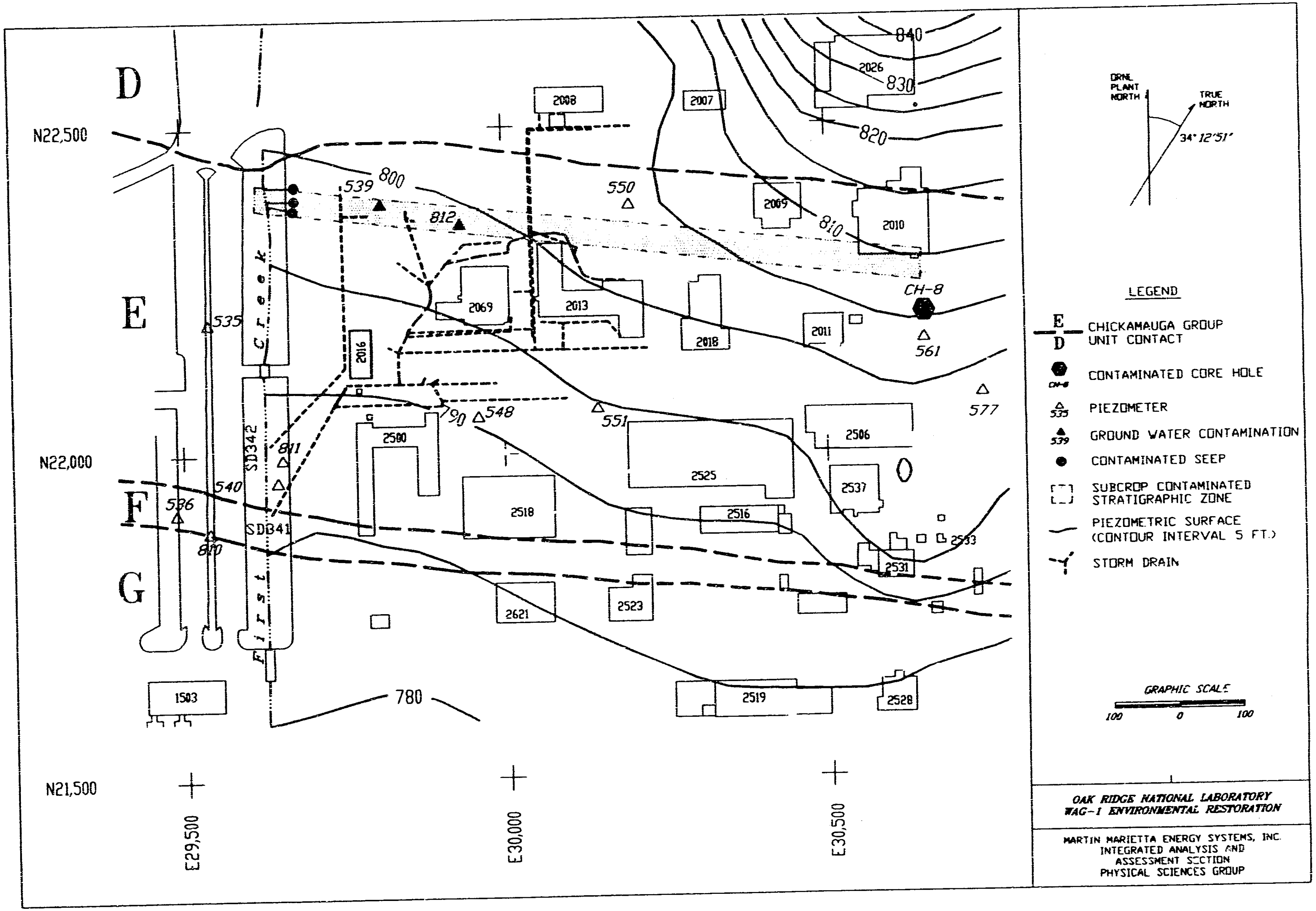

Fig. 4. Locations of contamination in the western portion of WAG 1 and interpreted plume configuration.

5. HYDROLOGIC INVESTIGATIONS

The identification of First Creek contamination in the location predicted by the stratabound groundwater flow concept led to further investigations of groundwater contamination in the western portion of WAG 1. The purpose of these investigations was to describe a contaminant plume and possibly identify a contaminant source. This section gives historical background information about groundwater contamination in the western portion of WAG 1 that further supports the stratabound contaminant migration shown in Fig. 4.

5.1 CONTAMINANT PLUME DESCRIPTIONS

Hydrogeologic investigations in WAG 1 related to the Remedial Action Program (predecessor to ER) were initiated in 1985. These began with the installation of piezometers to enable the measurement of basic aquifer properties, the monitoring of water level fluctuations, and the collection of water samples for scoping analysis of groundwater contamination. Data obtained from the piezometer construction were used to design the existing network of wells used to monitor groundwater quality along the perimeter of WAG 1.

Since 1986 radiological contamination, including alpha- and beta-emitting radionuclides and tritium, has been detected in groundwater and storm drain discharge water from the western perimeter of WAG 1 originating north of Central Avenue. Figure 4 shows the locations of all piezometers sampled in the CH-8 radiological contamination investigation in the western portion of WAG 1. Those found to be contaminated are highlighted.

Analytical results for historical and recent radiological analyses from well 812, piezometer 539, and First Creek outfalls 341 and 342 are presented in Table 2. Analytical results for a contaminant scoping water sample collected from piezometer 539 (located near the western edge of WAG 1) showed radiological contamination in 1986 (Table 2). Consequently, a water quality well (well 812) was sited and constructed nearby on the WAG 1 boundary. This well has shown radiological contamination throughout its monitoring record. Before this analysis, radiological contamination in these two piezometers had never been explained adequately. In 1988 the storm drains feeding outfalls 341 and 342 were lined using the InsituForm process in an attempt to exclude the contaminated groundwater from discharging to First Creek via these drains. The data in Table 2 indicate that the lining job did not completely eliminate radiological discharges to First Creek via outfalls 341 and 342.

Figure 4 also shows the location of the storm drains that discharge via outfalls 341 and 342 to First Creek. Many crossings and apparent interconnections exist within the storm drain systems. Connections and interflows undoubtedly occur between branches of the storm drain trenches and trenches of other utilities not shown on Fig. 4. Most of the drain pipes discharging through outfalls 341 and 342 were lined with InsituForm in about 1988; however, construction records indicate that portions of the pipeline north of Building 2013 and the section extending toward piezometer 539 were not completely lined.

Table 2. Historical and recent radiological analytical results (pCi/L) for storm drain outfalls 341 and 342, well 812, and piezometer 539

	Well 812				Piezometer 539				Storm drain 341			Storm drain 342		
Date	Gross alpha	Gross beta	Tritium	Total rad strontium	Gross alpha	Gross beta	Tritium	Strontium-90	Gross alpha	Gross beta	Tritium	Gross alpha	Gross beta	Tritium
18-Sep-86	-	-	-	-	-	-	-	-	20	3,240	-	73	13,230	-
01-Oct-86	-	-	-	-	-	-	-	-	108	2,565	-	454	11,340	-
13-Oct-86	-	-	-	-	-	-	-	-	216	6,210	-	270	8,370	-
16-Oct-86	-	-	-	-	98.4	3,390.2	6,814.5	-	-	-	-	-	-	-
27-Oct-86	-	-	-	-	-	-	-	-	270	7,560	-	262	6,480	-
14-Apr-87	-	-	-	-	-	-	-	-	130	7,020	-	259	19,170	-
28-Apr-87	-	-	-	-	-	-	-	-	62	5,400	-	248	15,660	-
27-May-87	-	-	-	-	-	-	-	-	116	8,100	-	132	11,610	-
12-Dec-88	232.2[a]	17,820[a]	7,560[a]	7,560[a]	-	-	-	-	-	-	-	-	-	-
24-Jan-89	148.5[a]	11,340[a]	5,400[a]	6,210[a]	-	-	-	-	-	-	-	-	-	-
08-May-89	-	-	-	-	-	-	-	-	42	4,860	-	42	4,185	-
20-Jun-89	129.5[a]	9,990[a]	5,670[a]	3,240[a]	-	-	-	-	-	-	-	-	-	-
28-Jun-89	-	-	-	-	-	-	-	-	111	8,100	-	51	2,835	-
19-Oct-89	180.9[a]	11,340[a]	12,420[a]	5,670[a]	-	-	-	-	-	-	-	-	-	-
29-Sep-90	-	-	-	-	1150[a]	12,100[a]	13,500[a]	5,880[a]	-	-	-	-	-	-
04-Oct-90	297[b]	16,200[b]	11,340[b]	8,100[b]	-	-	-	-	-	-	-	-	-	-
18-Mar-91	-	-	-	-	210[a]	10,729[a]	11,990[a]	3,783[a]	-	-	-	-	-	-
26-Mar-91	259.2[b]	14,310[b]	10,800[b]	7,560[b]	-	-	-	-	-	-	-	-	-	-
01-Apr-90	-	-	-	-	-	-	-	-	-	3,510	-	-	324	-
01-Nov-91	170[c]	7,800[c]	18,000[c]	-	180[c]	7,200[c]	17,000[c]	-	43	1,800	1800	180	10,000	12,000
24-Feb-92	297[a]	12,690[a]	9,450[a]	7,830[a]	-	-	-	-	-	-	-	-	-	-
15-Apr-92	-	-	-	-	-	-	-	-	102.6	2,700	972	186.3	7,020	5,400

[a]Filtered sample.
[b]Unfiltered sample.
[c]Filtered sample analyzed at Bechtel National, Inc. close support laboratory.

To investigate possible locations of contaminant influx into the storm drain system, grab samples were obtained from the storm drain network at access locations in the vicinity of Building 2013 for radiological analysis. Sampling occurred more than 72 h after a precipitation event to minimize sample dilution. It should be noted that the engineering drawings of the storm drain network did not always coincide with field observations, and not all access locations are included in the engineering drawings.

Figure 5 shows the locations of storm drain and outfall sampling and the analytical results of gross beta activity in picocuries per liter. Analytical results for all analytes are listed in Table 3. Table 3 also lists field physicochemical results and compares storm drain invert elevations and groundwater elevations from September 30 and October 1, 1991, measurement. These results indicate that the plume is discharging into the storm drain network to the north of Building 2013 and along First Street and that contaminants are discharging in the piezometer 539 seep. The analytical results and the apparent storm drain system connections suggest that the Building 2013 storm drains discharge via outfall 341 and that the First Creek storm drain discharges via outfall 342.

The comparison of storm drain invert elevations and low-base groundwater elevation in Table 3, in addition to observed seepage into the storm drains, indicates that plume discharge into the storm drain network in the western portion of WAG 1 occurs continually. Also apparent in Table 3 is a relation between field physicochemical and analytical results which shows that radiologically contaminated samples also have values of conductance of 0.20 and greater and values of pH less than 8.0.

5.2 CONTAMINANT PLUME ANALYSIS

Figure 6 is a strike-parallel, scaled cross section of the shallow subsurface showing radiological contaminant concentrations (picocuries per liter, filtered) in CH-8 from the Westbay sampling intervals, in a storm drain catchment basin north of Building 2013, and in piezometers along the contaminant plume pathway and in First Creek. The maximum, scaled-head value tensors from isolated intervals indicate that the discharge pressure gradient from CH-8 to First Creek is greater than the vertical pressure gradient within CH-8. This gradient distribution, coupled with weathered bedding planes and strike-set fractures, results in plume evolution within the stratigraphic zone in a direction nearly orthogonal to the general observed head surface rather than along the conventionally interpreted flow lines.

Minor vertical leakage of contaminant along the preferred, lateral-migration pathway (as shown in Fig. 1) is likely responsible for contaminants 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) is responsible for high-contaminant concentrations in that outfall. Because measured water elevations in Fig. 5 represent low-base conditions, the degree of connection between groundwater and the storm drain is likely greater during high-base conditions.

Incompletely lined portions of the storm drain system in the vicinity of Building 2013 and piezometer 539 are considered to be the source of radiological contaminants in storm drain outfalls 341 and 342. Note that water was observed to be upwelling into and exiting from sample location M-15. These storm drains appear to capture the top of the plume and may provide a local constant-head boundary that is intercepting the plume and may retard its continued expansion in a westward direction.

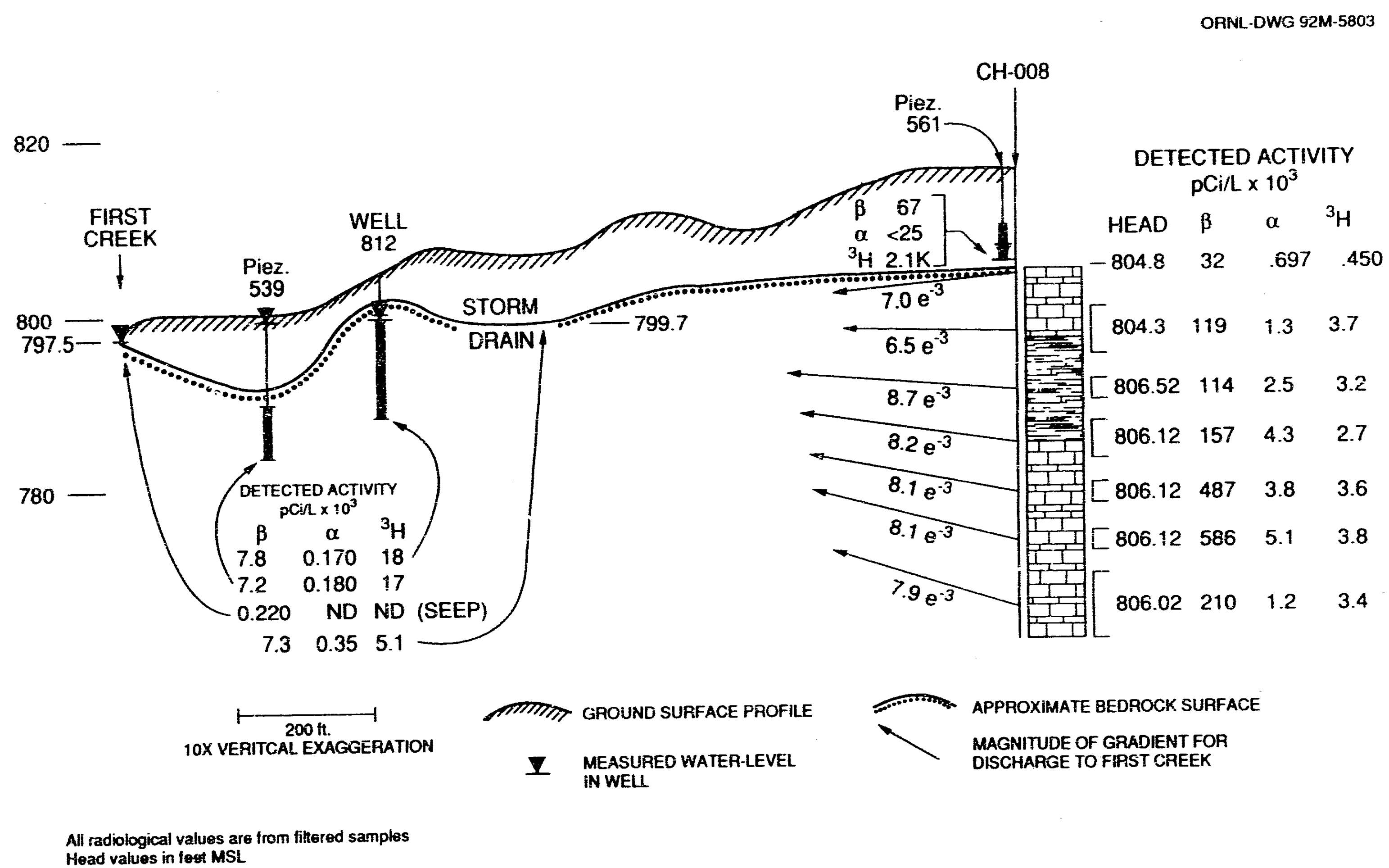

Fig. 5. Hydrogeologic cross section of head and contaminant concentrations for selected wells and First Creek.

Table 3. Storm drain network analytical results

Sampling location	Gross alpha (pCi/L) [error]	Gross beta (pCi/L) [error]	Tritium (p/Ci/L) [error]	pH	Temp (°C)	D.O.	Con (msv/cm)	Turb (ppm)	Storm drain invert elevation (ft/msl)	Groundwater elevation (ft/msl)
341 outfall	103 [19]	2,700 [270]	972 [918]	8.1	18.1	9.8	0.09	007	NA	NA
342 outfall	186 [27]	7,020 [270]	5,400 [1,080]	8.0	17.8	9.9	0.05	008	NA	NA
M-19E	267 [32]	7,020 [270]	6,750 [1,080]	7.7	17.9	9.7	0.22	008	789.5	±791
M-19W	4 [4]	17 [8]	ND	8.2	19.6	9.8	0.05	012	789.5	±791
M-6	12 [7]	270 [27]	ND	8.2	19.3	10.0	0.06	010	791.9	±792
M-4E	16 [8]	267 [27]	ND	8.2	18.4	10.1	0.05	005	794.9	±796
539 SEEP	46 [14]	1,458 [54]	ND	7.5	16.1	8.2	0.20	022	NA	NA
MH-100	10 [6]	270 [27]	ND	8.0	19.3	10.0	0.02	007	797.8	±797
MH-101S	3 [4]	4 [7]	ND	7.6	24.3	10.2	0.20	012	797.8	±799
M-15	351 [27]	7,290 [270]	5,130 [1,080]	7.8	21.6	9.9	0.24	028	799.7	±800
MH-102	ND	14 [8]	ND	8.1	20.5	9.1	0.01	010	800.3	±801
MH-103	297 [27]	7,830 [270]	6,480 [1,080]	7.5	19.1	9.4	0.22	018	799.9	±801
MH-105N	297 [27]	8,370 [270]	5,130 [1,080]	7.7	19.1	9.2	0.20	006	800.3	±796
MH-105E	2 [3]	65 [11]	ND	8.2	18.9	10.2	0.04	008	800.3	±796

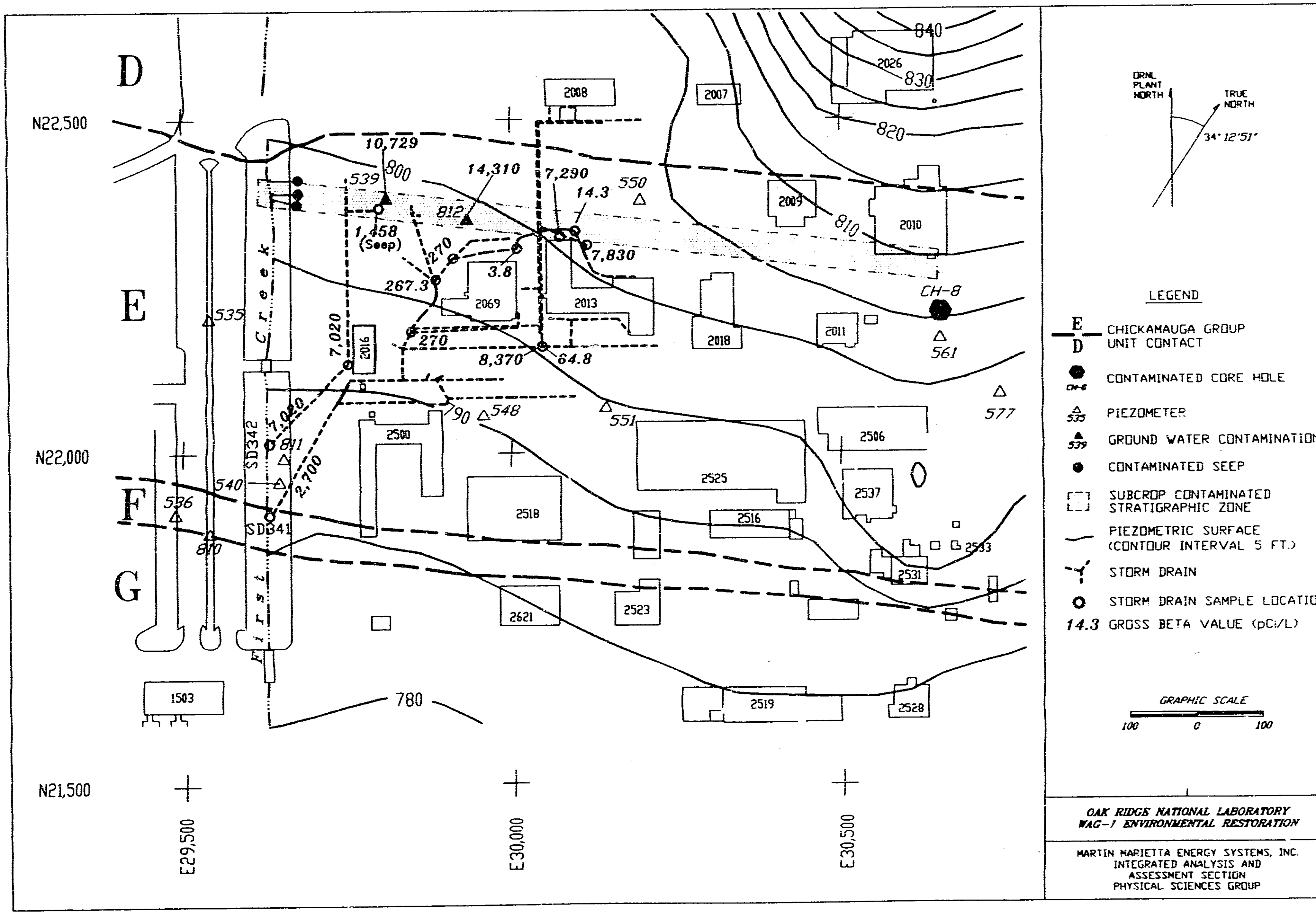

Fig. 6. Gross beta contamination in contaminant plume, sampled storm drains, and storm drain outfalls.

Figure 6 also depicts general characteristics of the groundwater flow system that may be used in continued site investigations, conceptual model development, and numerical model analysis. Radiological data indicate that the highest levels of gross beta contamination (by two orders of magnitude) are in CH-8. Conversely, two orders of magnitude higher tritium concentrations occur in piezometers 539 and 812 and outfall 342. This suggests either (1) a single source area from which highly mobile tritium has largely migrated through the groundwater system while the bulk of the retarded alpha- and beta-emitting contaminants are yet to reach First Creek, or (2) the plume is an admixture of contaminants from more than one source area.

Currently, radiological constituents suggest that the area immediately north of North Tank Farm is a likely source area for alpha and beta contamination. Tritium in piezometer 539 and well 812 may be part of the same plume or may be derived from a separate, currently unidentified source. Continued investigations that include a well-designed subsurface exploration and sampling program as part of Phase II RI/FS are expected to resolve source area uncertainties and lead to refined conceptual models of the flow field.

6. CONCLUSIONS

The water table gradient (Fig. 4) and Darcian principles would suggest a relatively diffuse contaminant plume migrating in a southerly direction to a First Creek discharge location near its confluence with White Oak Creek. The absence of radiological contaminants in piezometers near and downgradient from CH-8 confirms that local flow and transport are not wholly governed by the overall hydraulic gradient.

The results indicate that the stratabound concept of groundwater flow and contaminant transport in WAG 1 is a viable component of an overall conceptual model of the flow field. Sole reliance upon Darcian principles to predict local groundwater contaminant plume migration is inadequate in all of the WAG 1 setting. Empirical data now demonstrate that stratabound groundwater flow is operable in three of the four major rock units on ORR—the Conasauga, Knox, and Chickamauga Groups. These data also indicate that groundwater contaminant migration on ORR is an extremely localized phenomenon that is not readily identified or characterized in large-scale studies that assume conventional porous medium conditions.

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 in WAG 1. The development of this highly accurate predictive capability can be used to more sharply focus continued groundwater field investigations in WAG 1 and elsewhere on ORR (e.g., down-dip migration). 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 WAG 1 flow field and enhanced restoration.

7. RECOMMENDATIONS

Based on the data currently available, it is apparent that contamination is migrating through the bedrock portion of the shallow aquifer beyond the western boundary of WAG 1 and that some fraction of the contaminant plume discharges via the partially lined storm drain system north of Central Avenue. Before design and construction of any interim plume interception facility, additional data are needed to determine the vertical and areal extent of contamination and to determine the methods of plume control that could be effective.

It is apparent that at least a fraction of this plume is collectible by passive gravity interception. One obvious concept for plume control is to enhance the groundwater collection capability of contaminated portions of the storm drain system and to divert collected groundwater from these areas to treatment, thus reducing the flux of contaminants reaching First Creek.

To determine the vertical and areal extent of contamination, additional groundwater sampling locations are required, including at least one additional core hole suitable for multizone sampling and both shallow and bedrock wells of simple construction capable of yielding samples for radiological analysis. The plume characterization should include a component of investigation west of First Creek in the observed plume-transmitting bedrock zone to determine if contaminants are migrating beneath the creek in the bedrock.

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