TECHNICAL MEMORANDUM **CH2MHILL**

Site 10 Hot-Spot Remediation, Revised Conceptual Design

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Background

The initial conceptual design for hot-spot groundwater remediation at Site 10 of the Allegany Ballistics Laboratory Superfund Site was presented in a CH2M HILL Technical Memorandum dated January 21, 1998. That conceptual design called for pumping of two extraction wells (existing wells 10GW11 and 10EW1) located in the western and central parts of the Site 10 area where elevated concentrations of trichloroethylene (TCE) have been detected and the direction of groundwater flow is almost uniformly eastward. This modification of the design adds a third extraction well farther to the east in a part of the Site 10 area where the pattern of groundwater flow is more complicated.

The purpose of the new well is to expand the hydraulic capture zone of the remediation system to encompass the area that is estimated to have total volatile organic compound (VOC) concentrations greater than 100 μg/L. The extent of this target VOC plume is shown in Figure 1. Its delineation is based on historical sampling data from monitoring wells in the Alluvial Aquifer and interpretation of the contaminant migration pattern suggested by groundwater levels measured in the Phase II aquifer testing (CH2M HILL, 1997).

Previous analysis of groundwater flow at Site 10 has been limited to mathematical modeling in which the natural flow pattern could be approximated as uni-directional flow. In the Phase I Aquifer Testing Report (CH2M HILL, 1996), a uniform eastward hydraulic gradient was assumed across the entire Site 10 Area, because no field data had yet been generated to contradict that assumption. The installation of more wells in the Phase II testing program revealed the more complicated potentiometric surface shown in Figure 2. It shows flow from the western and southern portions of the area converging toward a northeast-trending potentiometric trough that is apparently centered approximately on Well 10GW7 and may pass between wells 10GW13 and 10GW16. The eastern portion of the target VOC plume is adjacent to this potentiometric trough. To analyze the potential effectiveness of an additional extraction well in the eastern lobe of the VOC plume, it was necessary to represent the groundwater flow system in the Alluvial Aquifer with a numerical model that could handle the non-uniform aquifer properties and irregular boundary conditions suggested by Figure 2.

Model Development

Conceptual Model

Setup of the numerical model was based on a simplified concept of the groundwater flow system in the Alluvial Aquifer. The intention was not to produce a calibrated general-purpose simulation model of Site 10 groundwater. Rather, the numerical model was developed as an extension of the previous mathematical models that would be able to represent the observed irregularities in the potentiometric surface of the Alluvial Aquifer. The field data presently available do not provide a definitive explanation of the flow convergence toward Well 10GW7. Figure 2 suggests the presence of a linear subsurface feature that conducts groundwater with greater facility than the surrounding aquifer materials. It could be a narrow channel of relatively clean gravel and cobbles at the base of the alluvium, a major fracture zone in the underlying bedrock, or some other type of high-conductivity feature. Infiltration into a nearby storm sewer is another possible explanation. However, it is unlikely that a sewer would have been installed below the water table. The numerical model was based on the assumption of a generic high-transmissivity feature. It was assumed that flow in the Alluvial Aquifer is two-dimensional, and that the zone of flow convergence is caused by a narrow band of highly transmissive sediments coinciding with the centerline of the potentiometric trough shown in Figure 2. Hydraulic interaction with the underlying Bedrock Aquifer was assumed to be negligible.

The Alluvial Aquifer was simulated as a confined aquifer, meaning that the transmissivity is not affected by changes in groundwater levels. This simplification was used because most of the groundwater flow in the alluvium is attributed to the sand, gravel, and cobble layer at its base. The water table is several feet higher than the top of the basal gravel. Therefore, moderate variations in saturated thickness would not result in significant changes in transmissivity.

The areal distribution of transmissivity in the alluvium was based on evaluation of step-drawdown tests and constant-rate pumping tests reported in previous studies (CH2M HILL, 1996; CH2M HILL, 1997). In the eastern part of the Site 10 area, testing of Well 10GW11 produced a transmissivity estimate of 1,130 square feet per day (ft^2/day). A test at Well 10EW1, in the central part of the area yielded an estimate of 652 ft^2/day. On the eastern side of the area, test results for wells 10EW3, 10EW4, and 10EW5 ranged from 352 ft^2/day to 484 ft^2/day. Based on these estimates and the variations in hydraulic gradient illustrated in Figure 2, the zonal distribution of transmissivities show in Figure 3 was assumed. The general pattern is one of high transmissivity in the west, low transmissivity in the east, and a transitional zone comprising four vertical bands of intermediate transmissivity in the central region. This pattern is interrupted by a narrow diagonal band of very high transmissivity that corresponds to the observed potentiometric trough.

Model Implementation

The numerical model was implemented using the modular three-dimensional finite-difference modeling code known as MODFLOW (McDonald and Harbaugh, 1988). This code was developed by the United States Geological Survey, and has been widely accepted as a reliable simulator of the basic equations of flow in porous media. It was also used to evaluate the potential effects of extraction wells for Site 1 at Allegany Ballistics Laboratory.

The model was set up in a finite-difference grid of one layer consisting of 59 rows and 80 columns of rectangular cells. Each cell was 25 feet square. The grid covers a rectangular area 2,000 feet wide and 1,475 feet high, corresponding approximately to the area shown in Figure 2.

To generate the observed regional hydraulic gradients in the modeled area, fixed-head boundary conditions were assigned to the finite-difference cells on the outer edges of the grid. This type of boundary condition is one of the three possible choices available in the MODFLOW code. The others are specified-flux boundaries, and head-dependent flux boundaries. The choice of boundary conditions is important because of their potential to affect the simulated response of the aquifer to the pumping of extraction wells. Fixed-head boundary conditions allow groundwater to flow into or out of the modeled area as necessary to maintain the assigned water levels at the edges of the grid. This means that the drawdown caused by pumping the extraction wells will not reach the edges of the grid. Hence, the use of fixed-head boundary conditions is conservative in the sense that their effect, if any, will be to reduce the size of the simulated capture zones.

Figure 4 shows the simulated steady-state potentiometric surface produced by the numerical model. Although the simulation results display a fairly close resemblance to the observed potentiometric surface shown in Figure 2, this model is not to be interpreted as a calibrated general-purpose simulation model for Site 10. Rather, it is a numerical expression of the hypothetical conceptual model described above. It is realistic to the extent that it produces a simulated flow pattern similar to the pattern observed at the site and uses transmissivities based on site-specific test results. The only adjustments that were made in the initial setup to improve the calibration of the model were changes in the transmissivity values assigned in the diagonal high-transmissivity band. Values ranging from 1,000 ft^2/day to 50,000 ft^2/day were tried. The two zones shown in Figure 3, with transmissivities of 6,000 ft^2/day and 35,000 ft^2/day, produced the best results. No attempt is made here to describe the aquifer materials that might be associated with transmissivities as high as 6,000 ft^2/day and 35,000 ft^2/day. These two high-transmissivity zones simply represent a hypothetical feature that could produce the observed flow pattern.

Modified Groundwater Extraction System

Simulation of a Three-Well Extraction System

The original hot-spot remediation system (CH2M HILL, 1998) was capable of hydraulically containing and recovering contaminants in the high-concentration area in the western and central part of the site, but not all VOCs above 100 µg/L in the eastern lobe of the target plume. These capabilities were predicted by the mathematical models used in the original design and are confirmed by the newly developed numerical model.

To obtain complete hydraulic capture of the target plume shown in Figure 1, a third extraction well (to be called 10EW2) must be added approximately 90 feet north-northeast of Monitoring Well 10GW7. The simulated hydraulic behavior of the resulting three-well extraction system is shown in Figure 5. The simulated pumping rate of the third well was 7.5 gallons per minute (gpm). This estimated pumping rate is based on the assumption that the transmissivity of the alluvial aquifer in the new well location is 400 ft^2/day and that the static (unpumped) saturated thickness is 16 feet. Under these conditions, an extraction rate of 7.5 gpm should produce approximately 7 feet of drawdown, leaving a water column of 9 feet in the extraction well. This projection also assumes a well efficiency of 80 percent. Combined with pumping rates of 15 gpm at Well 10GW11, and 12 gpm at 10EW1, the three-well system would produce a total of 34.5 gpm.

Several different locations for the third extraction well were tried in a series of model simulations. The initial locations were closer to the original hot-spot extraction wells, slightly to the north-northwest of Monitoring Well 10GW7. The simulations showed that a third well in that location would not capture the northeastern end of the target plume. If the third well is located too far to the east, there will be a gap in the capture zone between it and Well 10EW1. At the locations and pumping rates shown in Figure 5, the three wells produce an uninterrupted capture zone encompassing the target VOC plume. However, this conclusion is dependent on the actual hydraulic properties of the groundwater flow system being reasonably similar to the hypotheses used to formulate the model. The actual hydraulic properties of the groundwater flow system must be checked as the new extraction well and the new performance monitoring wells are being installed.

Monitoring Hydraulic Performance

To verify that the groundwater extraction system hydraulically confines the target VOC plume, it will be necessary to install five new alluvial monitoring wells and one new monitoring well in the bedrock. The proposed locations of the new monitoring wells are shown on Figure 6.

Two new alluvial monitoring wells (10GW23 and 10GW24) are to be installed east of extraction well 10EW1 to verify that the horizontal hydraulic gradient results in flow toward the extraction well. One of these new alluvial wells will be installed next to the existing bedrock monitoring well 10GW20. This will allow measurement of vertical gradients to confirm that flow is upward from the bedrock.

Two more new alluvial monitoring wells (10GW25 and 10GW26) will be installed east of the new third extraction well. They will be used to demonstrate that inward gradients are being maintained at the eastern edge of the target plume.

In addition, a new well pair (10GW21 and 10GW22) is needed in the gap between the existing monitoring wells 10GW13 and 10GW16, where the high-transmissivity feature is believed to be conducting groundwater out of the Site 10 area. These wells, in the bedrock and alluvium, will provide stratigraphic and hydraulic information that may explain the nature of the suspected high-transmissivity feature. They will also be monitored to evaluate the hydraulic effects of the extraction system on groundwater flow in this critical area.

Well Installation and Testing

The suspected irregular hydrogeologic characteristics of the eastern portion of the Site 10 Area may significantly influence the remedial effectiveness of the proposed three-well extraction system. It is important that the additional subsurface information obtained from installing the new wells be assimilated as quickly as possible so that the planned system can be adjusted, if necessary, in response to field conditions.

The wells should be installed by a drilling method that produces the information needed for detailed lithologic logging. It must also be able to complete an efficient gravel-packed well at the bottom of the alluvial aquifer. Each of the wells should be logged to identify the existence and thickness of the expected cobble layer and the elevation of the top of bedrock. Each of the new alluvial monitoring wells should be yield tested as soon as installation and development are completed. To more fully investigate the properties of the bedrock, the new bedrock monitoring well should be subject to a 6-hour step drawdown test. The new wells should also be sampled so that the delineation of the target VOC plume can be refined.

After construction and development, the new extraction well should yield tested. It is likely that the productivity of the new well will be somewhat different than was assumed in the conceptual design (7.5 gpm at 7 feet of drawdown). If step-drawdown testing shows that it cannot sustain a rate of more than 4.0 gpm when the drawdown is half the static water column, the well is not likely to give satisfactory remediation performance. In that case, one or more additional extraction wells may be needed. Should this situation arise, a decision on the number and location of the additional extraction wells should be based on subsurface data obtained from installation and yield testing of the proposed new alluvial monitoring wells. To maximize the efficiency of this process, the new extraction well (10EW2) should be drilled and yield-tested first. Then, monitoring wells 10GW21, 10GW22, 10GW23, and 10GW24 should be installed in numerical order. If the yield test of extraction well 10EW2 shows satisfactory productivity, monitoring wells 10GW25 and 10GW26 will be installed as shown in Figure 6. A step-drawdown test will then be run in 10EW2 to more fully characterterize its efficiency and the hydraulic properties of the aquifer. If the yield test shows insufficient productivity, the plan will have to be modified. Scheduling of the drilling should be closely coordinated with the well installation activities at Site 11 to minimize costs and avoid unnecessary delays while data are evaluated and decisions made.

References

CH2M HILL (1996). *Draft Phase I Aquifer Testing at Allegany Ballistics Laboratory Superfund Site.* prepared for Atlantic Division, Naval Facilities Engineering Command, October 1996

CH2M HILL (1997). *Draft Phase II Aquifer Testing at Site 10 at Allegany Ballistics Laboratory Superfund Site.* prepared for Department of the Navy, Atlantic Division, Naval Facilities Engineering Command, October 1997

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McDonald, M.G. and A.W. Harbaugh. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. *Techniques of Water Resources Investigations of the United States Geological Survey,* Book 6, Chapter A1. U.S. Government Printing Office, Washington, D.C.

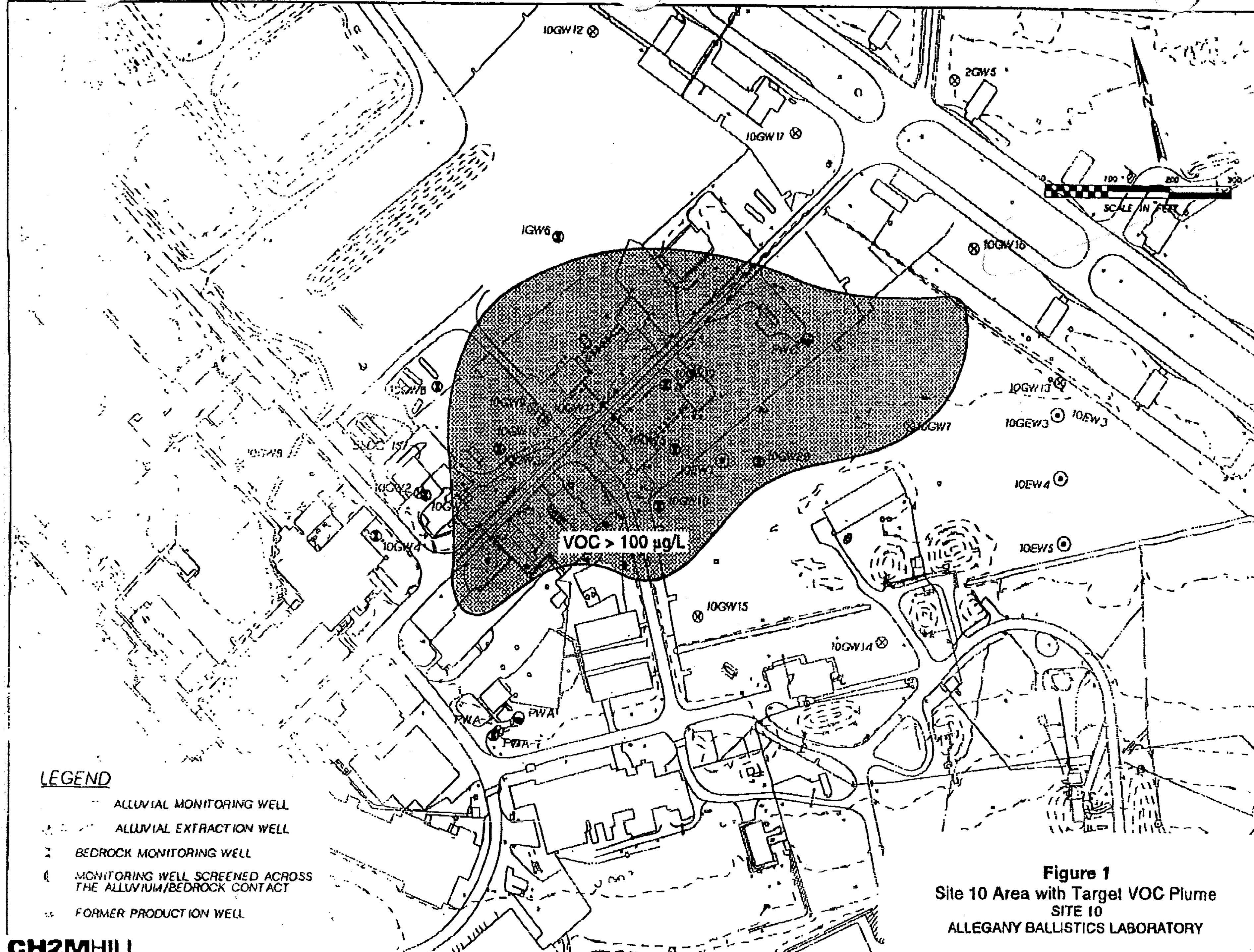

Figure 1
Site 10 Area with Target VOC Plume
SITE 10
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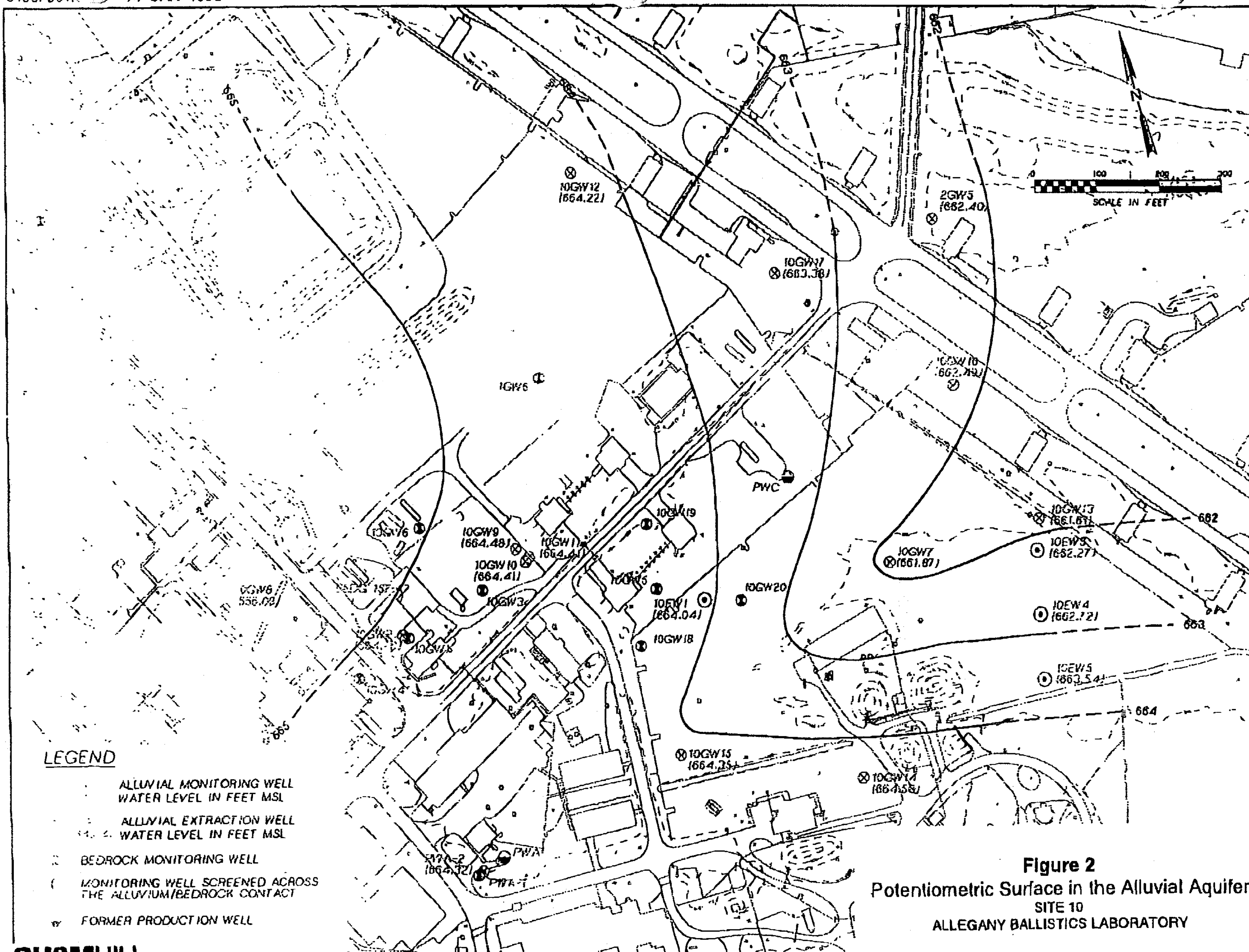

Figure 2
Potentiometric Surface in the Alluvial Aquifer
SITE 10
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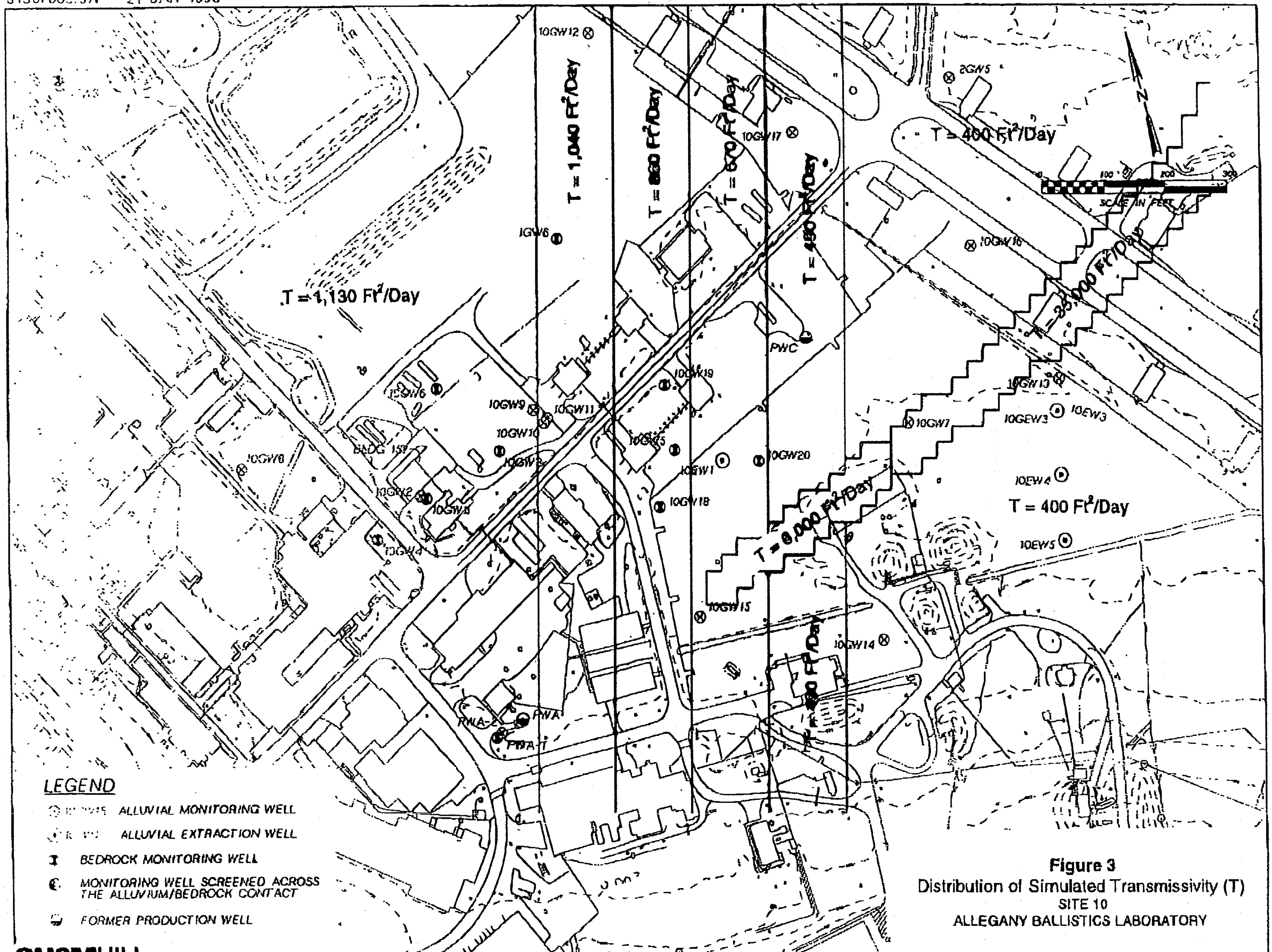

Figure 3
Distribution of Simulated Transmissivity (T)
SITE 10
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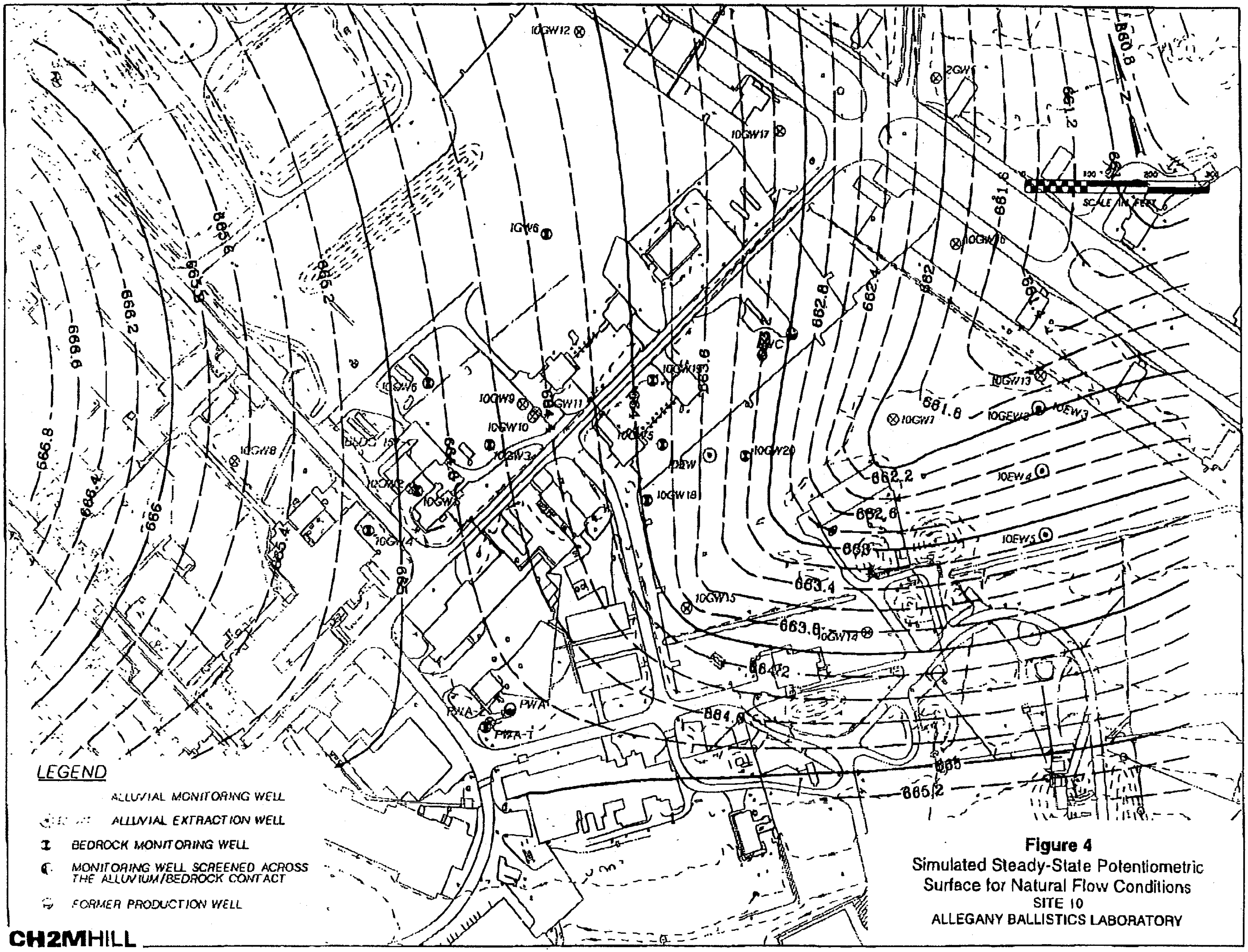

Figure 4
Simulated Steady-State Potentiometric Surface for Natural Flow Conditions
SITE 10
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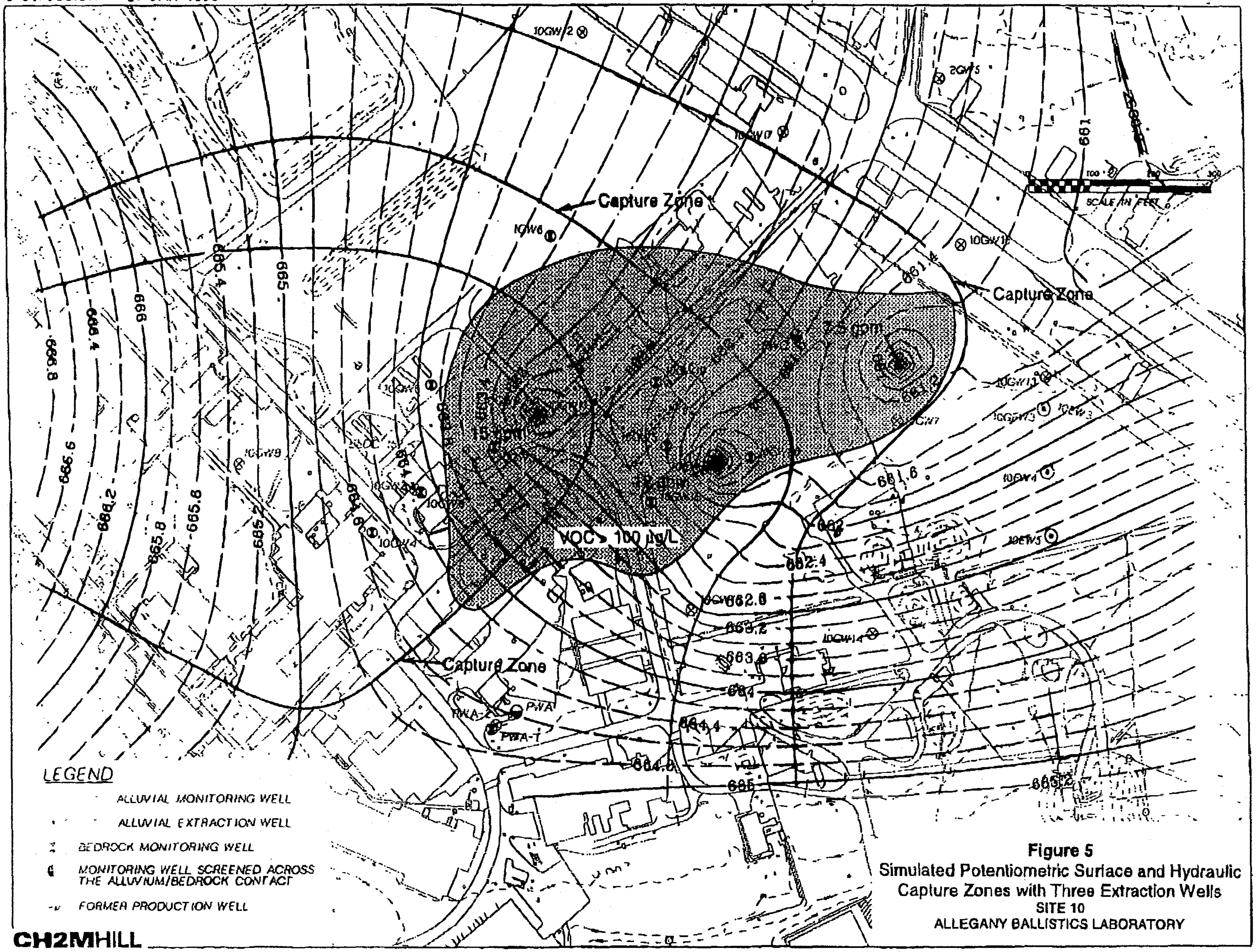

Figure 5
Simulated Potentiometric Surface and Hydraulic Capture Zones with Three Extraction Wells
SITE 10
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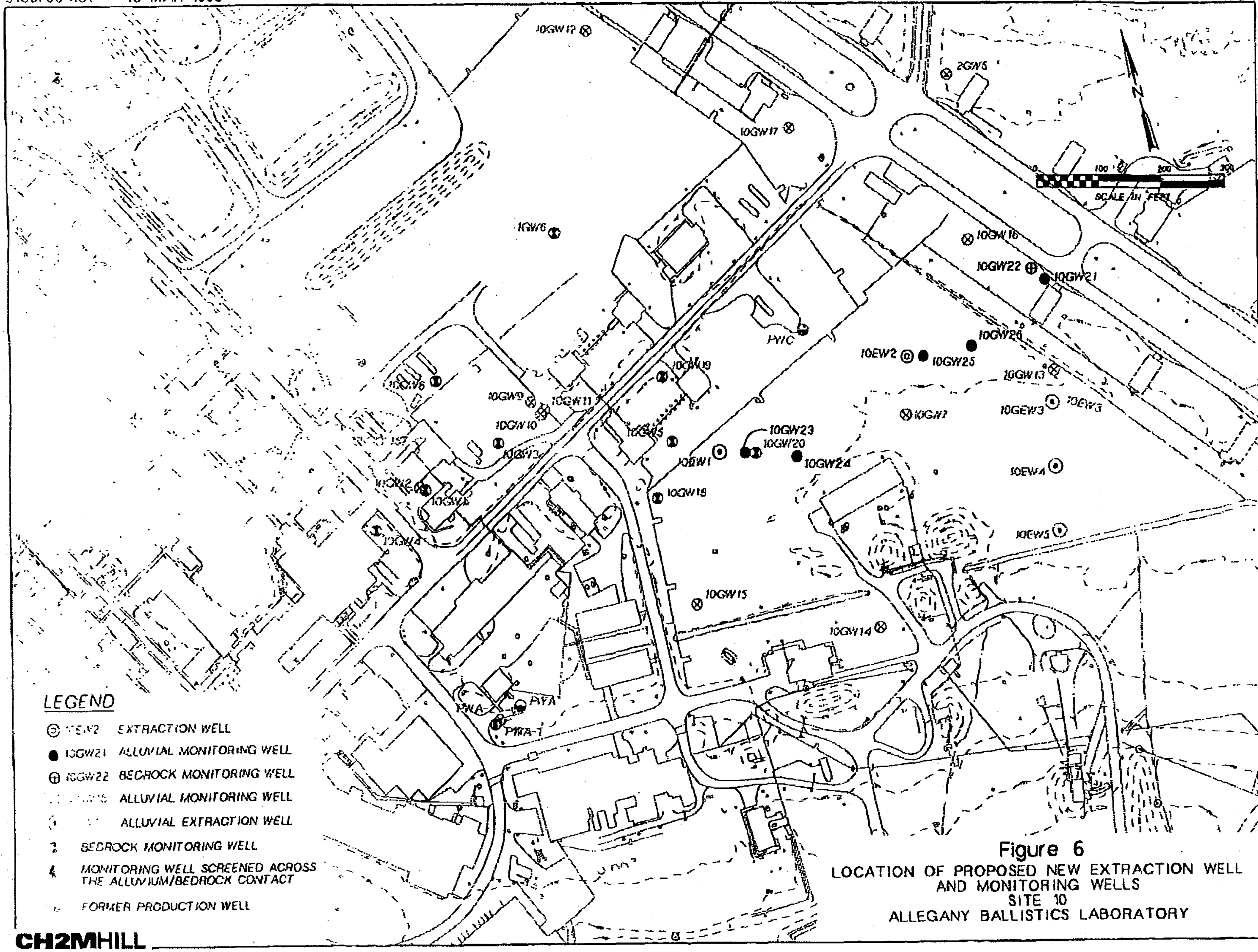

Figure 6
LOCATION OF PROPOSED NEW EXTRACTION WELL AND MONITORING WELLS
SITE 10
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