# An analysis of the design and performance of the clay cap used to control groundwater recharge into the fractured bedrock beneath the former sodium burn pit (FSDF) at the former Boeing-Rocketdyne Santa Susana Field Laboratory

BY

**William C. Bianchi, Ph.D.**

**October 5, 2006**

Disclaimer: This study was prepared for the Santa Susana Field Laboratory Advisory Panel, a project of the Tides Center. The work of the Panel was conducted under a contract with the California Environmental Protection Agency pursuant to funds provided by the California Legislature. The statements and conclusions in this report are those of the contractor and not necessarily those of the California Environmental Protection Agency. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

# AN ANALYSIS OF THE DESIGN AND PERFORMANCE OF THE CLAY CAP USED TO CONTROL GROUNDWATER RECHARGE INTO THE FRACTURED BEDROCK BENEATH THE FORMER SODIUM BURN PIT (FSDF) AT THE FORMER BOEING-ROCKETDYNE SANTA SUSANA FIELD LABORATORY

William C. Bianchi, Ph.D.

## BACKGROUND

The sodium burn pit area at the Santa Susana Field Laboratory was utilized for the disposal of toxic materials. The pit area received annual rainfall for many years and those constituents that were mobilized by this rainfall have entered the bedrock beneath the pit area. The original soil profile at the FSDF was described in the Characterization Report (ICF Kaiser 1997, Vol. 1, sec 4.2.1), as "The undisturbed surface soils are described as micaceous silts and clays with fine-grained sand and traces of coarse-grained sand and fine gravel in some instances. Disturbed soils are generally siltier and sandier than undisturbed soils. Subsurface soils were generally poorly graded silty sand and sand." The thickness of soil mantel over the bedrock in many places was less than a foot and at its greatest five feet (ICF Kaiser 1997, Vol. 2, Appendix D). Because of the porous nature of the original soil a considerable inventory of pollutants now resides in the fractured bedrock below.

The proposed physical solution now in place designed to isolate the pollutant materials in the bedrock consists of placement of what is defined as a "clay cap", a soil backfill put in place after the original soil and the pollutants it contained were removed down to the bedrock basement of the pit area (Interim Measure Work plan, July 9, 1999). The thickness of this cap is at least 1 foot and no greater than 12 feet. This backfill was excavated from a barrow pit area on the facility. The laboratory soil particle size analysis (see Infiltration Monitoring Work plan, Former Sodium Disposal Facility, IT Corp. April 14, 2000, appendix A and A1) puts this fill material in the silty clay to silty clay loam soil class according to textural standards (USDA Soil Survey Manual #18). The field water transmission performance of these textural classes as viewed by geohydrologists is shown in Figure 1. As seen here this textural range places the water transmitting properties in the class of a poor aquifer, not in the impervious range. Again, this cap was meant to prevent future percolation of rainfall into the crack matrix of the bedrock and thus eliminate further downward mobilization of pollutants.

The surface of the cap has been configured to collect any sheet flow from rainfall and discharge it out of the area of the backfill. This minimizes the amount of rainfall entry into the surface of the cap. When the fill was completed the surface was Hydro- Mulched (seeded) and trees planted. The vegetative cover was to provide a pathway for any accumulated moisture in the soil profile to be transpired by the plants out of the vegetative root zone depth and thus diminish the net recharge deeper into the back fill and prevent deep percolation into the fractured bedrock. Two natural low spots in the bedrock which would channel flow off site were gravel packed to enhance possible flow off site if water were to reach that depth.

**INSTRUMENTATION**

(See Infiltration Monitoring Work Plan – Former Sodium Disposal Facility, Santa Susana Field Laboratory, IT Corporation, Project 881344, April 14, 2000)

Since 2000 the performance of the cap has been monitored with three devices installed to measure soil water movement in the backfill after its placement. A device called a piezometer which is merely a pipe placed vertically to a given depth in the soil profile that measures the free water pressure at that depth, in this case any water that might pond on the surface of the bedrock from vertical or lateral percolation into the fill. Two piezometers are located at low points in depressed channels in the bedrock that have been gravel packed to accumulate water flow along them, and the other two piezometers at points on the bedrock-fill contact. Also installed were two lysimeters, pans that intercept and collect and measure the water that penetrates to their depth of placement. They are 10 foot square pans and are a foot above the bedrock at about 7 and 11 foot depths below ground surface. The third element of instrumentation involves three clusters of instruments that follow the volumetric moisture content at depth in the soil profile on a near continuous basis. This gives a picture of the changes in water content with depth in the soil profile with rainfall, surface evaporation and plant root uptake. Rainfall is also measured presumably on site. However surface runoff is not measured.

## NO DEFINED GOAL FOR CAP PERFORMANCE

Nowhere does the Department of Toxic Substance Control (DTSC) require in the Interim Management Work Plan a goal for the performance of the clay cap. The strategy seems to be that a monitoring system will substitute for a standard to be met by the project. Conceivably this standard should be no discharge into the fractured bedrock out of the cap. DTSC has left to future monitoring observations in the cap their determination as to whether the cap has functioned properly or not. The performance of the monitoring system in adequately describing what is occurring in the in the cap leaves what actually occurs in the fractured bedrock a diffuse uncertainty at best.

Our SSFL Panel requested from the SSFL Project Manager for DTSC any review, evaluation, or analysis DTSC had performed of the Annual Operation and Maintenance and Infiltration Monitoring Reports as filed over the years for Rocketdyne – Boeing but as yet has received no response.

## ACTUAL PERFORMANCE OF CAP AS DEFINED BY THE MONITORING SYSTEM

The DTSC Interim Management Work Plan required the filing of a monitoring report on an annual basis. Reports have been filed by the Boeing Co. (Shaw Environmental, Inc.) covering observations since December of 2000. Included in these annual reports are measurements from the piezometer network, the lysimeters, the soil moisture probe clusters and rainfall for the period July1 to June 30.

### Piezometer Observations

The piezometers were placed in the two foot zone just above the bedrock- backfill contact and 4 to 6 inches into the sandstone encountered there. They measure water that might accumulate above the bedrock- backfill contact and any significant pressure head that could develop there. Two were sited at the low end of gravel packed bedrock channels beneath the backfill and the other two on its margins. No significant water level was observed in these piezometers until

March 7, 2005 after over 42 inches of rainfall between mid October ’04 and the end of April ‘05. The two located in the gravel packed bedrock lows and one of the peripherals responded by mid April ‘05. The water level in the piezometer at the low point in the bedrock persisted through mid September ’05, well into the dry season. Bedrock wells outside the site boundary showed water elevations above the base of the site backfill and the conclusion reached in the ’04-’05 Annual Report was “The detection of measurable water at PZ Test 1 (also2 and 3) is thus taken to be a reflection of the rise of the groundwater level to above the rock contact in the deep channel monitored by this piezometer.” During the ’05-’06 reporting period about 17.9 inches of rain (just above normal) between mid October and mid May produced a response in the lowest piezometer only. Again the explanation for this was a rise in the regional water table. The implications of this conclusion would be that recharge of the fractured bedrock aquifer in the zone beneath the “capped” area is in large part from the surrounding area. Thus mobilization of the pollutant inventory in the bedrock fractures is present and ongoing despite the cap. The alternate explanation would be that the graveled lows are functioning as lysimeters and indicate that the cap is not functioning when rainfall over the fill area is excessive and recharge through the cap becomes significant.

**Pan Lysimeter Observations**

In every year since their installation water has accumulated in the pan lysimeters (see Table 1). Measurable quantities were first noted in August of ’01 from rainfall of 5.4 inches plus irrigation to start the vegetative cover on the fill and that added for compaction. Significantly more accumulated in’02-’03 from above normal rainfall of 25.2 inches (normal is about 14 inches) in the period November through May but it was almost November before the water reached the pans at 7 and 11 feet below ground surface. But they were dry (no longer accumulating) by December. The data from ’03-’04 is confused by collection problems. The ’04-’05 rainfall was a near record for the LA area, at the site it was 45.2 inches starting in mid October of ’04. Both pans responded with significant accumulations again with a delay in arrival until well into the dry season (late august). But again were dry (no longer accumulating) by the end of October. Because of this lag in the time it takes for the flow from rain that penetrates through the soil profile and beyond the plant cover root zone the response to the ’05-’06 wet season is not present in the data so far.

The above response is consistent with the nature of unsaturated flow in soil profiles. When water is applied to the soil surface, the moisture content increases to at or near saturation to a depth depending upon the quantity and rate added. This slug of water drains down under gravity until the flow is controlled by the soils capacity to retain water against the gravitational downward pull. This quasi-equilibrium in water content is achieved roughly after two or three days after application. This moisture content is dependent on the soils texture and is defined as its Field Capacity (Diagnosis and Improvement of Saline and Alkali Soils, USDA Agricultural Handbook No. 60, 1954). Downward movement does not cease but becomes very slow and dependent upon the pre-existing profile moisture content into which the slug of moisture is moving. If the soil is dry, the front is sharp between wet and dry where conductivity is very low. When wet unsaturated soil conductivity is several orders of magnitude higher, as in the above, the front is diffuse and flow is still unsaturated and downward until it reaches the pan level. Now that the vegetative cover is somewhat established and water application only dependent on rainfall, the cap profile is coming into equilibrium with the seasonal rain penetration beyond the root zone. The pan catch lag behind the first significant period of accumulated rainfall of 6 inches or so is several months, indicating that the cap profile is capable of a moisture flow greater than that measured.

**TDR Probe Observations**

The TDR probe data from ’01 thru ’04 (see Figs 7A-C, Annual Operation and Maintenance Report-July 2003 through June 2004, August 31, 2004) indicates that the response to surface water infiltration is quite variable in terms of the profile depth. The shallow probe depths are in reasonable agreement; however comparing cluster 1 and cluster 2 would indicate that the response in the 4 to 6 foot zone in cluster 1 could be responding to a horizon of greater permeability. The 4 to 6 foot zone in cluster 1 fills first in response to the rain events between November ‘02 and January ’03 and drains out more rapidly in the June through Sept. '03 dry period. Both in cluster 1 and 2, the deeper probes respond similarly, but here again in February of '04 cluster 2 rose more rapidly and drained more rapidly than cluster 1. One would expect textural variability and layering to be present in the backfill and result in such moisture storage changes. Thus the back fill is not homogenous and anisotropic as the modelers would have it

(LEACHM Modeling) but will have leakier areas in some locations than in others. The ’03 and ’04 data do indicate advancement in vegetative moisture extraction during the growing season. Unfortunately, without evaluation of the net water entering the system (rainfall less runoff), a water budget evaluating movement beyond the rooting using the transient storage changes displayed by this instrumentation are not possible. The Report data for ’05-’05 shows a slight increase in scatter in measured moisture content in the mid depth during the growing season that could be the first indication of root contact with the sensor surface as will be discussed later.

**MONITORING SYSTEM WEAKNESSES AND INSTRUMENTATION PROBLEMS**

The monitoring program and measurements have not been designed to allow any estimates of the net infiltration into the fill. There is no runoff collection and measurement and no indication of where the rainfall station is located. A measurement leading to annual and rain event infiltration could be valuable historical evidence for how the surface intake rate of the fill is performing with time.

With the establishment of a vegetative cover on the backfill comes the development of root growth into the engineered fill. Root growth will increase the surface soil permeability down to the depth of rooting and over time could greatly increase the infiltration capacity of the surface soil. In turn this will increase the deep percolation beyond the rooting zone. Thus if the monitoring system is the only control on the performance of the project it should be continued until an equilibrium is reached in the intake rate of the soil surface. No direct measurements of infiltration capacity are part of the current monitoring. The depth to which this plant root induced increase in permeability occurs depends on the plants that become established. Some native plants are extremely deep-rooted -- oak trees up to 40 feet -- and they will extend roots into the fractured bed rock. While the LEACHM modeling assumed a surface and subsurface layer permeability that might be created under laboratory compaction conditions with the backfill soil, the future field permeability could well be one to two orders of magnitude greater in the near future. The model should be re-evaluated on this basis.

The TDR instrumentation that they have placed in the profile to measure the deep percolation associated with irrigation and rainfall and its assumed depletion by evapotranspiration has problems. If a dense vegetative cover is successfully established the associated root system could have a major effect on the measurement system. My experience with moisture sensors placed into soil profiles with active developing root systems is that roots tend to establish along the least resistance path which is adjacent to the surface of the probe. Thus, eventually the observed measurements are affected more by plant water stresses than that in the bulk soil (Bianchi, W.C. & Tovey, R., Continuous Monitoring of Soil Moisture Tension Profiles, Transactions of ASAE, Vol. 3, pp.441-443, 1968). Thus bulk soil observations will be biased on the dry side, evidence of this should appear in the scatter of day time versus night data points. In the description of the installation of the TRD probes it is stated that their volume sensitivity is only to an annulus of a half-inch around the sensor ( Section 4.3, Infiltration Monitoring Work Plan, April 2000) making this root development bias more significant as the rooting develops through time.

The lysimeter observations will be subject to the same bias as above. Roots will tend to accumulate in the capillary fringe zone above the perched water on the pan surface. Oak trees can send down roots to a depth of 40ft and well beyond their drip line. Here again future pan lysimeter observations may not represent what is happening over the total caped area relative to deep percolation.

The data collected from the pan observations and probe observations indicate that there is vertical flow down through the compacted backfill. The piezometer data indicated that no perching occurred at the bedrock interface until ’04-’05 when rainfall was well above normal and the surface infiltration rate increases due to vegetative cover development may have become apparent. The dry piezometers during periods of normal rainfall may not always exclude the possibility of entry of free water into groundwater through the bedrock fractures as evidenced by the fact that water was deposited in the lysimeter's at 7 and 11 feet below ground surface. The past lack of observed perching on bedrock could be explained either by chance placement of the piezometers relative to the project area as a whole, or as a short duration saturated water flow at the contact between the fill and bedrock between measurement intervals. This is alluded to in the August 2002 Annual Report where the highest moisture flux estimated from the lysimeters of ($2 \times 10^{-8}$ cm/sec) occurred and resulted in the statement, “Because this value for the flux is expected to be smaller than the hydraulic conductivity of either the soil or bedrock it is not expected to result in free water at the soil-bed rock interface."

**CONCLUSIONS**

The real problem here is the mobilization of the pollutants that are now entrained in the bedrock fractures beneath the area. While removal of the bulk of the polluted soils eliminated a major source and the cap may decrease moisture movement directly downward through the backfill, the issue of mobilization within the fractured bedrock can also be associated with the flow pattern of percolation from outside of the boundaries of the burn pit area. This has been proposed as the explanation of the '04-'05 piezometer responses. There is no telling what the inventory of pollutants and their mobility is in the fractured structure beneath the area, but the TCE observations indicate that they are moving (Report on Annual Groundwater Monitoring 2000, Santa Susana Field Laboratory, Ventura County California, Haley & Aldrich, Inc., and February 8, 2001). A most mobile constituent has reached the regional groundwater.

Another fact on flow through fractured bedrock is that there are fewer but higher transmitting pores, larger pores, than in a soil matrix but much less total porosity so a low flux (flow /unit area) may produce saturated flow. Also, there's no reason not to believe there is unsaturated gravitational flow in fractured rock materials as well. A groundwater monitoring program has been in place since the late 1980's on wells beneath the burn pit area (Hadley & Aldrich, 2001) which presents an important observation relative to the flow path in the fractured bedrock is apparent. The wells sampled consist of vertical holes cased and presumably grouted through the first 30 feet of bed rock but open below. The wells range in depth from 120 to 640 feet. The TCE sampling history shows the ND (non-detect) incidence is correlated with the deep wells which would be consistent with the fact the fractured stratified formations dip at 30 degrees to the northwest of the disposal area. Thus the preferred path for water and pollutant movement is in this direction along the high permeability fractured strata. To better intercept this flow would take horizontal boring down slope of the area.

Residential development on the site was evaluated as a potential future land use for the area (Draft Final Interim Measures Risk Assessment, July 9 1999, Appendix D, Section D.4.2. pg 15).

If the ultimate intent of the Boeing Company is to utilize the Brown Fields process as an opportunity to develop the area, water will have to be imported. And, unless no landscaping is allowed over the developed area and all waste water is exported, the increased groundwater recharge from the development could significantly contribute to flow into and through the fractured bedrock below, thus mobilizing of the pollutant inventory under the entire Field Laboratory area into the regional water resources.

**MEMBRANE CAP ALTERNATIVE**

DTSC has concluded that a membrane cap is not necessary. The basis for this is the observation that water collects under the sealed surface in visible quantities and in 1998 some 40,000 gallons of water was pumped from the tarped burn pit (Response to Comments on the Draft Interim Measures for the Former Sodium Burn Pit, December 1999). The functioning tarp phenomenon here is the movement in vapor phase of subsurface soil moisture upward to the cooler surface of the impermeable tarp surface and condensation during night times when the air temperatures are below ambient soil temperature. The difference between the thermal conductivity and the vapor and/or unsaturated soil conductivity results in the accumulation of free water at and near the contact interface. It is not an indication that the vertical downward movement is enhanced by a membrane seal but just the reverse. Now with the experienced water table rise during the ’04-’05 wet period when 45.2 inches of rain caused the regional water table to rise under the filled area the ’97-’98 experience where 41.24 inches of rain fell reinforces the importance of lateral flow component into the burn pit area and fill.

The monitoring observations have shown that vertical water flow has occurred to the depth of the deeper pan lysimeter, or 11 feet. Installation of a membrane seal and diversion out of the area influenced by the residual pollutants would cut off all direct vertical water movement downward through the current backfill and would guarantee that this component of water flow would be eliminated. However, the latest data (Annual Operation and Maintenance Report-August 31, 2004) was interpreted as indicating that the observed rise of the water table to above the bedrock backfill contact was due to peripheral flow into the area below the cap. This can only lead to the conclusion that for complete diversion of any future precipitation recharge movement into the deeper bedrock zone, and the isolation of the fracture pollutant inventory there, will require the elimination of that contribution to vertical flow from the area peripheral to the fill boundary. And as previously stated if imported water is brought to the area for future development, it can only augment fracture zone flow and pollutant mobility above that already occurring from rainfall recharge.

Source: Ground-Water Recharge Hydrology
USDA ARS 41-161

# Hydraulic Conductivity In Different Units As Related to Particle Size Definitions

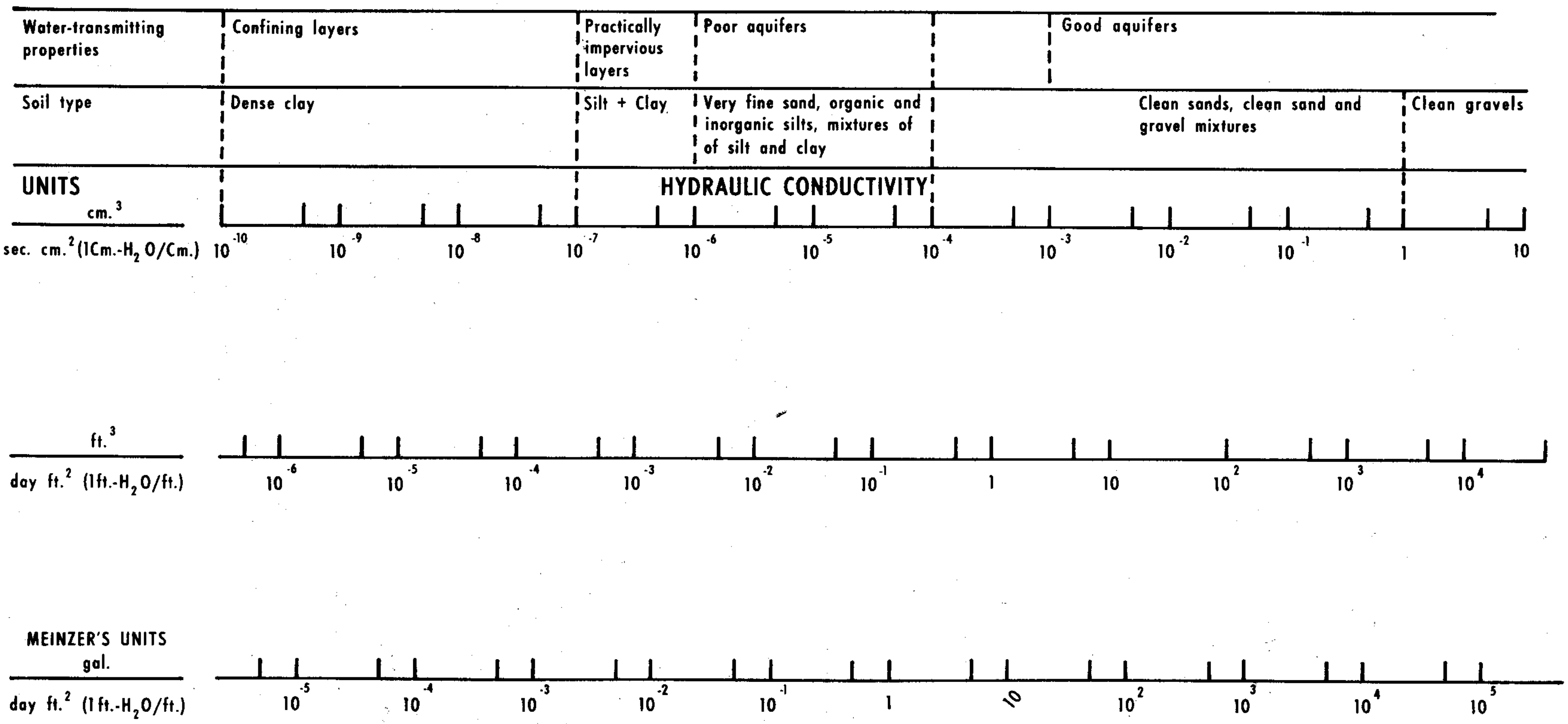

TABLE-1 LYSIMETER RESPONSE '00-'06

| YEAR July1-June30 | RAINFALL inches | PERIOD | PANS START ACCUMULATION | PANS ARE DRY | VOLUME - liters #1 | #2 |
|---|---|---|---|---|---|---|
| '00-'01 | (1) 16.6 | 1/10/01 to3/6/01 | #1-8/10/01 #2-8/24/01 | 11/30/01 | 6.51 | 4.01 |
| '01-'02 | (2) 5.4 | 10/15/01 to2/25/02 | #1-7/1/02 #2-7/20/02 | 11/27/02 | 17.4 | 11.8 |
| '02-'03 | 25.2 | 11/6/02 to5/10/03 | #1-10/29/03 #2-10/29/03 | 12/3/03 | 1.41 | 0.91 |
| '03-'04 | 14.8 | 12/20/03 to2/28/04 | #1-?/?/04 (3) #2-?/?/04 (3) | 11/?/04 (3) | 7.3 | 1.8 |
| '04-'05 | 45.2 | 10/25/04 to3/28/05 | #1-8/22/05 #2-8/25/05 | 10/31/05 | 8.9 | 4.7 |
| 05-'06 | 17.9 | 10/17/05 to4/18/06 | #1-?/?/06 (4) #2-?/?/06 (4) | #1-?/?/06 (4) #1-?/?/06 (4) | ?(4) | ?(4) |

(1) An added 2.4 inches applied in May- June
(2) Fire hose leakage cited as entering the area
(3) Field data aqusition changed
(4)No data presented after 7/05/06