

Tannery wastes definition, risk assessment and cleanup options, Berkeley, California*

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Abstract

United States tanneries generate up to 100,000 (wet) tons of hair-burn and chrome sludges and contaminated soils. A facility closure investigation at a tannery in Berkeley, California showed sludges containing concentrations of Cr in the range of 1,000 to 40,000 mg/kg on a dry weight basis. California Code of Regulations defines total chromium above a concentration of 2,500 mg/kg in soil or sludge as hazardous waste. Chromium desorption from the soil matrix and Cr solubility are low. Migration of chromium in the soil water occurs either as a soluble Cr(VI) species, HCrO_4^- and CrO_4^{2-} or as Cr(III) or Cr(VI) in soluble complexes with organic or inorganic substances. Investigations at the Berkeley tannery indicate these tannery sludges exhibit low mobility and have Cr(III) to Cr(VI) ratio over 200. A risk assessment was completed to assess the possible effects on public health, but they were determined to be insignificant. Cleanup options evaluated were offsite disposal, encapsulation, or land treatment.

1. Introduction

The Manasse-Block (M-B) Tannery in Berkeley, California (see Fig. 1), which began tannery operations in 1905, initiated a site investigation in 1986 in anticipation of their closing and selling the factory. The potential buyer of the property proposed a change in land use from industrial to mixed commercial and residential. This potential development increased concerns about how suitable the land was for commercial and residential purposes if soil and groundwater contamination existed. The determination of closure criteria for the tannery was the responsibility of the City of Berkeley. Site characterization studies at the tannery identified chrome sludges as by far the most pervasive form of contamination. Such contamination is commonly associated with tanneries across the U.S.A. Additional contaminants at the M-B Tannery included sulfonated oils from the vegetable retanning process and diesel fuel,

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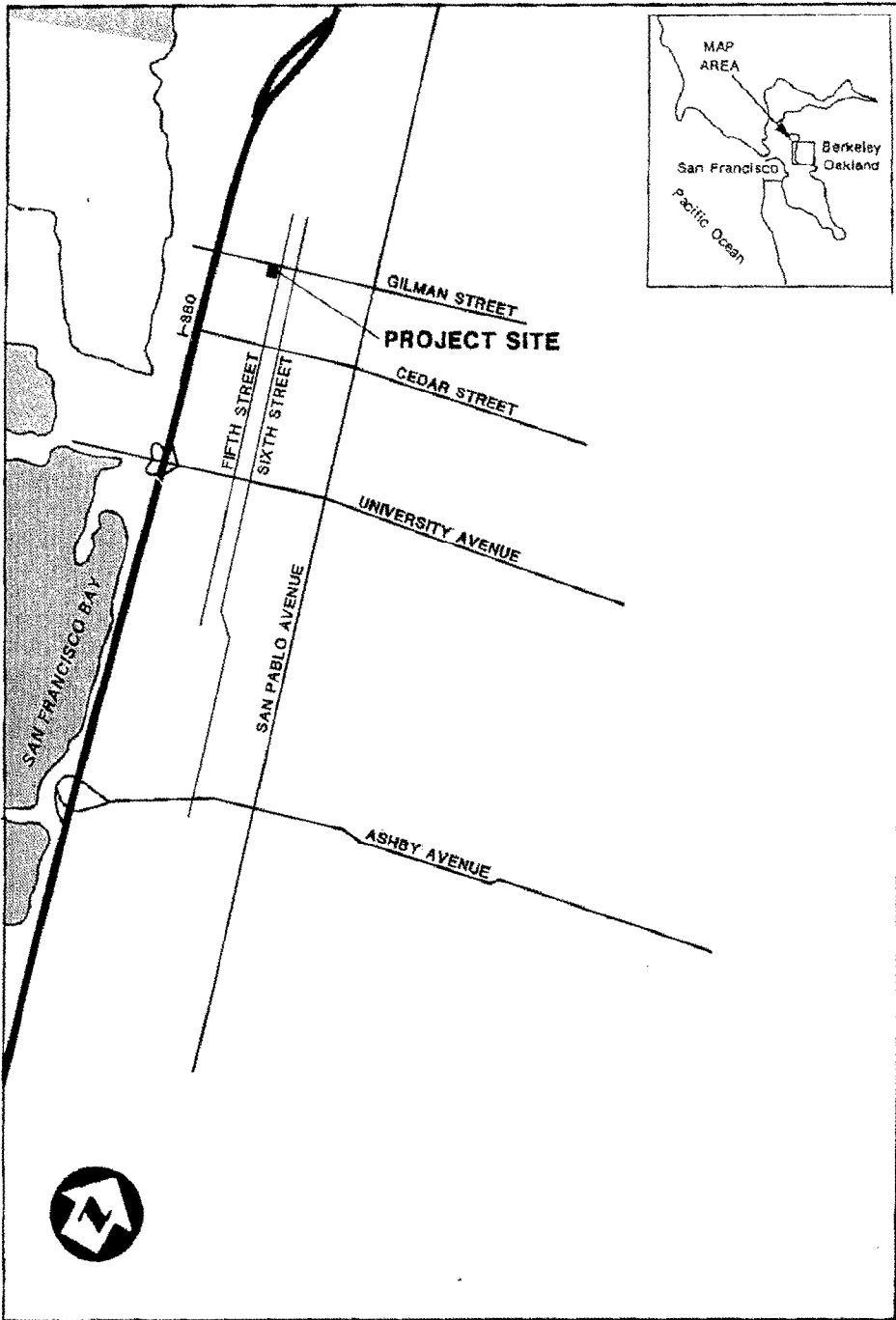


Fig. 1. Site location M-B tannery, Berkeley, CA.

which leaked from two underground fuel storage tanks used at the tannery as fuels before conversion to natural gas in the 1940s.

A major concern of the closure was the potential mobility of the chromium-contaminated sludge left in place and the extent of hexavalent versus trivalent chromium. It was critical to establish the extent of hexavalent chromium for the risk assessment because Cr(VI) is more toxic than Cr(III).

2. Tanning processes

United States tanneries generate 80,000 to 100,000 (wet) tons of sludge annually, primarily from the chrome tanning processes [1]. Chrome tanning usually produces two types of sludges: hair-burn and chrome. Hair-burn or dehairing sludges result from the initial stages of the tanning process, while chromium-rich sludges result from the mineral tanning stage.

At the Manasse-Block Tannery the tanning process, which was the source of the chromium, consisted of three stages: the dehairing stage, the mineral tanning stage, and the vegetable retanning stage.

During the dehairing or hair-burn stage of the tanning process, salt-cured hides are mechanically scrapped and soaked in a $\text{Ca}(\text{OH})_2$ lime solution that has a small amount of sodium sulfate in it. The liquids have a pH value of 11. The hair is then scraped off the hides and washed in a water and pancreatic-enzyme solution. (The pancreatic enzyme helps open the pores.) This solution has a pH value of 9. After the hides are washed, they are "pickled" in a bath of sulfuric acid, salt, and sodium or calcium formate (as a buffer). The "pickling" process is carried out in rotating drums, and the solution has a pH of 4–4.5. The residual sludge from this process has been reported to contain high concentrations of organic carbon, total N, Ca, Mg, and Na, but relatively low Cr [2] (see Table 1).

TABLE 1

Chemical composition of leather tanning sludges (December 1983, analysis performed by SCS Engineers)

Composition	Hair-burn	Chrome
Moisture (%)	67.0	71.5
Total organic carbon (%)	13.0	15.4
Total Kjeldahl nitrogen (%)	3.78	3.15
$\text{NH}_3\text{-N}$ (mg/g)*	6,280	4,200
Na (mg/kg)*	12,400	7,230
Ca (mg/kg)*	41,600	18,250
Mg (mg/kg)*	2,360	8,400
Cr (mg/kg)*	78.7	38,600

*Dry weight basis.

During the mineral tanning stage, a chromium(III) solution $\text{Cr}(\text{SO}_4)_3$, and a NaHCO_3 fixer are added to the hides in the rotating drums. The result is a chrome sludge with high Cr(III) concentrations and high concentrations of organic carbon, total, N, Ca, Mg, and Na (Table 1).

During the vegetable retanning stage, the hides are split, shaved (to achieve uniform thickness), and washed in water that contains chemical residues. The hides are then put in rotating drums containing vegetable extracts, dyes (coal tar derivatives), and sulfonated oils. When the hides come out of the drums, they are pressed on a setting machine to take out wrinkles and to remove any remaining oil. After that, they are dried, softened, glazed and sprayed with a water soluble finish containing pigments and binders, and then given one final pressing.

The tanning process caused chromium and sulfonated oil laden sludges beneath the main Tannery Room. The maximum concentration of chromium, and oil and grease were 40,000 mg/kg and 62,000 mg/kg, respectively.

3. Regulatory considerations

In May 1980, the U.S. Environmental Protection Agency (EPA) identified the leather-tanning sludges that result from chrome processing as hazardous wastes based on their total chromium content, which may be as high as 21,000 to 55,000 mg/kg, on a dry weight basis [3]. The sludges were later removed because the chromium occurs primarily in the less toxic, and generally less mobile, trivalent form [Cr(III)] [4,5]. Nevertheless, the problem of safely disposing of the sludges remains, as does the possibility of reclassification if hexavalent chromium [Cr(VI)] concentrations in sludge extracts are found to exceed 5.0 mg/L. The California Code of Regulations, Title 22, Section 66699, regulated by the California Department of Health Services (DHS), defines sludges or solids as hazardous waste concentrations of particular chemicals that exceed the Total Threshold Limit Concentration (TTLC). The TTLC for total chromium (Cr(III) and Cr(VI)) is given as 2,500 mg/kg and is 500 mg/kg for hexavalent chromium. Title 22 also lists the Soluble Threshold Limit Concentration (STLC) for Cr(III) and Cr(VI) as 560 mg/L and 5 mg/L in water. The EPA has declared that domestic water supplies should contain no more than 50 $\mu\text{g}/\text{L}$ total Cr, and aquatic environments no more than 100 $\mu\text{g}/\text{L}$ [6].

4. Characterization of contaminants

Site investigations initiated in 1986 at the Manasse-Block Tannery identified chromium and sulfonated oils as environmental contaminants associated with the tanning process. The investigation also identified petroleum hydro-

carbon (diesel fuel) as an environmental contaminant associated with leakage from two underground fuel storage tanks.

4.1 Chromium

The principal contributors to "available" chromium in soils are reaction products from soluble chromium compounds: Cr(III) and Cr(VI). Chromium(III) is precipitated in soils by adsorption, hydrolysis, and chelation reactions, and Cr(VI) by anion adsorption and subsequent reduction to Cr(III). Chromium is not acutely toxic to humans. However, Cr(VI) is more toxic than Cr(III) because of its high rate of adsorption through the intestinal tract [7]. As stated above Cr(VI) is likely to be reduced to Cr(III) in a natural environment, hence reducing its toxic implications. According to historical records, the chromium solutions used by Manasse-Block in the tanning process were in the form of Cr(III).

Figure 2 shows the site plan for the Manasse-Block tanning company. The chromium contamination centered in the Tannery Room, where eight drums of tanning solution with hides were located. Figure 3 shows the location of soil and water samples collected over the 1986 through 1988 time frame. As can be seen in Fig. 4, which shows the values of Cr(III) and Cr(VI) contamination, the majority of Cr contamination is in the Cr(III) form and is limited to the Tannery Room.

As shown on Table 2 and in Fig. 5, reported chromium levels in the Tannery Room (sites A, B, D, and E) are frequently higher than the corresponding TTLC for this metal. In all cases except for site D, however, the concentrations show significant reductions in chromium below three feet. This three-foot depth is roughly the upper depth boundary of the Bay Mud at each site. Bay Mud deposits, due to their fine-grained structure, probably act as an effective barrier to the downward migration of chromium. While the general rule that concentration decreases with depth was true of the tanning room, the depth-concentration trend in site D, contrary to the other sites, showed increasing chromium levels with depth. The increase chromium with depth at site D cannot be explained by a permeability contrast between the sediments, even though the site's sediments are essentially the same as those at the other sites beneath the tannery floor.

Outside of the Tannery Room two out of five surface samples exceeded TTLC with concentrations of 16,000 mg/kg and 12,000 mg/kg. The remaining three surface samples showed concentrations of 460 mg/kg, 180 mg/kg, and 1,300 mg/kg, respectively. The elevated surface sample results raised the concern that more extensive chromium contamination may exist across the site.

4.2 Oil and grease

There are no federal or California regulatory maximum concentration limits for vegetable oil and grease. A total oil and grease concentration of 62,000 mg/

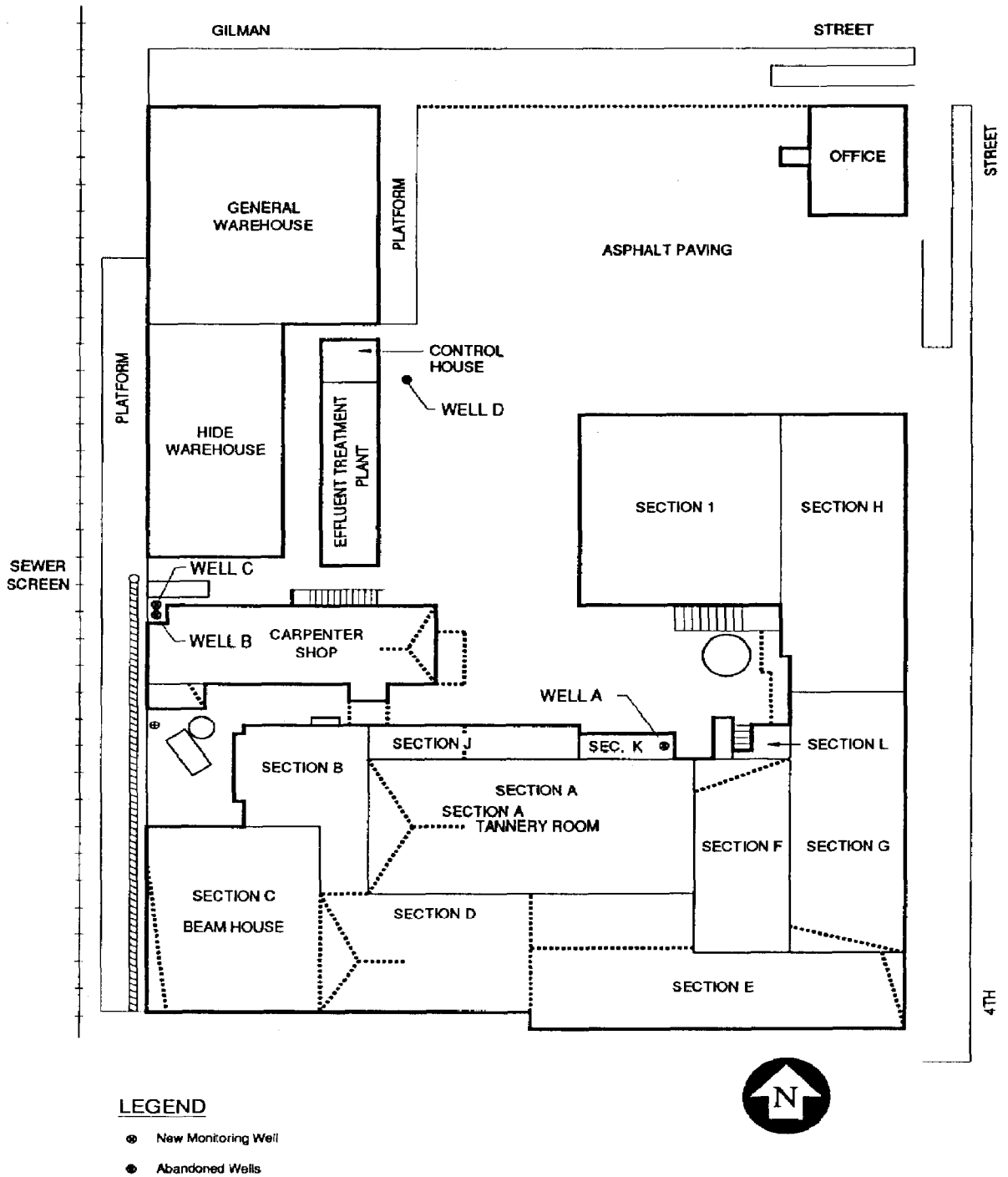
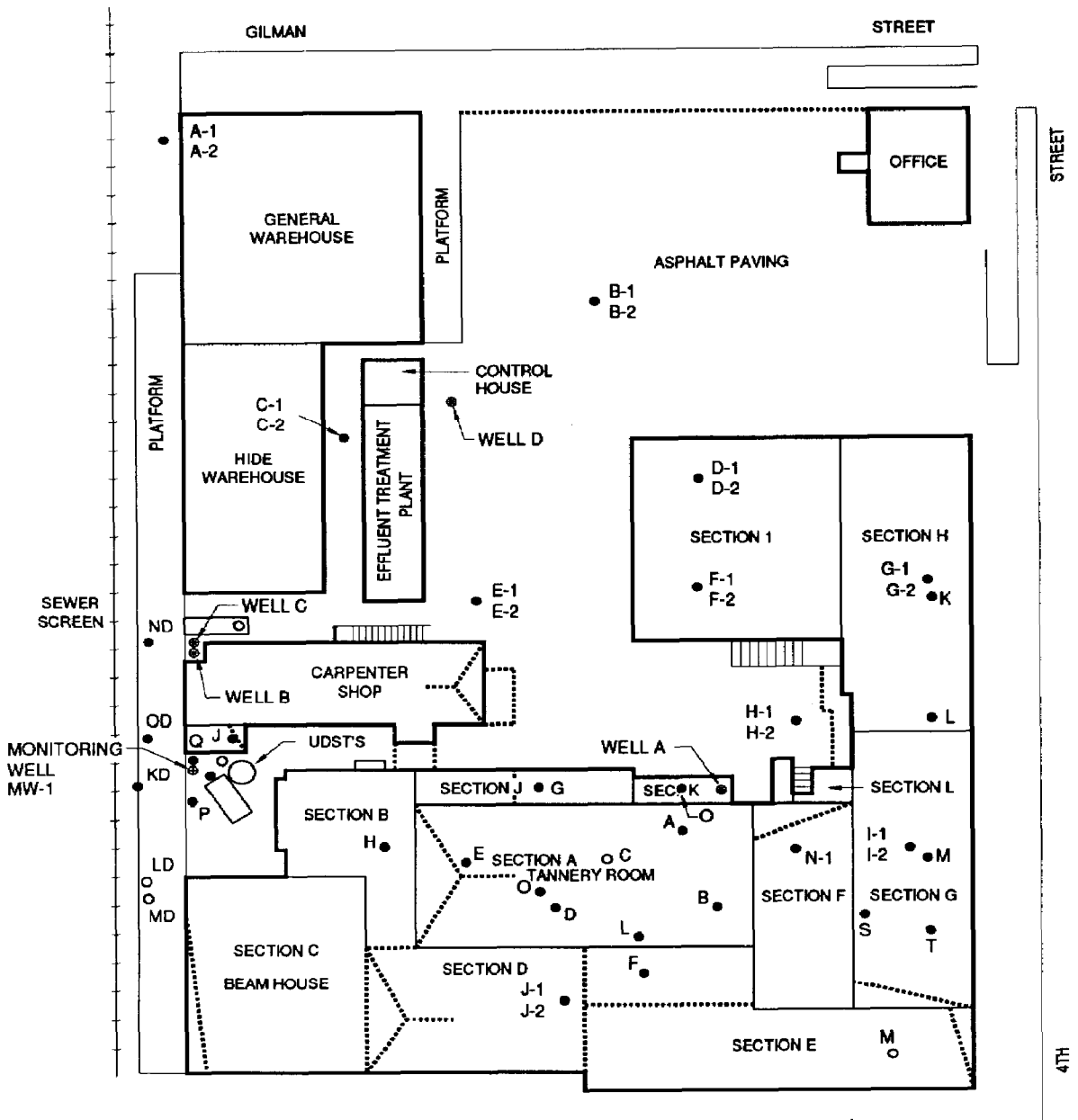


Fig. 2. Site plan M-B tannery.



LEGEND

- Soil Sample
- Water Sample
- UDST - Underground Diesel Storage Tank
- ⊕ New Monitoring Well
- ⊙ Abandoned Wells



Fig. 3. Filed work sampling locations at the Manasse-Block Tanning Company.

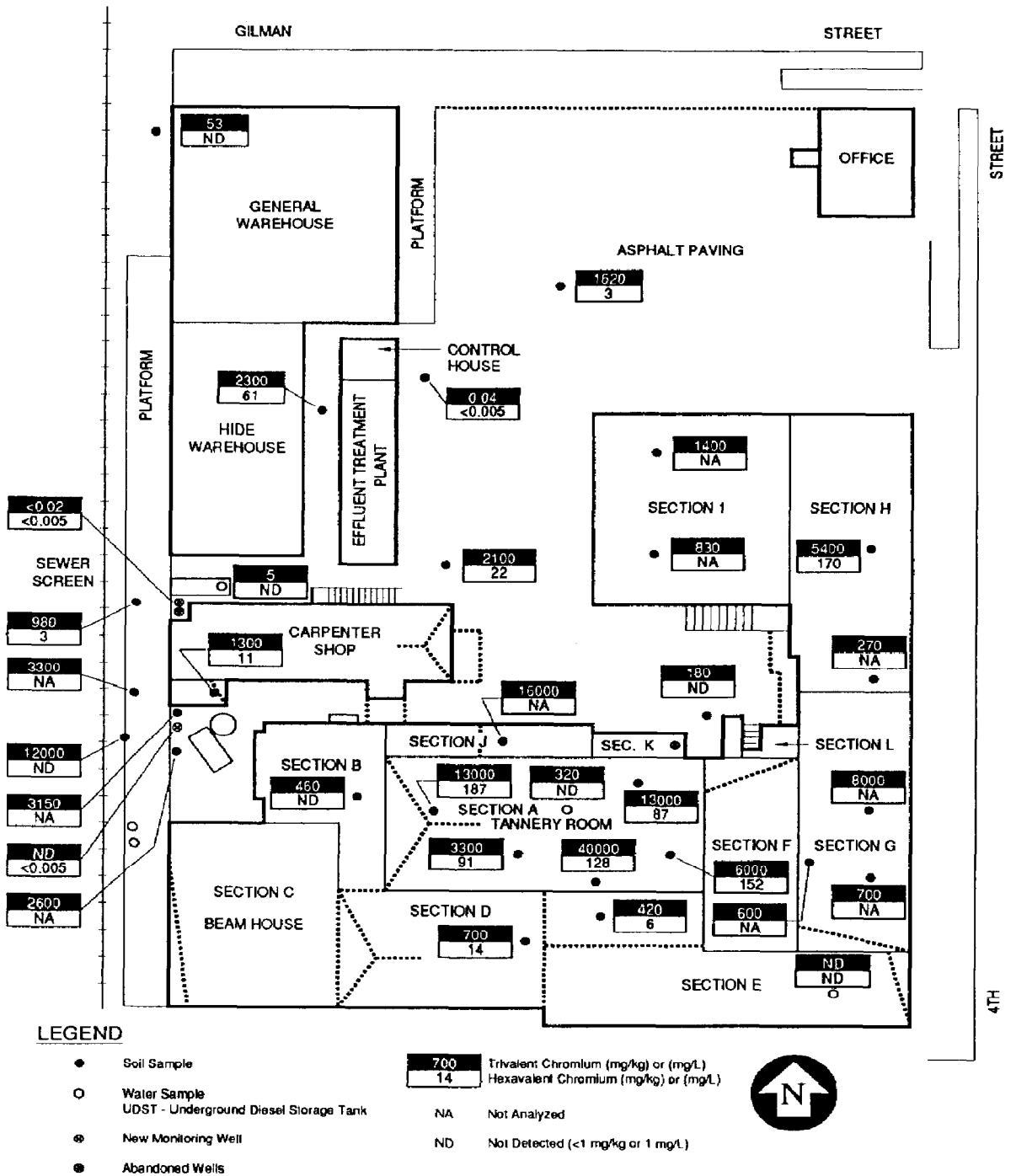


Fig. 4. Trivalent and hexavalent chromium concentrations measured across the M-B site.

TABLE 2

Analytical results (in mg/kg, unless otherwise noted) of Manasse-Block Tannery Room soil and water samples compared to California Code of Regulations, Title 22 Total Threshold Limit Concentration (TTLC)

Sample identification	Depth (ft)	Cr(III)	Cr(IV)	Oil and grease	Soil pH	Total Cr	TTLC Cr(VI)
A	0.1-0.5	330	NT	62,000	6.65	2,500	500
	1.5	13,000	87	28,000	6.9	2,500	500
	3.0	1,600	NT	3,500	7.1	2,500	500
	4.5	140	ND	220	7.8	2,500	500
B	0.1-0.5	470	NT	NT	4.75	2,500	500
	1.5	6,000	152	4,400	5.4	2,500	500
	4.5	150	ND	160	6.75	2,500	500
C	-	320 ^a	NT	54,000 ^a	6.2	5 ^b	500
D	0.5-1.5	460	NT	NT	6.44	2,500	500
	1.5	3,300	91	12,000	5.7	2,500	500
	2.3	3,600	NT	11,000	6.0	2,500	500
	4.5	8,400	68	230	4.57	2,500	500
E	0.1-0.5	22,000	NT	NT	5.84	2,500	500
	1.5	13,000	187	20,000	6.2	2,500	500
	2.5	7,000	N1	9,600	6.3	2,500	500
	4.5	130	ND	830	7.5	2,500	500
G	0.1-0.5	16,000	NT	990	6.14	2,500	500
H	0.1-0.5	460	ND	4,000	11.4	2,500	500
I	0.1-0.5	180	ND	850	7.56	2,500	500
J	0.1-0.5	1,300	11	14,000	7.56	2,500	500
K	0.1-0.5	12,000	ND	1,500	7.49	2,500	500
L	0.1-0.5	40,000	128	19,000	4.91	2,500	500
M	-	2.5 ^a		340 ^a	7.2	5 ^b	500

^amg/L.

^bSoluble Threshold Limit Concentration (STLC).

NT= Not tested for.

kg, however, is considered a significant concentration, which means soil removal or soil treatment may be required if, according to DHS and the California Regional Water Quality Control Board (RWQCB), "environmental damage" could result from not remediating the oil and grease [8,9]. Oil and grease in the soils beneath the tannery resulted from contamination by lubricating greases used in the tanning equipment and by sulfonated oils used in the manufacturing process to lubricate fibers. Sulfonated oils are water soluble. The DHS evaluates oil and grease concentration on a site-by-site basis. Likewise, the RWQCB has no formal guidelines for evaluating oil and grease concentrations, but may recommend the use of an informal method, the so called "bucket

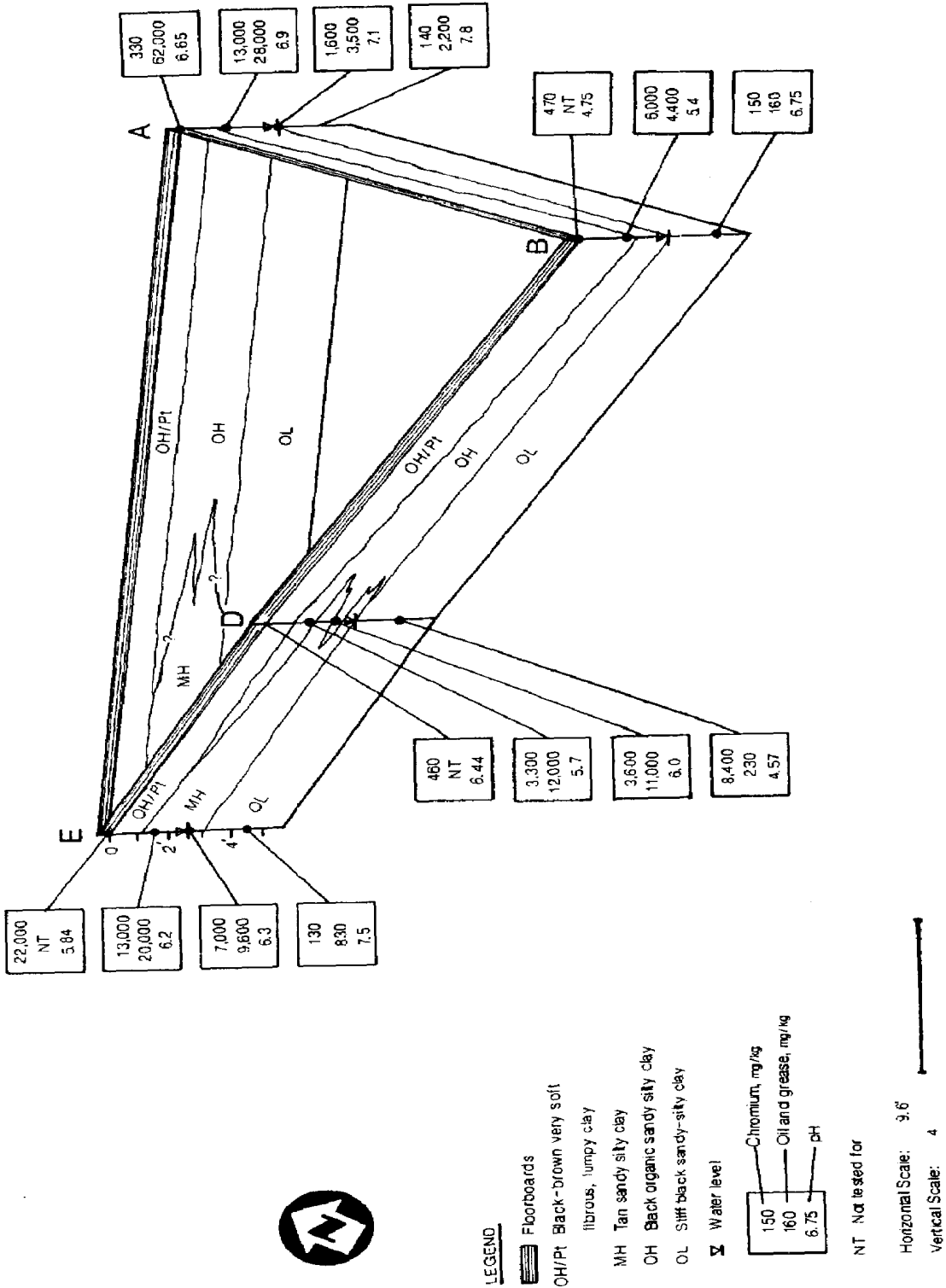


Fig. 5. Fence diagram showing geology and results of soil analyses in the Tannery Room.

test", to assess oil and grease concentrations if sufficient oil and grease persist to cause an oil slick. If, however, the oil and grease are confined to the unsaturated soil zone and no direct water infiltration of the soil occurs, then the RWQCB does not necessarily require removal of the soil.

Of the four samples collected from a depth of 4.5 feet in the Tannery Room, all showed relatively low oil and grease levels compared with samples taken at lesser depths (see Table 2). Again, the Bay Mud at three-foot level probably provides an effective barrier against downward migration. Elevated oil and grease concentrations were limited to the area in or immediately adjacent to the Tannery Room.

4.3 Petroleum hydrocarbons

One 10,000 gallon and one 1,000 gallon underground diesel fuel tank, located on the western property boundary, leaked fuel into the surrounding soil and groundwater. Soil concentrations were at a maximum of 40,560 mg/kg total petroleum hydrocarbons (TPH) with groundwater concentrations at 0.23 mg/L.

The California code of regulations does not have any maximum concentration limit for TPH in soil or water, but the DHS uses 1,000 mg/kg as maximum concentration above which TPH in soil needs to be excavated and treated and/or properly disposed of. The RWQCB evaluates the TPH effects on groundwater by site borers but uses 100 mg/kg in soil as a criterium for requiring a groundwater investigation. The potential excavation of TPH laden soils was complicated because the contaminated soils were underneath a building classified as an historical landmark.

5. Mobility of chromium

The chemical reactions that influence chromium mobility in soils are complex. Chromium (III) is thermodynamically stable at moderate pH (pH 2 to 8) and occurs in both cationic (Cr^{3+} , $\text{Cr}(\text{OH})^{2+}$, $\text{Cr}(\text{OH})_2^+$, and less commonly $\text{Cr}_2(\text{OH})_2^{4+}$ and $\text{Cr}_3(\text{OH})_4^{5+}$) and anionic ($\text{Cr}(\text{OH})_4^-$) species [10]. Chromium (VI) is stable in more oxidized environments ($E_h > 10$ mV, pH > 6) in three principal anionic species (HCrO_4^- , CrO_4^{2-} , and less importantly $\text{Cr}_2\text{O}_7^{2-}$) [11].

Generally, the presence of elevated levels of Cr(VI) indicate industrial pollution. Many organisms have been found to exhibit negative health effects when exposed to Cr(VI) in low concentrations. Both Cr(III) and Cr(VI) are somewhat kinetically inert and can exhibit an apparent stability to redox reactions under conditions in which they should be thermodynamically unstable [12,13]. However, in the presence of organic material in acid solutions, Cr(VI) is readily reduced to Cr(III) [14]. In addition, the presence of some organic compounds, such as citric acid, appears to enhance oxidation of Cr(III) to

Cr(VI) [15]. James and Bartlett also observed that Cr(III) oxidized readily to Cr(VI) under typical field soil conditions if oxidized manganese is present [16].

Tri- and hexavalent chromium can both be adsorbed to clay particles, hydrous Mn, and Fe oxides, with Cr(III) being most prone to adsorption [17]. As a further complication, several studies have observed that Cr(III) and Cr(VI) can readily complex with inorganic and organic compounds. Thus it is possible for either form to be transported in soluble complexes under conditions in which they would otherwise be expected to be removed from solution by precipitation or adsorption [18,16].

From the above discussion it appears that chromium could migrate from the tannery sludge beneath the floorboards of the Tannery Room under the recorded conditions, in several ways. Chromium(III) or (VI) species could form soluble complexes with organic or inorganic substances or Cr(VI) could be transported in solution as HCrO_4^- or CrO_4^{2-} . However, the latter process would require the presence of Cr(VI) initially in the applied sludges, or some oxidation of Cr(III) to Cr(VI) under field conditions. James and Bartlett observed oxidation of Cr(III) to Cr(VI) in a laboratory experiment with a mixture of tannery sludge and a moist field soil [16]. While this could occur, the hydrologic barrier provided by the Bay Mud deposits beneath the Tannery Room effectively perches any solution.

6. Remedial alternatives evaluation and selection

An evaluation of remedial alternatives based on the site characterization data and regulatory requirements for closure indicated that some, but not all, of the contaminated soil could be removed for off-site disposal or treatment. The Tannery Room area was remediated by excavating and disposing off-site approximately 600 cubic yards of soil contaminated with chromium and with oil and grease. The residual chromium in the soil outside of the Tannery Room, which clearly exceeded background concentrations (and sometimes exceeded TTLCS), was considered too much of an economic burden to remove considering the low potential for public health or environmental damage. Similarly, in the area where petroleum hydrocarbons had leaked into the soil and groundwater, the excavation of all soil with concentrations above 1,000 mg/kg was prohibited due to its location beneath a historical landmark building. Approximately 300 cubic yards of hydrocarbon-contaminated soil were removed along with the underground fuel storage tanks. Residual soil contamination as high as 2,000 mg/kg remained.

7. Tannery facility closure options

Two closure options were pursued for this site: (1) RCRA clean-closure by removing all contaminants in the soil with concentrations above regulatory

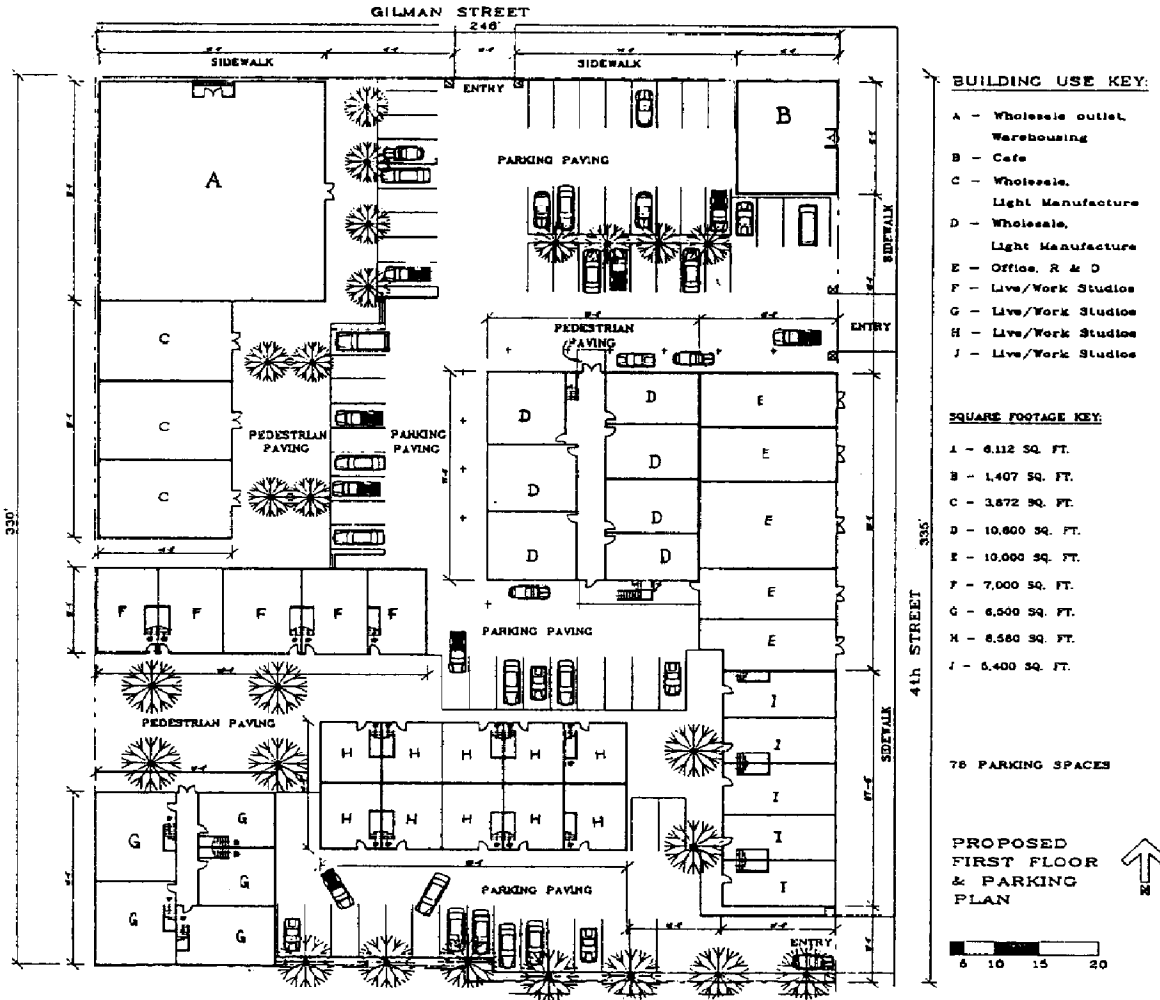


Fig. 6. Proposed site use: Alternative 1.

concern, and (2) closure-in-place after remediating areas of major contamination. Because both options rely on the results of the risk assessment it is described first.

A health risk assessment was performed to evaluate the risks involved if residual contamination was left on-site and no further remediation was done. The health risk assessment was particularly germane considering that a post-closure site developer was asking for a change in land use. The site would change from an area of heavy industrial use to an area of commercial-residential use with up to 200 residences. Figure 6 shows the proposed site development plan.

7.1 Procedure and rationale for risk assessment

The approach to the no-action or baseline evaluation is designed to evaluate possible threats to public health from the site under existing conditions. This

analysis provides a better understanding of the nature of chemical releases from a site, the potential pathways for human exposure, the degree to which such releases, if any, could violate applicable standards and criteria, and the measure of the potential threat to public health as a result of such releases. The goals of the risk assessment for the Tannery site were (1) to assess the risk posed by residual constituents in the absence of site remediation, and (2) to determine site-specific performance goals, or clean-up standards. The risk assessment followed guidelines set forth in the Superfund Public Health Evaluation Manual [19] and the California Site Mitigation Decision Tree [8]. These guidelines are based upon a process recommended by the National Research Council [20] comprising four parts: hazard identification, dose-response assessment, exposure assessment, and risk characterization.

7.1.1 Hazard identification

The hazards at the site were defined by the agencies based upon the results of soil sample analyses.

7.1.2 Dose-response assessment

Dose-response data were used to estimate “safe” exposure levels to contaminants, i.e., levels that are unlikely to produce adverse effects on human health. Dose-response data were obtained from state and federal sources. The DHS maintains a list of Applied Action Levels for select chemicals: DHS stipulated that these were to be the first source of guidance for the risk assessment. Where these were not available, EPA Reference Doses (RFDs) for systemic toxicants and Carcinogenic Potency Factors (CPFs) for carcinogens were used. In the absence of guidance from either of these sources, other EPA sources such as EPA health advisories were used.

7.1.3 Exposure assessment

To perform the exposure assessment, the magnitude, frequency, duration, and routes of exposure were determined for exposed populations. Table 3 shows the pathways contributing to total exposure at each exposure point. Two of these exposure pathways are associated with the construction phase of the proposed project.

7.1.4 Risk characterization

The risk characterization is made by combining the dose-response parameters obtained from state and federal sources with the results of the exposure assessment to obtain a numerical estimate of the risk to human health. Risk for non-carcinogenic effects is expressed in terms of the Hazard Index, where a value over 1 indicates a potential for health risks. Carcinogenic health risk is measured as excess lifetime cancer risk. State law requires that total carcinogenic risk should not exceed one in a million.

TABLE 3

Pathways contributing to total exposure at each exposure point

Exposure point	Exposure pathway
Construction workers	Inhalation of fugitive dust during construction, dermal contact with soils, incidental ingestion of soils
Children on site	Incidental ingestion of soils, hypothetical future groundwater ingestion
Adults on site	Incidental ingestion of soils, dermal contact with soils, hypothetical future groundwater ingestion
Trespassers	Incidental ingestion of soils

TABLE 4

Calculation of chronic hazard index residential alternative (best estimates)

Exposure point/ indicator	Inhalation			Oral			Total hazard index
	CDI ^a (mg/kg-day)	AIC ^b (mg/kg-day)	CDI:AIC	CDI (mg/kg-day)	AIC (mg/kg-day)	CDI:AIC	
Construction workers							
Cr(III)	4.82 10 ⁻⁷	5.1 10 ⁻³	9.46 10 ⁻⁵	1.31 10 ⁻⁸	1.00	1.31 10 ⁻⁸	0.0001
Cr(VI)	8.55 10 ⁻⁹	-	-	5.80 10 ⁻⁹	5.00 10 ⁻³	1.16 10 ⁻⁶	0.0000
Total							0.0001
Children on site							
Cr(III)	-	5.1 10 ⁻³	-	6.69 10 ⁻⁵	1.00	6.69 10 ⁻⁵	0.0001
Cr(VI)	-	-	0.00	8.72 10 ⁻⁵	5.00 10 ⁻³	1.74 10 ⁻²	0.0174
Total							0.0175
Adults on site							
Cr(III)	-	5.1 10 ⁻³	-	8.36 10 ⁻⁶	1.00	8.36 10 ⁻⁶	0.0000
Cr(VI)	-	-	-	2.15 10 ⁻⁵	5.00 10 ⁻³	4.30 10 ⁻³	0.0043
Total							0.0043
Trespassers							
Cr(III)	-	5.1 10 ⁻³	-	7.96 10 ⁻⁸	1.00	7.96 10 ⁻⁸	0.0000
Cr(VI)	-	-	-	2.51 10 ⁻⁸	5.00 10 ⁻³	5.02 10 ⁻⁶	0.0000
Total							0.0000

^aCDI = chronic daily intake; ^bAIC = acceptable intake-chronic; source Environmental Protection Agency Superfund Public Health Evaluation Manual, 1986 [17].

The site risk assessment evaluated the threat of residual contamination in the absence of any additional remediation at the site to workers and to the general public. The results strongly suggest that there is no significant health risk posed by residual chromium contaminated soil remaining at the site. Table 4 shows the Chronic Hazard Index for the four exposure points; all had a calculated hazard index of less than 1. The highest hazard index was associated with the exposure of children to the soil by ingestion. The implication of this risk assessment is that no additional soil needs to be removed and that the

surface capping associated with the proposed development plans (asphalt parking lot and building footprint) would prove sufficient to protect against infiltrating moisture mobilizing the chromium or surface exposure to residence of the property. An RCRA-based clean-closure pursuant to EPA regulations was not considered necessary.

7.2 Clean-closure

Until recently, clean-closure under RCRA involved removal of all residuals exceeding background concentrations. At the Manasse-Block site this would require further site characterization work followed by excavating to depths of 6 feet or more in some locations. Historical landmark buildings would also be threatened by this action. Clean-closure based on risk assessment is an innovative approach being taken pursuant to recent EPA regulations [21] for RCRA sites. To qualify for the site-specific removal option under RCRA, demonstration must be made that “the contaminants left in the subsoils will not effect any environmental media including groundwater, surface water, or the atmosphere in excess of Agency-recommended limits or factors, and that direct contact through dermal exposure, inhalation, or ingestion will not threaten human health or the environment” [21]. The hydrogeologic characterization has demonstrated that groundwater and surface water are not at risk from residual contaminants. This is due to the low solubility and mobility of chromium.

7.3 Closure-in-place

The closure-in-place option would be implemented if clean-closure and de-listing initiatives were unsuccessful. The risk-based clean-up goals agreed upon by the agencies determined the amount of soil requiring excavation. If this amount is so high that clean-closure of the whole site is not economically viable, it may be possible to clean-close part of the site and pile and cap the residuals on the rest of the site. In the case of clean-close, the cap design would be based upon risk considerations. If groundwater contamination is determined not to be at risk from site residuals, then the conventional design focused on prevention of infiltration would not be used. The design would be aimed at limiting erosion, direct contact, and fugitive dust generation.

Leaving the contamination in place in the shallow soil beneath certain areas of the site was considered an acceptable risk because using the maximum concentrations above the TTLC in this risk assessment did not present a substantial risk, and migration of chromium to groundwater is unlikely given the site stratigraphy and low solubility of chromium. The risk assessment indicated no public health threats associated with either the baseline condition of this site or the two post-closure alternatives for construction at the Manasse-Block site. The covering of the contaminated area by either buildings or a parking lot would reduce the potential for groundwater contamination because surface infiltration would be minimized. Soil landscaping was restricted to above ground

planter boxes not in communication with the soil beneath the asphalt parking lot. The residual soil contamination was recorded in the deed to prevent future exposure to the residual contamination that was left in place should the property be sold.

8. Tannery closure summary

Chromium and petroleum hydrocarbons in excess of California's DHS' maximum concentration levels were allowed to remain in place at the Manasse-Block tannery site due to the low risks predicted by the risk assessment. This closure-in-place was allowed with certain conditions of approval required in the building permit from the City of Berkeley. The conditions of approval included further groundwater monitoring requirements and prohibited landscaping or exposure of the site soils and closure based on future protection against site changes by recording the residual contamination in a deed restriction. Also considered were institutional concerns for historic landmark buildings and the extensive cost of total remediation.

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