West Lake
Landfill
UMC report –
Nov 84 draft
(2nd draft)

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Note: This is the <u>only</u> draft still in our possession. (Maybe the authors at U. of Missouri have some other.) This had been retyped by our CRESS (word processing) office, and is not a draft "as received" from UMC, to the best of my knowledge.

— Jerry J. Swift

p.s. This is the <u>only copy</u>.

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December 3, 1984

TO: James Berger
Steven Wyngarden

FROM: John T. O'Connor
Shankha K. Banerji

Please find enclosed a copy of the second draft of Engineering Evaluation of Options for Disposition of Radioactively Contaminated Residues Presently in the West Lake Landfill, St. Louis, Missouri.

I apologize for the delay and regret any inconvenience which this may have caused you. We have incorporated your initial comments into this draft, and we will begin work on the final draft after receiving any additional comments you might have. If you have any questions, do not hesitate to contact Dr. Banerji or myself.

/dc
Encl.

cc: S. Banerji
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DRAFT

ENGINEERING EVALUATION OF OPTIONS FOR DISPOSITION OF RADIOACTIVELY CONTAMINATED RESIDUES PRESENTLY IN THE WEST LAKE LANDFILL, ST LOUIS COUNTY, MISSOURI

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DRAFT REPORT

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SUMMARY

In 1973, approximately seven tons of uranium ore (U_3O_8) along with 8700 tons of radioactively contaminated barium sulfate residues were emplaced in the West Lake Landfill in St. Louis County, Missouri. This material resulted from decontamination efforts at a nearby plant where the material had been stored. Disposal in the West Lake Landfill was not authorized by the Nuclear Regulatory Commission (NRC) or its predecessor agencies. State officials were not notified of this disposal since the landfill was unregulated at the time. Since 1974, there has been concern by authorities and local residents as to whether this material poses a health hazard to workers and residents of the area. An evaluation of environmental impacts of possible remedial actions to be taken on the site was completed by the University of Missouri-Columbia (UMC). This project was contracted by NRC to Oak Ridge Associated Universities, which subcontracted with UMC to perform the evaluation.

The West Lake Landfill is located at the edge of the Missouri River floodplain in the northwestern Bridgeton, Missouri. The West Lake Quarry was opened on this site in the 1940s. Quarrying, stone processing, and asphalt and concrete batching are still conducted at the site. In 1962, landfilling of municipal and industrial solid wastes was begun, and the older quarry pits were filled in. Once these pits were filled, landfilling was begun above ground level and extended north onto the Missouri River floodplain. Portions of the landfill used prior to state regulation in 1974 are unlined. Rock in the old quarry pits is fairly impermeable, however there is little geologic impedance to leaching from the above ground portions of the fill. As a result, groundwater beneath the landfill has become contaminated with leachate as evidenced by water quality in the perimeter monitoring wells. Water analyses indicate that radionuclides and sore organic pollutants are being leached from the landfill. At the present time, no groundwater taken from this area or down gradient from this area is put to domestic use. The highest level of radioactivity found in groundwater was 20pci/l of total alpha activity, which is below the NRC guidelines of 30pCi/l for this parameter. Surface water quality is also impacted by radioactive and organic pollutants leaving the landfill.

In 1980-81, Radiation Management Corporation (RMC) of Chicago, Illinois, performed a detailed radiological survey of the West Lake landfill under contract of the NRC. This survey was necessary to determine the extent of

radiological contamination. Prior to this survey, little was known about the location or activity of radionuclide bearing soils in the landfill. The RMC survey included:

1) measurement of surface gamma exposure rates;
2) boring of auger holes and logging with a NaI(Tl) scintillation counter to evaluate sub-surface contamination;
3) Intrinsic Germanium (IG) analysis of soil samples and some auger holes was performed to determine the soils concentration of specific radionuclides, and to calibrate the NaI(Tl) readings;
4) water and vegetation analyses for gross alpha and beta activities to determine the presence or absence of contaminants; and
5) measurement of radon gas emanation and accumulation in a building on-site.

The RMC survey indicated that radioactivity is due to members of the naturally-occurring uranium-238 and uranium-235 series. Since no enrichment in U-235 was observed, and since U-235 abundance in nature is 5% that of U-238, does estimates are well within limits of error when the activity contribution of U-235 and its decay products is ignored. Prior to emplacement at the West Lake Landfill, processing of the ore consisted of extraction of radium and uranium with negligible removal of thorium. Left in an undisturbed state, radionuclides will establish a secular equilibrium. For a sample of material in such secular equilibrium, the activity of each radionuclide in a given decay series will equal the activity of every other radionuclide in that series. The implication of disturbance to secular equilibrium in the U-238 series is as follows. Radium-226 has been depleted with respect to thorium-230; since the material will tend toward secular equilibrium, Ra-226 activity will increase over time to a level far above that currently present at the West Lake Landfill. This increase in Ra-226 must be considered in evaluating the long-term hazard posed by this debris. For example, over the next 200 years, Ra-226 activity will increase ninefold over the present level.

In addition to radionuclide content of the soil debris, the location of contaminants was also determined. It was found that in two areas radioactive soil are present in the landfill. The northern area covers about 5.7 hectacres (ha). Radioactive debris forms a layer 0.6 to 2.5 meters (m) thick, which is exposed on the landfill surface and along the berm which forms the northwest face of the landfill. The southern area contains a relatively minor fraction of the debris (approximately 0.8 ha) with most of the contaminated soil buried by 3 to 4.5 m of clean soil.

To evaluate the health hazard posed by this radioactive debris, it is necessary to make dose estimates for groups of persons likely to be exposed to radiation from debris in the landfill. The possibility of housing construction on the site at some time far in the future must be considered since the individuals living on the landfill would receive a higher dose than any other group.

Present and future doses can be calculated using DOE procedures for a hypothetical Maximally Exposed Individual (MEI). The dose to a MEI approximates the maximum possible dose anyone could receive from radioactive debris in the West Lake Landfill. The calculated doses are above guidelines for exposure to individual members of the population. Thus, the requirement for some type of remedial action is indicated. Exposure is principally through one or all of the following routes:

1) inhalation of radon gas and deposition of its daughters in the lungs;
2) direct exposure to gamma radiation;
3) inhalation of airborne contaminant particles;
4) ingestion of contaminated water; and
5) ingestion of plants or animals which may bio-accumulate radionuclides.

The following remedial action options were evaluated in this study for feasibility of implementation, reduction in radiation exposures, environmental impacts, and cost.

Option A - No remedial action.

Option B - Stabilization on-site with land use restriction.

Option C - Removal and relocation of the material to an authorized disposal site.

Option D - Excavation and permanent storage on-site.

Option E - Extensive stabilization on-site with land-use restriction.

Option B, stabilization on-site with land-use restriction, was chosen as the best alternative. This alternative (B) would involve covering the contaminated soil with five feet of clean, clay silt borrowed from loess deposits near the landfill. This soil layer would reduce surface exposure, radon gas emanation, and infiltration water available to leach radioactive and non-radioactive wastes in the landfill. The berm along the northwest side of the landfill would be rebuilt to halt the erosion of radioactive soil which is now occurring. After this stabilization has been completed, the surface of the contaminated areas will be available for placement of another layer of demolition fill. Land use restrictions will insure that after closure the site is put to some use such that excavation on-site will be unlikely and future construction on the site will be discouraged. Establishment of an appropriate land-use pattern at the time of closure, rather than temporarily fencing off the area from all use, will be most effective in preventing inappropriate activity on the site far into the future. A park, golf course or parking lot(s) would all be acceptable future uses for the site. Estimated costs of stabilization work would be $218,000, with no future maintenance or monitoring other than that required) by MDNR for the sanitary fill operation.

1. INTRODUCTION

The West Lake Landfill is located in St. Louis County, Missouri, 10 kilometers (km) west-northwest of Lambert Field International Airport (Fig. 1.1). The site, located on St. Charles Rock Road in Bridgeton, Missouri, is an intensely active industrial complex on which limestone quarrying operations, concrete batching, and asphalt aggregate preparation take place. In addition, the site has been since 1962 used for landfill disposal of municipal refuse, industrial solid and liquid wastes, and construction demolition debris. The majority of the West Lake Landfill is located on the alluvial floodplain of the Missouri River. The landfill is bounded on the northeast by industrial development, and on three adjacent areas by vacant land. Land northwest and south of the landfill is farmed (Fig. 1.1).

In 1973, barium sulfate residues from uranium and radium processing were deposited in the West Lake Landfill. Previously, this debris was located at the Cotter Corporation's Latty Avenue facility in Hazelwood, Missouri. These residues were contained in soil removed from the Latty Avenue site during decontamination work. This disposition was unauthorized and contrary to the disposal location indicated in NRC records.

In May 1976, the St. Louis Post-Dispatch published an article (1) claiming that radioactive material had been disposed of in the West Lake Landfill. The U.S. Nuclear Regulatory Commission (NRC) promptly conducted an investigation, which concluded that approximately 6.4 metric tons (kkg) of uranium ore (U_3O_8) had been disposed in conjunction with 7900 kkg of leached barium sulfate residues. These residues had been mixed with an estimated 35,000 kkg of soil before transport by truck to the landfill.

Subsequent NRC-sponsored studies were directed at determining the radiological status of the landfill. In 1978, an aerial radiological survey revealed two areas within the landfill where the gamma radiation levels indicated radioactive material deposition.

A more extensive survey was initiated in November 1980. This survey was conducted by Radiation Management Corporation (Chicago) (RMC) under contract of the NRC(1). By July 1981, the deposit of surface gamma levels had been reduced by shielding due to the deposit of additional solid waste and drift atop the radioactive material.

During the 1980 survey by RMC, an assessment of soil contamination was then made using boreholes to more precisely determine the depth and extent of the radioactive material. Analyses for specific radionuclides in soil samples indicated that the radioactivity was due to naturally - occurring uranium and its daughters, as would be expected from uranium ore. Elevated levels of Th-230 were present, resulting from the separation of both radium and uranium from the ore. The radon daughters of U-238 (Rn-219 and Rn-222), which emanate from the contaminated soil, were surveyed by RMC in the summer of 1981. The radon flux observed from the ground surface to the atmosphere ranged from 0.2 to 868pCi/m^2s.

Analysis of water from monitoring wells indicated little dissolution of radium or other radionuclides despite the presence of elevated levels of heavy metals and chlorinated organic compounds.

The results of the RMC radiological survey indicated that no significant migration of radionuclides from the West Lake Landfill had occurred. The principal migration of radioactivity was through the gaseous emanation of radon.

In March 1983, Oak Ridge Associated Universities (ORAU) acting as an agent for NRC, contracted with the University of Missouri-Columbia Department of Civil Engineering to conduct an environmental impact assessment and engineering evaluation of possible remedial measures at the West Lake Landfill. Only the radiological aspect of the landfill was to be considered in the study; Appendix A provides a copy of the Statement of Work for the project. This report presents a description and results of the engineering and environmental evaluation of the West Lake Landfill. Most of the information presented herein was obtained from existing reports and memoranda with only limited collection of on-site data.

2. SITE DESCRIPTION

This chapter presents a history and complete environmental description of is to describe the West Lake Landfill site located in St. Louis County, Missouri.

2.1 Location

The 81 hectare (ha) West Lake Landfill is situated on St. Charles Rock Road in Bridgeton, Missouri. The south and southwest part of the landfill is bounded by Old St. Charles Rock Road (Figure 2.1). Other sides of the landfill abuts farmland and vacant land. Several commercial and industrial facilities are located near the landfill. The nearest residential area is a trailer park located approximately 1 km southeast. A major portion of the landfill (roughly the northern 3/4 of the site, including the northern area of contamination) is located on the floodplain of the Missouri River, which is approximately 2 km from the site.

The current zoning plan for properties adjacent to the Landfill is shown in Figure 2.2. This zoning plan was obtained from the Bridgeton Planning & Zoning Department. A portion of the landfill site is zoned M-1, which is designated as light manufacturing. The northwest part of the landfill is zoned as single family residential (R-1). This R-1 zoning indicates the use to which the land was originally intended. However, the landfill was extended over the land zoned R-1; and the zoning plan was simply not changed to reflect the new usage. Other discrepancies between land-use and zoning are found in the nearby Earth City Industrial Park (3). The land across the St. Charles Rock Road is zoned for light and heavy manufacturing. The remainder of the property surrounding the landfill is zoned residential and business. The site consists of a quarry, stone processing and storage area and several active and inactive landfills. A concrete batching plant and an asphalt aggregate plant are also located on the site.

2.2 History

The West Lake Landfill was started in 1962 for the disposal of municipal and industrial solid wastes, and to fill-in the excavated pits from the quarry operation that had been performed at the site since 1939 (4). The landfilling operation apparently did not meet present MDNR standards, with no environmental safeguards to protect surface and ground water contamination. In 1971, State and Federal officials closed the old part of the landfill because of improper handling of wastes and other violations.

The first new part of the landfill was opened in 1974. The bottom is lined with clay and a leachate collection system has been installed. Leachate is pumped to a treatment system consisting of a lime precipitation unit followed in series by an aerated lagoon and two unaerated lagoons. The final lagoon effluent is discharged into St. Louis Metropolitan Sewer District sewers. The new landfill is presently operating under a Missouri Department of Natural Resources (MDNR) permit.

The owners maintain that the quarrying operation is expected to cease within one year due to a lack of "good rock" left at the site.

In 1973, the Cotter Corporation, (an AEC/NRC licensee) attempted to decontaminate its nuclear facilities at Latty Avenue in Hazelwood, Missouri. The decontamination procedure involved the mixing of about 7900 kkg of leached barium sulfate residues from uranium ore processing with an estimated 35,000 kkg of soil. The resultant mixture was to be disposed of in an AEC-approved site at Lambert Field Airport in St. Louis. In 1976, it was learned that an undisclosed amount of radioactive materials from the Latty Avenue plant had been buried in the West Lake Landfill. Subsequently, NRC's Region III office confirmed this finding through inspection and survey of the site (5). In 1980, NRC contracted with Radiation Management Corporation (RMC), Northbrook, Illinois, to do a detailed radiological survey of the West Lake Landfill site. RMC completed their study in 1981 and published their results in May 1982 (2). Details of the results of RMC study are in Section 2.11.

2.3 Ownership

The West Lake Landfill has been owned by West Lake Landfill, Inc. of 13570 St. Charles Rock Road, Bridgeton, Missouri, since the 1940s.

2.4 Contaminated Areas

Radioactive contamination at the West Lake Landfill has been found in two separate soil bodies containing the debris. Comparison of radionuclide quantities and the activity ratios between radionuclides not in secular equilibrium, indicates that radioactive contamination in the separate soil bodies was derived from only one source.

The northern area of contamination (Fig. 2-3) covers an area of 35 ha along the northwestern berm, beneath the Shuman building, and beneath much of the northern portion of the landfill. The contaminated soil forms a more or less continuous layer from one to four meters in thickness, and consists of approximately 100,000 m^3 of soil. Much of this contaminated soil is near or at the surface, particularly along the face of the northwestern berm. In April 1984, ORAU took surface soil samples containing as much as 700 pCi/g of Ra-226 per gram of soil (Appendix C.1).

The southern area of contamination (Fig. 2-4) covers approximately 0.7 ha and contains roughly 15,000 m^3 of contaminated soil. The soil body is located at a depth of three to five meters east of the landfill's main office. Soil has recently been added to the surface over the southern area of contamination. Surface exposure rates in this area have been greatly reduced due to this added soil, and in April 1984, only one point was found to exceed 20 mR/hr at one meter above the ground surface (6).

The northern body of contaminated soil lies above five to six meters of landfill debris. The soil profile beneath this soil body consists of one to two meters of floodplain topsoil overlying 10 to 15 m of sand and gravel alluvium. The southern body of contaminated soil is located over a former quarry pit, which was filled in with landfill debris. The depth of debris beneath the contaminated soil is unknown but is estimated at 15 to 20 m. Limestone bedrock underlies the landfill debris.

2.5 Topography

A substantial portion of the landfill site is located in the alluvial floodplain of the Missouri River. The site topography is subject to change because of the types of activities (e.g., landfilling and quarrying) being performed there. Figure 2.5 shows a contour map of the site as of June, 1980. The surface runoff follows several surface drains and ditches, which run in a northeast direction towards the Missouri River.

2.6 Geology

2.6.1 Bedrock:

Bedrock beneath the West Lake Landfill consists of Mississippian aged limestone of the Meramacean Series, which extends downward to an elevation of 58 m (190 ft) (7). The Warsaw Formation - also of Mississippian age - lies directly beneath the limestone. The Warsaw is made up of approximately 12 m of slightly calcareous, dense shale; this grades into shalely limestone towards the middle of the formation (Fig. 2.6) (8). The overlying limestone is of the St. Louis and Salem formations. It is dense, bedded, and fairly pure except for intermittent layers which contain abundant chert nodules. Bedrock beneath the site dips at an angle of 0.5° to the northeast. Eight kilometers east of the site, the attitude of the bedrock is reversed by the Florissant Dome; the bedrock dips radially outward from the apex of this dome at a low angle (9).

Since Karst (solution activity) often occurs in carbonate rocks, the possibility of its occurrence in the West Lake Landfill area must be considered. Brief observation of the quarry walls at the Landfill suggests that some solution of the limestone has occurred. But this solution activity has apparently been limited (see Section 2.7.1) to minor widening of joints and bedding planes near the bedrock surface. Although karst activity within the limestone is relatively minor, the upper surface of the bedrock is irregular and pitted due to solution (10). This alteration of the bedrock surface is greatest beneath the Missouri River alluvium.

2.6.2 Alluvium:

Alluvial material in this area may be divided into two categories, Missouri River alluvium, and upland alluvium. This is shown as the historical edge of the alluvial valley in Fig. 2-7. The division is made on the basis of alluvial composition, depositional history, and physical properties. Transition between these two types of alluvium occurs at the break in the slope which marks the edge of the river floodplain. The West Lake Landfill lies over this transition zone; therefore, subsurface material at the site varies considerably from southeast to northwest.

The Missouri River alluvium (Fig. 2.8) ranges in thickness from 12 m beneath the landfill site to over 30 m at midvalley (Fig. 2.9). The upper three meters of the soil profile consists of organic silts and clays that have been deposited by the Missouri River during floods (7). Below this surface layer, the soil becomes sandy and grades to gravel at depths greater than five to 10 m. Due to the effects of channel scour, which continues to grade the sediment after its initial deposition, the alluvium is fairly homogeneous in a horizontal direction and becomes progressively coarser with depth (11). At the edges of the floodplain, the alluvium is not as well graded, and a large amount of fine material is present in the deeper sand and gravel.

The upland alluvium (Fig. 2.10) is generally thinner than the floodplain alluvium. The soil is usually less than 12 m thick and consists mainly of loess, which was deposited during the age of Pliestocene glaciation. The loess consists of silt-sized particles that were transported by wind and deposited as a blanket over much of Missouri and Illinois. On the hills near the West Lake Landfill, the loess layer may be as much as 24 m thick. It consists of 6 to 9 m of fairly pure silt (Peoria loess) overlying 6 to 15 m of clay silt (Roxana loess) (10). This loess forms the hills to the southeast of the landfill; but it has long ago been removed from the landfill site and most of the surrounding valleys by erosion. The upper one meter of the loess has been altered to form a thin soil profile. It should be noted that loess has a vertical permeability which is far greater than its horizontal permeability (12). The total permeability of loess is greatly increased by disturbance. The individual silt grains are in generally quite angular, and therefore may not be effectively compacted by the methods commonly used to consolidate clay. The technique most effective in the compaction of loess would employ vibration beneath a surcharge. A relict soil profile from one to two meters thick lies beneath the loess and directly on top of the bedrock. This soil was formed as a residium prior to Pliestocene glaciation and was subsequently covered by the loess blanket. This soil is a highly consolidated clay containing abundant chert fragments (10).

In addition to the natural geologic properties of the landfill, human disturbance of the soil must also be considered; since material within the landfill itself can either limit or facilitate migration of leachate to the Missouri River alluvial aquifer.

In order to prevent downward movement of leachate, it is now a common practice to place a layer of compacted clay beneath sanitary landfills. Newer portions of the landfill (constructed since 1974) have two to three meters of clay at the base and around the sides. Waste is covered every day with 15 cm of compacted soil; the cover soil presently used is loess (CL and A4) of soil classifications taken from southeast of the landfill (13). If not properly compacted, this material may have a permeability of 0.0001 cm/sec or greater. It is not known what procedures for compaction were used at the landfill prior to 1974 since, the site was unregulated in both design and in materials which were accepted for disposal. It is believed, however, that there is no liner present beneath the northwestern portion of the landfill, and that sanitary (as well as some hazardous) material was placed directly on the original ground surface. Since waste was periodically covered with soil to minimize rodent and odor problems, the landfill probably consists of discrete layers of waste separated by thin soil layers. Both areas containing radioactive material are in these unlined above-ground portions of the landfill.

2.6.3 Seismology:

The primary seismic risk to the West Lake Landfill site (as well as to the entire St. Louis area) is the New Madrid Fault. This fault is located approximately 250 km to the SSW, near the town of New Madrid, Missouri. The risk from this fault is well-documented since a severe earthquake would likely destroy the city of St. Louis. The series of shock waves comprising the New Madrid earthquake, which occurred from December 16, 1811, to February 7, 1812, was one of the strongest quakes ever to occur and would have likely registered 9 or more on the modern Richter scale. According to the 1962 Geology and Soils Manual (Mo. State Highway Commission, Van Hoffman Press), this event consisted of 3000 tremors over 53 days which were felt as far away as San Francisco, CA. If such an earthquake occured at the present time, it is possible that the Missouri River level would be raised enough to overtop levees and flood the West Lake Landfill site. Flooding combined with shocks could result in failure and extensive erosion of the West Lake site and exposure of contaminated debris. No seismic design features were incorporated into the landfill site.

2.7 Hydrology:

2.7.1 Subsurface hydrology:

Groundwater flow in the area surrounding the West Lake site is through two aquifers: the Missouri River alluvium, and the shallow limestone bedrock. The base of the limestone aquifer is formed by the relatively impermeable Warsaw shale at an elevation of about 58 m (197 ft) above mean sea level (msl). This shale layer has been reached, but not disturbed by quarrying operations. Therefore, the Warsaw shale acts as an aquiclude, making contamination of the deeper limestone very unlikely. The shallow, Mississippian limestone beds have very low intergranular permeability in an undisturbed state (14). However, a strong leachate enters the quarry pit at an elevation of about 67 m (220 ft) msl (pt. A on Fig. 2.7). This leachate is migrating vertically through over 30 m of limestone. Explosive detonations associated with quarrying operations will tend to cause fracture propagation in the quarry wall. These fractures have probably extended less than 10 m into the rock from the quarry face. Beyond this, the rock will remain undisturbed. These fractures will tend to increase inflow to the quarry pit and allow percolation of leachate downward through the fractured zone. Thus, leachate inflow to the quarry pit is not evidence of large-scale contamination of the limestone aquifer. The only other mechanism by which leachate could travel rapidly through the limestone is transport through solution channels. Landfill consultants and quarry operators maintain that the limestone is fairly intact (15) and superficial observation by these researchers of the quarry walls seems to support this conclusion. Since the limestone is fairly impervious, and groundwater flow in most areas is from the bedrock into the alluvium, contamination of water in the bedrock aquifer does not appear likely.

The water table of the Missouri River floodplain is generally within three meters of the ground surface, but, at many points it is even shallower. At any one time, the water levels and flow directions are influenced by both the river stage and the amount of water entering the floodplain from adjacent upland areas. A high river stage tends to shift the groundwater gradient to the north, in a direction more parallel to the Missouri River. Local rainfall will shift the groundwater gradient to the west, towards the river and along the fall of the ground surface. This is inferred from water levels measured in monitoring wells at West Lake. The fact that groundwater levels commonly fluctuate a greater amount than the Missouri River level indicates that upland-derived recharge exerts a great deal of influence over groundwater flow at the West Lake site. This influence decreases towards the river.

The deep Missouri River alluvium acts as a single aquifer of very high permeability. This aquifer is relatively homogeneous in a downstream direction, and decreases in permeability near the valley walls. The deeper alluvium is covered by two to four meters of organic silts and clays that may locally contain a large fraction of sand-sized particles. Water levels recorded between November 1983, and March 1984, in monitoring wells at West Lake (16) indicate a groundwater gradient of 0.005, N 30°W beneath the northern portion of the landfill. This represents the likely direction of any possible leachate migration from the landfill (Fig. 2.7).

Recharge of the alluvial aquifer from upland areas comes from three sources: seepage from alluvium and bedrock bordering the valley, channel underflow of upland streams entering the valley, and seepage losses from streams as they cross the floodplain. Of these sources, streams and their underflow represent the main source of upland recharge to the alluvial aquifer. Streams entering the floodplain raise the water table in a fan-shaped pattern radiating outward from their point of entrance to the plain. In areas where streams are not present, the water slopes downward from the hills, steeply at first and then gently to the level of the free water surface in the Missouri River channel. The situations described above do not take into account the effect of variations in permeability of the shallow soil layer. Aerial photography of the site indicates that a filled backchannel (oxbow lake) type of soil deposit is present along the southwest boundary of the landfill (7). This deposit is probably composed of fine-grained material to the depth of the former channel (6 to 10 m). This deposit may tend to hamper communication between shallow groundwater on opposite sides of the deposit.

It is believed that landfilling operations in the older, northern part of the fill were not extended below the original ground surface in order for wastes in the landfill to remain above the water table. Since no other recharge sources exist above the level of the floodplain, the only water available to leach the landfill debris is that resulting from rainfall infiltration of the landfill surface. Because the underlying alluvial aquifer is highly permeable, there will be little "mounding" of water beneath the landfill. Due to the level surface of the northern portion of the landfill, it is likely that at least half of the rainfall infiltrates the surface. The remaining rainfall is lost to evaportanspiration and (to a lesser degree) surface runoff.

No public water supplies are drawn from the alluvial aquifer near the West Lake Landfill. It is believed that only one private well (Fig. 2.11) in the vicinity of the landfill is used as a drinking water supply. This well is 2200 m, N 35° W of the Shuman Building of the West Lake Landfill. Analysis showed water in this well to be fairly hard (natural origins) but otherwise of good quality (18).

Water in the Missouri River alluvium is hard (calcium-magnesium biocarbonate) and usually contains a high concentration of iron and manganese (14). The amount of dissolved solids present in the water of the alluvial aquifer varies greatly, with increasing purity toward mid-valley where groundwater velocity is greatest. A water sample from a well in the alluvium 3 km north of the landfill had a total dissolved solids content of 510 mg/l and total hardness of 415 mg/l of $CaCO_3$. Water in the limestone bedrock generally has a hardness greater than 180 mg/l as $CaCO_3$ equivalent (19). Total dissolved solids range from 311 to 970 mg/l. Water in the limestone aquifer may contain a large amount of sulfate of natural origin (14).

2.7.2 Surface hydrology:

Due to the extremely low slope of the Missouri River flood plain surface, precipitation falling on the plain itself generally is disposed of by infiltration rather than by surface runoff. The only streams present on the floodplain are those which originate in upland areas. Drainage patterns on the plain (Fig. 2.11) have been radically altered by flood control measures taken to protect Earth City and by drainage of swamps and marshes. Before these alterations, Creve Coeur Creek passed just south of the landfill, and drained a fairly large area. It has since been re-directed to discharge into the Missouri River upstream (south) of St. Charles. The old channel still carries some water, and empties into the Missouri at kilometer 45.2 (45.2 km upstream from confluence with the Mississippi River). Near the landfill, this stream is usually dry. As it crosses the flood plain, the creek passes through shallow lakes which provide a more or less continuous flow to the Missouri River throughout the year. A second stream, Cowmire Creek, crosses the floodplain east of the site. This stream flows northward and joins a backwater portion of the Missouri River at kilometer 35.4. Due to the relationship which exists between river level and groundwater level in portions of the floodplain near the river, these streams may either loose flow (at low stage) or gain flow (at high stage).

The present channel of the Missouri River lies about 3 km west and northwest of the landfill. Early land surveys of this area indicate that 200 years ago the channel was located several hundred meters to the east (toward the landfill) of its present course (20). The Missouri River has a surface slope of about 0.00018 (18). River stage at St. Charles (kilometer 45.2) is zero for a water level of 126.1 m (413.7 ft) msl (13). Average discharge of the Missouri River is 2190 m^3/s, with a maximum flow of 2850 m^3/s for the period of April through July, and a minimum flow of 1140 m^3/s in January and December (14). Some average properties of Missouri River water for the period 1951-1970 were: Alkalinity = 150 mg/l as $CaCO_3$, equivalent; hardness = 209 mg/l as $CaCO_3$ equivalent; pH = 8.1; and turbidity = 694 JTU.

Water supplies are drawn from the Missouri River at kilometers 46.6 and 33, respectively. The intake at kilometer 46.6 is for the city of St. Charles, and is located on the north bank of the river. The intake at kilometer 33 is for the St. Louis Water Company's North County plant (13).

The city of St. Louis also takes water from the Mississippi River, which joins with the Missouri River downstream from the landfill. In this segment of the river, the two flow-streams have not completely mixed and the Missouri River derived water still is flowing as a stream along the west bank of the Mississippi River channel (21). The intakes for St. Louis are on the east bank of the river such that the water drawn is derived from the upper Mississippi.

2.8 Meteorology

The climate of the West Lake area is typical of the Midwestern United States, in that there are four distinct seasons. Winters are generally not too severe and summers are hot with high humidity. First frosts usually occur in October; and freezing temperatures generally do not persist past March. Rainfall is greatest in the warmer months, with about one quarter of the annual precipitation occurring in May and June (Fig. 2.12) (22). In July and August thunderstorms are common, and are often accompanied by short periods of heavy rainfall (Fig. 2.12). Average annual precipitation is 896.9 mm, 434.3 mm of which occurs as snow. Average relative humidity is 68%, with values of over 80% common during the summer. The annual resultant wind is 4.25 m/s to the south. Wind during the period of December through April is generally to the northwest; while winds blow mainly to the south throughout the remainder of the year. A compilation of hourly wind observations shows that while the wind resultant is fairly consistent on a monthly basis, the wind actually shifts a good deal and is very well distributed in all directions (Fig. 2.13) (22 and 23).

Data used is for Lambert Field - 6 km east of West Lake. Temperature and precipitation data are representative of West Lake. However, due to differences in topography between Lambert and the site, the actual wind directions at West Lake may be slightly skewed in a NE-SW direction parallel to the Missouri River valley.

2.8 Water Quality

The existing water quality data is principally on groundwater in and around the landfill. Some data were available for the landfill leachate and surface water. While water quality data is compared to drinking water standards, it should be pointed out that the water is not used for this purpose at the present time.

Figure 2.7 shows the locations of the monitoring well in and around the landfill. These wells are sampled periodically by MDNR and representatives of the landfill owner. There exists three to four years of bi-annual data for some of these wells. In 1981, MDNR performed a special water quality monitoring study (18) and split some of these samples with RMC for radiological analysis (samples no. 2 and 3, Table 2, Appendix B) The MDNR study involved collection and analysis of five samples of shallow groundwater and two surface water samples from the perimeter of the landfill. Forty-one water samples were analyzed for radioactivity by RMC (Table 2, Appendix B). Of these samples, five were background, ten were on-site surface water, ten were shallow groundwater standing in boreholes, and sixteen were landfill leachate. From this data, background activity is estimated as 1.5 pCi/l gross-alpha and 30 pCi/l gross-beta. In November 1983 and March 1984, a number of groundwater samples and surface water samples were taken by landfill consultants and UMC, respectively, for determination of gross-alpha and gross-beta activity and, in the case of the former samples, analysis for primary pollutants and pesticides.

2.9.1 Groundwater Quality:

Most of the existing data on groundwater quality deals with chemical parameters; there is little information on radiological quality. The main emphasis of the MDNR groundwater monitoring program has been to monitor potential migration of pollutants from the sanitary landfill operation, and to determine local groundwater gradients.

Table 2.1 shows the ranges of chemical parameters in different wells. The chemical content of the water varies considerably, both from well to well and from one sampling to another. Water samples from the on-site monitoring wells generally have nearly neutral pH, high Chemical Oxygen Demand (COD), and a fairly large amount of dissolved metals. The high COD indicates organic matter is leaching from the landfilled materials as would be expected in a sanitary landfill. Reducing conditions and the neutral pH allows a relatively large amount of metal ions to dissolve and stay in solution. Reducing conditions, however, are favorable for absorption of metal ions onto soil material (17). The off-site wells (No. 51, 52, 53) show water of a good deal higher quality; but the data seem to indicate that contaminants are beginning to reach these wells. Evidence of this may be seen from the COD and mercury and zinc content of water from these wells. Contamination of these wells may originate from the leachate holding pond south of old St. Charles Rock Road which these wells were designed to monitor.

The RMC study had shown elevated quantities of organic solvent (phenols, chlorophenols, trichlorofluoromethane, toluene, tetrachloroethylene, and trichloroethylene) in auger hole water samples in Areas 1 and 2 (2). However, the water samples taken in November 1983 from monitoring wells around the landfill found low concentrations of inorganic and organic contaminants except for high dissolved solids, iron, and manganese levels in some samples (16). No pesticide residues were found in any of the monitoring well samples recently taken by landfill consultants (25).

RMC analyzed 26 groundwater samples from in and around the West Lake Landfill for gross-alpha and gross-beta activity. Ten samples were from boreholes and 16 were leachate. The leachate showed alpha activity near background and elevated levels of gross-beta activity (100 to 130 pCi/l). Isotopic analysis showed the high beta activity was produced by K-40. A high level of potassium present in leachate results in a large amount of the naturally occurring K-40 being present. Elevated K-40 is in no way related to radiological contamination of the landfill. Thus, at the present time, there is no evidence at radiological contamination of leachate collected for treatment. Groundwater samples showed beta activity near background and gross-alpha activity averaging 6 pCi/l. The highest gross-alpha level reported was 15 pCi/l in a temporary borehole west of the landfill - well number three of MDNR samples, 1981 (26). Some of the water samples exceeded the EPA gross beta drinking water standards. This may be attributed to naturally occurring K-40 activity, which is not a consequence of the radioactive material disposed on the site.

Recent radiological analysis performed on well water samples by the landfill owners showed gross alpha activity of only one well sample (18.2 pCi/l) exceed drinking water standard of 15 pCi/l. The gross beta levels for the well samples were within the allowable limits for drinking water of 50 pCi/l. The total radium level for all samples were less than 3 pCi/l which was lower than 5 pCi/l allowable for drinking water (27).

The results of radiological analysis of groundwater samples collected in March 1984 are shown in Table 2.2, with well locations shown in Figure 2.7. Sample No. 63 was surface water sample collected from a drainage ditch adjacent to St. Charles Rock Road northeast of the site. The highest gross-alpha activity level (20.5 ± 6.2 pCi/l) was in sample 60, which had only a slightly higher than the allowable 15 pCi/l in drinking water. The gross beta activities were not above 20.8 pCi/l. These results confirm earlier RMC data.

2.9.2 Surface water quality:

Less water quality data is available for surface water than for groundwater.

RMC analyzed 10 samples of surface water from on or around the landfill. Gross-beta activities averaged 34 pCi/l, which is slightly (probably insignificantly) above background. Gross-alpha activities averaged 9 pCi/l, which is well above background. One surface sample, RMC No. 7028 (taken from the northeast corner of the Shuman Building), was analyzed for gross-alpha and Ra-226. Results were 45.2 pCi/l gross-alpha and 1.2 pCi/l of Ra-226. These results indicate that some radionuclides other than Ra-226 and its daughters are the probable sources of this alpha activity.

UMC sample No. 63, taken in March 1984, from the slough north of the landfill along St. Charles Rock Road, showed gross-alpha and beta activities approximately equal to background.

Two samples of leachate seeping from the landfill surface were taken in April 1984 by UMC researchers. The leachate was dark and had a septic odor. These samples were analyzed for Total Organic Carbon (TOC) and showed 35 and 55 mg/l TOC as carbon. This is of the same order as the 50 to 200 mg/l TOC found in raw sewage. At the time this sample was collected, water table conditions were high and seepage was estimated as less than 0.03 m^3/min. Radioactivity analysis was not performed.

2.9.3 Potential for radiological contamination of surface and ground waters:

As mentioned in Section 2.7.1, there is little hydrologic barrier to leachate flow through the base of the landfill into the river alluvium. Surface waters flowing off of the site are rapidly diluted and do not pose hazards to area residents or fishermen. Groundwater contamination, on the other hand, could pose a hazard in the future since a well could be drilled into contaminated alluvial waters.

An important consideration in the estimation of potential water contamination is the leaching behavior of the radioactive soils. The main factors governing leaching behavior are: rate of dissolution of radionuclide bearing compounds, radionuclide sorptian from solution onto surface active soil particles, precipitation reactions, and complexation of radionuclide ions with organic chelating agents in solution.

In 1981, the NRC attempted to determine the leaching characteristics of wastes from the Latty Avenue site which were similar to those found at the West Lake site (28). These tests found that the pH of the solution had little effect on leaching due to the buffering of the soil. Variations in leaching time gave only slight differences in the amount of radionuclides removed. Thorium was least subject to leaching, while uranium and radium were leached in similar amounts. No radionuclides were leached in quantities greater than 2% of their concentration.

Radium sulfate limits radium solubility to 10 to 50 micro curies per liter. From groundwater analysis and NRC leaching tests, it is apparent that this much radium is not dissolved into surface and groundwater at the West Lake site. This is probably due to the fact that the dissolution reaction is slow due to a low concentration of Ra (available on particle surfaces) coming in contact with infiltrating groundwater. It is likely that when wastes were first emplaced in the landfill, the initial leaching rate was much higher than it now is. Future leaching out of the wastes may occur faster than in-growth of radium-226. If the decrease in leaching rate is faster than the rate of Ra-226 in-growth, there will be a net decrease in radium leaching over time.

Radionuclides in solution will be retarded in their movement through the groundwater system by sorption reactions with soil particles. Sorptian is greatest by clay particles and less for silt and quartz sand. The net effect of sorptian reactions will be to limit the spread of a contaminant plume through the alluvial aquifer.

Radionuclides may form complexes with large organic molecules, particularly humic acids produced by decay of organic debris present in the landfill. This complex formation, chelation, could increase the amount of radionuclides in solution to a level above that predicted by simple equilibrium calculations. The effects of chelation cannot be predicted without a highly detailed water analysis and computer modeling to determine a comprehensive equilibrium condition. Even this approach would only provide trends toward concentration equilibrium, or boundary condition. The rate of these multiple-step complexation reactions may be quite slow, and a great deal of laboratory work would be required to evaluate the amount of radionuclides held as chelates in solution leached from the landfill. Once this leachate has left the landfill and diluted into alluvial waters, an entirely different equilibrium condition would be established. A complete evaluation of radionuclide complexation is beyond the scope of this report. It can be stated that organics in solution will increase radionuclide concentrations in groundwater above those which would be present if the organics were absent. However, analysis of contaminated groundwaters does not indicate a large-scale mobilization of radionuclides on other metals.

2.10 Ecology

The West Lake Landfill is biologically and ecologically diverse. Rather than a single biological system (e.g., a prairie), it is a mosiac of small habitats associated with:

a) moist bottomland and farmland adjacent to the perimeter berm;
b) poor quality drier soils on the upland exterior and interior slopes of the berm;
c) an irregular waste ground surface associated with the inactive portion of the landfill: and
d) aquatic ecosystems present in low spots on the waste ground surface.

Generally, the natural systems which are present are limited by operations in the active portion of the landfill and form a corridor along the perimeter berm from near well site 75 (Fig. 2.7), on the Old St. Charles Rock Road, to the main entrance to the landfill near well site 68, St. Charles Rock Road (southern area, Figure 2.4). The northwest inactive portion of the landfill, i.e., the area in proximity to the Shuman Building (northern area, Figure 2.3) encompasses the largest set of natural systems. The following observation and descriptions demonstrate the biological richness of these sites.

The flora of the perimeter berm extending from the southwest to the area of the main entrance to the landfill is a series of contrasts. Along the Old St. Charles Road, the bottom and lower slope of the berm is heavily influenced by the nearby mature and silver maple, boxelder, oak, sycamore, green ash, and eastern cottonwood forest associated with the old channel of Creve Coeur Creek. At the corner between wells 59 and 60, large silver maple and boxelder trees have established in a dense stand in the moist soils at the base of the berm. The density of these trees declines on this slope extending toward the north (well 61) and the Shuman Building corner. The extension of this slope toward the northwest is dominated by a dense willow-like thicket in which a few eastern cottonwoods and a hawthorn tree have established. From this northwest corner of the landfill to the eastern limit of the forest between the landfill and St. Charles Rock Road (well 65), the exterior slope of the berm is dominated by dense stands of small and large eastern cottonwoods. This latter occurrence reflects the influence of the well-established eastern cottonwoods and sycamores associated with the permanent pond in this site. The ground cover along these exterior slopes consists of grasses, forbs, waste ground plants, seedling cottonwoods and willow-like shrubs. A well-manicured grass ground cover continues from the limit of the trees to the area around the main entrance of the landfill and well 68. These, together with the larger trees contribute to the partial stabilization of the steep exterior slopes.

The somewhat drier top and the short, interior slope of the berm, colonized by prairie grasses such as bluestem, Andropogon: blends into the irregular surface of the inactive portion of the landfill. Depressions in this surface allow for the collection of water and, as such, tall grasses, foxtail, and characteristic waste ground plants, e.g., ragweed, Ambrosia; mullein, Verbascum; pokeweed, Phytolacca; cinquefoil, Potentilla; sunflower, Helianthus; and plantain, Plantago; are replaced by characteristic wetland species, e.g., algae; Spirogyra; cattails, Typha; sedges, Carex; and smartweed, Polygonium. Young eastern cottonwoods have established at several of these wet sites. Generally, the surface vegetation of the inactive landfill gives way to barren waste ground around the Shuman Building and the barren terrain associated with recent landfill activities.

Animals were observed associated with these habitats. Cottontail rabbits, Sylvilagus; were encountered most frequently and their signs (fecal pellets) were observed over the landfill. Density of fecal material was particularly heavy in the thickets on the exterior slopes of the perimeter berm. In this regard, coyote, Canis latrans; feces containing rabbit fur were observed. Small mammals (rodents) were not seen but would certainly be present in these areas. Large ungulates also were not sighted but observation of tracks and feces of white-tailed deer indicated that they utilized the surface of the landfill.

With respect to avain species, only a crow, several robins and white-crowned sparrows were observed. This certainly does not reflect the extent to which birds utilize these habitats for our observations were made early in the spring. It is readily apparent that returning migratory passerines would utilize the surface vegetation and berm thickets for nesting cover and feed later in the season. It is also possible that waterflow could utilize the permanent ponds on the landfill and adjacent to St. Charles Rock Road. Twelve scaup and mallards were observed on the lagoon which serves as part of the landfill water treatment facility.

Permanent surface waters on the landfill were found to contain characteristic aquatic invertebrates and at least two species of amphibians. Casual examination of these shallow waters revealed three genera of snails, *Physa*, *Lymnaea*, *Helisoma*; and isopod, *Asnellus*; cyclopoid copepods; and cladocerans. Aquatic insect larvae were not observed; however, this does not rule out their presence. The sighting of a bullfrog tadpole, *Rana Catesbeiana*; and audition of spring peppers, *Hyla*; indicates these ponds are utilized as breeding sites. Fish were not observed on the ponds on the landfill surface; however, a dead gizzard shad, *Dorsoma cepedianum*; was sighted in the pond adjacent to St. Charles Rock Road. The only reptiles seen were the water snake *Natrix* and the garter snake *Thamnophis*.

Although the northwest inactive portion of the landfill is posted with "No Trespassing" signs, it was evident that humans do encroach on these habitats. Fishing tackle was found tangled in power lines and trees; while spent small guage shotgun shells were found on the surface and berm of the landfill.

2.11 Radiation

As a result of the St. Louis Post Dispatch article (1), the NRC initiated an investigation of the West Lake Landfill (see Section 1). A total of approximately 35,000 kkg of contaminated soil was reported to have been disposed of at this site. An aerial survey, performed for the NRC in 1978 (5), indicated external radiation levels as high as 100 R/hr and a second contaminated area, previously unknown, was also identified.

From August 1980 through the summer of 1981, the Radiation Management Corporation (RMC), under contract to the NRC, performed an on-site evaluation of the West Lake Landfill (2). The purpose of this survey was to clearly define the radiological conditions of the landfill site so that an engineering evaluation and an environmental assessment of the contamination would be possible.

The surveyed area was divided into 10-meter grid blocks. Measurements were made at one meter and at the surface using a NaI scintillation detector and a Geiger-Meuller (G-M) meter.

Levels of direct radiation decreased significantly from November 1980 to March 1981, mainly because of the addition of new fill material. A small region of a few hundred square meters in Area 1 exceeded 20 R/hr (Fig. 2-4). The portion of Area 2 which exceeding levels 20 R/hr decreased by 10% (Fig. 2-3). The highest radiation levels are in the vicinity of the Shuman Building. Several isolated spots of surface contamination were detected and have been attributed to erosion and runoff or suspected excavation (6).

Surface soil samples were collected for analysis from places where surface deposits were indicated and also from regions where the drainage characteristics are suggestive of contamination from runoff water from the original burial sites. Crop samples were also collected, based on the external surface measurements (2).

In general, surface contamination was limited to Area 2 and all soil samples contained only uranium and/or thorium decay chain nuclides and K-40. Off-site background samples were on the order of 2 pCi/g for Ra-226. On-site samples ranged from about 1 to 21,000 pCi/g Ra-226 and from less than 10 to 2,100 pCi/g U-238. Thorium-230 levels were found to be on the order of 20 times greater than Ra-226 concentrations.

Extensive subsurface monitoring and sampling was required in order to determine the depth and lateral extent of subsurface contamination. Scanning of auger holes with a NaI (Tl) scintillation detector was the basis for determining which representative holes would undergo intrinsic germanium (IG) detector gamma analysis. The (IG) detector allows determination of specific radionuclides, while the NaI(Tl) detector simply provides a count rate.

Subsurface deposits extended approximately two hectares beyond where surface radiation measurements exceeded action criteria. Contamination (5 pCi/g of Ra-226) was found to extend from the surface to a depth of about 6.1 m below the surface. In general, the subsurface contamination appears to be a continuous single layer, ranging from 0.6 to 4.6 m thick and covering a total area of 6.5 ha, as described in Section 2.4.

As noted earlier, water samples were taken from bore holes, off-site monitoring wells, standing water, runoff water, and leachate liquids. One sample of standing water exceeded the EPA gross alpha activity guidelines for drinking water. Several samples exceeded the EPA gross beta activity guidelines attributable to K-40. None of the off-site samples exceeded the EPA standard.

Radionuclides of concern as potential sources of airborne radioactivity are Ra-226, Ra-224 and Ra-223, which decay to Rn-222, Rn-220, and Rn-219, respectively. Rn-219 and Rn-220, however, are not likely to emanate into the atmosphere due to their very short half-lives (4 sec and 55 sec, respectively). The only samples to exceed the recommended concentration guide for radon daughters in unrestricted areas were the two samples taken from inside and near the Shuman Building in November 1980. Locations where the radioactive material is covered by approximately one meter of fill have radon flux levels close to background.

Other testing included vegetation analysis (in which no elevated activities of radiation were found) priority pollutant analysis, chemical analysis of on-site radioactive materials, and various off-site measurements for reference background levels.

Additional data has been collected by UMC personnel in 1983 and ORAU personnel (6) in March 1984. These data, which will be discussed in Section 3.2, confirmed the previous measurements by RMC, with the exception that higher levels of surface contamination were discovered in March 1984 on the slope of the berm (Figure 2.3). This appears to be due to surface erosion uncovering buried radioactive material, which was identified in the RMC report.

2.12 Demographics

The West Lake Landfill is located in the northwestern portion of the city of Bridgeton, Missouri, in St. Louis County. Earth City Industrial Park is located on the floodplain 1.5 to 2 km northwest of the fill. Population density on the floodplain is generally less than 10 persons per square kilometer; and the daytime population (including factory workers) is much greater than the number of full-time residents.

Major highways in the area include I-70 and I-270, which meet south of the landfill at Natural Bridge Junction. The Earth City Expressway and (new) St. Charles Rock Road lie, respectively, west and east of the landfill. The Norfolk and Western railroad passes about 1 km from the northern portion of the fill. Lambert Field International Airport is located six km east of the West Lake Landfill.

In addition to factories at Earth City, plants are also operated by Ralston-Purina and Hussman Refrigeration across St. Charles Rock Road from the site. The employees of these two plants probably comprise the largest group of individuals in close proximity to the contaminated areas for significant periods of time. The Ralston-Purina facilities are located 0.4 km northeast of the Shuman Building at the landfill. Considering that land in this area is relatively inexpensive and that much of it is zoned for manufacturing, industrial development on the floodplain will likely increase in the future.

Two small communities are present near the West Lake Landfill. Spanish Village consists of about 90 homes and is located 1.5 km southwest of the landfill; and a small trailer court lies across St. Charles Rock Road, 1.5 km southeast of the site. Subdivisions are presently being developed 2 to 3 km east and southeast of the landfill in the hills above the floodplain. Ten or more scattered houses lies east of the landfill along Taussig Road. The city of St. Charles, MO is located north of the Missouri River at a distance greater than 3 km from the landfill.

Zoning of areas adjacent to the West Lake Landfill is residential except for the land across St. Charles Rock Road, which is zoned for manufacturing and business (Fig. 2.2). Most of the landfill is zoned for light manufacturing (M-1). However, approximately 0.3 km of the northern portion of the landfill is zoned for residential use; this includes the contaminated area around the Shuman Building. The field northwest of the landfill between old and new St. Charles Rock Roads is farmed. Trends indicate that the population of this area will increase; but the primary land use will probably be for industrial facilities.

Section 3. EVALUATION OF RADIOLOGICAL ENVIRONMENT

3.1 Radiological Effects on Man, and Exposure Guidelines

3.1.1 Natural radioactive elements:

Minute quantities of naturally occurring radionuclides exist in our environment. These radionuclides and cosmic radiation make up what is known as background radiation, and very little can be done to reduce the level of background radiation.

Of naturally occurring radionuclides in the environment, there are three principal decay chains the thorium series, the actinium series, and the uranium series, which begin with Th-232, U-235, and U-238, respectively. These decay chains are shown in Table 3.1 through Table 3-3. The uranium series is the most abundant and is of primary concern at the West Lake site. This decay chain includes Rn-222, a radioactive noble gas which emanates from the soil and will concentrate in buildings where there is inadequate ventilation. Although radon concentrations in the natural environment do not normally reach significantly high levels, in areas of concentrated uranium and radium deposits these levels can occur well in excess of recommended limits.

Radioactive decay in these decay chains occurs by alpha ( ), beta ( ) or gamma ( ) emissions with the majority of these decays occurring by decay. The biological effect of radiation is dependent on the type of radiation and the energy deposited by this radiation within the body.

3.1.2 Pathways of radiation to man:

Man is affected by radiation from the uranium series by either intake by the body of radionuclides or direct exposure to penetrating radiation. There are essentially two ways in which the body can take in radionuclides: ingestion and inhalation. The effects and mechanisms of each of these are discussed below.

Ingestion can take place by intake of two potential sources: the contamination of drinking water or a food source. The contamination of drinking water results when rainfall (or other surface waters) leaches through the soil, carrying soluble radionuclides to the water table. Contamination of foods, on the other hand, results from the uptake of radionuclides from the soil by the respective plants.

The principal intake of gaseous radon occurs by inhalation. Upon inhalation, deposition in the lungs occurs and the decay process continues through the decay chain shown in Tables 3-1 through 3-3. Since a major part of the resulting Rn daughters result in decay (which has a very short range or travelling distance in tissue), the lunds are extremely sensitive to any uptake of radon. Other radioactive particles may also be inhaled in the form of dust particles. The likely presence of airborne particulates in remedial action operation therefore warrants the use of dust control procedures.

Gamma rays, are highly penetrating and will produce damage in any part of the body, although to a much lesser degree than is produced by decay.

Radiation measurements are thus used in conjunction with the aforementioned pathways for exposure to determine the probable exposure to man; from the calculated exposure, a risk (if any) can be quantitatively approximated.

3.1.3 Calculation of health effects:

The biological effect produced by radiation depends on the type of radiation, the energy absorbed by the body, and the particular part of the body exposed. Of the three types of radiation previously mentioned, is the most damaging, is the least, and is the intermediate. The units of radiation dosage are called rads, where 1 rad (R) is equivalent to the absorption of 100 ergs/g. The relative amount of biological effect to man caused by a given energy from the different types of radiation is called the "quality factor". The relative biological effect of absorbed radiation is expressed in units of rems. In this report, 1 rem is approximately equal to the absorption of 1 R for exposures to the body from gamma and beta rays.

Once specific doses to the population have been estimated, a statistical estimate of the resulting health effects can be made. Based upon the BEIR study (29) of 1980, the statistical estimate is for 1 induced cancer for every 10,000 person-rem of dose.

The NRC (27) has implemented the target criteria (30) given in Table 3-4 as the guidelines for soil contaminants which are applicable to the West Lake Landfill. Only soils containing specific activities less than those listed for Option 1 can be disposed of without restricting the method of burial. For specific activities listed in Options 2 through 4, special disposal criteria are specified. This is the case for the West Lake site as will be discussed below. Other criteria are also available and will be discussed in Section 3.3.

3.2 Evaluation of Radiation Source

The Radiation Management Corporation report (2) clearly identifies the radioactivity present in the landfill as naturally-occurring radionuclides in the decay chains of uranium-238 and to a much lesser extent uranium-235 and thorium-232.

Specifically, true areas of elevated radionuclide activity were identified, which have been designated Area 1 and Area 2. The location, size and extent of these two areas is discussed in Section 2.4. With respect to the characterization of the radionuclide present, there appear to be no differences since it is likely they are originated from the same location. As such, the following analysis will treat the total nuclionuclide inventory as a single quantity.

To confirm this RMC result and to determine if significant change had taken place since 1981, a brief radiological survey was completed by UMC personnel on September 21, 1983. Water samples were taken on March 21, 1984; and another abbreviated radiological survey was performed by ORAU personnel in March 1984 (6). These measurements confirmed that radiation levels were above natural background levels and that soil samples taken showed the presence of naturally-occurring radionuclides, including elements from the natural decay chains of uranium-235, uranium-238 and thorium-232.

One of the possible concerns for potential radiation exposures to persons from these decay chains is the emanation of radon gas, which occurs in each of the decay chains above. The possible radon radionuclides are radon-222, radon-219 and radon-220 from the parent radionuclides uranium-238, uranium-235 and thorium-232, respectively. However, since the half-life of radon-219 is short (4 seconds) and the half-life of radon-220 is also short (55 seconds), these radionuclides decay to a non-gaseous radionuclide before they can escape from the ground if even a minimal ground cover is present. Additionally, the parents of radon-219 and radon-220 are uranium-235 and thorium-232, respectively, which are often small compared to the uranium-238 concentration which leads to radon-222. Thus, only radon-222 is normally considered in calculating exposure from radon gas. Due to this, it is necessary to establish the concentration of the immediate parent, radium-226, which occurs in the uranium-238 decay chain. Other possible exposure mechanisms include ingestion which will be discussed later.

In examining the RMC report for surface soil (Table 3-5), soil radiochemical analysis (Table 3-6) and bore hole samples (Table 3-7), it is noted that the naturally-occurring equilibrium discussed above has been perturbed. Specifically, the uranium-238 to thorium-230 to radium-226 equilibrium has been disturbed. The RMC report indicates that the ratio of thorium-230 to uranium-238 is on the order of 2:1 to 10:1. This observation leads to the conclusion that the deposits in the West Lake Landfill are from the processing of uranium ores to extract the uranium content. It is assumed in the RMC report that the radioactive material at West Lake came from the former Cotter Corporation facility on Latty Avenue (presently occupied by Futura Coatings Company) in Hazelwood, Missouri. This location contained uranium which had been previously separated from uranium ores, leaving the thorium behind at relatively higher concentrations. Additionally, it is noted in the RMC report that the ratio of thorium-230 to radium-226 is on the order of 5:1 to 50:1. This indicates that radium has also been removed from the original ore; this operation was also known to have occurred at the Latty Avenue site. A review of the ORAU report (28), indicates thorium-230 to uranium-238 ratios of approximately 100:1 and thorium-230 to radium-226 ratios of approximately 50:1 in general agreement with RMC observations of the West Lake site (2). The ratio of the protactinium-231 to uranium-235 is about 60:1. Since protactinium-231 is a long-lived radionuclide in the uranium-235 decay series, this again indicates the magnitude of the depletion of uranium from the original equilibrium concentrations. Similarly, the abbreviated survey taken by ORAU (32) indicated thorium-230 to radium-226 ratios of 25:1 to 40:1.

Other data is available in the Latty Avenue site study (29) and the RMC report to establish other relative ratios of radionuclides. Table 2 from Ref. 28 (reproduced here as Table 3.8) on decontamination debris at the Futura Company site on Latty Avenue indicates a uranium-235 to uranium-238 activity ratio of approximately 0.05, which confirms the previous assumption that no enrichment or depletion or uranium-235 has occurred in these materials. Table 3.8 also indicates that the ratio of thorium-230 (from uranium-238) to naturally occurring thorium-232 is approximately 4000:1 indicating that the concentration of the natural element of thorium is small compared to that occurring in the uranium-238 decay chain. Similarly, the RMC report identifies only the lead-212 radionuclide from the decay of thorium-232 in its analysis, and its concentration is generally one to two orders of magnitude less than that for thorium-230. This indicates that thorium-232 is not significant and that this decay chain can be neglected in comparison to the uranium-238 decay chain.

The result of this general characterization of the site confirms that both uranium and radium have been depleted from the original ore, that the natural uranium-235 to uranium-238 ratio has not been changed and that the natural thorium-232 concentration in the ore is relatively low. The depletion of uranium from the ore appears to be in the range of 2:1 to 150:1. (The ratio of 2:1 may be due to the presence of unprocessed ores in the site; however, the majority of the samples taken indicate significant removal of uranium from the ore.) A portion of the data in Table 3.6 indicates a large thorium-230 to uranium-238 ratio in the range of 200:1 to 52,000:1. This suggests substantial depletion of uranium from the ore which is not possible. Therefore, this data is probably in error. The actual ratio is not critical, however, to the radioactive characterization of the site since the precise amount of uranium is not a major factor in calculating possible exposures to the public. Similarly, the ratio of thorium-230 to radium-226 is in the range of 5:1 to 150:1, indicating the magnitude of radium depletion from the ore. This ratio is more critical to the characterization of the site since it determines the long-term radium concentration (from the decay of thorium-230) and thus the long-term radon gas production rate. This will be considered more fully below.

To confirm the specific activities and surface exposure levels given in the RMC report (2), three soil samples and several direct radiation surveys were taken by UMC. Specifically, two points near surface soil sample 4 in Area 2 (i.e. grid location i00Q) and surface soil sample 3 in Area 2 (i.e. grid location Z00N) were surveyed for surface dose. The sample location i00Q is one of the most radioactive in the survey report and this was confirmed in this brief survey. The data are as follows:

Grid	Gamma (mR/hr)	Beta (mR/hr)
i00Q	2.0	1.5
Z00N	0.1	0.03

These measurements are about a factor of 2 higher than those reported in the RMC report. This may be due to some surface erosion, but is more likely due the GM detector used by UMC which is not specifically calibrated for the energies of the particles found here. In general, surface exposure rates averaged over the area of elevated radiation levels are 10 - 20 R/hr. In area 2, approximately 6% of the readings significantly above 20 R/hr were found, indicating a small area of high surface exposure rate. Of this level, most appear to be due to gamma-ray radiation. Soil samples were analyzed using gamma ray spectroscopy, and radionuclides such as bismuth-214, lead-214, protactinium-234m, thallium-208 (along with lesser amounts of other isotopes) were identified. The activity of bismuth-214 and lead-214 at grid location i00Q were determined to be 2000 pCi/g, approximately a factor of two greater than that reported in the RMC report. This may again be due to some surface erosion, but is more likely due to variances between two independent samples taken over two years apart. The protactinium-234 activity was 200 pCi/g, which agrees with the uranium-238 activity reported by RMC, as would be expected since the two isotopes should be in equilibrium over such a short time period. Finally, the thallium-208 was only 8 pCi/g, again indicating that the concentration of thorium-232 (the parent radionuclide in this decay chain) is low compared to the uranium-238 decay products. Similar results were found for the other soil samples analyzed.

Activities for radionuclides in the soil as measured by ORAU (6) indicate Ra-226 ranging from 1 to 600 pCi/g and Th-230 ranging from 10 to 20,000 pCi/g. This gives an independent check of activity levels and is in general agreement with RMC results. Similarly, measurements were made by UMC personnel on September 23, 1983, and are summarized in Appendix F. Again, general agreement was found. With these general confirmations of the RMC reported activities, an overall estimate of the source term in the landfill can be determined. Some estimations are necessary, however, since the previous data gives ranges of activity and ranges of radionuclide ratios. Since the radium-226 is one of the most critical radionuclides for possible exposure, it is used for the basis of calculation. Using the RMC data and averaging the auger hole measurements over the two volumes of radioactive material found in Areas 1 and 2, a mean concentration of 90 pCi/g was calculated for radium-226. Next, the ratios of thorium-230 to radium-226 must be established since the level of thorium-230 will determine the increase of radium-226 with time. The ratio of thorium-230 to radium-226 ranged from 5:1 to 150:1, with most of the data in the 30:1 to 50:1 range. To insure conservation in estimating the long-term effects of radium-226, a ratio of 100:1 was used for all further calculations. This is possibly a factor of 2.0 too large, and all subsequent estimates could be revised downward for a "best estimate" calculation. Similarly, the uranium-238 to thorium-230 ratio ranges from 2:1 to 200:1. This ratio is less critical to the radiological effects of the site and has been estimated to be 50:1 for purposes of calculation.

The total radionuclide inventory can be determined for a general comparison with the natural background. Since there are nine radionuclides in equilibrium with radium-226, this results in 90x9 = 810 pCi/g. Using the ratio of thorium-230 to radium-226 of 100:1, the thorium-230 activity is 9000 pCi/g. If the thorium-238 concentration (as well as uranium-234 which would be similarly separated from the ore) is a factor of 50 less than thorium-230, this results in 180 pCi/g plus three additional radionuclide in equilibrium with it, or 720 pCi/g. Thus, most of the activity is from thorium-230 at the present time. The total mass of radioactive material in the landfill was stated in the RMC report as 6.6×10^{11} grams. This was confirmed by visually integrating the volume of radioactive material from the graphs in the RMC report and multiplying by an average soil density, resulting in 1.5×10^{11} grams. Thus, the total activity is in the range of 1600 Ci to 7000 Ci. Table 3.9 summarizes these calculations. This can be compared with the quantity of naturally occurring uranium and thorium that is already in the landfill based upon the RMC report average background of 2.5 pCi/g of uranium-238 and all of its daughters. Assuming a total landfill area of 80 ha, utilized to a depth of 1.5 meters, the resulting activity is approximately 2500 Ci. This is mentioned for comparison purposes only.

Knowing the total radium-226 activity in the site, the release of radon-222 gas from the surface of the landfill can be estimated. The RMC report gives radon emission fluxes in $pCi/m^2/sec$ over the area of radioactive material. Using an average value of 450 $pCi/m^2/sec$ and a surface area of 6.5 ha above the radioactive material, an emission rate of 30 Ci/sec is calculated. This rate can also be approximated by noting the relative concentrations of radium-226 (which is the parent of radon-222). Any difference is due to the escape of radon-222 from the site. One hundred soil samples analyzed in the RMC report were examined and it was determined that the average concentration of bismuth-214 was 10% less than that of radium-226. Using the total activity of radium-226 of 90 pCi/g used above, and assuming that 10% of this escapes as radon gas, an emission rate of 25 Ci/sec is determined. This confirms the previous calculation. The result in working levels (WL) is in the 0.001 to 0.002 WL range, with a few outdoor isolated spots as high as 0.02 WL.

These calculations give the radon gas flux levels at the present time. However, due to the depletion of radium-226 relative to thorium-230, this radon gas flux level will not be constant over time. The long half-life of the thorium-230 parent will increase the radium-226 concentration until these two radionuclides are again in equilibrium. Assuming the ratio of activities of 100:1 used above, the radium-226 activity (and thus the radon-222 gas flux) will increase by a factor of five over the next 100 years, by a factor of nine 200 years from now, and by a factor of 35 1000 years from now. All radionuclides in the decay chain below radium-226 will also be increased by this amount. This must be considered in possible remedial actions for the future. These changes in activity, along with changes for all radionuclides over the next 1000 years, are shown in Table 3.10.

Radioactivity in water samples and vegetation samples were also measured in the RMC report (2). With respect to water samples, radium-226 levels are below 4 pCi/l at the time of measurement (1980-81). With the increase of radium-226 activity in the site with time, this concentration has the potential to increase. Gross-alpha activities were generally in the 1 to 100 pCi/l range and gross-beta activities were in 10 to 130 pCi/l range. UMC conducted measurements on March 21, 1984, which confirmed gross-alpha activity in the 1 to 20 pCi/l range and gross beta in the 6 to 20 pCi/l range. Subsequent isotopic analyses indicated that all beta activity can be attributed to potassium-40 and is not related to the contaminated uranium processing residues? at the site. With respect to vegetation samples, no elevated activities were found either on the site or in farm crop samples in an adjacent field (which may have been contaminated by possible run-off from the landfill).

3.3 Estimated Exposure to the Public

The previous section establishes an estimate of the total source of radioactivity present in the West Lake Landfill. These values can now be used to determine possible radiation exposure to the public. In this analysis it is helpful to refer to recently established guidelines for remedial action at sites of this type. Such guidelines can be found in Table 3.4 taken from an NRC Branch Technical Position (30) for various disposal options for wastes of this type. Similarly, EPA guidelines (31) are found in Table 3.11 with respect to radon and radium concentrations. As can be seen, essentially all the activities in the West Lake site indicate the need for remedial action.

To evaluate the radiological impact of various options for the future of this site, it is helpful to calculate resulting doses from the specific radioactive source concentrations identified in the previous section. Data found in ORO-832 (32) are useful in calculating dose using source-to-dose conversion factors for all the specific radionuclides present. For example, Tables 5.6 through 5.8 in ORO-832 (reproduced here as Tables 3.12 to 3.14) give source-to-dose conversion factors for different radionuclides for each of the possible pathways of exposure (i.e. external radiation, inhalation, ingestion, etc.). It must be noted that these tables assume that the radioactive material is exposed to the surface of the ground in a layer 1.5 meters thick and the area in question is open to unrestricted use. The earth assumption assumes that a family could potentially build a home on the site, drink its water from wells on the site, and grow most of its food from the ground at the site. If other potential uses of the site are considered which restrict its usage, the appropriate source-to-dose factors can be selected and modified as necessary. For example, the equations 6-1 and 6-5 in ORO-832 (reproduced here in Table 3.15, along with a description of use) can be used to determine doses for contamination which is below the surface of the ground. Since the concentrations in the landfill are clearly in excess of unrestricted use guidelines, it could be assumed that the landfill would be used only for industrial purposes, being occupied by workers a maximum of 60 hours per week (or 36% of the time). In this case, dose pathways through food and water are eliminated and the only significant dose pathways are external radiation and inhalation of radon or dust particles containing radioactive material. If it is also assumed that a minimum of 0.5 meters of soil cover is provided over the waste material, typical doses would be as given in Table 3.16. (This type of methodology can also be used to calculate the doses for several remedial options to be considered in the next section.) From Table 3.16 estimated bone lung and whole body doses are 520, 290 and 150 rem/year, respectively. These levels would be acceptable in accordance with current guidelines for exposure to the general public (in this case, workers at the site).

An analysis of Table 3.16 indicates that the greatest doses are from thorium-230 and radium-226. The thorium-230 is a large contributor due to its high specific activity of approximately 9000 pCi/g in the soil. Radium-226 is also significant as is typical of radioactive waste sites of this type. The dose calculated in Table 3.16 can be confirmed by the RMC measurements cited earlier. Assuming an average radon concentration corresponding to 0.002 WL, an occupancy factor of 60 hours a week and a WL to dose conversion factor of 5 mrem/hr/WL the dose from radon is 32 mrem/yr. This is an order of magnitude larger than the value of 334 mrem/yr in Table 3.16 which indicates the probable conservatism present in the calculational model in ORO-832 (32). It should be noted that this value will increase with time, a factor considered in Section 4.

The dose estimates given above are for persons working on the site. The next consideration is for individuals off-site who may be exposed due to the transportation of radioactivity from the site. There are two primary modes of transport: gas or dust transport through the air and migration via groundwater. In the case of radon-222, flux levels at the site boundary can be estimated by using a standard Gaussian plume model to predict dispersion in the atmosphere. The general form of such a model is given by:

where = C = concentration in pCi/m^3

Q = surface emanation rate (pCi/m^2-sec)

= wind speed (m/sec)

y = cross wind distance (m)

z = vertical distance (m)

H = height of emission point (m)

= dispersion coefficients in the y and z directions

This model assures a continuous source so that dispersion in the "x" or downwind direction is neglected. Since the source is an area source, with a "y" dimension of approximately 300 m, an effective point source at some virtual distance "x" must be determined. Assuming a neutral (mean) air stability class, the virtual source is at a distance of x = 900 m. The most probable wind at the site is in a northerly direction (see Figure 3-1) at 4.5 m/sec during 10.8% of the time. The site boundary is approximately 500 m away from the highest radon flux source location in this wind direction, or 500 + 900 meters from the virtual source. The dispersion coefficient in the "z" direction at this distance (and assuming neutral air stability) is approximately 50 m, the disperse coefficient in the "y" direction is 120 m and the source is assumed to be 450 pCi/m^2/sec as measured by RMC for the current rate conditions. Assuming that the source and exposed individuals are at approximately the same height, the result is 3.7x 10^{-3} WL (when the wind is in this direction), or 3.7 x 10^{-4} WL when the fraction of time the wind blows in this direction is considered. (Assuming a worst case of 100% occupancy at the site boundary, this working level corresponds to a dose of 15 mrem/year). Even with the increase of a factor of 35 over the next 1000 years is considered, this level becomes 0.012 WL, a factor of two greater than the guideline of 0.5 pCi/l or 0.005 WL given in Table 3.11 (31) assuming no remedial action. Similarly, considering the closest boundary to the radioactive material in Area 2, the dispersion approximately 0.1 km west can be calculated. In this case, the wind speed is 4 m/sec and blows in this direction 3.9% of the time, the dispersion coefficient is 85 m in the "y" direction and 40 in the "z" direction, and the source and exposed individual are again assumed to be at the same height. (This last assumption is conservative in that the source is on a bluff approximately 10 m above the field below and dispersion down to that level is very small in this relatively short distance.) The result is 1.3 x 10^{-5} WL now, and 4.7 x 10^{-4} WL 1000 years from now.

From the analysis above, it can be seen that doses at the site boundary are at least an order of magnitude below that on the site directly above the waste area. Similar reductions for thorium-230 doses at the site boundary would also be applicable, again reducing the dose to negligible levels.

With respect to water contamination at the West Lake Landfill, some potential exists for contamination of both surface and subsurface waters by radionuclides leached from the landfill. Surface water may carry radioactive material in solution or suspension. Particles of soil in suspension (resulting from soil erosion) are generally not carried far, but instead are deposited near the landfill. Rapid erosion is now occurring along the berm on the northwest face of the landfill (B-B', Figure 3-2); and testing by ORAU (6) showed that significant amounts of radioactive material are being transported to the base of the berm (26). Surface water may also contain dissolved radionuclides. These dissolved materials have a somewhat greater potential for being transported some distance from the site. No direct routes appear to exist for the flow of contaminated surface waters to area streams. During periods of heavy local rain and high groundwater, water may be ponded over portions of the floodplain adjacent to the landfill. Surface runoff from the landfill will be rapidly diluted in this standing water, so that radiation levels present in runoff water will be rapidly reduced to below background. Considering the landfill topography, it is unlikely that radionuclides will be carried north into the slough along St. Charles Rock Road by surface paths. Analysis of water from the slough (6) showed no elevated levels of radiation (sample 63, Table 3.17). Therefore, the main mechanism for surface water transport of radioactive materials from the West Lake Landfill is erosion and carriage off-site of contaminated soil particles. This erosion is now occurring along the northwest berm, and will increase in the future as the gullies develop further.

Groundwater may become contaminated as a result of rainfall infiltrating the landfill and leaching radionuclides from the soil as it percolates downward. This could possibly occur since the surface is poorly drained and there is apparently no impervious liner beneath the northwest portion of the landfill. The soil profile (Figure 2-3) consists of about 10 m of landfill debris and cover soil lying directly on the original topsoil of the floodplain surface. Since no groundwater recharge source exists above the floodplain level, the wastes will remain in a dry or partially saturated condition. Heavy rainfall may produce localized lenses of saturated soil, but this is temporary situation. Therefore, leaching of waste will only result from rainfall infiltration.

Two mechanisms will tend to limit the migration of radionuclides through the groundwater system. First, infiltration water will only be contact with the wastes long enough to dissolve a small amount of the radionuclide-containing compounds. Organic material in the water will tend to slightly increase the solubility of the radionuclides and prevent re-precipitation. This effect (chelation) is most effective at pH values above neutrality (33). Second, sorption of radionuclides from solution onto surface active soil particles will tend to slow the advance of any plume of radioactive contamination which might develop (34).

Considering the fact that wells within 50 m of the radioactive soil show radiation levels very near background (i.e. 10 pCi/l), it is reasonable to assume that diffusion and sorption in the aquifer will further dilute contaminates entering the aquifer within 100 m down gradient of the site to background levels. This is likely because the leachate volume produced is small as compared to the flow of water through alluvium beneath the site. Non-radioactive materials will probably present the greatest risk to potential users of this contaminated groundwater; the presence of these primary pollutants may make the water unfit for consumption.

Adjacent to the Missouri River, the groundwater flow regime is complicated by frequent reversals in the direction of flow. Here, the direction and rate of groundwater flow are controlled entirely by the river level. The effect of these reversals in flow will be to further diffuse any plume of contamination which approaches the river. Before reaching the Missouri River, landfill leachate, traveling through the groundwater system will be diluted to a level at which contaminants will be undetectable.

3.4 Conclusions

Based upon several radiological surveys of the West Lake Landfill site, an estimate of the type and quantity of radioactive material present at the site is possible. Specifically, the material consists of natural radioactive materials from which the uranium and radium radionuclides have been depleted.

Based upon this characterization of the material present and using established guidelines, some type of remedial action is needed to protect the public from unrestricted use of the site. Although many radionuclides in the radioactive material are at or near threshold for remedial action, Th-230 and Ra-226 levels are greater than specified by these guidelines. This also creates the situation where the Ra-226 activity will increase with time, requiring action to preclude possible increased exposure in the future. Calculations do indicate, however, that simple remedial action at the site will result in negligible exposure to the general public and only moderate exposure of the worst exposed individual who would routinely work at the site. These remedial action options will be discussed in the Section 4.

4. ENVIRONMENTAL IMPACT OF REMEDIAL MEASURES

4.1 Exposure Pathways

Under the various remedial measures considered, a number of potential exposure routes must be evaluated. These are:

1) direct exposure to gamma-radiation.
2) inhalation of radon gas.
3) inhalation of radioactive soil particles suspended in the air.
4) ingestion of radionuclide-bearing water.
5) ingestion of plants, fish or game that have become contaminated by uptake of radionuclides.

The methods described in Section 3 can be used to estimate the dose to a Maximally Exposed Individual (MEI)(32,33). This hypothetical individual would spend 100% of his/her time directly on the site, in its present condition, living in a house with a basement extending into the radioactive soil. The MEI would also grow all food on-site and drink water from a well down-gradient from the buried radioactive waste: This situation is known as the Intruder-Agriculture (IA) Scenario. This scenario represents the maximum radiation exposure any individual could conceivably receive from the debris at the West Lake Landfill. At the present time the bone dose to the MEI on-site would be 26.7 rem/yr (Table 4-1). This dosage is a good deal higher than the 5 rem/yr dosage allowable to radiation workers. While dosages to the whole-body and other organs are somewhat lower, all are above limits considered acceptable for members of the general population. Dosages will increase rapidly with time as radium concentrations increase. In 200 years, the highest dosage would be to the bronchial-epithelium and would be 99.4 rem/yr. Such a dosage could likely result in adverse heatlh effects to some individuals. The dosages indicated in Table 4-1 assume no more fill added to the contaminated areas. Thus, although the wastes would pose a potential hazard to a hypothetical MEI person living on the site in its present condition, the levels of radiation present at the West Lake Landfill are not now so high as to pose a clear and imminent danger to area residents or to landfill workers. Since land-use restrictions will be required if the wastes are left in place, the MEI would have to be considered as an individual living at the landfill boundary rather than directly on the landfill. Since virtually all exposure routes become negligible off-site (with the exception of contaminated groundwater ingestion), exposures to individuals at the landfill boundary would probably be well below the 0.5 rem/year guideline for individual members of the population. This is only true if one assumes that no contaminated water is ingested. Although stabilization of the site could reduce the leaching rate of radionuclides, hydrogeologic conditions at West Lake are such that nothing short of total removal of the radioactive debris will preclude radionuclides from entering the alluvial aquifer. This is apparent if one considers the fact that 10 years after emplacement, some radionuclides have already become apparent in monitoring wells near both areas of contamination.

These exposures to the MEI could be greatly reduced simply by covering the wastes with a layer of clean compacted soil. Exposure reductions by 0.6 and 1.5 m of cover soil are given in Appendix D-2.

Emplacemnt of a 1.5 m soil cover over the radioactive debris would prevent harmful exposures to residents or workers on the undisturbed surface. However, if any construction activity were undertaken on the

Table 4-1 MEI Dosages for the West Lake Site Under Option A

	DOSE* (rem/yr)			
Organ	Present	100 yr	200 yr	1000 yr
Whole body	2.1	8.6	14.7	55.1
Bone	26.7	60.3	92.4	304
Liver	3.2	8.8	14.2	49.9
Kidney	8.7	40.8	71.5	274
Whole Lung	8.5	20.9	32.8	111
Bronchial Epithelium	10.8	56.0	99.4	385
Working level (WL)** (dimensionless)	0.14	0.75	1.32	5.13

* For methods used, see Appendix D.1.

**WL is calculated from the (WL/S) factor of 0.0016 WL per pCi/g of Ra-226 at the time in question.

site, it is likely that the soil cover would be disturbed. Restrictions on land use should minimize this possibility.

Inhalation of radon gas presents one of the greatest potentials for exposure to persons on-site. In addition to radon, daughter products which decay from radon gas in the atmosphere will remain in the air for some time. Since Rn-222 is the only radon radionuclide with a long enough life to emanate from the surface in substantial quantities, it is the Rn-222 daughters which will be present in the atmosphere. The immediate daughters of Rn-222 (Po-218, Pb-214, Bi-214, and Po-214) all decay rapidly, with half-lives ranging from 27 minutes to less than one microsecond. Po-214 decays to Pb-210, which has a half-life of 21 years. Thus, Rn-222 in the atmosphere will decay rapidly to Pb-210; therefore, Pb-210 will be the predominant radon daughter present in the atmosphere. Pb-210 decays by beta emission and is of far less danger than alpha emitters such as Ra-226, Rn-222, Po-218, and Po-214 with respect to inhalation and deposition in the lungs. Since the radon daughters are not gases but individual molecules of a solid radionuclide, they will eventually be removed from the atmosphere. Removal will be by coordination with water molecules in the atmosphere and agglomeration with dust particles in the air followed by precipitation and settling of dust particles.

Although wind currents will tend to dissipate radon gas over the landfill to negligible levels, the gas and its daughter products tend to accumulate in low spots in buildings-particularly in basements or tightly sealed buildings, as noted in Section 3.1.1. Even in the fairly well-ventilated Shuman Building, Rn-222 gas accumulated to an unacceptable level (0.03 WL) on one occasion(2). Radon gas emanations may be reduced by covering the contaminated soil with a layer of clean fill to delay release to the atmosphere. The longest-lived radon radionuclide (Rn-222) will decay to 10% of its original activity within 13 days. Radon gas is brought to the surface principally by molecular diffusion of the gas. If the radon is produced in a saturated or moist soil, the gas will tend to dissolve and stay in soil water (35). As the soil dries, water vapor rising to the ground surface may tend to increase the release rate of radon. Differing soil moisture conditions are the main cause of the observed variations in radon flux levels observed on different days during the

RMC survey. In addition to soil moisture conditions, the release rate is also controlled by properties of the cover soil. Well-consolidated clay would be most effective in retaining the radon gas by producing a long, tortuous flow path to the surface. Water held by this fine-grained soil would also tend to retain the radon gas as described above (36). The amount of Rn-222 produced is a function of the amount of Ra-226 present. Therefore, radon gas production will increase in the future as the concentration of Ra-226 increases, as indicated in Table 4.2.

For a house with a basement constructed on the West Lake Landfill site under its present condition, Rn-222 could conceivably accumulate to as much as 0.14 WL (Table 4-1). Two hundred years in the future, Rn-222 production will have increased to give maximum indoor levels of up to 1.32 WL (33). The generally accepted limit is 0.02 WL. For a layer of contaminated soil two meters thick containing 90 pCi/g of Ra-226, a layer of compacted soil 0.6 m thick will reduce the Rn-222 flux from the ground to 7.0 pCi/m^2s; this is based on an International Atomic Energy Agency (IAEA) model (Appendix D.6.1). A model provided by the DOE Table 4-2 Radionuclide Concentrations in Soil over the Next 2000 Years

Activity (pCi/g)

time (yr)	U-238	Th-230	Ra-226
0	180	9000	90
100	180	8992	467
200	180	8985	828
500	180	8962	1819
1000	180	8924	3205
2000	180	8849	5198

estimates a Rn-222 flux of 20 pCi/m^2s for the situation stated (Appendix D-6.2). A 1.5m cover results in the flux rates of 3.1 and 6.2 pCi/m^2s as calculated by IAEA and DOE procedures, respectively. 20 pCi/m^2s is suggested by IAEA as the maximum allowable flux of radon from the surface (33). The 0.6m cover is required by MDNR for closure of sanitary landfills (37). The 1.5 m cover is considered as Option B in Section 4.4 of this report. Even if a soil cover is emplaced, future excavation and construction on the site could result in structures capable of accumulating radon to an unacceptable level. The worst case would involve a basement constructed on-site. If the radioactive soil is kept at the West Lake site, it will be necessary to insure that structures are not built on-site. Since it is only directly above the contaminated soil that problems of radon gas accumulation may occur, simple land use restrictions for the site could prevent such construction.

Inhalation of contaminated soil particles is only likely to pose a health hazard if the radioactive material is excavated or is on the surface. Since the original barium sulfate residue was somewhat thick and pasty, the contaminated material may not produce much dust during excavation. However, if excavation of the radioactive materials is undertaken, the area should be sprayed with water on at least a daily basis, more often if dust problems become evident during excavation. Dusting of the contaminated soil will not occur if the material is simply covered with a soil layer. Dusting is not currently a problem at the West Lake Landfill since there is a soil and vegetative cover over most of the site. The problem of airborne radioactive particles is fairly minor, and will only be of importance if extensive disturbance of the soil is initiated.

Ingestion of radionuclide-containing water could occur if a private well were drilled into the Missouri River alluvium directly down - gradient from the West Lake site. Dispersion and sorption reactions by the soil will attenuate radionuclide contamination within 500 to 1000 m from the site. Wells drilled farther than this from the landfill will probably never produce water containing greater than 5 pCi/l of radium. Also, water contaminated by leachate from the West Lake site would contain other dissolved metals and organic substances. These other dissolved substances will likely pose the greatest health hazard due to a larger volume of this type leachate produced; significant levels of other contaminants may migrate farther than 1000 m from the landfill.

Public water supplies for this area are currently derived from the Missouri River and do not pose a potential pathway for radionuclide ingestion. Future residents of this area will be supplied by this public water system. No wells are currently in use that might become contaminated. Since future uses of groundwater here are difficult to predict, possible ingestion of contaminated groundwater must be considered. There is nothing to prevent an individual from drilling a private well down-gradient from the landfill. It is also possible that some industry requiring a large volume of water will site a factory nearby and drill wells to obtain this water. It should be remembered that this alluvium is capable of producing a large flow of sediment-free water; and this may someday present a very attractive water source.

Contamination of alluvial waters could be avoided by removing the source, by reducing leachate production, or by retaining the leachate. The leachate could be retained, and slowed in its movement off-site by construction of a slurry wall to cut off flow through shallow alluvium. Such a wall would lengthen the flow path of leachate migrating off-site, and serve to more rapidly dilute leachate. Alternately, the volume of leachate produced could be lowered by reducing rainfall infiltration to the landfill. Such infiltration can be reduced by increasing runoff, evaporation, or transpiration (by plants) or any combination of these factors. A cover of well-compressed soil would reduce infiltration. This cover should have a fairly low permeability, and a sufficient slope to channel runoff from the landfill. This less pervious soil would keep the water that does infiltrate near the surface for a longer period of time, thus allowing more water to be lost to the atmosphere through evaporation and transpiration. Use of an asphalt cover over the contaminated areas would virtually eliminate infiltration and radionuclide leaching. However, subsidence of the landfill surface would likely crack the asphalt cover.

Radioactive contamination of subsurface water is a potential long-term problem. This hazard may be eliminated by complete decontamination of the site, or the problem may be reduced by the remedial measures noted above. At the present time, it is not believed that any individuals are being exposed to elevated levels of radiation as a result of waterborne contamination from the West Lake Landfill. Fish will not be contaminated since they are not exposed to water containing a significant level of radionuclides.

Ingestion of radionuclides accumulated by organisms living on and around the landfill presents a pathway for exposure to the public. Under certain conditions (e.g., lack of water, type of plant, etc.), plants growing on the landfill surface tend to concentrate radionuclides within their tissues. Perennial plants will be most effective in concentrating radionuclides, simply because they have more time to accumulate the material. Analysis of weeds from the landfill surface showed no elevated radiation levels (2). Wildlife feeding on contaminated perennials may themselves accumulate radionuclides. However, such wildlife typically feed on annual plants, which are unlikely to accumulate radionuclides due to their short growing season.

If the landfill is left in its present condition, the possibility exists that at some time in the future a garden might be planted there. Ingestion of garden plants or their fruits will only pose a health hazard if the garden is placed directly on the landfill under current site conditions. This is quite likely to occur if residences are constructed on-site in the future. Ingestion of contaminated vegetables would pose additional risks to these residents. Placement of soil cover over the contaminated areas would limit radionuclide uptake by plants by putting contaminated soil below or at the lower reaches of the garden plants' root systems.

All the exposure routes described in this section, will be present indefinitely, and may be either eliminated or minimized. Only decontamination will completely eliminate the potential for exposure pathways. Emplacement of a soil cover would reduce the already negligible potential for exposure.

4.2 Remedial Options for Disposition of Radioactive Debris in the West Lake Landfill

4.2.1 Option A - No Remedial Action:

The site would be left in its present condition. No remedial work would be done to reduce the potential for future radiation exposure. It is assumed, for reasons outlined in Section 4.3 of this report, that no further work would be done for final closure.

4.2.2 Option B - Stabilization Nn-site with Land-use Restrictions:

Both areas of contaminated soil would be stabilized in-place by means of a soil cap. This cap would reduce on-site surface exposures as well as leaching of radionuclides to the groundwater. The berm along the northwest face of the landfill would also be stabilized by soil addition to halt erosion of contaminated soil. Land-use restrictions would be placed on the stabilized site; and it would ultimately be converted to a public park for example.

4.2.3 Option C - Removal and Relocation of the Material to an Authorized Disposal Site:

Contaminated soil would be excavated and placed in steel drums for relocation to the Chem-Nuclear facility in Barnwell, South Carolina, for terminal disposal.

4.2.4 Option D - Excavation and Permanent Storage On-site:

Contaminated soil would be excavated and placed in bulk form in a secure trench constructed on the West Lake Landfill for terminal disposal.

4.2.5 Option E - Extensive Stabilization with Land-use Restrictions:

Contaminated soil would be stabilized on-site as under Option B, with the addition of a slurry cut-off wall to further minimize groundwater contamination. Land-use would be restricted and the site eventually converted to a public park.

4.3 Option A: No Remedial Action

"No remedial action" refers specifically to the case of the contaminated areas being left in their present condition after cessation of landfill and quarry operations abandonment of the site. It is assumed that no additional fill would be placed over the debris.

Since landfilling operations in the contaminated areas were completed prior to state regulation, no permits were granted for these portions of the site. Therefore, normal MDNR closure procedures do not apply to these portions of the landfill.

4.3.1 Work Required:

Under this option, no remedial work would be done on the West Lake site. The landfill and the radioactive soil would be left in its present condition. With the question of radioactive contamination having been resolved, the contaminated areas would be available for demolitian fill emplacement and final closure. It is not certain how much additional fill would be emplaced. For this reason, two cases for the future radiation environment are considered. The first case consists of no additional fill or closure work. The second case consists of 3 m of demolition fill being placed directly on the landfill surface; filling would be followed immediately by normal landfill closure operations. MDNR procedures and requirements for landfill closure are given in Appendix E.

Normal closure procedures consist of applying at least 0.61 m of compacted final cover. A 3 m layer of topsoil would be placed over the cover and upgraded to support vegetation. Establishment of a vegetative cover would require seeding, liming, and fertilization. Surface seeps of leachate would be eliminated. Maintenance of the monitoring wells would be required to allow continued sampling by MDNR, should MDNR require such action. The public must be discouraged from entering the site. After closure, a detailed description of the site would be filed with the county recorder of deeds. This description would include: a legel description of the site, types and location of wastes present, depth of fill, and description of any environmental control on monitoring systems requiring future maintenance (37). MDNR regulations also specifically prohibit excavation or disruption of the closed landfill without written approval of MDNR; no time frame is stated with this regulation (38).

For the case of additional fill followed by closure, a good deal of activity associated with normal landfilling work will go on in the northern area of contamination (Area 2) 3 m or more of demolition fill to be added before closure. Prior to filling, a permit for the work would be obtained from MDNR. A final closure plan must be approved by MDNR before this permit could be issued. To allow placement of this additional fill, the Shuman Building would have to be either demolished or moved.

4.3.2 Benefits Derived

For the case of no additional fill, no benefits derived.

For the case of additional fill and closure, exposures would be reduced, however, the problem of radioactive contamination would not be specifically addressed. Reductions in leaching and groundwater contamination would be significant but not as great as that achieved under any of the other options considered. The northwestern berm would probably not be stabilized, allowing continued erosion of contaminated soil.

4.3.3 Adverse Effects:

The possibility of radiation exposure to landfill workers and to area residents will not be addressed. Due to the nature of the radioactive debris, the amount of Ra-226 existing in the landfill will, over the next 200 years, increase to nine times the amount currently present; and over the next 1000 years, Ra-226 will increase to nearly 60 times the present concentration (Table 4-2). By leaving the site open to all uses - including the residential development for which it is currently zoned - the possibility will remain for construction on the contaminated site. Any building placed over the radium-bearing soil is likely to accumulate radon gas, and result in an unacceptable exposure to individuals in the buildings. Factories, as well as private residences, would experience this problem. Radon accumulation would be most acute in buildings with a basement excavated into the radioactive soil. Individuals who consumed food grown in a garden over this site would also risk ingesting radionuclides accumulated by the vegetables. Under the present conditions, future activity on the landfill may lead to unacceptable radiation exposures to residents, workers, or other individuals who spend significant amounts of time directly over the contaminated soil.

The current adverse effects on the West Lake environment would continue under Option A. These effects include a negligible reduction in air quality around the landfill as a result of radon release. However, as noted in Section 3.3, radon concentrations in air at the edge of the landfill are within limits; and dispersion of radon into the atmosphere will result in still lower exposures further off-site. Groundwater contamination will continue to some degree. Presently, only two monitoring wells around the perimeter of the site have shown radiation levels above those recommended for drinking water. The criteria exceeded was 15 pCi/l of alpha activity in well numbers 60 and 68 (Figure 4-1) showing 20.5 +/- 6.2 and 18.2 +/- 3.0 pCi/l, respectively. Thus, groundwater contamination by radionuclides does not appear to be an extensive problem at this time. Some contamination of the subsurface waters is now occurring, and will increase in the future as contaminants spread through the alluvium. This could pose a health hazard in the future if wells are drilled and the contaminated water is ingested.

The market value of the West Lake site itself is greatly reduced by the presence of the radioactive contamination since, without land use restrictions, radiation levels at the site would result in doses to hypothetical Maximally Exposed Individuals in excess of current EPA guidelines. The value of adjacent land to the West Lake site may also be reduced due to the proximity of the landfill and its contents.

4.3.4 Cost of Remedial Actions:

There would be no further costs under this option since no remedial actions would be taken.

4.3.5 Assessment of Option:

There exists the possibility that future activity on the site would result in a MEI receiving radiation exposures above recommended limits. Also, Option A does nothing to minimize future erosion of the contaminated berm and groundwater contamination, and leaves open those routes for potential exposure to individuals not living or working directly on the site.

With no remedial action (barring any commercial or residential development), the annual plant special that dominate the area would probably change over an extended period of time. Ecological succession would favor perennial plants, although annuals and ephemeral species associated with the most recently disturbed soils and subsequent landfill activities would continue to be present. Woody plants, eastern cottonwoods, and willows would continue to develop in the moist soils associated with the lower slopes of the berm and permanent ponds present on the surface of the landfill. The animals referred to in Section 2.10 would continue to utilize these habitats.

Radionuclides will accumulate in perennial plants; and it is conceivable that their presence on the surface of the landfill will increase. This could contribute to radionuclide accumulation in the eastern cottontail rabbits, which can live up to five years and dominate the large mammal community associated with the West Lake Landfill site. A negative impact, such as an increased chance of cancer occurrence, on the rabbits could result. In addition, if the observation of spent shotgun shells is indicative of human hunting pressure, it is further conceivable that radionuclides present in older rabbits could be ingested by successful trespassing hunters. This contribution of radiation dose to a member of the general population is minor when compared to most other pathways (e.g., inhalation).

4.4 Option B: Stabilization On-site with Land-use Restriction

Under this option, radioactive debris in the West Lake Landfill would be covered with a layer of soil of specific type at least 1.5 m thick; the berm along the northwest side of the landfill would be stabilized, and future land use would be restricted. After the contaminated areas have been stabilized, they would be available for the emplacement of an additional layer of demolition fill. The soil cover would reduce exposure rates at the ground surface, reduce emanations of radon gas, and reduce the leaching rate of wastes in those portions of the fill where the cover is emplaced. Stabilization of the berm would prevent erosion of the radioactive soil. Land-use restrictions would discourage future activities on the site that might lead to exposures to future residents or workers on-site. The work required under this option is described separately for the northern and southern areas of contamination (Areas 2 and 1, respectively).

4.4.1 Work Required:

Norther area (Area 2)

Since the Shuman building is located directly over shallow deposits of radioactive soil, radon gas accumulates in the building. Therefore, the building will be removed from the northern area of contamination since the cover layer (described above) cannot be emplaced unless the building is removed. The building may either be moved from the contaminated area or demolished - whichever choice is decided by the landfills operators. Subsurface portions of the building, such as the foundation, should be left in place since they may be contaminated.

The strip of land bordering the northwestern portion of the West Lake Landfill (Fig. 4-2) will be purchased to allow enough land space for stabilization of the slope of the berm (Fig. 4-3). The strip of land should extend at least 20 m outward into the field from the base of the berm. The power line which runs along the base of the berm will have to be relocated to allow for emplacement of the fill. Three poles will have to be moved. They may be either simply moved outward into the field or rerouted more directly across the field. The slope of the berm and the surface of Area 2 will be stripped of vegetation before the new fill is emplaced. The resulting brush may be placed in the demolition fill at the landfill itself or disposed of as is convenient. (Brush should not be left in place and covered since this may reduce the integrity of the soil cap.) Grass should be mowed, and may be left in place. All equipment and materials now stored over area 2 will be removed to other portions of the site or disposed of as is convenient to the owners. Gravel piles now found on Area 2 should be removed to other portions of the site after having been surveyed to ensure that contaminants have not been mixed with the gravel. However, at least 10 to 15 cm from the bottom of each gravel pile should be left in place and covered with the soil cap since this gravel may have become mixed with contaminated soil.

Such stabilization will place the contaminated soil well below the surface and prevent the erosion of radioactive materials which is now occuring along sections of the berm (6). Stabilization will require emplacement of a soil volume of approximately 20200 m^3, to give a final slope of 3:1 with 1.5 m of soil at the top of the berm. At least 1.5 m of soil cover will be used since calculations in Appendix D.6 show that this much soil will be required to reduce radon gas exhalation. The final slope of 3:1 on the berm will be shallow enough to prevent failure and, if properly vegetated, will resist erosion. This extension will extend 13 to 16 m outward into the field. After this cover is emplaced, it should be covered with at least 0.3 m of topsoil and seeded with native grasses to prevent erosion. The cover soil presently used in the landfilling operations may be used to stabilize the berm. This soil is a clay silt (loess) excavated from near the West Lake Landfill site.

The portion of Area 2 to be covered by the soil cap (Fig. 4-4) includes that portion of the landfill identified in the RMC survey as having surface exposure rates greater than 20 R/hr at one meter above ground level, along with those areas in which auger holes revealed radium-bearing soil within one meter of the surface. The shallow contaminants may be sufficiently shielded to produce low surface exposure rates; however, these shallow deposits will still produce radon emanations greater than the desired level of 20 pCi/m^2s. Therefore, the soil cover must be extended over these areas of shallow contamination. The cover soil used should be capable of compaction to a permeability of less than 10^{-7}cm/s in order to keep radon release soil leaching as low as possible. This value is based on common practices used for sealing of hazardous waste landfills. Due to problems of accurately measuring permeability of this magnitude, the value of 10^{-7}cm/s should be used only as a target criteria which should, if possible, be exceeded. If laboratory testing of the cover soil presently used at the West Lake Landfill indicates that this permeability can be achieved, this soil would be acceptable for use as the soil cap. Otherwise, clay soil will have to be imported from off-site to be used in construction of the soil cap. Use of a thicker, more permeabile layer of soil would be effective in reducing radon evaporations but not in the prevention of leaching. Since the volume of leachate is determined by the downward velocity of infiltrating groundwater, and since velocity is directly proportional to permeability, a higher permeability layer will allow more infiltration regardless of its thickness. The soil cap will have a minimum thickness of 1.5 m and a surface slope of from 2 to 42 to facilitate runoff. The slope will be directed radially outward from the center of the cap. An interceptor ditch will be provided around the cap to channel runoff and prevent gullies from being cut into the stabilized cover.

If the landfill operators do not choose to place additional demolition fill over the stabilized areas, a 0.3 m layer of topsoil will be placed over the cap and seeded with native grasses and mulched to prevent erosion. If additional fill is to be emplaced, the topsoil will not be necessary. Rather a 0.5 m layer of "rip rap" will prevent a buildup of infiltration water in new fill above the low permeability cap. The new fill will require final closure as specified by MDNR.

Zoning of the site is presently for residential, single family dwellings. Zoning must be changed to discourage future development of the site. Future zoning of the site should be for restricted use. The city of Bridgeton, MO, is responsible for the zoning of the West Lake Landfill site. Uses for which the stabilized site would be suitable are difficult to formulate. Merely fencing the area will do little to discourage use of the site several hundred years from now. For this time frame, little can be predicted with certainty about area land use. If the recent population shift from metropolitan St. Louis to suburban areas continues, the West Lake site may ultimately be in the center of a heavily populated area. The site's proximity to the cities of St. Louis and St. Charles and to Lambert Field Airport seem to make intense residential or industrial development of the West Lake area only a matter of time. Conversion of the site to a community park appears to be the best alternative for future land use. Regardless of the degree of development, a publicly-owned park is unlikely to be developed unless the area were abandoned for some time and then repopulated. Under this scenario, the park might be abandoned and the site put to residential or industrial use at some time far in the future.

The land title for the contaminated areas will be made to include a statement indicating the presence of radioactive contaminants. A restriction shall be placed in the deed to prevent placement of residences or factories on the site. Since excavation into the contaminated soil must be avoided, a specific statement barring excavation in this area will also be included in the land deed.

4.4.1.b Southern Area (Area 1)

Additional cover soil has been added Area 1 (Fig. 4.5) on two occasions since the 1981 land survey by RMC. This cover has altered the radiation environment of the site. It is believed that a total of 2 to 3 m of soil has been added to most of Area 1. Measurements by ORAU personnel in March 1984 (6) showed only a very small area which exeeded the exposure rate of 20 R/hr at one meter. A brief survey of th area with a hand-held G-M detector can be used to outline the exact area requiring additional cover. By extending the cover 20 m outward in all directions from the area showing an unacceptable surface exposure rate, the shallow wastes likely to give high rates of radon emanation will also be covered. The amount of radioactive debris in the southern area is relatively minor compared to that present in the northern area. Fill which has been added since 1981 has already shielded the radioactive material to a large degree. Therefore, the southern area does not pose quite as great a potential hazard as the northern area.

The radiation environment of the southern area of contamination is not as well-defined as that of the northern area due to work in the southern area after the RMC survey. Considering the ORAU measurements and the depth of fill already added to this area, a soil cover of 1.5 m thickness as described for the northern area will be used. This cover will be more than adequate to reduce surface exposure rates and radon emanation. This can be stated since wastes in the south are similar, if not identical in activity to those in the north and are already shielded to a large degree by fill. After the soil cover is emplaced a layer of topsoil 0.3 m thick will be emplaced and seeded and mulched. It is not believed that the operators have plans to place additional fill in this area in the future. However, if additional fill is to be emplaced, 0.5 m of rip rap will be used instead of the topsoil as outlined for the northern area.

Land use restrictions as described above should be placed on the contaminated area. Zoning here is for light manufacturing, and should be changed to restricted use.

4.4.2 Benefits Derived:

Surface exposure rates will be reduced to levels generally below 20 R/hr. This is inferred from surface exposure rates measured by RMC over areas where boreholes showed contaminated soil covered by one to two meters of relatively clean soil. These data suggest that surface exposure rates at one meter above the stabilized site will be reduced to around 10 R/hr when subsurface contamination is up to 500 pCi/g of Ra-226. Radon emanations will be reduced to below 20 pCi/m^2s for Ra-226 concentrations up to 500 pCi/g (Appendix D-6). These levels are within NRC guidelines for unrestricted sites. Any structure inadvertently placed on-site at some time in the future would probably not be capable of accumulating radon gas to a level greater than 0.02 WL, provided the structure was placed completely above ground with no basement.

The surface and berm stabilization will halt the off-site spread of contaminants by erosion. The increased surface slope and somewhat impervious cover should reduce the rate of groundwater contamination. Since the amount of rainfall infiltration determines leachate production, improved drainage and a relatively impermeable cover will

Table 4-3 MEI Dosages Under Option B

Dosage (rem/yr)*

Time(yr)	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium
0	0.006	0.101	0.004	0.025	0.001	0.007
100	0.018	0.224	0.019	0.079	0.008	0.036
200	0.028	0.341	0.033	0.130	0.018	0.092
1000	0.100	1.114	0.128	0.468	0.032	0.140

* for methods used, see Appendix D-2.

Table 4-4 Dose to a Single Worker for Implementation of Option B

Type Dose	Dose (rem)*
Whole Body	0.038
Bone	0.049
Liver	0.042
Kidney	0.073
Whole Lung	0.081
Bronchial Epithelium	0.008

* dose based on 320 man-hours, see Appendix D-2.

reduce infiltration and leachate production. MEI dosages under this Option B are given in Table 4-3.

4.4.3 Adverse effects:

Workers involved in clearing the site and emplacing the soil cover will be subject to some short-term, low-level radiation exposures. These exposures will be mainly inhalation of dust produced by work on the site. Due to the short time period required to implement this option, exposures will be very low (Table 4-4).

The Shuman Building will no longer be available for use by the West Lake Company. Restrictions on use of the area will likely to cause some inconvenience to the landfill owners and operators after closure.

The biological community which has developed over the northern area during the past 10 years will be destroyed. Due to continued activity in the southern area, very little vegetation is present there. Disruption of the biological community in Ares 1 and 2 will be a fairly minor short-term impact, since the vegetative cover will be reestablished within one to two years. The West Lake site is not a particularly unique or valuable habitat for wildlife.

4.4.4 Estimated Costs:

The overall cost of work required under Option B would be approximately $460,200 (Table 4-5). This work would require about 60 days to complete. Costs should not vary too greatly from those estimated here, since the extent of work required under this option is well-defined.

4.4.5 Discussion:

Remedial action taken under Option B will provide an acceptable reduction in the potential for exposures to area workers and residents. Barring violation of the land-use restrictions, there should exist little possibility of unacceptable radiation exposures to any individuals within the forseeable future.

Direct radiation levels on-site should be reduced to levels generally below 20 R/hr at one meter. Radon flux rates will be reduced to a level below 20 pCi/m^{2}s. The problem of groundwater contamination as a result of leaching of the radioactive soil (as well as other hazardous, non-radioactive debris) will be reduced to a large degree.

Costs of Option B are substantially lower than those incurred under any of the other options providing an acceptable reduction of exposure rate for the intended users of the site acceptable. Considering the costs, magnitude of contamination, and results of this work, Option B appears appropriate and is recommended for application to the West Lake Landfill site.

Table 4-5 Itemized Costs of Remedial Action, Option B

Item	Quantity	Unit price	Cost
Clearing and grubbing	2.9 ha	$1800/ha	$5,200
Remove Shuman Building	---	---	6,000
Relocate 3 power transmission poles	3	$2000 ea.	6,000
Stabilize berm (fill)	20200m^3	$6.50/m^3	131,300
Emplace soil cover	48000m^3	$4.50/m^3	216,000
Bury clean rubble	225m^3	$12/m^3	2,700
Seed and mulch cover	3.3 ha	$2100/ha	6,900

Subtotal	$ 374,100
Contingency @ 10%	37,400
Engineering and legal fees @ 5%	18,700
Land acquisition, 2 ha @ $15,000/ha	30,000
Estimated Total Cost	$ 460,200

Section 6
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Appendix A: Statement of Work for This Study

Appendix B: RMC Radionuclide Analyses of Water Samples from the West Lake Site

Sample #	Type of Sample*	Gross-Alpha (pCi/l)	Gross-beta (pCi/l)
7001	S	3.11 +/- 0.27	22.5 +/- 0.7
7002	S	8.00 +/- 0.79	23.4 +/- 1.0
7003	S	1.56 +/- 0.34	9.88 +/- 0.67
7019	S	1.91 +/- 1.15	30.0 +/- 3.6
7025	S	1.56 +/- 1.05	36.5 +/- 4.0
7028	S	45.2 +/- 2.8	87.8 +/- 6.1
7029	S	0.64	1.34
7030	S	0.52 +/- 0.60	35.1 +/- 3.9
7031	S	1.43	26.3 +/- 3.4
AVE	S	=8.84 , = 15.02	= 33.94, = 21.80
7004	B	1.04 +/- 0.15	19.7 +/- 1.0
7021	B	1.56 +/- 1.05	29.1 +/- 3.5
7027	B	1.04 +/- 0.85	32.5 +/- 3.6
7032	B	0.05	26.3 +/- 3.4
7033	B	1.04 +/- 0.92	29.0 +/- 3.5
AVE	B	= 1.17, = 0.23	= 27.32, = 4.29
7009	G	4.50 +/- 1.76	22.3 +/- 3.1
7010	G	2.60 +/- 1.35	15.2 +/- 2.6
7011	G	3.12 +/- 1.47	10.6 +/- 2.1
7012	G	7.10 +/- 2.20	16.6 +/- 2.7
7017	G	0.52 +/- 0.60	33.6 +/- 3.7
7018	G	6.76 +/- 2.16	36.1 +/- 4.0
7020	G	8.84 +/- 2.48	30.1 +/- 3.6
7026	G	2.0	38.9 +/- 3.9
2	G	15.0 +/- 2.6	41.0 +/- 4.1
3	G	2.9 +/- 0.8	7.6 +/- 2.0
AVE	G	= 5.70, = 4.11	= 25.20, = 11.64

Sample #	Type of Sample*	Gross-Alpha (pCi/l)			Gross-beta (pCi/l)		
7013	L	1.82			1.30	+/-	7
7014	L	1.35	+/-	0.74	130	+/-	7
7015	L	2.43	+/-	1.37	103	+/-	7
7016	L	1.62			98.9	+/-	6.4
7022	L	3.45	+/-	4.86	107	+/-	7
7023	L	2.63			122	+/-	7
7024	L	1.23			86.7	+/-	6.0
7034	L	1.43			10.3	+/-	6
7035	L	1.04	+/-	0.85	84.5	+/-	5.9
7036	L	2.63			69.6	+/-	5.4
1	L	7.3	+/-	8.8	80	+/-	20
4	L	2.9	+/-	4.35	26	+/-	29
(AVE)	L	= 3.08		= 2.06	= 95.6		= 28.5

Sample #	Type of Sample*	Radium-226(pCi/l)			Potassium-40(pCi/l)		
7014	L	1.2	+/-	0.3	138	+/-	21
7015	L	3.92	+/-	9.13	136	+/-	22
7016	L	1.62			98.9	+/-	6.4
7022	L	2.40	+/-	6.96	104	+/-	19
7028	S	1.15	+/-	2.24	124	+/-	35
AVE	4L + 1S	=2.21,		=1.01	=120.8,		= 15.3

*

S = Surface sample
B = off-site, background
G = groundwater from boreholes
L = Leachate

Appendix C: Characterization of Residues in the West Lake Landfill

Appendix C.1 - Estimation of Activity Ratios

Due to processing, both uranium and radium have been depleted from wastes in the West Lake Landfill. The result of these uranium and radium extractions has been the apparent enrichment of thorium. A number of data sets are available from which to estimate the ratios of depletion. These sources are:

1) RMC survey 1980 (2)
2) ORAU survey March 1984 (6)
3) ORAU survey (Latty Avenue), September 1981 (28)

The ratios of concern are defined as:

R_1 = Th-230; U-238

R_2 = Th-230; Ra-226

R_2' = Th-230; Bi-214

R_2' should closely approximate R_2 since Bi-214 in a daughter of Ra-226. The difference between these ratios (R_2 and R_2') is theoretically the amount of Rn-222 gas which has escaped the soil.

Evaluation of Data:

1) RMC Survey:

From Table 4 of the RMC survey (Soil Radiochemical Analysis)

Table C.1.1: Soil Radiochemical Analyses From RMC Survey (2)

Activities +/- 25% in (pCi/g)

Sample	Type	U-238	Th-230	Bi-214	R_1=	R_2' =
1	S	3.8	82	2.1	21.6	39.0
2	S	12	597	25	49.8	23.9
3	B	21	188	44	9.0	4.3
4	S	175	6095	1488	34.8	4.1
5	S	18	338	9.4	18.8	36.0
6	S	101	178,000	19,000	1762.4	9.4
7	S	54	46,100	2,600	853.7	17.7
8	B	82	29,200	1,800	356.1	16.2
9	S	127	27,200	2,000	214.2	13.6
10	S	1.0	52,000	3,900	52,000	13.3
Average		59.5	33,980	3,090	5,530**	17.8**

* S means surface sample
B means subsurface (borehole) sample
**Average R = the arithmetic average of individual R values

The high variability of R_1 (over nearly 4 orders of magnitude) indicates either a large variation in composition of the debris at the time of emplacement, or leaching of U-238, and Th-230, or both after emplacement. Leaching of U-238 from the soil seems to best explain the variations observed. Values for R_2' are much more consistent. Statistical analysis of R_2' by a "t" test for 90% confidence of R_2' yields a Th-230: Bi-214 ratio of 17.8 +/- 7.0.

2) ORAU survey

The following data was obtained from samples taken in March, 1984 by ORAU personnel from the berm along the northern edge of the West Lake Landfill.

Table C.1.2 Soil Radiochemical Analyses from ORAU survey (6)

	Activity (pCi/g)		
Sample	Ra-226	Th-230	Ra-226
B5	11.3	404	35.8
C5	6.8	241	35.4
D5	23.2	1,006	43.4
E5	1.4	13.0	9.3
F5	1.3	8.5	6.5
A6	2.4	99.3	41.4
B6	4.0	132	33.0
C6	3.9	142	36.4
D6	2.8	109	38.9
E6	5.2	181	34.8
F6	1.0	11.1	11.1
* S1	4.3	132	30.7
* S2	4.5	178	39.6
* S3	38.3	1,601	41.8
* S4	662	16,170	24.4
* S5	699	19,130	27.4
* S6	72.3	3,280	45.4
* S7	185	6,720	36.3
* S8	5.2	344	66.2

* surface sample

average R_2 = 33.56 using "t" test for 90% confidence of R_2 gives,

$$R_2 = 33.6 \pm 5.5$$

3) ORAU survey of Latty Avenue site, September 1981 (28)

The debris at Latty Avenue is similar in composition to that present in the West Lake Landfill. Two composite samples were taken from the Latty Avenue site and radionuclide concentrations were determined.

Table C.1.3 Soil Radiochemical from ORAU survey of Latty Avenue site (28)

Sample	U-238*	Th-230	Ra-226**		
Composite #1	82	8770	64	107	137
Composite #2	62	8950	50	144	179

* inferred from Pa-234m

** inferred from Bi-214

Average ratios are:

R_1 = 126 (pCi Th-230 per pCi U-238)

R_2 = 158 (pCi Th-230 per pCi Ra-226)

Appendix C-2 Method and Results of Leaching Tests Performed on Latty Avenue Debris by ORAU, September 1981 (29).

Two composite samples were taken from a pile of debris on the Latty Avenue site. These samples were analyzed by gamma-ray spectroscopy to give the radionuclide concentrations shown in Table C-2.1.

Leaching tests of soil composite samples were performed under varying conditions of pH (pH= 5 to 9) and time (30, 120, and 240 min.). conditions. 500 gram samples of the composite were well mixed with the leaching solutions and allowed to stand undisturbed for the indicated time period. Supernate was removed through a 0.45 micron membrane filter. The leached soil was then re-counted to determine the fraction removed (Tab D-2-2). Radionuclides counted were: U-235, Th-228, (inferred from Tl-208), and Ra-226 (inferred from Bi-214). U-235 and Th-228 concentrations were very low (5 pCi/g) and resulted in leaching fractions near the resolution limit of the equipment.

Results of this testing indicates that leaching rates of the wastes are fairly low and that uranium is probably the most mobile element. The insoluble nature of this debris would be expected since the waste has already been subjected to leaching processes specifically intended to remove radium and uranium. Thorium, which was not extracted, forms an insoluble hydroxide percipitate.

Table C-2.2 Results of the Leaching Tests on Latty Avenue Samples (28)

Length of Test(min)	Type of Results	Fraction Removed (%)		
		Uranium	Thorium	Radium
30	Range	0.25 - 0.75	1.4	0.035 - 0.18
	Average	0.47	1.4	0.076
120	Range	0.25 - 0.75	1.4 - 1.9	0.035 - 0.10
	Average	0.43	1.5	0.063
240	Range	0.25 - 1.3	1.4 - 1.4	0.035 - 0.12
	Average	0.68	1.1	0.080

Appendix D: Dose Estimation Procedures

As noted in Section 4-1, a scenario has been described under which an individual - the MEI - would incur the highest conceivable dosage from a typical site containing a low level of naturally occuring radionuclides. Generic dose estimates for a MEI living on such a hypothetical site have been developed by the U.S. Department of Energy (DOE) for use in its Formerly Utilized Sites Remedial Action Program (FUSRAP) (33). Results of the DOE analysis relates known radionuclide concentrations in soil to MEI dosages for that site. To develop these generic does estimates it was necessary to make assumptions about the characteristics of a typical FUSRAP site. Comparison of West Lake to this typical site shows that the dose estimates should have some validity (Table D-1).

The major difference between West Lake and typical sites for which the dose estimates were developed is a greater enrichment of thorium with respect to radium at West Lake. This difference is taken into account in the estimation procedures for the specific site.

The approach used for dose estimation is relatively simple. It consists of multiplying a dose to source ratio (D/S) by the soil concentration of the applicable radionuclide. Radionuclides originating from decay chains other than U-238 are taken as negligible. To account for variations from secular equilibrium within the U-238 series, separate D/S factors are used to give the dosage resulting from three segments of the decay series (Table D-2). The summation of the dosages from these three segments of the decay chain represents the total dosage to a MEI living on a typical site. Dosages to the MEI will increase in the future as Ra-226 concentrations increase. Future dosages to the MEI on the site left in its present condition are shown in Table D-3.

Relation of doses to specific health effects is difficult at best. In addition tothe uncertainties present in the dose estimate, further approximations are required to extrapolate the health effects of low dosages from data existing for the effects of high radiation doses. It has been suggested on the basis of three independent studies that a continuous exposure of 0.5 rem/yr to one million people will result in from 30 to 90 additional fatal cancers. This is the basis for the figure of one cancer mortality resulting from 10^4 person.rem/yr exposure.

Table D-1 Comparison of West Lake to a typical FUSRAP site (33)

Parameter of Interest	Typical FUSRAP site	West Lake Site
Predominant source of waste	uranium ore processing & handling	uranium ore processing & handling
U-238 concentration in soil	20-1400 pCi/g	180 pCi/g
Th-230 concentration in soil	50-500 pCi/g	9000 pCi/g
Ra-226 concentration in soil	10-500 pCi/g	90 pCi/g
Th-230: Ra-226 ratio	5:1	100:1
Th-230: U-238 ratio	2.5:1 to 0.4:1	50:1
Volume of contaminated debris	440,000 m^3	62,500 m^3
Area of site	2 ha	6.5 ha
Thickness of contaminated layer	1.5 m	0.6 to 2.5 m
Depth of wastes from surface	at or very near surface	surface to 4 m

Table D-2 Projected future soil concentrations of radionuclides at West Lake Landfill (in pCi/g)

Time (yr)	Ra-226	Th-230	U-238
0	90	9000	180
100	467	8992	180
200	828	8985	180
500	1819	8962	180
1000	3205	8924	180
2000	5198	8849	180
5000	7749	8626	180

Appendix D.1 Dosage Estimates Pertaining to Option A

West Lake is very similar to the typical FUSRAP site considered in ORO-831 and ORO-832 (33)(32). Wastes at West Lake are exposed in some areas, so the MEI would have to be considered as an individual living over this uncovered debris. For this reason, D/S factor S taken directly from ORO-832 are used (Table D-1-1). From these D/S factors, the dosages in Table D.1-2 are calculated.

Since MDNR requirements for closure (Appendix E) will require a minimum of 0.6 m cover, MEI dosages over the closed site probably represent more realistic values for the dosages. D/S factors for the closed site are given in Table D.1-3 and MEI dosages are given in Table D.1-4.

Table D.1-1 Generic Dose to Source (D/S) factors for the U-238 series radionuclides at a typical FUSRAP site (27)

Factor	Radionuclides Accounted for	Source	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epitheliu
(D/S1)	U-238, U-234	U-238	0.4	4	0.06	1.0	0.5	---
(D/S2)	Th-230	Th-230	0.06	2	0.2	0.1	0.6	---
(D/S3)	Ra-226 to Pb-210	Ra-226	17	89	15	85	33	120

For example:

the current radionuclide concentrations (S) in the West Lake landfill have been estimated as:

U-238, 180 pCi/g (S1 = 180)

Th-230, 9000 pCi/g (S2 = 9000)

Ra-226, 90 pCi/g (S3 = 90)

$$\text{Total bone dose} = S1\,(D/S1)_B + S2(D/S2)_B + S3(D/S3)_B$$

$$= 180(4) + 9000(2) + 90(89) = 26730$$

$$= 26.7 \text{ rem/yr}$$

other doses are calculated in an identical fashion to give the MEI dosages in Table D.1-3.

Table D.1-2 MEI dosages for the West Lake site in its present condition

				Dose (rem/yr)					
	Source Conc. (pCi/g)			Whole				Whole	Bronch
&1									
Time(yr)	U-238	Th-230	Ra-226	Body	Bone	Liver	Kidney	Lung	Epithe
&um									
&									
0	180	9000	90	2.1	26.7	3.2	8.7	8.5	10.8
100	180	8992	467	8.6	60.3	8.8	40.8	20.9	56.0
200	180	8985	828	14.7	92.4	14.2	71.5	32.8	99.4
500	180	8962	1819	31.5	180.5	29.1	155.7	65.5	218.3
1000	180	8924	3205	55.1	303.8	49.9	273.5	111.2	384.6
2000	180	8849	5198	89.0	481.0	79.8	442.9	176.9	623.8
5000	180	8626	7749	132.3	707.6	118.0	659.7	261.0	929.9

Table D.1-3 D/S factors for site after normal closure work

Ratio	Source (S) Radionuclide	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium

(D/S1)	U-238	0.12	1.91	0	0.43	0	0
(D/S2)	Th-230	0.016	0.67	0.035	0.16	0	0
(D/S3)	Ra-226	3.77	32.69	1.93	6.00	8.84	45.95

* alternation factors (A) are as shown in Table D-2.1

Table D.1-4 MEI dosages over closed landfill, Option A

Dose* (rem/yr)

Time	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium
0	0.51	9.3	0.49	2.1	0.080	4.1
100	1.9	22	1.2	4.3	0.41	21
200	3.3	33	1.9	6.5	0.73	38
500	7.0	66	3.8	12	1.6	84
1000	12	110	6.5	21	2.8	150
2000	20	180	10	33	4.6	240

* calculated for "source" concentrations, Table D-1.2.

Appendix D.2 Dose Estimates Pertaining to Option B

Due to land-use restrictions, the occupancy factor (Foc) is assumed to be 20% for all pathways except water ingestion, which uses Foc=1. Also, the ingestion pathways of "plant", "meat", and "milk" are assumed to be eliminated. Exposure by water consumption is reduced by a factor of 0.9 as a result of the estimated 90% reduction in the leach rate. Attenuation of radiation by the soil cover is calculated from F'=exp(-A*1.5), for a 1.5m soil cover. Thus, the total reduction factor (F) is given by:

$$F = F'Foc$$

and, $F = 0.2 \exp(-A*1.5)$

Values of the attenuation factor (A) used for the various pathways are given below (Table D.2-1). The D/S factors and MEI dosages for Option B are given in Tabld D.2-2 and Table D.2-3.

Table D.2-1 Attenuation Factors (A) used

Pathway	$A(m^{-1})$
External Radiation:	
ground	12
Internal Radiation:	
inhalation, radon	1.6
Ingestion,	
water	1.0
fish	0.4

Table D.2.2 Modified D/S ratios for West Lake site under Option B

Ratio	Whole Body	Bone	Liver	Kidney	Whole Lung
(D/S1)	0.02	0.301	*	0.070	*
(D/S2)	*	0.002	*	*	*
(D/S3)	0.030	0.325	0.040	0.142	0.002

* (D/S) less than 10^{-4}.

** pathway not applicable.

Table D.2.3 MEI dosages for Option B

	Dosage (rem/yr)					
	Whole				Whole*	Bronchial*
Time(yr)	Body	Bone	Liver	Kidney	Lung	Epithelium
0	0.006	0.101	0.004	0.025	0.001	0.007
100	0.018	0.224	0.019	0.079	0.008	0.036
200	0.028	0.341	0.033	0.130	0.018	0.092
500	0.058	0.663	0.073	0.271	0.023	0.110
1000	0.100	1.114	0.128	0.468	0.032	0.140
2000	0.160	1.761	0.208	0.751	0.055	0.250
5000	0.236	2.590	0.310	1.113	0.088	0.410

* doses to the whole lung and bronchial epithelium were evaluated separately (Table D.2.4).

Dose to an individual from radon inhalation:

The dose is given by:

$$D = Foc(C)(WLR_0)(D/E)$$

where:

Foc = occupancy factor; assumed Foc = 0.2

C = the outdoor air concentration of Rn-222 (pCi/m^3)

WLR_0 = the outdoor WL ratio; $WLR_0 = 0.2$

D/E = the dose exposure ratio; taken as 0.3 and 1.6 for the Whole Lung and Bronchial Epithelium, respectively

C is evaluated by the simplified equation below:

where: F = radon flux ($pCi/m^2.s$), from Table D.5.1

v = wind velocity = 4.25 m/s

h = height to which radon gas rises above ground; assume 2 m

x = distance across the landfill in the wind direction; use 200 m

C_o = 200F/4.25*2 = 22.2F

and D = (0.2)(22.2F)(0.2)(D/E)

D = 0.889F(D/E) mrem/yr

Table D.2.4 Dosage from radon and daughters under Option B

			Dose (mrem/yr)	
Time(yr)	*F(pCi/m	C(pCi/m	Whole Lung**	Bronchial Epithelium
0	4.7	110	1.3	7.1
100	24	560	6.8	36.1
200	61	1400	17	92
500	76	1800	21	110
1000	96	2300	27	140
2000	165	3900	47	250
5000	270	6400	76	410

* F is the average of DOE and IAEA model estimates for Rn-222 relcas through 1.5 m of clean cover.

** the total dose given in Table D.2.3 to the whole lung is that listed plus (0.0016)*(Ra-226-pCi/g) to account for external radiation dose resulting from radon and daughters in the air.

Estimates of health effects resulting from radiation exposures

Under Option B, the site is stablized and converted to a public park. In the tabulations below, it is assumed that a group of 100 individuals utilizes the park spends 20% of their time at the site. The dosage in person-rems per year could be calculated as follows:

Bone dosage = (100 persons)x(0.2 occupancy)x(0.006 rem/yr)

= 0.12 person.rem, during the present year

The table below (Table D.2.5) is completed in this manner.

Table D.2.5 Projected exposure (person.rem/yr) for Option B

(person.rem/yr)

Time(yr)	(t')*	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium
0	0	0.12	2.02	0.08	0.50	0.02	0.14
200	4	0.56	6.82	0.66	2.60	0.36	1.84
500	10	1.16	13.26	1.46	5.42	0.46	2.20
1000	20	2.00	22.28	2.56	9.36	0.64	2.80
2000	40	3.20	35.22	4.16	15.02	1.10	5.00
**(a)		0.282	3.80	0.873	1.27	0.159	0.829
(b)		0.0761	0.819	0.0813	0.358	0.0242	0.106
***N		72	810	100	340	26	120
N_c		0.007	0.081	0.010	0.034	0.003	0.012

* time is divided by 50 to account for continuous exposure over a 50 year commitment

** plotting of the dose vs. t' is assumed linear to give an equation of the form

$$\text{Dose} = a + bt'$$

*** integration of the area beneath the line plotted above yields the total person.rems of dose (N) dividing N by 10^4 person rem per fatal cancer yields the health effect in fatal cancers (n_c) over the next 2000 years.

Summing the calculated values of n_c for all organs yields a total value of $n_c = 0.147$. That is, there is a 14.7% chance of one individual contracting a fatal cancer over the next 2000 years from exposure to debris at West Lake as stabilized under Option B. This is for one individual of a group of 2000. The risk of any individual contracting a fatal cancer from any source is 12.5% (28). Thus, 250 individuals from this same group would be expected to die of cancer. Comparison of 0.147 fatalities to 250 gives some indication of the hazard of this debris relative to the normal likelihood of fatal cancer.

Dose Estimates for Workers Under Option B

It is estimated that work would require about eight weeks to complete. Doses would be primarily from inhalation of radon and contaminated dust.

Dosage from dust inhalation:

The dose resulting from inhalation of contaminated dust suspended in air is calculated by:

$$D = F_{oc}C_pS7300(D/E)$$

where D = dose (mrem/yr)

F_{oc} = the occupancy factor

C_o = the dust concentration in air (g/m^3)

S = radionuclide concentration in air (g/m^3) which dust is derived (pCi/g)

(D/E) = the Dose to Exposure Factor and 7300 is the respiration (m^3/yr)

For eight weeks work at 40 hour per week,

Foc = 3.66 E-2

The dust concentration in air resulting from construction activity is taken as 600 E-6 g/m^3 (32); 100 E-6 of which is estimated to come from the contaminated soil, with the rest coming from clean fill soil.

C_o = 100 E-6 g/m^3

From the (D/E) factors given in Table 4.3 of ORO-832 (32), only thorium will be capable of producing a dose greater than 2 mrem. The dose equation given above is rearranged to provide the contribution of dust inhalation to the specific (D/S) factors given in Table D.2.7.

For example:

$$(D/S) = Foc\ C_D\ 7300\ (D/E)$$

for the thorium contribution to the whole body exposure, (D/E) = 1.4E-2, and

$$(D/S) = (3.66E-2)(100E-6)(7300)(1.4E-2)$$

$$(D/S) = 3.74E-4$$

D/S factors derived in this manner are highly conservative since they assume surface contamination, significant disturbance of the soil, no dust control measures, and exposure for the duration of remedial work.

<u>Dosage from radon inhalation</u>

Dosages are estimated as in Appendix D.2 (pg. D.2.3).

$$D = Foc\ C_o(WLR_o)(D/E)$$

$Foc = 3.66E-2$

$WLR_o = 0.2$

$D/E = 0.3$ and 1.6 for the Whole Lung and Bronchial Epithelium respectively

$C_o = 670\ pCi/m^3$, for an estimated radon flux of 30 $pCi/m^2.s$

Whole Lung Dose = (3.66E-2)(670)(0.2)(0.3) = 1.5 mrem

Bronchial Epithelium Dose = (3.66E-2)(760)(0.2)(1.6) = 7.8 mrem

Considering the external exposure pathways of "ground", and dust and radon is air, and the internal pathways of dust and radon inhalation the following (D/S) factors are derived from Option B. An occupancy factor of 3.66E-2 is used.

Table D.2.7 (D/S) factors for Option B

(D/S) in mrem total exposure per (pCi/g)

Factor	Source(s)	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium
(D/S1)	U-238	0.004	0.004	0.002	0.002	0.018	---
(D/S2)	Th-230	0.0004	0.0013	0.0008	0.0037	0.0051	---
(D/S3)	Ra-226	0.37	0.41	0.38	0.44	0.33*	0*

* partial dose, remaining dose calculated directly (above).

For the current soil concentration (s),

U-238, S1 = 180 pCi/g

Th-230, S2 = 9000 pCi/g

Ra-226, S3 = 90 pCi/g

the projected doses to an individual worker are as follows:

Table D.2.8 Doses to workers for implementation of Option B

Type of Dose	Dose to a single Worker	Dose to 20 workers (man.rem)
Whole body	0.038	0.75
Bone	0.049	0.99
Liver	0.042	0.84
Kidney	0.073	1.47
Whole Lung	0.081	1.62
Bronchial Epithelium	0.008	0.16
Total exposure =		5.83 man.rem

Comparison of this exposure (5.8 man.rem) to the figure of 10^4 man.rem per fatal cancer shows the relatively minor hazard to workers involved in implementation of Option B.

Appendix D.3 Dose Estimates Pertaining to Option C

Since the West Lake site would be decontaminated under this option, dosages to individuals on the site in the future would be reduced to near background. Some radioactive debris would inevitably be missed during excavation, however, the amount remaining and the resulting dosages would be negligible.

Dose estimates for workers involved in excavation and handling of contaminated soil under Option C:

The pathways of external radiation and dust and radon gas inhalation will produce doses to the workers. Dust will be controlled by spraying with water daily or more often if dust becomes apparent. Also, the workers will be issued dust masks. These measures should reduce the dose from the inhalation pathway by at least 75% (F = 0.25). External radiation cannot be reduced without the use of some technique of remote handling. Hydraulic mining with water jets could be considered. However, the fairly plastic nature of the soil would make this type of excavation time consuming. Also, the spent water would have to be collected and particulate and dissolved matter removed. Increased handling could result in overall higher exposures for the workers if hydraulic excavation were used. This method would also be more costly than conventional excavation. For these reasons, conventional excavation with a drag-line would be the preferred method of removing the contaminated soil.

Dose analysis was structured identically to that for Option B, with the following exceptions:

- Since the work is expected to take 3 months to complete, the occupancy factor is taken as 0.0548.

- The airborne concentration of contaminated soil is estimated as 200 micrograms/m^3 of air with dust control measures.

The resulting dosages are given in Table D.3-1.

Table D.3-1 Estimated dosages to decontamination workers under Option C

Organ	Individual dose (mrem)	Total Dose* (man.rem)
Whole body	60	1.2
Bone	406	8.1
Liver	80	1.6
Kidney	154	3.1
Whole Lung	47	0.9
Bronchial Epithelium	12	0.2

Total = 15.1 man.rem for entire operation

* Dose to 20 workers

Comparison of the 15.1 man.rem dose to the value of 10^4 man.rem per fatal cancer indicates a 0.15% chance of one of the workers contracting fatal cancer as a result of this work. Over half of this dosage is to the bone, and results from thorium inhalation. If excavation of the debris is undertaken, it will be absolutely essential to reduce dust concentrations in the air as much as possible, even though a 406 mrem bone dose is below the limit of 500 mrem per year allowable to an individual (233).

Since debris will be contained in drums during transport and crewmen on trains would not be in close proximity to the drums for a significant time, the dosages during transport would be negligible as compared to dosages during excavation.

Appendix D-4: Dose Estimates Pertaining to Option D

Under this Option, debris would be excavated and permanently stored in a secure trench on-site. Exposures to decontamination workers are expected to be roughly the same as those under Option C. Considering the uncertainties involved in dose estimation, it is a conservative assumption to take the dosages to workers under Option D as identical to those in Table D.3-1.

Unlike Option C, there would be future doses to the public. The trench described under this option should eliminate ground water contamination. Future use of the site as a public park eliminates all other internal exposure except radon inhalation. The other contribution to doses would be external "ground" radiation. A 4 m soil cover would reduce this exposure by a fraction of exp (-12x4) = 1.4E - 21. Thus, ground radiation becomes negligible. And the dose estimation simplifies to the problem of determining radon gas release.

Using the air C oncentrations (C) of Rn-222 in Table D.4-1, and the methodology of Appendix D-2, the MEI dosages (which were assumed above to come only from Rn and daughter inhalation) shown in Table D.4-2 may be calculated. Occupancy is assumed as 20%. From dose estimates, health effects can be projected as previously in Table D.2-5. From this analysis, health effects can be projected as previously in Table D.4-2. This anlaysis suggests that there is a 0.4% chance of one individual over the next 2000 year contracting fatal cancer from exposure to the site as stabilized under Option D.

Table D.4-1 Rn-222 Flux from Trench, Option D

		Rn-222 Flux ($pCi/m^2.s$)*		Air Concentrations(c)**
Time	Ra-226 (pCi/g)	IAEA Procedure	DOE Procedure	of Rn-222 (pCi/m^3)
0	90	0.3	0.2	4.2
100	467	1.6	1.3	23
200	828	2.8	2.3	40
500	1819	6.1	5.0	86
1000	3205	10.7	8.8	150
2000	5198	17.4	14.3	250

* assumes the following:

6 m depth of contaminated soil;

4 m clean cover;

soil "tortuosities" are 3 and 4 for the debris and cover , respectively;

for methods of calculation, see Appendix D.6.

** calculated as in Appendix D.2; $C = xF/ h(=)pCi/m^3$

assuming $x = 120m$ - across the trench;

$h = 2m$ - height above ground to which radon rises;

= 4.25 m/s - the average wind speed;

and using Rn flux values from the IAEA procedure above

Table D.4-2 MEI dosages under Option D

	Individual Dose (rem/yr)			Group Dose (person rem/yr)***	
Time	Whole Lung	Bronchial Epithelium		Whole Lung	Bronchial Epithelium
0	5.0E-5*	2.7E-4**		0.005	0.027
100	2.8E-4	1.5E-3		0.028	0.15
200	4.8E-4	2.6E-3		0.048	0.26
500	1.0E-3	5.5E-3		0.10	0.55
1000	1.8E-3	9.6E-3		0.18	0.96
2000	3.0E-3	1.6E-2		0.30	1.6
			a	0.017	0.097
			b	0.0073	0.039
			N	6.55	35.08
			n_c	0.00066	0.0035

Total n_c = 0.0042

* whole lung dose = (0.2)(4.2)(0.2)(0.3) = 0.05 mrem/yr = 5E-5 rem/yr

** Bronchial epithelium dose = (02.)(4.2)(0.2)(1.6) = 0.27 mrem/yr.
= 2.7E-4 rem/yr

*** for 100 individuals, the total dose (person rem) over 2000 years is approximated by linear regression of the annual group dose (person rem/yr) against time divided by a 50 year commitment to estimate the number of fatal cancers (n_c) expected to result from exposures under this option.

Appendix D.5: Dose Estimates Pertaining to Option E

Dosages to the MEI under Option E would be essentially the same as those for Option B, except that exposure through ingestion of contaminated water is reduced. It is assumed that the soil cap and slurry wall will be capable of eliminating leaching of radionuclides to the ground water system and the D/S ratios listed in Table D.5-1 are derived. For the projected soil concentrations of radionuclides given in Table D.2, the dose estimates in Table D.5-2 are obtained. Proceeding as in Appendix D.1, the total person.rems of exposure expected over the next 2000 years is calculated and is used to project possible health effects based on the assumption that 10^4 person/rems of continuous annual exposure will result in one fatal cancer. Assuming that a group of 20 individuals is exposed and their occupancy factor is 0.2, results of this analysis indicate a 7% chance of one individual over th next 2000 years contracting fatal cancer due to exposure to the site as stabilized under Option E.

For decontamination workers, the D/S ratios developed for Option B are assumed to be valid. From the time required to complete this work, the occupancy factor is taken as 0.073. And estimated doses to deconatmination workers under Option E are given in Table D.5-3. The total exposure in person.rem indicates a 0.1% chance of one worker contracting fatal cancer from this work.

Table D.5-1 D/S ratios for the MEI under Option E

Ratio	Whole Body	Bone	Liver	Kidney
(D/S1)	0	0.002	0	0
(D/S2)	0	0.002	0	0
(D/S3)	0.01	0.125	0.020	0.092

Table D.5-2 MEI dosages for Option E

MEI dosage (rem/yr)

Time(yr)	Whole Body	Bone	Liver	Kidney	Whole Lung	Bronchial Epithelium
0	0.002	0.030	0.002	0.008	0.001	0.007
100	0.005	0.077	0.009	0.043	0.008	0.036
200	0.008	0.122	0.017	0.076	0.018	0.092
500	0.018	0.246	0.036	0.167	0.023	0.110
1000	0.032	0.419	0.064	0.295	0.032	0.140
2000	0.052	0.668	0.104	0.478	0.055	0.250
5000	0.077	0.986	0.155	0.713	0.088	0.410

Table D.5-3 Dose to decontamination workers under Option E

Type of Dose	Dose to a single Worker (rem)	Dose to 20 workers (man/rem)
Whole body	0.076	1.52
Bone	0.098	1.96
Liver	0.084	1.68
Kidney	0.146	2.92
Whole Lung	0.162	3.24
Broncial Epithelium	0.016	0.32
	Total Exposure =	11.64 man/rem

D.6 Estimation of Radon Emanation

Two approaches were considered for prediction of radon release from soil at West Lake. The first method involves use of a mathematical model to describe radon release from a known concentration of the Rn-222 parent Ra-226. The second method is the use of a natural analogue model based on a large number of field measurements; this model also relates Rn-222 release to the soil concentration of Ra-226.

1) International Atomic Energy Agency procedure (26):

Rn-222 produced = Ra-226 Activity (dps)x volume (=) nuclei/m^3

$$P = A_1V$$

Rn-222 release to soil air = jAV (=) nuclei/m^3

$$R' = jAV$$

where: j = emanation factor ranging from 0.3 to 0.03 for loose to tight soil for thick debris, a self-confinement factor (e) is calculated by:

$$e = (^{Hef}/H)(\text{hyp-tan}(H/Hef))$$

where H = debris thickness (height)

Hef = effective height, calculated by

$$Hef = (DA/KT)^{1/2}$$

where DA = molecular diffisivity of Rn-222 to air (1.02 E-5 m^2/s)

K = 2.1 E-6 S^{-1}(for Rn-222)

T = tortuosity of flow path in soil (1.5, for uniform sand)

The radon flux (F_o) from an uncovered pile of debris can be estimated by:

$$F_o = ejA_1H \ (=) \ dps/m^2$$

Release from a tailings pile covered with (h) meters of clean soil is obtained by multiplying with uncovered flux (F_o) by a confinement factor (G)

G = exp (- cover thickness/effective height of cover)

$G = \exp(-h'/H'ef)$

and the covered flux (F) = GF_o.

Sample calculations for IAEA model:

for the situation,

H = 2m contaminated soil

h' = 1.5m clean cover

A = 90 pCi-Ra-226/g-soil

A = 90 E-12 x 3.7 E10 = 3.33 dps

T = 2 for debris; T = 4 for compacted cover

j = 0.1

2) U.S. Department of Energy Procedure (27):

The following formula has been proposed by the DOE for estimating radon emenation from radium bearing soil.

$$J/S = PsE(kD)^{1/2} \exp(-ac)(1 - \exp(-aL_z))$$

$$a = (K/D)^{1/2} = \text{attenuation factor}$$

where:

J/S = flux to source ratio (=) pCi-Rn-222/m^2.s

P_s = bulk density of soil = 1.7E6g/m^3

D = diffusivity of Rn = 1.2E - 6 m^2/s

E = release factor = 0.2 (=) dimensionless

C = cover soil thickness (=) m

L_z = contaminated layer thickness (=) m

K = 2.1 E - 6 S-1 for Rn-222

Sample calculation:

$L_z = Z_m$ S = 90 pCi, Ra-226

c = 0m (no cover)

Table D.6.1 Rn-222 Flux (pCi/m^2.s) from a 2m contaminated layer as a function of Ra-226 and cover soil thickness

		IAEA Proc.				DOE Proc.			
		Cover thickness (m)				Cover thickness			&)
Time(yr)	Ra-226 conc. in soil (pCi/g)	0	0.6	1.5	3.0	0	0.6	1.5	& 3.0
0	90	12*	7.0	3.1	0.79	45	20	6.2	& 0.9
100	470	63	37	16	4.1	240	110	32	& 4.5
200	830	110	64	28	7.2	420	190	57	& 8.0
500	1820	240	140	62	16	910	410	130	&17
1000	3200	430	250	110	28	1600	730	220	&31
2000	5200	700	400	180	46	2600	1180	360	&50
5000	7750	1040	600	270	68	3900	1760	530	&74
(J/S ratio)		-	-	-	-	0.501	0.227	0.069	&0096

* for soil containing 90 pCi/g of Ra-226 and a cover layer of 0m; flux is 12 pCi/m^2.s

2.6.3 Seismology:

The primary seismic risk to the West Lake site, as it is to the entire St. Louis area, is the New Madrid fault. This fault is located approximately 250km to the SSW, near the town of New Madrid, Missouri. The risk from this fault is well documented as a severe earthquake would likely destroy the city of St. Louis. The New Madrid earthquake which occured from December 16, 1811 to February 7, 1812 were among the strongest quakes ever to occur and would have likely registered 9 or more on the modern Richter scale. This event consisted of 3000 tremors over 53 days which were felt as far away as San Francisco, CA*. If such an earthquake occured at the present time, it is possible that the Missouri River level would be raised enough to overtop levees and flood the West Lake site. Flooding combined with shocks could result in failure and extensive erosion of the West Lake site and exposure of contaminated debris.

4.5 Option C - Removal of Radioactive Soil to an Authorized Disposal Facility

This option will involve excavation and removal of all contaminated soil and debris from the West Lake Landfill and relocation to an authorized disposal facility near Barnwell, South Carolina. The Barnwell site is licensed by the NRC (#46-13536-01) for the disposal of commercial radioactive waste and is operated by Chem-Nuclear Systems, Inc. This landfill is located approximately seven kilometers northeast of Barnwell in southwestern South Carolina. The Barnwell facility would be a permanent repository for the West Lake debris.

4.5.1 Work Required:

Vegetation over Areas 1 and 2 (Figs. 4-6 and 4-7) would be cleared and placed in the demolition portion of the West Lake Landfill. Since no uptake of radionuclides by plants has been observed, it is reasonable to assume that the vegetation is fairly "clean" (i.e., uncontaminated) and does not require special handling.

All equipment stored on the two contaminated areas will be removed to another portion of the site. Piles of crushed rock will also be removed. The lower 5 to 10 cm of rock should be left in place for disposal with other contaminated materials, since this gravel may have become mixed with contaminated soil at the surface.

The Shuman Building will be removed, as described under Option B. In Option C, however, below-ground portions of the building (the foundations) may contain some radioactive soil and will be disposed of with the contaminated soil, as outlined below.

The areas known to contain radioactive contamination at levels above the action criteria (20 R/hr at 1 m) will be excavated initially. Next, a survey of the excavated area will determine the extent of contamination remaining. Excavation will continue until unacceptable levels of contamination have been removed. Excavation should be continued for about 5 m in the lateral direction and about 0.5 m in the vertical direction past where the contamination is found. This will insure that all the radioactive soil is removed. Immediately after excavation, the soil will be placed in 208-liter (55 gal.) drums for transport. Containment in the drums will prevent the spread of dust and loose soil during transport.

To further reduce exposures to workers involved in excavation and handling of the contaminated soil, the areas undergoing excavation should be sprayed with water to reduce dusting of the radioactive soil. If dusting is visibly apparent during operations, the workers should be issued dust masks to prevent inhalation of contaminated soil particles. Due to the fairly low level of contamination present, these should be sufficiently precautionary to prevent spread of contaminants and to minimize radiation exposure to workers (Table 4-6).

4.5a

It is known that some hazardous wastes were emplaced in the West Lake Landfill; and it is believed that some of this disposal was carried out at the same time filling was going on in the northern area of contamination (Area 2). It is possible that the deeper radioactive debris present in the southern part of the northern area of contamination is overlain by some type of hazardous waste. It is likely that that portion of the debris is overlain by a meter or more of sanitary fill. The fill is about ten years old now; and organics from the sanitary fill should be fairly well-stabilized by now. However,

Table 4-6 Estimated Dosage to Decontamination Workers for Option C*

Organ	Dosage to a Single Worker (mrem)
Whole Body	60
Bone	410

Liver	80
Kidney	150
Whole Lung	50
Bronchial Epithelium	12

* Method used for estimated dose are detailed in Appendix D.3.

some of the hazardous materials known to be present at some point in the landfill could present a serious danger to workers should they excavate into this material. Debris in the southern area of contamination is overlaid by a meter or more of sanitary fill (39).

The drums of soil would be hauled from the site by truck to the nearest railroad which is approximately 2 km away. The drums will be shipped by rail to the town of Barnwell, SC, where they will again be loaded on trucks to be transported the 7 km to the Chem-Nuclear facility. Once received, the material will be handled by landfill personnel, and the safety of the material will be then be the responsibility of Barnwell facility personnel.

4.5.2 Benefits Derived:

Under Option C, the West Lake Landfill would be completely decontaminated, eliminating the risk of future exposures from the radiation currently found at this site. The site could be released for unrestricted use after decontamination. Some of the non-radioactive hazardous materials in the West Lake fill would also be removed incidentally with the radioactive contaminants.

The final cover would be more suitable for establishment of a final vegatative cover.

4.5.3 Adverse Effects:

Under Option C, there would be some short-term, low-level exposures to workers directly involved in excavation and handling of the contaminated soil (Table 4-6). These exposures will be minimized as much as possible by the precautions described in Section 4.5.1..

Valuable space in the Barnwell disposal facility would be put to poor use by the emplacement of a large volume of low-level radioactive wastes. And a good deal of time, effort, and money would be expended to remove contaminants which probably do not warrant such extensive remedial measures.

The biological community which has developed over the finished landfill surface would be destroyed; however, the landfill does not supply a habitat of substantial size or uniqueness to any animals at the present time.

4.5.4 Estimated Costs:

Estimated costs under Option C would be $23,001,400 (Table 4-7). The actual cost may vary from this somewhat due to the unknown extent of debris to be excavated. The major costs under this option will be for packaging, transport, and burial in the Barnwell facility. It is reported that this option could be completed in about 3 months.

4.5.5 Discussion:

Option C could be implemented, with the results being total site decontamination which would allow the site to be released for unrestricted use. However, the cost of this option is quite high in comparison to other options involving remedial actions..

Comparing only the end results at the West Lake Landfill Option C would appear to be the most favorable course of action. But the cost of complete site decontamination and removal to a remote site does not appear to be justified by the magnitude of the problem at West Lake. There could be a serious hazard to workers involved in excavation due to

Table 4-7 Itemized Costs of Remedial Action - Option C

Item	Quantity	Unit Price	Cost	Reference
Clearing and grubbing	2.9 ha	$1800/ha	$5,200	30
Remove Shuman Bldg.	---	---	6,000	31
Bury clean rubble	230 m^3	$12/m^3$	2,700	*
Excavate contaminated soil	$70000m^3$	$5/m^3$	350,000	*
Site decontamination	$27600m^3$	$1.35/m^2$	37,300	31
Packing and transport to Barnwell facility	$70000m^3$	$190/m^3$	13,300,000	31
Charges for emplacement in Barnwell facility	$70000m^3$	$90/m^3$	6,300,000	31
		Subtotal	$20,001,200	
		Contingency @ 10%	2,000,100	
		Engineering and legal fees @ 5%	1,000,100	
		Estimated Total Cost	$23,001,400	

* Based upon best estimate.

exposure to other (non-radioactive) debris. Also, the Barnwell facility is designated for disposal of higher level radioactive materials than the soil at West Lake, which contains a fairly low level of contamination in a very large volume of soil. Since the Barnwell facility is not really intended for disposal of such low-level radioactive material, burial of the West Lake material would be a waste of valuable space in this licensed facility.

The magnitude of contamination and benefits derived do not seem to justify the costs of Option C. Since acceptable results may be achieved by other means, this option is not recommended.

4.6 Option D: Excavation and Permanent Storage On-Site

Under this option, radioactive soil would be excavated much as in Option C. The difference being, that the soil would not be transported to an existing authorized disposal facility. Rather, the debris would be placed in a specially prepared trench (Fig. 4-8) at the West Lake site. The soil would not be placed in drums, but simply excavated and placed in the trench. This would be a permanent repository for the radioactive soil. The trench would be surrounded by an impervious clay liner to minimize leachate production and transport into the groundwater system. The cap should give both acceptable rates of surface exposure and radon gas release.

4.6.1 Work Required:

As under Option C, surface vegetation, machinery, and piles of crushed rock will be removed from the surface of areas to be excavated (Fig. 4-6 and 4-7). The Shuman Building will be removed as described for Option B. Design considerations and dimensions for this trench are presented in Appendix F.

Once the trench has been prepared to accept the soil, excavation of contaminated soil may begin. As under Option C, an initial excavation will remove the area of known contamination, and a clean-up phase will remove all soil containing radiation above the action criteria of 15 pCi/g of Ra-226. As soon as the soil has been excavated, it will be hauled to the trench and emplaced. The contaminated soil should be sufficiently compacted to prevent settling and maintain the integrity of the soil cap. As fill is being emplaced, the pipe for a monitoring well will be extended upward from the base of the gravel under drain. This well should be designed in a manner so as to allow future installation of a submersible pump for drawing off leachate should this become necessary.

During excavation and handling of the radioactive soil, dust control precautions as described for Option C, should be implemented.

Some restriction should be written into the land title to bar construction over the trench. This restriction should be the same as that described for Option B, except that restrictions would only be required for the area directly above the trench.

4.6.2 Benefits Derived:

Exposure rates above the trench would be reduced to acceptable levels, with the 4 m soil layer nearly eliminating radon emanations. Radioactive soil will no longer be subject to erosion and carriage off-site. The impermeable liner in the trench should prevent leaching of the wastes by maintaining the soil in a dry state. This should virtually eliminate the problem of groundwater contamination. Under this Option D, all exposure pathways would be blocked. The resulting doses to the public should be far below recommended limits, unless the land use restriction noted above is ignored and future construction involves excavation into the radioactive soil. Estimated dosages to the public after completion of Option D are given in Table 4-8.

The areas excavated would be available for emplacement of additional fill. The finished fill would be favorable for development of a vegatative cover.

4.6.2 Adverse Effects:

Under this option, the radioactive material would still be stored at a site not specifically designated for the disposal of radioactive waste. NRC guidelines would not be met due to the possibilities of subsurface contamination. Therefore, the site could not be released for unrestricted use. Future activities on the site after the landfill has been closed and surrounding land uses have changed, may result in disturbance of the trench and possibly in exposure to future users or workers. This would only cause problems if construction were undertaken directly on-site and excavations were made into the trench or its cap.

Some short-term low-level exposures would be incurred by personnel involved in excavation and burial of the soil. Since the time involved in working with the soil would be fairly short, these dosages would be low. The main dose will result from inhalation of contaminated dust particles. Estimated dosages to decontamination workers are given in Table 4-9.

Problems could be encountered in the future if leachate accumulates in the trench. If the cap is more permeable than the base and walls of the trench, infiltration water would tend to build up in the trench.

Table 4-8 Estimated MEI Dosages Under Option D

	Dose (mrem/yr)*	
Time (yr)	Whole lung	Bronchial Epithelium
0	0.05	0.27
100	0.28	1.5
200	0.48	2.6
1000	1.8	9.6
2000	3.0	16

* for methods used, see Appendix D.4.

Table 4-9 Estimated Dosage to Decontamination Workers Under Option D

Organ	Dose to Worker* (mrem)
Whole body	60
Bone	410
Liver	80
Kidney	150
Whole lung	50
Bronchial Epithelium	12

* for methods used, see Appendix D.4.

If this buildup were to progress far enough, leachate could eventually fill the trench and overflow the top of the trench. For this reason, a monitoring well should be installed in the trench to observe the volume and radiological quality of any leachate which might built up in the trench. If leachate containing high levels of radionuclides (20 pCi/l of Ra-226 is suggested as a criteria) does build up, this leachate would have to be treated after pumping. Treatment could consist of lime flocculation to reduce radionuclide levels before leachate is discharged into the municipal sewer. It is possible that radionuclides leached out of the debris would naturally precipitate in the limestone underdrain layer by the same chemical precipitation reaction employed in their removal by lime flocculation.

4.6.4 Costs:

Costs for Option D would be approximately $2,076,900 (Table 4-10). The estimated costs are somewhat variable since the exact limits of excavation cannot be defined until work is commenced. This work would require approximately 120 days to complete.

4.6.5 Discussion:

Costs of Option D will be high in comparison to Option B, but substantially less than the transport of materials to Barnwell, SC (Option C).

Although the site would not be available for unrestricted use, the possibility of future exposures to the public are fairly small, since surface exposures and radon emanations are reduced to a low level. Restricting land use will hopefully prevent extensive activity over the site of the trench. Construction of a park, ballfield, parking lot, etc., which would not require excavation would be desirable, since this would prevent other construction on-site which does involve excavation.

Table 4-10 Itemized Costs of Remedial Action Option D

Item	Quantity	Unit Price	Cost	Reference
Prepare secure trench	80,000m^3	$8.75/m^3	$700,000	30
Clearing and grubbing	2.9 ha	1800/ha	5,200	30
Remove Shuman Bldg.	---	---	6,000	*
Bury clean rubble	230m^3	12/m^3	2,300	*
Excavate contaminated soil	70,000m^3	5/m^3	350,000	*

Site decontamination	26,720m^2	1.35/m^2	37,300	31
Emplace contaminated soil	70,000m^3	10/m^3	700,000	*
Monitoring well	---	---	5,000	*
Seed and mulch cover	0.08 ha	2100/ha	200	30
		Subtotal	$ 1,806,000	
		Contingency @ 10%	180,600	
		Engineering and legal fees @ 5%	90,300	
		Estimated Total Cost	$ 2,076,900	

*based on best estimate.

Option D could be implemented to give acceptable dosages, even if to individuals vuiolated land-use restrictions and lived directly over the undisturbed trench. However, such results of Option D would come at a fairly high cost. Option D represents a level of decontamination intermediate between Options B and C. If a level of decontamination greater than Option B is desired, this option would be viable and preferable over Option C. The advantages over Option C would be a lower cost and the avoidance of using the authorized facility at Barnwell for low-level wastes.

4.7 Option E - Extensive Stabilization with Land-Use Restriction

Under Option E, radioactive soil would be left in place at the West Lake site. The wastes would be stabilized by means of a soil cover (as under Option B) and a down-gradient slurry wall around the contaminated soil. The slurry wall would be intended to prevent migration of leachate off-site. This remedial action would be somewhat more effective than Option B in reducing the potential for groundwater contamination. However, costs incurred would be substantially higher than those for Option B. Benefits would be nearly identical to those derived by the soil cover and berm stabilization alone, with the sole advantage of Option E over Option B being greater protection to groundwater in the Missouri River alluvium.

4.7.1 Work Required:

Vegetation, machinery, piles of crushed rock and the Shuman Building would have to be removed as described for Option B.

A slurry wall (Fig. 4-9) would be constructed. The construction of this slurry wall ould be accomplished by excavating a trench (approximately 1 m wide) to the depth of bedrock. This trench is bored out in the presence of a mud weighted with bentonite (clay) to prevent collapse of the walls and groundwater intrusion into the trench. The trench is excavated in sections 6 to 8 m long. Once a section of trench has been excavated, concrete is poured by tremie into the trench to displace the slurry. The final slurry walls would each consist of a concrete slab about 1 m thick extending to bedrock and partially encircling the bodies of radioactive soil in both Areas 1 and 2. A total of approximately 1300 linear meters of wall would be constructed to depths varying from 5 to 15 m.

After each of the slurry walls has been emplaced, fill would be added along the face of the berm to stabilize the slope. Finally, a soil cover would be placed over the contaminated areas. Stabilization of the berm and placement of the soil cover will be performed as outlined for Option B.

Zoning of the northern and southern areas (Areas 2 and 1, respectively) of contamination will be changed to discourage the construction of factories or residences on the site. Also, a land-use restriction as described under Option B will be placed in the land deed for the contaminated areas to discourage future activity in the contaminated areas. The site could eventually be made into a public park.

4.7.2 Benefits Derived:

Benefits of Option E would be similar to those described under Option B, with the additional benefits of reduced groundwater contamination. Even if the walls are not capable of completely retaining leachate, the migration of contaminants would be diverted. The effects of diffusion and sorption would therefore, be increased. The plume of contaminants would be dispersed and the possibility of elevated levels of radionuclides appearing in the groundwater down-gradient from the landfill would be reduced. Dose estimates for the MEI (Table 4-11) indicate acceptable exposures over the next 1000 years or more, provided the wastes are not disturbed.

4.7.3 Adverse Effects:

Adverse effects of Option E would be virtually the same as those of implementating Option B. The estimated dosage to contamination workers (Table 4-12) would be acceptable. Due to the relatively extensive amount of work required in constructing the slurry walls, there may be a slightly greater disturbance to the ecology of both Area 1 and Area 2. However, effects on this ecology would be temporary, and no unique or particularly important habitats would be lost.

4.7.4 Estimated Costs:

Costs of work required for Option E would be approximately $5,377,100 (Table 4-13). This cost will be highly variable, since the exact amount of slurry wall cannot be determined until work is begun. Since the walls should extend to bedrock, the depth of soil and landfill debris will govern the depth of the required wall. Slight errors in estimating the depth of alluvium could result in large errors in the cost estimate. It is estimated that it would take 6 to 8 months to complete this option.

4.7.5 Discussions:

Construction of the two segments of the slurry wall, in addition to other stabilization work, would overcome the only disadvantage of Option B. That is, Option E would be much more effective in reducing groundwater contamination than would Option B.

Since the layers of radioactive soil extend over a large area in Area 2, a very long slurry wall will be required to isolate the waste. The cost of constructing the two slurry walls ($4.29 million) would be greater than costs incurred under Options B and D but less than complete decontamination and removal to Barnwell, SC (Option C).

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5. CONCLUSIONS

Radioactive contamination present in the West Lake Landfill is serious enough to warrant some type of remedial action. At the present time, no individuals are exposed to hazardous levels of radiation. However, steps must be taken to prevent future users of the site from incurring exposures that could be hazardous. The requirement of remedial action is based on the following:

1) radioactive soil is eroding from the northwestern face of the berm, and being transported by erosion off-site;
2) radon gas has already been observed to accumulate to an unacceptable level in a structure on-site (the Shuman Building);
3) some degree of radiological contamination has been found in the perimeter monitoring wells;
4) surface exposure rates over much of the contaminated areas are greater than 20 R/hr.

The recommended remedial action, Option B - Stabilization on-site with land-use restriction, will require additional cover for the radioactive sites in Areas 1 and 2 of about 1.5 m soil. The soil cover area should be graded to promote surface drainage covered with a layer of topsoil and seeded with native grass to stabilize it. The berm along the northwest side of the landfill would be stabilized and extended to prevent soil erosion and exposure of buried radioactive materials. The Shuman Building would be demolished or moved to another part of the landfill.

Under Option B, zoning for the West Lake site should be changed from the present residential class to restricted use class. The land title for the contaminated areas should include a statement indicating the presence of radioactive contaminants and building restriction requirement. It is recommended that the site be ultimately converted to a public park. The estimated cost of Option B is $460,200.

The other options considered were: Option A - Leave the buried radioactive materials in place with no remedial action; Option C - removal of contaminated soil to Barnwell, South Carolina; Option D - Excavation, placement and permanent storage in a secure trench on-site; Option E - Stabilize the site as in Option B with additional containment by a slurry wall surrounding the debris. These options were not recommended because of relatively high costs and/or inappropriate use of space in a licensed waste disposal facility (Options C, D and E), or because hazards would remain to population (Option A).

Appendix F: Secure Trench for Option D

The purpose of placing the radioactive debris in a secure trench will be to prevent exposures to the public. The three primary functions of the trench will be to: eliminate direct gamma-ray exposure at the ground surface, reduce radon emanation, and prevent leaching of radionuclides to the groundwater system.

Design of the trench is based upon the "secure landfill concept" (39). Additional safeguards are provided for the trench described below due to the lack of natural permeability barriers at the West Lake site, and also due to the long period for which the radioactive debris will remain hazardous.

Debris will be excavated from the area beneath and north of the Shuman Building and stockpiled on the surface south of the excavation over contaminated soil still in place. The excavated area will be cut to a maximum elevation of 460'(msl) over the area to be covered by the trench. The base of the trench will cover an area 120m x 120m and have negligible slope. Low spots will be filled with borrow soil compacted to at least 90% of its standard Proctor density (SPD). In this appendix, borrow soil refers to a clayey-silt loess (USCS type CL) presently being excavated southeast of the site for use as daily cover in the landfilling operation. Once the base for the trench has been leveled to a final elevation of about 460ft(msl), a blanket of borrow soil at least 1.5m thick compacted to at least 90% SPD will be emplaced. Specification of compaction of this underlayer is based on the requirement of avoiding subsidence which could cause cracking and failure of the clay liner. A clay liner will be placed above the underlayer. The liner will be 0.5m thick and have a permeability less than 10^{-8} cm/s. Use of an impermeable plastic liner was rejected due to the relatively short lifetime of the plastic (a few hundred years at the most) as compared to the length of time the radiation hazard will be present. The clay liner is a much more permanent permeability barrier. Sides of the trench will be built at a 3:1 slope up to the level of the surrounding undisturbed landfill surface (about 470 feet(msl)). The walls will consist of an underlayer and liner as described for the base. A layer of crusher-run limestone 0.5m thick will be placed on top of the liner to allow monitoring of leachate buildup in the trench and to facilitate pumping should leachate buildup become a problem.

After the base and walls of the trench have been built, the previously excavated debris will be placed in the trench. The remaining radioactive debris will be excavated and placed in the trench. As excavation proceeds, it will become apparent how much trench volume will be required to contain the entire volume of contaminated soil. At this point, the walls of the trench will be raised to an appropriate level. Excavation and filling can then proceed to completion of the decontamination work. The final thickness of debris is expected to be from four to six meters. The debris will not be compacted.

A cover as described below will be placed over the debris. A 1m layer of borrow soil compacted to 90% SPD will be placed over the debris. A clay liner 0.5m thick of permeability less than 10^{-8}cm/s will be placed over the borrow soil blanket. A 0.5m layer of crusher run limestone from the on-site quarry will be placed over the clay layer to prevent buildup of infiltration water over the liner. A cover soil layer of average thickness about 2m will be placed over the rock layer. The cover soil should be compacted and built with a surface slope of from 2% to 4% to minimize erosion. 0.3m of topsoil will be placed over the cover layer and seeded and mulched to establish a vegatative cover.

Appendix E: Missouri State Regulations Governing Closure of Sanitary Landfills, Permitted by MDNR

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Division of Geology and Land Survey

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*** Print Diagnostics for: WEST LAKE LANDFILL RPT

Total Formatting Exceptions = 16   Total Listed Below = 16

The Following Two Formats Will Be Used:

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84.0.0/16	0033-Line Exceeds Paper Width
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84.0.0/27	0013-Text And/Or Header Margin Text Overflow
84	0034-Text Exceeds Paper Length
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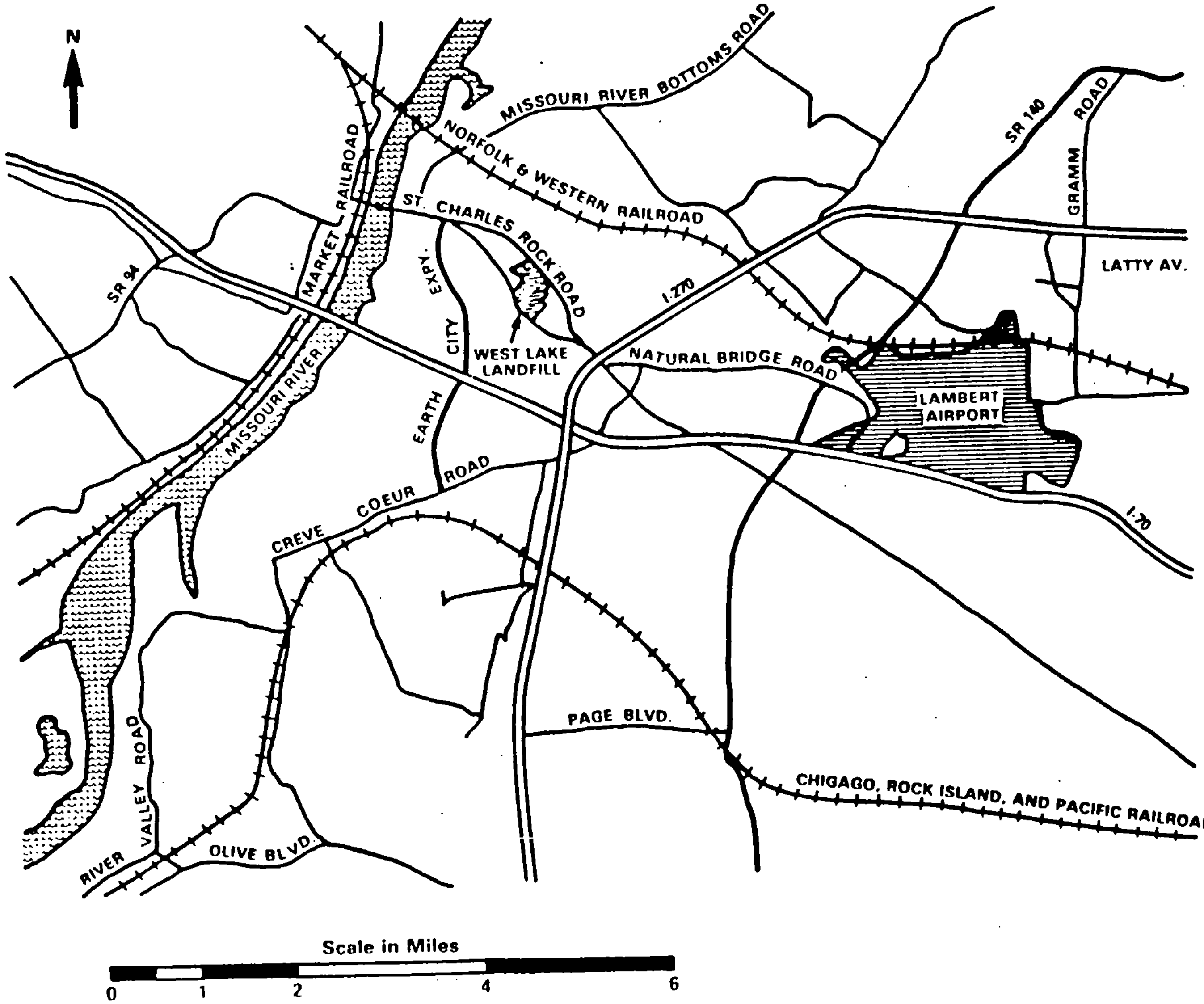


Figure 1.1 Location of West Lake Landfill

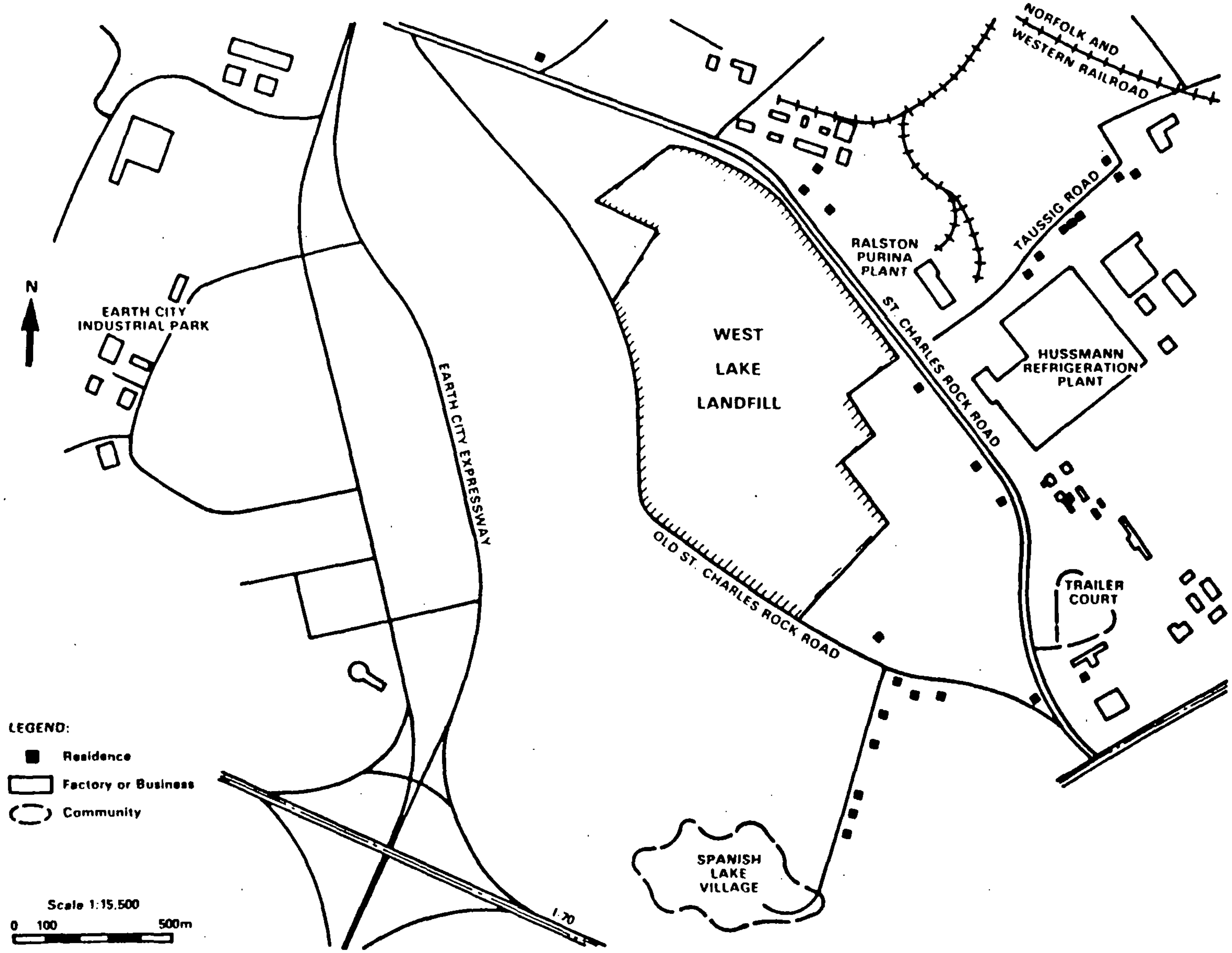


Figure 2.1 Land use around West Lake Landfill site (July 1986)

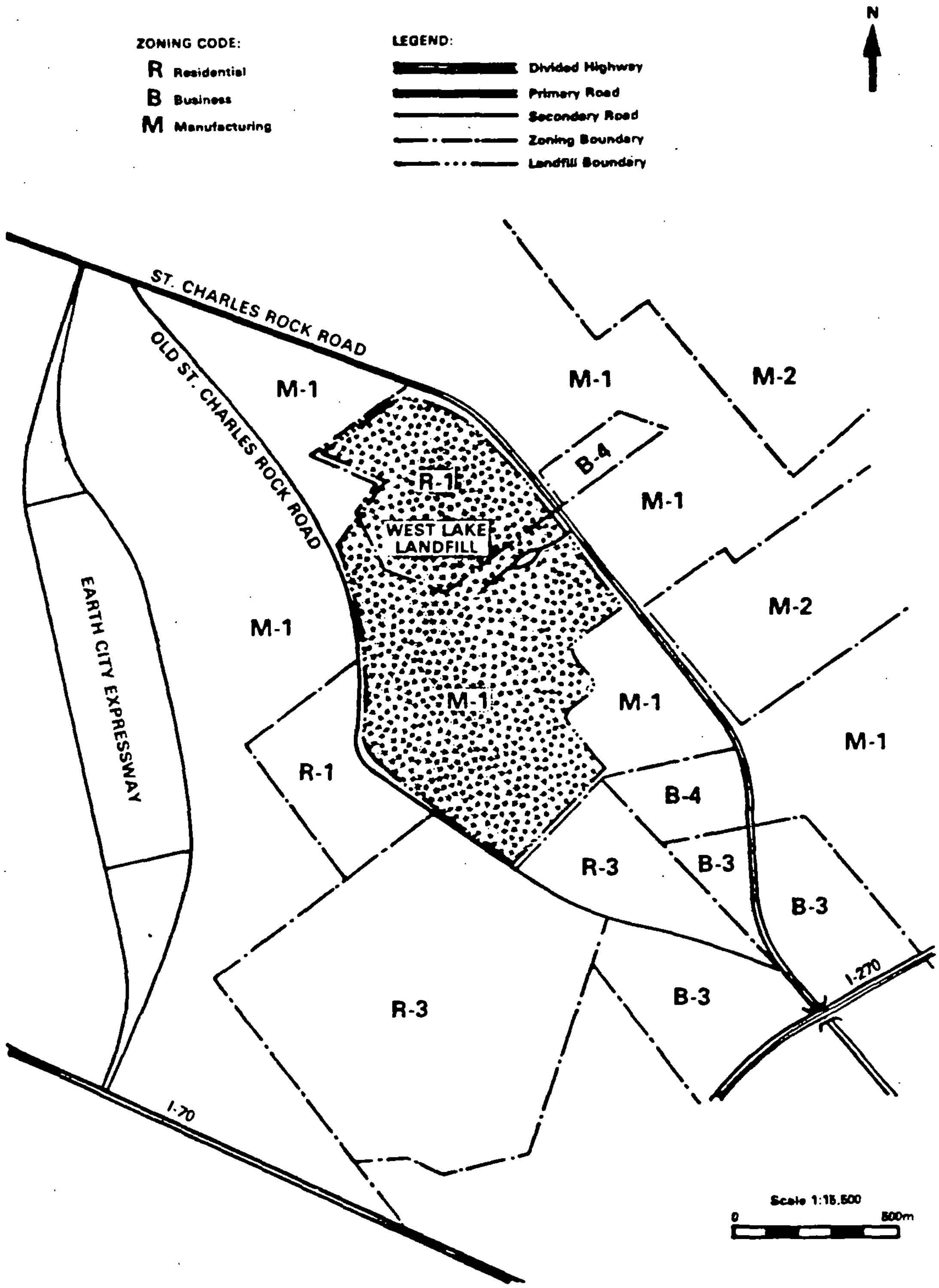


Figure 2.2 Zoning plan of West Lake area (June 1984)

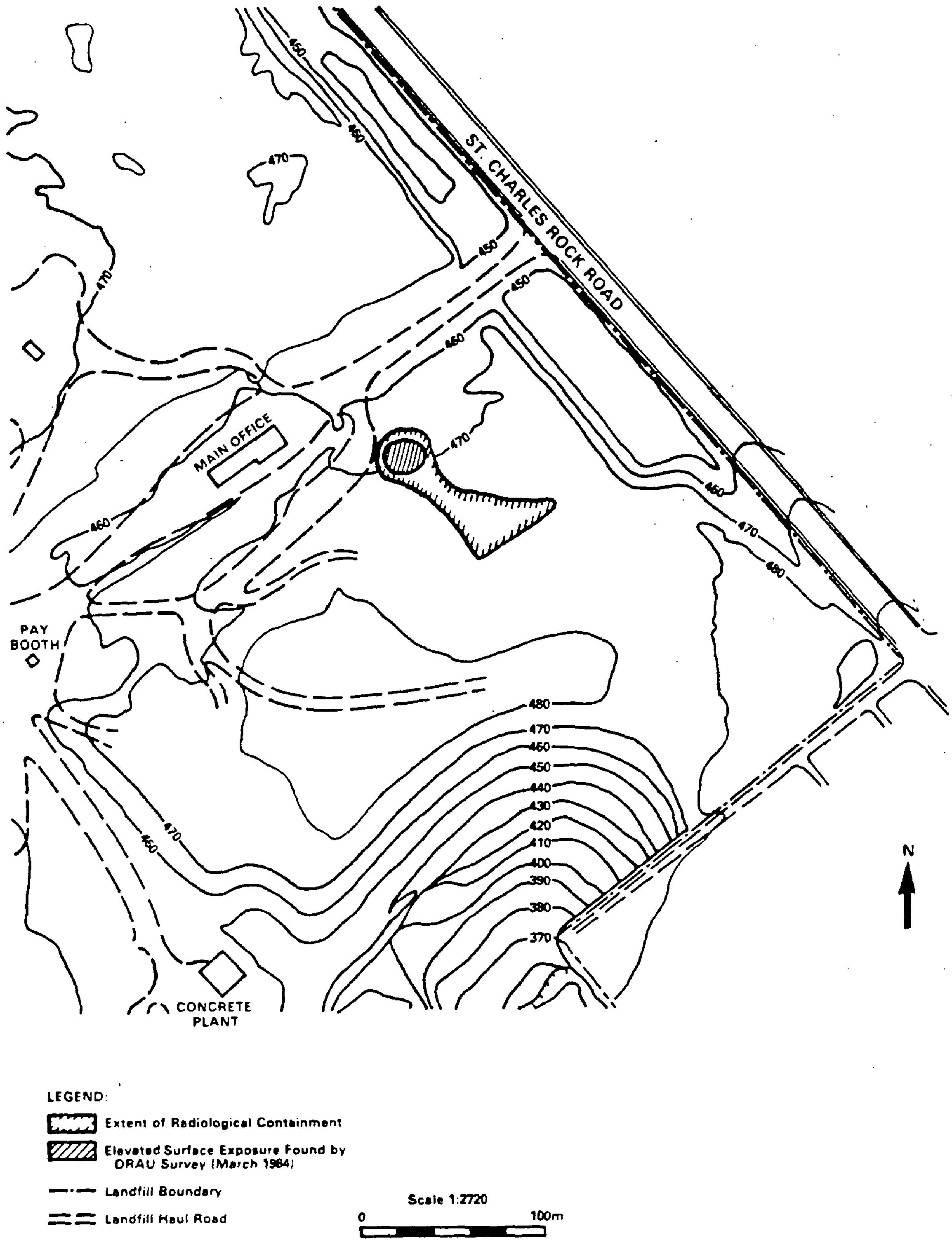


Figure 2.3 Extent of contamination, Area 1 (July 1986)

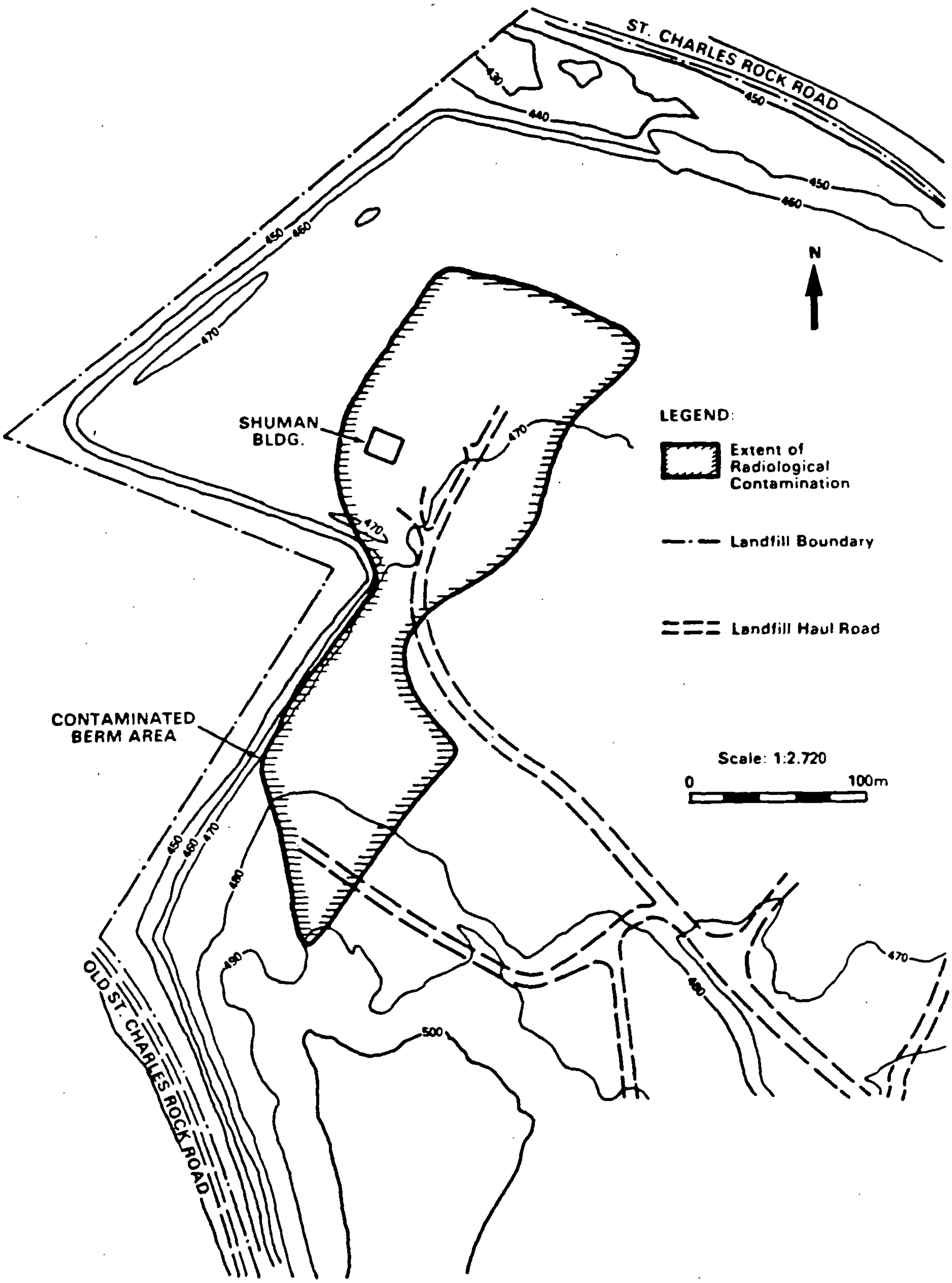


Figure 2.4 Extent of contamination, Area 2 (July 1986)

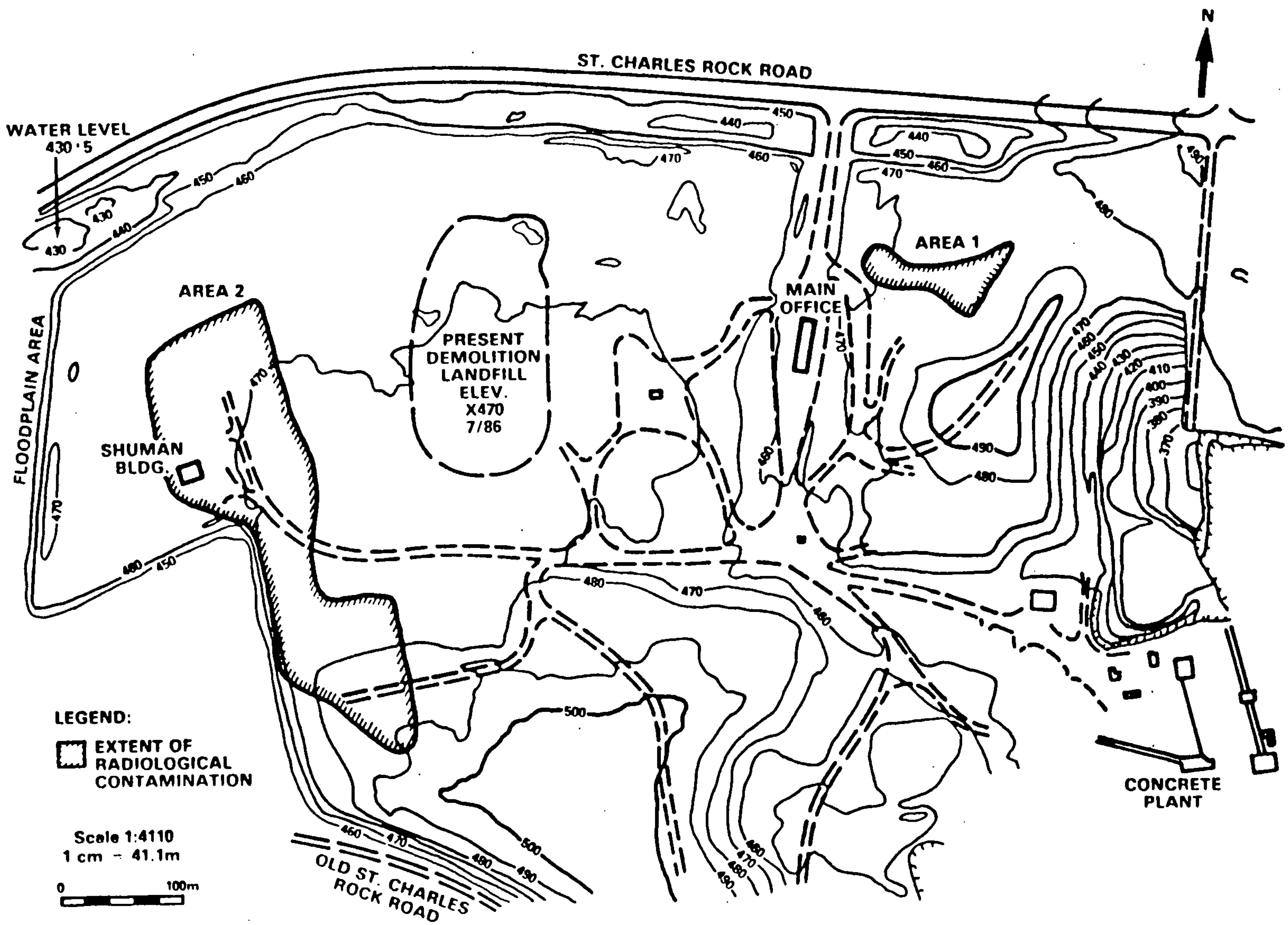


Figure 2.5 Site topography (July 1986)

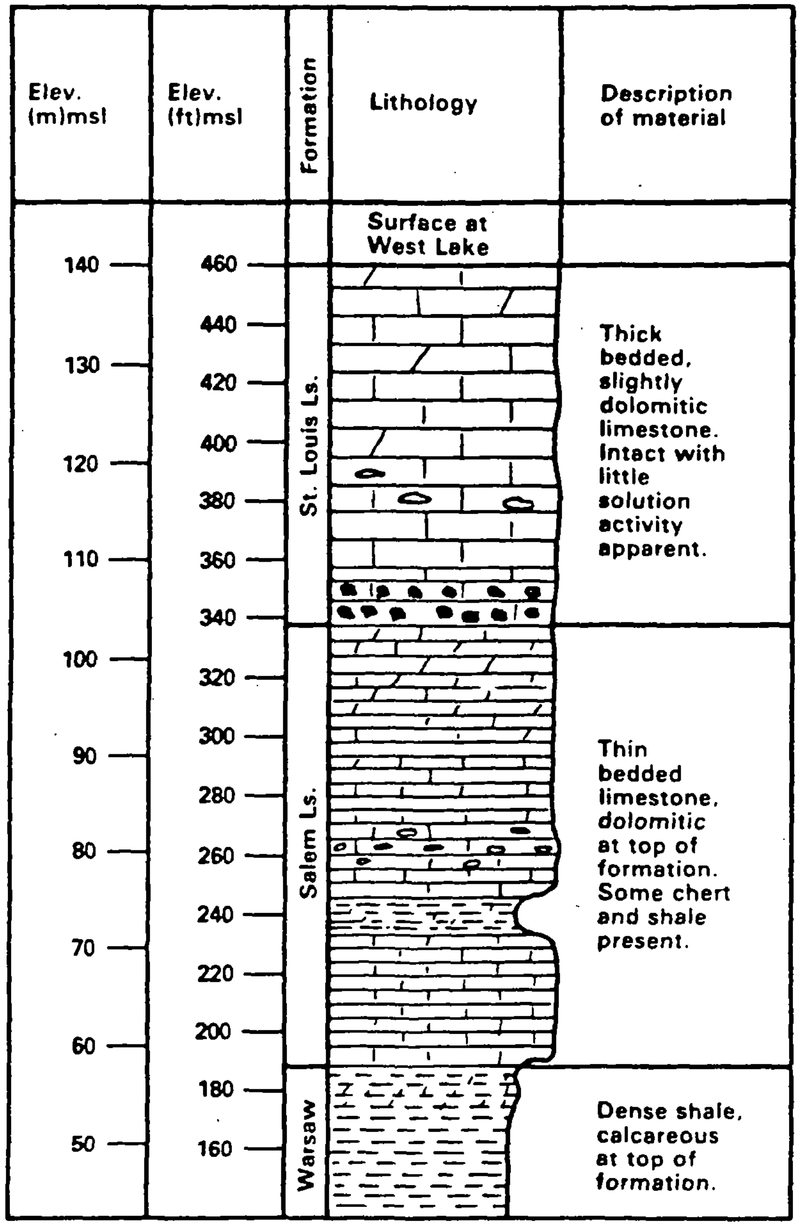


Figure 2.6 Bedrock stratigraphy (June 1984)

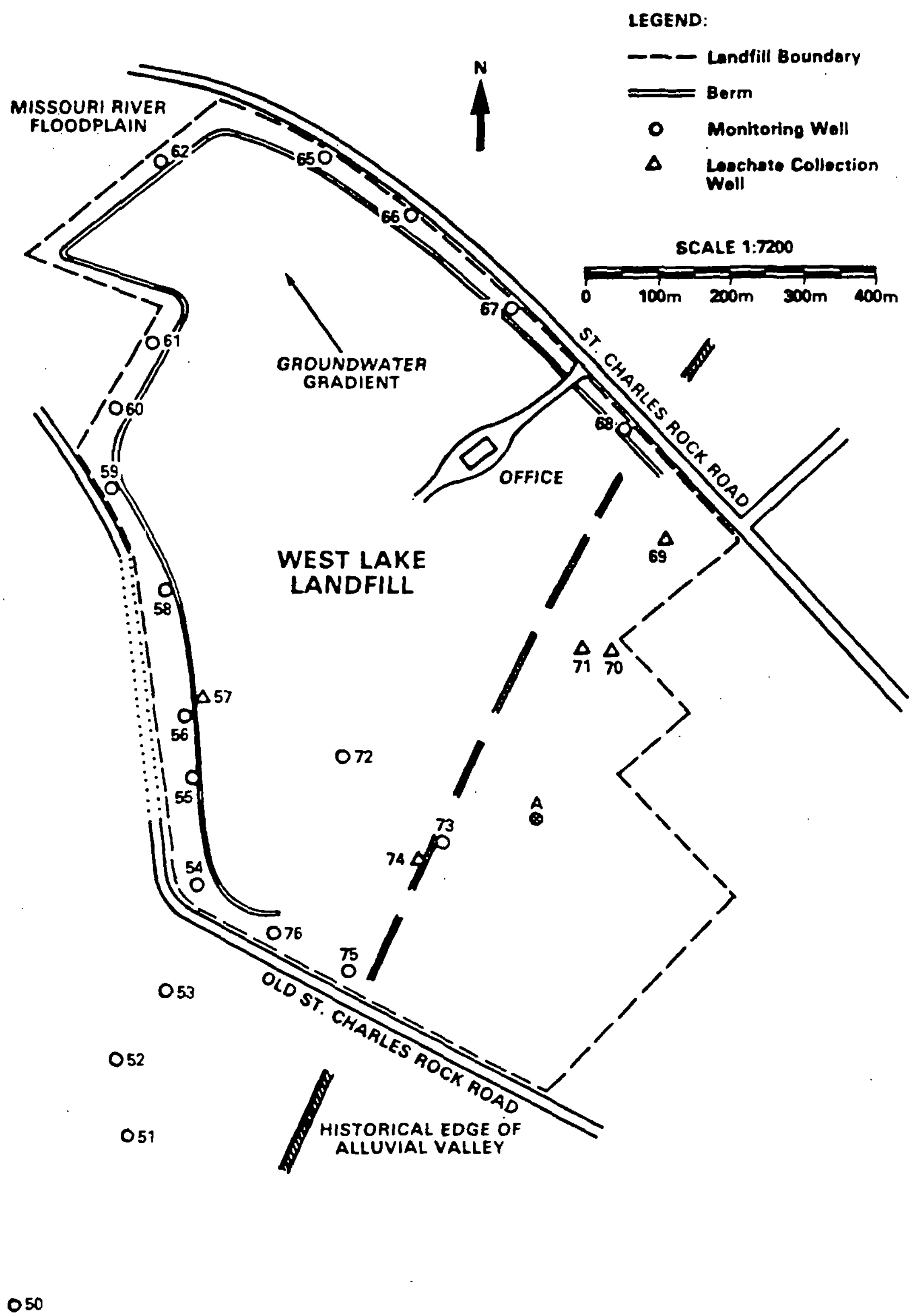


Figure 2.7 Location of monitoring wells (June 1984)

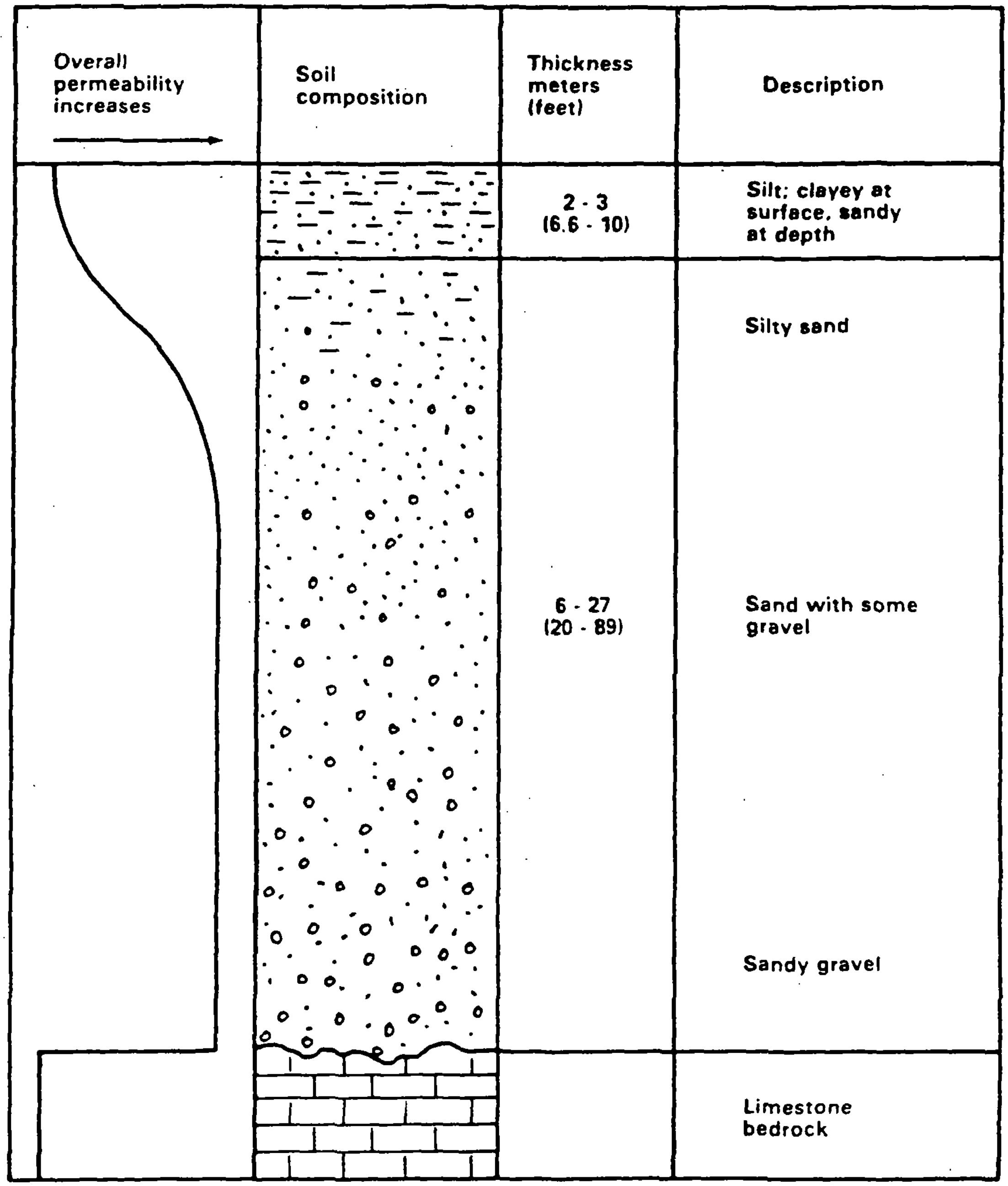


Figure 2.8 Soil profile of river alluvium (June 1984)

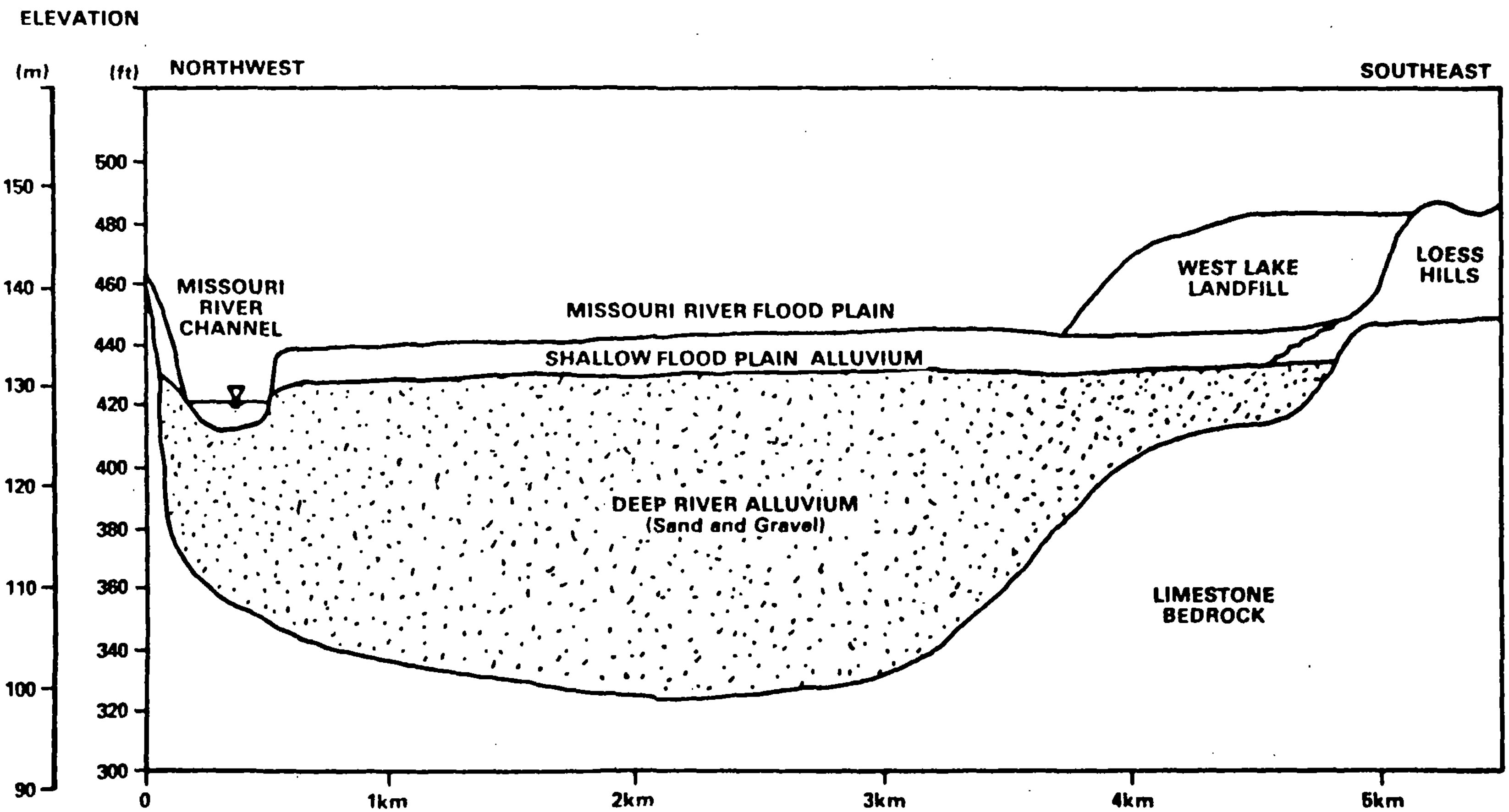


Figure 2.9 Cross-section of Missouri River alluvial valley (July 1986)

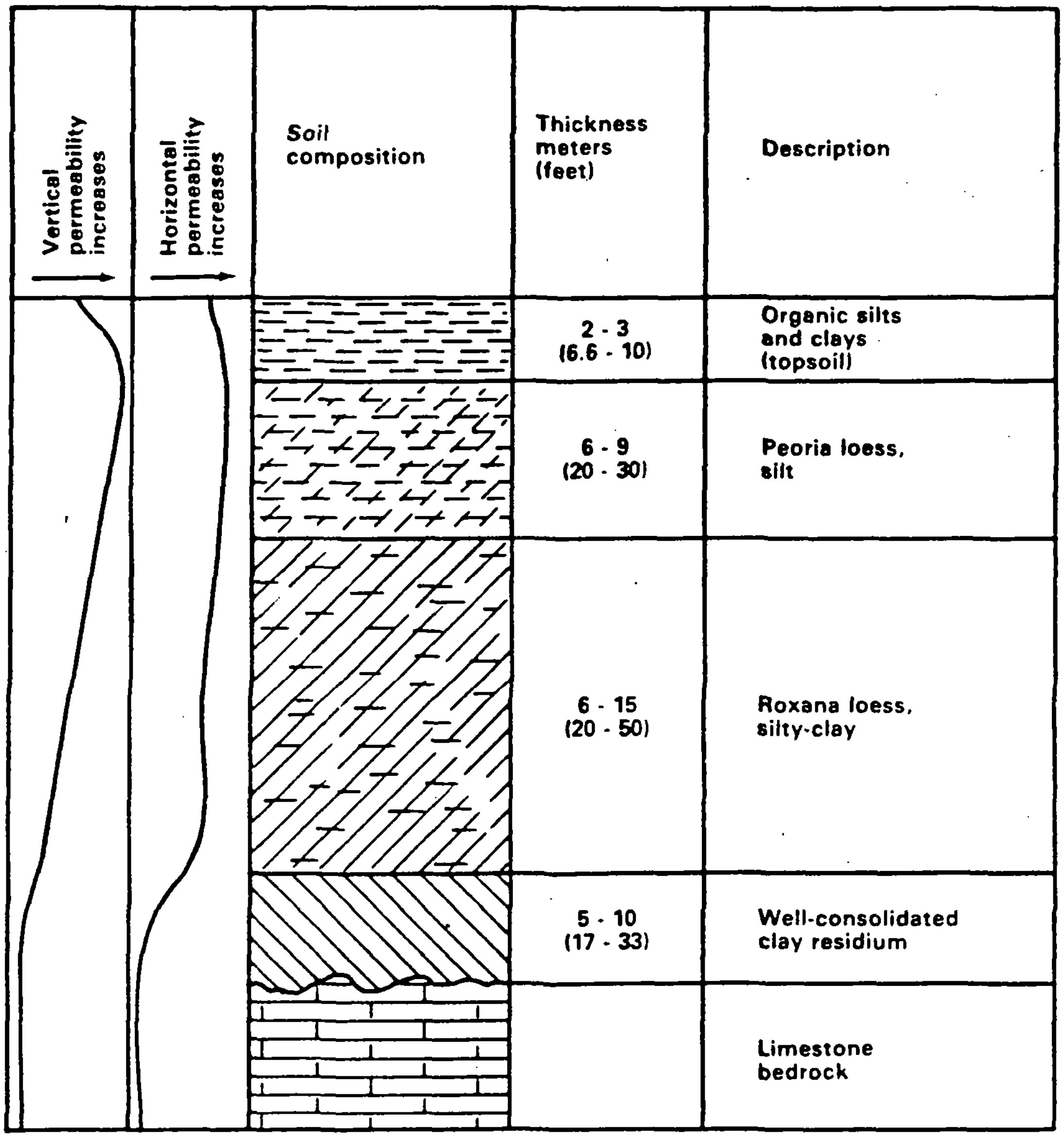
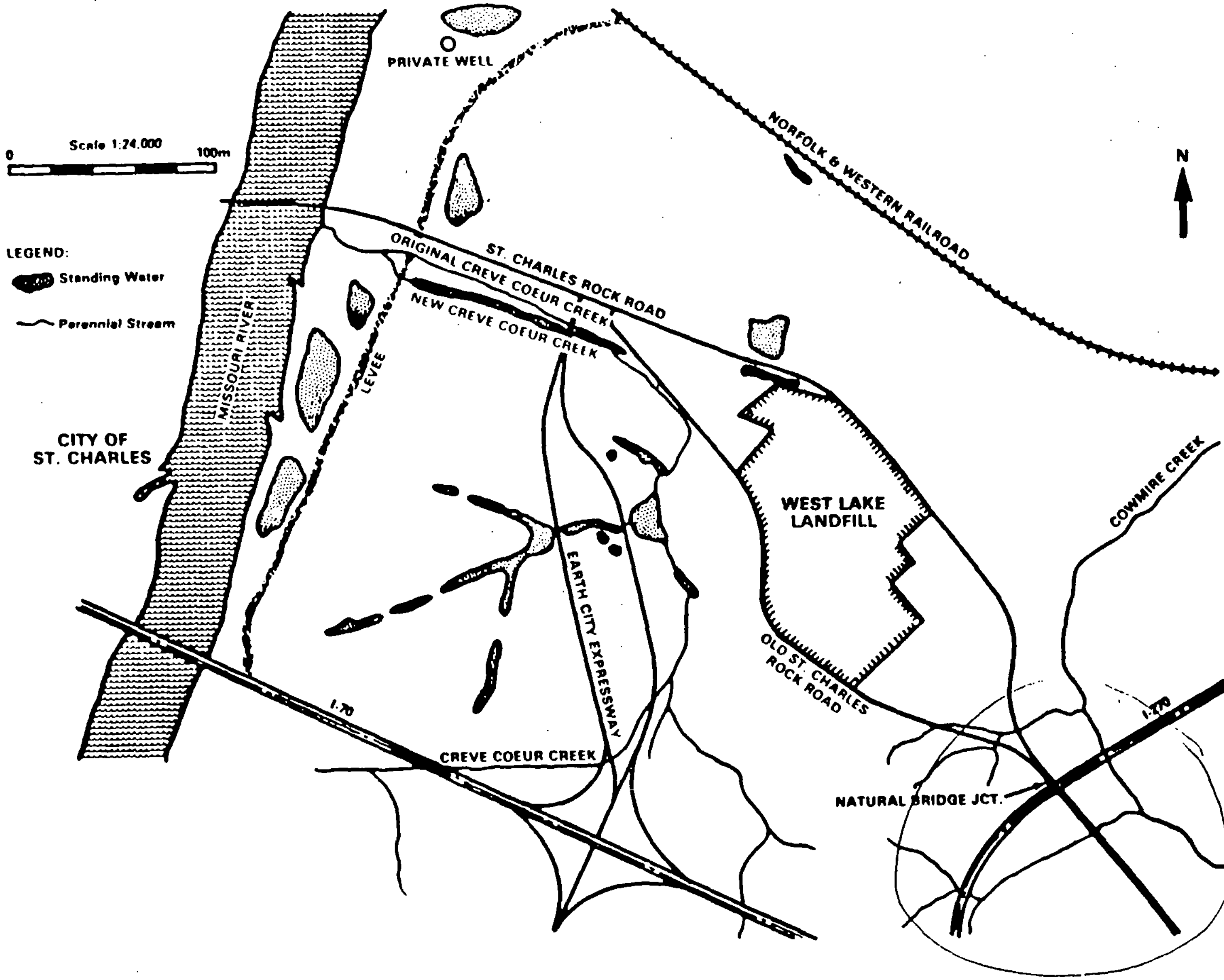


Figure 2.10 Soil profile of upland loessal soil (June 1984)



? Are these perennial streams

Figure 2.11 Surface hydrology of West Lake area (July 1986)

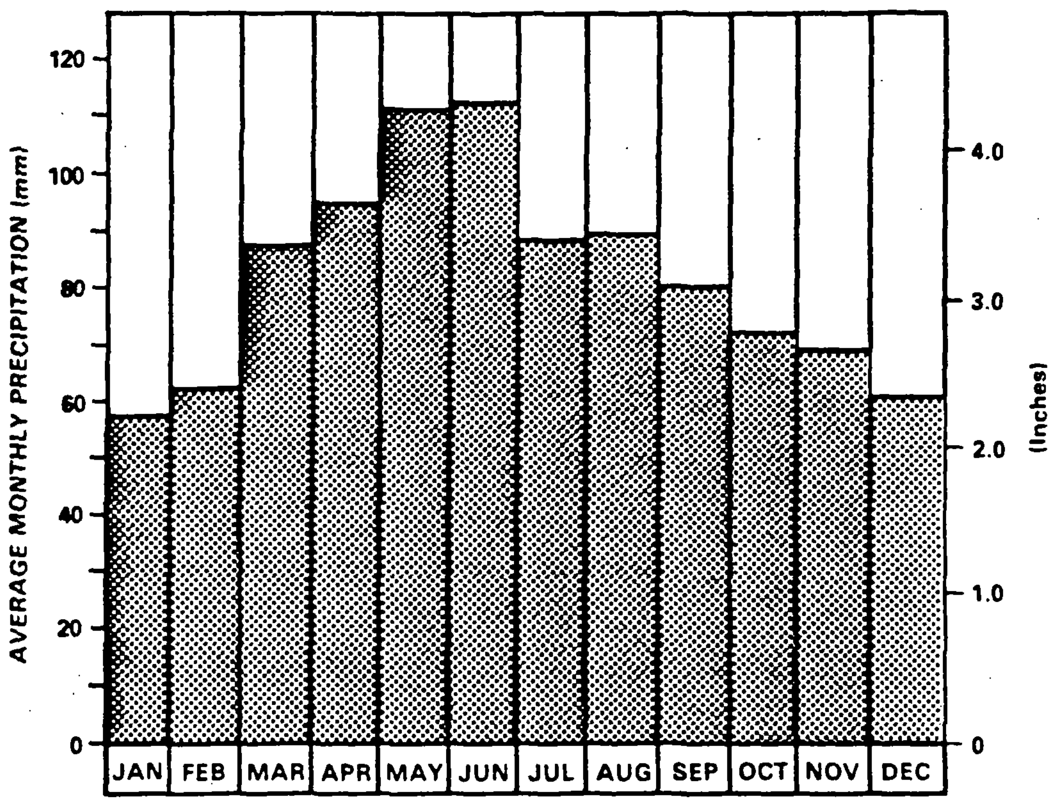
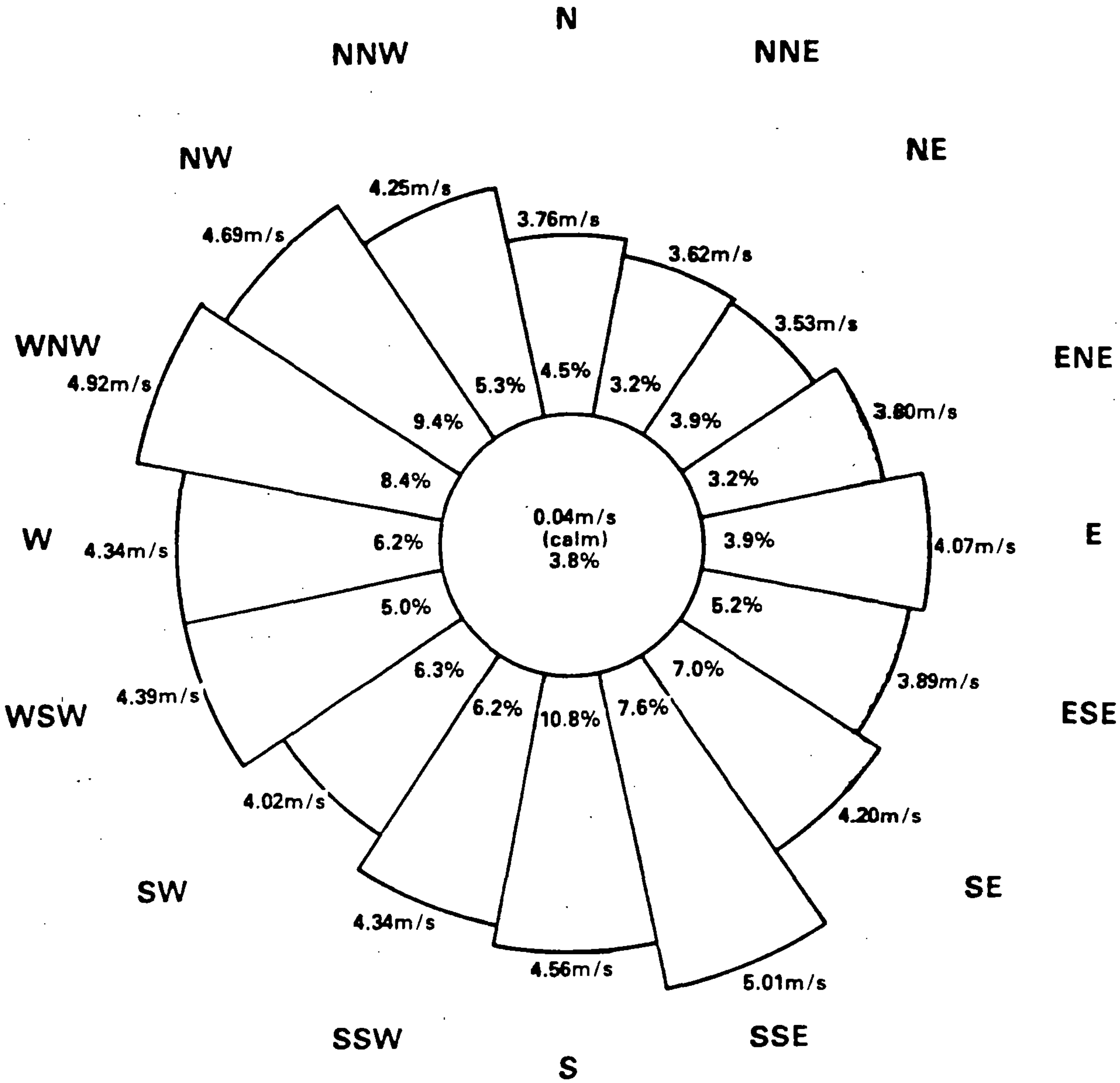


Figure 2.12 Average monthly precipitation at Lambert Field International Airport (July 1986)



Wind rose is for Lambert Field International Airport, Hazelwood, Missouri, and shows the percentage of hourly observations in each direction along with the average speed in that direction; for example: wind blew from the north 4.5% of the time at an average speed of 3.76 m/s.

Figure 2.13 Wind distribution for West Lake area (June 1984)

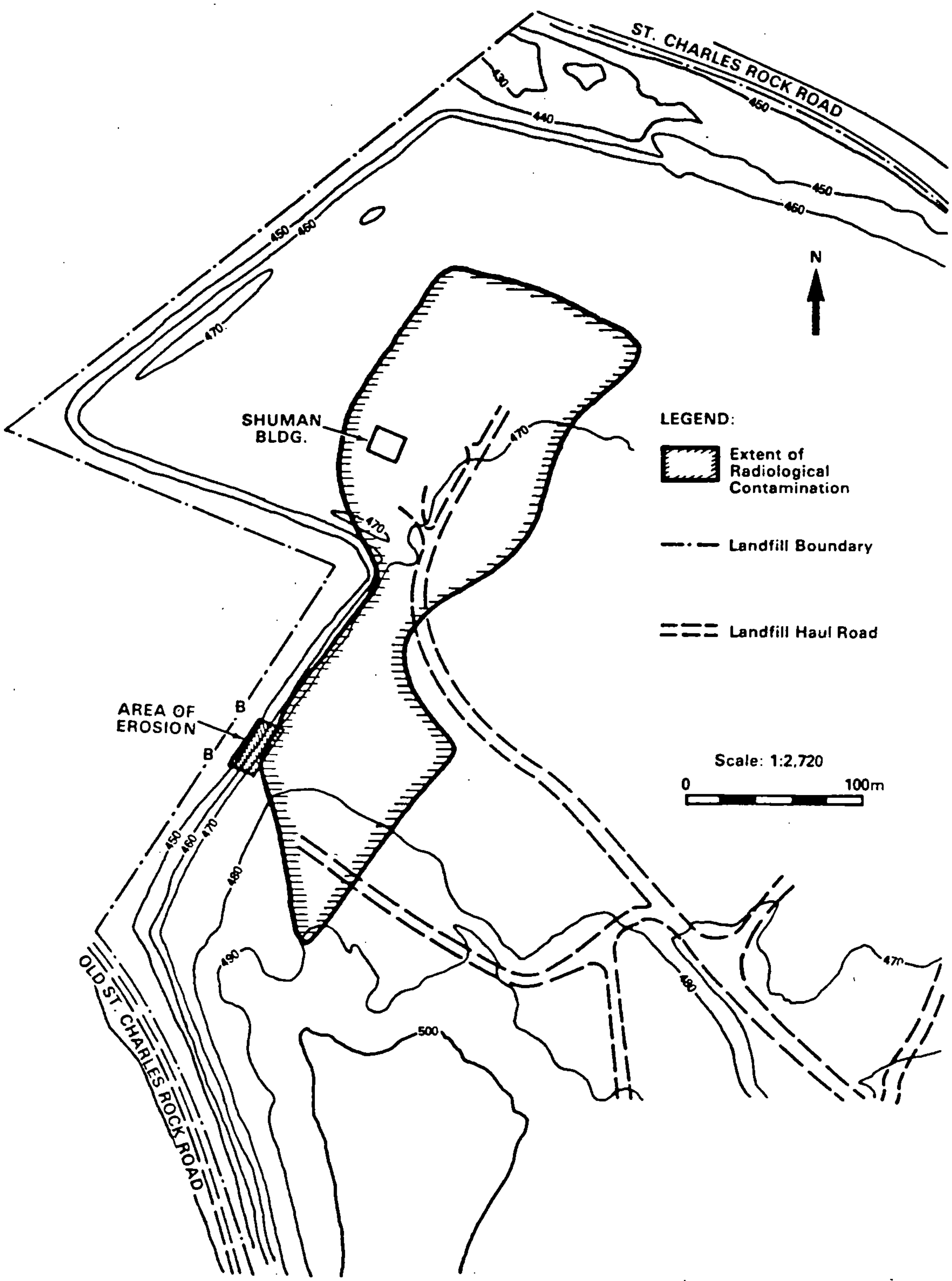
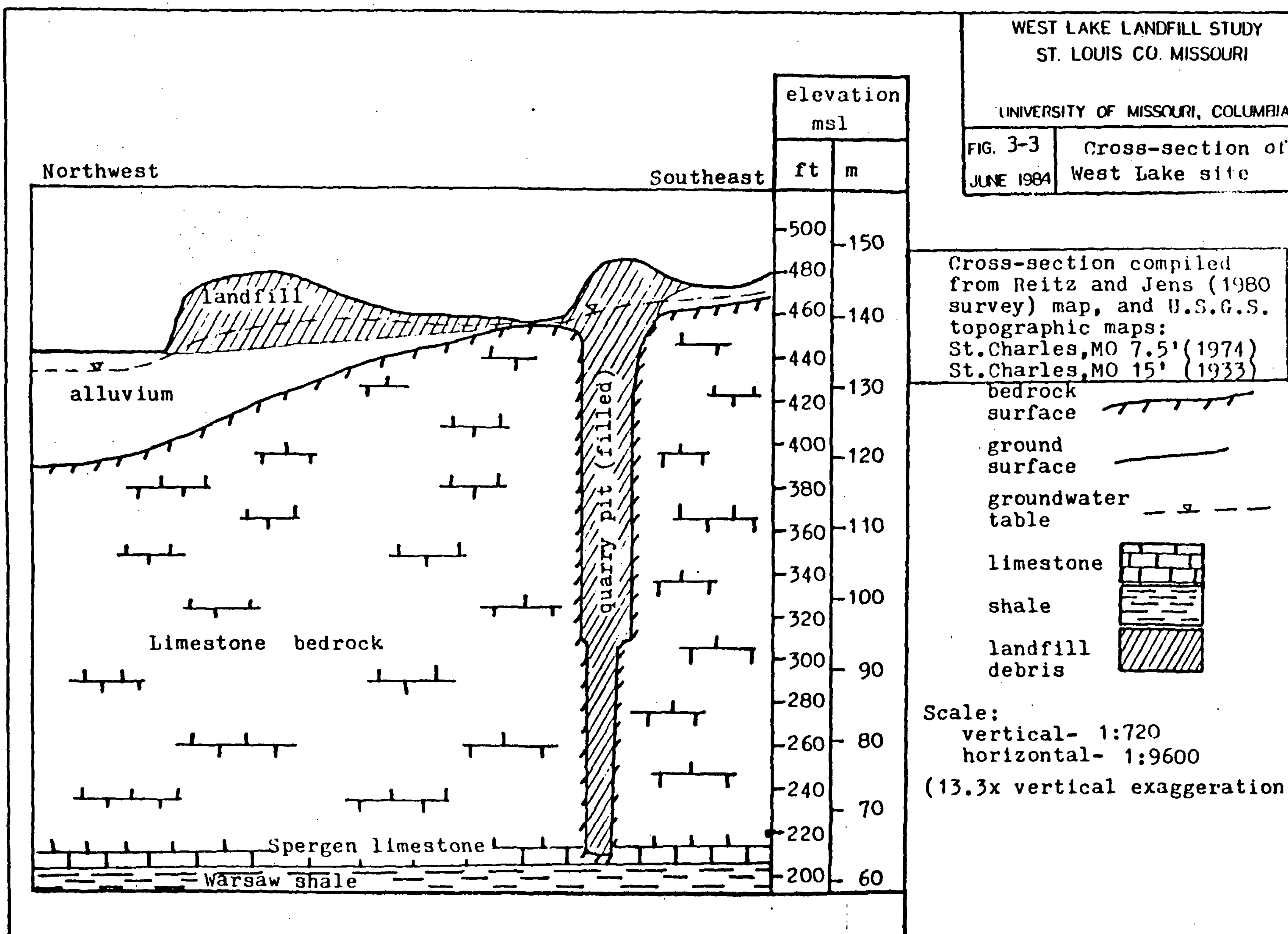


Figure 5.1 Contaminated Area 2 erosion site


WEST LAKE LANDFILL STUDY
ST. LOUIS CO. MISSOURI
UNIVERSITY OF MISSOURI, COLUMBIA
FIG. 3-3
JUNE 1984
Cross-section of West Lake site
elevation msl
ft
m
Northwest
Southeast
landfill
alluvium
quarry pit (filled)
Limestone bedrock
Spergen limestone
Warsaw shale
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
150
140
130
120
110
100
90
80
70
60
Cross-section compiled from Reitz and Jens (1980 survey) map, and U.S.G.S. topographic maps:
St.Charles,MO 7.5' (1974)
St.Charles,MO 15' (1933)
bedrock surface
ground surface
groundwater table
limestone
shale
landfill debris
Scale:
vertical- 1:720
horizontal- 1:9600
(13.3x vertical exaggeration)

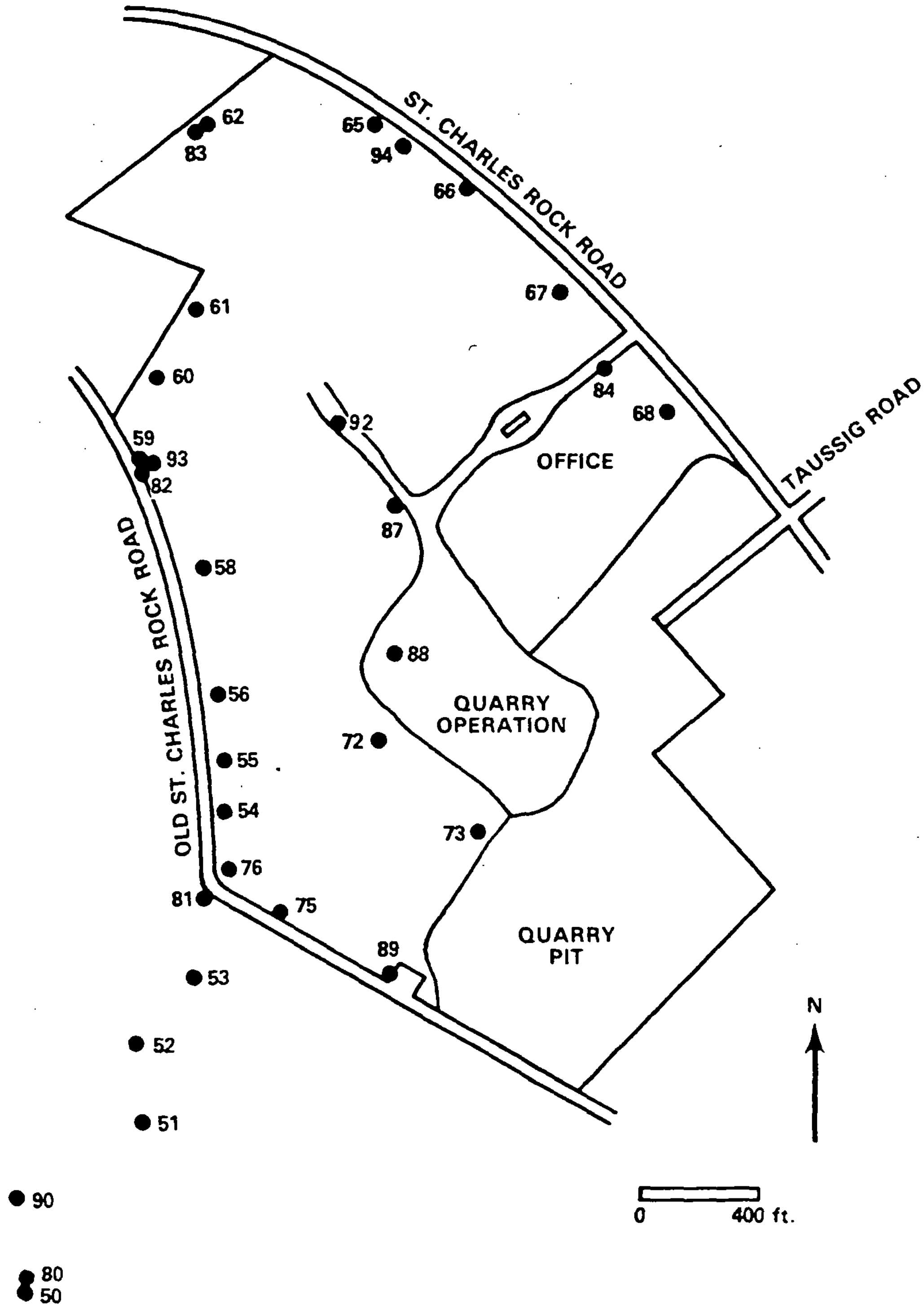
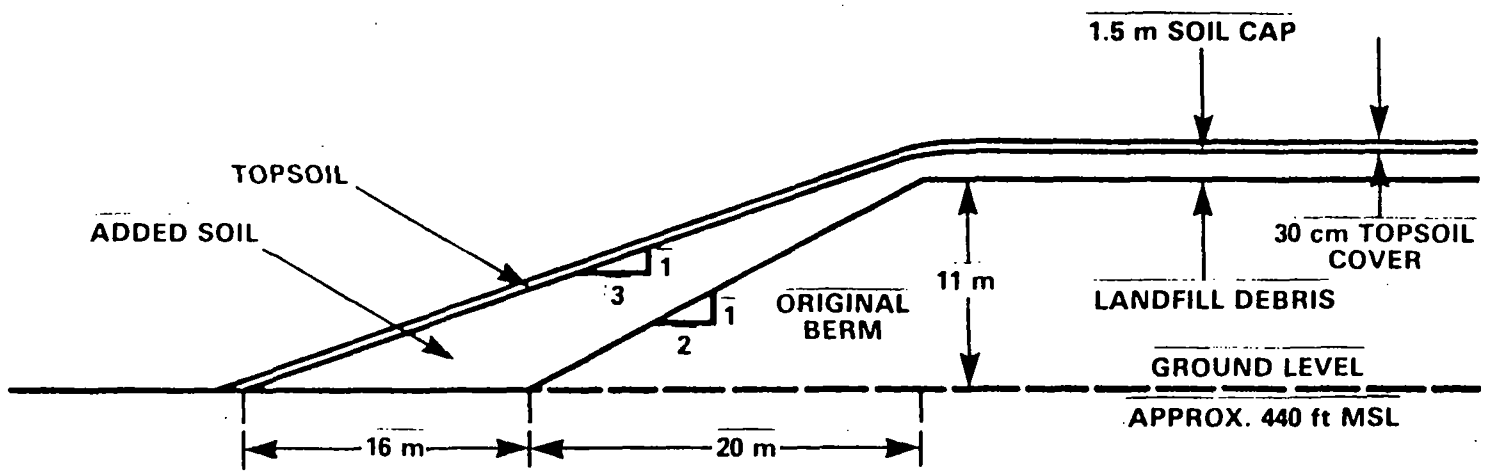


Figure 3.17 Well sampling locations at West Lake Landfill
(May 7 and 8, 1981)



Scale: 1:394
2.54 cm = 10 m

Figure 5.2 Cross-section of stabilized berm for option C

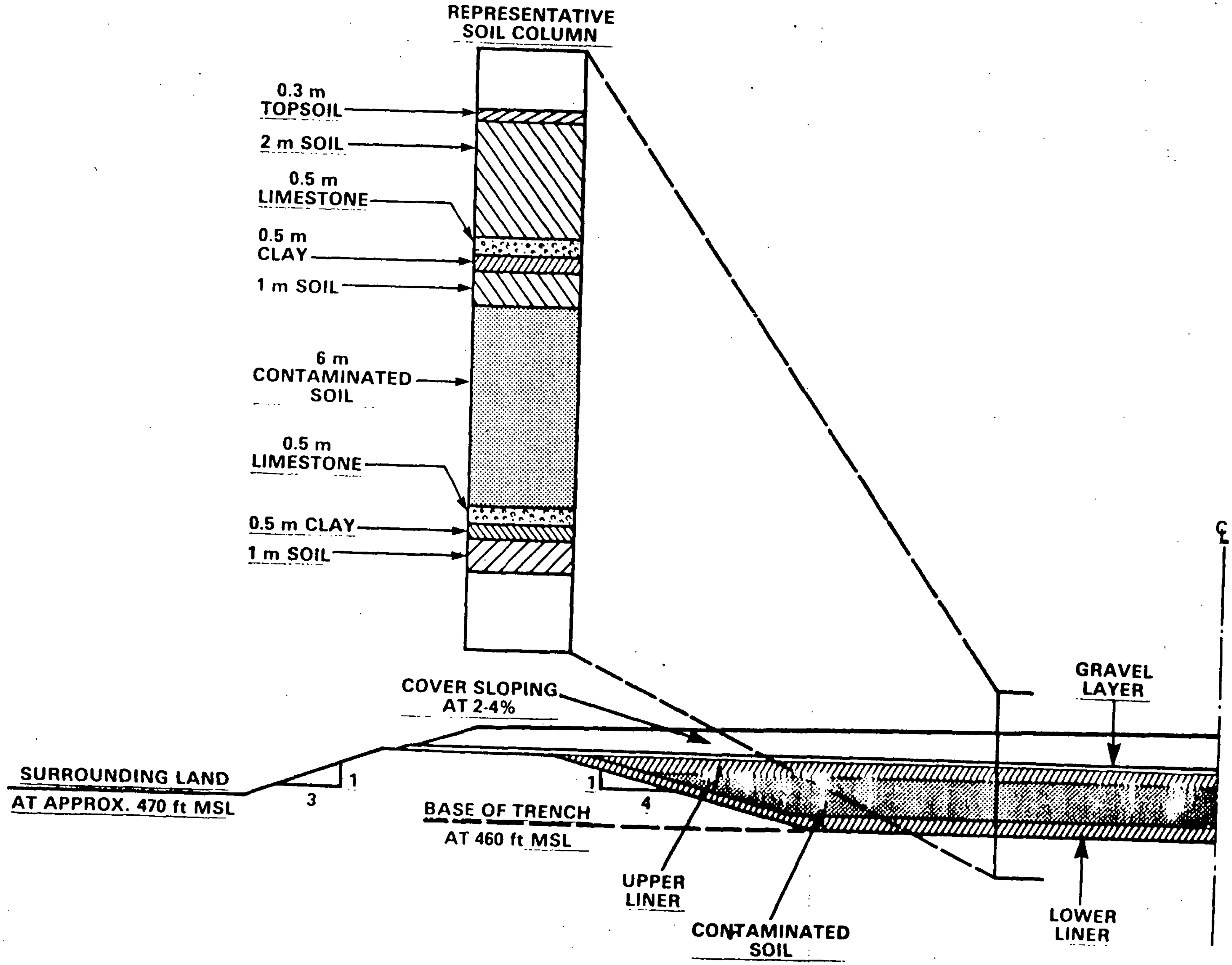


figure 5.3 Cross-section of trench for option E

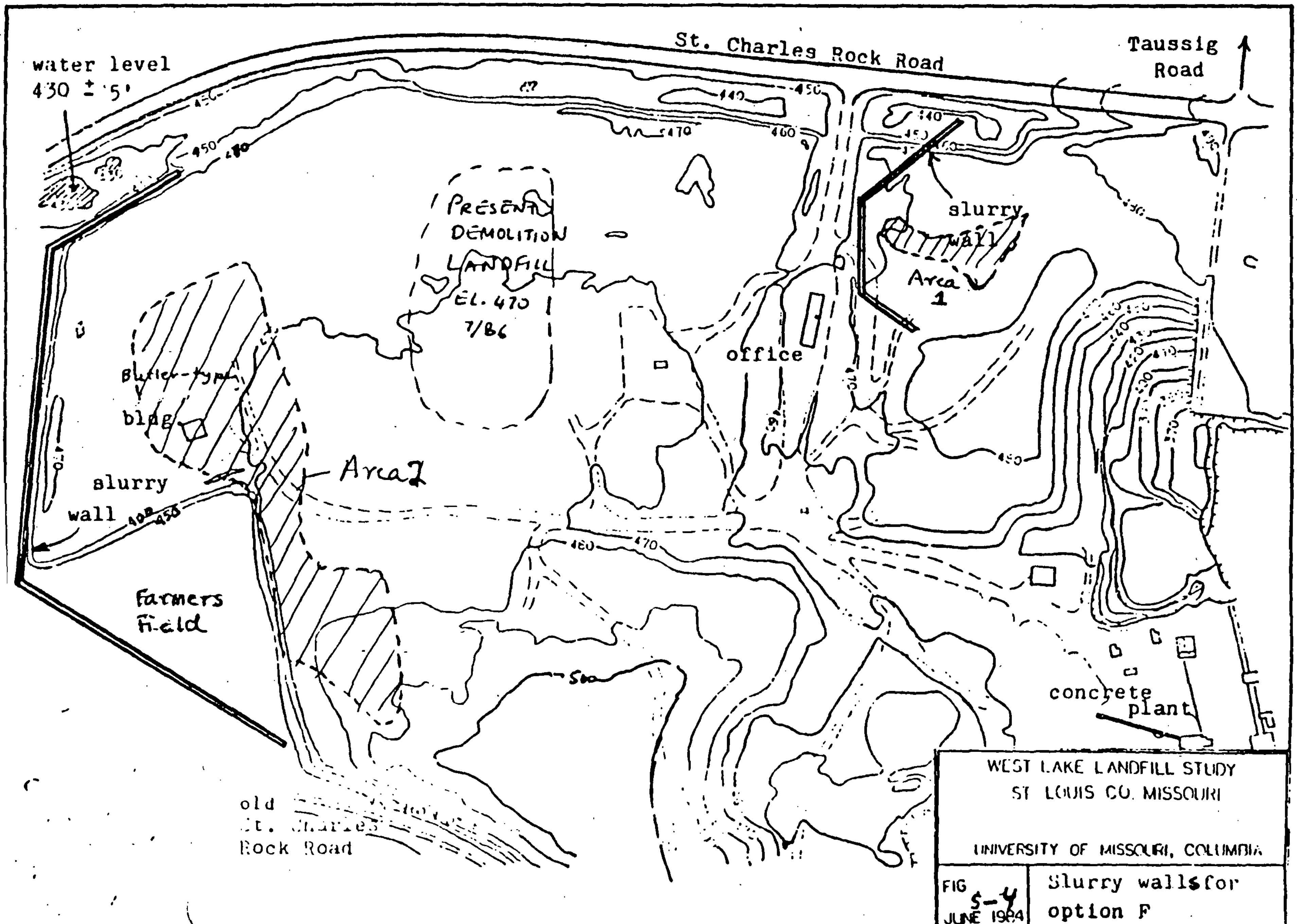


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FIG 5-4 JUNE 1984	Slurry walls for option F

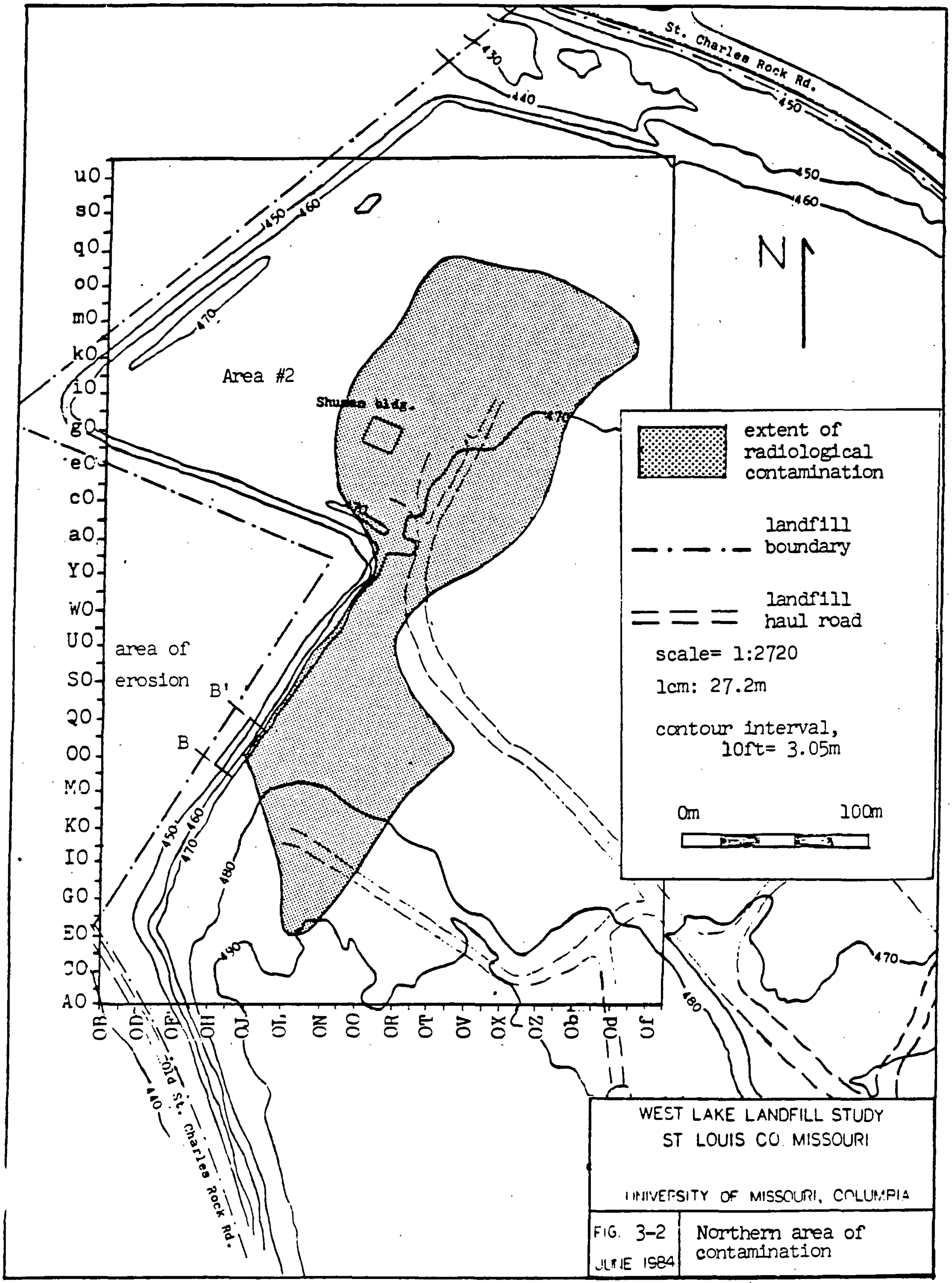
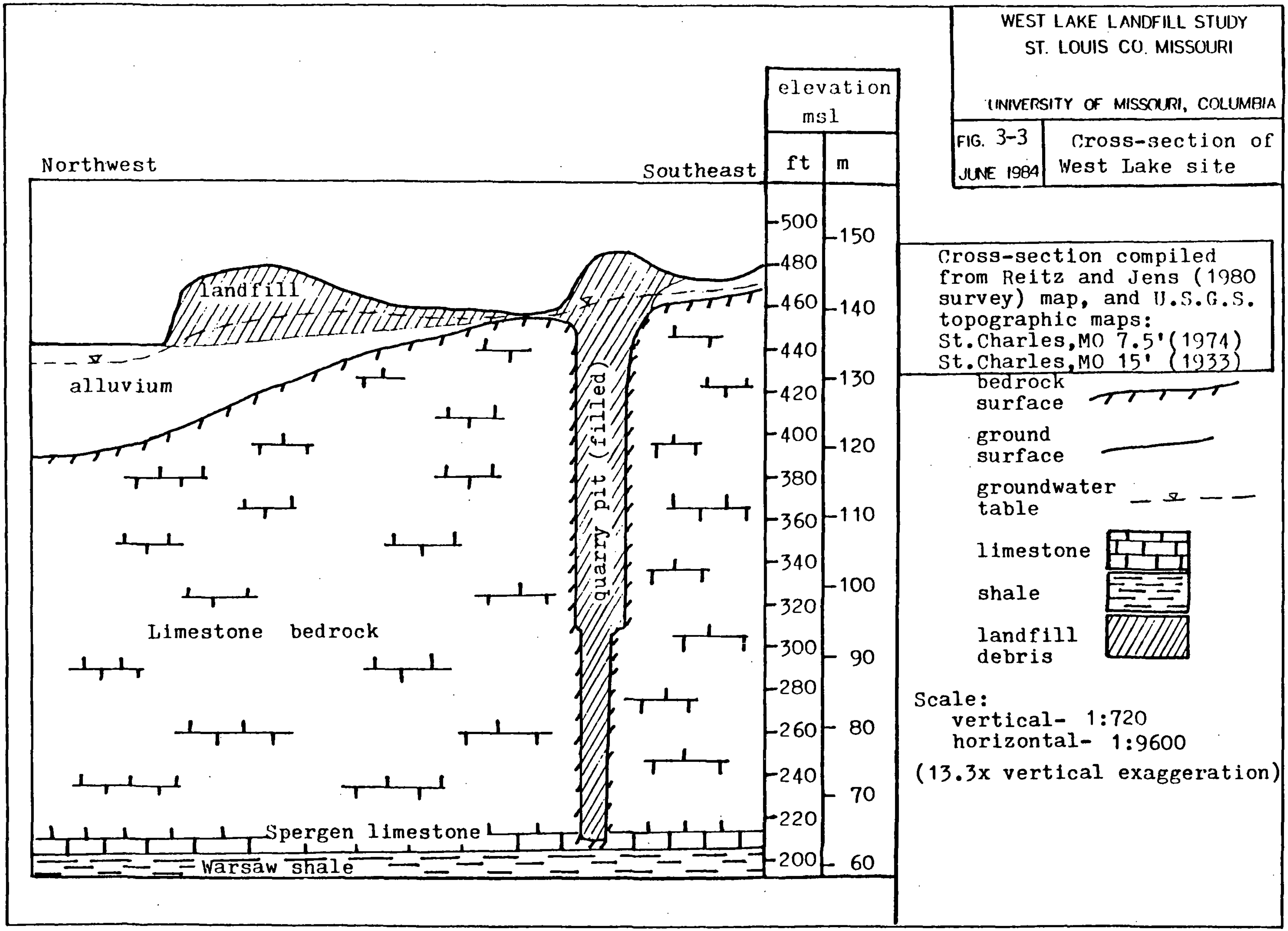


FIG. 3-2 Northern area of contamination


WEST LAKE LANDFILL STUDY
ST. LOUIS CO. MISSOURI
UNIVERSITY OF MISSOURI, COLUMBIA
FIG. 3-3
JUNE 1984
Cross-section of West Lake site
elevation msl
ft
m
Northwest
Southeast
landfill
alluvium
quarry pit (filled)
Limestone bedrock
Spergen limestone
Warsaw shale
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
150
140
130
120
110
100
90
80
70
60
Cross-section compiled from Reitz and Jens (1980 survey) map, and U.S.G.S. topographic maps:
St.Charles,MO 7.5'(1974)
St.Charles,MO 15' (1933)
bedrock surface
ground surface
groundwater table
limestone
shale
landfill debris
Scale:
vertical- 1:720
horizontal- 1:9600
(13.3x vertical exaggeration)

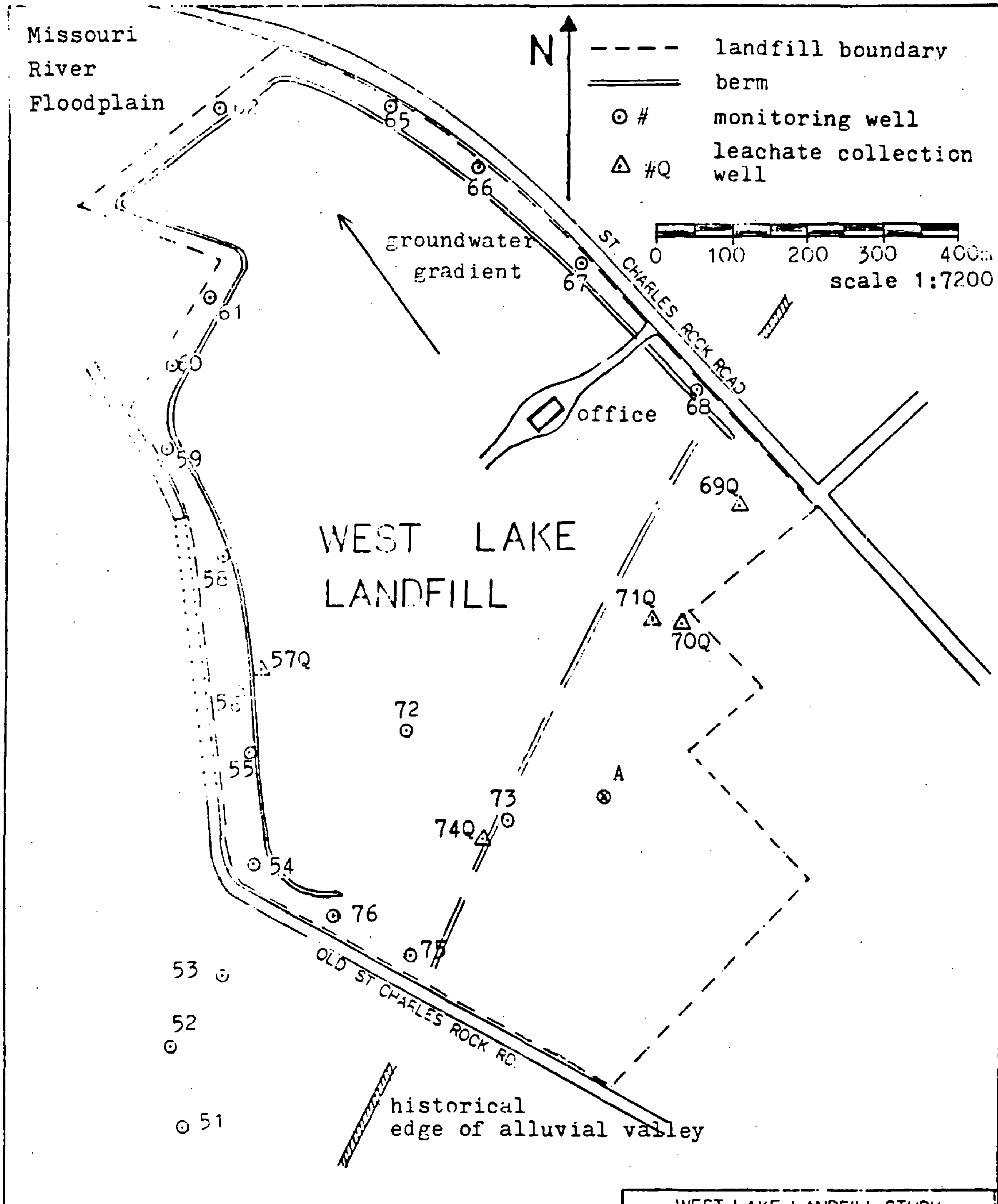


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FIG. 4-1 JUNE 1984	Locations of monitoring wells

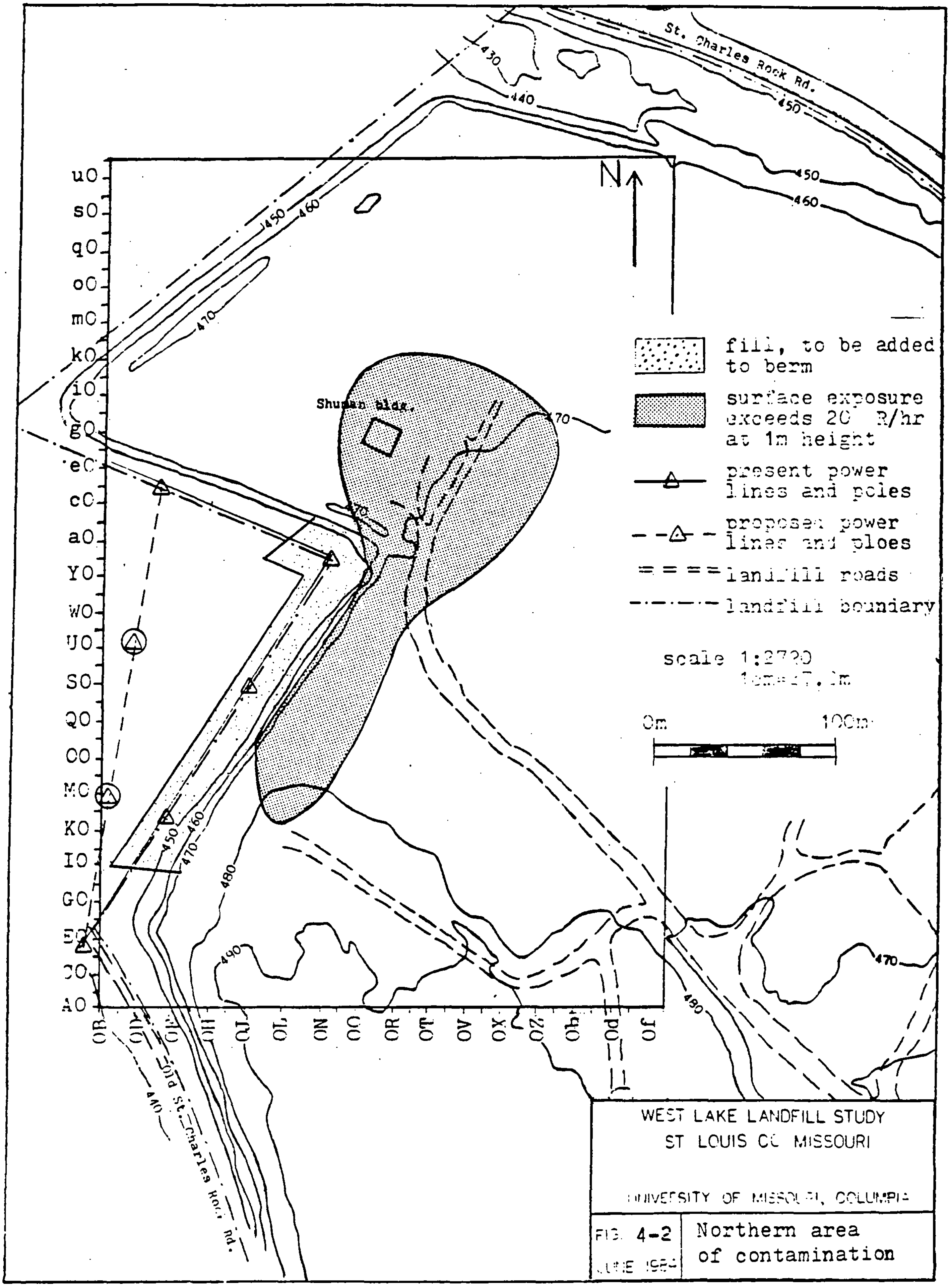
St. Charles Rock Rd.
N
fill, to be added to berm
surface exposure exceeds 20 R/hr at 1m height
present power lines and poles
proposed power lines and ploes
landfill roads
landfill boundary
scale 1:2720
0m
100m
Shuman bldg.
St. Charles Rock Rd.
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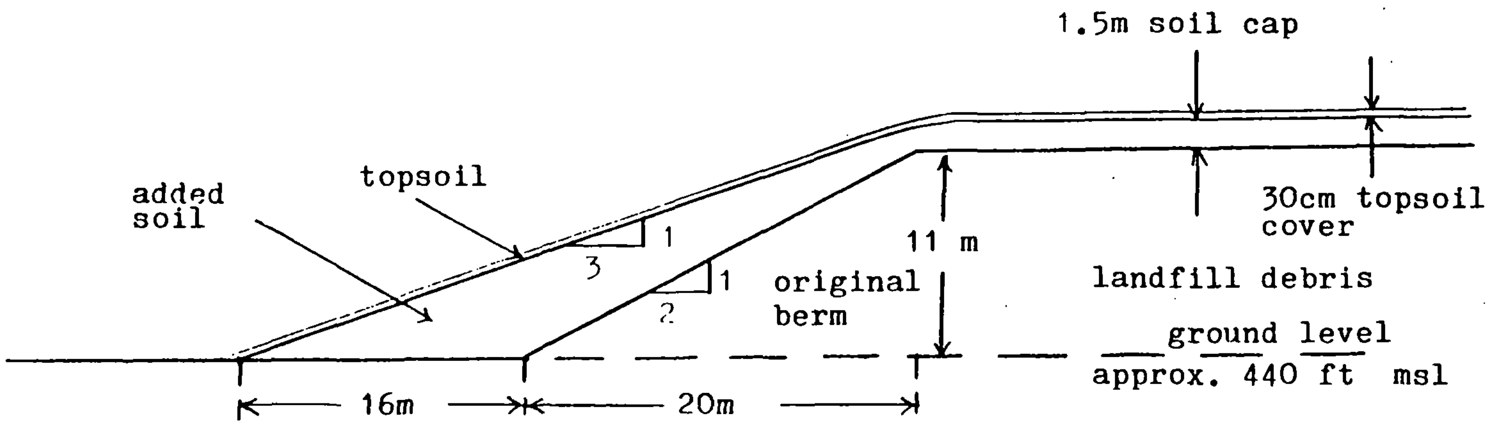
FIG. 4-2
JUNE 1984
Northern area of contamination



scale 1:394

2.54cm = 10m

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FIG. 4-3 JUNE 1984	Cross-section of stabilized berm

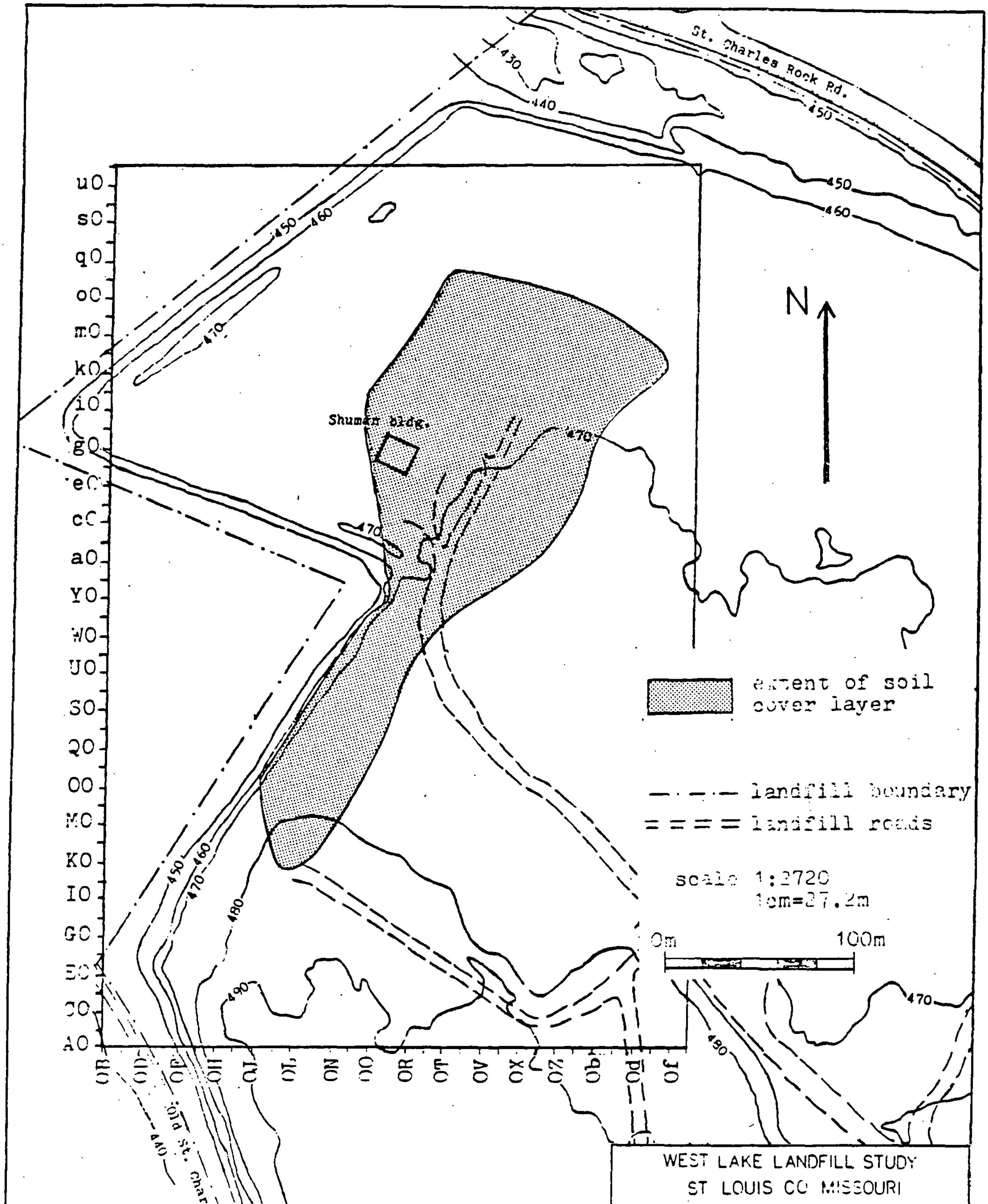

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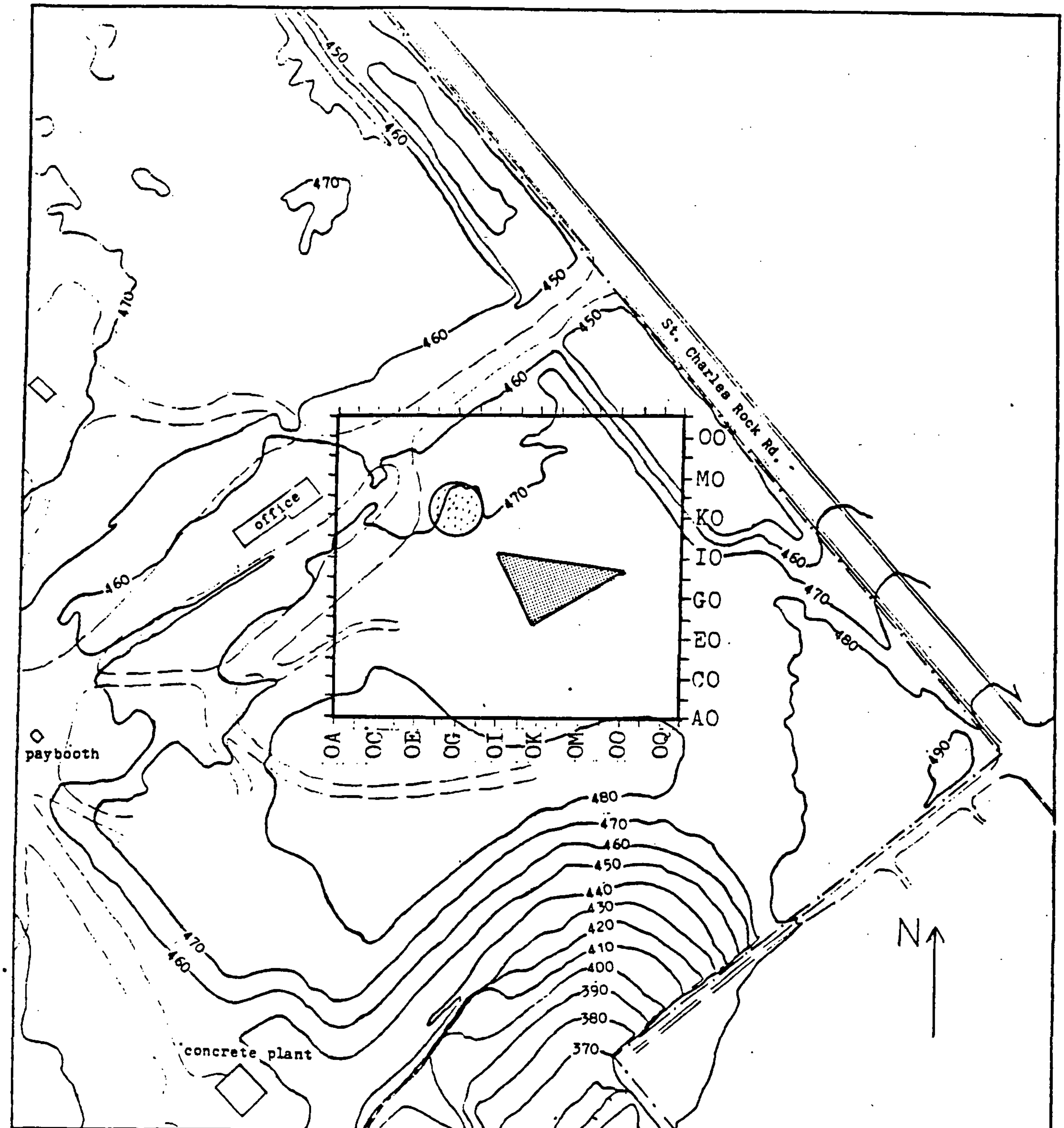
FIG 4-4 Northern area of contamination

JUNE 1984



surface exposure exceeds 20 R/hr at 1m (1984)

area of known subsurface contamination 15 pCi/g Ra-226

landfill boundary

landfill roads

1:2720
1cm=27.2m

0m 100m

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FIG. 4-5 Southern area of contamination
JUNE 1984

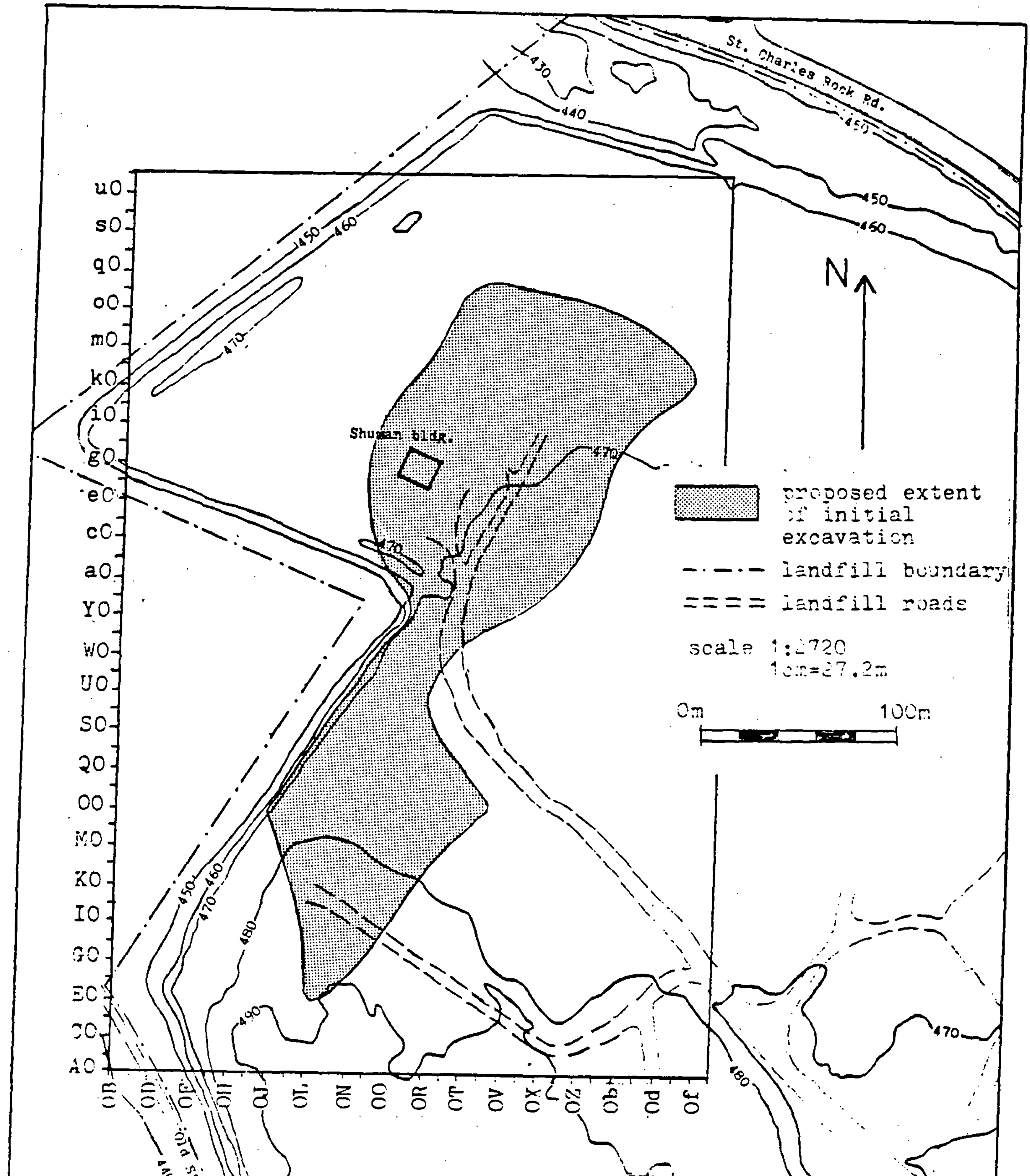

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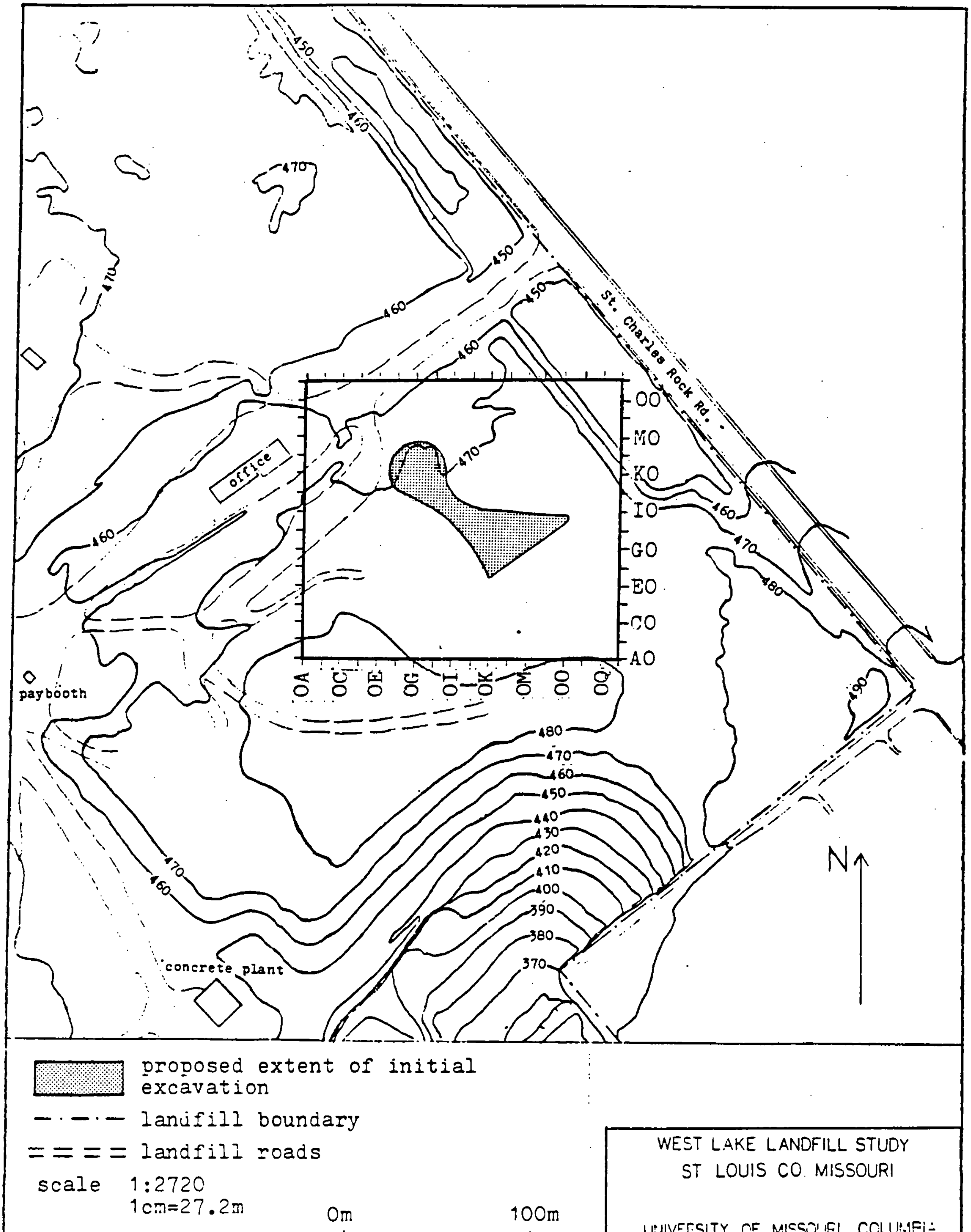
FIG. 4-6 JUNE 1984 Northern area of contamination


St. Charles Rock Rd.
office
paybooth
concrete plant
450
460
470
480
490
440
430
420
410
400
390
380
370
OO
MO
KO
IO
GO
EO
CO
AO
OA
OC
OE
OG
OI
OK
OM
OO
OQ
N
proposed extent of initial excavation
landfill boundary
landfill roads
scale 1:2720
1cm=27.2m
0m
100m
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4-7
Southern area of contamination

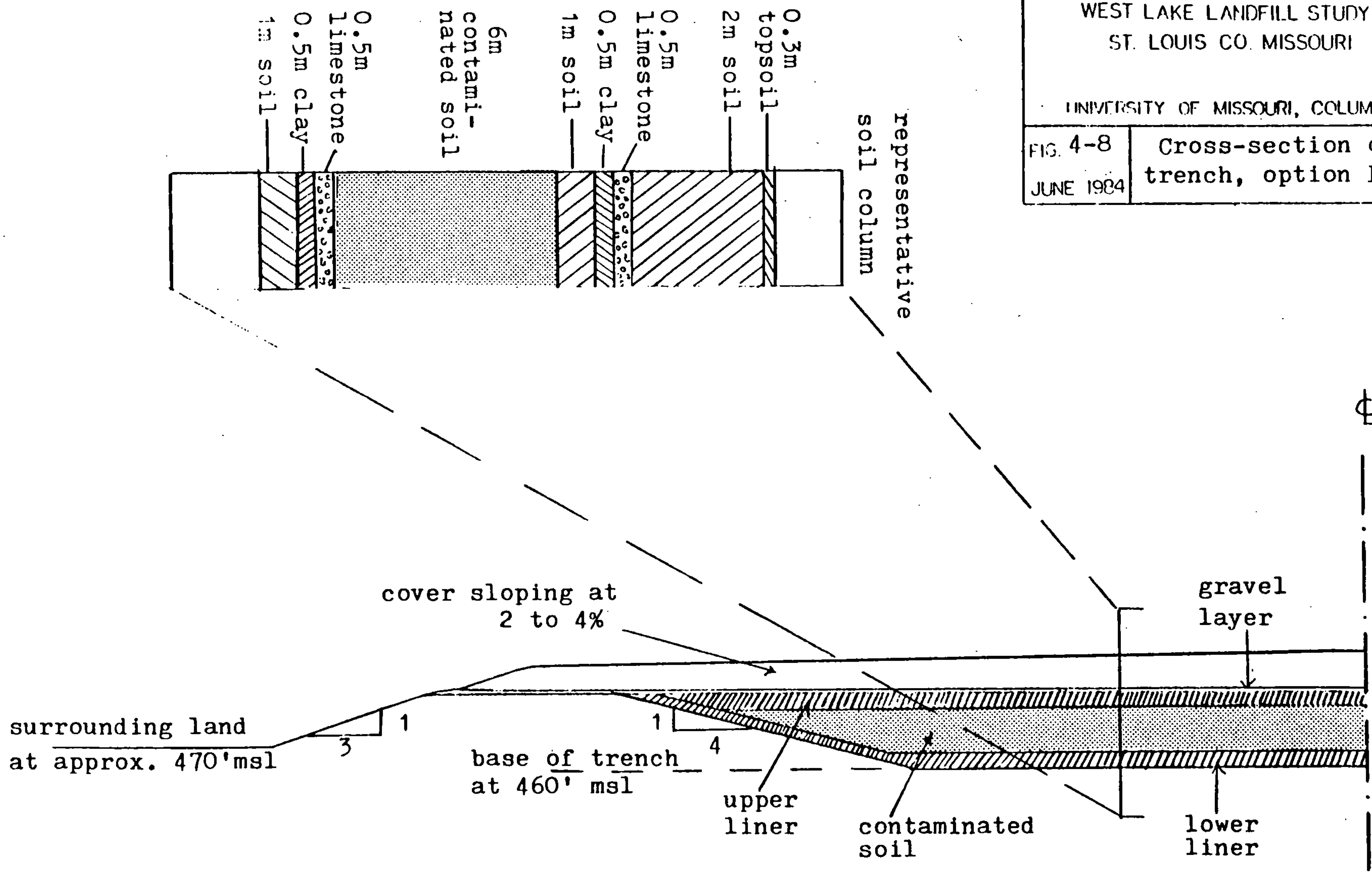

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FIG. 4-8 Cross-section of trench, option D

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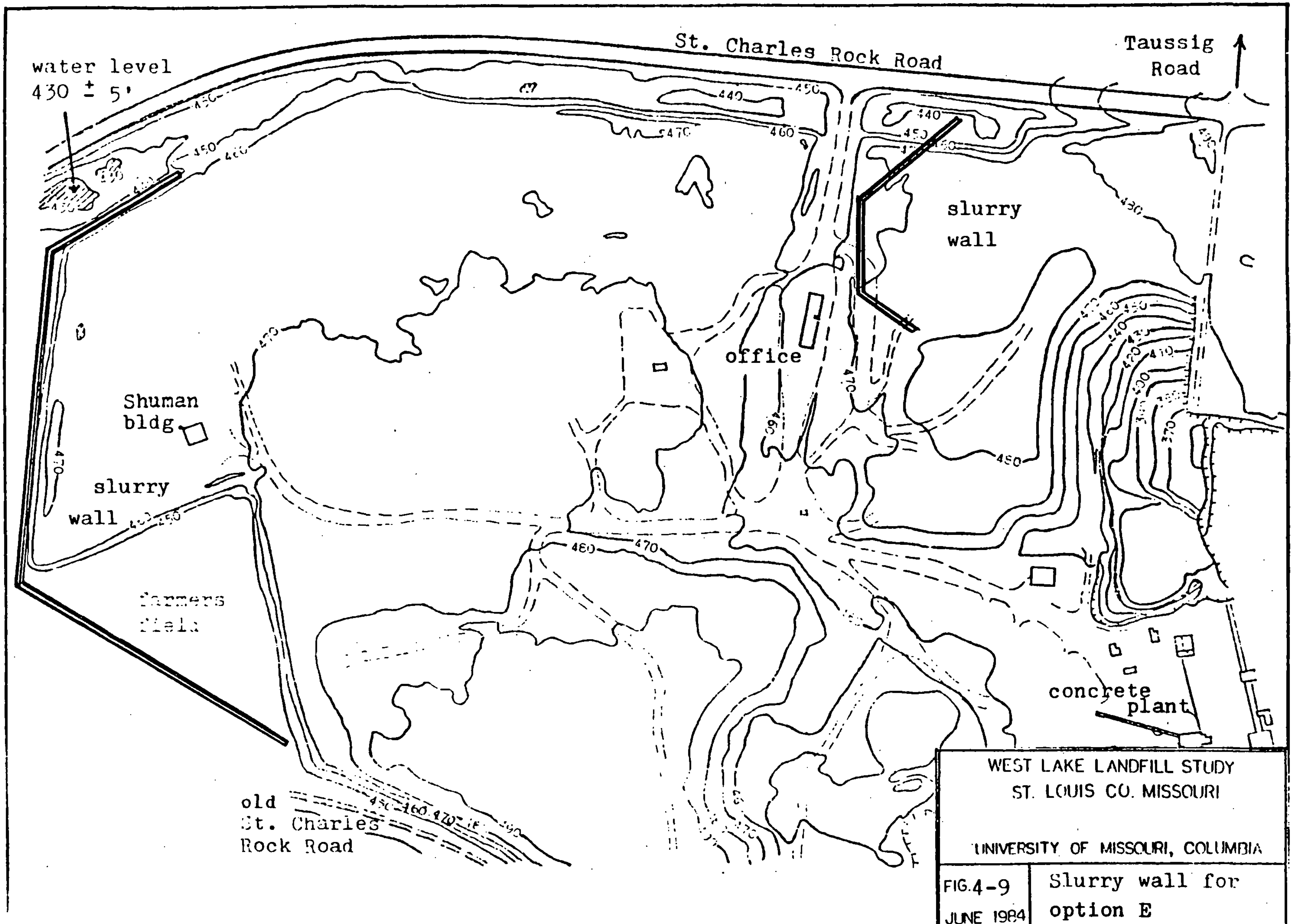

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FIG. 4-9 Slurry wall for option E
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