FMC NORTHERN ORDNANCE DIVISION
MINNEAPOLIS

FEASIBILITY STUDY

FMC and BNR Lands Groundwater Regime

Submitted Pursuant to June 8, 1983
Administrative Order and
Interim Response
Order by Consent, Section III, Paragraph C

January 1985
Ref. No. 1518

CONESTOGA-ROVERS & ASSOCIATES LIMITED

EXECUTIVE SUMMARY

The following report evaluates the impact of the FMC Site, using 10^{-6} excess cancer risk criterion, with particular emphasis on the existing Minneapolis Water Works intake on the Mississippi River, but also with reference to potential future human receptors.

The report concludes that in light of the remedial activities undertaken to date and the hydrology of the site, contaminants carried by the groundwater to the identified present and potential receptors do not pose a significant health risk even using a most conservative set of assumptions. Specifically, the report concludes that:

- Existing empirical data indicate that trichloroethylene (TCE) is the groundwater contaminant of concern at the Site, and that TCE decreases in concentration in the range of from two to three orders of magnitude while migrating from the Site to the Mississippi River.

- The worst case incremental loading of TCE to the Minneapolis Water Works intake attributable to the Site is 0.375 ppb (assuming no aquifer attenuation) or 0.004 ppb (assuming aquifer attenuation).

- These concentrations would result in an excess cancer risk of between 10^{-6} and 10^{-7} for the 0.375 ppb incremental loading and of between 10^{-8} and 10^{-9} for the 0.004 ppb incremental loading for a consumer of untreated water at the Minneapolis Water Works intake; these risks are not significant and are within acceptable levels without any further remedial action.

- Likewise for future potential human receptors, excess cancer risks are within acceptable levels - i.e., zero for the Anoka County Parkland area and from 10^{-6} to 10^{-8} for a future City of Minneapolis Ranney Well situated in the vicinity of the Site.

The analysis of the report shows that no further study of remedial action alternatives need be conducted. A necessary predicate for the requiring of any further remedial action under the Consent Order and National Contingency Plan does not exist in that the impact of the Site on the current receptor (the Minneapolis Water Works intake) and potential future receptors identified by the Agencies is presently and is predictated to remain at or below the criterion of 10^{-6} for excess cancer risk.

In order to confirm and verify that the groundwater contaminant levels at the Site, and between the

Site and the Mississippi River, decrease from or do not significantly exceed present levels in the future, it is recommended that a comprehensive groundwater monitoring program be developed and implemented.

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1.0 INTRODUCTION

1.1 PURPOSE AND STRUCTURE OF REPORT

This report is submitted in accordance with Section III (Additional Work on FMC Site) paragraph C, of the June 8, 1983 Administrative Order and Interim Response Order by Consent (Consent Order)*/ between FMC Corporation (FMC), the Minnesota Pollution Control Agency (MPCA), and the United States Environmental Protection Agency (USEPA), (hereafter referred to collectively as the Agencies). The Consent Order requires FMC to:

> "conduct a feasibility study following completion of the remedial investigation specified in paragraph A above to identify and assess remedial action alternatives and recommend the most appropriate remedial action(s). The feasibility study shall be conducted following procedures outlined in the National Contingency Plan, 40 C.F.R. § 300.68 (a-j) and § 300.70, as promulgated by the U.S.EPA on July 16, 1982."(1)

FMC prepared a feasibility study work plan(23) addressing the requirements of the Consent Order. This work plan was submitted for approval by the Agencies on September 25, 1984. Conditional approval to

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*/ See, Bibliography, Item (1). Hereafter, Bibilography Items will be referred to by number alone - i.e., (1).

proceed with the work plan was given by the Agencies (MPCA letter dated October 15, 1984; USEPA letter dated October 22, 1984) */.

Further discussions with the Agencies resulted in final approvals (MPCA letter dated December 6, 1984; USEPA letter dated December 7, 1984) that required, *inter alia*, evaluation of the impact of the FMC Site, using the 10^{-6} excess cancer risk criterion, on the following receptors:

Current Receptor - the Minneapolis Water Works intake on the Mississippi River.

Potential Future Receptors - i) Anoka County's use of groundwater as a drinking water source for the proposed park west of Anoka County Highway No. 1.

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*/ The work plan was approved by the Agencies with the additional requirement that, without regard to what the risk assessment might show, FMC also evaluate remedial actions which would be designed to meet contaminant levels of 10^{-6} and 10^{-5} excess cancer risk criteria at several evaluation locations. In accordance with this Agency request, FMC is submitting under separate cover a report entitled "Evaluation of Remedial Action Alternatives", January, 1985.

ii) The use of the groundwater by the Minneapolis Water Works through a proposed "Ranney" well system as conceptualized in the preliminary report submitted to the City of Minneapolis.(24)

This feasibility study (FS) report is organized in the following manner:

Section 1 discusses the general background of the Site including past disposal practices and investigations and remedial activities completed to date.

Section 2 describes the geology of the Site, and the operative flow and contaminant transport systems within the groundwater regime.

Section 3 evaluates the impact of the Site on present and future potential human receptors.

Section 4 provides conclusions generated by the above three sections.

1.2 SITE BACKGROUND

1.2.1 Description

The Site is an unimproved piece of land located in the City of Fridley, Anoka County, Minnesota as illustrated on Figure 1. The Site is divided into two distinct areas on the basis of ownership. The larger area, approximately 13 acres, is owned by FMC and is located directly south of the FMC plant. This parcel of land (hereafter referred to as the FMC lands) is bounded by FMC plant lands to the north, the Anoka County Highway No. 1 (East River Road) to the west, the Burlington Northern Railway (BNR) marshalling yards to the east, and the second parcel of land addressed by the FS to the south.

The second parcel of land (hereafter referred to as the BNR lands) was owned by FMC and sold in 1969 to the BNR who is the current owner. These lands, approximately five acres, are bounded by the FMC lands to the north, the BNR marshalling yard to the east, and East River Road to the west and south. Figure 2 identifies the two areas (hereafter collectively referred to as the Site) addressed under the FS.

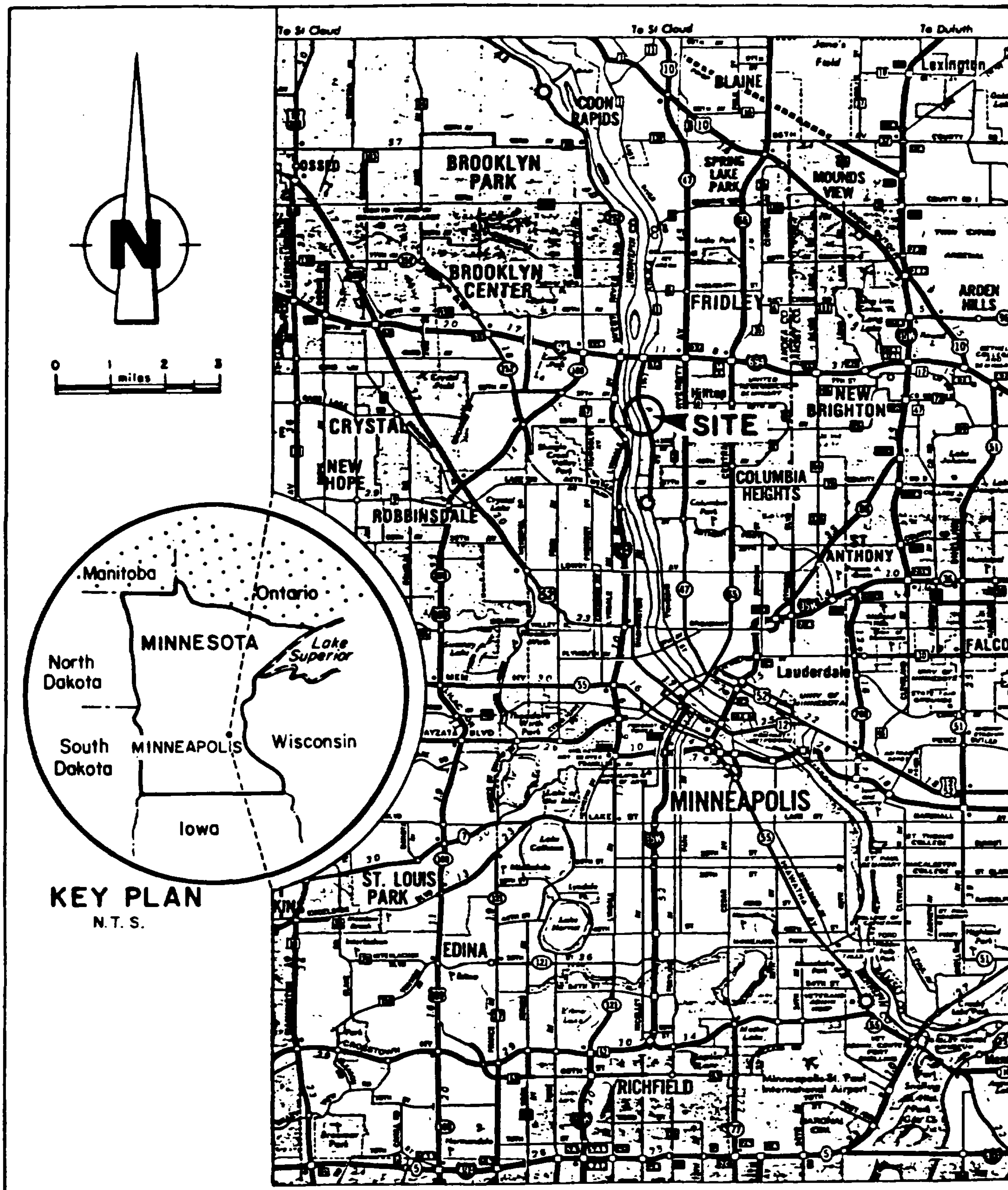

figure I

LOCATION PLAN

FMC Northern Ordnance Plant

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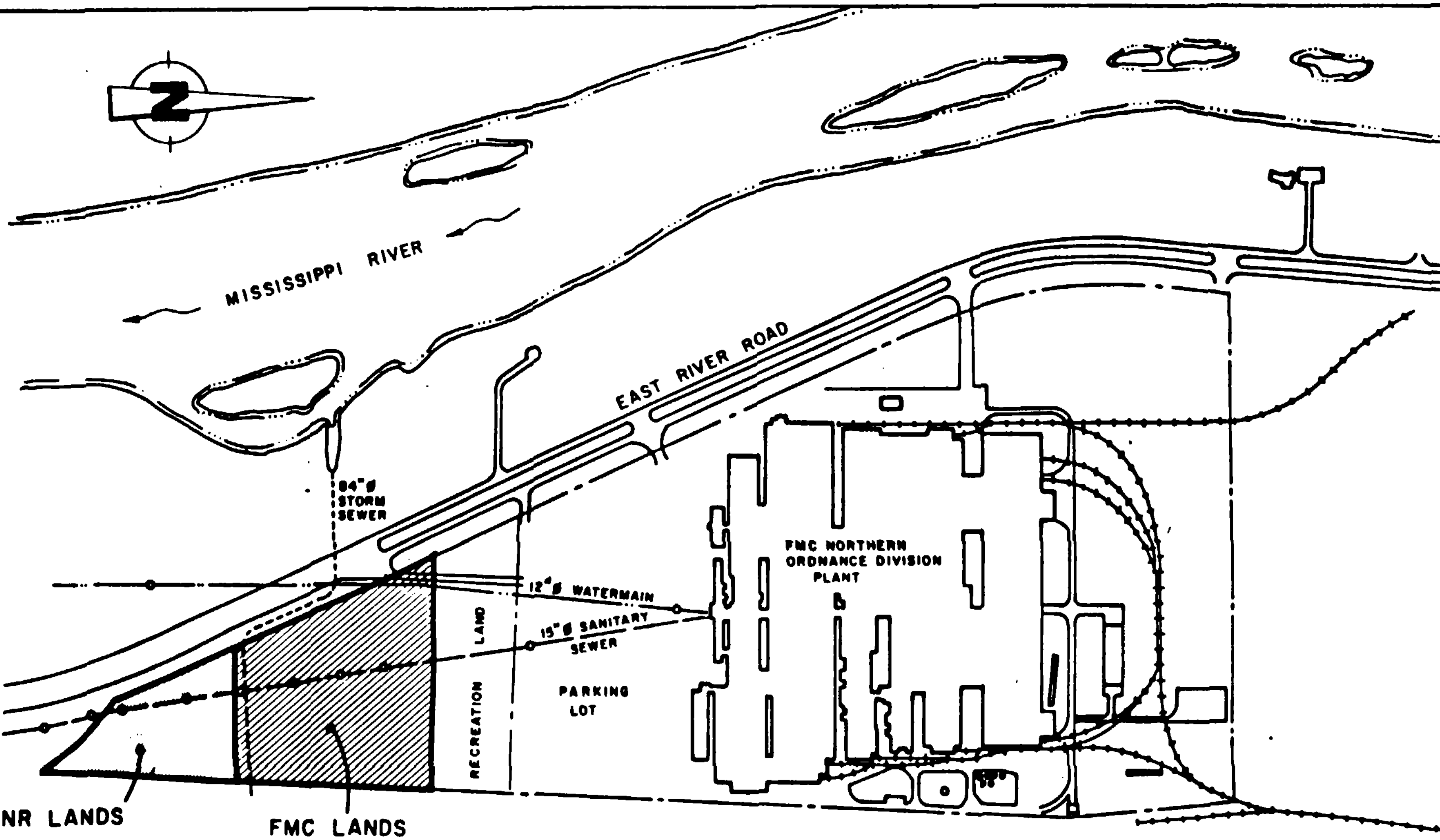

figure 2

SITE PLAN

FMC Northern Ordnance Plant

CRA

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The Site and lands immediately adjacent to the north, east and south, are currently zoned "Heavy Industrial". The property to the west of the Site, which is separated from the Site by East River Road, is owned by Anoka County and is zoned "Single Family Dwellings", although there are no occupied structures on the property. The Mississippi River is located directly west of the County lands.

The County lands were purchased from FMC on July 7, 1982 for development as recreational parkland under the Great River Roads Project which was federally funded. Construction of this recreational area is scheduled to be completed in 1985. Property improvements will include picnic grounds with washroom facilities and drinking fountains.

A 15-inch diameter sanitary sewer traverses the central portion of the Site in a north-south direction while an 84-inch diameter storm sewer is located beneath the Site in an east-west orientation approximately 40 feet north of the BNR lands. A total of 41 groundwater monitoring wells have been installed on and adjacent to the Site since 1981. In addition, a containment and treatment facility (CTF) has been constructed in the northeast corner of the Site for the storage and treatment of contaminated site soils. The CTF was constructed in the summer of 1983 under a Remedial Action

Plan stipulated by the Consent Order. A more detailed discussion of the remedial construction program is provided in Section 1.3. Figure 3 illustrates known surface and subsurface features associated with the Site.

1.2.2 History

The FMC plant, located north of the Site, was first constructed during the period 1940 to 1941 as a naval ordnance manufacturing facility. From 1941 to 1964, the facility was owned by Northern Ordnance, Inc., a subsidiary of the Northern Pump Company, and during this period the Site was used for burning and disposal of general plant wastes including industrial liquids. In 1964, FMC acquired the Northern Ordnance, Inc. operation and the disposal site from Northern Pump Company. Disposal continued on the Site until 1969 at which time FMC ceased on-site disposal. A portion of the Site, as described in Section 1.2.1, and as shown on Figure 2, was sold to Glacier Park Company (subsidiary of the BNR) in 1969.

Wastes disposed at the Site have included chlorinated and non-chlorinated solvents, oils, paint and paint sludges, bottom ash and construction rubble. In 1980, an investigative program was initiated to identify to what degree past disposal practices had impacted the environment. Investigative programs completed to date are described in Section 1.2.3.

1.2.3 Investigations

In December 1980, FMC, at the request of the MPCA, commenced an investigation of the Site to determine the nature and extent of contamination. This work has continued for three years and has included:

i) Review and evaluation of historical disposal practices and related company records thereof;

ii) Site excavation surveys including testpits and continuous trenches (up to 12 feet in depth), and magnetometer and ground-penetrating radar surveys to determine the nature and extent of buried waste materials;

iii) Soil sampling to determine the extent and concentration of soil contaminants;

iv) Installation of groundwater monitoring wells to determine both the lithological characteristics of the area and groundwater elevations;

v) Aquifer sampling to determine groundwater quality; and

vi) Pumping tests to determine aquifer permeabilities and hence groundwater flow rates.

In addition to the FMC investigative work, the MPCA has conducted a sampling program of the Mississippi River, the FMC plant NPDES discharges, Minneapolis city water both at the intake and following treatment, and one standby municipal well in Fridley (Fridley Well 13). FMC financed a portion of the costs of the MPCA sampling program and continues to finance the analytical costs associated with periodic sampling of the Minneapolis city water and the standby well in Fridley.

In conjunction with the above investigations, FMC has prepared and submitted to the USEPA and the MPCA a number of written studies, assessments and reports. These are identified in the Bibliography as references 2 through 22.

The investigations and studies completed to date have identified a limited number of containers buried on the Site, and a number of areas containing soils contaminated as a result of the past Site disposal practices. In addition, organic contamination was found to exist in the overburden aquifers beneath the Site. In all cases the major contaminant class identified in groundwater was the volatile organic group.

1.3 REMEDIAL ACTION COMPLETED TO DATE

Between June and September 1983 a remedial construction program was carried out in accordance with a Remedial Action Plan approved by the MPCA and USEPA as embodied in Appendix A to the Consent Order[1]. Construction tasks required by and carried out under the Consent Order included:

i) Construction of a secure containment and treatment facility (CTF) for the containment of soils identified to be contaminated with organic volatiles, and/or lead and chromium. The CTF was constructed as a double-lined facility having a low-permeability underliner and overliner, and provision for leachate collection and leak detection. All components of the CTF were designed and constructed to comply with standards for a RCRA hazardous waste in-ground storage facility.

ii) Excavation and placement of contaminated soils within the CTF by June 30, 1983.

iii) Excavation, overpacking, sampling and disposal of drummed waste at an off-site, RCRA permitted disposal facility.

iv) Construction of a gas extraction and treatment system to treat, by activated carbon, volatile contaminants removed from the CTF.

v) Restoration and revegetation of all excavated areas.

In total, approximately 38,600 cubic yards of contaminated soils were excavated from the unsaturated zone at the Site and placed in the CTF. All areas of contaminated soil excavation were backfilled with overburden material excavated during the CTF construction.

Previous investigative work, which had been carried out at the Site prior to the remedial construction, identified isolated areas containing buried drummed waste on the FMC lands. Under the Remedial Action Plan, all drums were excavated, overpacked and disposed at a RCRA permitted facility. In addition, during the remedial construction, isolated areas of buried drummed waste were encountered in the BNR lands. These drums were handled in the same manner as the drums excavated from the FMC lands. In total 44 drums were eventually removed from the FMC and BNR lands, and disposed at the SCA Chemical Waste Services Landfill in Model City, New York. Transport and disposal was documented using Minnesota and New York State hazardous waste manifests.

The gas extraction and treatment system, constructed as part of the CTF, was designed for continuous operation, drawing volatile organic vapors from the CTF through a series of gas extraction wells. The organic vapors are treated by carbon adsorption using activated carbon filters. The gas extraction system is intended to reduce the quantity of volatile contaminants in the CTF over time, in turn reducing the long-term potential for adverse impact to the environment by the contained soils.

All work carried out under the Remedial Action Plan was observed and approved by representatives of the MPCA. The completed work is being monitored under a groundwater protection plan,[18] which has been approved by the MPCA and USEPA.

1.4 NATURE AND EXTENT OF SITE HAZARD (CURRENT SITUATION)

1.4.1 General

Contamination identified at the Site to date is predominantly volatile organic compounds in both the saturated and unsaturated alluviums. Of the priority pollutant volatile organic compounds (VOC's) determined to be present in the groundwater, trichloroethylene (TCE) comprises approximately 75 percent of the total VOC mass.

1.4.2 Unsaturated Soils

Excavation of approximately 38,600 cubic yards of contaminated soils from the unsaturated zone at the Site was completed during the remedial construction program discussed in Section 1.3. All soils having a VOC concentration of one part per million (ppm) or greater were excavated.

It is estimated that residual soil contamination amounts to approximately 470 pounds of total VOC's in the unsaturated overburden soils at the Site. Of this total, approximately 82 pounds remain in the FMC lands and approximately 388 pounds remain in the BNR lands. Appendix A presents a discussion of the calculations completed to estimate the residual VOC contaminant mass in the unsaturated soils at the Site.

The impact to the Site groundwater from residual soil contamination in the unsaturated overburden is through contaminant leaching by surface water infiltration. The rate of discharge of contaminants from the unsaturated overburden to the groundwater is dependent on precipitation frequency and duration, the permeabilities of the overburden soils, the rate of desorption of the contaminants from the soil particles and the depth of the unsaturated overburden. On the basis of the loadings presented in Appendix B, it has been determined that residual VOC contamination in the unsaturated Site soils would result in minimal impact to groundwater quality beneath the Site.

1.4.3 Groundwater

Beneath the BNR lands a continuous, low-permeability clay aquitard separates the surficial and the underlying alluvium. In this area, available data indicate that the upper alluvium contains VOC contamination while the lower alluvium is uncontaminated.

Under the FMC lands, the stratigraphy was found to be similar to the BNR lands; however, VOC contamination was identified in both the lower and upper alluvium.

The groundwater flow and the resulting contaminant migration from the Site have been determined to be generally westerly toward the Mississippi River. An exception to this flow pattern occurs in the westerly portion of the BNR lands, where the upper alluvium groundwater flow and contaminant migration appear to be in a southerly direction. This variation in the groundwater flow direction was suggested to be caused by a channel in the clay till.[19,20]

Currently the closest receptor potentially impacted by contaminated groundwater migrating from the Site is the Minneapolis Water Works intake on the Mississippi River downstream from the Site. In addition, the Agencies have identified the following as potential future receptors to be considered under this FS:

i) Anoka County's use of groundwater as a drinking water source for the proposed park west of East River Road.

ii) The use of the groundwater by the Minneapolis Water Works to augment the present City Water Supply by the installation of a "Ranney" well system.

The impact of the Site on these receptors is discussed in Section 3.

2.0 SITE HYDROGEOLOGY

In response to Section III, paragraph A of the Consent Order[1], FMC conducted a Remedial Investigation (RI) of the Site groundwater. The RI was completed in two phases. The Phase I report[17] was submitted to the Agencies in November 1983, while the Phase II report[20] was submitted in August 1984. This section of the FS summarizes the information generated during the RI, and uses this information to further postulate as to the mechanics of groundwater contaminant migration from the Site.

2.1 GEOLOGIC SYSTEM

The Site occupies a portion of a relatively flat flood plain lying at an approximate elevation of 835 feet (NGVD - National Geodetic Vertical Datum) on the east bank of the Mississippi River in Fridley, Minnesota.

A river connected sand and gravel aquifer system underlies the Site and in turn is underlain by bedrock of the St. Peter Sandstone and the Prairie du Chien Formations. The Mississippi River acts as a discharge zone for both the surficial and bedrock aquifers identified at the Site.

The surficial aquifer system consists of an upper aquifer (water table aquifer), a clay aquitard and a lower confined aquifer. Aquifer materials consist of sands with occassional sandy gravels and silts.

The water table aquifer is not continuous across the Site because the elevation of the underlying clay aquitard exceeds the elevation of the water table in portions of the FMC lands. The elevation of the water table varies from a high of approximately 815 feet at Well 24, to lows of approximately 803 feet in the north at Well 19A, and 812 feet in the BNR lands to the south. Figure 4 illustrates the location of monitoring wells at and adjacent to the Site.

An extensive water table aquifer, as defined by Wells 36, and 46 to 52, underlies the BNR lands. The groundwater in this aquifer in this area shows a localized southward flow direction. The flow direction in this area is controlled by the geometry of the underlying clay aquitard. The general flow direction in this aquifer is expected to be westerly with discharge into the Mississippi River. Representative slug test results show in-situ permeabilities ranging from 89 to 320 ft/day (3.1×10^{-2} to 1.1×10^{-1} cm/sec). Average linear groundwater velocities in the range of 173 to 623 ft/year have been determined using these permeability data, the water table gradient of 0.0016,[20] and an assumed porosity of 0.30.

The water table aquifer in the FMC lands was identified at Wells 19A and 24. The water levels measured at Well 24 indicated that this portion of the aquifer is continuous with that identified on the BNR lands. Insufficient data exist to determine the velocity, direction and amount of groundwater flow off site in the vicinity of Well 19A.

A clay aquitard underlies the Site. This unit thickens towards the east where it attains a thickness of 26 to 29 feet. On-site thicknesses are generally in excess of 15 feet with the exception of the vicinity of Well 15 where five feet of clay were encountered. The clay thins toward the west and is 7-feet thick at Well 39. The clay was not identified at Well 38 or at Well 42 to the north.

Drilling to date has indicated that the clay aquitard is continuous across the Site. However, the presence of contaminants in the lower aquifer beneath the FMC lands suggests that discontinuities or more permeable strata within the clay formation may be present. Suspect areas at the Site include the 84-inch diameter storm sewer installation and the former excavated burn pit area adjacent to Well 15.

The upper surface of the clay has been shown to have considerable topographic expression.[21] Clay elevations exceed 830 feet in the northeast portion of the FMC lands and range as low as 775 feet at Well 36 on the BNR lands. Between these two areas, the upper surface generally is undulating. Available borehole data also indicate that the lower surface of this formation has considerable relief.

Laboratory data[22] show the vertical permeability of the clay aquitard to be in the range of 9×10^{-5} to 2×10^{-4} ft/day (3×10^{-8} to 7×10^{-8} cm/sec). These values suggest that the clay is a significant aquitard. Under conditions of unit hydraulic gradient, average linear groundwater velocities of 1.3 to 2.7 in/year (3.3 to 6.7 cm/yr) would be expected in this unit.

A confined aquifer underlies the clay aquitard at the Site. This unit thickens toward the west where it attains a maximum thickness of approximately 100 feet at Well 38 adjacent to the Mississippi River. On-site aquifer thicknesses range from a minimum of five feet at Well 27, to 77 feet at Well 30. Aquifer thicknesses generally decrease eastward because of the increase in elevation of the underlying bedrock surface. The bedrock does not outcrop at the Site but may do so at some distance to the east beyond the Site boundary.

In-situ permeabilities were determined by slug testing a number of wells completed in this aquifer. Values typically range from six to 65 ft/day (2.1 x 10^{-3} to 2.3 x 10^{-2} cm/sec). Analysis of a pumping test[20] conducted on Well 29 resulted in a formation permeability of 14 ft/day (4.9 x 10^{-3} cm/sec).

Piezometric elevations measured in wells completed in this aquifer range from approximately 812 feet at the east of the Site to approximately 810 feet at the western Site boundary. Lower piezometric levels have been found between the Site and the Mississippi River. The general flow direction is westerly towards the river with gradients measured at the Site on the order of 0.004. Steeper gradients were measured towards the river. Average linear groundwater velocities in this unit range from 30 to 317 feet/year. Groundwater flow within this aquifer is generally horizontal. However, a vertical component of flow is apparent from the piezometric levels recorded at nested observation wells.

Piezometric data[20] have shown a consistent upward component of flow at Observation Wells 11 through 14 during the period July 1983 to July 1984. A uniform gradient of 0.0035 has been determined from these data. Wells in this nest (11 through 14) were constructed without a seal immediately above the screen; thus, the measured piezometric levels are an approximation of the average levels recorded over that thickness of the aquifer intersected by the borehole. Piezometric levels at the base of the aquifer are therefore expected to be higher than those recorded from Well 11 since the calculated uniform upward flow gradient is an average over the whole aquifer thickness.

A consistent downward flow component of 0.0027 was determined from data collected at Wells 17 and 18 located in the northeast corner of the Site.

The surficial aquifer system at the Site is underlain by bedrock of both the St. Peter Sandstone as well as dolomites of the Prairie du Chien Formation. The St. Peter Sandstone contains a basal section of shales and silts[20] which results in this unit having a lower permeability than that of the overlying confined aquifer. While this unit underlies the Site, it was not observed in bedrock Well 42 installed immediately to the north of the Site. Here, the underlying Prairie du Chien Formation is in direct contact with the surficial deposits. The Prairie du Chien is a major exploited water supply aquifer in the region. Solution cavities and fractures account for the permeability of this unit. The transmissivity of this lower unit has been estimated to be on the order of 4,400 ft^2/day ($4.7 \times 10^{-3} m^2/sec$).[20]

A qualitative assessment of the permeability of the Prairie du Chien Formation can be gauged from an examination of the piezometric levels recorded in this unit.

A head loss of 0.22 feet has been recorded between Well 32, completed at the eastern Site boundary, and Well 43, situated adjacent to the Mississippi River. The gradient between these two wells is approximately 0.0002. This is an order of magnitude lower than that determined in the confined sand aquifer and indicates that the lower unit has a significantly greater permeability. A permeability of 500 ft/day (1.8×10^{-1} cm/sec) is consistent with this gradient. Groundwater velocities at least as great as those calculated for the confined sand aquifer (30 to 317 feet/yr) are expected to exist in the Prairie du Chien aquifer.

2.2 FLOW SYSTEM

The groundwater flow direction at the Site is generally to the west, discharging into the Mississippi River. Water levels in the water table aquifer exceed the piezometric levels in the confined aquifer. Flow through the confining clay at the Site is thus downwards.

Flow in the confined aquifer is horizontal with a consistent component of upward flow at Wells 11 through 14 located near the western Site property boundary. Further east on the Site, at Wells 17 and 18, a consistent downward component of flow has been identified.

Gradients within the confined sand aquifer are expected to be controlled in part by the geometry and the head distribution within the underlying Prairie du Chien formation. Upward flow from the bedrock in the vicinity of the river may account for the upward gradients observed in the confined aquifer at the western Site property boundary.

Piezometric levels in the confined aquifer at the eastern portion of the Site exceed those recorded from the deeper bedrock wells. Downward flow to the bedrock accounts for the component of downward flow recorded in the confined aquifer at Wells 17 and 18.

The flow system at the Site consists of downward flow at the eastern Site boundary with flow upward between the Site and the river. Groundwater discharges from the system to the Mississippi River. However, the influence of the Prairie du Chien Formation on this system is likely to be complex. This Formation has significant spatial variation in permeability. The permeability, when combined with an increase in elevation to the east and the discontinuity of the lower permeability St. Peter Sandstone, suggests that flow directions and rates are variable. The spatially variable flow directions recorded by Papadopulos[20] from the confined aquifer probably reflect variable flow conditions within the underlying bedrock.

2.3 CONTAMINANT MIGRATION

A variety of organic wastes were disposed of at this Site. It is believed that most of the wastes were deposited as liquids in open pits or in drums on the western portion of the Site. Contaminants, principally TCE, were detected in the water table aquifer beneath the BNR lands and in both the water table aquifer and the confined aquifer beneath the FMC lands.

Contaminant movement in saturated porous media is governed by a number of processes, the most important of which are the rate and direction of groundwater flow. The processes of dispersion, diffusion, chemical and biological reaction, adsorption and desorption may also exert varying degrees of influence over the pattern of migration.

A groundwater flow system has been described at the Site in which the principal flow direction is westerly. On-site infiltration is expected to migrate vertically downwards to the water table and then laterally towards the river in the water table aquifer. Where this aquifer is absent, infiltrating water would move laterally above the clay to some point where saturated conditions exist. The pronounced permeability contrast between the surficial sand (10^2 ft/day) and the underlying clay (10^{-4} ft/day) indicates that in excess of 99 percent of infiltrating water migrates laterally through the surficial sand aquifer rather than vertically down through the clay.

The presence of contaminants in the lower aquifer is not readily explained by the described flow system. Windows through the clay aquitard (possibly the excavated former burn pit or the 84-inch diameter storm sewer) or pronounced variations in the permeability of this unit may explain this phenomenon. Two other mechanisms are possible; namely that wastes were deposited east of the Site in an area where the lower aquifer outcrops or that reactions with the organic wastes induced significant changes in the permeability of the clay aquitard, thus allowing significant vertical migration of contaminants.

2.3.1 Horizontal Contaminant Distribution

The average concentrations of TCE recorded from sampling and analysis of on-site wells are presented on Figure 5. A pronounced spatial variation in TCE concentration is apparent. The most extreme case is between Wells 15 and 28 which are located 100 feet apart. Well 28 concentrations averaged 1 ppb of TCE while Well 15 had an average TCE concentration of 15,760 ppb. One sample from each of Wells 15 and 30 indicated TCE concentrations at saturation (10^{-6} ppb). These data were considered to be anomalous as samples collected one day later showed values typical for these wells.

The observed spatial variability suggests nearby point sources rather than a distributed source of contamination. If contaminants were entering the main aquifer at some distance upgradient, then the effects of dispersion would be such that a line of wells along the downgradient Site boundary would indicate a more uniform concentration of contaminants than presently exists.

It has been concluded that Well 15 is situated in or adjacent to a point source of contaminants. It was noted above that the confining clay at this well is 5-feet thick, whereas on-site clay thicknesses are generally in excess of 15 feet.

Similarly, Wells 14 and 30 are believed to be located near contaminant source points. However, because clay thicknesses at these wells are in excess of 20 feet, any contaminant source impacting the wells may be located some distance upgradient to the east and not immediately adjacent to them.

Contaminants entering the confined aquifer at Well 15 are expected to migrate downgradient to the southwest. Reference to the potential distribution, as shown on Figure 5, indicates that Wells 37, 45 and 38 lie downgradient from Well 15. Samples obtained from the two wells nearest Well 15 (37 and 45) showed a decrease in TCE concentration of two orders of magnitude from that recorded in Well 15. Well 38 situated near the river showed a further order of magnitude decrease in TCE levels. Upgradient Well 27 contained very low levels of TCE (<2 ppb).

Well 39, downgradient of Wells 14 and 30, indicated a decrease in TCE concentrations of two orders of magnitude between the Site and the river. However, because Wells 14 and 30 are thought to lie some distance downgradient from the contaminant source, the concentration decrease between the contaminant source and the river may be greater than the observed two orders of magnitude.

Significant contaminant levels were also found in on-site bedrock Well 31 and off-site bedrock Well 42 situated 1100 feet to the north of the Site. The flow system indicates that the observed contaminant distribution in these wells was not attributable to on-site contaminant sources.

2.3.2 Vertical Contaminant Distribution

It has been inferred from Papadopulos[20] that contaminants are distributed throughout the total thickness of the confined aquifer. This is conceivable for wells located off-site and downgradient to the west, but is less likely for wells located near the contaminant source.

A component of upward flow was measured at Wells 11 through 14. The flow direction at this point would serve to limit the downward movement of contaminants. It is, therefore, expected that the contaminant plume would be restricted to the upper portions of the confined aquifer. A similar situation would be expected to exist at Wells 15 and 30. Contaminants however, were also detected at depth in the confined aquifer at Well 30 (which intersects the complete thickness of the aquifer) and in the nested wells (Wells 11 and 12). These data suggest a contaminant source at some point upgradient from these wells.

Discrete depth sampling and analysis from fully penetrating wells indicated a general decrease in TCE levels with depth.[20] However, it is likely that the fully penetrating well screens and the methods of well installation contributed significantly to the vertical spreading of contaminants.

2.3.3 Rates of Contaminant Migration

Contaminant species that do not react in any manner with the porous media are termed conservative and they migrate at the same rate as the groundwater. However, organic contaminant species typically are adsorbed to some extent onto the porous media and thus migrate at a rate less than that of the groundwater. The extent to which contaminant species are adsorbed is controlled in part by the availability of organic carbon, grain size and composition of the porous media as well as by the physical and chemical properties of the contaminant in question.

Estimates of the degree to which contaminant migration is retarded can be determined from the relationships developed by Schwartzenbach and Westall[23] using the known octanol-water partitioning coefficient. Because of lack of data specific to Site soils, organic carbon content of aquifer soils in the range of 0.001 to 0.01 were assumed to calculate retardation factors for TCE. For assumed organic carbon contents of 0.001, 0.005 and 0.01, TCE retardation factors of 1.7, 4.4 and 7.9, respectively, were calculated. A retardation factor is a measure of the velocity of the water relative to that of the contaminant through the aquifer. A TCE retardation factor of 1.7 means that the groundwater velocity in the aquifer is 1.7 times greater than that of the TCE.

The process of adsorption serves not only to slow the rate of contaminant migration but also to reduce contaminant levels at any point downstream. Thus, it is inconceivable that contaminants crossing the Site boundary at any instant would be discharged to the River at the same concentration at which they left the Site.

In addition to adsorption, dilution and dispersion also serve to decrease contaminant levels downgradient of the Site. Upward flow from the bedrock serves to dilute contamination in the confined aquifer. This flow is likely to be significant as the aquifer thickens towards the river.

Existing data are insufficient to construct a simulative model of this system. However, as observed from the historical distribution of groundwater contaminant levels at and adjacent to the Site, the net effect of dilution, dispersion and retardation is that concentrations of contaminants in groundwater discharged across the Site boundary are reduced by two to three orders of magnitude by the time they are discharged to the Mississippi River.

3.0 ASSESSMENT OF SITE IMPACT TO PUBLIC HEALTH

3.1 GENERAL

Past disposal activities have resulted in contamination of groundwater beneath the Site. Contaminants are carried in solution in groundwater flow from the Site and thus are available for consumption by downgradient users of the groundwater and surface waters to which the groundwater discharges. This section of the FS assesses the degree of adverse impact to potential present and future users of groundwater or surface waters contaminanted by the Site.

3.2 CONTAMINANTS PRESENT IN GROUNDWATER AND THE MISSISSIPPI RIVER

Analyses of groundwater samples collected at and downgradient of the Site have identified VOC contamination.[20] Calculations of the relative mass of the individual contaminants indicate that approximately 75 percent of the contaminant mass flux across the boundary of the Site is comprised of TCE. In addition, as noted in Section 2, a decrease in groundwater contaminant concentrations of two to three orders of magnitude has been observed between the Site and the shoreline of the Mississippi River.

Analysis of 40 samples collected from the Minneapolis Water Works raw water intake between 1981 and 1983 identified TCE present on 26 occasions at concentrations ranging from 0.2 ppb to 1.7 ppb. Other compounds which were sporadically reported as present, the number of samples in which they were found, and the concentration range are as follows: 1,2-dichloroethylene (5: 0.5 to 0.6 ppb); 1,1-dichloroethylene (1: 0.3 ppm); and 1,1,1-trichloroethane (2: 1.2 and 1.4 ppb).

Analysis of 12 samples collected from Wells 21, 38, 39 and 43 adjacent to the Mississippi River downgradient of the Site, from September to November, 1983 identified TCE in all samples at concentrations ranging from 3 to 246 ppb. Concentrations ranging from 1 to 16 ppb, 2 ppb and 1 to 64 ppb were identified for 1,2-dichloroethylene (4 occasions) , 1,1-dichloroethylene (2 occasions) and 1,1,1-trichloroethane (5 occasions), respectively. In addition, Well 21 was sampled on two occasions in 1982 and in January 1983. TCE was present in all three samples at concentrations between 4 and 23 ppb while 1,1,1-trichloroethane was not detected in any sample. Further, 1,2-dichloroethylene was detected in all samples and 1,1-dichloroethylene was detected in two samples at concentrations of 2 to 5 ppb and 1 to 3 ppb, respectively.

Sampling of the intake and of the shoreline wells were not performed concurrently. The sampling teams, the analytical laboratories and the analytical protocols were

were different for the two sets of samples. Therefore, no valid correlation can be demonstrated between the presence of any of the four compounds referred to above. Since that TCE was present in all shoreline monitoring well samples and in the majority of treatment plant intake samples, it represents the Site contaminant that potentially provides the largest time-weighted health exposure risk at the intake. While both 1,2-dichloroethylene and 1,1-dichloroethylene have lower 10^{-6} excess cancer risk criteria, the fact that they are present less frequently and in lower concentrations than TCE in the intake and shoreline monitoring well samples results in a lower time-weighted exposure risk to potential users of groundwater or surface water. Therefore, it has been concluded that TCE is the primary groundwater contaminant of concern at the Site.

3.3 CONTAMINANT MIGRATION PATHWAYS AND ENVIRONMENTAL FATE

As described in Section 2, TCE migrates from the Site in solution in the groundwater and eventually is discharged from the aquifer to the Mississippi River. TCE discharged to the river is carried downstream in the direction of the Minneapolis Water Works intake. TCE is drawn into the intake at a reduced concentration from the groundwater concentration due to dilution from mixing with the river flow. The degree of dilution is dependent upon the volume of flow and the effective portion of this flow in which mixing occurs between the aquifer discharge area downgradient of the Site and the Water Works intake. Papadopulos[20] conservatively estimates, assuming no attenuation of contaminants by the aquifer matrix between the Site and the river, that the Site is responsible for a maximum transient increase in total VOC's in the Minneapolis Water Works intake of approximately 0.5 ppb (or 0.375 ppb for TCE which comprises 75 percent of the total VOC's). Using the average daily flow in the Mississippi, the increase in total VOC's attributable to the Site at the intake is estimated to average approximately 0.08 ppb.

In reality, attenuation in the aquifer will reduce the mass flux of contaminants entering the river and the intake. Empirical evidence from groundwater monitoring at the Site and the river shoreline suggests that the reduction is in the range of two to three orders of magnitude (see, Section 2.3.1, supra). Using an attenuation factor of two orders of magnitude, the maximum incremental increase in total VOC's at the intake attributable to the Site is estimated to be approximately 0.005 ppb. The TCE fraction of the VOC loading would, therefore, be approximately 0.004 ppb.

A consideration of the methods and the time frame of Site waste disposal, and of the analytical data generated from groundwater sampling from 1982 to 1984, leads to the conclusion that the contaminant transport system from the Site to the river is presently is relative equilibrium. Thus, contaminant levels in the groundwater from the Site will in the future decrease, or will not significantly exceed, those presently observed.

3.4 RECEPTORS OF GROUNDWATER CONTAMINATION

Receptors of contaminated groundwater identified by the Agencies because of their potential impact on human consumption are of two types, namely present receptors and potential future receptors.

A survey conducted in 1982 (17) indicated that the alluvial aquifer between East River Road and the Mississippi River was not used as a potable water supply source in the vicinity of the Site. Therefore, the closest point of consumption is the Minneapolis Water Works intake, at which point groundwater from the Site has mixed with the Mississippi River.

Two potential future receptors have been identified by the Agencies. These are as follows:

i) Anoka County parkland to be developed in 1985 between thr Site and the River. The park development will be provided with drinking fountains and toilets.

ii) A system proposed by the City of Minneapolis to supplement the City water supply, currently derived solely from the Minneapolis Water Works intake, by aquifer pumping from a river-side location near the Site.(24)

3.5 RECEPTOR RISK ASSESSMENT

3.5.1 Applicable Human Health Standard

The standard used in the assessment of receptor risk was the TCE unit cancer risk value of 2.8 ppb (Federal Register 45:78318-79379, November 28, 1980). This concentration represents an incremental increase in cancer risk of one in one million (10^{-6}) for a 70 kg adult consuming two liters of contaminated water per day for 70 years.

3.5.2 Present Receptor

As discussed in Section 3.3, the worst case incremental loading of TCE to the Minneapolis Water Works intake attributable to the Site is 0.375 ppb (assuming no aquifer attenuation) or 0.004 ppb (assuming aquifer attenuation). These concentrations would result in an excess cancer risk of between 10^{-6} and 10^{-7} for the 0.375 ppb incremental loading and of between 10^{-8} and 10^{-9} for the 0.004 ppb incremental loading for human consumption of untreated river water from the intake.

3.5.3 Potential Future Receptors

3.5.3.1 Anoka County Parkland

The proposed park development is bounded on the east by East River Road. A potable watermain owned by the City of Fridley is located adjacent to East River Road. Fridley Ordinance 205.12 prohibits the installation of a potable water supply well when a municipal potable water service is in reasonable proximity to the consumer.

Discussions held with the Anoka County Park Development Division and its consultant indicate that the park development will be serviced from the existing Fridley municipal water supply.

The park development does not require groundwater potentially impacted by the Site for potable use, and therefore, no risk to this receptor exists.

3.5.3.2 City of Minneapolis Supplemental Water Supply

A proposed "Ranney" well system, to augment the City of Minneapolis water supply in the summer season, has been identified by the Agencies as a potential receptor of contaminants migrating from the Site. This section discusses the hydraulic impact that the "Ranney" well system would have on the Site, and the impact that the Site would have on the concentrations of VOC contaminants at the "Ranney" well discharge.

An investigation was conducted by the Ranney Company into the water supply potential of a river-connected water table sand and gravel aquifer on the east bank of the Mississippi River approximately 2,700 feet south of the Site(23) (Figure 6).

The aquifer within the vicinity of the proposed "Ranney" well extends approximately 80 to 100 feet below the bottom of the river, and consists dominantly of sand and gravels along with some interbedded clays. These clays may occupy as much as 50 percent of the vertical thickness of the aquifer at any one point, but are not continuous in the vicinity of the proposed well.

The aquifer at the site of a pumping well utilized in the Ranney Study, is 107 feet thick. This well was pumped at 1,500 GPM for a total of 72 hours. Drawdowns were measured in a number of observation wells installed around the pumping well.

The observed cone of depression was noncircular in plan view because of two boundary conditons. The river on one side contributed a significant volume of water to pumping, while to the east, the aquifer becomes very thin and contributed very little water. It was calculated [23] that 50 percent of the pumped volume was derived from the river. The drawdown cone thus extended along the river bank to the north and, to a lesser extent, to the south from the pumping well.

One observation well (SW3) is located immediately north of the Minneapolis Water Works building and west of the BNR lands at an approximate distance of 2,700 feet north from the pumping well. Approximately one foot of drawdown was experienced at this point after three days of pumping. Some of this drawdown is attributable to a lowering of the stage of the Mississippi River. However, this well responded to pumping within one hour of the beginning of the test. On the basis of the information presented, it can be concluded that minor drawdowns were experienced under the Site in response to this test.

The cone of depression appeared to reach a quasi-stable position after three days of pumping. Therefore, continued pumping at the same rate is not likely to have a greater impact at the Site.

Non-pumping water levels show a gradient in the confined aquifer towards the river. At present, gradients are in the order of 0.004. A lowering of head by one foot in response to pumping would increase the gradient, and hence groundwater flow velocity, by as much as 20 percent. Similarly, the estimated mass flux would increase by approximately 20 percent. However, because of the hydraulic control exerted on the system by the adjacent river, the change in hydraulic gradient is likely to be less than the 20 percent estimated.

A "Ranney" well collector at this site is expected to have a maximum capacity of 5,000 GPM.[23] Such a pumping rate is expected to induce a 3-foot change in water levels in the area of the Site.

The present flux as determined by Papadopulos[19] of both the groundwater and the total VOC's leaving the Site are presented on Table 1.

TABLE 1

OFF-SITE GROUNDWATER AND CONTAMINANT FLUX

FMC CORPORATION
MINNEAPOLIS, MINNESOTA

	BNR Area	FMC Area	Bedrock	Total
Total VOC flux (gms/day)	87*	47*	7*	141
Total TCE flux (gms/day)	65	35	5	106
Groundwater flux (ft^3/day)	2100*	1100*	3300*	6500
TCE Groundwater Concentration (ppb)	1099	1133	56	575

* Taken from Papadopulos (1984)

The flux of TCE was estimated to be 75 percent of that of the VOC's. Table 1 also presents the resulting contaminant concentrations in the groundwater.

Earlier in this report, it was shown that a reduction in contaminant levels of at least two orders of magnitude occurs between the site and the river. By assuming that any "Ranney" well is located at least a similar distance from the Site (approximately 1,000 feet), the present TCE mass flux of 106 grams/day leaving the site is expected to be reduced to 1.06 grams/day at the hypothetical "Ranney" well. When diluted by the pumped discharge (5,000 GPM), the resulting average concentration would be 0.04 ppb.

This approximation overlooks the effects of pumping on the piezometric head distribution and hence the velocity field within the aquifer. In order to obtain a TCE concentration of 2.8 ppb in the pumped water (10^{-6} excess cancer risk criterion), it would be necessary to multiply the hydraulic gradient and also TCE mass flux by a factor of 67.5.

It is not possible that such a gradient change can be induced except in the immediate vicinity of the pumping well. The control that the Mississippi River exerts on the piezometric surface indicates that in response to the proposed pumping, only two to three feet of drawdown may be experienced at the Site. By this assumption, the groundwater gradient at the Site could at most be doubled, leading to a maximum incremental concentration of TCE in the pumped water of 0.08 ppb.

This analysis is independent of the amount of groundwater pumped from the confined aquifer. The earlier pumping test [23] showed that as much as 50 percent of the water pumped from a river side well was derived from the river itself. In the case of a "Ranney" well pumping at 5,000 GPM, this figure is expected to be higher, perhaps in excess of 60 percent. Similarly, the percentage contribution from the bedrock aquifers may range from five percent to 20 percent. The balance, anywhere from 20 to 45 percent is derived from the confined aquifer.

On the basis of the position of the bedrock boundary indicated from analysis of the earlier pumping test (Figure 6), it was inferred that approximately 50 percent of the area east of the river contributes groundwater to the pumped well. The Site, and its upflow area of capture occupies about 20 percent of this contributing area. Therefore, the percentage of water derived directly from under the site ranges from four to nine percent. By again doubling the hydraulic gradients and hence contaminant fluxes, and by assuming a two order of magnitude reduction in contaminant levels between the Site and the well, a resulting TCE concentration in the pumped water of between 0.5 to 1.04 ppb is estimated as shown in Table 2.

These calculations do not consider the impact that any off-site contamination may have on the quality of the pumped water. The resulting values therefore, are the increment in contaminant levels contributed by the Site. With the requirement that the well be located at least 1,000 feet from the Site and adjacent to the river, well location is not critical to this assessment. However, the distribution of contaminants not associated with the Site will influence the resulting total contaminant levels at the well.

The impact of the Site on water quality pumped from the proposed supplemental water supply system is such that the excess cancer risk measured at the point of discharge to a hypothetical user is in the range of 10^{-6} to 10^{-8}.

TABLE 2

CONTRIBUTION OF SITE
GROUNDWATER TO PROPOSED RANNEY WELL

FMC CORPORATION
MINNEAPOLIS, MINNESOTA

Percent Contribution	
river	50 - 60
bedrock	5 - 20
balance from confined aquifer	45 - 20
From under site	9 - 4
TCE flux leaving site	1150 ppb
Arriving at well	11.50 ppb
In pumped water	1.04 - 0.5 ppb

4.0 CONCLUSION

The above analysis shows that no further study of remedial action alternatives need by conducted. Under the National Contingency Plan (NCP) and particularly 40 C.F.R. § 300.68, as referenced in the Consent Order,, the threshold criterion to be assessed in determining whether remedial actions should be considered is whether contamination poses a danger to public health. Public health risk has also been identified by the Agencies in connection with this FS.

Here, a necessary predicate for the requiring of any further remedial action under the NCP does not exist in that the impact of the Site to the current receptor (the Minneapolis Water Works intake) and potential future receptors identified by the Agencies, is below the criterion of 10^{-6} for excess cancer risk. As discussed above, this properly takes into account the population at risk, the amount and properties of the substances present and pertinent hydrological factors in evaluating welfare concerns. Thus, this approach is fully consistent with the provisions and intent of the NCP and the FMC Consent Order which have as their ultimate objective the elimination of unacceptable levels of risks - levels which simply are not present here.

5.0 RECOMMENDATIONS

The derivations in Sections 2 and 3 of flow and contaminant transport systems at and downgradient of the Site and associated health impact evaluations were based on limited data and a relatively short-term groundwater quality data base.

In order to ensure and confirm that contaminant levels in groundwater attributable to the Site continue to pose no significant risk to identified receptors, it is recommended that a comprehensive groundwater monitoring program be developed and implemented.

All of Which is Respectfully Submitted
CONESTOGA-ROVERS & ASSOCIATES LIMITED

Richard G. Shepherd, P. Eng.

Bruce A. Monteith, P. Eng.

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APPENDIX A

CALCULATION OF TOTAL CONTAMINANT MASS
IN UNSATURATED SOILS

A.1 INTRODUCTION

The FMC site (Site) located south of the Northern Ordnance Division of FMC Corporation (FMC) plant in Fridley, Minnesota is composed of two parcels of land. The northerly parcel, approximately 13 acres, is owned by FMC (FMC lands), while the southerly parcel, approximately five acres, is owned by the Burlington Northern Railway (BNR lands). Both parcels of land were used for the disposal of industrial wastes, including liquid wastes, between 1941 and 1969.

During the period December 1980 to June 1983, several investigative programs were completed at the Site by FMC to determine the impact on soils and groundwater by prior waste disposal practices. These investigative programs identified volatile organic soil contamination in the unsaturated overburden soils. In June 1983, a Remedial Action Plan was initiated at the Site in response to an Administrative Order and Interim Response Order by Consent (Consent Order) between FMC, the United States Environmental Protection Agency, and the Minnesota Pollution Control Agency. The Consent Order required all unsaturated soils containing concentrations of total Priority Pollutant volatile organics (VOC's) in excess of one part per million (ppm) to be excavated and disposed of in an on-site constructed containment and treatment facility (CTF). Figures A.1 and A.2 delineate the final limits of

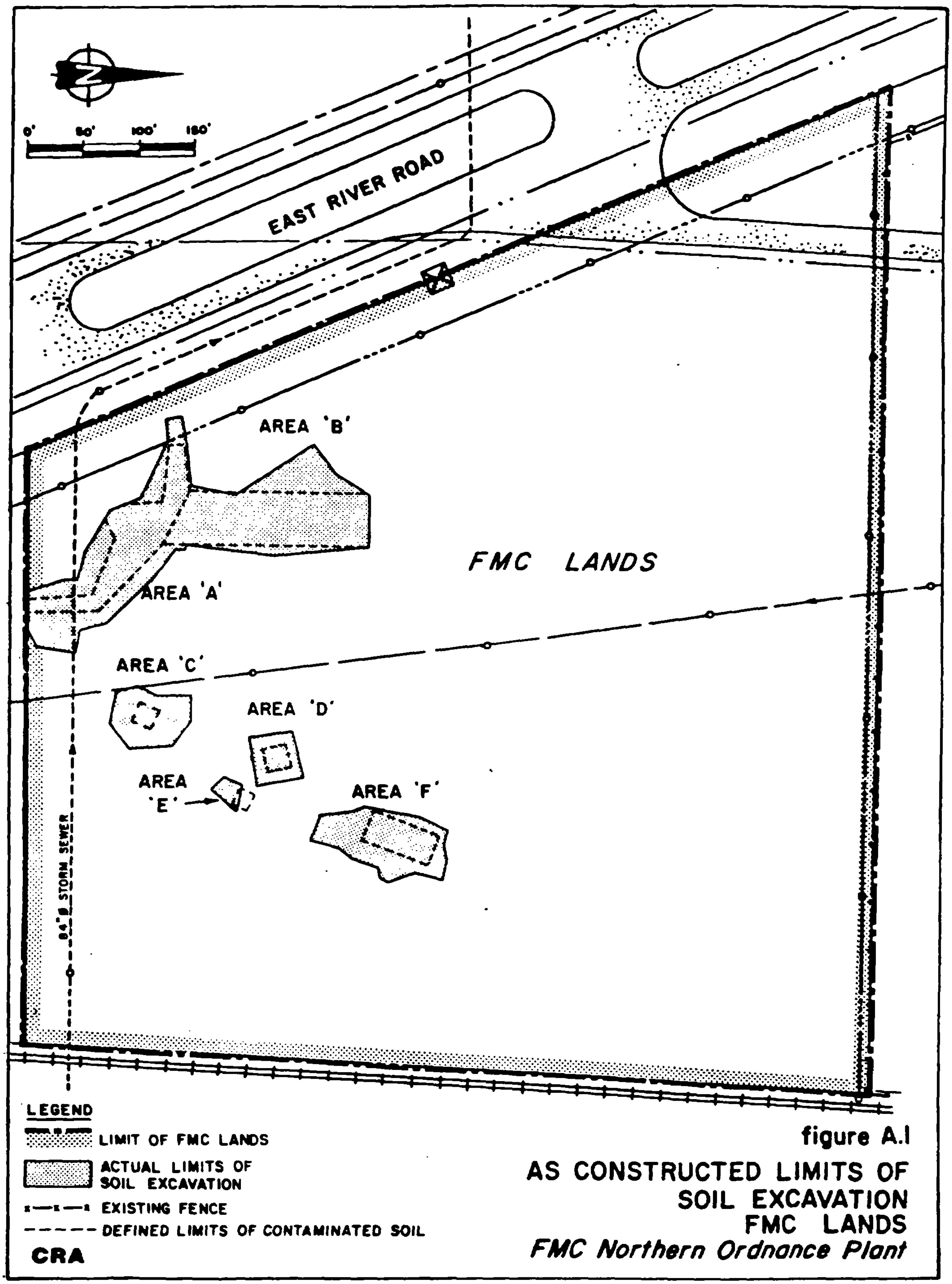

figure A.1

AS CONSTRUCTED LIMITS OF SOIL EXCAVATION FMC LANDS

FMC Northern Ordnance Plant

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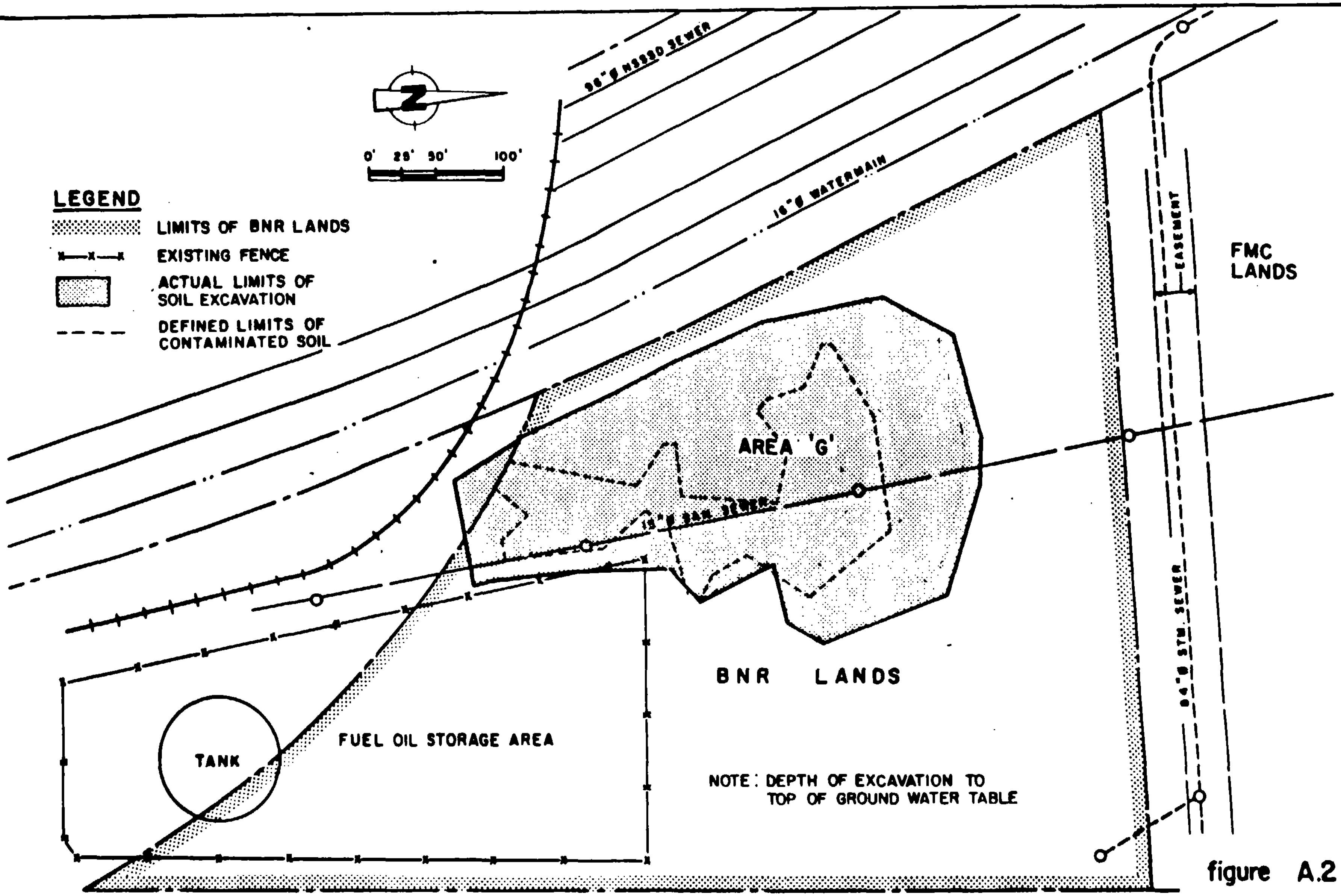

figure A.2

AS CONSTRUCTED LIMITS OF SOIL EXCAVATION
BNR LANDS
FMC Northern Ordnance Plant

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contaminated soil excavation in the FMC lands and BNR lands, respectively. Excavation and placement of contaminated soils in the CTF was completed on June 30, 1983.

This Appendix presents a discussion of the calculations performed to determine the mass of residual VOC's remaining in the unsaturated overburden soils following soil excavation at the Site. The calculation of the mass of residual VOC's was used in Appendix B to evaluate the potential contaminant discharge rate from the unsaturated zone to the Site groundwater over time. Data used in the residual contaminant mass calculation were obtained from the data base of all analytical data collected at the Site to date.

A.2 AREAL EXTENT OF SOIL CONTAMINATION

Soil sampling locations from previous Site investigations are illustrated on Figures A.3 and A.4 for the FMC lands and BNR lands, respectively. These sampling locations represent soils which were not excavated under the Remedial Action Plan.

The vertical extent of contamination associated with unsaturated site soils is assumed to be, on average, limited to the upper 13.5 feet and 21.35 feet for the FMC lands and BNR lands, respectively. These average depths are calculated based on the approximate depth to the underlying clay till and/or the approximate depth of the surficial groundwater table encountered during the contaminated soil excavation. Below these depths, the presence of contaminants is assumed to be associated with groundwater contamination.

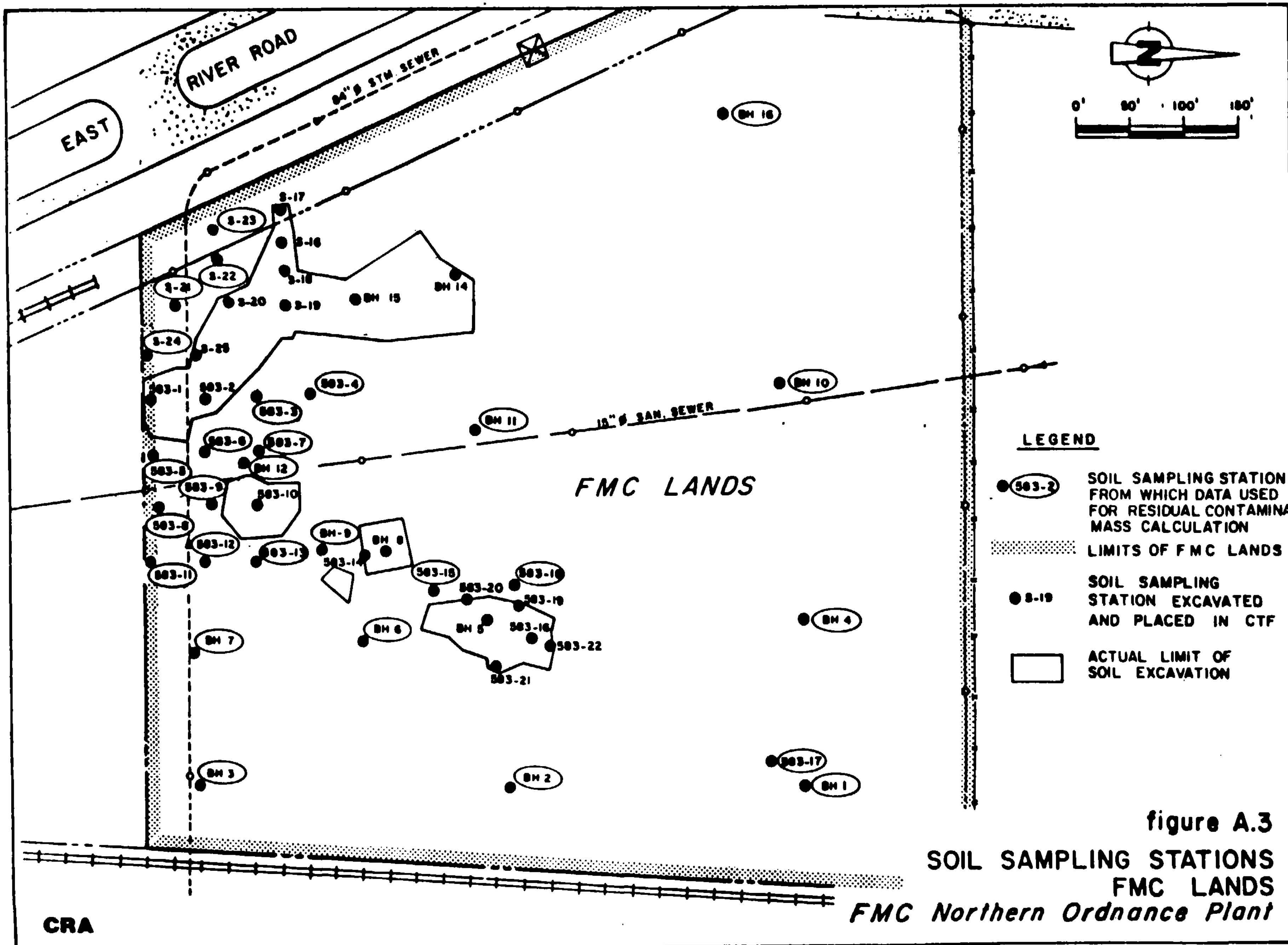

figure A.3
SOIL SAMPLING STATIONS
FMC LANDS
FMC Northern Ordnance Plant

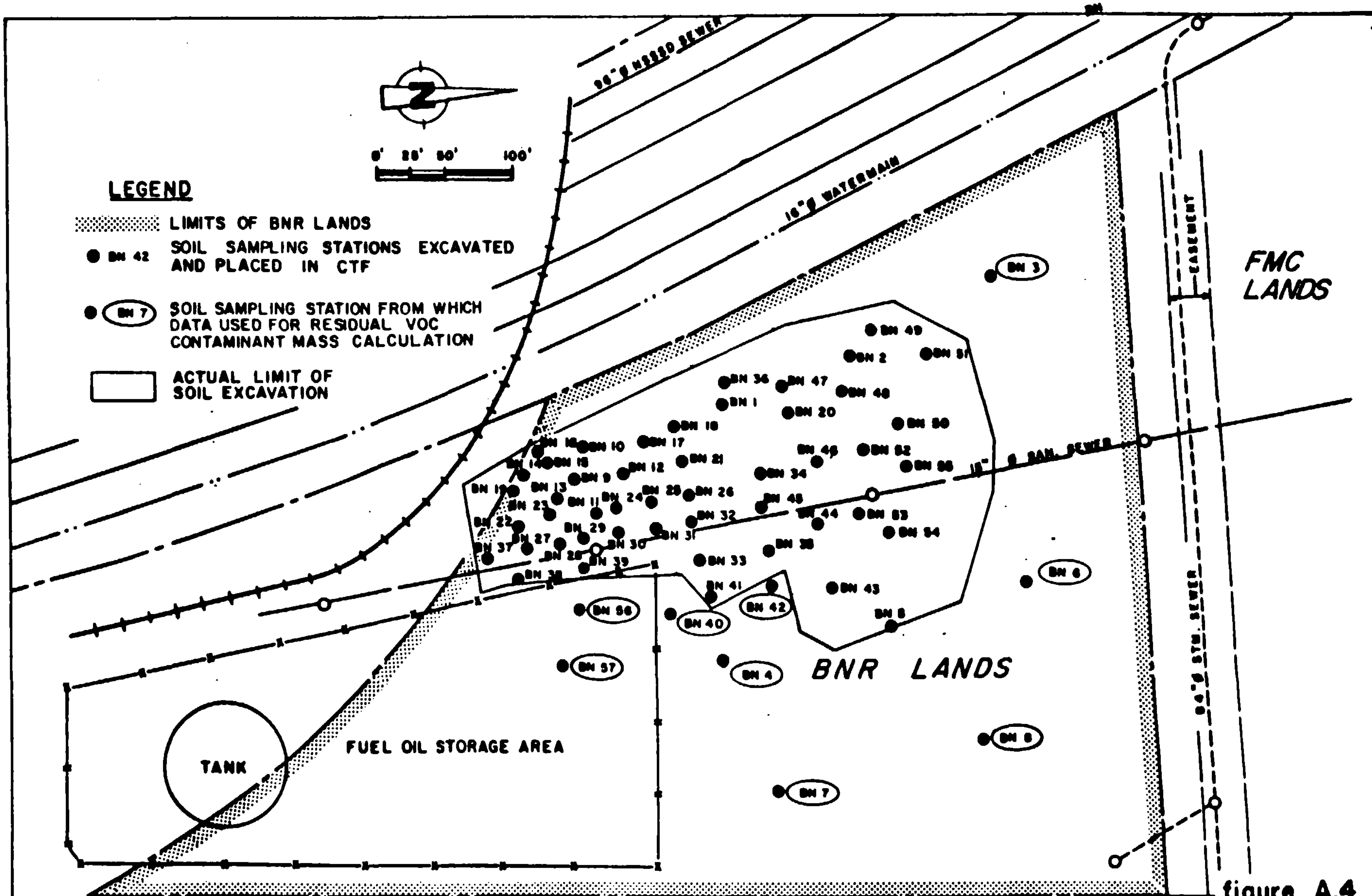

figure A.4

CONTAMINANT MASS LOADING SOIL SAMPLING STATIONS
BNR LANDS
FMC Northern Ordnance Plant

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A.3 ASSUMPTIONS FOR CALCULATION OF SOIL RESIDUAL CONTAMINANT MASS

The residual mass of VOC's in on-site unsaturated soils was calculated based on the following assumptions:

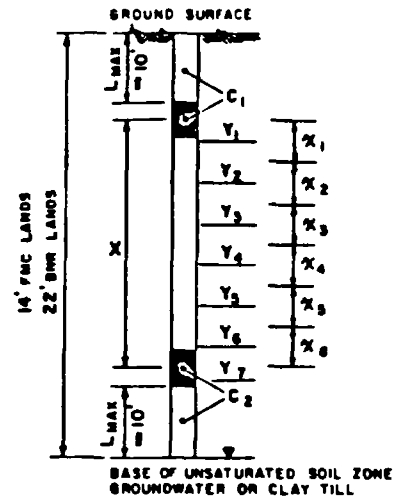
i) The reported VOC concentrations for soil samples at a sampling station are representative for the areal extent of soil extending half the distance to an adjacent sampling station. In areas of poor areal distribution of data, arbitrary areal limits were set based on site physical features and knowledge of past disposal practices.

ii) For the purposes of calculating the residual VOC mass, the average depth of unsaturated soils was rounded off to 14 feet and 22 feet for the FMC lands and BNR lands, respectively. Calculation depth intervals have been selected at 2-foot increments starting from zero to two feet and continuing to the 12-foot to 14-foot interval and 20 foot to 22 foot interval for the FMC lands and BNR lands, respectively. For each interval of depth, the VOC concentrations have been interpolated from the center point between two vertically adjacent samples. The data are also extrapolated to a maximum of ten feet from the top of the shallowest sample and from the bottom of the deepest sample. If there is only one sample for a particular location, the extrapolation is only five feet beyond the upper and lower limit of the sample interval. Figure A.5 presents a schematic of how the interpolation is completed.

iii) When parts of two sample data were within one depth interval, the assigned concentration is a weighted average of the two numbers. This weighting was by length of sample within that particular depth interval. Figure A.5 presents a schematic of how this weighting is performed.

iv) Whenever the analytical data were reported as concentrations below the method detection limit, the concentrations were assumed to be half of the reported detection limit unless no detection limit was given (very few instances) in which cases the concentrations were assumed to be zero.

a,)



VOC INTERPOLATION AT TWO FOOT INCREMENTS

L_{MAX} = MAXIMUM DEPTH OF EXTRAPOLATION
X = DISTANCE BETWEEN TWO SAMPLES
C = IDENTIFIED CONTAMINANT CONCENTRATION
Y = INTERPOLATED CONTAMINANT CONCENTRATION
x = LENGTH OF INTERPOLATED SAMPLE

EG.

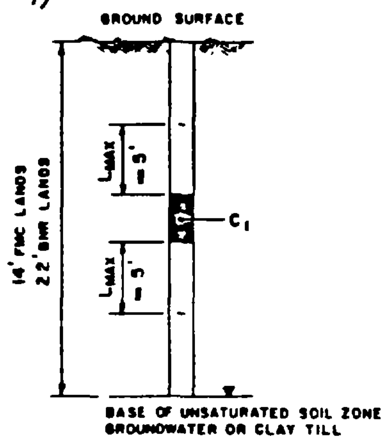
$$Y_1 = C_1 + \left(\frac{C_1 - C_2}{X}\right) \times 0$$

$$Y_2 = C_1 + \left(\frac{C_1 - C_2}{X}\right) \times x_1$$

$$Y_3 = C_1 + \left(\frac{C_1 - C_2}{X}\right) \times (x_1 + x_2)$$

NOTE: CONCENTRATION C_1 & C_2 CARRIED OVER DISTANCE L.

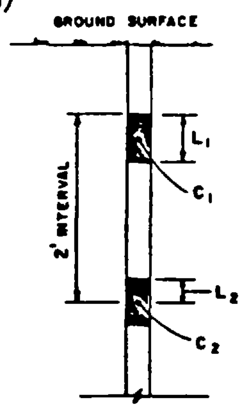
b,)



VOC INTERPOLATION FOR SINGLE SOIL SAMPLE

NOTE: CONCENTRATIONS INTERPOLATED AT 2' INTERVALS AS PRESENTED UNDER METHOD (a) ABOVE

c,)



VOC INTERPOLATION FOR TWO SAMPLES IN SAME INTERVAL

$$C_{AVG.} = \frac{C_1 L_1 + C_2 L_2}{L_1 + L_2}$$

figure A-5

CONTAMINANT MASS INTERPOLATION SCHEMATIC
FMC Northern Ordnance Plant

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A.4 CALCULATED LOADING

The on-site residual VOC contaminant masses for the FMC lands and BNR lands were calculated to depths of 14 feet and 22 feet, respectively. These calculations were performed assuming that 100 percent of the soil contamination was distributed through the entire unsaturated overburden soils. Table A.1 presents the calculated contaminant mass for each volatile organic chemical identified in the Site unsaturated overburden soils. The percentage of each individual VOC to the total mass of the VOC fraction is also included in Table A.1.

The total mass of VOC's in the soils on the FMC lands and BNR lands is calculated to be approximately 82 pounds and 388 pounds, respectively. The majority of the contaminant mass is comprised of methylene chloride for soils on the FMC lands, and trans-1,2-dichloroethylene for soils on the BNR lands. Trichloroethylene was the second most predominant contaminant in terms of calculated mass in the unsaturated soils on the FMC lands and fourth most predominant on the BNR lands. Trans-1,2-dichloroethylene, methylene chloride and toluene were more prevalent on the BNR lands than trichloroethylene.

TABLE A.1

UNSATURATED SOIL RESIDUAL VOC CONTAMINANT MASS

FMC Corporation
Minneapolis, Minnesota

Chemical Number	Name	Calculated Weight of Chemical Present in Site Soils (Pounds)		Percentage Of Individual Mass To Total Mass of Volatile Organics	
		FMC Lands	BNR Lands	FMC Lands	BNR Lands
1	acrolein	0	0	0.0	0.0
2	acrylonitrile	0	0	0.0	0.0
3	benzene	0.2	12.4	0.2	3.2
4	bis(2-chloroethoxy)methane	0	0	0.0	0.0
5	bromomethane	0	0	0.0	0.0
6	carbon tetrachloride	0	0	0.0	0.0
7	chlorobenzene	0	0	0.0	0.0
8	dibromochloromethane	0	0	0.0	0.0
9	chloroethane	0	0	0.0	0.0
10	2-chloroethylvinylether	0	0	0.0	0.0
11	chloroform	0	1.1	0.0	0.3
12	bromodichloromethane	0	0	0.0	0.0
13	dichlorodifluoromethane	0	0	0.0	0.0
14	1,1-dichloroethane	0	0	0.0	0.0
15	1,2-dichloroethane	0	4.7	0.0	1.2
16	1,1-dichloroethylene	0	0	0.0	0.0
17	1,2-dichloropropane	0	0	0.0	0.0
18	1,3-dichloropropylene	0	0	0.0	0.0
19	ethyl benzene	0	8.7	0.0	2.2
20	bromomethane	0	0	0.0	0.0

continued...

TABLE A.1 (cont'd)

UNSATURATED SOIL RESIDUAL VOC CONTAMINANT MASS

FMC Corporation
Minneapolis, Minnesota

Chemical Number	Name	Calculated Weight of Chemical Present in Site Soils (Pounds)		Percentage Of Individual Mass To Total Mass of Volatile Organics	
		FMC Lands	BNR Lands	FMC Lands	BNR Lands
21	chloromethane	0	0	0.0	0.0
22	methylene chloride	72.3	60.0	88.1	15.5
23	1,1,2,2-tetrachloroethane	0	0	0.0	0.0
24	tetrachloroethylene	2.2	0	2.7	0.0
25	toluene	0.9	27.2	1.1	7.0
26	cis-1,2-dichloroethene	0	0	0.0	0.0
27	trans-1,2-dichloroethylene	0	244.3	0.0	63.0
28	1,1,1-trichloroethane	0.3	5.2	0.4	1.3
29	1,1,2-trichloroethane	0	0	0.0	0.0
30	trichloroethylene	6.1	24.0	7.4	6.3
31	trichlorofluoromethane	0.1	0	0.1	0.0
32	vinyl chloride	0	0	0.0	0.0
		82.0	387.6	100.0	100.0

The contaminant mass values generated by this contaminant mass inventory calculation were utilized in Appendix B to evaluate the potential impact on the groundwater under the Site from the residual VOC contaminant mass presently in the unsaturated overburden soils. It should be noted that the mass calculation presented herein is a conservative representation of the total VOC mass remaining in the soils based on the contributing areas assumed for each soil sampling station.

APPENDIX B

POTENTIAL IMPACT OF SOIL RESIDUAL VOLATILE ORGANIC CONTAMINATION ON SITE GROUNDWATER

B.1 INTRODUCTION

The purpose of this Appendix is to provide an estimation of the potential impact on groundwater quality beneath the Site from residual volatile organic (VOC) soil contamination which may migrate under the influence of infiltrating surface water. Residual VOC masses in Site soils calculated in Appendix A were used in the evaluation of potential groundwater impact. Because of differences in unsaturated overburden thickness between the FMC and BNR lands, VOC contaminant discharge rates have been calculated separately for each area.

B.2 ON-SITE SOILS

Previous investigative sampling programs at the Site have included soil borings both for chemical analysis of soil samples, and for the installation of groundwater monitoring wells. Overburden soils encountered in the unsaturated zone during these investigative programs were generally characterized as fine grained, silty sands with some gravel.

B.3 PORE VOLUME

The total surface area of the BNR lands and FMC lands available for the vertical migration of residual contaminants is approximately 184,403 square feet (s.f.) and 439,497 s.f., respectively. An area of approximately 125,625 s.f. at the northeast corner of the FMC lands, where the CTF is constructed, is not included in the total surface area for this part of the Site. This area has an impermeable overliner and is therefore not available for surface recharge/infiltration.

The total depths of soils from the ground surface to the groundwater is approximately 21 feet and 24 feet for the FMC lands and BNR lands, respectively. These depths were determined during the 1983 Site remedial construction program.

Previous investigative work completed on-site has identified a low permeability aquitard beneath the site with an undulating upper surface which ranges in depth from five feet to 26 feet below the ground surface. On the basis of the average depth to the undulating clay surface, and the approximate depth of groundwater, an average depth of 13.5 and 21.35 feet of unsaturated soils are calculated for the FMC lands and BNR lands, respectively. These average depths represent the average vertical distance that infiltrating surface water will travel before mixing with the groundwater.

On the basis of a visual examination of soil samples collected at the Site and an estimation of grain size distribution, it is estimated that the overburden unsaturated soils have a porosity of 30 percent. ("Soil Mechanics in Engineering Practise", Terzaghi and Peck; "Groundwater", Freeze and Cherry). By multiplying the assumed porosity by the Site surface area and the average effective depth of unsaturated overburden, the soil pore volume for the unsaturated soil regime is determined. This pore volume is calculated to be 50,408,552 liters (13,315,903 gallons) for the FMC lands, and 33,448,780 liters (8,835,817 gallons) for the BNR lands.

B.4 RATE OF LEACHATE GENERATION

The rate of leachate generation is dependent upon the total annual precipitation over the Site. Local climatological data for the Minneapolis/St. Paul area shows that an average of 16.78 inches of rain and 40 inches of snow fall over the area on an average annual basis. Assuming that 50 percent of the total depth of snowfall when melted is available for infiltration into the overburden, ("Introduction to Hydrology", Veissmen, Knapp/Lewis/ Harbough), a total of approximately 37 inches of precipitation would accumulate over the Site on an annual basis. It is estimated that 15 percent of the total annual precipitation would infiltrate into the overburden. The remaining 85 percent would be lost to surface runoff, evaportranspiration, and evaporation. On this basis, approximately 6,223,292 liters (1,644,194 gallons) and 2,611,161 liters (689,869 gallons) of precipitation would infiltrate into the overburden on an annual basis on the FMC and BNR lands, respectively.

The volume of water which reaches the water table during any one year is assumed to equal the volume of water infiltrating into the unsaturated zone in any one year. By this approximation, the annual flow to the water table is therefore 6,223,292 liters (1,644,194 gallons) for the FMC lands and 2,611,161 liters (689,869 gallons) for the BNR lands.

B.5 LOADING TO AQUIFER

Sampling and analysis of Site soils completed to date have identified VOC contamination in the unsaturated overburden soils. Soils having VOC contamination in excess of one ppm were removed and placed in the CTF during the summer of 1983. Residual VOC soil contamination is, therefore, limited to concentrations less than one ppm.

Of the volatile organic chemicals identified in the groundwater beneath the Site, trichloroethylene (TCE) is the predominant species. Since TCE has been identified at the highest concentrations of any of the VOC's in the groundwater, and since TCE has been determined to be the groundwater contaminent of concern, TCE has also been selected as a surrogate parameter in evaluating the potential impact of residual soil contamination on Site groundwater. In addition, total VOC's are also selected as a parameter.

The total residual VOC mass calculation presented in Appendix A shows that approximately 37,195 grams (82 pounds) of VOC's, and 2,767 grams (6.1 pounds) of TCE are present in the unsaturated overburden soils on the FMC lands. A total of approximately 175,812 grams (388 pounds) of VOC's and 10,886 grams (24 pounds) of TCE are present in the unsaturated overburden soils on the BNR lands.

On the basis of field experiments conducted near Ottawa, Canada (Gloucester Project, National Hydrology Research Institute, Ottawa, Canada, April 1984), it is estimated that approximately 16 percent of the total available TCE mass will be desorbed during the flushing of the first pore volume. However, this value (16 percent) is applicable in saturated porous materials. Values for desorption of TCE from unsaturated porous media were not presented in this report. Since infiltrating water moves preferentially through water filled pores rather than through pores filled with air and adsorbed contaminants in unsaturated materials, the rate of contaminant desorption will be lower. A conservative value of 8 percent is assumed for the fraction of TCE mass stripped from the unsaturated zone during flushing of the first pore volume.

Thus it is expected that approximately 2,976 grams (6.6 pounds) of VOCs and approximately 221 grams (0.5 pounds) of TCE will be removed from the unsaturated zone on the FMC lands during flushing of the first pore volume. Similarly, for the BNR lands, corresponding values are 14,065 grams VOCs (31 pounds) and 871 grams TCE (1.9 pounds), respectively.

B.6 BASE GROUNDWATER FLOW

Data presented in the report entitled "Final Report - Phase I & II Investigation Programs", S.S. Papadopulos & Associates Inc., August 1984, estimated the total groundwater flow rate within the alluvial sand below the clay aquitard, which crosses the westerly property boundary of the FMC lands, to be 2,100 ft^3/day. Assuming that the total depth of the lower aquifer on the FMC lands is approximately 70 feet, and that the leachate after contact with the aquifer is assumed to mix with the upper ten feet of the aquifer, the total estimated volume of groundwater passing under the FMC lands and mixing with infiltrating leachate is 8,496 liters/day (1.6 gallons/min.).

Groundwater flow beneath the BNR lands was identified to be in a southerly direction along a channel in the underlying clay aquitard. Papadopulos estimated the total groundwater flow rate within this channel to be 1,100 ft^3/day. Since VOC contaminants were identified to full depth in all groundwater monitoring wells constructed on the BNR lands, it is assumed that leachate after contact with the aquifer will mix to full depth. Therefore the total estimated volume of groundwater passing under the BNR lands which mixes with surficial leachate is 31,152 liters per day (5.7 gallons/min.).

B.7 MIXING AND DILUTION

Multiplying the base groundwater flows calculated in Section B.6, by the duration for the movement of one pore volume through the unsaturated overburden soils as calculated in Section B.4, the total resultant volume of groundwater available for mixing would be 25,114,176 liters (6,635,165 gallons) for the FMC lands, and 145,670,000 liters (38,486,000 gallons) for the BNR lands. Mixing one pore volume of leachate (50,408,552 liters, FMC lands; 33,448,780 liters, BNR lands) gives a combined resultant volume of water of 75,522,728 liters (19,953,105 gallons) for the FMC lands and 179,120,000 (47,324,000 gallons) liters for the BNR lands. It is to be noted that for the purposes of these calculations it is assumed that the incoming groundwater does not contain VOCs.

Mixing the volume of water calculated above with eight percent of the total contaminant mass (contaminant loading) gives final contaminant concentrations attributable to the unsaturated Site soils of the resultant groundwater that would migrate off-site during the first pore volume flushed through the unsaturated zones. Table B-1 presents a summary of the resultant groundwater contaminant concentrations.

TABLE B-1

RESULTANT GROUNDWATER CONTAMINANT CONCENTRATION

FMC Corporation
Minneapolis, Minnesota

AREA	CONTAMINANT	TOTAL MASS OF CONTAMINANTS (grams)	8% OF TOTAL CONTAMINANT MASS (grams)	RESULTANT CONCENTRATION (ug/l)
FMC Lands	Total Volatile Organics	37,195	2,976	39.4
	Trichloroethylene	2,767	221	2.9
BNR Lands	Total Volatile Organics	175,812	14,065	78.5
	Trichloroethylene	10,886	871	4.9

B.8 CONCLUSIONS

The total average annual precipitation over the Site which potentially would infiltrate into the overburden soils is 37 inches. Of this total, approximately 6,223,292 liters (1,644,194 gallons) and 2,611,161 liters (689,869 gallons) are estimated to infiltrate per year into the overburden on the FMC lands and BNR lands, respectively.

The resultant contaminant loading to the upper alluvium groundwater following the flushing of one pore volume in the unsaturated overburden would be 2,976 grams (6.6 pounds) of total VOCs and 221 grams (0.5 pounds) of TCE over the FMC lands, and 14,065 grams (31.0 pounds) of total VOC's and 871 grams (1.9 pounds) of TCE over the BNR lands. One pore volume would be flushed over a period of 2,956 days and 4,676 days for the FMC lands and BNR lands, respectively.

It is to be noted that these rates of contaminant removal are representative of the first pore volume of leachate generated and that subsequent pore volume leachate strength would be expected to drop significantly. Furthermore, the above rates are based on an estimate of the soils maximum capacity for vertical leachate movement. For these loading calculations it is assumed that the precipitation infiltrates vertically and that all surrounding areas are clean and do not contribute to the resultant groundwater loading.

Therefore the impact of precipitation infiltrating through the unsaturated overburden on the confined aquifer would be insignificant over both the FMC lands and the BNR lands. On the basis of this conclusion remedial actions incorporating surface infiltration controls (e.g. capping) are not required at the Site to achieve acceptable groundwater quality relative to adverse impacts on downgradient groundwater receptors.

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February 11, 1985

Mr. Kerry Street
U.S. Environmental Protection Agency - Region V
230 South Deerborn Street
Chicago, Illinois 60604

Dear Mr. Street:

Enclosed is our review of the Feasibility Study - FMC and BNR Lands Ground-water Regime, submitted by FMC as required by the June 8, 1983 Administrative Order and Interim Response Order by Consent between FMC, the U.S. Environmental Protection Agency, and the Minnesota Pollution Control Agency.

While FMC addresses the "no-action" alternative, we feel the uncertainty associated with their risk assessment must lead one to evaluate other remedial action alternatives.

If you have any questions, please do not hesitate to contact either Gerry Grisak or myself.

Sincerely,

Robert W. Andrews
Senior Staff Consultant

RWA/sah

Enclosure

cc: Edward DiDomenico, PRC
Gerry Grisak, INTERA

RECEIVED
FEB 12 1985
PM