Reconnaissance investigation of three areas in Montana for hydrogeologic suitability to host a hazardous waste disposal facility
by Alice Roberta Stanley

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
The hydrogeologic environment of hazardous waste disposal sites constitutes an important second line of protection from potential leachate migration. Site suitability factors include seismicity, topography, climate, soil characteristics, depth to water table, hydraulic conductivity and gradient of underlying aquifers, nature of fractured bedrock, lineament analysis, thickness and homogeneity of bedrock, ground distance to known faults, location of local recharge and discharge areas and water quality.

Regional and subregional analysis of hydrogeologic suitability factors included review of available data, field reconnaissance, water chemistry analysis, and digital image enhancement of Landsat multi-spectral scanner imagery for lineation patterns. Three regions in Montana were identified and ranked according to their hydrogeologic suitability for hazardous waste disposal. Area One, the Sumatra-Ingomar area in eastern Montana appears to be hydrogeologically most suitable to host a hazardous waste disposal site. It is underlain by the Late Cretaceous Bearpaw Shale. The Bearpaw Shale is a predominately dark gray bentonitic shale, which yields small quantities of water unfit for domestic consumption and is not a potential aquifer.

Area Two, the Roundup-Winnett area and Area Three, the Denton-Lewistown Area appear to contain some marginally suitable areas to host sites. These areas are underlain by Cretaceous Colorado Group which is typically unfavorable as a source of groundwater with the exception of its lowest sandstone member.

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APPROVAL

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Alice Roberta Stanley

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The hydrogeologic environment of hazardous waste disposal sites constitutes an important second line of protection from potential leachate migration. Site suitability factors include seismicity, topography, climate, soil characteristics, depth to water table, hydraulic conductivity and gradient of underlying aquifers, nature of fractured bedrock, lineament analysis, thickness and homogeneity of bedrock, ground distance to known faults, location of local recharge and discharge areas and water quality.

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INTRODUCTION

Reason for Study

In 1976, Congress defined hazardous waste in the Resource Conservation and Recovery Act (RCRA, 1976) as

> "a solid waste, or combination of solid wastes, which...may cause or significantly contribute to an increase in mortality...or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed."

Since that time, over 60,000 different types of chemicals and chemical compounds currently being produced in the United States have been identified as hazardous or potentially hazardous (Magnuson, 1985). Because of congressional concern over the U.S. Environmental Protection Agency's (USEPA) management of the hazardous waste program (Epstein and others 1982, Magnuson 1985), RCRA was reauthorized in 1984 with more specific and restrictive technical requirements for hazardous waste management. One of the new provisions brings generators of small quantities of hazardous waste, under the regulatory program. Those who generate less than 1000 kilograms (2200 pounds) of hazardous waste per month and greater than 100 kilograms (220 pounds) per month are considered "small quantity generators" for regulatory purposes and are responsible for the proper disposal of their hazardous wastes. Because the six-month grace period for small quantity generators expired March 24, 1987 (U.S. Environmental Protection Agency, 1986a), the demand for an affordable means of disposal is expected to increase.

Presently in Montana there is no disposal site designed to accommodate hazardous waste. Small generators of hazardous waste that wish to comply with RCRA will need to find a safe and legal method of transportation, short term storage, treatment and disposal of their wastes. The financial burden of long distance waste shipments combined with the increased probability of transportation accidents as small generators are forced to ship their wastes out of Montana, and the possibility that Montana may not have access to disposal sites outside the state in the future has created a need to explore the feasibility of developing a hazardous waste disposal facility within the state.

Historically, instances of inappropriate site selection for hazardous waste disposal have caused significant and irreparable environmental damage and human suffering (Epstein and others, 1982). Most landfills operate for 10 to 20 years (Montaque, 1984); postclosure routine maintenance and leak-monitoring is required by law for up to 30 years, after which, if no leak has been detected, the site becomes the responsibility of the federal government (U.S. Environmental Protection Agency, 1986b). No ensuing treatment of a leak is required other than what is provided in the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). CERCLA was reauthorized in October, 1986 as the Superfund Amendments and Reauthorization Act 1986 (SARA).

The U.S. Environmental Protection Agency (USEPA) believes that more than 90 percent of the estimated 180,000 hazardous waste surface impoundments are designed and located in a manner that could result in groundwater contamination (U.S. Environmental Protection Agency, 1985). Most experts agree that landfills eventually will leak their contents into surrounding groundwater, despite their linings (Lee and Jones, 1984; Josephson 1981). There is considerable evidence that the clay liners commonly used to contain hazardous waste landfill disposal systems are failing to contain wastes (Montague, 1984; Epstein and others, 1982; Anderson, 1982). Organic wastes such as xylene, methanol and acetone generated in Montana (Montana Department of Health and Environmental Sciences, 1984; Wilson, 1986) tend to interact with packed clay and cause cracking (Green, 1983; Lee and Jones, 1984). An engineered protective barrier may retard movement of the leachate during the 30 year post-closure monitoring period prescribed by RCRA but it is likely to fail eventually, allowing buried chemicals to mix and migrate to surface or groundwater reservoirs.

While the chemical constituents of each hazardous waste presents a singular threat to human life and the environment, mixtures of hazardous chemicals can be even more threatening to the environment. Acids, for example, tend to enhance the mobility of heavy metals. Organic toxicants, which are nearly immobile in aqueous solution, became highly mobile when in contact with solvents (Ghassemi and others, 1985). Because of the high potential for leakage, the geologic environment at a landfill or treatment facility must be considered as an important second line of defense against migration of the hazardous waste into the environment. Only a site that is hydrologically safe can be considered as possibly suitable for hosting a hazardous waste facility. This is of special importance to Montana because the state not only uses groundwater to provide for approximately 44 percent of its domestic water supply (Martin, 1986) but is also a headwaters state to nearly a third of the continental United States.

The prospect of increased demand for a hazardous waste facility in Montana, coupled with the high risk of hazardous leakage emanating from such a facility have necessitated an evaluation of the state to locate areas for disposal where natural conditions provide multiple barriers between a hazardous waste disposal facility and ground and surface waters.

Objective of Study

The primary objective of this study is to answer the question: are there regions in Montana hydrogeologically suitable for landfill hazardous waste disposal? Supporting objectives are: to identify hydrogeologic suitability criteria appropriate for Montana and to locate and evaluate areas in Montana hydrogeologically acceptable for hosting a hazardous waste disposal facility. This study is reconnaissance in nature and is limited to a technical evaluation of hydrogeologic factors important for landfill hazardous waste disposal siting on a regional scale in Montana. Any actual facility emplacement must be preceded by a comprehensive, site-specific evaluation of any area under consideration.

Review of Previous Work

In 1980, the Solid Waste Management Bureau of the Montana DHES published a management guidance document for pesticide disposal in Montana (Montana Department of Health and Environmental Sciences, 1980). The report outlines operating procedures, technical problems and program costs of pesticide waste management. In Part VI of the document, DHES lists criteria with suggested parameters for site selection of a pesticide waste landfill facility. The report discusses potentially suitable geologic units and candidate disposal sites.

A regional evaluation of Montana for hazardous waste disposal was completed by David Bowen for the Montana Department of Health and Environmental Sciences (DHES) in 1981. Bowen developed a series of 1:1,000,000 maps of Montana based on environmental factors such as soils, physiography surface geology, and hydrogeology. Economic, social and ecological factors were not mapped but were addressed in his study. Bowen's report is a highly generalized but useful overview of some of the environmental factors essential to hazardous waste facility site selection in Montana. Although Bowen did not map regions that might be suitable to host a hazardous waste disposal facility, his factor maps and accompanying discussion help to delineate large regions of potentially suitable sites in Montana.

The Bowen (1981) study and the DHES (1980) report provide useful background material for ensuing evaluations of Montana for hazardous waste disposal sites. However, Bowen's (1981) study contains only a superficial treatment of factors essential to suitable site selection in Montana and the DHES (1980) study narrowed its scope to include only pesticide waste disposal for two specific candidate sites. There is no evidence in the DHES report of a regional evaluation for other potentially suitable sites. This study attempts to combine the factor-dependant systematic process of Bowen's efforts with the geographic focus of the DHES Pesticide Management Document so that the most suitable areas in Montana become apparent. In this way, key hydrogeologic parameters are considered for areas likely to contain suitable sites in Montana.

A 1984 report to the Montana Department of Health and Environmental Sciences entitled Hazardous Waste Management Facility Study (IT Corporation, 1984) presented an evaluation of existing information concerning the quantities and types of waste generated in Montana. It included a conceptual design of a hazardous waste container storage facility with associated cost estimates. The report also briefly outlined costs and benefits of alternative hazardous waste management facilities. The study did not attempt to site the facility but provides a useful guide for estimating the land area and construction requirements of a facility scaled to accommodate the amount of hazardous waste Montana can expect to generate by 1988.

Procedure

Research for this study was designed to answer the question: are there regions in Montana hydrogeologically suitable for landfill hazardous waste disposal? Three areas were selected for evaluation. These areas were chosen because the initial regional appraisal of Montana concluded that surface geology, seismic activity, structural configuration and surface and ground waters had the highest probability of meeting the criteria discussed later in this report.

A regional evaluation of Montana was made based on available data and Bowen's (1981) report. A series of overlay maps were developed from Bowen's study and used to identify regions in Montana most likely to contain hydrogeologically suitable areas for hosting a hazardous waste disposal site. These overlays were presented at a conference of Montana scientists for discussion in June, 1985. Several areas in Montana were then selected for hydrogeologic examination based on the initial regional evaluation and on the conference workshop results. A summary of workshop discussions and recommendations are presented in Appendix A. Figure 1 shows regions in Montana initially considered for hydrogeologic reconnaissance

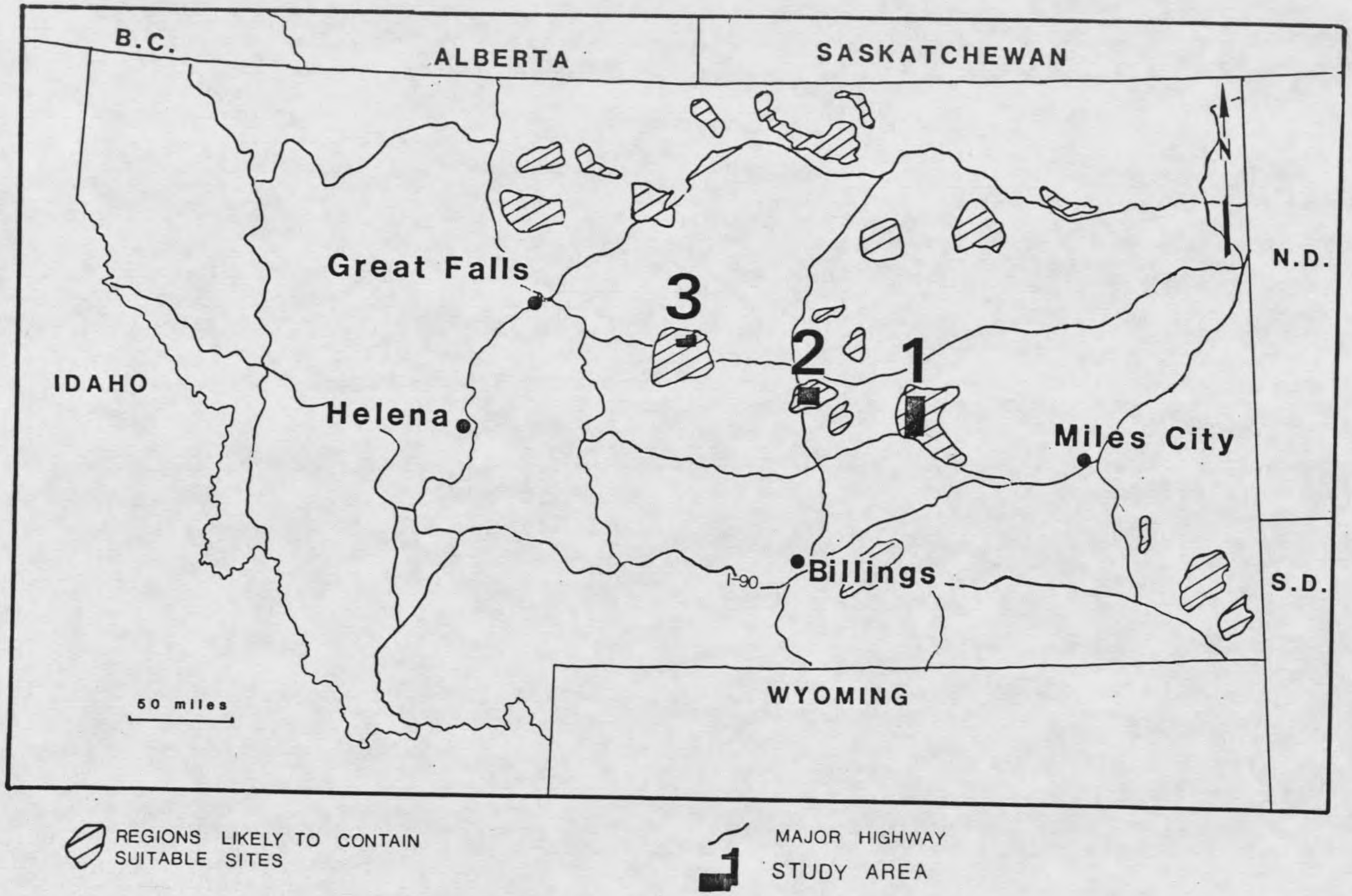

Figure 1. Regions in Montana initially considered for hydrogeologic reconnaissance evaluation, (compiled from Bowen,1981)

evaluation. Hatched areas represent regions most likely to contain suitable sites based on Bowen's 1981 study and workshop results. The black regions represent the areas chosen for this study.

Time and resource limitations of the study precluded a detailed investigation of all the areas delineated in Figure 1. Glaciated regions were not considered for field reconnaissance because their heterogeneous and often fractured (Grisak and others, 1980; Grisak and Cherry, 1975) nature decreases predictability of fluid flow, and because glacial sediments in Montana often contain channel gravels that act as local usable aquifers (Davis and Rogers, 1984). The Billings area was also considered for field evaluation but was rejected for three reasons: (1) proximity to the Lake Basin Fault Zone, (2) proximity to the Yellowstone River flood plain and (3) proximity to near surface usable groundwater. Based on the preliminary analysis and conference results, Areas One, Two and Three appeared most likely to contain suitable disposal sites.

Area One (located near Sumatra and Ingomar) and Area Two (located near Roundup and Winnett) were selected for field reconnaissance. Area Three (the Lewistown-Denton Area) was evaluated using only existing information and was not field-checked to the same degree as Areas One and Two. The Lewistown-Denton Area was originally chosen for review because of its apparent suitability for hazardous waste disposal and because of its central location in Montana. The area was not evaluated in detail because of time constraints and because initial review indicated that ground and and surface water characteristics were not as suitable for hazardous waste disposal as in Areas One and Two.

An additional suitability factor that may be highly important but is not considered in this study is distance of transport from waste generators to study areas. Hazardous waste spills occurring during transit can have serious consequences. Unlike the rigorous disposal site selection process, a spill site can happen anywhere and affect local and regional ground and surface waters for years. For this reason, distance of waste transport, type and route of transportation, time of year for waste transport and size of load may be significant considerations when evaluating any region for hazardous waste disposal facility siting. However, because the relationship between all these factors and the amount and nature of transport spills in Montana is unknown, distance from waste generator to study areas cannot be adequately factored into this evaluation and is reluctantly ignored.

The selected areas were evaluated using established criteria with parameters adapted for Montana's hydrogeologic environment. Analytical methods are discussed in the following section. After evaluation, each area is ranked according to its potential suitability to host a hazardous waste landfill disposal site. Rather than identifying specific sites, this research was designed to identify regions where site-specific analysis might be focused in the future. A site specific study must include more extensive investigations using analytical techniques such as detailed geologic mapping to pinpoint units of high conductivity, geomorphic mapping to assess landscape stability, monitoring well tests to accurately determine local groundwater flow characteristics, soil analysis for type and depth, a detailed survey for frequency and location of surface water flows and engineering studies to address installation.

METHODS

Each study area was evaluated and defined in terms of the set of factors outlined in the following section. Each factor was assessed for its usefulness in a regional rather than site-specific study and its applicability to Montana. These factors were drawn from numerous sources including published site evaluation procedures and case histories (Aller and others, 1985; LeGrand, 1983; Longmire, Gallaher and Hawley, 1980; Montana Department of Health and Environmental Sciences, 1980; U.S. Environmental Protection Agency, 1986a; U.S. Environmental Protection Agency, 1986b; Cartwright, Gilkeson and others, 1981).

Field techniques included fracture orientation measurements and analysis, bail tests of shallow wells, and geologic mapping. Areas having observable linear surface trends were evaluated for orientation of lines of vegetation, the surface expression of vertical cracks and zones of oxidation, and linear stream beds to determine orientation of fractures. Orientation readings were made with a Brunton compass. Hydraulic conductivities of the near surface unconfined perched aquifers in weathered shale and shale-derived alluvium were determined by measuring the rate of the rise in water level in response to bail tests (Hvorslev, 1951; Freeze and Cherry, 1979). Slotted two-inch PVC pipes were inserted into hand-augered holes to depths ranging from four inches to ten feet. Bail tests were chosen to determine hydraulic conductivity because of the low permeability of the aquifer (Ferris and others, 1962; Bouwer and Rice, 1976). Reconnaissance geologic mapping in Area One was accomplished for this study using field observations and preliminary U.S. Soil Conservation soils maps for Rosebud County at a scale of 1:24,000. Soils maps were used to aid in determining the contact between the Bearpaw Shale and the Hell Creek Formation: the Hell Creek Formation tends to develop silty to sandy loam soils while the Bearpaw Shale tends to develop silty clay to clay soils. Geology in Area Two, mapped in 1954 on a scale of 1:64,000 by Johnson and Smith, was field checked.

Analytical evaluation of collected data includes the following methods. Water quality analyses of collected surface and perched groundwater samples were performed by the water analytical lab at the Montana Bureau of Mines and Geology in Butte. Surface water samples were collected by the grab method from the only sources available: stock water ponds and springs; groundwater samples were collected from shallow wells emplaced near seeping springs. Water samples were vacuum filtered through a 0.45 micromillimeter-size filter, three bottles at each sample area were collected: one was preserved with nitric acid and filtered, one was filtered with no acid and one was unacidified and unfiltered. The bottles were kept refrigerated until analysis. Holding time before delivery to the laboratory ranged from two to six days.

A Spatial Data EYE-COM II image enhancement system was used for computer edge-enhanced fracture analysis of lineation patterns on Landsat satellite images using the FORTRAN programs SOBEL and GRADE.

Several standardized methodologies are currently in use for evaluating a potential hazardous waste disposal site. Each of the three study areas was evaluated using the two models: the LeGrand Standardized System for Evaluating Waste Disposal Sites (LeGrand 1983), and DRASTIC: a Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings (Aller and others, 1985). These methods were useful for this study because they consider major factors for hydrogeologic suitability systematically and objectively and are designed to be used as a screening mechanism prior to more intensive investigation. Their function in this report is twofold: results from the application of each method of analysis can be used (1) as independent confirmation of the suitability of the study areas evaluated in this report, and (2) as means to compare the Montana study areas with existing sites outside the state. The following discussion details the application methodology of each model and addresses their usefulness for this study. The LeGrand and DRASTIC methods of evaluation and their application to the Montana study areas are discussed in detail later in this report.

The LeGrand System

The LeGrand standardized system for evaluating waste disposal sites was developed by Harry LeGrand in 1983 to assess the relative suitability of multiple sites. It was designed for hydrogeological evaluation on a site-specific basis but can also be applied to a regional investigation on a scale appropriate to Montana. The LeGrand method assigns each of eight major hydrogeologic factors a numerical value that reflects the suitability of a prospective site and the relative influence of site hydrogeologic characteristics on leachate migration. The final rating is a single number that represents the potential for contamination of groundwater and surface water.

The DRASTIC System

DRASTIC (Aller and others, 1985) is a standardized system developed by the National Water Association and the U.S. Environmental Protection Agency for evaluating groundwater pollution potential using hydrogeologic settings. DRASTIC is an acronym reflecting its factors of evaluation: Depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and hydraulic Conductivity of the aquifer. It is a ranking system that uses a combination of weights and ratings to produce a numerical value that is an indication of groundwater contamination vulnerability. The seven major factors for consideration in the model are weighted differently depending on the degree of confinement of the aquifer and special weight is given to a single factor, such as highly fractured bedrock, if it is so dominant that it overrides all other parameters. For several reasons the author did not find DRASTIC as useful as the LeGrand method for this investigation.

The role of topography appears to be designed to fit more humid conditions and could not be applied to Montana without changing the model. The DRASTIC system rates areas as less vulnerable to groundwater pollution if they have slopes greater than 18°. Steep slopes tend to compel escaping leachate to become surface runoff rather than infiltrating leachate; this is desirable only if (1) usable groundwater is immediately threatened by a leachate plume and not if the nearest usable groundwater is 1000 feet below surface as is often the case in the semi-arid west, and if (2) one has a great deal of faith in the leachate protection and monitoring system engineered for each site.

Also areas of high relief tend to be geomorphologically unstable because of higher mass movement and stream erosion rates, an undesirable feature of a hazardous waste disposal site. For confined aquifers, the DRASTIC model reduces the impact of topography relative to other parameters by adjusting its weighted value, but does not adjust the rating value itself: steeper slopes are still considered more desirable over well-confined aquifers.

Net recharge, another of DRASTIC's seven major factors for analysis is difficult to determine unless a detailed site-specific evaluation is made. While precipitation and evaporation are known, net recharge is poorly known. An example of this problem is saline seep in Montana where significant recharge can occur simply in response to changing agricultural practice (Miller, 1971) model provides generalized recharge values which are too regional and inexact to be useful.

HYDROGEOLOGIC EVALUATION OF MONTANA

Critical Hydrogeologic Factors

There are many hydrogeologic factors that control the behavior of contaminants in groundwater. The following are the most critical to site selection in Montana. Each factor is evaluated for its contribution to the containment and isolation of waste for as long as it is hazardous. Factors that affect fluid flow prediction and contaminant degradation are also considered.

Tectonics and Seismicity

Any area having moderate to high seismicity is unsuitable for hosting a hazardous waste disposal site because of the potential damage to a facility and its engineered leakage-prevention apparatus, and because reactivated shear zones that generate the earthquakes commonly result in fractured bedrock.

Montana can be divided into three tectonic provinces (Taylor and others, 1986):

1. the Rocky Mountain Fold and Thrust Belt in the western part of the state,
2. the Laramide-style basement cored uplifts and volcanics of Southwestern Montana, and
3. broadly folded Phanerozoic rocks in the eastern half of the state.

Much of the western half of the state has been strongly influenced by major compressional tectonic events which produced thrust faults and folds. These events probably ended during the Eocene Epoch 55 to 38 million years before present. Western Montana is currently undergoing extension (Lageson and Zim, 1985) which produces a terrain of normal faults superimposed on the older compressional features. Both the compression and extensional deformation produce characteristics which are undesirable for hazardous waste disposal siting. Such deformation provides extensive and complex avenues for contamination to reach important aquifers and surface water. These features can also juxtapose aquifers so that aquifer isolation is difficult to establish with certainty.

Contemporary extensional tectonic activity is an additional factor making the western part of Montana a poor region to consider. Figure 2 shows the location of earthquakes felt over a 110 year period. Because the eastern region is the least tectonically complex of the three, it is a more desirable structural setting for a hazardous waste disposal site. The increase in structural simplicity decreases the uncertainty of hydrogeologic evaluation in this eastern region.

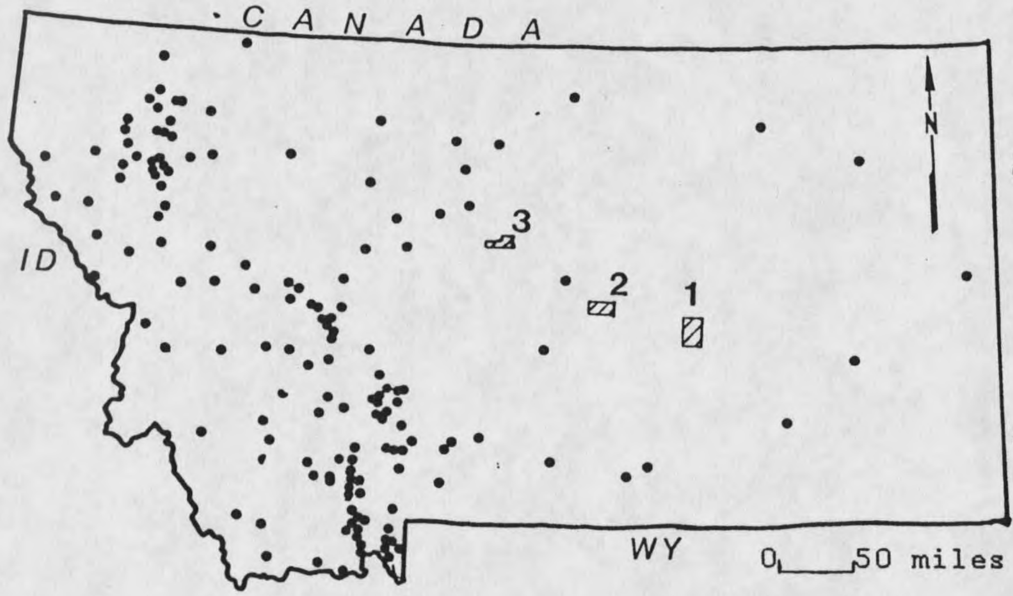

Figure 2. Location of Montana Earthquakes felt between 1869 and 1979, (Qamar and Stickney, 1983)

Structure

The complexity of a groundwater system tends to mirror the structural complexity in a region. Complicated interaquifer relationships and heterogeneous aquifer regimes are characteristic of Montana's western mountainous regions. There are several reasons to avoid the structurally complex areas of western Montana for hazardous waste landfill disposal sites. The most critical are highly fractured and faulted bedrock, exposed karstic limestones and extensive exposure of important regional aquifers.

Topography

Areas with extreme relief are often associated with surface or structural instability. There is some disagreement concerning the advisability of construction of a disposal site in areas with high relief. Some researchers (Aller and others, 1985) recommend facility emplacement in areas with slopes greater than four percent in order to deter leachate infiltration. In this way, topography helps to increase the likelihood that a pollutant will be in a local flow system rather than infiltrate to great depth and avoid detection. Other researchers, (Longmire and others, 1980; Shilepsky and Pulford, 1983; Duvel, 1979; LeGrand, 1983) recommend that ground and surface water supplies will best be protected in the more geomorphologically stable areas having slopes of less than five percent. This view of the role of topography is adopted for this study.

There are several reasons why a steep slope is an undesirable characteristic of a hazardous waste disposal site in Montana. Areas of high relief tend to be geomorphically as well as structurally unstable. Mass movement and stream erosion rates increase with increased elevation difference causing landforms to undergo a great deal of change over the lifetime of a hazardous waste site and its postclosure threat to the environment. In addition to the inherent instability of areas with high and variable relief, near-surface unconfined aquifers tend to have higher gradients and are more likely to discharge to the surface. Compelling migrating leachate to remain on the surface rather than infiltrating is desirable only if usable groundwater is immediately threatened by a leachate plume and if a well-engineered monitoring system will be in working order for thousands of years, much longer than the maximum postclosure monitoring period required by the EPA. In particular, if aquifers are far below the site and separated from the site-base by clays and shales, then vertically downward directed flow lines associated with low slopes is the preferred leachate path.

In Montana, the western one-third of the state has relatively high topographic relief with elevations ranging from 12,799 feet to 1800 feet above sea level (Taylor, 1974). Relief in the eastern two-thirds of the state can be described as rolling topography with gently inclined drainage divides and local areas of sharply dissected badlands (Montagne and others, 1982), and mountains tend to be isolated uplifts.

The Great Plains region of Montana in the eastern two-thirds of the state contains relief that may reduce the potential for groundwater contamination from a potential leachate plume; hence it is the more topographically suitable region for hazardous waste disposal.

Local topography must also be considered. Areas containing depression basins or extensive flood plains are undesirable because of the potential for ponding or inundation by flooding (Longmire and others, 1980).

Soils

The soil layer and the weathered product of the soil's parent material should perform one of two functions depending on the nature of the soil and the contaminants. Soil should protect the groundwater by preventing water access and transmission of wastes or it should attenuate and retard the movement of contaminants as the plume infiltrates. Factors influencing the transport of organic and inorganic chemicals through soil are soil pH, cation exchange capacity, rainfall patterns, time, soil permeability and texture (Corey and Dowdy, 1983; Weber, 1984; Hornick, 1983).

Soil chemical and physical characteristics are generally considered important factors of hazardous waste disposal site evaluation. However, because soils in Montana tend to be thin with little horizon development, functions such as attenuation or containment which tend to be performed by the soil layer in less arid climates must be performed by the weathered bedrock from which the soil is derived.

Eastern Montana's cool dry climate and relatively youthful landscape causes physical weathering and soil development to predominate over chemical and biological weathering so that soils tend to retain properties such as permeability of their parent materials (Montagne and others, 1982). Clay minerals in Montana soils, for example, are usually inherited from parent material rather that formed in place. For this reason and because the thin nature of the soils in the study areas increase the importance of containment and attenuation properties of underlying weathered bedrock, mappable soil units are based on surficial geology for this study. Veseth and Montagne (1980) divided the more than 700 kinds of soils in Montana into the 13 major soil types outlined in Table 1.

Based on their potential to isolate and detoxify a hazardous waste leachate plume should leakage occur, two of Veseth and Montagne's 13 soil types and their parent surface geologic units are regionally suitable for hosting a hazardous waste treatment or disposal site:

Soils developed from soft black shales, (Table 1):

These Cretaceous shales cover an extensive area of central and eastern Montana. They weather to montmorillonitic clay loams and silty clays that behave plastically when wet and have slow to very slow permeabilities, ideal characteristics for hazardous waste disposal. The Colorado Shale and Montana Group are included in this category.

Soils developed on soft shales that are interbedded with moderately hard sandstones, (Table 1):

Soil units developed on the Claggett Shale form deep clay loams with very slow permeabilities and behave plastically when wet. These

Table 1. Major soil types of Montana based on parent materials (adapted from Veseth and Montagne, 1980).

1. Soils developed from volcanic ash
2. Soils developed from high gravel terraces
3. Soils developed from Tertiary valley-fill
4. Soils developed from soft sandstone, siltstone, and claystone
5. Soils developed from soft black shale
6. Soils developed from soft shales interbedded with moderately hard sandstones
7. Soils developed from soft red shales and hard sandstones
8. Soils developed from limestone and dolomite with interbedded shales
9. Soils developed from extrusive igneous rocks
10. Soils developed from intrusive igneous rocks
11. Soils developed from fine-grained metamorphic rocks
12. Soils developed from coarse-grained metamorphic rocks
13. Soils developed from glacial lake sediments and till

characteristics are desirable for hazardous waste disposal (Griffin and Chiean, 1979; LeGrand, 1983).

The two soil units described above are regionally suitable for hosting a landfill hazardous waste disposal facility in Montana; the following soil types may be locally suitable but are not extensive on a regional scale.

- o Soils developed on soft Tertiary valley fill sediments in the broad intermontane basins of western Montana,
- o Soils developed on soft red shales interbedded with hard sandstones,
- o Soils developed on limestone and dolomite with interbedded shales, and
- o Soils developed on glacial lakes and till.

Stratigraphy

The nature and thickness of the bedrock between site base and the nearest groundwater aquifer are important factors to consider when evaluating a potential hazardous waste disposal site. The strata immediately underlying the site should be laterally and vertically homogeneous to increase predictive accuracy of transport models. Hydraulic conductivities should be less than 10^{-7} cm/s (Montana Department of Environmental Sciences, 1980; LeGrand, 1983; Longmire and others, 1980) for a minimum thickness of 150 feet (Longmire and others, 1980). Some caution should be used when assessing hydraulic conductivities for hazardous waste disposal siting.

Because fluid properties of hazardous waste leachates are often unknown and their mobility may be different from that of water, hydraulic conductivities based on water flow may be misleading. Many rocks having a low primary small scale matrix, such as shale or granite or gneiss are also susceptible to fracturing. Therefore fracture permeability as well as the hydraulic conductivity of the matrix and the fluid properties of the leachate must be considered.

The attenuation characteristics of fine-grained soils, weathered bedrock and underlying stratigraphy such as clayey glacial till and shale are generally considered favorable for hazardous waste disposal. Small inter-connected pores and high clay content allows for large contact area and long contact time between earth materials and contaminants (Cartwright and others, 1981). Studies by R.A. Griffin and others (1977) of the attenuation of pollutants in landfill leachate showed that in general, as pH increases (pH >6) heavy metals tend to precipitate and are removed from the migrating groundwater system through an exchange adsorption reaction affected by pH and ionic competition. Cation metals such as Pb^{2+}, Cd^{2+}, Zn^{2+}, Cu^{2+}, Hg^{2+} and Cr^{3+} tend to be adsorbed or precipitated at higher pH. Griffin also determined that montmorillonitic earth materials are more effective adsorption mediums than those high in kaolinite or illite.

Organic compounds such as polychlorinated byphenols (PCB's), tend to have low solubility in water (Chou and Griffin, 1983; Mackay and Wolkoff, 1973) and easily adsorb on particulate matter. These organic compounds are not taken up by plants and are not readily volatized and so become a permanent component of contaminated soils. Organic solvents such as acetone and xylene can dramatically increase the mobility of PCB's, pesticides, herbicides and heavy metals. (Cartwright and others, 1981).

Attenuation characteristics of earth materials as well as mobility of contaminants is a complicated and interactive process that is easier to predict once wastes are segregated. In order to reduce mobility of contaminants, acids, bases and organics should be buried separately. Acids should be isolated (meaning buried in a separate landfill) from heavy metals, and solvents should be isolated from heavy metals, PCBs and pesticides (Griffin and Chiean, 1979).

Factors to consider when evaluating stratigraphy for leachate containment and attenuation are: nature and thickness of bedrock, lateral and vertical homogeneity, texture (fine-grained rock units are more likely to contain and attenuate contaminated groundwater) and mineral content (clay minerals have high exchange capacity, an attenuation property that is preferable for toxicity reduction).

Thick aquitards or aquicludes between site base and a usable groundwater aquifer will help to contain and detoxify leachate for as long as it threatens the environment. An ideal bedrock would be a very thick, fine-grained homogeneous sedimentary deposit with the capability to deform plastically rather than brittley with applied stress and would contain no valuable minerals.

Highly suitable site bedrock would develop thick, alkaline, montmorillonitic clay soils, and act as an aquiclude to underlying aquifers. Aller and others (1985), recommend kaolinitic clay soils because they are less expansive when wet than montmorillontic soils. Montmorillonitic soils form large cracks when dry which increases soil permeability and their relative instability creates difficult road and facility construction conditions. While both clays are probably well suited for hosting a hazardous waste disposal site, montmorillonitic soils appear to be more suitable because of their superior capacity to attenuate wastes (Griffin and others, 1977). Cracks that form in dehydrating montmorillonitic soils are believed to be surface features (Hillel, 1982),however, the possibility of deep cracks in dried montmorillonitic clays should be investigated during site-specific evaluation.

Eastern Montana's Cretaceous shales were chosen as most suitable to host a hazardous waste disposal site; the Bearpaw Shale and several members of the Colorado Shale may have the requisite thickness, permeabilities, and homogeneity for site selection. They are discussed in more detail later in this report.

Climate

The amount of leachate generated at a site and its rate of migration is controlled in part by the volume of water added to the system. In areas of high precipitation and low evapotranspiration, groundwater tables tend to be higher and precipitation is more likely to mix with and transport waste chemicals. Climate is usually ignored by site assessment methods because most states have little choice in the matter, however Montana enjoys a wide range of climatic variation as a result of the state's diverse topography and expansive land mass. The climate ranges from semiarid in the eastern plains (average annual precipitation ranges from 10 to 14 inches) to generally humid in the western mountains where precipitation can be as high as 100 inches per year (Taylor and others, 1974).

The best climate for hazardous waste disposal contributes the least amount of water to the system. Arid and semi-arid regions such as those found in eastern Montana with high evapo-transpiration rates are therefore most suitable.

Hydrology

Protecting existing and future water supplies from hazardous waste contamination is probably the single most important role of a site's geologic environment. Not only is it desirable to prevent contamination of local water supplies, ground and surface waters can also act as extensive transportation mechanisms dispersing contaminants throughout an interconnected system. Because groundwater discharge locations are often unknown and surface water can move contaminants rapidly before detection, the extent and location of a threatened water supply may be a more important issue than its current usefulness. The following discussion outlines the factors critical to prevent contamination of surface and ground waters.

Surface Water

For many reasons, areas with usable surface water should be avoided when searching for a suitable area for hazardous waste landfill disposal. Not only is most of Montana's surface water accessed daily by human beings, and the biosphere in general, it can act as a rapid transport agent for contaminated water to other surface water supplies, groundwater and adjacent land. A landfill disposal site should be located a great distance (more than two miles) from any perennial stream or river (Cartwright and others, 1981; Montana Department of Health and Environmental Sciences, 1980; Longmire and others, 1980) and outside any area subject to flooding. The two-mile limit was selected for this study as an intermediate value between distances recommended by other researchers. The U. S. Environmental Protection Agency requires no distance between a hazardous waste facility and surface water, however, facilities located on a 100-year flood plain must follow special rules. Longmire and others, (1980) recommend a site be located no closer than five-miles from maximum floodplain in New Mexico. This conservative value was not applied to central and eastern Montana because extensive flash floods do not present as great a danger as they do in the American Southwest and the recharge and discharge areas of usable aquifers tend to be far apart. However, if a hazardous waste disposal site should be considered in western Montana, the five-mile minimum distance from surface water is a reasonable limitation. This is because active aquifers in western Montana tend to be near surface, unconfined, highly transmissive and very interactive with surface water. Small reservoirs, irrigation ditches and stock ponds must be evaluated for importance because they may be contaminated if located near a site.

Montana contains the headwaters to several of North America's largest river systems. Rivers and streams from Montana flow westward into the Columbia River system, north to the South Saskatchewan which flows into Hudson's Bay, and southeast into the Mississippi River system. In addition to the difficulties inherent in surface water reclamation, Montana's exceptional hydrologic position as a headwaters state requires an exceptionally responsible approach to hazardous waste siting.

Groundwater

Most experts agree that landfills can be expected to leak their contents eventually into surrounding groundwater, despite their linings (Josephson, 1981; Lee and Jones, 1984; U.S. Environmental Protection Agency, 1985). Groundwater is a highly valuable natural resource in many parts of Montana where it is often more readily available than surface water. Areas overlying alluvial aquifers are particularly important to avoid. These aquifers tend to be highly transmissive (Fetter, 1980), are usually near surface water supplies and are used extensively for drinking, stockwater, and irrigation throughout western and central Montana (Davis and Rogers, 1984)

Springs and saline seep areas are to be avoided as well. They usually represent the discharge point of a groundwater system and are likely to reestablish themselves after draining and facility construction. Placing a hazardous waste disposal facility in an area with a near-surface groundwater table could result in a "bathtub" effect where wastes and water accumulate on ground surface. Thus a site may become a hazard to surface water. Because leachate has no chance to infiltrate the ground surface, little or no attenuation takes place (Cartwright and others, 1981).

If pollutants from a hazardous waste site should reach an aquifer, the groundwater can become hopelessly contaminated (U.S. Environmental Protection Agency, 1985; Epstein and others, 1984). Common hazardous waste contaminants of groundwater are pesticides, heavy metals and acids, (Ghassemi and others, 1985). Proposals currently under consideration for recovering seriously contaminated aquifers are exceptionally expensive with the average cost of aquifer restoration estimated at 500 million to one billion dollars (U.S. Environmental Protection Agency, 1982). Once contaminated, aquifers containing groundwater having long residence times are effectively lost as a water resource (Gillham, 1982).

Even more serious is the potential for contaminated groundwater to transport pollutants long distances. Often many discharge areas as well as interaquifer relationships are unknown because they are great distances from the study area. If the contaminated aquifer extends beyond the confines of the region undergoing assessment it may be months or years before a contaminated spring is discovered.

In 1984, Davis and Rogers identified nine general groupings of usable geohydrologic units in Montana. These units produce substantial quantities of water and should not be threatened by hazardous waste leachate. Table 2 shows the stratigraphic position of the following aquifers:

1. Quaternary alluvium, terrace deposits and glacial deposits
2. Wasatch and Ft. Union Formations
3. Hell Creek Formation and Fox Hills Sandstone
4. Judith River Formation and associated units
5. Eagle Sandstone and associated units
6. Kootenai Formation and associated units
7. Ellis Group
8. Madison Group

The U.S. Environmental Protection Agency recommends that hazardous waste facilities should not be located in areas of "vulnerable hydrogeology". These are areas in which "the predominant natural hydrogeologic conditions are conducive to the subsurface migration of contaminants in a manner that may adversely affect drinking-water sources" (U.S. Environmental Protection Agency, 1986b). Vulnerability criteria is the time of travel of groundwater along a 100 foot flowline (TOT_{100}) between the base of the hazardous waste unit and drinking water supplies. The U.S.EPA has recommended that the TOT_{100} be greater than 100 years for a hazardous waste facility. This is a recommendation, not a requirement. Other researchers, (Longmire and others, 1980, Montana Department of Health Environmental Sciences, 1980, and LeGrand, 1983) recommend

Table 2. Generalized stratigraphic chart showing usable geohydrologic units in Montana (after Davis and Rogers, 1984).

AGE	AQUIFER
Quaternary	Alluvium
	Terrace Deposits
	Glacial Deposits
Tertiary	
Cretaceous	Hell Creek Formation
	Fox Hills Sandstone
	Judith River Formation
	Eagle Sandstone
	First Cat Creek Sand
Jurassic	Ellis Group
Mississippian	Madison Group

that a facility overlie at least 100-150 feet of unfractured aquiclude. The more conservative 150-foot value was selected for this study because large portions of Montana can easily meet a stringent depth-to-groundwater criteria.

Summary

In summary, most experts agree that landfills can be expected to leak their contents eventually into the surrounding natural environment, despite their linings. For this reason, it is important to locate areas for disposal where natural conditions provide multiple barriers to reasonably assure long-term hazardous waste containment. The criteria established in this report are relatively restrictive when compared with siting criteria developed for use in other parts of the United States for two reasons: (1) because of the importance of maintaining the high quality of Montana's clean and plentiful water resources both to the State and the Nation, and (2) because Montana appears to contain large areas that are probably well-suited to host a hazardous waste disposal site.

A suitable hazardous waste disposal site should have the following hydrogeologic characteristics:

Tectonics and Seismicity: located in an area having low seismicity and a relatively inactive tectonic history. The site would be located on the craton away from major lineaments.

Structure: structurally simple, unfractured or having only surficial fractures related to unweighting rather than crustal movement, with plastic rather than brittle deformation.

Topography: a geomorphically stable area having slopes less than five percent, and where flooding or ponding cannot occur.

Soils: deep clay loam soils rich in sodium montmorillonite, developed from thick sequences of soft shales.

Stratigraphy: overlying at least 150 feet of unfractured, homogeneous, fine-grained, argillaceous sequences of sedimentary deposits containing no economic minerals, and having a maximum hydraulic conductivity of 10^{-7} cm/s. Examples of suitable stratigraphic units in Montana are the Cretaceous Bearpaw Shale and shale members of the Colorado Group.

Climate: semiarid climate with high evapotranspiration and moderate temperatures.

Hydrology: no seeps, perennial streams or standing bodies of water within two miles of the site and deeply buried, very small unused confined aquifers as the closest usable groundwater down gradient from the site.

<u>Other important characteristics not addressed in this study:</u> landuse, anticipated economic value, population density, proximity to waste generators, railroad lines and a well-maintained highway.

HYDROGEOLOGIC DESCRIPTION AND ASSESSMENT OF THE STUDY AREAS

The three areas that appeared to be hydrogeologically most suitable for hazardous waste disposal in Montana based on topography, ground and surface water characteristics, geomorphology, and surface geology are shown on the location map of Figure 1. Areas One and Two were selected for field reconnaissance because available data was limited for these regions and because they initially appeared to be most suitable. Evaluation of Area Three was based on available data because results from the initial regional review showed that the Denton-Lewistown Area is not well-suited for hazardous waste disposal. Well water quality and quantity analysis are plentiful for this area and Area Three was already well mapped.

The following discussion contains a description of the three selected areas in terms of the hydrogeologic criteria for evaluation outlined in the preceding sections.

Area 1. Sumatra-Ingomar

The Sumatra-Ingomar area is approximately 66 square miles and is located entirely within the northwest portion of Rosebud County, Montana in Townships T.12 N., R.34 E. and T.11 N., R.34 E. The Sumatra-Ingomar area is a sagebrush plain of rolling hills and low ridges dissected by intermittent streams. Slopes within the study area range from flat to nearly vertical at headcuts but are predominately less than five percent.

Surface Geology

The late Cretaceous Bearpaw shale is approximately 1100 feet thick (Johnson and Smith, 1964) and constitutes most of the exposed sedimentary section in the study area. The overlying Fox Hills and Hell Creek Sandstones outcrop in the Southwest corner of the area. Figure 3 shows surficial geology and surface drainage of the area. The Bearpaw Shale is a medium-gray to dark gray thinly bedded marine shale which is silty to sandy in the upper unit where the Bearpaw grades into the Fox Hills Sandstone. The formation is characterized by abundant beds of bentonite ranging in thickness from a few inches to 1.5 feet. These beds occur throughout the formation. Occasional zones of ferruginous concretions and fossiliferous calcareous

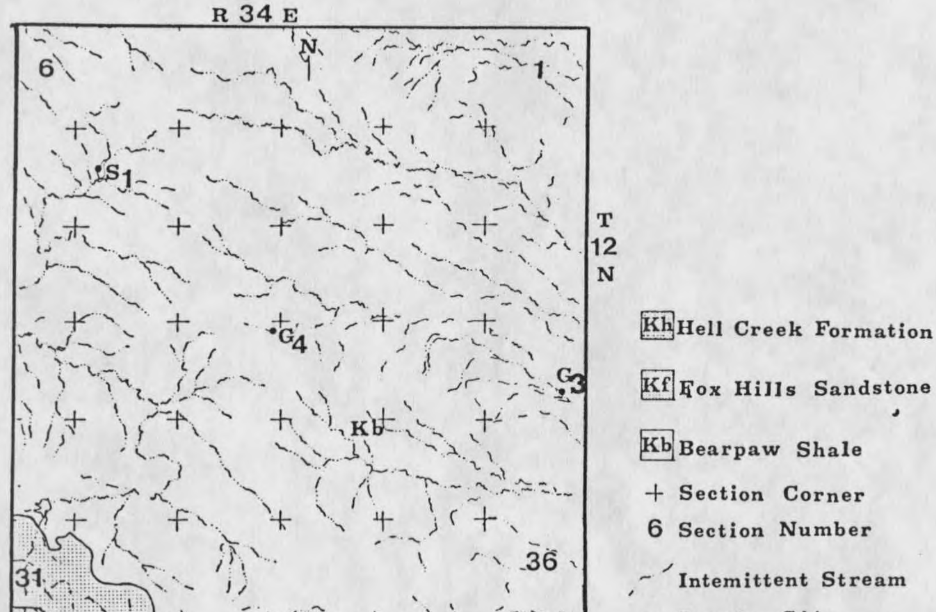

Figure 3. Geologic map of the Sumatra-Ingomar Area showing surface drainage patterns and water well locations.

concretions also appear throughout the formation. The Bearpaw shale contains 40 to 50 percent clay minerals (Merewether, 1973), bentonite beds are approximately 90 percent montmorillonite. The clay minerals consist of 70 to 80 percent montmorillonite, 15 to 20 percent illite and about five percent chlorite (Abel, 1975). Bearpaw Shale readily increases in volume with an increase in moisture content. The shale and weathered product becomes plastic and weaker in proportion to the amount of water absorbed. The swell potential for the Bearpaw is five to 20 percent (Abel, 1975). Exposures of the Bearpaw Formation throughout the study area show a homogeneous shale with thin horizons of bentonite and carbonate concretions. Other researchers have observed similar homogeneity in the Bearpaw throughout Montana (Aller and others, 1985; Tourtelot, 1962; Johnson and Smith, 1964).

The Bearpaw is a highly fissile and very weak platy shale when weathered. Some outcrops of the shale contain oblate to irregular-shaped septarian fossiliferous calcareous concretions averaging 8 to 10 inches in diameter and calcitic cone-in-cone structures. Weathered Bearpaw Shale breaks into irregular conchoidal blocks. Depth of weathering was observed in a backhoe pit by members of the Solid and Hazardous Waste Bureau (Thorvilson, 1985) 10 to 15 feet in the study area. Total depth of the weathered zone is unknown. Soils developed from the Bearpaw in pits dug at recharge areas are laced with gypsum crystals to depths averaging 30 inches indicating little leaching.

The Fox Hills Sandstone is a marine sandstone aquifer that conformably overlies the Bearpaw Shale. It represents the last marine regression of the Western Cretaceous Seaway in Montana and primarily consists of fine-grained friable sand with lesser amounts of siltstone and shale. The Fox Hills crops out in the southwest portion of the Sumatra-Ingomar area as a light yellowish-gray very fine-grained friable sandstone that contains ironstone concretions. The Fox Hills Sandstone is capped by the more resistant Hell Creek Formation which is a fluvial and deltaic deposit primarily consisting of calcareous sandstone with thin beds of siltstone and shale. The Fox Hills and the Hell Creek Formations dip gently to the east-southeast (Feltis, 1982) and are often considered together as an aquifer which is regionally important as a source of water.

Stratigraphy

The regional stratigraphy is based on well logs of the Sumatra oil field, Davis and Roger's (1984) assessment of groundwater quality data in Montana, Johnson and Smith's (1964) stratigraphic interpretation, and USGS Oil and Gas Investigations Map OM-211 (Smith, 1962). Figure 4 shows a generalized column of the stratigraphy underlying Area One. The Early to Mid Cretaceous Colorado Shale is about 1,900

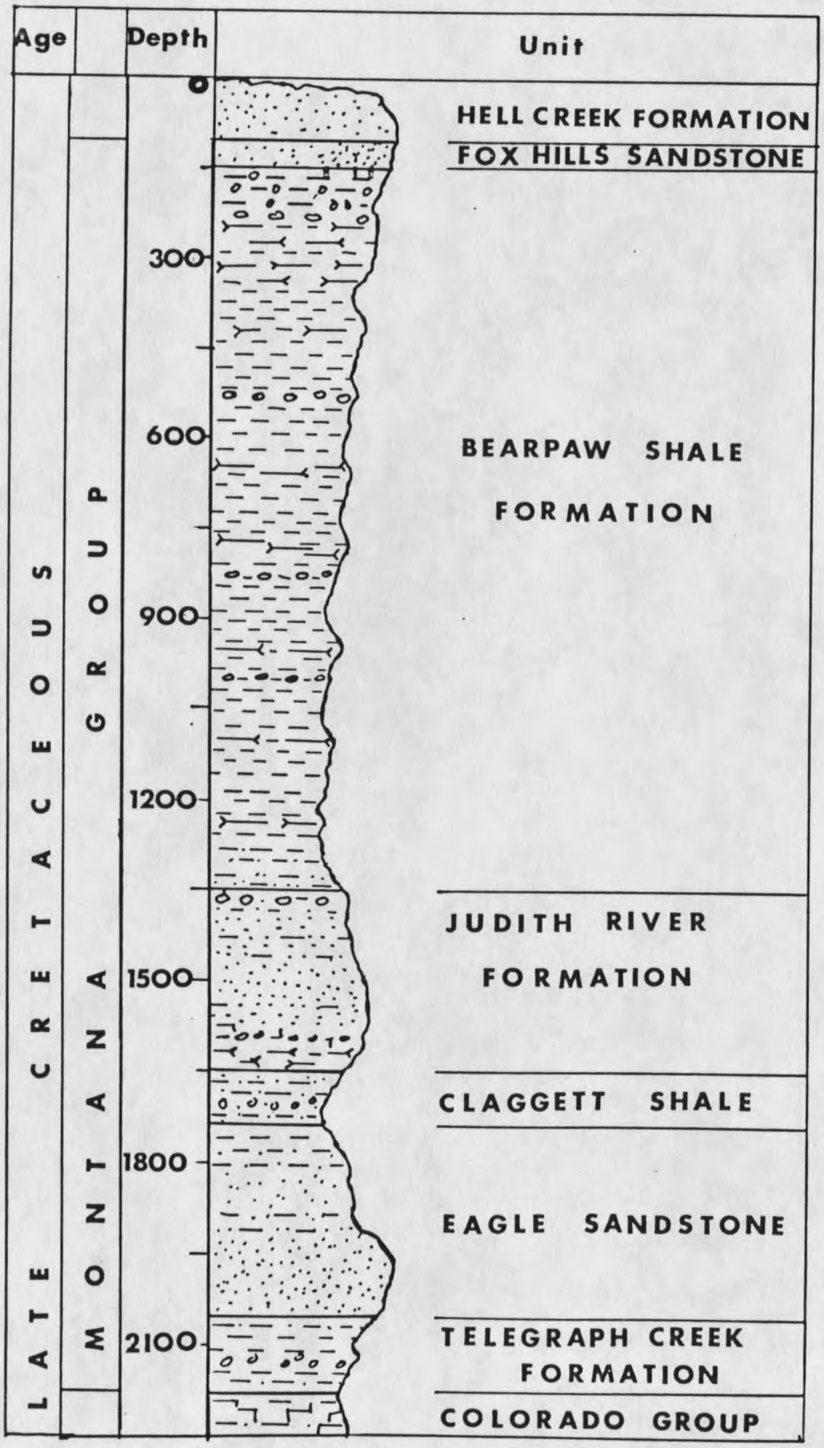

Figure 4. Generalized stratigraphic section of Cretaceous rocks underlying the Sumatra-Ingomar Area

feet thick in the study area and conformably underlies the Upper Cretaceous Telegraph Creek Formation.

The Telegraph Creek Formation consists of about 200 feet of sandy shale, interbedded sandstone, and thin beds of ironstone concretions. The Telegraph Creek Formation grades vertically into the overlying Eagle Sandstone (Johnson and Smith, 1964).

Outcrops of the cliff-forming Eagle Sandstone Formation are conspicuous in areas to the west of the study area. The top of the Eagle Sandstone is 1500-2000 feet below ground surface in the study area, it serves as a low-yield aquifer in areas west of the Ingomar-Sumatra Area with variable water quality but generally adequate for stock or domestic use (Freeze and Cherry, 1980; Peavy and others, 1985). The Eagle Sandstone underlies the Clagget Shale which consists of approximately 600 feet of alternating beds of thin-bedded shale and sandstone.

The Claggett Shale conformably overlies the Eagle Sandstone. The Claggett Shale is a marine shale interbedded with layers of bentonite and is approximately 150 feet thick in the study area. The Upper Cretaceous Judith River Formation is approximately 300 feet thick and overlies the Claggett Shale. The Judith River Formation consists of marine and nonmarine sandstone interbedded with siltstone, shale and coal seams. It serves as an aquifer throughout eastern Montana with a regional hydraulic gradient from west to east and discharges to the Missouri River (Davis and Rogers, 1984). In the study area, the Judith River Formation appears to have a local gradient of about two percent to the southwest (Feltis, 1982). Discharge is to the Musselshell River. The Judith River Formation is conformably overlain by approximately 1100 to 1300 feet of Bearpaw Shale in the study area.

The Bearpaw Shale is exposed throughout most of Study Area One where it is predominately a medium-gray to brownish gray marine shale. Sandy shale and shaley sandstone in the upper part of the Bearpaw comprise a transitional zone between open-water marine deposits of the Bearpaw and near-shore marine deposits of the overlying Fox Hills Formation (Johnson and Smith, 1964; Bowen, 1915).

The Upper Cretaceous Fox Hills Sandstone consists primarily of sandstone with lesser amounts of siltstone and shale, it is directly hydraulically connected with the lower part of the Hell Creek Formation. The two units compose the Fox Hills-Lower Hell Creek aquifer (Davis and Rogers, 1984) which ranges from 0 to about 250 feet thick in the study area (Smith, 1962). The Hell Creek Formation consists primarily of lenticular sandstone with inter-tonguing siltstone and shale. The Fox Hills and Hell Creek Formations outcrop in the southwest corner of the study area (see Figure 3).

Parts of the study area near the larger drainages are underlain by three to six feet of shaley alluvium which shows piping. These areas should be identified in a site-specific study because they are more susceptible to erosional processes and are likely to have high and less predictable infiltration rates.

Structure and Tectonics

Figure 5 shows regional structural relationships near the study area. Phanerozoic rocks in this part of Montana have been folded into a series of asymmetric anticlines and synclines but except for the Sumatra Syncline in the southwest portion of the area, most of the study area is structurally simple. The regional dip of the Bearpaw is to the east; however because of gentle warping of Phanerozoic sedimentary rocks, the Bearpaw Shale and underlying formations in the study area dip gently to the southwest (Feltis, 1982).

A major regional lineament (the Cat Creek Lineament) has been mapped by Thomas (1974) to the north and east of the study area as shown in Figure 6. The Cat Creek Lineament is a member of a series of northeasterly- and northwesterly-trending lineaments that have been mapped in the eastern two thirds of Montana by Thomas (1974) and are shown in Figure 6. Note the location of the Sumatra-Ingomar area (Area 1) and its proximity to the Cat Creek

Lineament. These lineaments are thought to be the surface expression of Proterzoic zones of weakness in continental basement rocks (Thomas, 1974; Shurr, 1975; Hindman, 1972).

These fundamental faults are believed to define a framework of basement blocks which moved differentially to reactivate the faults throughout geologic history and probably controlled Phanerozoic depositional patterns as

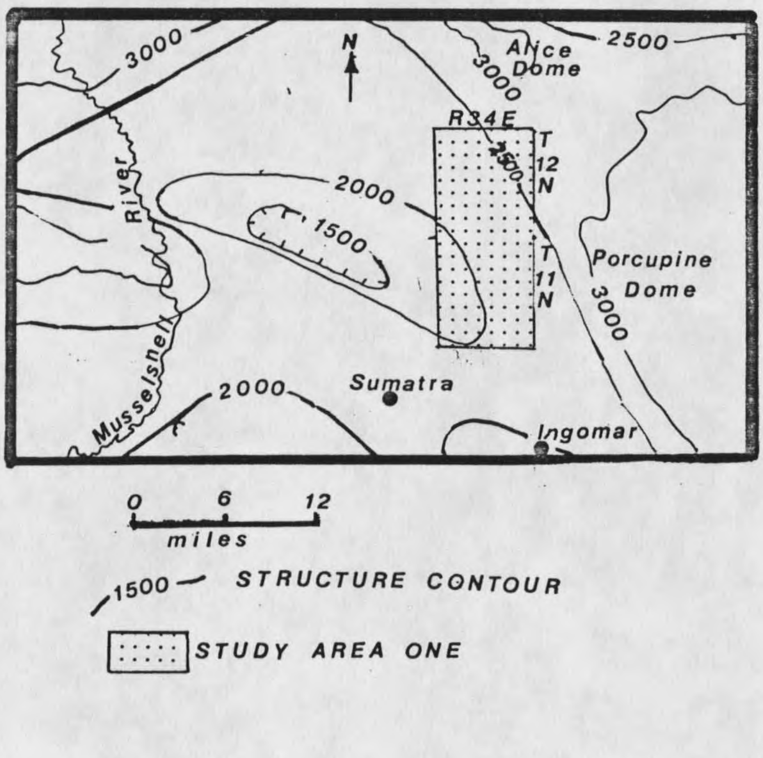

Figure 5. Regional structural geology of the region near and including the Sumatra-Ingomar Area, (after Feltis, 1982)

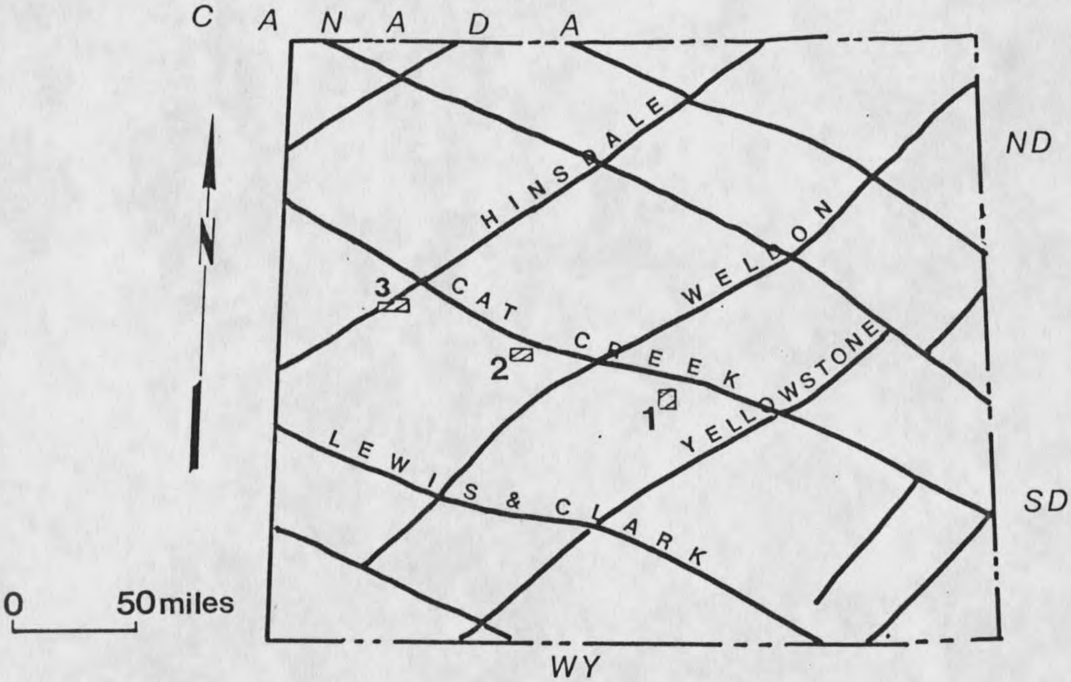

Figure 6. Lineament patterns in Central Montana, (after Thomas, 1974)

they adjusted vertically and horizontally in response to tectonic stress. Basement block down-dropping is evidenced by basinal infilling deposits which are diagrammatically shown in Figure 7 as nonparallel lines of sediment. The basement block grabens have since been uplifted to form the present structural configuration. Much of the current topography of eastern Montana is genetically related to basement weakness zones adjusting laterally and vertically to regional compressive forces.

F. E. Thomas (1974) interpreted the Cat Creek Anticline as a narrow zone of en echelon drag folds produced as a result of simple shear on basement weakness zones. The resultant differential movement of basement blocks along pre-existing zones of weakness is illustrated in Figure 7, a schematic cross section drawn normal to the Cat Creek Lineament.

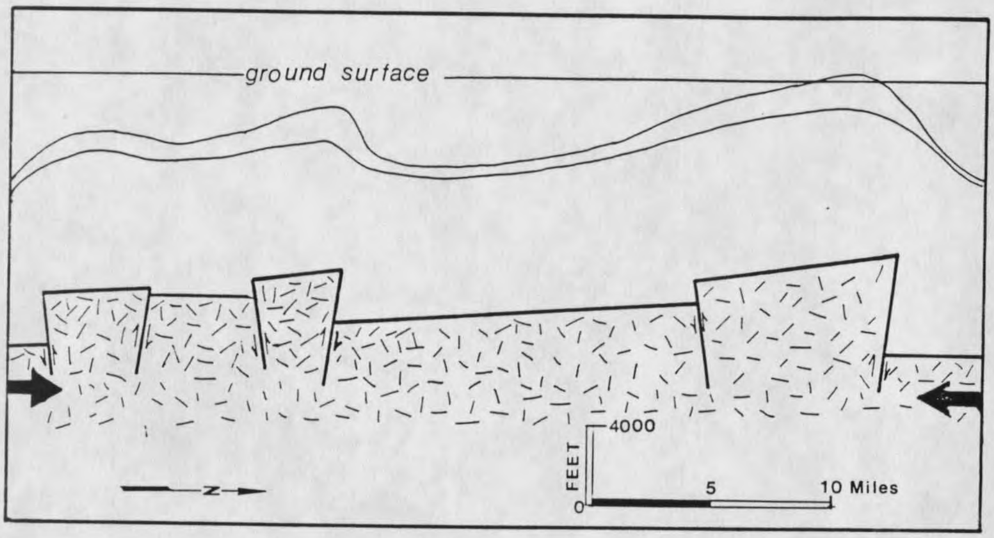

Figure 7. Idealized structure cross-section of Central Montana, (after Thomas, 1974)

Movement of the basement blocks is thought to have been reactivated as late as Mid Oligocene. If the southeast-northwest trending Cat Creek Lineament is related to periodic reactivation of deep-seated faulting, then vertical fractures with similar orientations in overlying sediments may extend to great depth. This is an undesirable characteristic for a hazardous waste disposal site.

Fractures caused by deep seated faulting due to crustal disturbances are not evident in the field as surface jointing or other linear features, although other researchers have detected infrequent surface jointing with no apparent directional trends in regions near the study area (Johnson and Smith, 1964; Abel, 1975). Computer edge enhancement analysis of satellite images reveals a distinct northwest linear trend north of, and very close to the study area where the Cat Creek Lineament is manifested as a series of domes. Figure 8 is a computer edge-enhanced photograph of the area covered in Figure 5. Note the obvious linear features in the vicinity of Alice and Porcupine Domes. The study area is outlined in white. While field evidence and edge enhancement analysis of the region reveal no linear trends in the study area, stream patterns in the Northeast corner of Area One (see Figure 3), are obviously more linear than anywhere else in the area. No other trends have been detected in the field but it is possible that fracturing from the Cat Creek Lineament may extend south into the study area. A detailed investigation for southern extension of the Cat Creek Lineament is recommended for site specific evaluation.

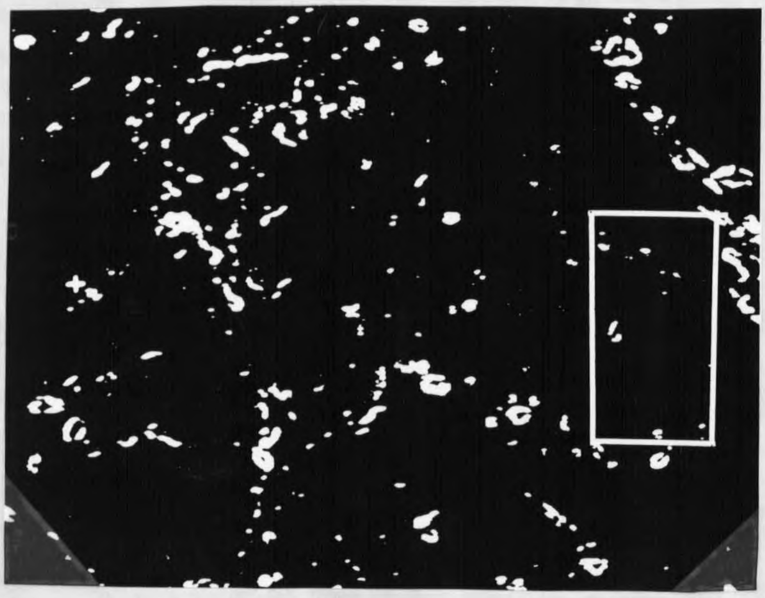

Figure 8. Digitized edge-enhanced Landsat image of the region near and including the Sumatra-Ingomar Area. The study area is outlined in white.

Soils

Soil chemical and physical characteristics are generally considered an important factor of hazardous waste disposal site evaluation. However, because soils in Study Area One tend to be thin with little horizon development, they are of little value as a mechanism of attenuation or containment and are not weighted heavily as a factor of consideration in this study.

Soils developed on the Bearpaw Shale are, for the most part, poorly developed residual grayish brown clay soils and strongly salt-affected (Soil Conservation Service, 1986). Soils of the Sumatra-Ingomar Area are mapped by the U.S. Soil Conservation Service primarily as clayey, montmorillonitic frigid, Ustic Torriothents underlain at depths ranging from 0 to 20 inches by platy shale. Parts of the area are underlain by three to six feet of shaley alluvium which show piping. These are undesirable soils for hazardous waste disposal because of unpredictable hydraulic conductivities and flow paths associated with the piping and the potential geomorphic instability of the pipes.

Typical ground surfaces in Area One are very dry before water infiltration begins. In this condition they are loose and porous, particularly the "popcorn" surfaces of the weathered bentonitic shales. Infiltrating water initially penetrates into voids between aggregated clay but this is curtailed by swelling. The bentonitic shale continues to absorb water and swell until the ground becomes impervious to infiltration.

Surface Water

There are no perennial streams within or near the study area but there are two watersheds which are divided by a low ridge. Figure 3 shows the drainage pattern for the Sumatra-Ingomar area. The watershed in the northwest portion of the area drains into the Musselshell River approximately 14 miles to the west. The rest of the area is a part of the Yellowstone drainage to the southeast.

Stream density is high in the Bearpaw shale area because of low bedrock permeability and thin soil horizons. Stream drainage pattern is erratic throughout most of the area and reveals no obvious linear features other than the dominant drainage directions toward the southeast to the Yellowstone drainage and to the west-northwest toward the Musselshell drainage. The northeast corner of the study area shows linear streams trending northwest-southeast, an orientation coincident with both the dominant drainage pattern in the area as well as the Cat Creek Lineament shown in Figures 5 and 6. It is possible that the linear nature of the intermittent streams in the northeast corner of Study Area One is the surface expression of deep seated faults related to the Cat Creek Lineament. If so, then the potential for related fractures is high in the northeast corner of the study area.

Surface water in the area is evident as stock watering ponds which store spring run-off and storm drainage, and rare springs seeping slowly from contacts between weathered shale or alluvium and a bentonite unit. Only two stock ponds containing water were observed and sampled in June, 1986 (S_1 and S_2 in Figure 3). Analytical results for water samples collected in the Sumatra-Ingomar Area are shown in Table 2. Copies of water quality analysis reports are included in Appendix B.

Table 3. Analytical results for water samples collected in the Sumatra-Ingomar Area.

Constituent	SAMPLE NUMBERS Surface water S-1	S-2	Groundwater G-3	G-4
	(milligrams per liter)			
Fe	--	--	--	--
Ca	34.8	65.5	125	498
Mg	6.1	19.1	62.3	2679
Na	20.0	249	268	11240
K	4.9	6.9	6.7	70.7
Mn	.01	.004	--	1.2
SiO_2	7.3	1.9	.6	8.7
HCO_3	122.5	247.9	18.3	1116
CO_3	4.9	0	25	--
Cl	2.1	5.3	2.8	222
SO_4	46.6	552	1050	34140
NO_3	.02	.04	.04	24
Fl	.3	.3	.5	40
$CaCO_3$	112	242	569	12270
TDS	250	1017	1559	--
pH	8.57	8.2	9.83	8.23
	S-1	S-2	G-3	G-4
	(micrograms per liter)			
Ag	--	--	--	.9
Boron	160	163	260	2310
Cd	--	--	--	22
Cr	--	--	77	--
Li	13	27	100	3580
Md	--	--	--	33
Ni	--	--	--	82
P	.1	--	.1	--
Sr	200	450	960	1030
Zn	11	7	4	14
As	1.4	.3	.7	.9
Se	.4	5	3.5	40

The stock water ponds have total dissolved solids (TDS) values of 250 and 1017 mg/l. These ponds are filled with surface run-off.

All water in the area contained large quantities of boron, lithium, and strontium when compared with U.S. drinking water and livestock standards (Freeze and Cherry, 1979).

Groundwater

Water wells drilled into the Bearpaw Shale have been dry with the exception of some highly mineralized water recorded in near surface joints and bedding planes (Abel, 1975). Hydraulic conductivity of the Bearpaw Shale measured about 200 miles north of the study area is 10^{-8} to 10^{-7} cm/s (Abel, 1975). It is unknown to the author whether these values are the result of in-situ testing or lab analysis.

Perched water exists locally in parts of the area. Evidence of near surface groundwater was observed as two springs (shown as G_3 and G_4 in Figure 3) at the contact between shale and bentonite units. Both springs produced highly mineralized water. Water quality analyses are shown in Table 3. The relatively impermeable nature of the Bearpaw Shale at bentonite beds appears to restrict flow paths to within weathered shale. Hydraulic conductivities within the perched near-surface water zones were measured by bail tests (Hvorslev, 1951) in shallow wells at 10^{-5} to 10^{-6} cm/s. These values reflect hydraulic conductivities in the shaley alluvium and weathered bedrock, not in the unweathered shale.

Water wells in the surrounding region produce primarily from the Hell Creek and Fox Hills formations which lie stratigraphically above the Bearpaw Shale. Some wells, especially those servicing the Sumatra Oil field to the west of the area produce from the Judith River Formation (approximately 1400 feet below ground surface), the Eagle Sandstone and the Kootenai (approximately 1530 feet and 3000 feet below ground surface respectively).

There is one water well in the study area (see Figure 3); it is producing approximately seven gallons per minute from the Fox Hills Formation at a total depth of 200 feet (static water level is 140 feet). This well is in a unit topographically and stratigraphically above the Bearpaw Shale. It was drilled in 1950 and is currently used for stock watering. Leachate emanating from a disposal facility located on the Bearpaw Shale should not influence these wells which are producing from an aquifer hydraulically upgradient from the shale.

The portion of the study area immediately underlain by Bearpaw Shale appears to have a low potential for groundwater contamination resulting from hazardous waste leachate. There are no known wells producing from the Bearpaw Shale in Montana. Only highly mineralized near-surface groundwater was observed in the form of springs discharging above bentonite beds at sampling locations G_3 and G_4 in Figure 3. Based on surface observations, the Bearpaw Shale formation appears to be a homogeneous shale with thin horizons of bentonite and calcareous concretions and therefore, can be expected to behave as a very thick aquiclude. The nearest aquifer underlying Study Area One is the Judith River Formation, approximately 1180 feet from ground surface. It is a regional aquifer with well yields averaging 10 gal/min in regions near the study area (Department of Natural Resources and Conservation well records; Davis and Rogers, 1984). The Judith River Aquifer has a local gradient of 1° to 2° to the west-southwest toward the axis of a syncline located just outside the southwest corner of the study area (Feltis, 1982).

The portion of the study area immediately underlain by the Hell Creek and Fox Hills Sandstone is unsuitable for hazardous waste disposal if it is important to maintain the integrity of the local Hell Creek-Fox Hills aquifer. Hydraulic conductivities in the Hell Creek-Fox Hills aquifer are high relative to the Bearpaw Shale and lack the attenuation properties of shale so that leachate migrating into the Hell Creek-Fox Hills aquifer is unlikely to be contained or degraded to the extent it would be in the Bearpaw Shale.

Summary

Most of the Sumatra-Ingomar Area appears to be hydrogeologically well suited to host a hazardous waste disposal facility. The following hydrogeologic conditions that characterize the area are summarized with respect to their contribution to the isolation or attenuation of wastes.

Conditions that are favorable for hazardous waste disposal in the Sumatra-Ingomar study area:

1. no seismicity has been recorded within or near the area,
2. flat topography (typical gradient less than five percent): surface runoff is less likely to travel long distances rapidly without detection and infiltrating leachate is likely to move vertically,
3. hydraulic conductivities of the bentonitic shale preclude leachate infiltration to underlying aquifers,
4. thick beds of bentonite present which may be useful for facility construction and natural retardation of leachate movement,
5. structural geology is uncomplicated; most of the area appears to be unfractured which enhances the predictability of groundwater flow patterns,

6. the area has a semi-arid climate which keeps the amount of water introduced to the system to a minimum,
7. soils are predominately sodium montmorillonitic clay loams and silty clays, properties that improve attenuation capabilities,
8. no perennial stream lies within or near the area so there is low potential for surface water pollution and rapid transport of contaminated fluids,
9. the nearest usable groundwater down gradient from the area is a confined aquifer (the Judith River Aquifer) with gradients less than two to three percent, overlain by a 1180-foot aquiclude of homogeneous Cretaceous bentonitic shale.
10. perched groundwater in the area is scarce, highly localized and unusable.

Despite its high suitability for hazardous waste disposal, there are some inherent difficulties with this site which would have to be addressed during a site-specific evaluation.

Conditions that are unfavorable for hazardous waste disposal in the Ingomar-Sumatra study area:

1. the shrink-swell properties of the montmorillonitic shale could be expected to create engineering difficulties for site buildings and road construction,
2. while surface exposures of Bearpaw Shale reveal a homogeneous unit, the formation has never been

extensively studied so it is possible that permeable units may exist locally within the shale,

3. the proximity of Area One to the Cat Creek Lineament coupled with the linear nature of the streams in that portion of the study area nearest the Cat Creek Lineament suggest that site specific studies should evaluate for the possibility of deep fractures,
4. the soils are thin throughout Area One, especially those developed on shale. Because soils play an important role in leachate attenuation, poorly developed soils are unfavorable for hazardous waste disposal siting. More importantly, the thin nature of the soils may be indicative of geomorphic instability,
5. parts of the area are underlain by three to six feet of shaley alluvium which shows piping; because these areas are more susceptible to erosional processes and are likely to have high and less predictable infiltration rates, such areas would be poor sites and should be avoided, and
6. perched shallow groundwater exists locally in parts of the area.

Portions of the Sumatra-Ingomar Area appear to be hydrogeologically well suited to host a hazardous waste disposal site. Figure 9 shows areas of relative suitability for hosting a hazardous waste disposal facility in the Sumatra-Ingomar Area.

Highly suitable areas have slopes less than five percent, are directly underlain by Bearpaw shale, contain no surface water, no observed springs, no wells, and no evidence of deep fracturing, soils are silty clays and clays.

Marginally suitable areas have slopes greater than five percent, are directly underlain by Bearpaw Shale, contain some surface water in the form of stock watering ponds or small, slowly seeping springs, no wells exist in the area, there may be some evidence of deep fracturing in the form of linear streams and computer-enhanced satellite images, and soils are silty clays to clay loams.

Unsuitable areas have slopes greater than five percent, are directly underlain by the Hell Creek-Fox Hills Aquifer and contain a water well, surface water exists in stock water ponds and soils are silty clay loams to sandy loams.

The area is located at least 120 miles from Billings where a large part of the state's hazardous waste is concentrated, this is not a serious drawback if the present amount of waste generated is maintained.

A more detailed examination would necessarily follow to determine the extent of the perched water table and to test for fracture permeability and geomorphic instability before a site could be established.

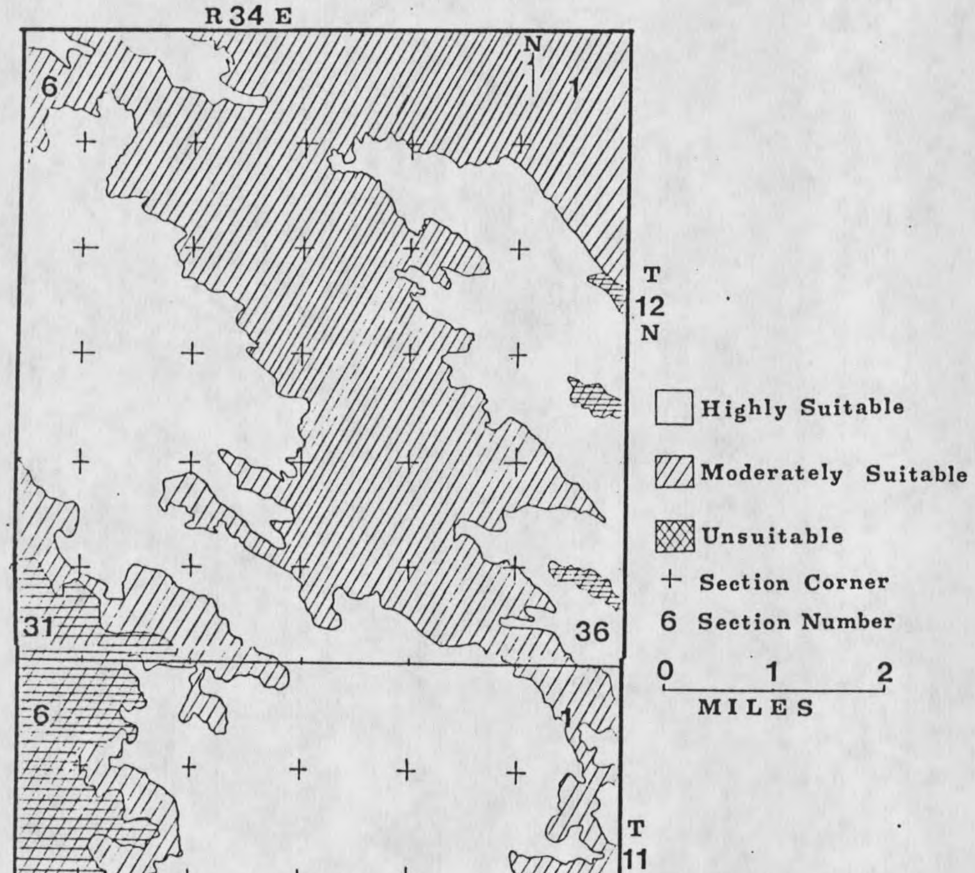

Figure 9. Local hydrogeologic suitability of the Sumatra-Ingomar Area for hosting a hazardous waste disposal facility

Area 2. Roundup-Winnett

The Roundup-Winnett Area includes approximately 24 square miles of Petroleum County about 12 miles south of the town of Winnett and about 30 miles north of Roundup. The Roundup-Winnett Area is located in townships T.13 N., R.25 E. and T.13 N., R.26 E.

Stratigraphy and Surface Geology

Colorado Shale

The surficial geology in the Roundup-Winnett Area is stratigraphically below the Bearpaw Shale exposed in Area One. The Cretaceous Colorado Shale outcrops throughout most of the area. Exposed section consists of about 1900 feet of sandy marine shale interbedded with fine-grained sandstones, thin beds of bentonite, and zones of ironstone and limestone concretions. Eight of the nine members of the Colorado Group outcrop in the study area. Figure 10 shows a generalized stratigraphic column that includes the exposed stratigraphy in the Roundup-Winnett Area. The surface geology of Area Two is shown in Figure 11.

The lowest Colorado Shale unit, usually referred to as the First Cat Creek Sand in driller's logs is not exposed

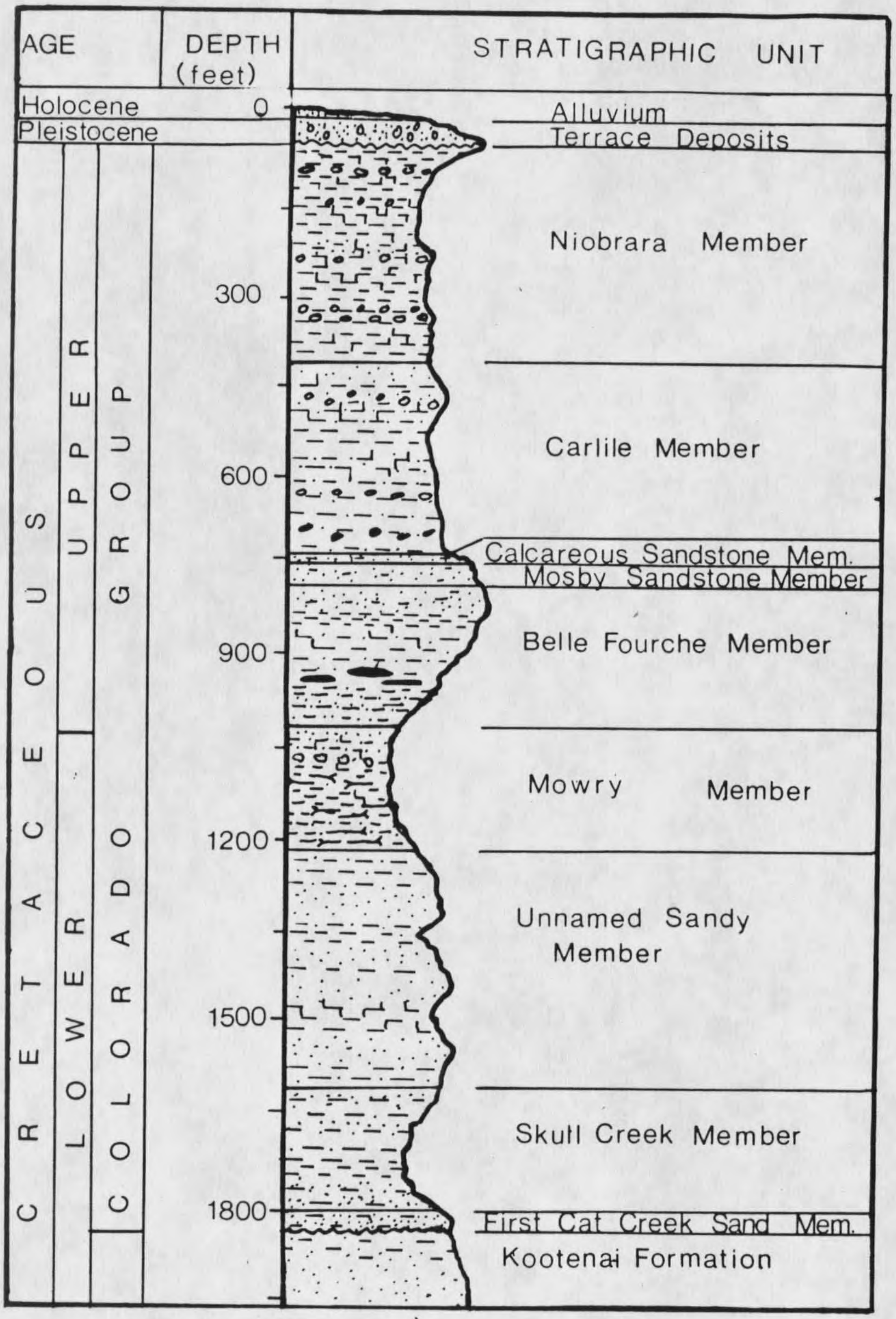

Figure 10. Generalized stratigraphic section of Cretaceous rocks underlying the Roundup-Winnett Area. (after Smith, 1962; Johnson and Smith, 1964)

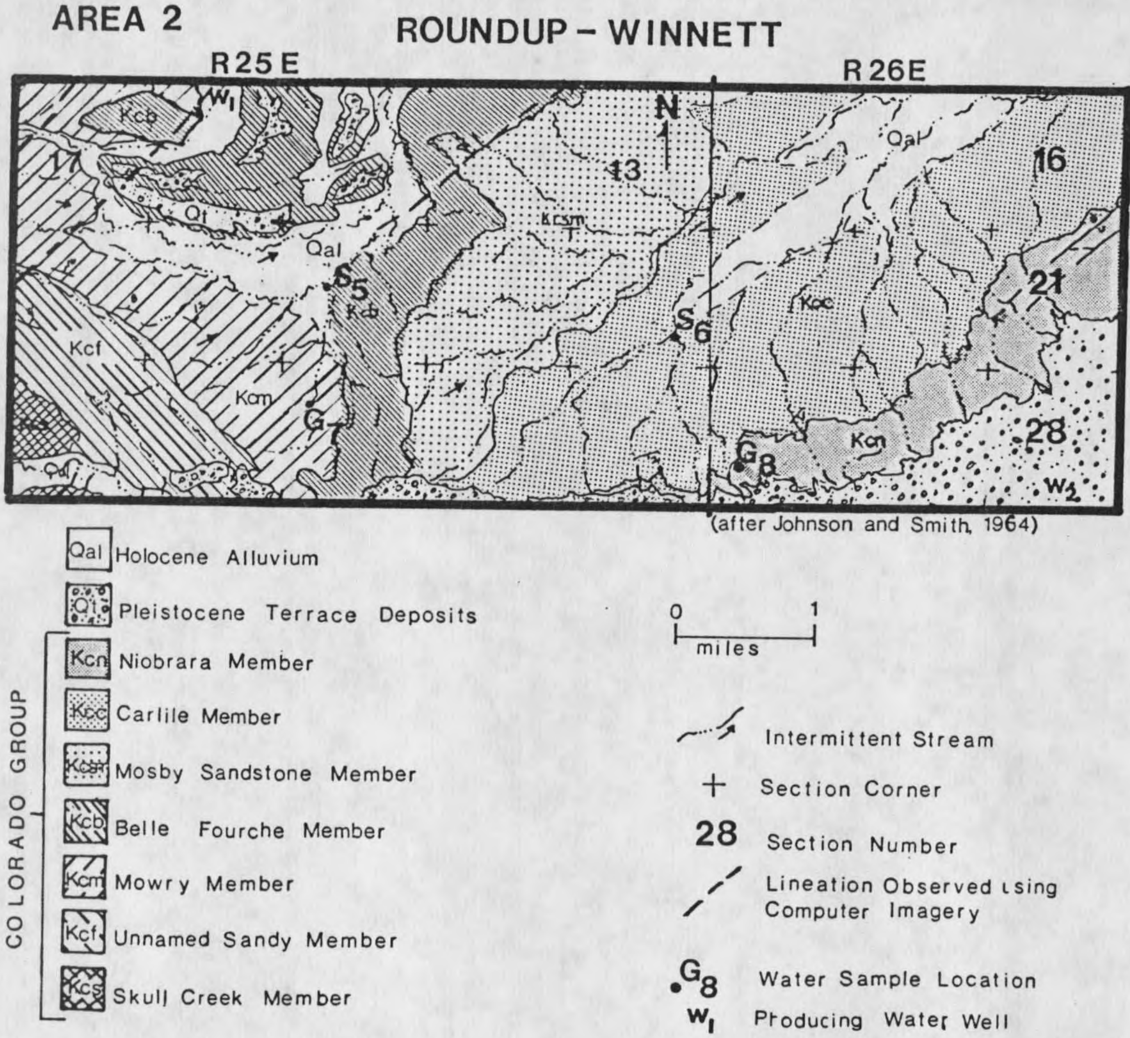

Figure 11. Geologic Map of the Roundup-Winnett Area showing surface drainage patterns and water well locations (after Johnson and Smith, 1964)

in the study area; it overlies the Early Cretaceous Kootenai Formation. The First Cat Creek Sand is about 70 feet thick (Johnson and Smith, 1964) and produces fresh water locally for low well yields near the Roundup-Winnett study area. The First Cat Creek aquifer recharges locally where the unit outcrops just west of the study area.

The Skull Creek member of the Colorado Shale lies conformably above the First Cat Creek Sandstone. The Skull Creek is composed mostly of gray shale which is slightly sandy in the upper and lower parts of the member with thin bentonite beds in the upper part of the member (Johnson and Smith, 1964). Ironstone and carbonate concretions are scattered throughout the shale. The Skull Creek member is 175 to 200 feet thick in the study area and underlies the Unnamed Sandy Member.

The Unnamed Sandy Member is about 350 feet thick and contains sandy shale interbedded with fine-grained ledge-forming sandstone. One stock water well (shown as W_1 in Figure 11) produces from the Unnamed Sandy Member in the study area (DNRC water well records). Because the unit serves as a local aquifer, it is an undesirable surface unit for hazardous waste disposal.

The Mowry Member of the Colorado Shale overlies the unnamed Sandy Member. A badlands topography of weathered shale and rapidly eroding headcuts in the study area is formed where the Mowry and the overlying lower half of the

Belle Fourche members of the Colorado Shale outcrop. The Mowry Member is approximately 190 feet thick in the study area and composed principally of dark gray shales interlaminated with sandstone. Abundant bentonite layers of thicknesses less than one foot were observed as well as several thin concretionary limestone beds.

The Mowry Member grades into the Belle Fourche Member. The lower half of the Belle Fourche contains beds of bentonite up to 3 1/2 feet thick and horizons of oblate ironstone concretions about one foot thick and as much as five feet long. It grades upward into a ledge forming fossiliferous sandstone. The entire Belle Fourche Member is approximately 300 feet thick and is overlain by the Mosby Sandstone of the Colorado Shale. The Mosby Sandstone Member contains abundant fossils and forms a prominent escarpment in the study area. It is about 29 feet thick and is composed primarily of sandstone interbedded with sandy shale. There are no wells producing from the sandy portion of the Belle Fourche Member or the Mosby Sandstone in the study area but because of the expected higher transmissivities of sandstone, it is a poor unit to host a hazardous waste disposal site. The Calcareous Sandstone Member is only a few feet thick and overlies the Mosby Sandstone; it is sometimes considered part of the Mosby Sandstone (Cobban, 1953). The Calcareous Shale Member contains a bed of closely spaced medium-gray septarian limestone concretions.

The Carlile Member of the Colorado Shale is about 300 feet thick in the study area. It consists of dark gray fossiliferous shale and sandy shale sequences interbedded with horizons of ironstone concretions and septarian limestone concretions veined with dark brown calcite crystals. The Carlile Member conformably underlies the Niobrara, the uppermost unit in the Colorado Shale Formation.

The Niobrara Member is a light gray calcareous shale containing thin beds of bentonite and many limestone concretions. It is about 380 feet thick in the study area.

Five of the nine members of the Colorado Shale contain shale that may be suitable for hazardous waste disposal siting: the Niobrara, Carlile, Mowry, the lower half of the Belle Fourche and the Skull Creek members contain shale units possibly desirable for hazardous waste containment. However, unlike the Bearpaw Shale in Area One, these five members of the Colorado Group have many drawbacks. They tend to be interbedded at irregular intervals with sandy shales and sandstones, both of which will produce anomalous and less predictable groundwater flow patterns. The Niobrara Member is highly calcareous in the study area and can be expected to behave less plastically with stress than the other suitable members, and so, in theory, will be more subject to fracture permeability at depth. Based on field observations and lithologic descriptions in the literature, the entire Colorado Group appears to have a higher calcium carbonate content than the Bearpaw Shale. This is evidenced by the occurrence of more units of calcareous shale identified in the Colorado Group, a higher number of horizons of calcareous concretions observed in outcrop and near-surface fracturing indicating brittle deformation. The apparent higher calcium content of the Colorado Group can be expected to decrease the ability of bedrock underlying a disposal site in this area to deform plastically when stressed.

The lower half of the Belle Fourche Member, and the Mowry Member appear to be the most suitable surface geologic units in Area Two for hazardous waste disposal because of their thick shale units and interbedded bentonite layers. However extensive surface jointing was observed in that part of the study area where these members outcrop and parts of the area underlain by exposed Mowry and Belle Fourche shales are geomorphically unstable because of rapidly eroding headcuts and "badland" development. The upper half of the Skull Creek Member appears to be a suitable shale for hosting a hazardous waste disposal site; the lower half is more sandy grading into the Lower Sandstone Member otherwise known as the

First Cat Creek Sand which has been drilled for both oil and water throughout the region. The vertical proximity of the Skull Creek Member to a usable aquifer reduces its suitability for hazardous waste disposal.

The Calcareous Sandstone, the Mosby Sandstone, the upper Belle Fourche, and the Unnamed Sandy members of the Colorado Group are composed of sandstone and bentonitic sandy shale. These are undesirable surface geologic units for a hazardous waste disposal site because they are lithologically heterogeneous and can be expected to have higher transmissivities than nearby shale units making leachate flow rates and discharge locations difficult to predict, thus increasing the potential for surface and ground water contamination before leak detection.

Terrace Deposits

Remnants of Early Pleistocene terrace deposits directly overly the exposed Colorado Shale sequence in portions of the study area. The deposits are primarily composed of unconsolidated to poorly cemented angular to subrounded pebble conglomerates interbedded with lesser amounts of sand. They are about 10 to 40 feet thick in the study area. In general the deposits are unconsolidated but lenses of calcium-carbonate cemented gravels are present locally.

One stock water well produces water from the terrace deposits and is shown as W_2 in Figure 11. These units are unsuitable for hazardous waste disposal sites because of their high hydraulic conductivities and because they are used as a groundwater supply locally.

Alluvium

Holocene alluvial deposits of silt and fine-grained sand cover the flood plain of the Yellow Water Creek drainage. The alluvium ranges regionally from 0 to 10 feet (Johnson and Smith, 1964). The Yellow Water Creek is an intermittent stream located about one-half mile north of the study area; its flood plain alluvium tends to widen in areas of less resistant underlying bedrock such as the Carlile Shale and lower Belle Fourche members. Because the study area does not include the mainstem of Yellow Water Creek, the flood plain alluvium is probably less than 10 feet thick in Study Area Two. The Yellow Water Creek alluvium is not an important factor because it occurs locally, tends to overly shale and is probably less than a few feet thick in the study area. Portions of the study area underlain by alluvium are considered marginally suitable for hosting a hazardous waste disposal site.

Structure and Tectonics

The Roundup-Winnett area is flanked by more structurally complex regions than Area One. Figure 12 shows regional structural geology. It is possible that all of Study Area Two lies within a fracture zone related to the Cat Creek Lineament which is manifested as a series of northeasterly-trending faults mapped north of the area. Figure 12 shows the structural configuration of the region encompassing Area Two. Faults that have been mapped by Johnson and Smith (1964) are shown as solid lines.

This region was further evaluated for lineaments using computer-enhanced edge analysis of Landsat satellite images. Figure 13 is a photograph of the computer enhanced image of the same region mapped in Figure 12. The study area is outlined in white. Note the distinctive northwest oriented lineation composed of a series of en echelon northeast trending faults (the trend is highlighted by shading): that is probably the Cat Creek Lineament. Figure 13 demonstrates that the faults of the Cat Creek Lineament probably extend well into the study area and are mapped as dashed lines in Figure 12.

Exposures of the Mowry Member of the Colorado shale in the study area are prominently jointed. Oxidized cracks and preferential plant growth along joints has produced a conspicuous linear pattern, graphically shown in the Rose

Diagram in Figure 14, with a dominant trend of N. 50°-65° E., and a secondary trend of N. 30°-45° W. This surface

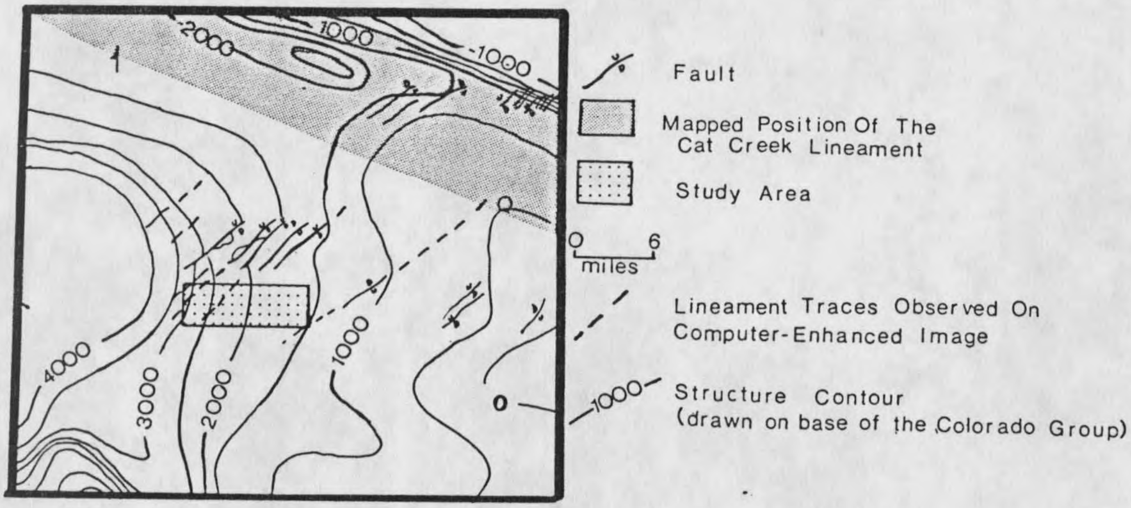

Figure 12. Regional structural geology of the region near and including the Roundup Winnett Area, (adapted from Feltis, 1984 and Johnson and Smith, 1964)

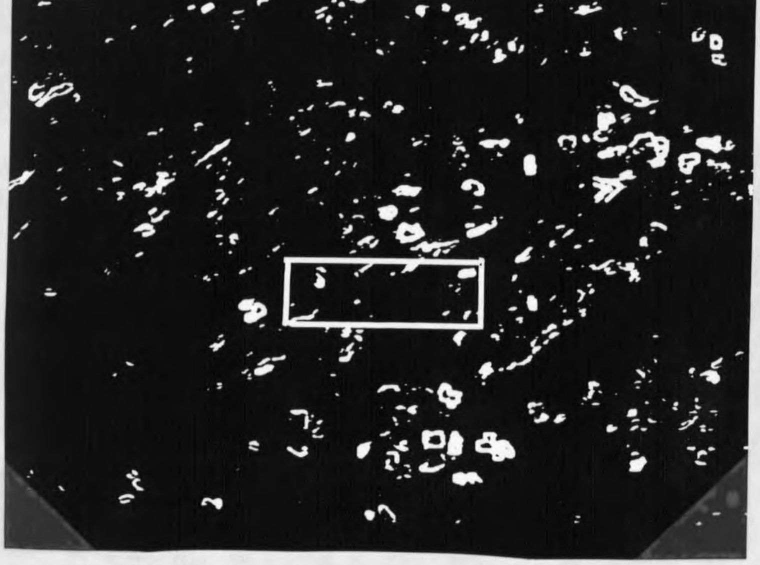

Figure 13. Digitized edge-enhanced Landsat image of the region near and including the Roundup-Winnett Area.

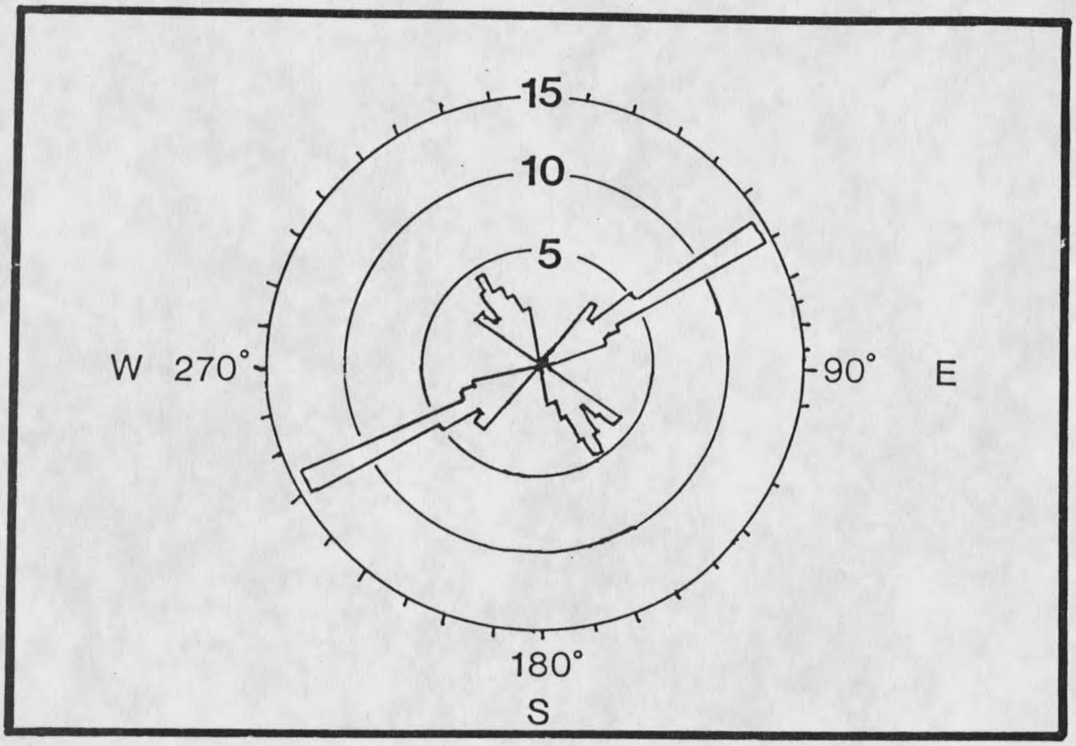

Figure 14. Rose diagram showing the orientation of fractures in increments of five degrees observed in the Mowry and Lower Belle Fourche shales of Area Two. Concentric lines represent the number of measurements taken.

joint pattern is subparallel to the general trend of tensional faulting revealed by computer edge enhancement analysis of satellite images for lineament traces.

Because of the correlation in orientation between field evidence of surface fracture traces in the study area and the extended fracture traces from the Cat Creek Lineament, it is probable that there is significant fracture permeability in this area which was formed in response to the same stresses responsible for the Cat Creek Lineament.

Vertical fractures are generally believed to be a shallow phenomena, especially in shale (Fetter, 1980; Lattman and Matzke, 1961). However, some vertical fractures in Arizona have been traced to depths of 3000 feet (Lattman and Matzke, 1961). If the Cat Creek Lineament is related to periodic reactivation of deep-seated faulting in the basement rock, as is probably the case, then vertical cracks in the overlying Colorado Shale may be the result of reactivated faults and may extend to much greater depths than is typical. This is an undesirable characteristic for a hazardous waste disposal site.

Surface Water

Dominant surface water drainage direction is to the north and east. No perennial streams exist within the area, however Flatwillow Creek flows eastward and northward and is approximately 3.5 miles south of the area at its closest point. The Yellow Water Reservoir Storage Project is located 0.7 miles north of the study area. Because surface water is rare in the study area and observed only in two stock watering ponds, surface water quality analyses were made on water from stock ponds at the sample locations shown in the map of Figure 11 as S_5 and S_6. Results from water quality analyses of samples collected in Area Two are shown in Table 4. Copies of water quality analysis reports are in Appendix B. Surface water is marginally suitable for stock. Ranchers in the area claim that the stock ponds are not dependable sources of water because they are fed by surface runoff from rain and snow melt so they tend to dry up in late summer and are sometimes dry year around (John Hughes, 1986, personal communication).

The general lack of presence of surface water in the area is a desirable characteristic for hazardous waste siting. However, the Yellow Water Reservoir is less than a mile north of the study area, therefore, if it is important to preserve the integrity of the reservoir, the portion of the study area nearest the Yellow Water Reservoir Storage Project is unsuitable for hazardous waste disposal.

Groundwater

Evidence of groundwater is rare in Area Two; only two springs were observed seeping from exposed contacts between weathered shale and shale bedrock and between terrace alluvium and underlying Colorado Shale. Perched groundwater exists locally.

Bail tests of the perched groundwater in the weathered shale were made on shallow wells at the spring locations G_7

Table 4. Analytical Results for Water Samples Collected in the Roundup-Winnett Area.

Constituent	SAMPLE NUMBERS: Surface water S-5	Surface water S-6	Groundwater G-7	Groundwater G-8
	(milligrams per liter)			
Fe				1.4
Ca	118	212	158	388
Mg	41.8	177	110	1307
Na	183	161	727	2076
K	10.2	10	12.6	23.3
Mn	.15	2.3	.24	.06
SiO_2	3.0	--	--	9.0
HCO_3	43.3	--	--	110
CO_3	--	--	--	--
Cl	4.5	4.9	6.9	41.6
SO4	793	1742	2354	10360
NO_3	.36	.06	.02	.02
Fl	1.0	1.8	4.1	6.6
$CaCO_3$	466.7	1258	847	6348
TDS	1198	--	--	14322
pH	7.02	3.9	4.53	6.5
	S-5	S-6	G-7	G-8
	(micrograms per liter)			
Al	--	3410	3080	150
Ag	3	6	--	8
Boron	436	380	1140	220
Cd	--	--	3	8
Cr	--	6	2	5
Li	198	720	1160	1530
Md	--	20	--	--
Ni	--	700	120	200
P	--	.1	--	--
Sr	500	210	2370	5670
Zn	6	1180	260	120
As	--	.3	--	1
Se	--	.8	.5	6.1

and G_8 shown in Figure 11. Hydraulic conductivity in perched aquifer material within the weathered shale and alluvium was measured at 10^{-4} cm/s. As in Area One, this perched groundwater is highly mineralized. Water quality analyses are shown in Table 4, bail test data and calculations for hydraulic conductivities are shown in Appendix C. The springs have total dissolved solids values ranging from 4,500 mg/l to 14,322 mg/l with high concentrations of $CaCO_3$, SO_4, boron, lithium and strontium.

There are two wells operating within the study area shown as W_1 and W_2 in Figure 11. Well number W_1 produces from the Unnamed Sandy Member of the Colorado Shale at a depth of 290 feet. Well number W_2 produces from the terrace deposits and is drilled to a depth of 40 feet. Nearby wells outside Study Area Two produce usable water from the Pleistocene terrace deposits, the First Cat Creek Sand the (Lower Sand Member of the Colorado Group) and the Third Cat Creek Sand (or Kootenai Formation). Refer to Table 2 and Figure 10 for a stratigraphic location of these aquifers.

The nearest usable groundwater aquifers below the study area are the Unnamed Sandy Member and the First Cat Creek Sandstone. For the Unnamed Sandy Member, depth to aquifer ranges from 110 feet in the eastern part of the study area where the Niobrara outcrops to 0 feet in the western part of the study area where the aquifer probably recharges. For the First Cat Creek Sand, depth to aquifer ranges from 125 feet for the area where the Skull Creek Member is exposed in the western portion of the study area to 1500 feet in the portion of the area underlain by the Niobrara Member. The part of the study area immediately underlain by the Carlile Shale Member is approximately 1360 to 1050 feet above the First Cat Creek Sand. The Belle Fourche Member and the Mowry Shale are approximately 900 to 600 feet above the Lower Sand Member.

Summary

Most of the Roundup-Winnett area is only marginally suitable for hazardous waste disposal. The following hydrogeologic conditions that characterize the area are summarized with respect to their contribution to isolate or attenuate wastes:

Conditions that are favorable for hosting a hazardous waste disposal facility include:

1. flat rolling topography throughout most of the area underlain by Colorado Shale,
2. very low hydraulic conductivities of exposed shale that is unfractured; shale can be expected to preclude leachate infiltration to underlying aquifers,
3. thick beds of bentonite present in the shale which may be useful for facility construction and natural retardation of leachate movement,
4. the area has a semi-arid climate which helps to keep the amount of water introduced to the system to a minimum,

5. no perennial stream exits within the area, perched groundwater is unusable because of high concentrations of total dissolved solids and undesirable constituents and the surface water is undependable and suitable only for stock water use, and
6. nearest aquifer is greater than 500 feet below ground surface for most of the area directly underlain by Colorado Shale.

The following characteristics contribute collectively to the marginal to poor suitability throughout parts of Area Two:

1. bentonitic earth materials may cause road and building construction and maintenance problems,
2. most of the exposed stratigraphic section is lithologically heterogeneous containing sandstone units and shales interbedded with sand stringers,
3. complex structure in the surrounding region may complicate groundwater flow patterns,
4. fractured bedrock was observed in the field and computer enhanced satellite images provide evidence that the Cat Creek Lineament probably extends further south than previously recognized and may affect part of the study area,
5. parts of the area underlain by exposed Mowry and Belle Fourche shales are geomorphically unstable because of rapidly eroding headcuts and "badland" development,

6. soils are thin throughout the area, resulting in reduced attenuation capabilities,
7. perched groundwater is rare but exists locally as near-surface groundwater draining from the terrace deposits resulting in rapidly eroding headcuts,
8. portions of the study area serve as a recharge area for an underlying local aquifer.

Most of the Roundup-Winnett study area has some major obstacles to satisfying the hydrogeologic parameters necessary to select an environmentally safe site. Figure 15 shows areas of relative suitability for hosting a hazardous waste disposal facility in Area Two.

Highly suitable areas have slopes less than five percent, are directly underlain by shale members of the Colorado Group, they contain no perennial streams or stock watering ponds, and have no observed springs, no wells, and no evidence of deep fracturing.

Marginally suitable areas have slopes greater than five percent, are directly underlain by shale or Holocene alluvium, they contain some surface water in the form of stock watering ponds or small, slowly seeping springs, no wells exist in the area, and there may be some evidence of deep fracturing in the form of field observed jointing and computer-enhanced satellite images.

Unsuitable areas have slopes greater than five percent, show evidence for geomorphic instability in the form of rapidly eroding headcuts, are directly underlain by sandy members of the Colorado Group or by Pleistocene Terrace Deposits, they contain no perennial streams but surface water exists in stock water ponds or in a reservoir less than one mile away, and water wells may be present.

A more detailed examination would be necessary to determine the extent of the perched water table, to determine the homogeneity of the shale between land surface and nearest aquifer and to test for fracture permeability and geomorphic instability before a site could be established.

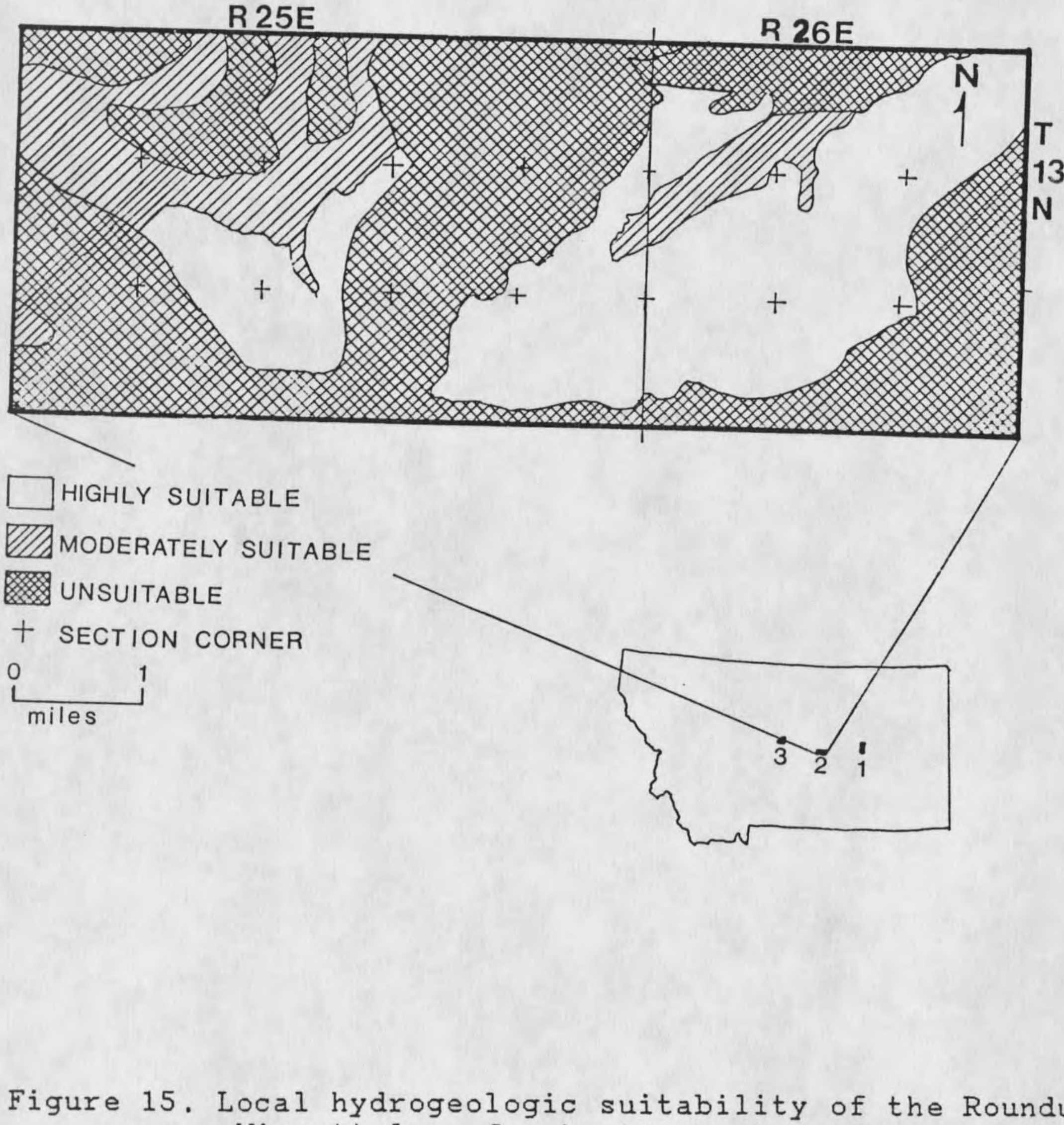

Figure 15. Local hydrogeologic suitability of the Roundup-Winnett Area for hosting a hazardous waste disposal facility.

Area 3. Denton-Lewistown

Area Three comprises about 18 square miles. The study area straddles the county line between Judith Basin and Fergus counties and is located in parts of Townships T.17 N., R.14 E. and T.17 N, R.15 E. Refer to Figure 16 for the location of the Denton-Lewistown Study area. Field reconnaissance analytical techniques were not performed in Area Three.

This area was selected for evaluation because the initial regional appraisal concluded that surface geology, seismic activity, structural configuration and surface and ground waters would probably meet the criteria discussed in the first part of this report. Closer inspection of available data for the area revealed serious drawbacks to its suitability for hosting a hazardous waste disposal site. Because of time constraints, only two of the three study areas could be evaluated in the field; the Denton-Lewistown area was not chosen for field reconnaissance for the following reasons: (1) in terms of established hydrogeologic criteria, it appeared to be the least suitable of the three study areas to host a hazardous waste disposal site and therefore not as worthwhile an investment of time, (2) more available data and geologic analysis already exists for Area Three than for Areas One and Two, thereby reducing the need for field reconnaissance, and (3) Area Three is underlain by the same geologic units as Area Two (Colorado Shale, Pleistocene terrace deposits and Holocene alluvium), so that much of the analysis in Area Two for geologic suitability can be applied to the Denton-Lewistown Study Area.

Surface Geology and Stratigraphy

The Colorado Shale exposed in Area Three ranges from approximately 1070 feet to 700 feet thick (Zimmerman 1966; DNRC water well records; Feltis, 1980; Feltis 1974; Vine 1956). It is dark gray to black shale containing horizons of limestone concretions and bentonite. The soft shale strata is easily weathered and eroded. Because the Colorado Shale is poorly exposed in the area, the individual members have not been separated. Dark gray fissile shale outcrops in Area Three contain horizons of septarian carbonate concretions similar to those observed in the Niobrara and Carlile outcrops in Area Two. No cliff-forming sandstones were observed, nor any ironstone concretions or bentonite beds characteristic of the lower Belle Fourche or Mowry members of the Colorado Shale. Stratigraphic location of the exposed shale and field observations provide evidence that outcrops of the Colorado Shale in Study Area Three are probably composed of the

Niobrara and Carlile members. Refer to the discussion of the Roundup-Winnett area for a review of the Colorado Shale. Remnant Pleistocene terrace deposits directly overlie the Colorado Shale. The terrace deposits consist of coarse, consolidated gravel beds that are isolated remnants of what may have been an extensive gravel surface (Vine 1956). Terrace deposits in the study area are 10 to 25 feet thick (DNRC water well records) and are correlated with the Sangamon interglacial stage (Schafer, 1949). Because the highly permeable terraces serve as local aquifers (Zimmerman 1966, DNRC water well records, Davis and Rogers, 1985) and develop fine loamy soils (Hogan and others, 1967) they are used extensively for agriculture. The gravel deposits are also an important source for road building and construction material (Vine 1956).

Quaternary alluvium developed from Colorado Shale exists locally in the study area near intermittent streams. Thickness is unknown. Figure 16 shows the mapped location of the alluvium, Terrace deposits and Colorado Shale in Study Area Three.

Structure

Study Area Three lies within a topographic depression known as the Judith Basin and is partly enclosed by several isolated mountain ranges. The Judith Basin is a large,

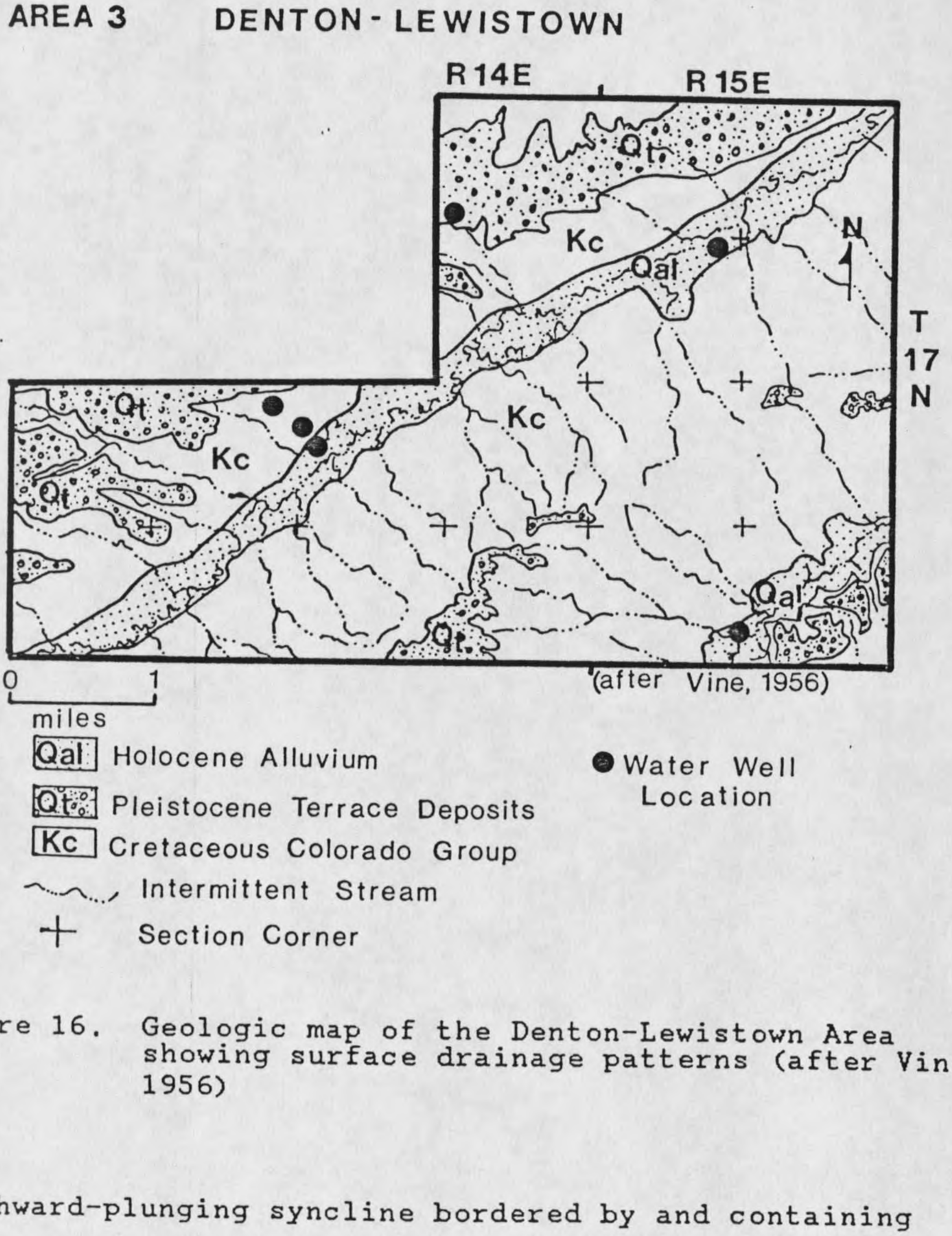

Figure 16. Geologic map of the Denton-Lewistown Area showing surface drainage patterns (after Vine 1956)

northward-plunging syncline bordered by and containing smaller anticlinal folds. Figure 17 shows the structural configuration of the region that includes Study Area Three. The location of the Hinsdale Lineament as mapped by Thomas

(1974) in Figure 6 is a shaded zone in Figure 17. The regional dip in the area is toward the northeast. Because of the difficulty of recognizing faults in the dark Colorado Shale and cultivated terraces it is likely that many fractures have not been mapped. Figure 6 shows lineament patterns in Montana that have been mapped by

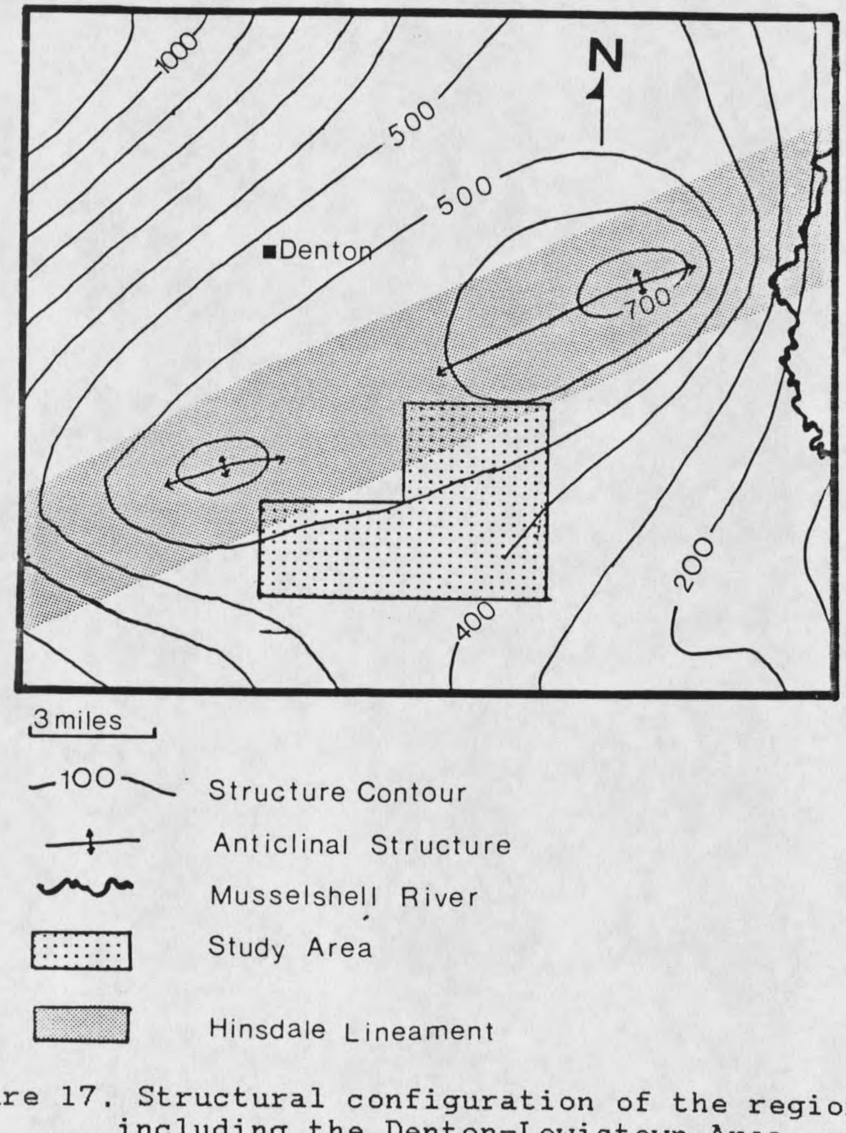

Figure 17. Structural configuration of the region near and including the Denton-Lewistown Area, contour lines are drawn on the top of the Madison Group, datum is sea-level (from Feltis, 1974).

various researchers, note that Area Three appears to be intersected by a major northeast-trending lineament. This is an indication that fractured bedrock resulting from local faulting is probably present. However, observations of Area Three revealed no surface evidence of fracturing, this may be because much of the shale is covered by terrace deposits and cultivated land.

Topography and Soils

Differential soil development is controlled by the irregular topography of Area Three. High coarse-grained terrace deposits cover about 25 percent of the area and develop highly transmissive soils with poor attenuation capabilities. Low-lying portions of the area directly underlain by Colorado Shale develop thin, fine-grained soils.

Because deep soils are present they are an important factor in the Denton-Lewistown area. There are primarily three types of soils developed as a result of the combination of parent material and local topography (Hogan and others 1967). Soils occurring on the nearly level or gently sloping alluvial benches tend to be deep to moderately deep, dark-colored clay loams to gravelly clay loams over very gravelly material. These soils take in water readily, have good moisture storage capacity and are well-drained. They are easily tilled and surface soil provides a good seed bed. These are undesirable for hazardous waste disposal because of poor attenuation capability and high transmissivities. Soils occurring at the edge of alluvial benches develop from clay alluvium and transported weathered shales. These soils are moderately deep and dark-colored. They take in water slowly, are well-drained and have good moisture storage capacity, desirable characteristics for hazardous waste disposal. Soils occurring on shallow clays and the rough topography of exposed Colorado Shale are moderately light colored and very shallow where present. The soils are generally noncalcareous but in some places they are weakly calcareous. Crystals of gypsum are common in the upper part of the shale. These silty-clay soils are suitable for hazardous waste disposal.

Hydrology

Approximately 15 inches per year of precipitation falls on Area Three. While this is not a high rate it is not as dry as the semi-arid conditions found in the other two study areas. The higher rate of precipitation coupled with the results of irrigation create a noticeably wetter environment than in Study Areas One and Two.

Surface Water

The Denton-Lewistown area lies within the Missouri Basin drainage system. Drainage direction is to the northeast towards the Judith River. Figure 16 shows drainage patterns for Area Three. Gravel terraces tend to be irrigated with groundwater pumped from sources below the Colorado Shale or from the Terrace deposits themselves. Springs emanating from the base of irrigated terraces were observed throughout the study area. Stagnant ponds of surface water tend to form in the low-lying shale portions of the area and probably evaporate before significant infiltration takes place.

Groundwater

Groundwater is the source of domestic and irrigation water throughout the area; it is pumped from near-surface and deep aquifers and discharged by seeps in the terrace deposits and by springs at the terrace gravel/shale contacts. The irregular topography resulting from the composite of high terrace deposits and low-lying areas directly underlain by shale results in high-gradient near-surface groundwater flow paths having many discharge areas.

Based on records for the Montana Department of Natural Resources and Conservation and from the Montana Bureau of Mines and Geology, six producing water wells are identified in the study area (refer to Figure 16 for well locations). Table 5 outlines the source and yield of each well in Area

Table 5. Source and yield of producing water wells in the Denton-Lewistown Area

Well ID	Lithologic Zone of production	Yield
s_1	Terrace Deposits	10 GPM
S_{14a}	Colorado Group	1 GPM
S_{14b}	Colorado Group	2 GPM
S_{18}	Morrison Formation	150 GPM
S_7	Morrison Formation	20 GPM
S_{19}	Kootenai Formation	150 GPM

Three. Wells area identified by their section numbers. Groundwater recharge in the terrace deposits is derived from precipitation and irrigation return flow. The Colorado Shale in the study area contains no important aquifers (Vine 1956). Many of the water-bearing beds underlying the Judith River basin are exposed and recharged in the mountains or foothills to the southwest of the area. Principal aquifers below the study area are the Kootenai Formation, the Morrison Formation, and the Madison Limestone. These are accessed throughout the Judith Basin (Zimmerman 1966). Refer to Table 2 in the introduction for a generalized stratigraphic section of geohydrologic units in Montana.

Landuse

In the Denton-Lewistown Area, landuse can not be disregarded as an important factor for hydrogeologic investigations. When irrigated, the highly permeable terrace deposits provide a source of spring water to the low-lying poorly drained shale areas. These result in occasional shallow ponds of stagnant water. Water wells are scattered throughout the study area and in the surrounding region, increasing the need for an adequate barrier between a waste site and usable groundwater. Cultivated land comprises approximately one third of the area. In light of the fact that Montana contains vast expanses of land where crops are not grown, the relatively intensified use of land in Area Three decreases significantly the hydrogeologic suitability for hosting a hazardous waste disposal site.

Summary

The Denton-Lewistown Area appears to be hydrogeologically poorly suited to host a hazardous waste disposal facility. The following hydrogeologic conditions characterize the area.

Conditions that are favorable for hazardous waste disposal in the Denton-Lewistown study area:

1. little to no seismicity has been recorded within or near the area,
2. at least 75 percent of the area is directly underlain by bentonitic Cretaceous shale,
3. no perennial stream lies within the area,
4. the nearest major groundwater down-gradient from 75 percent of the area is a deep confined aquifer (the First Cat Creek Sand).

The Denton-Lewistown area is poorly suited for hazardous waste disposal because of the following characteristics:

1. coarse-grained terrace deposits cover about 25 percent of the area and are hydrogeologically unsuitable for hosting a hazardous waste disposal facility,
2. soils on the terrace deposits are highly transmissive with poor attenuation capabilities and soils are thin to absent on the areas directly underlain by Colorado Shale,
3. deep-seated fractured bedrock may exist because of the area's proximity to the Hinsdale Lineament,
4. an average precipitation rate of 15 inches per year falls on area Three and is augmented by pumped groundwater used for irrigation,

5. perched groundwater and stagnant surface water discharged by springs at the base of the terrace deposits are evident throughout the portion of the area underlain by shale
6. irregular topography resulting from the composite of high terrace deposits and low-lying areas directly underlain by shale results in high-gradient, near-surface groundwater flow paths having many discharge areas,
7. the nearest usable groundwater down-gradient from that part of the area underlain by terrace deposits is unconfined and near-surface.

The Denton-Lewistown Area was chosen for evaluation because of its apparently suitable hydrogeological characteristics and because the area is centrally located with respect to both small and large generators of hazardous waste in Montana.

Most likely, the limiting factor for site suitability of Area Three is the high concentration of landowners; a factor not considered by this study. Based on hydrogeologic criteria, the Denton-Lewistown study area is, for the most part, unsuitable for hazardous waste disposal. Local surface and near-surface groundwater flow patterns are greatly influenced by irrigation practices. Fractured bedrock, though undetected to date probably exists if the area is transected by the Hinsdale Lineament and poor exposures of suitable bedrock limit site selection options.

Figure 18 shows areas of relative hydrogeologic suitability for hosting a hazardous waste disposal facility in the Denton-Lewistown Area.

Highly suitable areas have slopes less than five percent, are directly underlain by the Niobrara and Carlile Members of the Colorado Shale, are greater than one mile from a perennial stream or stock ponds or other surface water, contain no observed springs, no wells, and no evidence of deep fracturing, soils are silty clays and clays. Because of the proximity of the Hinsdale Lineament and the high occurrence of springs and cultivated land, there are no highly suitable regions in Area Three.

Marginally suitable areas are directly underlain by Colorado Shale, contain some surface water in the form of stock watering ponds, shallow standing water and springs, contain no wells, there is evidence of deep fracturing in the geologic literature, and soils are silty clays to clay loams. Marginally suitable areas are hatched in Figure 18.

Unsuitable areas may have slopes greater than five percent, may be directly underlain by highly permeable terrace deposits, may contain water wells or near-surface groundwater and may be cultivated farmland. Unsuitable areas are shown as unhatched in Figure 18.

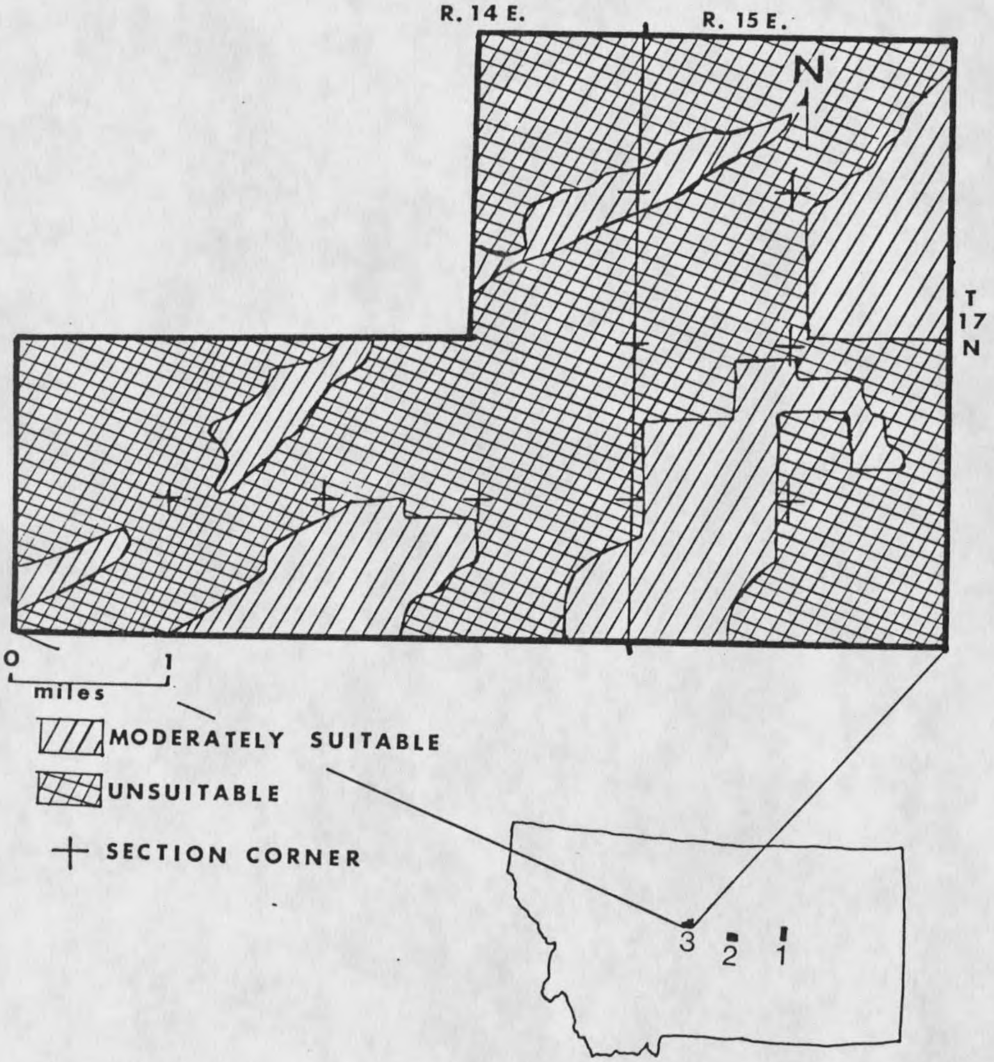

Figure 18. Local hydrogeologic suitability in the Denton-Lewistown Area for hosting a hazardous waste disposal facility.

SUITABILITY ASSESSMENT OF STUDY AREAS USING TWO STANDARD METHODS OF EVALUATION

Several standardized methodologies are currently in use for evaluating a potential hazardous waste disposal site. Each of the three study areas was evaluated using the two models described in the methods section of this report: the LeGrand Standardized System for Evaluating Waste Disposal Sites (LeGrand, 1983), and DRASTIC: a Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings (Aller and others, 1985). Results from application of each method of analysis to the study areas provides an independent confirmation of the suitability of the study areas evaluated in this report and are useful as a means to compare the Montana study areas with existing sites outside the state.

The LeGrand Method

The LeGrand method assigns each of eight major hydrogeologic factors a numerical value that reflects the suitability of a prospective site and the relative influence of site hydrogeologic characteristics on leachate migration. The final rating is a single number that represents the potential for contamination of groundwater and surface water.

Because a LeGrand rating is an indication of a site's potential to contaminate groundwater, a highly suitable site will have a very low rating. An ideal site will have a LeGrand rating of -16. In the case of a hazardous waste landfill, no ideal sites are possible, any candidate site has its limitations. The LeGrand factors are as follows:

Distance: The distance between contamination source and a point of water use such as a well or stream.

Depth to water table: the recommended depth to water table is a function of rock type, local topography, climate and infiltration capacity. Many contaminants can attenuate completely or partially in the unsaturated zone so a long distance between site base and usable groundwater is a desirable feature.

Water table gradient influences the rate and direction of flow. It is important to know whether a contaminant is moving toward or away from a water supply and at what speed.

Nature of the earth materials immediately underlying the site. Bedrock and soils having low hydraulic conductivities and effective sorptive capacities serve as the second line of defense against leachate migration should the protective system engineered around the waste site breakdown.

Fractures in bedrock can serve as conduits for undiluted waste. Unfortunately depth and lateral extent of fracturing is often difficult to determine.

Extensive usable aquifers situated in the path of a potential leachate plume are undesirable features for site evaluation.

Lithology of an aquifer underlying a potential site can be described in terms of its hydrologic characteristics.

Waste type is a consideration for contamination potential at a landfill. This is because the dangerous and persistent nature of hazardous compounds relative to that of most waste in a city landfill, for example, increases the risk for contamination.

Based on these eight primary criteria, each of the three study areas is rated with a single number that represents the potential for contamination of ground or surface water.

Study Area 1: Sumatra-Ingomar

Based on LeGrand analysis, Study Area One appears to be hydrogeologically best suited to host a hazardous waste disposal facility. The Sumatra-Ingomar Area exhibits the following LeGrand characteristics:

Distances on ground from possible site locations to a point of water use exceed 6200 feet for more than 90 percent of the study area for greater than five percent of the year.

Depth to water table of usable groundwater is greater than 200 feet for the recommended area (for that part of Area One underlain by Bearpaw Shale).

Gradient of the nearest usable groundwater aquifer (the Judith River Formation) is approximately one to two percent. No water supply exists within 200 feet of 90 percent of the recommended area.

The bedrock immediately underlying the site is estimated to have hydraulic conductivities less than 10^{-7} cm/s and is greater than 1,000 feet thick. Unconsolidated materials over bedrock is composed predominately of weathered montmorillonitic shale.

Location and extent of vertical fractures is unknown but estimated to be limited to the northeastern portion of the study area.

Extent of the nearest usable aquifer (the Late Cretaceous Judith River Formation which is used throughout central Montana) is great.

Lithology of the nearest usable aquifer includes nonmarine to marine sandstone, siltstone and mudstone.

The degree of seriousness of the waste is high.

Worksheets were developed for use with the LeGrand method of evaluation to derive a single rating number. A worksheet and sample calculations are shown in Appendix D. Using the work sheet developed for the LeGrand procedure, the LeGrand rating for Area One is calculated to be -13.

Study Area 2: Roundup-Winnett

Based on LeGrand analysis, Study Area Two appears to be marginally suited to host a hazardous waste disposal facility. The Roundup-Winnett Area exhibits the following hydrogeologic characteristics:

Distances on ground from possible site locations to a point of water use exceed 6200 feet for more than 80 percent of the recommended study area (that part of the area directly underlain by the Niobrara and the Carlile Members of the Colorado Shale) for greater than five percent of the year.

Depth to water table of usable groundwater is greater than 200 feet for greater than 80 percent of the recommended area.

Gradient of the nearest usable groundwater aquifer (the First Cat Creek Sand) ranges from flat to greater than two percent. No water supply exists within 200 feet of 90 percent of the recommended area.

Bedrock immediately underlying the site is primarily interbedded sandstones and shales with varying hydraulic conductivities. Unconsolidated materials over bedrock is clay with no more than 50 percent sand. Thickness of unconsolidated bedrock is less than nine feet.

Location and extent of vertical fractures is unknown but estimated to exist extensively throughout the area.

Extent of the nearest usable aquifer, the First Cat Creek Sand is moderate, aquifer sensitivity is moderately high because of the presence of fractures in overlying bedrock and its near-surface location in parts of the study area.

Lithology of the nearest usable aquifer is fine-grained sandstone.

The degree of seriousness of the waste is high.

The LeGrand rating for the Winnett-Roundup Area if bedrock is highly fractured is +5.

If bedrock is not fractured or if vertical cracks are surficial features only, the LeGrand rating is -5.

Study Area 3: Denton-Lewistown

At a LeGrand rating of +12 in fractured bedrock this area appears to be hydrogeologically unsuitable for hazardous waste disposal. The limiting factor in Area Three is land use which can be expressed in terms of distance from source of contaminant to a point of water use in terms of LeGrand characteristics.

The Denton-Lewistown Area exhibits the following characteristics:

Distances on ground from possible site locations to a point of water use are less than 250 feet for 72 percent of the area; an unsuitable characteristic for landfill siting.

Depth to water table of usable groundwater is greater than 200 feet for the recommended area (that part of Area Three underlain by Colorado Shale).

Gradient of the nearest usable groundwater aquifer (the First Cat Creek Sand) is approximately one to two percent towards a water supply within 3000 feet of the recommended area.

Bedrock immediately underlying the site is Colorado Shale and terrace deposits, unconsolidated materials over the shale is clay with no more than 50 percent sand, over the terrace deposits is sandy loam.

Location and extent of vertical fractures is unknown but estimated to be extensive because of the study area's proximity to regional lineaments.

Extent of the nearest usable aquifer is moderate.

Lithology of the nearest usable aquifer in the terrace deposits is coarse consolidated gravel. Lithology of the nearest usable aquifer underlying the Colorado Shale (the First Cat Creek Sand) in the study area is fine-grained sandstone.

The degree of seriousness of the waste is high.

The LeGrand rating for Area Three if underlying bedrock is highly fractured is a +12. If underlying bedrock in the recommended area is unfractured or if cracks are only surficial features, then the LeGrand rating for Area Three is -2.

Using the LeGrand method, this preliminary study found the Sumatra-Ingomar area to have the most suitable hydrogeologic characteristics of the three study areas for landfill hazardous waste disposal.

LeGrand applied his model to some existing North American waste disposal sites and derived the values shown in Table 6. LeGrand values for the three areas evaluated in this study are also shown in Table 6; sites are ordered from top to bottom with the most suitable site at the top. These values are only for comparative purposes;

LeGrand ratings for a potential or existing site will vary depending on engineered conditions at the site and the best judgement of the appraiser.

The Sumatra-Ingomar area ranked very well with a -13 rating. The Roundup-Winnett area with a +5 rating (if bedrock is highly fractured) or -5 rating (for unfractured bedrock) and the Denton-Lewistown area which has a +12 rating (fractured bedrock) or a -2 rating (unfractured bedrock) have serious drawbacks. Notice that despite the poor ratings of two of the three study areas, they still appear to rank moderately high when compared to other U.S. sites that have been assessed by this method. Legrand recommends that those sites ranking better than a +3 be considered suitable after site modification.

The Drastic Method

DRASTIC (Aller and others, 1985) was developed for evaluating groundwater pollution potential by using hydrogeologic settings. DRASTIC is an acronym reflecting its factors of evaluation: Depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and hydraulic Conductivity of the aquifer.

Table 6. LeGrand ranking of selected North American waste sites

Landfill Site	Waste Type	Ranking
*Sumatra-Ingomar (Area 1)	HZW	-13
Lycoming County, PA	SL	- 8
*Roundup-Winnett (Area 2)	HZW	- 5
Oakridge, TN	RW	- 2
*Lewistown-Denton (Area 3)	HZW	- 2
Hopewell, VA	HZW	+ 1
Hanford, WA	RW	+ 2
Olentagy River, OH	HZW	+ 3
*Roundup-Winnett (Area 2) (fractured bedrock)	HZW	+ 5
Reactor Testing Site, ID	RW	+ 5
Savannah River, SC	RW	+ 5
Barstow, CA	RW	+ 9
Chalk River, Canada	RW	+10
*Lewistown-Denton (Area 3) (fractured bedrock)	HZW	+12

SL=Sanitary landfill
HZW=hazardous waste disposal site
RW=radioactive waste disposal site
*Study areas as ranked by this report

It is a ranking system that uses a combination of weights and ratings to produce a numerical value that is an indication of groundwater contamination vulnerability. The higher the calculated DRASTIC value, the higher the groundwater contamination vulnerability.

The DRASTIC method of evaluation was applied to Study Areas One and Two where the relevant data was collected or confirmed in the field. Calculations showing DRASTIC factors and their weighted values are shown in Appendix D.

Area 1: Sumatra-Ingomar DRASTIC hydrogeologic Scenarios:

1. Perched water table in a clay loam/silty clay soil of thin or absent soil: 104-118

Probable DRASTIC value:...106

2. Deep aquifer, no fractures in confining layers: 56-73

Probable DRASTIC value (depending on soil type):...61

3. Deep aquifer with fractures in confining layers: 72-90

Probable DRASTIC value:...84

The Sumatra-Ingomar Area has a range of 61 - 106 for DRASTIC final values.

<u>Area 2: Roundup-Winnett DRASTIC Scenarios:</u>

1. Cat Creek aquifer, low slope (0-6%), unfractured vadose zone. shrinking clay soil and vadose zone material of bedded ls, sh, and ss...57-89
probable DRASTIC value... <u>80</u>

2. Cat Creek aquifer, fractured vadose zone...91-120
probable DRASTIC value...<u>100</u>

3. Perched water table...112-137
probable value...<u>125</u>

The Roundup-Winnett Area has a range of <u>80-125</u> for DRASTIC final values.

Table 7 lists selected DRASTIC ratings for over 40 different hydrogeologic settings in the United States as evaluated in the DRASTIC study. Higher scores signify settings expected to be hydrogeologically vulnerable to contamination from a hazardous waste treatment or disposal facility. Settings that correspond to Areas One and Two are marked with an asterix on the table.

The usefulness of the DRASTIC system as it applies to this type of study is discussed in detail in the methods section of this report. Because of difficulties with the net recharge and topography components of the DRASTIC method of analysis, this researcher has less confidence in this approach and prefers the LeGrand method. Although the DRASTIC approach has drawbacks, the method serves as a useful guide for identifying and assessing essential criteria.

Table 7. Hydrogeologic settings and associated DRASTIC indices from Aller (1985).

HYDROGEOLOGIC SETTING	RATING
alluvial basins (internal drainage	122
alluvial fans	105-122
alluvial mountain valleys	128-184
alluvium	107-140
alternating ss,ls,sh-deep regolith	131
*alternating ss,ls,sh-thin soil	129
beaches, beach ridges and sand dunes	202
bedrock of the uplands and mountains	92
braided river deposits	185-190
buried valley	156
coastal beaches	196-201
coastal deposits	191
coastal lowland deposits	140
*confined regional aquifers	53
*consolidated sedimentary rocks	87
glacial deposits of interior valleys	131
glacial lake deposits	135
glacial till over bedded sedimentary rock	78-99
glacial till over crystalline bedrock	103
glacial till over outwash	127-129
glacial till over solution limestone	129
glaciated mountain valleys	180
hydraulically connected lava flows	156
lava flows not connected hydraulically	105
moraine	125-166
mountain crests	70
mountain flanks	83-106
mountain slopes	74-164
outwash	109-176
outwash over bedded sedimentary	156
outwash over solution limestone	186
playa lakes	110-111
resistant ridges	88
river alluvium with overbank	124-136
river alluvium without overbank	187-191
sand dunes	150
solution limestone	196-218
swamp	202-224
thick regolith	100
thin till over bedded sedimentary	111
triassic basins	106
unconsolidated & semi-cons. surficial aquifer	184
volcanic uplands	165
wide alluvial valleys (external drainage)	158-180

* Settings considered in this study are indicated by an asterix.

SUMMARY AND CONCLUSIONS

Hazardous waste is an umbrella term for a wide range of insidious substances all of which have one or more of the following characteristics: iqnitability, corrosivity, chemical reactivity and toxicity. If spilled or leaked during handling or disposal the synergistic nature of these wastes can dramatically increase the threat they pose to the environment, especially in the form of increased incidence of volatile chemical reactions and greater mobility of hazardous chemical compounds.

Montana may soon be faced with the responsibility of disposing of its own hazardous waste. Though fraught with problems, landfills continue to be the least expensive in comparison with other disposal technologies and account for up to 80 percent of the disposed hazardous waste (Josephson 1981). There is considerable evidence that the clay liners commonly used to contain hazardous waste landfill disposal systems are failing to contain leachate. If the objective of hazardous waste disposal is to isolate and contain the residue of wastes for as long as they remain hazardous, then a suitable geologic environment for a disposal site is necessary to act as a second line of defense from potential leakage into the distribution system of ground and surface waters.

There appear to be areas in Montana that are hydrogeologically suitable to host a hazardous waste disposal facility. The purpose of this study was to locate and evaluate those areas that are most suitable on a reconnaissance basis. Invoking established hydrogeologic criteria, two areas in Montana were evaluated on a field reconnaissance level and one area was evaluated using published information.

The Sumatra-Ingomar area in eastern Montana appears to be hydrogeologically most suitable to host a hazardous waste disposal site, the Roundup-Winnett area may also contain suitable sites. The Denton-Lewistown area was evaluated based on existing data and appears to contain no highly suitable hazardous waste disposal sites but does appear to contain marginally suitable sites.

This study is preliminary in nature and is limited to a technical evaluation of hydrogeologic factors important for landfill hazardous waste disposal siting on a regional scale in Montana. Subsequent facility emplacement must follow a comprehensive, site-specific evaluation of any area under consideration. It is likely that large areas exist in Montana containing suitable sites that were not examined in this study. Areas of exposed Pierre Shale in Carter County, Montana, for example and the glaciated region in northern Petroleum County where the till is thin may also contain highly suitable sites and should be considered for future studies.

RECOMMENDATIONS

Montana appears to have several options for a hydrogeologically well-suited hazardous waste disposal site. Because of this, the State would be remiss if a disposal setting was chosen with even a moderate potential to contaminate surface or ground waters. For this reason this study recommends the following:

1) Apply the hydrogeologic criteria outlined in this report when assessing areas or sites in Montana for hazardous waste landfill disposal or treatment. Because surface and ground waters can serve not only as widely distributed sources of water, but as hosts and transporting agents for contaminants, protecting Montana's water from contamination is probably the single most important objective for hazardous waste disposal site selection.

2) Because a primary concern in hazardous waste management is to prevent water contamination, hydrogeologic factors should be given equal or greater weight than other considerations when making the final site selection.

3) Commission a study to evaluate the frequency and magnitude of hazardous waste spills that occur in transit, this is necessary to determine the environmental cost/benefit ratio of transporting wastes to remote locations.

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APPENDICES

APPENDIX A

WORKSHOP DISCUSSION AND RECOMMENDATIONS

AGENDA

MONTANA ROOM
COLONIAL INN

Tuesday, July 9, 1985

8:00 - 8:30	Registration, coffee and donuts
8:30 - 8:40	Introduction (Steve Custer)
8:40 - 8:55	Montana Department of Health and Environmental Sciences: a perspective by Duane Robertson
8:55 - 9:10	U.S. Environmental Protection Agency: a perspective by Jim Harris
9:10 - 9:25	Overview of previous studies: Bowen's Report to the Montana Department of Health and Environmental Sciences. (Steve Custer)
9:25 - 9:45	Break
9:45 -10:30	Environmental Factors: small group discussion
10:30 -11:00	Environmental Factors: synthesis
11:00 -11:30	Socio-economic Factors: small group discussion
11:30 -12:00	Socio-economic Factors: synthesis
12:00 - 1:30	Lunch
1:30 - 2:00	Do we agree with the areas Bowen identified as suitable for field examination? small group discussion
2:00 - 2:20	Synthesis of small group discussions
2:20 - 2:35	Break
2:35 - 3:30	Where would you recommend field focus occur? Whole group discussion

-End-

Introduction

Steve Custer opened the workshop with the question that is at the center of this research. "Are there areas capable of hosting a hazardous waste disposal facility in Montana?" This problem is important for a variety of reasons. All people in the state generate hazardous waste, either directly or indirectly through the use of household pesticides and herbicides, solvents and paints, as well as indirectly in the form of hazardous byproducts generated during manufacturing. Montana's industrial hazardous waste contributers include agriculture, petrochemical refining, small businesses and university and private laboratories to name a few.

The problem was brought to focus through the experimental collection effort last year conducted in Missoula by the Solid Waste Bureau. So much waste was brought in that the collection could not continue and the experiment was closed. The hazardous wastes are currently being shipped out of the state. However, current compacts are written in a way that allows these sites to be closed to outside users by the state that controls them. There are also transportation hazards and potential future volume problems that may lead to the need for a site in Montana. Historically the need for a site is driven by crisis and the crisis tends to drive political decisions with inadequate scientific control on the site. This research and workshop are part of a planning effort to lay a sound hydrogeologic foundation for planning should a site need to be identified in the state. It is important to note that this work is not designed to find a site, but rather to determine what areas in Montana, if any, are capable of hosting a hazardous waste disposal facility.

The workshop is part of a larger study that began by drawing together a preliminary draft of a project by Dave Bowen done in 1981. Bowen identified areas which might host a hazardous waste facility at a scale of 1:3,000,000. The work produced a series of maps of the state for factors which were considered important to the problem. The study did not compile the maps on a single overlay to identify the most likely areas for investigation, nor did it include field checking. The first stage of the research then was to compile the Bowen maps. Using these maps, this workshop was assembled to assess the work and obtain guidance from a broad cross section of Montana scientists in state and federal agencies. After the workshop, 1:250,000 scale maps will be compiled for areas this group feels should be examined. The funds available probably do not allow more than two or three sites to be selected. Once the general maps are completed, two or three 7.5 minute quadrangles will be selected for field evaluation. Field work will include geologic, hydrologic and water quality factors. With this information, we will try to answer the question: Are there areas in Montana which are capable of hosting a hazardous waste facility?

COMMENTS BY DUANE ROBERTSON
(Solid Waste Bureau, Montana Department of Health and Environmental Sciences)

State Perspective on the Problem

Currently, only those who generate 1000 kilograms (kg) of hazardous waste per month fall under governmental regulations; there are 15 such generators in the state who produce approximately 300 tons of hazardous waste a year. The waste production threshold will change to 100 kg/mo late this summer. When this happens approximately 1000 businesses such as auto shops, labs and dry cleaning establishments will be regulated. Furthermore, the small hazardous waste generators will be required to identify all materials they are disposing. When this happens it is anticipated that the local landfills will bar small hazardous waste generators. This will either significantly increase the demand for out-of-state shipment and possibly increase illegal dumping of hazardous wastes.

To deal with this problem the Solid Waste Bureau has obtained two grants. The first is to provide for a hazardous waste collection and transfer facility in Montana. It is funded through the state Resource Indemnity Trust account and is au-thorized to begin fiscal year 1987. A second legislative appropriation of 10,000 dollars for siting was also authorized. The Solid Waste Bureau is holding this money until the Water Center grant that is sponsoring this workshop has been completed, at which time the money will be used for more detailed borings and tests to assess potential sites.

Mr. Robertson then responded to questions. He pointed out that public acceptance of hazardous waste facilities is a difficult but important element. Nuclear waste is probably not an issue. He believes that even though funding for the the collection and transfer facility siting project is not scheduled to begin for another year, Montana appears to be addressing the issue sooner than many other western states.

COMMENTS BY JIM HARRIS
(U. S. Environmental Protection Agency)

Federal Perspective on the Problem

Jim Harris pointed out that experiments in the area of hazardous waste disposal by landfill have not been successful. Controls and technology are not available to adequately deal with the problems connected with landfill disposal. The reauthorized Resource Conservation and Recovery Act (RCRA) has banned land disposal and mandates studies to deal with the problem. This leaves the question: what is land disposal? The concept includes landfill, piles, impoundments, injection, salt domes, mines and caves, and land treatment. The ban on land treatment may be unfortunate, because some wastes are biodegradable and are heavily used by industry in Montana and elsewhere. The problem is that land disposal of any type is very hard to monitor.

Because of the ban on land disposal, many alternatives are being researched. We should not be restricting our view to land fill, but should also consider alternative technological approaches such as detoxification facilities, recycling, incineration, and land treatment.

A series of solvents will be specifically regulated in November 1986 including PCB, Dioxine, organic and inorganic solvents, and As, Cd, Cr, Pb, Ni, Hg, Se, Th, materials with pH less than 2 and halogenated waste. All these materials must be disposed of in a way that protects the environment as long as the waste is hazardous. This time period is not yet determined.

At this point Jim responded to questions. Landfill will be allowed after 5.5 years from the reauthorization only if the site meets new facility standards and if the generator shows that this method is the only economically viable alternative. No substances can be disposed in liquid form; currently EPA demands solidification not absorption. There are not detoxification or incinerator facilities currently operating in Montana, but there have been some inquiries. The seriousness of these inquiries is not clear since they are preliminary. There may be some incineration facilities at Paradise and Somers operated by Burlington Northern Railroad during the closing of their facilities, but these incinerators will probably be closed when the task is finished. During the discussion a statement was made that there is no known hazardous waste landfill in the United States that has not leaked.

Mr. Harris was asked if it was correct that the current EPA position is that there must be fluid present to monitor below a disposal site if a site was to be approved because without fluid no detection was possible. Mr Harris responded yes this seemed to be the case because lysimeters and the like do not work well in the arid west. There was some concern expressed by the participants regarding this paradox since the most ideal site would be one with no water. Later in the workshop Mr. Harris suggested that significantly more work be focused on economic and social factors than on site factors because current EPA guidelines suggested that the site would not be a land disposal site. If an excursion of waste is found to be present, EPA would demand removal and reprocessing of all the material at the site, replacement of faulty liner(s) and continued monitoring. Some participants at the workshop expressed concern regarding this approach because the law says that upon closure only 30 years of monitoring are required. Mr. Harris expressed confidence that such a postclosure monitoring schedule could easily be extended. No resolution to this problem was sought because it is peripheral to the problem at hand, and Mr. Harris did not want to eliminate site factors. He did reiterate however that the economic factors needed more attention than they have recieved to date.

Finally Mr. Harris offered to send copies of the Reauthorized RCRA and an english summary to those interested. His address is in the enclosed list of participants.

WORKSHOP SUMMARY

The workshop format was that of small group discussions. A series of questions were addressed in four sessions. This was designed to encourage brainstorming and the search for consensus so that the input of as many people could be drawn on for advice, ideas and recommendations.

The structure of the workshop was designed to focus discussion on one set of issues at a time. As a result, a summary of participant discussion and conclusions are presented in three parts:

Session 1. What environmental factors can be added to Bowen's report that are important to hazardous waste disposal facility siting?

There was general agreement within the group that most of the environmental criteria employed by Bowen are important factors for area assessment. In addition, participants recommended that we avoid glaciated regions because glacial tills tend to be fractured and have complex textural variability which is difficult to predict. Areas of past or present tectonic instability, particularly faulting and fold axes were also considered unsuitable for site locations. There was some concern that tectonically deformed areas might contain suitable sites if one looked at scales larger than 1:3,000,000 for areas between or adjacent to structural features.

The following environmental factors were not considered in Bowen's report but were recommended by the participants as important criteria in site assessment:

1. local wind pattern: what lies downwind of the area? How strong are the winds in the area?
2. Avoid fractured bedrock.
3. Depth to aquifer should be great.
4. Avoid anticlinal areas because of open fractures and oil and gas exploitation.
5. Consider using synclines.
6. Avoid the Lebo shale; it overlies a major aquifer rock and is commonly exposed near an aquifer.
7. Determine groundwater flow patterns in the area of the selected regions and in adjacent regions for recharge and discharge areas. An unanswered question that was raised was: where within the groundwater flow path should a site be located?
8. Avoid areas of past or potential mineral exploration.
9. Gradients greater than five percent may have more value than Bowen suggests; some site designs require a steeper gradient.
10. Everyone agreed that field area investigations at this point should be limited to areas underlain by thick Cretaceous shale.

Session 2. What socioeconomic factors can be added to Bowen's report that are important to hazardous waste disposal siting?

Because Bowen's report focused on environmental factors for hazardous waste disposal siting, it did not adequately assess socioeconomic issues. The following factors were offered by workshop participants as important considerations. No consensus was reached as to their relative importance, indeed most participants agreed that another study is needed to examine these factors as they relate to hazardous waste problems:

1. transportation distance from source to site
2. mode of transportation
3. local demand for the facility
4. amount of material to be transported in future
5. proximity of site to population center
6. number of sites
7. types of sites needed (ie short-term storage, processing, collection or disposal)
8. international, state, and reservation border concerns
9. mineral rights.

Some participants suggested Montana consider working with other states to establish a regional facility in addition to existing facilities at the best possible location, whether within Montana or elsewhere.

It was apparant that there is a need to better understand the risk and cost factors of rail and highway transportation. There was some disagreement concerning the importance and the mode of transportation of hazardous wastes from the source to a collection point and from that point to the disposal site.

Participants agreed on the following points:
- A socioeconomic study will be needed.
- Such a study will be highly political.
- Areas chosen for field reconnaisance should not be near one another in order to assess the suitability of diverse regions.
- Public education should begin now.

Sessions 3 and 4 Based on the factors the group agrees are important, do we agree with the areas Bowen identified as suitable for field examination? In which areas would you recommend field work be focused?

A variety of criteria were used to identify the best areas to examine:

-the area should be underlain by Cretaceous shale,
-the area should not be glaciated,
-the area should be near a transportation net,
-the area should be near hazardous waste generators or near a collection facility, and
-land use.

Most of these factors were identified as important by Bowen. There was general agreement that rejection of any of the sites identified by Bowen is unwise based on the limited amount of information as yet compiled. The purpose of this part of the workshop was to identify the best two or three areas on which to focus field research.

There was some discussion regarding whether there might be acceptable sites in the western part of the state. Tertiary bentonite beds such as the Climbing Arrow Formation or silty clay beds in Glacial Lake Missoula deposits were considered for potential sites. A consensus was reached that these areas were not suitable because leakage would have potentially high dispersivity due to the following geologic and hydrologic factors that characterize western Montana:

- -the area is typically high relief,
- -rocks tend to be intensly folded and faulted,
- -large regions of fractured and weathered crystalline rocks,
- -alluvial valleys tend to be filled with gravel deposits interbeded with silts and muds,
- -surface waters form the headwaters for several major U. S. rivers,
- -the region has recharge areas for major aquifers, and
- -has high seismic risk.

Refer to the enclosed map (Figure 19), for those areas selected for field reconnaisance by this study. Areas 1, 2 and 3 are most likely to contain a suitable site for hazardous waste disposal in Montana.

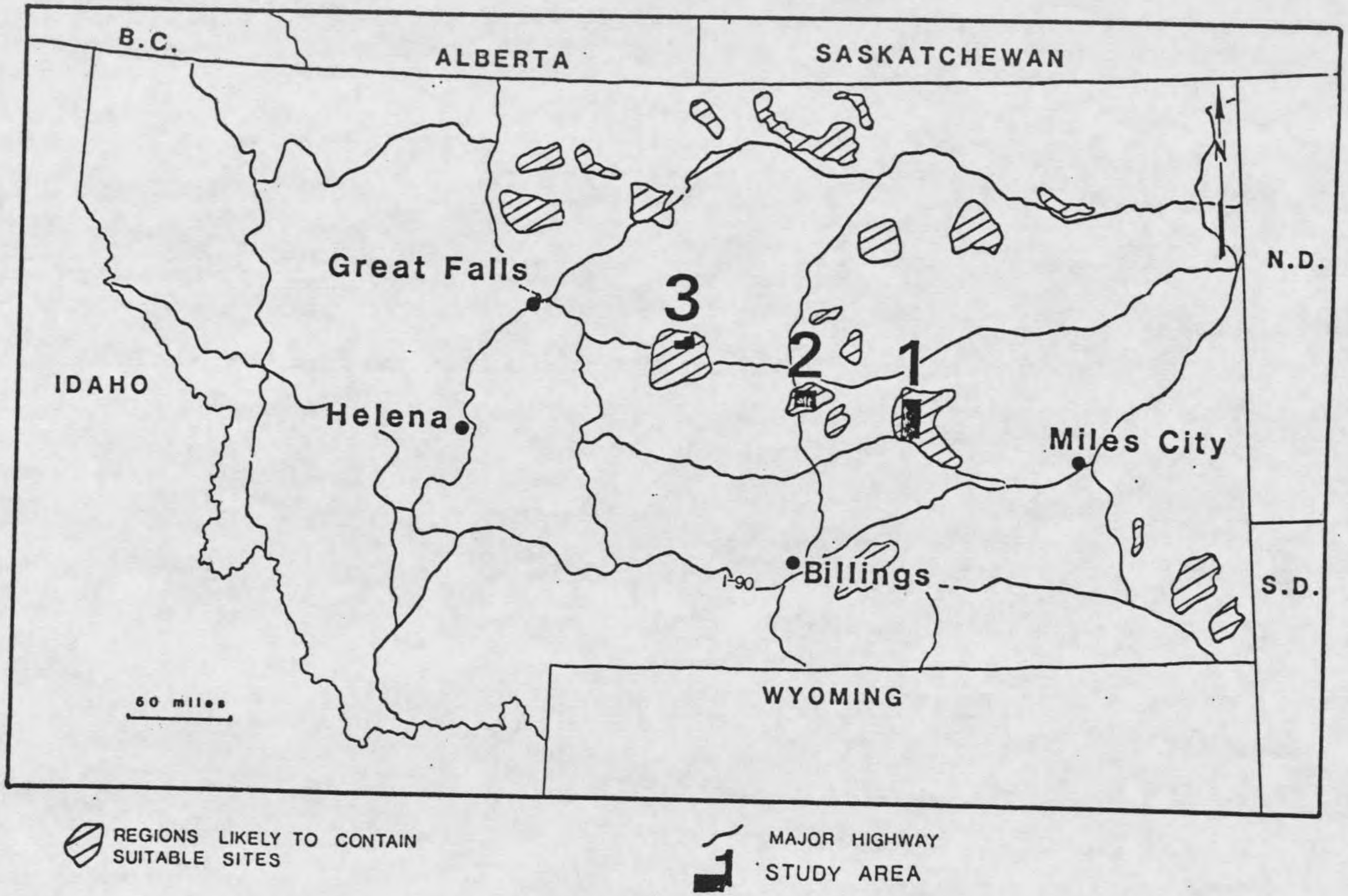

Figure 19. Regions in Montana initially considered for hydrogeologic reconnaissance evaluation, (compiled from Bowen,1981)

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APPENDIX B

WATER QUALITY ANALYSIS OF COLLECTED SAMPLES

SAMPLE SITE S-1

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0570

STATE MONTANA
LATITUDE-LONGITUDE 46D48'00"N 107D28'15"W
UTM COORDINATES Z N E
TOPOGRAPHIC MAP MCGINNIS BUTTE SW 7 1/2'
GEOLOGIC SOURCE 211MNTN* * *
DRAINAGE BASIN EB
AGENCY + SAMPLER MSU *AS
BOTTLE NUMBER F-1
DATE SAMPLED 18-JUN-86
TIME SAMPLED 16:30 HOURS
LAB + ANALYST MBMG*WO
DATE ANALYZED 01-AUG-86
SAMPLE HANDLING 3220
METHOD SAMPLED GRAB
WATER USE STOCK

COUNTY ROSEBUD
SITE LOCATION 12N 34E 08 BC 01
MBMG SITE
STATION ID 464800107281501
SAMPLE SOURCE POND
LAND SURFACE ALTITUDE 3090. FT < 10
WATER FLOW RATE
FLOW MEAS METHOD
STAFF GAGE
STREAM STAGE
DEPTH TO SAMPLE .5 FT (E)
TOTAL DEPTH OF WATER 15. FT (E)
STREAM WIDTH

SAMPLING SITE
DRAINAGE BASIN MUSSELSHELL RIVER BETWEEN FLATWILLOW CREEK AND HALFBREED C
RE

		MG/L	MEQ/L			MG/L	MEQ/L
CALCIUM	(CA)	34.8	1.74	BICARBONATE	(HCO3)	122.5	2.01
MAGNESIUM	(MG)	6.1	0.50	CARBONATE	(CO3)	4.9	0.16
SODIUM	(NA)	20.0	0.87	CHLORIDE	(CL)	2.1	0.06
POTASSIUM	(K)	4.9	0.13	SULFATE	(SO4)	46.6	0.97
IRON	(FE)	<.002		NITRATE	(AS N)	.02	0.00
MANGANESE	(MN)	.008	0.00	FLUORIDE	(F)	.3	0.02
SILICA	(SIO2)	7.3		PHOSPHATE TOT	(AS P)		
TOTAL CATIONS			3.23	TOTAL ANIONS			3.22

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) -0.11

CALCULATED DISSOLVED SOLIDS	187.37	TOTAL HARDNESS AS CACO3	112.00
SUM OF DISS. CONSTITUENT	249.53	TOTAL ALKALINITY AS CACO3	108.64
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	323.	RYZNAR STABILITY INDEX	7.27
FIELD PH		LANGLIER SATURATION INDEX	0.65
LABORATORY PH	8.57	SODIUM ADSORPTION RATIO	0.82

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP, AIR	90.		
ALUMINUM, DISS (UG/L-AL)	<30.	NICKEL, DISS (UG/L AS NI)	<10.
SILVER, DISS(UG/L AS AG)	<2.	PHOSPHATE, TO, DIS(MG/L-P)	.1
BORON, DISS (UG/L AS B)	160.	STRONTIUM, DISS (UG/L-SR)	200.
CADMIUM, DISS(UG/L AS CD)	<2.	TITANIUM DIS(UG/L AS TI)	4.
CHROMIUM, DISS (UG/L-CR)	<2.	VANADIUM, DISS(UG/L AS V)	3.
COPPER, DISS (UG/L AS CU)	<2.	ZINC, DISS (UG/L AS ZN)	11.
LITHIUM, DISS(UG/L AS LI)	13.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM, DISS(UG/L-MO)	<20.	O-PHOSPHATE, DISS(MG/L-P)	.2
BROMIDE, DISS(MG/L AS BR)	<.1	ARSENIC, DISS(UG/L AS AS)	1.4
MERCURY, DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	.4

REMARKS: CLEAR, LARGE STOCK POND

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER, FT = FEET, MT = METERS, (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL, BIO = BIOLOGICALLY AVAILABLE.

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COST:
BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
53.7	15.5	26.9	3.9	1.9	30.3	62.7	5.1

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0570

SAMPLE SITE S-2

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0576

STATE	MONTANA	COUNTY	ROSEBUD
LATITUDE-LONGITUDE	46D42'00"N 107D26'05"W	SITE LOCATION	11N 34E 22 BBAA 01
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	YABLONSKI RANCH 7 1/2'	STATION ID	464200107260501
GEOLOGIC SOURCE	110ALVM*211MNTN*	* SAMPLE SOURCE	SPRING
DRAINAGE BASIN	LB	LAND SURFACE ALTITUDE	3020. FT < 10
AGENCY + SAMPLER	MSU *AS	SUSTAINED YIELD	
BOTTLE NUMBER	D-5	YIELD MEAS METHOD	
DATE SAMPLED	18-JUN-86	TOTAL DEPTH OF WELL	
TIME SAMPLED	11:20 HOURS	SWL ABOVE(-) OR BELOW GS	
LAB + ANALYST	MBMG*WO	CASING DIAMETER	
DATE ANALYZED	04-AUG-86	CASING TYPE	
SAMPLE HANDLING	3220	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	UNUSED		

SAMPLING SITE GALT, LOUISE* .1 MI SE OLD FOX HOMESTEAD
GEOLOGIC SOURCE ALLUVIUM (QUATERNARY)

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	65.5	3.27	BICARBONATE (HCO3)	237.9	3.90
MAGNESIUM (MG)	19.1	1.57	CARBONATE (CO3)	0.	
SODIUM (NA)	249.	10.83	CHLORIDE (CL)	5.3	0.15
POTASSIUM (K)	6.90	0.18	SULFATE (SO4)	552.	11.49
IRON (FE)	<.002		NITRATE (AS N)		
MANGANESE (MN)	.004	0.00	FLUORIDE (F)	.04	0.00
SILICA (SIO2)	1.9		PHOSPHATE TOT (AS P)	.3	0.02
TOTAL CATIONS		15.85	TOTAL ANIONS		15.56

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) -0.87

CALCULATED DISSOLVED SOLIDS	1017.24	TOTAL HARDNESS AS CACO3	242.17
SUM OF DISS. CONSTITUENT	1137.94	TOTAL ALKALINITY AS CACO3	195.12
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	1517.	RYZNAR STABILITY INDEX	6.59
FIELD PH		LANGLIER SATURATION INDEX	0.81
LABORATORY PH	8.20	SODIUM ADSORPTION RATIO	6.96

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. AIR	92. F		
ALUMINUM, DISS (UG/L-AL)	<30.	NICKEL,DISS (UG/L AS NI)	<10.
SILVER, DISS(UG/L AS AG)	9.	PHOSPHATE,TO,DIS(MG/L-P)	<.1
BORON,DISS (UG/L AS B)	163.	STRONTIUM,DISS (UG/L-SR)	450.
CADMIUM,DISS(UG/L AS CD)	<2.	TITANIUM DIS(UG/L AS TI)	6.
CHROMIUM, DISS (UG/L-CR)	<2.	VANADIUM,DISS(UG/L AS V)	<1.
COPPER,DISS (UG/L AS CU)	<2.	ZINC, DISS (UG/L AS ZN)	7.
LITHIUM,DISS(UG/L AS LI)	27.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	<20.	O-PHOSPHATE,DISS(MG/L-P)	.2
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.3
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	.5

REMARKS: STANDING WATER
SPRING IS LOCATED IN THE BANK OF AN INTERMITTENT STREAM * SAMPLE
TAKEN FROM STANDING WATER

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER, FT = FEET, MT = METERS, (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL, BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 27-AUG-86
PROCESSING PROGRAM: F1730P V3 (09/1/83)
COST:
BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
20.6	9.9	68.3	1.1	1.0	74.0	25.1	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0576

SAMPLE SITE G-3

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0571

STATE MONTANA
LATITUDE-LONGITUDE 46D46'00"N 107D42'40"W
UTM COORDINATES Z N E
TOPOGRAPHIC MAP MCGINNIS BUTTE SW 7 1/2'
GEOLOGIC SOURCE 211MNTN*
DRAINAGE BASIN LB *
AGENCY + SAMPLER MSU *AS
BOTTLE NUMBER C-1
DATE SAMPLED 17-JUN-86
TIME SAMPLED 17:00 HOURS
LAB + ANALYST MBMG*WO
DATE ANALYZED 04-AUG-86
SAMPLE HANDLING 3220
METHOD SAMPLED GRAB
WATER USE STOCK

COUNTY ROSEBUD
SITE LOCATION 12N 34E 24 DBD 01
MBMG SITE
STATION ID 464600107424001
* SAMPLE SOURCE POND
LAND SURFACE ALTITUDE 2905. FT < 10
WATER FLOW RATE
FLOW MEAS METHOD
STAFF GAGE
STREAM STAGE
DEPTH TO SAMPLE
TOTAL DEPTH OF WATER .5 FT (E)
STREAM WIDTH 12. FT (E)

SAMPLING SITE GALT, LOUISE
DRAINAGE BASIN BIG PORCUPINE CREEK OF THE YELLOWSTONE RIVER

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	125.	6.24	BICARBONATE (HCO3)	18.3	0.30
MAGNESIUM (MG)	62.3	5.13	CARBONATE (CO3)	25.0	0.83
SODIUM (NA)	268.	11.66	CHLORIDE (CL)	2.8	0.08
POTASSIUM (K)	6.7	0.17	SULFATE (SO4)	1050.	21.86
IRON (FE)	<.002		NITRATE (AS N)		0.00
MANGANESE (MN)	<.001		FLUORIDE (F)	.04	0.00
SILICA (SIO2)	0.6		PHOSPHATE TOT (AS P)	.5	0.03
TOTAL CATIONS		23.19	TOTAL ANIONS		23.10

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) -0.21

CALCULATED DISSOLVED SOLIDS	1549.95	TOTAL HARDNESS AS CACO3	568.55
SUM OF DISS. CONSTITUENT	1559.24	TOTAL ALKALINITY AS CACO3	56.71
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	2058.	RYZNAR STABILITY INDEX	5.47
FIELD PH		LANGLIER SATURATION INDEX	2.18
LABORATORY PH	9.83	SODIUM ADSORPTION RATIO	4.89

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. AIR	90. F		
ALUMINUM, DISS (UG/L-AL)	<30.	NICKEL,DISS (UG/L AS NI)	<10.
SILVER, DISS(UG/L AS AG)	<2.	PHOSPHATE,TO,DIS(MG/L-P)	.1
BORON,DISS (UG/L AS B)	260.	STRONTIUM,DISS (UG/L-SR)	960.
CADMIUM,DISS(UG/L AS CD)	<2.	TITANIUM DIS(UG/L AS TI)	10.
CHROMIUM, DISS (UG/L-CR)	<2.	VANADIUM,DISS(UG/L AS V)	5.
COPPER,DISS (UG/L AS CU)	<2.	ZINC, DISS (UG/L AS ZN)	4.
LITHIUM,DISS(UG/L AS LI)	100.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	<20.	O-PHOSPHATE,DISS(MG/L-P)	<.1
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.7
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	3.5

REMARKS: UNTREATED RAW SAMPLE IS IN THE 250 ML BOTTLE * FILTERED SAMPLE IS IN 500 ML BOTTLE *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI ON PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 27-AUG-86 COST:
PROCESSING PROGRAM: F1730P V3 (09/1/83) BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
26.9	22.1	50.3	0.7	0.3	94.7	1.3	3.6

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0571

SAMPLE SITE G-4

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0574

STATE MONTANA
LATITUDE-LONGITUDE 46D47'15"N 107D26'30"W
UTM COORDINATES Z N E
TOPOGRAPHIC MAP MCGINNIS BUTTE SW 7 1/2'
GEOLOGIC SOURCE 211BRPW*110ALVM*
DRAINAGE BASIN LB
AGENCY + SAMPLER MSU *AS
BOTTLE NUMBER 1-B
DATE SAMPLED 17-JUN-86
TIME SAMPLED 15:15 HOURS
LAB + ANALYST MBMG*NO
DATE ANALYZED 04-AUG-86
SAMPLE HANDLING 3220
METHOD SAMPLED GRAB
WATER USE UNUSED

COUNTY ROSEBUD
SITE LOCATION 12N 34E 21 AD 01
MBMG SITE
STATION ID 464715107263001
* SAMPLE SOURCE SPRING
LAND SURFACE ALTITUDE 3140. FT < 10
SUSTAINED YIELD
YIELD MEAS METHOD
TOTAL DEPTH OF WELL
SWL ABOVE(-) OR BELOW GS
CASING DIAMETER
CASING TYPE
COMPLETION TYPE *
PERFORATION INTERVAL

SAMPLING SITE GALT, LOUISE* SPRING FLOWS INTO STREAM BED
GEOLOGIC SOURCE

		MG/L	MEQ/L			MG/L	MEQ/L
CALCIUM	(CA)	498.	24.85	BICARBONATE	(HCO3)	1116.	18.29
MAGNESIUM	(MG)	2679.	220.39	CARBONATE	(CO3)	0.	
SODIUM	(NA)			CHLORIDE	(CL)	222.	6.26
POTASSIUM	(K)	70.7	1.82	SULFATE	(SO4)	34140.	710.79
IRON	(FE)	<.002		NITRATE	(AS N)	24.	1.71
MANGANESE	(MN)	1.20	0.04	FLUORIDE	(F)	40.	2.11
SILICA	(SIO2)	8.7		PHOSPHATE TOT	(AS P)		
TOTAL CATIONS			247.10	TOTAL ANIONS			739.17

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA)

CALCULATED DISSOLVED SOLIDS
SUM OF DISS. CONSTITUENT
FIELD CNDUCTVY, MICROMHOS
LAB CNDUCTVY, MICROMHOS 38207.
FIELD PH
LABORATORY PH 8.23

TOTAL HARDNESS AS CACO3 12270.27
TOTAL ALKALINITY AS CACO3 915.31
FIELD ALKALINITY AS CACO3
RYZNAR STABILITY INDEX 3.45
LANGLIER SATURATION INDEX 2.39
SODIUM ADSORPTION RATIO

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. AIR	92. F		
SILVER, DISS(UG/L AS AG)	<2.	NICKEL,DISS (UG/L AS NI)	82.
BORON,DISS (UG/L AS B)	2310.	PHOSPHATE,TO,DIS(MG/L-P)	<.1
CADMIUM,DISS(UG/L AS CD)	22.	STRONTIUM,DISS (UG/L-SR)	1030.
CHROMIUM, DISS (UG/L-CR)	77.	TITANIUM DIS(UG/L AS TI)	13.
COPPER,DISS (UG/L AS CU)	<2.	VANADIUM,DISS(UG/L AS V)	<1.
LITHIUM,DISS(UG/L AS LI)	3580.	ZINC, DISS (UG/L AS ZN)	14.
MOLYBDENUM,DISS(UG/L-MO)	33.	ZIRCONIUM DIS(UG/L - ZR)	<4.
BROMIDE,DISS(MG/L AS BR)	<.1	O-PHOSPHATE,DISS(MG/L-P)	.1
MERCURY,DISS(UG/L AS HG)	<.04	ARSENIC,DISS(UG/L AS AS)	.9
SODIUM,DISS.(MG/L AS NA)	1124.0+01	SELENIUM, DISS (UG/L-SE)	40.
DISSLD SOLIDS(CALC MG/L)	4948.0+01		

REMARKS: YELLOW * FILTERED TWICE
SPRING AT CONTACT OF ALLUVIUM REWORKED SHALE AND BEARPAW SHALE * THE
UNTREATED RAW SAMPLE IS IN A 250 ML BOTTLE; FILTERED IN 500 ML BOTTLE
LAB: NA 11240 MG/L GIVES .28 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L =
MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) =
ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE. TOT = TOTAL.
BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 W1 OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 09-SEP-86
PROCESSING PROGRAM: F1720P V3 (09/1/83)

COST:
BY: TP *BCS
PRINTED: 09-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
10.1	87.2	0.0	0.7	0.9	96.7	2.5	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0574

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

SAMPLE SITE S-5
WATER QUALITY ANALYSIS
LAB NO. 86Q0575

STATE	MONTANA	COUNTY	PETROLEUM
LATITUDE-LONGITUDE	D ' "N D ' "W	SITE LOCATION	13N 25E 27 01
UTM COORDINATES	Z N E	MBNG SITE	
TOPOGRAPHIC MAP	ROUNDUP	STATION ID	
GEOLOGIC SOURCE	211CLRD* * *	SAMPLE SOURCE	POND
DRAINAGE BASIN	EC	LAND SURFACE ALTITUDE	
AGENCY + SAMPLER	MSU *AS	WATER FLOW RATE	
BOTTLE NUMBER	R-7	FLOW MEAS METHOD	
DATE SAMPLED	19-JUN-86	STAFF GAGE	
TIME SAMPLED	16:00 HOURS	STREAM STAGE	
LAB + ANALYST	MBMG*WO	DEPTH TO SAMPLE	.5 FT (E)
DATE ANALYZED	06-AUG-86	TOTAL DEPTH OF WATER	15. FT (E)
SAMPLE HANDLING	3220	STREAM WIDTH	
METHOD SAMPLED	GRAB		
WATER USE	UNUSED		

SAMPLING SITE HUGH, JOHN
DRAINAGE BASIN FLATWILLOW CREEK

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	118.	5.89	BICARBONATE (HCO3)	43.3	0.71
MAGNESIUM (MG)	41.8	3.44	CARBONATE (CO3)	0.	
SODIUM (NA)	183.	7.96	CHLORIDE (CL)	4.5	0.13
POTASSIUM (K)	10.2	0.26	SULFATE (SO4)	793.	16.51
IRON (FE)	<.002		NITRATE (AS N)	.36	0.03
MANGANESE (MN)	.15	0.01	FLUORIDE (F)	1.0	0.05
SILICA (SIO2)	3.0		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		17.56	TOTAL ANIONS		17.43

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) -0.36

CALCULATED DISSOLVED SOLIDS	1176.34	TOTAL HARDNESS AS CACO3	466.69
SUM OF DISS. CONSTITUENT	1198.31	TOTAL ALKALINITY AS CACO3	35.51
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	1637.	RYZNAR STABILITY INDEX	8.74
FIELD PH		LANGLIER SATURATION INDEX	-0.86
LABORATORY PH	7.02	SODIUM ADSORPTION RATIO	3.69

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP, AIR	86. F		
ALUMINUM, DISS (UG/L-AL)	<30.	NICKEL,DISS (UG/L AS NI)	<10.
SILVER, DISS(UG/L AS AG)	3.	PHOSPHATE,TO,DIS(MG/L-P)	<.1
BORON,DISS (UG/L AS B)	436.	STRONTIUM,DISS (UG/L-SR)	510.
CADMIUM,DISS(UG/L AS CD)	<2.	TITANIUM DIS(UG/L AS TI)	10.
CHROMIUM, DISS (UG/L-CR)	<2.	VANADIUM,DISS(UG/L AS V)	<1.
COPPER,DISS (UG/L AS CU)	<2.	ZINC, DISS (UG/L AS ZN)	6.
LITHIUM,DISS(UG/L AS LI)	198.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	<20.	O-PHOSPHATE,DISS(MG/L-P)	1.1
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.3
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	.6

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 27-AUG-86 COST:
PROCESSING PROGRAM: F1730P V3 (09/1/83) BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
33.6	19.6	45.4	1.5	0.7	95.2	4.1	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0575

SAMPLE SITE S-6

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0572

STATE	MONTANA	COUNTY	PETROLEUM
LATITUDE-LONGITUDE	47D02'30"N 108D29'37"W	SITE LOCATION	15N 25E 24 01
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	ROUNDUP	STATION ID	485220108293701
GEOLOGIC SOURCE	211CRLL* *	* SAMPLE SOURCE	POND
DRAINAGE BASIN	EC	LAND SURFACE ALTITUDE	3174. FT < 50
AGENCY + SAMPLER	MBMG*AS	WATER FLOW RATE	
BOTTLE NUMBER	R-4	FLOW MEAS METHOD	
DATE SAMPLED	20-JUN-86	STAFF GAGE	
TIME SAMPLED	14:00 HOURS	STREAM STAGE	
LAB + ANALYST	MBMG*WO	DEPTH TO SAMPLE	.5 FT (E)
DATE ANALYZED	06-AUG-86	TOTAL DEPTH OF WATER	12. FT (E)
SAMPLE HANDLING	3220	STREAM WIDTH	
METHOD SAMPLED	GRAB		
WATER USE	STOCK		

SAMPLING SITE HUGHES, JOHN
DRAINAGE BASIN FLATWILLOW CREEK

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	212.	10.58	BICARBONATE (HCO3)	0.	
MAGNESIUM (MG)	177.	14.56	CARBONATE (CO3)	0.	
SODIUM (NA)	161.	7.00	CHLORIDE (CL)	4.9	0.14
POTASSIUM (K)	10.0	0.26	SULFATE (SO4)	1742.	36.27
IRON (FE)	1.41	0.08	NITRATE (AS N)	.06	0.00
MANGANESE (MN)	2.33	0.08	FLUORIDE (F)	1.8	0.09
SILICA (SIO2)	10.3		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		32.56	TOTAL ANIONS		36.51

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA)

CALCULATED DISSOLVED SOLIDS		TOTAL HARDNESS AS CACO3	1257.90
SUM OF DISS. CONSTITUENT		TOTAL ALKALINITY AS CACO3	
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	2743.	RYZNAR STABILITY INDEX	
FIELD PH		LANGLIER SATURATION INDEX	
LABORATORY PH	3.92	SODIUM ADSORPTION RATIO	1.98

PARAMETER	VALUE	PARAMETER	VALUE
ALUMINUM, DISS (UG/L-AL)	3410.0+01	NICKEL,DISS (UG/L AS NI)	700.
SILVER, DISS(UG/L AS AG)	6.	PHOSPHATE,TO,DIS(MG/L-P)	.1
BORON,DISS (UG/L AS B)	380.	STRONTIUM,DISS (UG/L-SR)	210.
CADMIUM,DISS(UG/L AS CD)	<2.	TITANIUM DIS(UG/L AS TI)	20.
CHROMIUM, DISS (UG/L-CR)	6.	VANADIUM,DISS(UG/L AS V)	4.
COPPER,DISS (UG/L AS CU)	17.	ZINC, DISS (UG/L AS ZN)	1180.
LITHIUM,DISS(UG/L AS LI)	720.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	20.	O-PHOSPHATE,DISS(MG/L-P)	.2
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.3
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	.8

LAB: EST H+ .12, GE++ 1.41, AL 34.1, AND ZN 1.18 MG/L GIVES 36.5 MEQ/L
LAB: CATIONS FOR .03 SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
COST:
LAST EDIT DATE: 05-SEP-86 BY: TP *BCS
PROCESSING PROGRAM: F1730P V3 (09/1/83) PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
32.7	44.9	21.6	0.8	0.4	99.6	0.0	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0572

SAMPLE SITE G-7

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86R0577

STATE	MONTANA	COUNTY	PETROLEUM
LATITUDE-LONGITUDE	46D51'16"N 108D32'29"W	SITE LOCATION	13N 25E 27 C 01
UTM COORDINATES	Z N E	MBMG SITE	
TOPOGRAPHIC MAP	ROUNDUP	STATION ID	465116108322901
GEOLOGIC SOURCE	110ALVM*211CLRD* *	SAMPLE SOURCE	SPRING
DRAINAGE BASIN	EC	LAND SURFACE ALTITUDE	3418. FT < 10
AGENCY + SAMPLER	MSU *AS	SUSTAINED YIELD	
BOTTLE NUMBER	Q-9	YIELD MEAS METHOD	
DATE SAMPLED	19-JUN-86	TOTAL DEPTH OF WELL	
TIME SAMPLED	14:10 HOURS	SWL ABOVE(-) OR BELOW GS	
LAB + ANALYST	MBMG*WO	CASING DIAMETER	
DATE ANALYZED	13-AUG-86	CASING TYPE	
SAMPLE HANDLING	3220	COMPLETION TYPE	*
METHOD SAMPLED	GRAB	PERFORATION INTERVAL	
WATER USE	UNUSED		

SAMPLING SITE
GEOLOGIC SOURCE ALLUVIUM (QUATERNARY)

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	158.	7.88	BICARBONATE (HCO3)	0.	
MAGNESIUM (MG)	110.	9.05	CARBONATE (CO3)	0.	
SODIUM (NA)	727.	31.62	CHLORIDE (CL)	6.9	0.19
POTASSIUM (K)	12.6	0.32	SULFATE (SO4)	2354.	49.01
IRON (FE)	.006	0.00	NITRATE (AS N)	.02	0.00
MANGANESE (MN)	.24	0.01	FLUORIDE (F)	4.1	0.22
SILICA (SIO2)	37.5		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		48.89	TOTAL ANIONS		49.42

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA)

CALCULATED DISSOLVED SOLIDS		TOTAL HARDNESS AS CACO3	847.29
SUM OF DISS. CONSTITUENT		TOTAL ALKALINITY AS CACO3	
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	4452.	RYZNAR STABILITY INDEX	
FIELD PH		LANGLIER SATURATION INDEX	
LABORATORY PH	4.53	SODIUM ADSORPTION RATIO	10.87

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP, AIR	86. F		
ALUMINUM, DISS (UG/L-AL)	3080.	NICKEL,DISS (UG/L AS NI)	120.
SILVER, DISS(UG/L AS AG)	<2.	PHOSPHATE,TO,DIS(MG/L-P)	<.1
BORON,DISS (UG/L AS B)	1140.	STRONTIUM,DISS (UG/L-SR)	2370.
CADMIUM,DISS(UG/L AS CD)	3.	TITANIUM DIS(UG/L AS TI)	9.
CHROMIUM, DISS (UG/L-CR)	2.	VANADIUM,DISS(UG/L AS V)	<1.
COPPER,DISS (UG/L AS CU)	<2.	ZINC, DISS (UG/L AS ZN)	260.
LITHIUM,DISS(UG/L AS LI)	1160.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	<20.	O-PHOSPHATE,DISS(MG/L-P)	.8
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.1
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	.5

LAB: EST H+ .03, AL 3.08, SR 2.37 MG/L GIVES 49.3 MEQ/L CATIONS FOR .14
LAB: SIGMA *

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER, FT = FEET, MT = METERS, (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED, TR = TOTAL RECOVERABLE, TOT = TOTAL, BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 27-AUG-86
PROCESSING PROGRAM: F1730P V3 (09/1/83)

COST:
BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
16.1	18.5	64.7	0.7	0.4	99.6	0.0	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86R0577

SAMPLE SITE G-8

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE,MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO. 86Q0573

STATE MONTANA
LATITUDE-LONGITUDE 48D51'06"N 108D28'54"W
UTM COORDINATES Z N E
TOPOGRAPHIC MAP ROUNDUP
GEOLOGIC SOURCE 211CLRD*111CLVM* *
DRAINAGE BASIN EC
AGENCY + SAMPLER MSU *AS
BOTTLE NUMBER R-1
DATE SAMPLED 20-JUN-86
TIME SAMPLED 16:10 HOURS
LAB + ANALYST MBMG*WO
DATE ANALYZED 06-AUG-86
SAMPLE HANDLING 3220
METHOD SAMPLED GRAB
WATER USE UNUSED

COUNTY PETROLEUM
SITE LOCATION 13N 26E 30 CCC 01
MBMG SITE
STATION ID 485106108285401
SAMPLE SOURCE SPRING
LAND SURFACE ALTITUDE 3371. FT < 10
SUSTAINED YIELD
YIELD MEAS METHOD
TOTAL DEPTH OF WELL
SWL ABOVE(-) OR BELOW GS
CASING DIAMETER
CASING TYPE
COMPLETION TYPE *
PERFORATION INTERVAL

SAMPLING SITE
GEOLOGIC SOURCE COLORADO SHALE OR FORMATION (OF COLORADO GROUP)

	MG/L	MEQ/L		MG/L	MEQ/L
CALCIUM (CA)	388.	19.36	BICARBONATE (HCO3)	110.2	1.81
MAGNESIUM (MG)	1307.	107.52	CARBONATE (CO3)	0.	
SODIUM (NA)	2076.	90.31	CHLORIDE (CL)	41.6	1.17
POTASSIUM (K)	23.3	0.60	SULFATE (SO4)	10360.	215.70
IRON (FE)	.002	0.00	NITRATE (AS N)	.02	0.00
MANGANESE (MN)	.060	0.00	FLUORIDE (F)	6.6	0.35
SILICA (SIO2)	9.0		PHOSPHATE TOT (AS P)		
TOTAL CATIONS		217.79	TOTAL ANIONS		219.02

STANDARD DEVIATION OF ANION-CATION BALANCE (SIGMA) 0.38

CALCULATED DISSOLVED SOLIDS	14265.87	TOTAL HARDNESS AS CACO3	6348.45
SUM OF DISS. CONSTITUENT	14321.78	TOTAL ALKALINITY AS CACO3	90.38
FIELD CNDUCTVY, MICROMHOS		FIELD ALKALINITY AS CACO3	
LAB CNDUCTVY, MICROMHOS	12857.	RYZNAR STABILITY INDEX	7.31
FIELD PH		LANGLIER SATURATION INDEX	-0.41
LABORATORY PH	6.50	SODIUM ADSORPTION RATIO	11.34

PARAMETER	VALUE	PARAMETER	VALUE
FIELD TEMP. AIR	82. F		
ALUMINUM, DISS (UG/L-AL)	150.	NICKEL,DISS (UG/L AS NI)	200.
SILVER, DISS(UG/L AS AG)	8.	PHOSPHATE,TO,DIS(MG/L-P)	<.1
BORON,DISS (UG/L AS B)	220.	STRONTIUM,DISS (UG/L-SR)	5670.
CADMIUM,DISS(UG/L AS CD)	8.	TITANIUM DIS(UG/L AS TI)	18.
CHROMIUM, DISS (UG/L-CR)	5.	VANADIUM,DISS(UG/L AS V)	12.
COPPER,DISS (UG/L AS CU)	29.	ZINC, DISS (UG/L AS ZN)	120.
LITHIUM,DISS(UG/L AS LI)	1530.	ZIRCONIUM DIS(UG/L - ZR)	<4.
MOLYBDENUM,DISS(UG/L-MO)	<20.	O-PHOSPHATE,DISS(MG/L-P)	.1
BROMIDE,DISS(MG/L AS BR)	<.1	ARSENIC,DISS(UG/L AS AS)	.1
MERCURY,DISS(UG/L AS HG)	<.04	SELENIUM, DISS (UG/L-SE)	6.1

EXPLANATION: MG/L = MILLIGRAMS PER LITER, UG/L = MICROGRAMS PER LITER, MEQ/L = MILLIEQUIVELENTS PER LITER. FT = FEET, MT = METERS. (M) = MEASURED, (E) = ESTIMATED, (R) = REPORTED. TR = TOTAL RECOVERABLE. TOT = TOTAL. BIO = BIOLOGICALLY AVAILABLE.

OTHER AVAILABLE DATA QW WA S2 WI OW PW AT OTHER
OTHER FILE NUMBERS:

PROJECT:
LAST EDIT DATE: 05-SEP-86
PROCESSING PROGRAM: F1730P V3 (09/1/83)

COST:
BY: TP *BCS
PRINTED: 05-SEP-86

PERCENT MEQ/L (FOR PIPER PLOT)

CA	MG	NA	K	CL	SO4	HCO3	CO3
8.9	49.4	41.5	0.3	0.5	98.6	0.8	0.0

NOTE: IN CORRESPONDENCE, PLEASE REFER TO LAB NUMBER: 86Q0573

APPENDIX C

STANDARD METHODS OF ANALYSIS AS APPLIED TO THE STUDY AREAS

STANDARD METHODS OF ANALYSIS

There are several standardized methodologies currently in use for evaluating a potential hazardous waste disposal site. Each method considers a set of factors for multiple sites in a systematic and objective manner and is designed to be used as a screening mechanism prior to more intensive investigations. These models are useful for assessing large geographical regions for areas that may contain suitable sites and for comparative purposes.

Each of the three study areas was evaluated using the two models: the LeGrand Standardized System for Evaluating Waste Disposal Sites (LeGrand 1983), and DRASTIC: a Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings (Aller and others 1985). The following discussion addresses the usefulness of the two models and presents the application each system to the three areas in this study.

THE LEGRAND STANDARDIZED SYSTEM FOR EVALUATING WASTE DISPOSAL SITES

This method of evaluation was developed by Harry LeGrand in 1983 to assess the relative suitability of multiple sites. It considers major factors for hydrogeologic suitability systematically and objectively and is designed to be used as a screening mechanism prior to more intensive investigation. Its function in this report is as a means to compare the Montana study areas with existing sites outside the state.

There are eight major hydrogeologic factors considered in the LeGrand method of site analysis. For every area under consideration each of the LeGrand factors are evaluated for site suitability characteristics. Each factor is then assigned a numerical value that reflects its suitability rating and its relative influence on leachate migration. The final rating is a single number that represents the potential for contamination of groundwater and surface water.

An ideal site will have a LeGrand rating of -16. In the case of a hazardous waste landfill, no ideal sites are possible, any candidate site has its limitations. The LeGrand factors are as follows:

distance: The distance between contamination source and a point of water use such as a well or stream,

depth to water table: the recommended depth to water table is a function of rock type, local topography, climate and infiltration capacity. Many contaminants can attenuate completely or partially in the unsaturated zone so a long distance between site base and usable groundwater is a desirable feature,

water table gradient influences the rate and direction of flow. It is important to know whether a contaminant is moving toward or away from a water supply and at what speed,

permeability of the rocks immediately underlying the site. Shales and clay soils serve as the second line of defense against leachate migration should the protective system engineered around the waste site breakdown. Clays are best suited to host a hazardous waste landfill because of their low permeabilities and affective sorptive capacities,

vertical fractures in bedrock can serve as conduits for undiluted waste. Unfortunately depth and lateral extent of fracturing is often difficult to determine,

extensive usable aquifers situated in the path of a potential leachate plume are undesirable features for site evaluation,

lithology of an aquifer underlying a potential site can be described in terms of its hydrologic characteristics.

waste type is a consideration for contamination potential at a landfill. This is because the dangerous and persistent nature of hazardous compounds relative to that of most waste in a city landfill, for example, increases the risk for contamination.

Based on these eight primary criteria, each of the three study areas is rated with a single number that represents the potential for contamination of ground or surface water. A low rating signifies a low potential for contamination.

Area 1. Sumatra-Ingomar

Based on LeGrand analysis, this area appears to be hydrogeologically best suited to host a hazardous waste disposal facility. The Sumatra - Ingomar Area exhibits the following characteristics:

Distances on ground from possible site locations to a point of water use exceed 6200 feet for more than 90 percent of the study area for greater than five percent of the year.

Depth to water table of usable groundwater is greater than 200 feet for the recommended area (that part of Area 1 underlain by Bearpaw Shale).

Gradient of the nearest usable groundwater aquifer (the Judith River Formation) is approximately one to two percent. No water supply exists within 200 feet of 90 percent of the recommended area.

Unconsolidated materials over bedrock is clay with no more than 50 percent sand.

Thickness of unconsolidated bedrock is less than nine feet.

Extent of the nearest usable aquifer is great.

Sensitivity of nearest usable aquifer is low because of the thickness and low permeability of the overlying stratigraphy.

The degree of seriousness of the waste is high.

LeGrand Description:	3	0003CF	
LeGrand Par Value:	-16	3	
	-13+	0 =	-13

Area 2. Roundup-Winnett

Based on LeGrand analysis, this area appears to be marginally suited to host a hazardous waste disposal facility. The Roundup-Winnett Area exhibits the following hydrogeologic characteristics:

Distances on ground from possible site locations to a point of water use exceed 6200 feet for more than 80 percent of the recommended study area (that part of the area directly underlain by the Niobrara and the Carlile Members of the Colorado Shale) for greater than five percent of the year.

Depth to water table of usable groundwater is greater than 200 feet for greater than 80 percent of the recommended area. Gradient of the nearest usable groundwater aquifer (the First Cat Creek Sand) ranges from flat to greater than two percent. No water supply exists within 200 feet of 90 percent of the recommended area.

Unconsolidated materials over bedrock is clay with no more than 50 percent sand.

Thickness of unconsolidated bedrock is less than nine feet.

Extent of the nearest usable aquifer is moderate.

Sensitivity of nearest usable aquifer is low because of the thickness and low permeability of the overlying stratigraphy.

The degree of seriousness of the waste is high.

LeGrand Description for the Winnett - Roundup Area if bedrock is highly fractured: 10 0028CI

LeGrand Par Value: $\frac{10 \quad 3}{0+ \quad 5} = \underline{+5}$

if bedrock is not fractured or if vertical cracks are surficial features only: 5 0023CH

$\frac{-12 \quad 1}{-7+ \quad 2} = \underline{-5}$

Area 3. Denton-Lewistown

At a LeGrand rating of +12 in fractured bedrock this area appears to be hydrogeologically unsuitable for hazardous waste disposal. The limiting factor in Area 3 is land use which can be expressed in terms of distance from source of contaminant to a point of water use in terms of LeGrand characteristics.

The Denton - Lewistown Area exhibits the following characteristics:

Over 1/2 the land in Area 3 is farmland. This translates into distances of less than 250 feet to a point of water use for 72% of the area; an unsuitable characteristic for landfill siting.

Depth to water table of usable groundwater is greater than 200 feet for the recommended area (that part of Area 3 underlain by Colorado Shale).

Gradient of the nearest usable groundwater aquifer (the First Cat Creek Sand) is approximately one to two percent towards a water supply within 3000 feet of the recommended area.

Unconsolidated materials over bedrock is clay with no more than 50 percent sand.

Thickness of unconsolidated bedrock is less than nine feet.

Extent of the nearest usable aquifer is moderate.

Sensitivity of nearest usable aquifer is low because of the thickness and low permeability of the overlying stratigraphy.

The degree of seriousness of the waste is high.

LeGrand Description if underlying bedrock in the area is highly fractured: 15 5028CI

LeGrand Par Value: $\frac{-10 \quad 1}{+\,5+ \quad 7} = \underline{+12}$

LeGrand Description if underlying bedrock in the recommended area is unfractured or if cracks are only surficial features:

10 5023CH

$\frac{-12 \quad 3}{-\,2+ \quad 0} = \underline{-2}$

In conclusion, using the LeGrand method, this preliminary study found the Sumatra-Ingomar area to have suitable hydrogeologic characteristics for landfill hazardous waste disposal.

fractured bedrock (circle)

unfractured bedrock (square)

DENTON- LEWISTOWN AREA

Step 1

Determine the distance on ground between contamination source and water supply

Point value	0	1	2	3	4	5	6	7	8	9
Distance in meters	2000+	1000-2000	300-999	150-299	75-149	50-74	35-49	20-34	10-19	0-9
Distance in feet	6200+	3100-6200	1001-3100	501-1000	251-500	161-250	101-160	61-100	31-60	0-30

Step 2

Estimate the depth to the water table below base of contamination source more than 5% of the year.

Point value	0	1	2	3	4	5	6	7	8	9
Meters	60+	30-60	20-29	12-19	8-11	5-7	3-4	1.5-2.5	.5-1	0
Feet	200+	91-200	61-90	36-60	26-35	16-25	9-15	3-8	0-2	0

Step 3

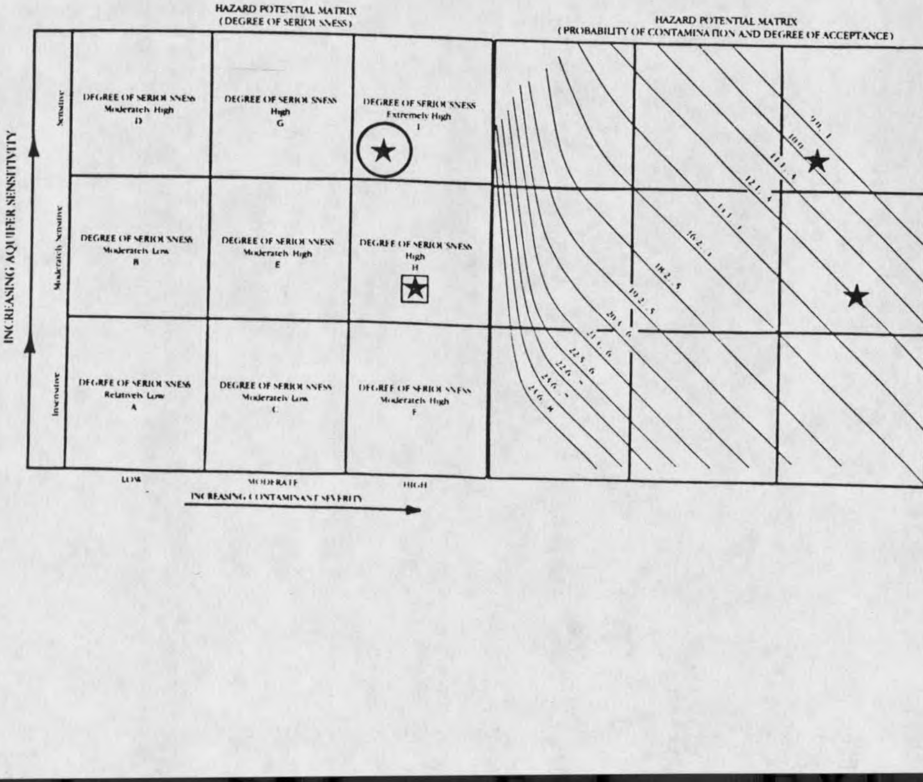
Estimate water table gradient from contamination site

Point value	0	1	2	3	4	5
Water table gradient and flow direction	Gradient away from all water supplies that are closer than 1000 meters	Gradient almost flat	Gradient less than 2 percent toward water supply but not the anticipated direction of flow	Gradient less than 2 percent toward water supply and is the anticipated direction of flow	Gradient greater than 2 percent toward water supply but not the anticipated direction of flow	Gradient greater than 2 percent toward water supply and is the anticipated direction of flow

Step 4

THICKNESS OF UNCONSOLIDATED MATERIALS OVER BEDROCK, IN METERS / THICKNESS IN FEET

	Clay(1)		Clay with no more than 50% sand		Sand with 15-30% clay		Sand with less than 15% clay		Clean fine sand		Clean gravel or course sand		
More than 30	0A(2)		2A		4A		6A		8A		9A		More than 95
	I(3)	II(4)	I	II	I	II	I	II	I	II	I	II	
25-29	0B	1C	1D	2F	3E	4G	5F	6E	7F	8E	9G	9M	75-94
20-24	0C	2C	1E	3D	4D	5E	5G	6F	7G	8F	9H	9N	60-74
15-19	0D	3B	1F	4C	4E	6C	5H	7D	7H	8G	9I	9O	46-59
10-14	0E	4B	2D	5B	4F	6D	5I	7E	7I	9D	9J	9P	28-45
3- 9	1B	6B	2E	7B	5C	7C	5J	8D	7J	9E	9K	9Q	10-27
Less than 3	2B	8B	3C	8C	5D	9B	5K	9C	7K	9F	9L	9R	Less than 10
Bedrock at land surface: I = 5Z, II = 9Z													



○ fractured bedrock

□ unfractured bedrock

ROUNDUP-WINNETT AREA

Step 1

Determine the distance on ground between contamination source and water supply

Point value	0	1	2	3	4	5	6	7	8	9
Distance in meters	2000+	1000-2000	300-999	150-299	75-149	50-74	35-49	20-34	10-19	0-9
Distance in feet	6200+	3100-6200	1001-3100	501-1000	251-500	161-250	101-160	61-100	31-60	0-30

Step 2

Estimate the depth to the water table below base of contamination source more than 5% of the year.

Point value	0	1	2	3	4	5	6	7	8	9
Meters	60+	30-60	20-29	12-19	8-11	5-7	3-4	1.5-2.5	.5-1	0
Feet	200+	91-200	61-90	36-60	26-35	16-25	9-15	3-8	0-2	0

Step 3

Estimate water table gradient from contamination site

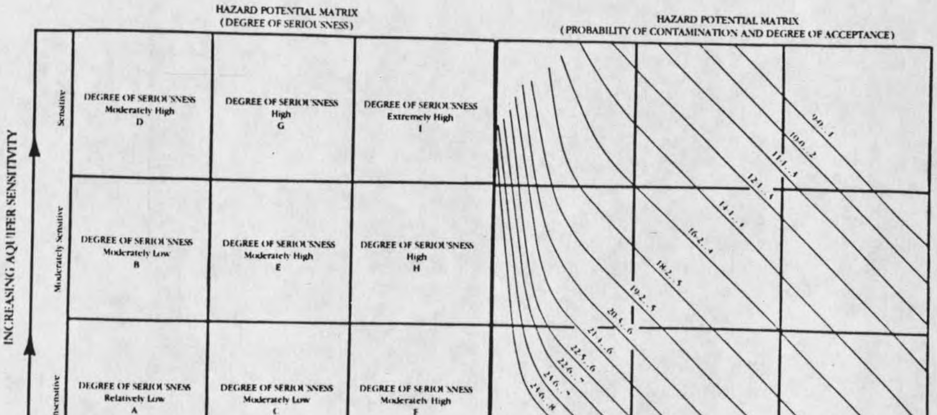
Point value	0	1	2	3	4	5
Water table gradient and flow direction	Gradient away from all water supplies that are closer than 1000 meters	Gradient almost flat	Gradient less than 2 percent toward water supply but not the anticipated direction of flow	Gradient less than 2 percent toward water supply and is the anticipated direction of flow	Gradient greater than 2 percent toward water supply but not the anticipated direction of flow	Gradient greater than 2 percent toward water supply and is the anticipated direction of flow

Step 4

THICKNESS OF UNCONSOLIDATED MATERIALS OVER BEDROCK, IN METERS

	Clay(1)		Clay with no more than 50% sand		Sand with 15-30% clay		Sand with less than 15% clay		Clean fine sand		Clean gravel or coarse sand		
More than 30	0A(2)		2A		4A		6A		8A		9A		More than 95
	I(3)	II(4)	I	II	I	II	I	II	I	II	I	II	
25-29	0B	1C	1D	2F	3E	4G	5F	6E	7F	8E	9G	9M	75-94
20-24	0C	2C	1E	3D	4D	5E	5G	6F	7G	8F	9H	9N	60-74
15-19	0D	3B	1F	4C	4E	6C	5H	7D	7H	8G	9I	9O	46-59
10-14	0E	4B	2D	5B	4F	6D	5I	7E	7I	9D	9J	9P	28-45
3- 9	1B	6B	2E	7B	5C	7C	5J	8D	7J	9E	9K	9Q	10-27
Less than 3	2B	8B	3C	8C	5D	9B	5K	9C	7K	9F	9L	9R	Less than 10
Bedrock at land surface; I = 5Z, II = 9Z													

THICKNESS IN FEET



SUMATRA*INGOMAR AREA

Step 1

Determine the distance on ground between contamination source and water supply

Point value	0	1	2	3	4	5	6	7	8	9
Distance in meters	2000+	1000-2000	300-999	150-299	75-149	50-74	35-49	20-34	10-19	0-9
Distance in feet	6200+	3100-6200	1001-3100	501-1000	251-500	161-250	101-160	61-100	31-60	0-30

Step 2

Estimate the depth to the water table below base of contamination source more than 5% of the year.

Point value	0	1	2	3	4	5	6	7	8	9
Meters	60+	30-60	20-29	12-19	8-11	5-7	3-4	1.5-2.5	.5-1	0
Feet	200+	91-200	61-90	36-60	26-35	16-25	9-15	3-8	0-2	0

Step 3

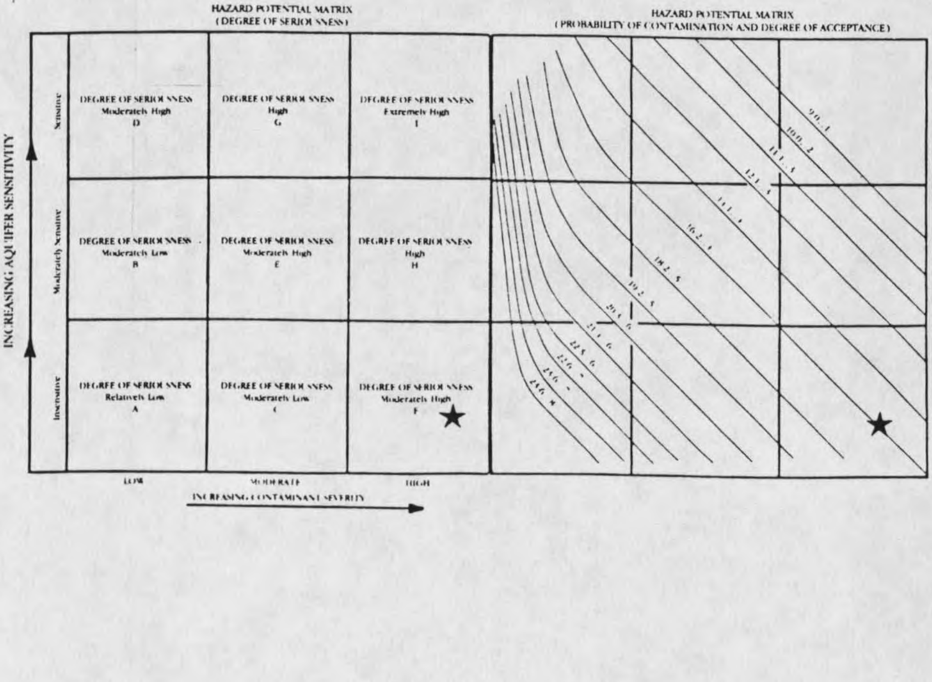
Estimate water table gradient from contamination site

Point value	0	1	2	3	4	5
Water table gradient and flow direction	Gradient away from all water supplies that are closer than 1000 meters	Gradient almost flat	Gradient less than 2 percent toward water supply but not the anticipated direction of flow	Gradient less than 2 percent toward water supply and is the anticipated direction of flow	Gradient greater than 2 percent toward water supply but not the anticipated direction of flow	Gradient greater than 2 percent toward water supply and is the anticipated direction of flow

Step 4

THICKNESS OF UNCONSOLIDATED MATERIALS OVER BEDROCK IN METERS / THICKNESS IN FEET

	Clay(1)		Clay with no more than 50% sand		Sand with 15-30% clay		Sand with less than 15% clay		Clean fine sand		Clean gravel or course sand		
More than 30	0A(2)		2A		4A		6A		8A		9A		More than 95
	I(3)	II(3)	I	II	I	II	I	II	I	II	I	II	
25-29	0B	1C	1D	2F	3E	4G	5F	6E	7F	8E	9G	9M	75-94
20-24	0C	2C	1E	3D	4D	5E	5G	6F	7G	8F	9H	9N	60-74
15-19	0D	3B	1F	4C	4E	6C	5H	7D	7H	8G	9I	9O	46-59
10-14	0E	4B	2D	5B	4F	6D	5I	7E	7I	9D	9J	9P	28-45
3- 9	1B	6B	2E	7B	5C	7C	5J	8D	7J	9E	9K	9Q	10-27
Less than 3	2B	8B	3C	8C	5D	9B	5K	9C	7K	9F	9L	9R	Less than 10
Bedrock at land surface: I = 5Z, II = 9Z													



DRASTIC: A STANDARDIZED SYSTEM FOR EVALUATING GROUNDWATER POLLUTION POTENTIAL USING HYDROGEOLOGIC SETTINGS

DRASTIC is named for its factors of evaluation: Depth to water table, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and hydraulic Conductivity of the aquifer (Aller 1985). DRASTIC was developed by the National Water Well Association and the EPA. It is a ranking system that uses a combination of weights and ratings to produce a numerical value that is an indication of groundwater contamination vulnerability. The DRASTIC system is probably most useful when evaluating a multi-state region in the eastern part of the U.S. for groundwater pollution potential rather than the more specific regions examined in this study. For several reasons the author did not find DRASTIC as useful as the LeGrand method for this investigation.

The regional maps designed to be used in conjunction with DRASTIC analysis produce results which are somewhat generalized for the scale of the areas evaluated in this study. All three study areas, for example, lie within a single hydrogeologic region as defined by DRASTIC. There are actually several major aquifers exposed in this region and several very different hydrogeologic settings. Therefore, conclusions drawn from analysis based on such highly generalized material could easily be incorrect.

Another major factor for DRASTIC analysis (topography) appears to be designed to fit more humid conditions and could not be applied to Montana without changing the model. The DRASTIC system rates areas as less vulnerable to groundwater pollution if they have slopes greater than 18°. Steep slopes tend to compel escaping leachate to become surface runoff rather than infiltrating leachate; this is desirable only if (1) usable groundwater is immediately threatened by a leachate plume and not if the nearest usable groundwater is 1000 feet below surface as is often the case in the semi-arid west, and if (2) one has a great deal of faith in the leachate protection and monitoring system engineered for each site. Also areas of high relief tend to be geomorphically unstable because of higher mass movement and stream erosion rates, an undesirable feature of a hazardous waste disposal site.

Finally, net recharge, another of DRASTIC's seven major factors for analysis is difficult to determine unless a detailed site-specific evaluation is made. While precipitation and evaporation is known, net recharge is poorly known. An example of this problem is saline seep in

Montana where significant recharge can occur simply in response to changing agricultural practice. The DRASTIC model provides generalized recharge values which are too regional and inexact to be useful.

DRASTIC EVALUATION

Area 1. Sumatra-Ingomar

Factor	Value	Rating	Weight
Depth to water table			
for aquifer	100+ ft.	1	5
for perched watertable	0-5 ft.	10	5
Net Recharge			
deep confined aquifer			
without fractures	0-2 in.	1	4
with fractures	2-4 in.	3	4
perched water	4-7 in.	6	4
Aquifer Media			
deep aquifer	ss/sh	6	3
perched	sh	2	3
Soil Media			
clay loam		3	2
silty loam		4	2
silty clay		7	2
thin or absent		10	2
Topography			
0-2% slope		10	1
Impact of Vadose Zone			
deep aquifer (fractured	sh	5	5
deep aquifer (unfractured)	ss	2	
perched	silt/claly	1	5
Hydraulic Conductivity of the aquifer			
deep aquifer (unfractured)	100-300	2	3
perched	1-100	1	3

Area 1. Sumatra-Ingomar DRASTIC Scenarios

rating

1. Perched water table in a clay loam/silty clay soil media or thin or absent soils............104-118
   Probable value.................................106

2. Deep aquifer without fracures in confining layers................................56-73
   Probable value (depending on soil type and K......61

3. Deep aquifer with fractures in confining layers:72-90
   Probable value.................................84

The Sumatra-Ingomar Area has a range of 61-106 for DRASTIC final values.

Area 2. Roundup-Winnett

Factor	Value	Rating	Weight
Depth to water table			
Cat Creek aquifer	100+ ft.	1	5
Perched water table	0-5 ft.	10	5
Net Recharge			
Cat Creek aquifer	0-2	1	4
Perched water table	4-7	6	4
Aquifer Media			
Cat Creek aquifer (thin bedded sandstone)		7	3
Perched water table (shales and sandstone)		5	3
Soil Media			
Thin to absent soils		10	2
clay loams		3	2
Topography			
	0-2%	10	1
	2-6%	9	1
Impact of Vadose Zone			
Cat Creek (unfractured vadose zone)			
silt/clay		1	5
bedded ls,ss,sh		5	5
Cat Creek (fractured vadose zone)		8	5
Perched water table			
silt/clay		1	5
Hydraulic Conductivity of the aquifer			
Cat Creek aquifer	100-300	2	3
Perched water table	0-100	1	3

Area 2. Roundup-Winnett DRASTIC Scenarios

1. Cat Creek aquifer, low slope (0-6%), unfractured vadose zone. shrinking clay soil and vadose zone material of bedded ls, sh, and ss.................57-89
   probable value..80

2. Cat Creek aquifer, fractured vadose zone..........91-120
   probable value..100

3. Perched water table..............................112-137
   probable value..125

The Roundup-Winnett Area has a range of 80-125 for DRASTIC final values.