INFORMATION SERIES 14

HAZARDOUS WASTES in COLORADO

A PRELIMINARY EVALUATION OF GENERATION AND GEOLOGIC CRITERIA FOR DISPOSAL

by Jeffrey L. Hynes and
Christopher J. Sutton

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
AND
COLORADO DEPARTMENT OF HEALTH
DENVER, COLORADO 1980

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EXECUTIVE SUMMARY

A major side effect of our technology-oriented society is the need to provide secure disposal of hazardous wastes. Across the nation it has been realized that the indiscriminate dumping of toxic materials will eventually create disastrous consequences including widespread groundwater contamination and other critical public health hazards. In 1979, the Colorado General Assembly ordered a study of this problem in Colorado in order to assess the hazardous waste disposal situation in the State.

The Colorado Department of Health began and is continuing to inventory industrial waste generation in the State. Potential generators of hazardous waste in the State, including those with fewer than ten employees, were sent questionnaires. A total of 1562 questionnaires were distributed and 955 or 61 percent thus far have been returned. Ninety two percent (92%) of the firms with greater than 250 employees responded; thus, the reported figures represent at least the minimum quantity of wastes generated in Colorado.

More than 855,000 tons of potentially hazardous wastes are generated annually in the State. Approximately 86,000 tons (or about 10 percent) would be considered extremely hazardous due to their inherent characteristics. Over 402,000 tons of the reported wastes are considered to be bulk, low toxicity wastes. 99.7 percent of the total industrial waste stream is generated along the Front Range and almost 40 percent (or about 313,000 tons), is generated in Region 3 which includes the Denver metro area and Clear Creek and Gilpin Counties.

Final disposition of hazardous wastes currently includes: 1) landfilling at inadequately designed facilities, the most common disposal method; 2) storage/disposal on-site; 3) landfarming/recycling/reclaiming, and 4) incineration at private facilities.

The information collected thus far provides a good beginning for developing a hazardous waste management program in Colorado. The results of the survey indicate:

- That a hazardous waste disposal site is urgently needed in the State to properly dispose of hazardous wastes without creating serious public health problems.

- That the large majority of hazardous wastes generated in Colorado are presently being disposed of at inadequately designed landfills and serious environmental consequences may result from this practice. Steps should be taken immediately to alleviate this situation.

- That inspection and subsurface monitoring should be performed at those existing sites determined to have the greatest potential for environmental contamination and clean-up measures should begin.

- That at least one hazardous waste facility, if any are constructed, should be located along the Front Range within reasonable access to the metropolitan areas.

- That a waste exchange program may be a viable option in Colorado considering the volume of wastes generated in the State. The technology is presently available for the recycling, reclaiming and reuse of certain wastes and these alternate approaches should be actively encouraged.

Long-term secure burial, which isolates these wastes from the human environment, is presently the most efficient and cost effective disposal method available. Evaluation of a site for such use should include the collection of extensive hydrologic, geologic, and physiographic data on the particular site and the following criteria should be followed in this selection process:

- Contaminants from waste disposal sites should not degrade ground or surface water quality. The wastes must be separated from groundwater aquifers by no less than 150 vertical feet of strata whose average permeability is less than 10^{-7} cm/sec.

- Disposed hazardous wastes should be at least one mile from the probable maximum floodplain of perennial surface waters.

- Sites should be located in suitable geologic strata including the Pierre, Mancos, Lewis, and San Jose formations in the State. These formations comprise large areal extents of thick, homogeneous, relatively impermeable shale or claystone.

- Disposed wastes should be placed in excavations developed completely within the bedrock units and sealed from overlying surficial material with an engineered, impermeable cap.

- The location should be in seismically and structurally sound areas and isolated from geologic hazards and erosional problems associated with extremes in slope, wind conditions, precipitation, and runoff.

- The ultimate suitability of any formation will be dependent upon the geochemical reactions between the clay-rich host rock and the wastes received.

This report represents a statewide evaluation of geologic formations which may be suitable for location of a hazardous waste disposal facility. Several areas of the State contain sites that would suitably meet the stringent criteria for disposal of hazardous wastes. (See enclosed map for the distribution of the geographically suitable areas of the State). Guidelines are also presented to aid in the preparation and review of acceptable engineering reports required on any proposed site.

Finally, the legislature required a study of the legal ramifications of legislation which would maintain hazardous waste disposal sites for the exclusive use of wastes originating in Colorado. There has been an entire series of U.S. Supreme Court cases which are closely analagous to the situation described. They demonstrate clearly that attempts by the State to either exclude outright the use of its hazardous wastes disposal facilities, or to exclude the use de facto by charging exorbitant fees to out-of-state users will be challenged and usually successfully.

Any proposed legislation must contain the specific facts as discussed below to withstand constitutional scrutiny.

1) For outright exclusion, the legislation should include facts which demonstrate that the movement of hazardous wastes over long distances is inherently dangerous to the health and safety of the people of the State. The chances of successful exclusion are enhanced greatly if the extreme danger involved is stressed and in-state disposers of hazardous waste are distinguished by their proximity to the site rather than by their residency in the State.

2) Exclusion through the use of differential fees may be possible if it can be shown conclusively that the fee distinction is imposed as a partial cost equalization. Obviously the larger the difference in fees between in-state and out-of-state users, the greater is the burden on the State to justify the differentiation.

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I. HAZARDOUS WASTE GENERATION IN COLORADO

INTRODUCTION

The proper management of hazardous waste has become an ever increasing concern throughout the nation. Serious incidents, such as the Love Canal situation in Buffalo, New York, and the recent discovery of a large quantity of polychlorinated biphenyls (PCB) near Boulder, Colorado, demonstrate dramatically the need for complete control and secure containment of toxic materials requiring disposal.

Because the extent of the problem in Colorado was unknown, the legislature authorized the Department of Health to conduct a study of hazardous-waste disposal in the State. Senate Bill 336 appropriately deals with the collection of information to establish a data base from which informed decisions about hazardous wastes can be made.

The goal of the survey was to estimate the quantities and types of potentially hazardous wastes generated by industry. Generation, rather than disposal, was the subject of the survey because that information is needed to determine sound hazardous-wastes management policies. If an in-state chemical-waste facility is available for legal and secure disposal, it will almost certainly be used by industry if only to minimize transportation and packaging costs.

Presently, all the potentially hazardous wastes generated in the State of Colorado are dealt with in one of the following ways:

1) They are disposed of at substandard or inadequately designed landfills and therefore may eventually present a serious environmental or ground water contamination problem;

2) They are transported out-of-state to one of several chemical waste landfills in this region, i.e. Idaho, Oklahoma, Kansas or Nevada;

3) They are reclaimed for reuse or are recycled in some manner;

4) They are stored on site for possible future reclamation or disposal; or

5) An unknown quantity is dumped into sanitary sewers or disposed of by other illegal methods.

High packaging, transportation and final disposal costs prohibit the large majority of companies from using the out-of-state disposal means. Therefore, many companies are forced to dispose of their hazardous wastes at sanitary landfills not capable of permanently containing these materials.

A hazardous-waste-management program should be established to guide and control the final disposal of such materials in Colorado. The program should also include identifying and evaluating those existing sanitary landfills in the state previously used for hazardous waste and which have serious potential for causing serious future environmental damage.

Definition

A hazardous waste is any waste, or combination of wastes, that presents or creates potential dangers to human health and safety or to living organisms in the environment.

Those characteristics of a material that the EPA uses to determine if a waste is hazardous are flammability, corrosivity, reactivity, toxicity, infectiousness, and radioactivity. The major concerns of waste disposal sites would be fire and explosions with flammables, leaking containers with corrosives, explosions with reactive chemicals, health hazards and environmental contamination from toxic wastes, materials contaminated with infectious organisms, and radioactive materials.

The Federal Resource Conservation and Recovery Act of 1976 (RCRA) defined a hazardous waste as:

"A solid waste or combination of solid wastes, which because of its quantity, concentration, or physical, chemical or infectious characteristics may:

(a) Cause or significantly contribute to an increase in mortality or increase in serious irreversible or incapacitating reversible illness; or

(b) Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed."

Some examples of hazardous industrial materials include sludges containing heavy metal salts; acid baths; electroplating solutions; contaminated solvents; and halogenated hydrocarbons.

Regulation

There is presently no agency in the State of Colorado authorized to regulate the movement or disposal of hazardous wastes. Some legislative authority is needed for the Colorado Department of Health to administer a comprehensive waste-management program consistent with RCRA requirements.

The two pieces of existing State legislation which attempt to control waste disposal and transportation of hazardous materials are the "Solid Waste Disposal Sites and Facilities Act", Title 30, Article 20, Part I, and Senate Bill 121, "Concerning the Transportation of Hazardous Materials". However, these laws are not specifically designed to manage the handling of industrial hazardous waste materials in the State.

At the federal level, there is the Resource Conservation and Recovery Act of 1976 (RCRA) and the Toxic Substances Control Act (TSCA). Under TSCA, the Environmental Protection Agency is mandated to identify chemicals that may pose unreasonable risks to human health and the environment and initiate action to reduce such risks.

RCRA is designed to establish "cradle to grave" control over all hazardous wastes generated by industry. The implementation of the program is the responsibility of the EPA, but Congress recognized that the program would be enforced best at the State level. If the State declines to accept the responsibility, the federal agencies would subsequently be responsible for regulating the activities within the State.

The Survey

The Colorado legislature recognized the need for more information on the hazardous waste problem in Colorado and passed Senate Bill 336 which requested that "a statewide study of disposal of hazardous wastes be conducted by the Department of Health (which) is necessary prior to enactment of specific legislation governing the disposal of such wastes."

The Division of Radiation and Hazardous Wastes Control performed a statewide survey to determine the magnitude of the hazardous waste problem in Colorado and to develop a data base for a hazardous waste management program.

Senate Bill 336 was passed in July, 1979 and the legislature asked for a completed report by January 10, 1980. This allowed for approximately six months to design, distribute, collect, tabulate, and evaluate the survey and therefore the time element became one of the most important considerations in the process. A mailed questionnaire was used to collect data because of the advantage of quick response. The disadvantages of such a survey are discussed later.

The survey was designed to determine the amounts, types, composition, and current disposition of special industrial wastes, including on-site treatment and other management practices for disposal and/or handling of these wastes. Certain waste types were intentionally omitted from the survey. These included mining wastes, fly ash, foundry sand, slag, hospital wastes, and contaminated packagings. The reasons for excluding these are outlined in the discussion.

SUMMARY OF FINDINGS

A total of 1562 survey questionaires were distributed throughout the State and 61.5 percent response was received. A 92 percent response to the survey was obtained from the larger corporations, (those having more than 250 employees) canvassed in the survey. The following data were obtained from the responses to our survey.

1) Industry in Colorado generates more than 855,000 tons of potentially hazardous wastes per year. This figure includes liquid and solid wastes combined. See discussion for conversion information.

2) 99.7 percent of that total is generated in Regions 2, 3, 4, and 7 which make up the "Front Range" counties.

3) Region III consisting of Adams, Arapahoe, Boulder, Clear Creek, Denver, Douglas, Gilpin, and Jefferson Counties generated about 38.7 percent, or 313,000 tons, of the total hazardous wastes generated in the State.

4) More than 86,000 tons or approximately 10 percent of the hazardous wastes generated in Colorado can be considered extremely hazardous, and because of their characteristics would require special handling and containerization. Over 402,000 tons, 47 percent of the total waste stream, are large volume, low toxicity waste types which have been treated prior to disposal.

5) The major waste types generated in Colorado are acidic and brine solutions, sludges, contaminated waste water, and solvents. 48.3 million gallons of acidic wastes and 28.1 million gallons of brine solutions were reported as annual waste volumes. This represents 28.2 percent and 15.3 percent, respectively, of the State's total. Heavy metal sludges, oil sludges, and waste-water treatment sludges account for

115,600 tons or 13.4 percent of the waste stream. Rinse waters and other waste waters total 18.6 million gallons yearly (10.9 percent) and waste solvents amount to about 10 million gallons/year or 5.8% of the total waste generation.

6) Polychlorinated biphenyls (PCB's) are presently being accumulated in Colorado at a reported rate of about 42 tons per year. This includes liquid and contaminated solid wastes. This figure should begin to decline in the near future but, due to the widespread use of PCB in the past, these materials will continue to accumulate for many years to come. The EPA regulations for PCB disposal require that liquid wastes with greater than 500 ppm PCB, must be stored until adequate incineration facilities are available. Contaminated solid wastes can only be disposed of at EPA approved chemical waste landfills. All PCB materials therefore must presently be shipped out of state to chemical waste landfills in the region.

7) Current methods of final disposition for the hazardous materials of this study include: 1) land filling at disposal sites in the state, the most common disposal method; 2) transporting to out-of-state disposal sites; 3) storing/disposing on-site; 4) landfarming/recycling/reclaiming/treating; and 5) incineration at private facilities.

8) Treatment/reuse/recycling were reported in the survey to be responsible for a 30.1 percent reduction in quantities of hazardous wastes to be disposed.

9) Of 1562 industrial firms surveyed, 219 or 14 percent were found to contribute significantly to the hazardous waste stream produced in the State.

CONCLUSIONS AND RECOMMENDATIONS

1) There are no existing facilities designed for the disposal and "permanent containment" of the hazardous wastes generated in the State of Colorado. The large majority of such wastes are presently going to substandard facilities not designed to handle these wastes and therefore the potential exists for widespread contamination of groundwater and the environment throughout the State.

   A hazardous-waste-disposal site is needed immediately in Colorado to properly dispose of the large volumes of hazardous materials without creating a serious hazard. The Federal and/or State hazardous-waste management programs are about to take effect and will require the proper disposal of these materials. Unless a site is approved and made available these wastes will have to be shipped out-of-state to acceptable disposal facilities and this would impose considerable costs on industry in Colorado for transporation, packaging, and disposal.

2) Geographically the site(s) should be located along the Front Range urban corridor where 99.7 percent of these wastes are generated. A site should be located somewhere reasonably close to the Denver metropolitan area (Region III) where almost 40 percent of the total hazardous waste is generated. Whether a single site could handle the entire quantity would depend on the size, location, and facilities of the site.

3) Recycling, reclaiming, treatment, and reuse of certain wastes are presently able to reduce the quantities of hazardous wastes to be disposed of by 50 percent or more. Further use of these alternate approaches should be encouraged. The technology is available to reclaim solvents, and to re-refine waste oils. Waste oils are presently being reclaimed to a

certain extent, but no re-refining is occurring in the State. Solvents can be distilled and reused.

4) There are no existing commercially operated incinerators in Colorado. This means that highly toxic or carcinogenic organics, including all PCB liquid wastes, must be shipped out-of-state.

5) Hazaraous wastes are now and have been going to inadequately designed landfills and the potential exists for serious ground-water and other environmental pollution. Inspection and monitoring should be performed to determine which of these sites have the most serious potential for environmental contamination and steps should be taken to begin cleanup/ containment of these sites.

   Federal funding, "Superfund", is presently being considered in the U.S. Congress for these situations and steps should be taken to secure funding for cleanup efforts in Colorado.

6) A waste exchange program may be a viable possibility in Colorado considering the volume of wastes currently requiring disposal. Some steps might be taken to allow the Department of Health to promote such a program statewide through a private outlet(s). This type of program could reduce the volume of hazardous waste for disposal and provide companies with inexpensive raw materials.

DISCUSSION

The Survey

Several factors were considered to determine which industries should be surveyed to give the best possible estimate of the quantities of hazardous wastes generated in Colorado. The primary selection method arrived at was to contract with the University of Colorado Business Research Division to provide a list, by county, of all the companies registered in Colorado that have particular standard industrial classification (S.I.C.) codes. Their source was the 1979 edition of the Directory of Colorado Manufacturers, which they compile and publish.

The S.I.C. code selections were based on EPA studies showing the types of industry that have the greatest potential for generating hazardous wastes. Other industry types were added by the staff and the Hazardous Materials Subcommittee, if the industry was thought to contribute to the hazardous waste stream.

The list of industry types sampled included:

1) Chemicals and allied products
2) Petroleum refining and related industries
3) Rubber and miscellaneous plastics products
4) Primary metal industries
5) Fabricated metal products
6) Machinery except electrical
7) Electrical and electronic machinery equipment and supplies
8) Instrument measuring, analyzing, and controlling instruments, photographic medical and optical goods.

A list of approximately 1500 businesses was provided and surveys were sent to every business including those with fewer than 10 employees.

The remainder of the canvassed population was selected to estimate the quantity of hazardous wastes generated at other than industrial sites. Major hospitals, universities, and Federal and State facilities such as laboratories, across the State were asked to respond to surveys. Lastly, other businesses and groups, that were initially overlooked, were sent questionnaires. These included public utilities, tanneries, paint stripping shops, and so forth. The final number of surveys distributed was 1562.

Due to the time constraints placed upon the project, it was decided that the fastest approach for obtaining the information would be to use a mailed survey questionnaire and then to follow-up on those not responding with telephone calls and second mailings if necessary.

The initial problem was to devise a questionnaire that:

1) Would elicit all the pertinent information;
2) Be general enough to be used efficiently by the wide variety of industries being sampled;
3) Be simple and clear enough that persons without technical backgrounds would be able to understand it and respond effectively; and
4) Have the information in a format easily processed for classification and tabulation purposes.

Questionnaires from California, Oregon, Kansas, and New York were used to develop a comprehensive survey to satisfy the points listed above. A sample questionnaire appears in Appendix A.

The questionnaire was divided into several sections. The first section requested general information such as company name, officers, major products or service, size of facilities, and number of employees.

The second section asked for information concerning resource conservation and recovery. The information requested included a list of the basic raw materials and process intermediates; if the company used a waste exchange program; what, if any, recycling or reclaiming is practical at the site; etc.. The third and final section was the actual hazardous material survey form.

On this part of the form the company was asked first to classify the waste according to one of the code types provided. These codes were provided for several reasons. Because of the broad range of possible waste materials involved, the code types were designed to define more clearly the specific types of wastes to which the survey pertained. We felt the company would better be able to classify its waste type than someone later attempting to do this using purely descriptive information. The numerical code system also simplified the tabulation, and made it more amenable to future uses on a computer system. Next, the company was asked to provide more specific information on the composition of the waste, actual concentrations, if known, the present volumes of waste generated, and a projection of waste to be generated over the next five years.

The questionnaire then requested information concerning the disposition and handling of the wastes such as: volume and length of time the material/waste was stored on-site, the methods used for on-site storage, how the waste was transported off-site and by whom, whether the waste is treated or reclaimed, and by what methods, and where the waste was finally disposed of.

Procedure

The questionnaire and a return envelope was mailed with a cover letter explaining the nature of the survey. The cover letter requested that the survey form be completed and returned within 21 days of receipt. After 3 weeks, follow-up calls were made by the division staff to trace those survey questionnaires from which replies had not yet been received. December 14 was listed as the latest possible date that surveys could be received and tallied for reporting. Although it was generally considered that a more personalized approach should be used, on-site interviews were strictly ruled out because of the time constraints placed on the Waste Control Division.

Analysis

The data were collected and tallied manually as the replies were received. A computer was not used for final tabulation primarily because the time needed to prepare a program was not available. The information received was diversely reported due to the variety of industries surveyed, and to the individual interpretation of each respondent. Therefore, each survey form showing hazardous wastes needed to be reviewed and adjusted as necessary for accuracy and uniformity of reporting.

The review included separating the wastes reported into one of three categories: non-hazardous; hazardous; or extremely hazardous. Low-toxicity, bulk wastes were included as hazardous in the final tabulation. However, the classifications are subject to change to maintain uniformity with RCRA- and EPA-proposed regulations. The review was based primarily on the EPA criteria for hazardous-waste classification, flammability, toxicity, reactivity, corosivity, and infectiousness. The Federal RCRA hazardous-materials list, the California hazardous-materials list, and the Toxic Substances Registry were used to support these classifications. Only hazardous and extremely hazardous wastes were included in the tally. If upon review, additional information was needed, the company was contacted by telephone.

Report

The survey indicates that Colorado generates a total of approximately 855,000 tons of hazardous wastes. This is comprised of about 84 million gallons and 432,000 tons of hazardous or potentially hazardous materials consigned for disposal. 86,000 tons of this, or about 10 percent of both liquid and solid wastes, would be considered extremely hazardous.

Of the 855,000 tons of waste reported, approximately 402,000 tons (47 percent) were bulk wastes. This separates to 171,000 tons of solid materials and 46 million gallons of liquid wastes. These wastes were of low to moderate toxicity, but due to the large volume generated, they were included in the hazardous category. It was determined that the wastes were of sufficient toxicity that it would be undesirable to receive these in a municipal-waste landfill. The volumes of material generated could contribute substantially to ground-water and other environmental contamination problems at these sites.

99.7 percent of the total waste stream reported was generated by industries located in the Front Range counties. This fact was not surprising, in that industry other than mining is also predominantly concentrated in the Front Range area.

The data were tabulated by county and reported by regions (see map). The regional reporting was used to protect the confidentiality of the information where county reporting might indicate clearly the producer of the waste. See Tables I-V for complete regional breakdown of hazardous-waste generation in the State of Colorado.

Region III, including Adams, Arapahoe, Boulder, Clear Creek, Denver, Douglas, Gilpin, and Jefferson Counties generate the largest segment, 38.7 percent of the hazardous wastes in the State. This finding was expected as the majority of the population and industry is located in this region of the State. Region VI, including El Paso, Park, and Teller Counties, was second in total amount of potentially hazardous waste generated. This amounted to 257,000 tons or approximately 30 percent of the total, and again reflects population density and industry concentration of the area. Region VII, including Pueblo, Huerfano, and Las Animas Coiunties, was another major producer with 28 percent of the total or about 239,000 tons of waste. Region II, comprised of Larimer and Weld Counties, generate a total of 24,500 tons of hazardous waste, representing 3 percent of the State total. These figures are indicative of the kinds and quantity of hazardous waste that industry in Colorado generates on a regular basis. It represents hazardous waste that must be adequately and safely disposed of on a continuing basis.

The above figures do not include certain materials such as mining waste, fly ash, foundry sands, packagings, special incident clean-up wastes, or hospital wastes. There are several reasons for excluding these materials.

Mining waste, fly ash and foundry sands were not included principally because they are generated in such large quantities that they would inflate the total waste picture out of reasonable proportion. Fly ash, foundry sands, some slags, and contaminated packaging (steel drums, for example) would probably not be considered hazardous under Section 3001 of RCRA. As such, these materials would not have to be disposed of at chemical-waste landfills. Hospital wastes were excluded from the final tally primarily because the reported figures were so diverse in quantity and nature that their significance and accuracy was questionable. Without the opportunity to thoroughly follow-up on the data, it was decided to not address such waste at this time.

To report a single tonnage figure for hazardous-waste generation, a conversion factor of 10 lb per gallon was used for liquid wastes. The major liquid wastes reported were contaminated acids and alkalies, solvents, and sludges. The main component of acid and alkali wastes is water (density 8.33 lb per gallon). Acids and alkalies with metal or other inorganic contamination in liquid wastes would increase the average density to about 10 lb per gallon. Solvent densities average around 7 to 8 lb per gallon and sludges 10 to 13 lb per gallon. Therefore a reasonable estimated average weight for hazardous liquid wastes would be approximately 10 lb per gallon.

The quantities quoted above were obtained from 1562 survey forms sent to businesses that might potentially create hazardous wastes. Responses were received from 61.5 percent of the firms polled. Of the companies with greater than 250 employees, we received 49 replies out of 53 questionnaires sent, or a 92 percent response. From the telephone follow-up, we found that many of the smaller firms had not returned the surveys because they "had no hazardous wastes" to report. In general, the cooperation of the firms was very good, considering that the information requested was detailed, comprehensive, and often somewhat technical, therefore requiring a considerable amount of time to fill out properly. The reported figures are believed to represent at least the minimum quantity of the hazardous industrial wastes generated in Colorado.

Limitations

The limitations inherent in a mailed survey are obvious but the time constraints placed on the Division in performing the survey forced the use of this survey method. The primary disadvantage of using this method is not getting responses from the entire population polled. In this instance a 61.5

percent response can be considered sufficient to project total State hazardous-waste generation. Although the larger companies had a much better response rate, the results still cannot be considered complete or totally accurate. All that can be said is the actual quantity is at least equal to the figure reported.

A second disadvantage of the mailed survey is that each person filling out the questionnaire tends to make their own interpretations of the information the survey asks for or needs. This causes exceedingly diverse reporting and responses, and may adversely affect the accuracy of the survey.

This situation could be partially improved thorough use of a follow-up survey, which could most easily be achieved by telephone. The time and personnel restrictions placed on this project made an adequate follow-up survey impossible. Only a limited follow-up was attempted. This consisted of calling those companies who did not respond immediately, and sending a second copy of the questionnaire. No attempt was made to verbally contact those filling out the survey to achieve greater uniformity in the responses received.

Lastly concerning the accuracy of the report, it was dependent on complete and frank responses by the reporting individuals. If the person reporting wished to exclude certain items, no verification was possible because the time available would not permit any in-depth investigation of the results. As such, we are reporting the data received and we have little or no independent verification of these figures.

This survey is considered an initial estimate of the quantity and kinds of hazardous wastes generated in the State. Survey replies are still being received at this writing, including some from potentially significant producers of chemical wastes. No final analysis of the survey data was attempted for this reason. A more accurate and comprehensive report will be compiled in the future from the information collected if time and funding permits.

COLORADO PLANNING AND MANAGEMENT REGIONS

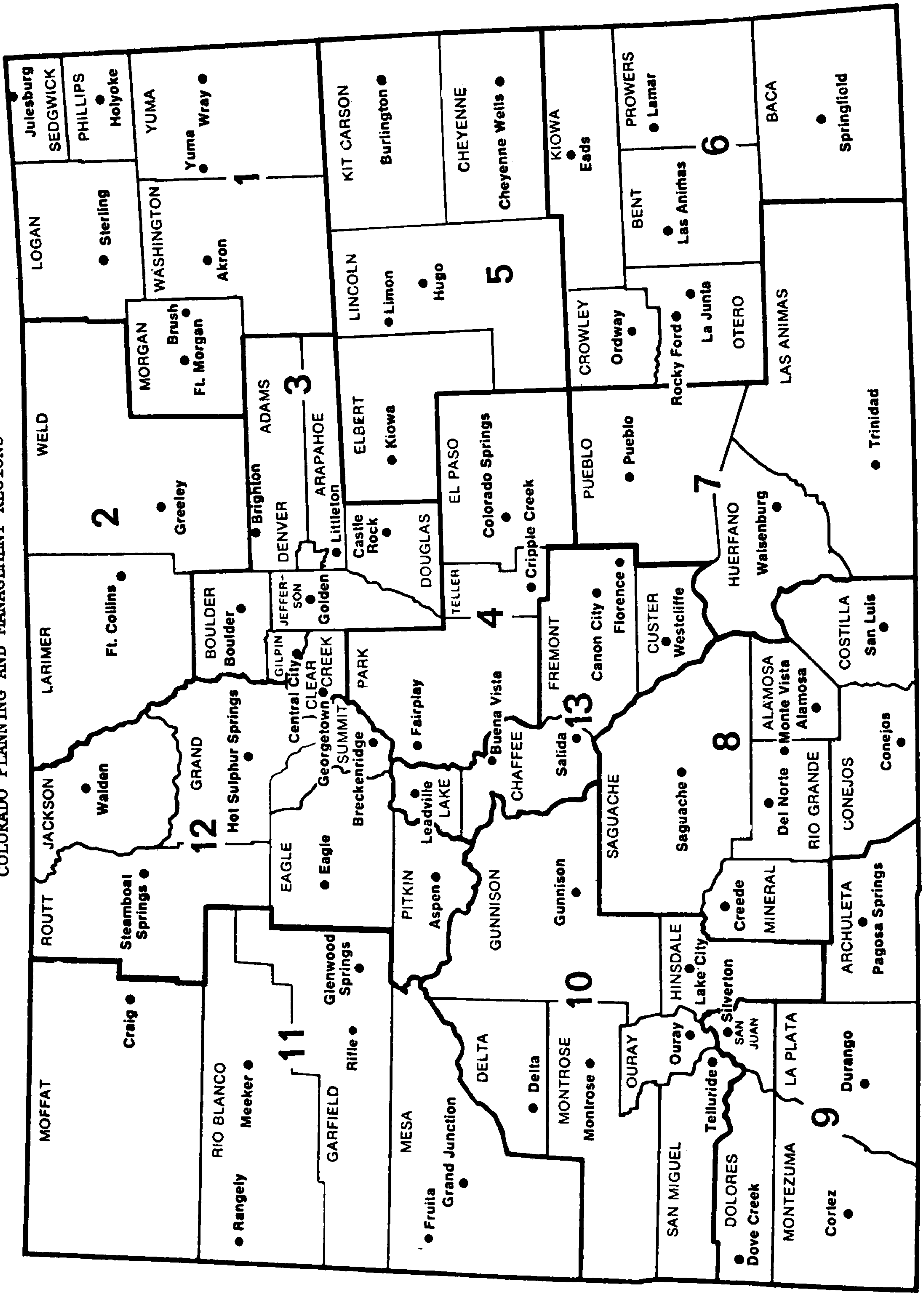

TABLE 1

REGIONAL BREAKDOWN OF HAZARDOUS WASTES GENERATION IN THE STATE OF COLORADO

	Hazardous		Extremely Hazardous		Totall Tonnage	% of Colorado Annual Waste Inventory
	Gallons	Tons	Gallons	Tons		
Region 1	40	-	-	3.	3.	-
*2	4,578,247	1,266.	45,513	92.	24,477.	2.86
*3	25,589,483	150,831.	1,361,519	47,541.	333,127.	38.94
*4	45,240,105	482.	6,143,755	308.	257,710.	30.13
5	-	-	-	-	-	-
6	131,610	69.,	600	-	730.	0.08
*7	521,367	236,028.	600	-	238,983.	27.94
8	-	-	-	-	-	-
9	3,300	226.	-	-	243.	0.03
10	150	93.	-	15.	109.	0.01
11	300	29.	-	-	31.	-
12	-	-	-	-	-	-
13	-	20.	-	-	20.	-

*Front Range Regions 2, 3, 4, and 4 account for 99.7% of hazardous waste generated S Statewide.

[1]A conversion factor of 10 pounds per gallon was used for liquid waste.

TABLE 2

REGION 2

HAZARDOUS WASTE GENERATION BY TYPE

	Gallons	Tons
Acids	75,292	0.1
Alkalies	280,150	10.0
Inorganic Liquids & Solids	-	2.9
Organic Liquids & Solids	214,761	88.0
Sludges	4,018,295	690.0
Baghouse Waste	-	6.0
Alum/Tin Dross	-	12.0
Misc. Contaminated Items	-	2.0
Spill Residues & Prod. Wastes	-	545.0
Solder, Flux, Wave Oil	1,650	2.6
Rinse & Other Wastewaters	23,000	-
Mixed Oils	8,000	-

TABLE 3

REGION 3

HAZARDOUS WASTE GENERATION BY TYPE

	Gallons	Tons
Acids	8,384,743	0.1
Alkalies	187,763	152.5
Inorganic Liquids & Solids	5,016,050	25,504.0
Organic Liquids & Solids	1,644,745	4,800.0
PCB Solids & Sludges	5,811	-
Sludges	7,705,281	9,202.0
Alum/Tin Dross	-	80.6
Baghouse Waste	-	11.5
Boiler Wash	1,000	-
Brine Solutions	-	130,462.2
Fluorescent Tubes	-	7.7
Misc. Contaminated Items	-	3,278.9
Non-Emulsified Waste Oil	54,140	-
Emulsified Oil	57,550	-
Epoxy/Resin Waste	1,000	-
Explosives	-	11.0
Halogenated Still Bottoms	1,500	209.0
Low Level Radioactive Waste	5,000	5,000.0
Misc. Package Chemicals	-	31.1
Non-Halogenated Still Bottoms	-	66.0
Photographic Chemical Waste	1,870	-
Spill Residues	-	48.8
Sewage Sludge	-	2.0
Spent Activated Carbon	-	50.0
Spent Cartridge Filters	-	315.0
Spent Catalyst	-	221.5
Waste Tars	-	540.0
Rinse & Other Wastewaters	3,725,300	-
Other Mixed Oils	158,060	-
Other Mixed Waste	7,000	88.0
Other Rejected Goods	3,300	11,000.0

TABLE 4

REGION 4

HAZARDOUS WASTE GENERATION BY TYPE

	Gallons	Tons
Acids	36,168,030	-
Alkalies	181,600	-
Inorganic Liquids & Solids	9,043,200	1
Organic Liquids & Solids	50,525	-
Sludges	183,500	741.
Baghouse Waste	-	4.2
Misc. Contaminated Items	-	2.
Low Level Radio. Cont. Wastes	-	-
Off Spec. Pesticides	655	0.3
Polyester Resins	-	36.
Solder, Flux, Wave Oil	300	2.5
Spent Cartridge Filters	-	1.3
Rinse & Other Wastewaters	5,750,000	-
Other Mixed Oils	5,400	-

TABLE 5

REGION 7

HAZARDOUS WASTE GENERATION BY TYPE

	Gallons	Tons
Acids	-	18,384
Alkalies	60,000	-
Inorganic Liquid & Solids	-	-
Organic Liquids & Solids	-	-
PCB Solid & Sludges	550-	-
Sludges	6,050	51,785
Alum/Tin Dross	-	234
Asbestos	-	4
Baghouse Waste	-	10
Non-Emulsified Oil	207,081	-
Grease	30,000	-
Scrap Batteries	-	9.5
Sewage Sludge	-	30
Waste Lime	-	5,484
Waste Tars	-	348
Rinse & Other Wastewaters	49,686	-
Other Mixed Oils	168,000	-
Other Mixed Waste	-	160,092

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APPENDIX A

COLORADO DEPARTMENT OF HEALTH

4210 EAST 11th AVENUE·DENVER, COLORADO 80220·PHONE 320-8333

TO: Heads of Colorado Industrial and Commercial Firms

DATE: September 19, 1979

SUBJECT: Survey of Industrial Waste Generation

Proper disposal of industrial waste is of increasing concern to the business and public sectors of Colorado. You are requested to complete the enclosed survey form, which will provide data on the quantities and types of wastes produced by about 1000 businesses in Colorado and assist the State Health Department to insure that properly managed treatment, storage, and disposal facilities exist for such hazardous wastes.

Information requested in this survey is required by Senate Bill No. 336 which mandates the Colorado Health Department to establish criteria on disposal sites. The Subcommittee on Hazardous Materials, which I chair, approved the survey form as requesting information which should meet the requirements of EPA's inventory of hazardous waste generators which will be conducted next year. The Subcommittee is a group comprised of representatives from Colorado industries that generate, treat, and store chemical and other industrial wastes.

The information provided will be protected by State Health Department regulations which prevent disclosure of proprietary information; the data will be used only in combination with data from others to provide summaries of types and quantities of hazardous wastes produced in major regions of the State. Representatives on the Subcommittee were satisfied that confidentiality would be assured by this procedure.

You are requested to complete this survey form and return it to the Department's Hazardous and Solid Waste Section within 21 days. Questions on the form or necessary assistance should be addressed to the Department (320-8333, Ext. 6246) within this time period. Respondents who provide fully completed forms will not be contacted.

Thank you for your cooperation on this effort of interest to all citizens of Colorado.

Sincerely,

Jay T. Knutson

Jay T. Knutson, Chairman
Subcommittee on Hazardous Materials

Concurrence: Albert J. Hazle

Albert J. Hazle, Director
Radiation and Hazardous
Wastes Control Division

AGENCY USE ONLY	
ID	______
Mail ______ Phone #	______
Personal Interview	______
Interviewer	______
Date	______
Primary SIC	______
Secondary SIC	______

STATE OF COLORADO

INDUSTRIAL WASTE SURVEY

General Information

1) Company Name ______________________________

Mailing Address ______________________________
Street City State Zip

Plant Location /__/ Same as above

____
Street City State Zip

2) If Subsidiary, Name of Parent Company ______________________________

3) Individual Responsible for Plant Operations

____
Name Title Phone

4) Individual Providing Information

____
Name Title Phone

5) List Major Products or Services
1st ______________________________
2nd ______________________________
3rd ______________________________

6) Number Employed in Your Operations

1-20 /__/ 21-50 /__/ 51-100 /__/ 101-500 /__/ 501 or More /__/

7) Physical Size of Operation

Land Area ______________ acres Covered Floor area ______________ ft.

8) Present Age of Existing Facilities

Less than 5 years /__/ 5-30 years /__/ More than 30 years /__/

PLEASE RETURN QUESTIONNAIRE WITHIN 21 DAYS TO:

Radiation and Hazardous Wastes Control Division
Colorado Department of Health
4210 East 11th Avenue
Denver, Colorado 80220

Company Name

____

Resource Recovery

1) Are your waste managers familiar with the proposed federal guidelines on hazardous wastes under RCRA (Resource Conservation and Recovery Act of 1976)

Yes /__/ In Part /__/ No /__/

Would you like to be sent more information about this program?

Yes /__/ No /__/

2) Do you presently recycle or exchange waste products? Yes /__/ No /__/

If yes, please list below:

Material Recovered	Annual Amount	By Your Company	By Others
________	________	/__/	/__/
________	________	/__/	/__/
________	________	/__/	/__/
________	________	/__/	/__/

If no, what are the constraints?

/__/ not enough volume

/__/ haven't attempted it

/__/ other - specify ______________________________

/__/ no available market

/__/ not economically feasible

____

3) Are you in favor of initiating a waste exhange program in Colorado? Yes /__/ No /__/

Would your company like to use such a program? Yes /__/ No /__/

4) Please list major raw materials used in your manufacturing processes:

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

INDUSTRIAL WASTE INFORMATION SHEET
(All information will remain confidential)

FOR EACH MAJOR WASTE TYPE, (AS DEFINED ON THE WASTE TYPE CODE KEY), PLEASE FILL OUT ONE INFORMATION SHEET, TWO ARE PROVIDED, MAKE EXTRA COPIES AS NEEDED.

1) Waste Type Code # ______________ (Refer to key)

2) Major Chemical Components of Waste Type

		Concentration		
1.	______________	______________	/__/wt%	/__/ppm
2.	______________	______________	/__/wt%	/__/ppm
3.	______________	______________	/__/wt%	/__/ppm
4.	______________	______________	/__/wt%	/__/ppm
5.	______________	______________	/__/wt%	/__/ppm

3) Annual Volume Generated (estimate) 1980 ______________ Projected 1985 ______________
(gal/yr, ton/yr, lb/yr)

If projected volume varies significantly, is it due to:
/__/increase/decrease production /__/pollution controls /__/other (specify) __________

4) Frequency of Waste Production /__/seasonal /__/occasional /__/continual
/__/other ______________

5) Is the waste type combined with other types in storage or disposal?
/__/yes /__/no If yes, specify ______________

6) On Site Storage
a. Method: /__/drum, /__/roll-off container, /__/tank, /__/lagoon, /__/other __________

b. Typical length of time waste stored __________/__/days, /__/weeks, /__/months

c. Typical volume of waste stored __________/__/tons, /__/gallons

d. Is storage site diked? /__/yes /__/no

e. Surface drainage collection /__/yes /__/no

7) Transportation
a. Waste hauled off site by /__/you /__/others

b. Name of waste hauler ______________ Phone __________

____
Street City State Zip

8). Treatment and Disposal
a. Treatment or disposal: /__/on site /__/off site

b. Waste is /__/reclaimed /__/treated /__/land disposed /__/incinerated
/__/other (specify) ______________

c. Off site facility receiving waste

Name of Facility ______________ Phone __________

____
Street City State Zip

WASTE TYPE CODE KEY

INORGANIC WASTE TYPES

Acids

101 acid solutions containing heavy metals*
102 acid solutions containing non-metals
103 acid solutions containing other metals
104 battery acid
105 other acid solutions
106 spent etching solution
107 spent pickle liquor

Alkalies

111 alkaline solutions containing cyanide
112 alkaline solutions containing heavy metals
113 alkaline solutions containing non-metals
114 alkaline solutions containing other metals
115 cyanide solutions
116 other alkaline solutions
117 spent etching solution

Inorganic Liquids & Solids

121 non-solvent inorganic liquids
122 non-solvent inorganic liquids with heavy metals
123 non-solvent inorganic liquids with other metals
124 other inorganic solids
125 inorganic gases

ORGANIC WASTE TYPES

Solvents

301 halogenated solvents containing heavy metals
302 halogenated solvents with other metals
303 other halogenated solvents
304 other non-halogenated solvents
305 other solvents with heavy metals
306 other solvents with other metals
307 unknown solvents
310 mixture of solvents

Organic Liquids & Solids

311 halogenated organic liquids
312 halogenated organic liquids with heavy metals
313 halogenated organic liquids with other metals
314 other organic liquids
315 other organic liquids with heavy metals
316 other organic liquids with other metals
317 halogenated organic solids
318 other organic solids

ORGANIC WASTE TYPES (CONTINUED)

Sludges

501 ammonium thiosulfate sludge
502 brine sludge
503 chemical solvent sludge
504 copper mud
505 degreasing sludge
506 descaling sludge
507 drag-out sludge including sump and pond sludges
508 dye solids and sludges
509 filter press sludges and solids
510 graphite and carbon solids and sludges
511 heavy metal sludges & solids
512 ink solids and sludges
513 lime sludge
514 metal finishing solids and sludges including grinding waste
515 oil sludges
516 paint solids and sludges
517 paper sludges
518 PBB solids and sludges
519 PCB solids and sludges
520 phenolic solids and sludges
521 phosphate sludge
522 polymer solids and sludges
523 pseudo-metal sludges
524 scrubber sludges
525 silicon tetrachloride sludge
526 sulfur sludge
527 tetraethyl lead sludges
528 wastewater treatment solids and sludge
599 other sludges

* Heavy metals include: Copper, silver, zinc, cadmium, mercury, arsenic, lead, chromium, manganese, iron, and nickel

Miscellaneous

601 aluminum or tin dross
602 asbestos
603 baghouse waste and other dust collector waste
604 boiler wash
605 bottom ash
606 brine solutions
607 broken fluorescent tubes, bulbs, and lamps
608 contaminated and/or obsolete process equipment
609 contaminated clothing and rags
610 contaminated containers, essentially empty, including packaging material
611 contaminated pallets and wood
612 contaminated sand, clay, or other soils
613 non-emulsified waste oil
614 emulsified oil (50% emulsified oil)
615 epoxy resin waste
616 epoxy waste
617 explosives
618 fermentation cake
619 fly ash
620 gelatins, waste
621 grease
622 halogenated still bottoms
623 halogenated tank residue
624 lab animals and human blood waste
625 lagoon bottoms
626 lagoon tops
627 low-level radioactive contaminated waste
628 magnesium dust or solids
629 melmaine resin waste
630 melamine waste
631 miscellaneous packaged laboratory chemicals
632 non-halogenated still bottoms
633 non-halogenated tank residue including washdowns
634 off-spec chemicals and returned product
635 off-spec, obsolete or rejected pesticides
636 off-spec or rejected pharmaceuticals
637 off-spec, rejected or contaminated paint batches
638 other mineral oils
639 peroxide waste liquid or solid
640 photographic chemical waste
641 phenolic resin waste
642 polyester resins
643 residues from spill clean-ups and production wastes
644 scrap batteries
645 scrap cathode ray tubes
646 sewage sludge
647 solder, flux, or wave oil
648 spent activated carbon
649 spent cartridge filters
650 spent catalyst or catalyst fines
651 tannery waste
652 textile coating solutions
653 waste lime and carbonate dust
654 waste tars

Miscellaneous (Continued)

655 rinse water & other wastewaters
656 other mixed oils
657 other mixed waste
658 other obsolete or rejected goods

PART II

SITING CONSIDERATIONS FOR HAZARDOUS WASTE DISPOSAL

by

Jeffrey L. Hynes
Patrick A. Longmire
Tom Hatton

Colorado Geological Survey

II. SITING CONSIDERATIONS FOR HAZARDOUS WASTE DISPOSAL

INTRODUCTION

One acceptable method for achieving long-term isolation of hazardous wastes from the environment is secure burial at a carefully selected and managed disposal site. Even if other hazardous waste management alternatives such as resource recovery, neutralization, and incineration were employed to the maximum extent possible, there will still be a need for secure burial sites to handle the residues from the above processes and those wastes not amenable to them.

The hydrologic, geologic, and physiographic conditions at a proposed burial site can have significant impact on the success or failure of the facility with respect to long-term isolation. Certain minimum physical criteria are presented in this report to set the stage for the more detailed discussions found later in this text. Factors other than the physical properties of the site and surrounding area will also play vital roles in the ultimate selection, development, and operation of safe, secure hazardous-waste-disposal sites in Colorado.

Due to the longevity, persistance, insidiousness, and toxicity of many types of hazardous wastes, the goal we have established is absolute containment for at least 1,000 years. This goal places the following limitations on a proposed site:

(1) Surface, ground, and meteoric water must be precluded from coming in contact with waste to the maximum practicable extent.

(2) Fluid wastes or waste by-products, liquid or gaseous, must not be allowed to leak from the containment facility to the surrounding environment.

(3) The site should be naturally resistant to water and wind erosion. Modification by engineering design should assure the cap and burial layer will not be breached after final closure and abandonment, allowing escape of hazardous waste or its by-products.

(4) Geologic and hydrologic conditions at the site should be such that long-term containment of the waste is achieved with minimal maintenance.

(5) Design of the facility and monitoring systems should allow for immediate recognition of an actual or imminent loss of containment, or onset of processes that are likely to threaten containment over longer periods of time.

(6) Site location, design, management, and geologic setting should allow for secure closure, facilitates continuing post-closure surveillance, and permit remedial actions if necessary.

Colorado's semiarid climate and vast expanses of potentially suitable host rock in areas of sparse population will be of considerable benefit in establishing the optimum situation in which to carry on this extremely critical and necessary task.

HYDROLOGY*

The most important consideration in the development of suitability criteria for hazardous-waste-disposal sites is the protection of ground and surface water from contamination by leaking wastes or their by-products. Surface water can be contaminated by pollution from either runoff or by the discharge of polluted ground water. The range of natural conditions affecting ground-water flow is complex and varies with each geologic situation. Scenarios are presented here to help the reader achieve a basic understanding of the problems involved.

Ground Water*

When water or aqueous waste is present in an unconfined aquifer*, it is usually separated into two zones; the unsaturated zone*, or zone of aeration

Definition is cited in the Glossary (Appendix C) and the saturated zone. The top of the saturated zone is usually called the water table. The unsaturated zone exists between the surface of the ground and the top of the saturated zone. Within this zone the rate and direction of water movement is controlled by gravity, the type of material, electro-chemical surface forces, moisture, and plant demands, and is predominantly vertical. Water will undergo overall downward movement during wet periods, due to gravity, and upward movement during dry periods due to capillary tension and evapotranspiration*. Commonly a permeable* topsoil or surficial deposit may be underlain by a less permeable unit (aquitard*). In this situation liquid will migrate downward until it reaches this barrier, then it will flow laterally. Figure 1 depicts this type of movement of groundwater.

The situation illustrated in Figure 1 must be avoided for waste-disposal sites. Lateral movement of contaminants in surficial, highly permeable material can result in pollution of the environment in a short period of time. To preclude this problem, excavation into the relatively impermeable bedrock and deposition of the waste entirely within the bedrock is mandatory for hazardous-waste disposal.

The movement of fluids in bedrock depends on many geologic factors. Site-specific investigations are needed to determine the general flow of ground water in and adjacent to the site and the potential for its contamination from a waste site.

Aquifers*

An aquifer is any geologic rock or soil unit that contains water which is, or can be, utilized by man. Protection of such aquifers is extremely important. Maximum practicable isolation of a hazardous-waste-disposal site from any underlying aquifers must be achieved. A minimum separation from any aquifer must be established as a criteria for site-suitability evaluations.

Evaluation of the bulk permeability (hydraulic conductivity) and fracture transmisivity of the host rock will determine if isolation criteria in excess of the minimum are needed for a specific site. This evaluation can be applied to measure the impacts to ground and surface water and recharge areas.

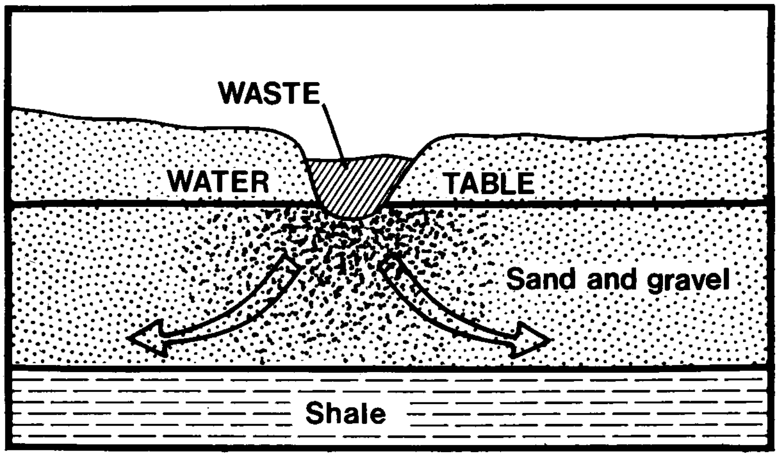

Figure 1. Typical flow paths in permeable surficial deposits underlain by less permeable strata (modified from Schneider, 1970).

Surface Water

The same precautions against pollution apply for surface water as well as ground water. A minimum distance should be maintained from any perennial stream or body of standing water. Pollutants can reach streams by runoff or through subsurface flow. A thorough investigation of this situation should be conducted during site-specific studies. The long-term flooding potential of a site must also be evaluated.

A disposal site should be located outside any area subject to the probable maximum flood (PMF). The PMF represents discharges that may be expected from the most severe meteorological and hydrological conditions (Dalrymple, 1964). Estimation of the PMF involves many factors which contribute to the "worst case" possible. Factors such as soil moisture*, slope, drainage area, and probable maximum precipitation (PMP) are used to calculate the PMF (U.S. Bureau of Reclamation, 1974). A site should also be evaluated for the impact of the PMP (U.S. National Weather Service, 1977, 1978). Sheet erosion and inundation can directly affect the site. Mitigation procedures should be considered and designed based on PMP calculations.

Colorado

Most of the research and experimentation concerning the hydraulic conditions related to waste-disposal sites has been performed in climates more humid than Colorado. Many researchers consider impermeable rocks to be unsuitable for waste disposal. This is because water can be retained and overflow of products from the waste site can occur. Rocks which are slightly permeable allow some migration of products from the site. This decreases the possibility of overflow and also increases the opportunity for alteration of the chemical substances by mineral constituents of the rock. However, the climate in Colorado is semiarid and the possibility of prolonged saturation of a well chosen site by precipitation is remote. For this reason rock types which are as impermeable as possible should be considered as the optimum burial medium. In this way the waste can be isolated from the environment for a considerable length of time.

Ground-water resources are utilized to a significant extent in most of Colorado (Figures 2 and 3). The availability, quantity, and quality of the water depends on many geologic factors. Bedrock aquifers usually consist of sandstone, siltstone, limestone, and conglomerate. Alluvial aquifers composed mainly of sands and gravel are also utilized extensively throughout Colorado, such as in the San Luis Valley and the Denver Basin. Rock units with low permeabilities, such as shale* and claystone*, are utilized as ground-water supplies only locally where certain conditions such as intense fracturing exist. These units are generally preferable for hazardous-waste sites, but sites should not be developed in areas where these units are used as sources of water supplies. The same conditions that make such an area possible as a water-supply source make it less desirable for waste isolation and containment.

General Hydrologic Criteria

- A minimum vertical thickness of 150 ft of undisturbed material with an in-place permeability no greater than 1×10^{-7} cm/sec (0.1 ft/yr) to the nearest aquifer (or potential aquifer).

- In closure of each cell, the base of the impermeable cap should be placed below the interface between bedrock and the overlying surficial material. The landfilled waste material should lie entirely within the containing medium and below the level of the original bedrock.

- A thorough evaluation of specific sites should include:

  (1) direction and rate of ground water flow,

  (2) depth to the water table,

  (3) identification of all aquifers in the area and evaluation of their relationship to the site and its hydrology,

  (4) location and description of all wells and exploratory borings in the vicinity of the site.

- The bottom of any proposed excavation should be a minimum of 100 ft above the historical high-water table.

- A minimum surface distance of one mile to any perennial stream channel or ground-water recharge zone or isolation of the site from these features by local topography.

Sources of Information

Information on ground-water resources in Colorado is available from State and Federal sources. The Colorado Department of Natural Resources, Division of Water Resources, Colorado Water Conservation Board, and the Colorado Geological Survey have extensive water resource data, both published and unpublished. Publications are also available from the U.S. Geological Survey.

Figure 2. Map showing developed groundwater resources of Colorado (from Colorado Land Use Commission, 1974)

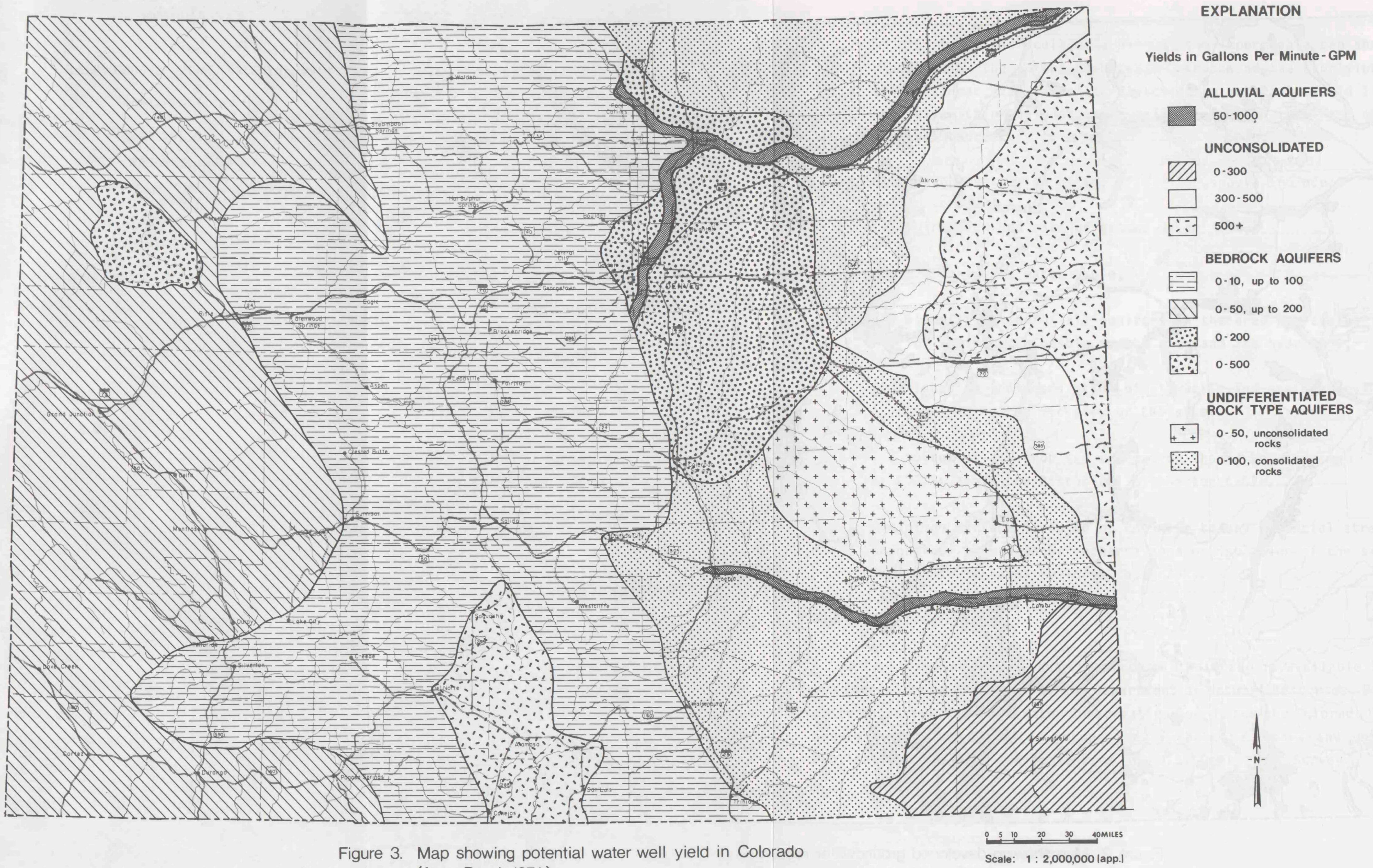

Figure 3. Map showing potential water well yield in Colorado (from Pearl, 1974.)

Selected References

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GEOLOGY

Introduction

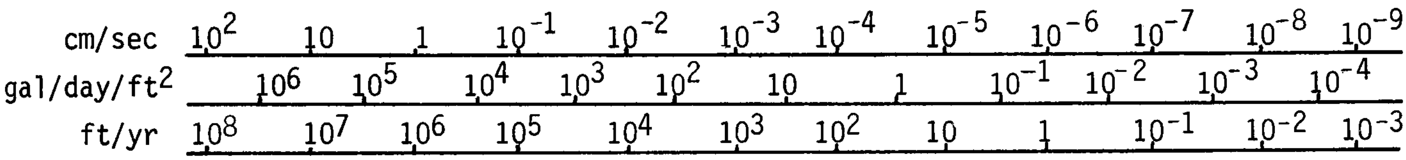
Geologic conditions within the immediate vicinity of a proposed waste-storage facility must be thoroughly considered in order to evaluate the security of the waste material. The type and percentage of the various mineral constituents which make up the rock (lithology*) play an important role in isolating the waste from the surrounding environment and in neutralizing or retarding many of the noxious components associated with it. The permeability of the burial medium, a measure of the ability of fluids to migrate through the rock, is the most important physical parameter to consider for the safe isolation of the waste material and any toxic by-products.

Other important properties of the burial medium are thickness, areal extent, and geologic relationship to other formations, particularly aquifers. The thickness must be sufficient, when coupled with low permeability, to successfully contain the waste for very long periods of time. In order to have a sufficient area and volume to construct a disposal site, including a buffer zone, the formation must have a fairly large areal extent.

Geologic hazards* such as avalanches, landslides, rockfalls, mudflows, debris fans, unstable slopes, faulting, and ground subsidence must be avoided. The potential burial site and vicinity should be evaluated for the presence of various potential or critical mineral* commodities which could be rendered unrecoverable by the presence of the site. The proximity of buried hazardous waste could severely complicate, if not preclude, any future development or exploitation of mineral resources.

Lithology

In order to establish and assure maximum integrity in isolating hazardous-waste materials and their by-products from the environment, geologic guidelines must be developed and adhered to. A rock formation that is selected as a proposed waste disposal medium must have favorable properties which in general are found only in certain rock types. Shale and claystone, the most abundant type of sedimentary rocks found on the surface of the earth, are characterized by high clay content. This results in a marked ability to impede the migration of fluids through the rock. As shown in Figure 4, unaltered shales have permeabilities ranging from an upper limit of 10^{-7} cm/sec (10^{-3} gallons/day/ft^2) to a lower limit of 10^{-14} cm/sec (10^{-10} gallons/day/ft^2). A shale with a permeability of 10^{-7} cm/sec will allow fluids under a unit head to migrate approximately 0.1 ft/yr.



Clean gravel	Clean sands; mixtures of clean sands and gravels; fractured igneous and metamorphic rocks	Very fine sands; silts; mixtures of sand, silt, and clay; limestone, and sandstone	Unweathered clay and shale

Figure 4. Permeability ranges of different soil and rock types (modified after Todd, 1959).

Shales are also attractive host rocks for hazardous-waste disposal because the individual particles that make up the rock can, in many cases, effectively adsorb the metal ions present within the waste material or its byproducts. This adsorption* is a function of the ion-exchange capacity* of various clay minerals present within the shale. Although all shales exhibit these properties to some extent, detailed investigations will be needed to determine the specific suitability of a particular shale.

Colorado

Figure 5 shows the geographic distribution of formations in Colorado most suitable for hazardous-waste disposal. Cretaceous Pierre Shale is exposed extensively throughout eastern Colorado. It is a 5,000 to 7,500-ft-thick sequence of marine sedimentary rocks, predominantly shales, with several distinct sandstone zones. Due to its great areal extent and its characteristic stratigraphic zones, the Pierre Shale has been studied extensively by numerous investigators. Several recent studies have been undertaken to determine precisely the mineralogical and geochemical properties of the shale units comprising the Pierre. Because of these quantitative studies, the suitability of the Pierre as a hazardous-waste-host rock can be evaluated in a more definitive fashion than can several other candidate formations.

A critical yet unresolved question concerning the hydrologic integrity of the Pierre is the effect of placing chemical hazardous wastes, such as PCB* (Polychlorinated Biphenyl), dioxene, benzene, and so forth, within the formation. Recent studies have shown that simple radioactive* elements such as plutonium and other transuranic-actinide* metals occurring as free ions can be effectively adsorbed by shale, thus being retained for long periods of time. The Illinois Geological Survey is presently conducting geotechnical tests pertaining to the adsorption and decomposition of PCB and Dicamba by shale and micro-organisms. Thus far, their studies indicate that shale does effectively retain these hazardous chemical compounds.

The Mancos Shale is fairly extensively exposed in western Colorado and is, in part, equivalent to the Pierre Shale. Also Cretaceous in age, the Mancos ranges in total thickness from 3,500 to 5,000 feet and consists of large sections of marine shale separated by repetitive sequences of thin sandstone lenses. Slightly less suitable for a hazardous waste disposal site than the Pierre due to its lesser areal extent and lower surface stability, the formation is exposed in areas of geomorphic instability associated with high relief and steep slopes, which may result in high erosion rates.

Several other shale formations appear to provide potentially promising locations for disposal of hazardous waste in Colorado. The Lewis Shale of

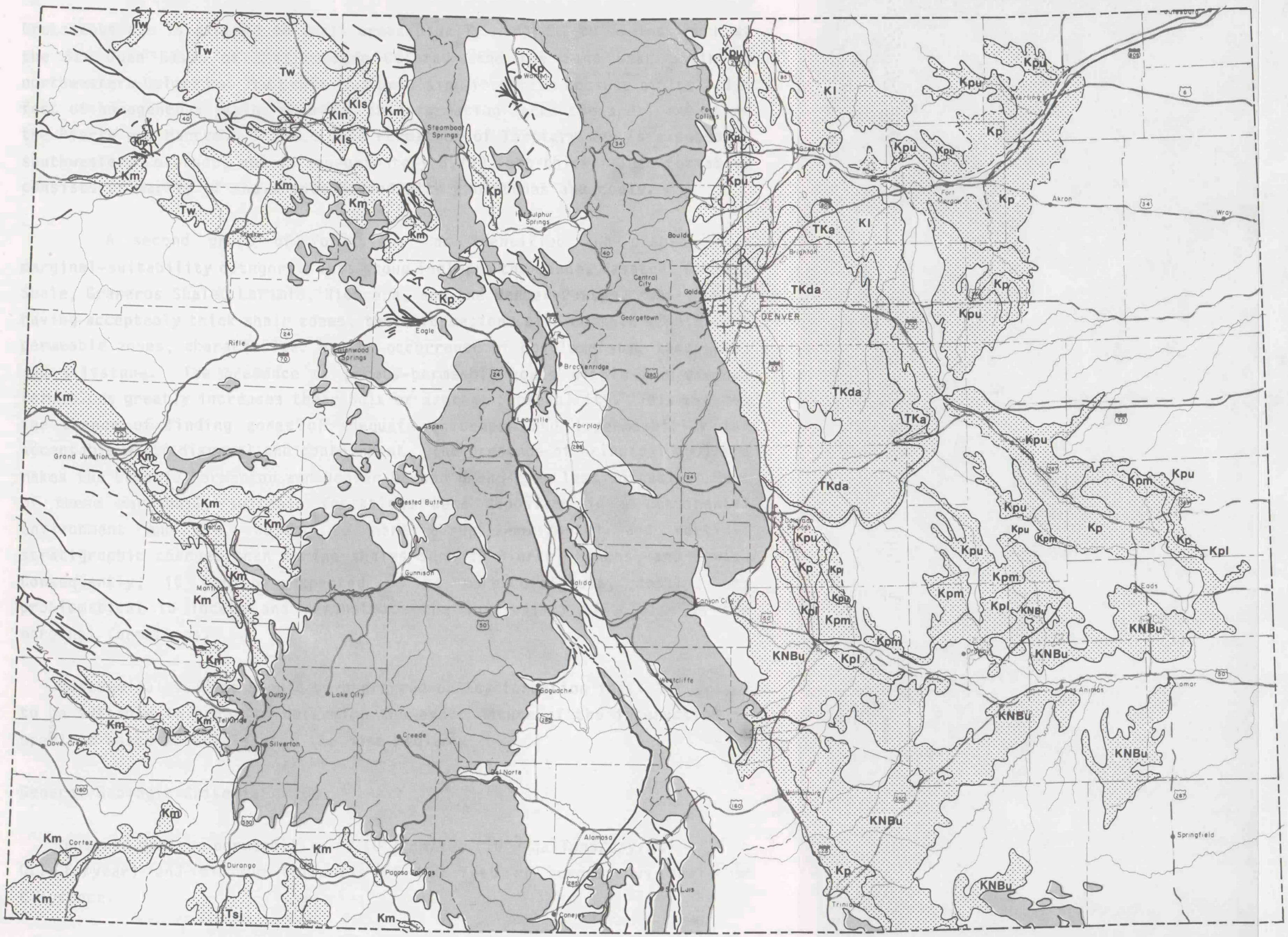


Figure 5. Map showing distribution of geologic formations suitable for hazardous waste disposal in Colorado. (from Tweto, 1979)

0 5 10 20 30 40 MILES

Scale: 1 : 2,000,000 (app.)

EXPLANATION

Lithologic Summary of Selected Host Formations

WESTERN SLOPE

Tertiary Age

*Tsj	San Jose Formation 1200 ft of shale and clay with minor amounts of sand. Several zones are characterized by 200 ft sections of shale.
Tw	Wasatch Formation 5150 ft maximum thickness of predominately shales with interstratified sandstone lenses. Some sections contain up to 200 ft of homogeneous clay size material.

Cretaceous Age

Kln	Lance Formation 550 ft of interbedded shale, sandstone, and minor coal beds. Sections with up to 200 ft of homogeneous shale occur locally.
*Kls	Lewis Shale A maximum of 1800 ft of homogeneous clay with minor argillaceous limestones.
*Km	Mancos Shale Up to 5000 ft of predominately homogeneous shale with minor sandstones and limestones.

FRONT RANGE AND EAST

Tertiary Age

TKda	Dawson Arkose including the Denver and Arapahoe Formations. The Denver Fm is 1060 ft. thick, composed of shale-claystone-basalt flows and conglomerate. Contains sections up to 180 ft thick of homogeneous shale with lenses of fine-grained sand. The Denver Formation yields small to moderate amounts of water to domestic and stock wells. The underlying Arapahoe Formation is one of the principle aquifers within the Denver basin.
TKa	Arapahoe FM, 1740 feet thick, consists of sandy to clayey shale and clay with a few beds of sandstone.

Cretaceous Age

Kl	Laramie Formation As much as 1800 feet thick, containing interbedded claystones, shales, and sandstones with commercial coal seams near the base. Lithology varies considerably with locality. Lower Laramie is an important aquifer in eastern Colorado.
*Kp	Pierre Shale Thickness of homogeneous shale ranges from 6900 ft in south-central portion of state to 5800 ft in north-central portion of state. Discreet sandstone zones occur in upper and middle sections.

*Kpu - upper unit

Kpm - middle unit

*Kpl - lower unit

KNBu	Niobrara and Benton Formations undifferentiated.

Niobrara Formation, including Smoky Hill member, 700 feet thick, contains thick sections (150 feet) of shale with minor sandstones and chalk lenses.

Benton Formation including Carlile and Graneros members approximately 600 feet of shale with minor sandstone and limestone lenses. Siliceous clays common.

* - indicates most favorable formations

Igneous and metamorphic rocks ranging in age from Precambrian to recent. Generally not suitable for shallow disposal.

Contact

Fault

-N-

Cretaceous age is exposed in small areas usually marginal to basins, such as the San Juan basin of southwestern Colorado and the Sand Wash basin of northwestern Colorado. The Lewis is a promising formation because of its 1,800 feet of homogeneous shale. However, this formation lacks the areal extent of the Pierre and Mancos. The San Jose Formation of Tertiary age is exposed in southwestern Colorado, and is approximately 3,700 feet thick. This formation consists primarily of shale interbedded with sandstones and coals.

A second group of formations was identified and placed in a marginal-suitability category. This group includes the Lance, Wasatch, Carlile Shale, Graneros Shale, Laramie, Niobrara, and the Denver-Dawson. While still having acceptably thick shale zones, these formations also contain significant permeable zones, characterized by the occurrence of conglomerate, sandstone, and siltstone. The presence of porous-permeable zones within the various formations greatly increases their bulk or average permeability. This reduces the chance of finding zones of adequate thickness and impermeability for acceptable waste disposal and containment. The presence of principal aquifers makes the Laramie Formation and Denver-Dawson group even less suitable. Most of these marginally suitable formations were deposited in a continental environment and are subject to more abrupt horizontal and vertical stratigraphic changes than marine shales such as Pierre, Mancos, and Lewis. Consequently, it can be expected to be more difficult, costly, and problematical to locate and demonstrate the suitability of a site on the marginal formations.

Geochemical studies should be performed on any formation initially judged to be suitable in order to determine the exact nature of the interaction of specific waste materials with the host medium.

General Geologic Criteria

Required maximum permeability of 10^{-7} cm/sec (10^{-3} gallons/day/ft^2 - 0.1 ft/year) and minimum thickness of 150 feet of homogeneous shale or claystone.

Formation Suitability Ranking

Group I Formations with highest probability of developing a safe storage facility for hazardous waste:

1. Pierre Shale - upper and lower sections, Plains area, eastern Colorado
2. Mancos Shale - northwestern, southwestern Colorado
3. Lewis Shale - northwestern Colorado
4. San Jose Fm - southwestern Colorado

Group II Formations with marginal probability of developing a safe storage facility for hazardous waste:

1. Pierre Shale - middle section, eastern Colorado
2. Denver-Dawson - Eastern Plains, eastern Colorado
3. Laramie - Eastern Plains, eastern Colorado
4. Niobrara - eastern, southeastern Colorado
5. Benton - eastern Colorado
6. Wasatch Fm - northwestern Colorado
7. Lance Fm - northwestern Colorado

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STRUCTURE

Structural geology is the study of the deformation of rocks, including folding, faulting*, and jointing*. Areas of intense tectonic* activity, past or present, usually display complex structural patterns. The study of structural features can lead to a better understanding of the stability of an area. Tectonic activity usually tends to modify the bulk characteristics of rock units in a manner that is deleterious to the suitability of the rock as a hazardous-waste-diposal medium. Certain structural features, such as jointing and faulting, are not conducive to the integrity of waste-disposal sites in that they can foster increased hydraulic conductivity* that leads to leakage and increased susceptability to erosion and surface instability.

Faults

Faults occur in most areas that have been subject to high levels of stress. In general, the more complex the structure, the more faults are present, and/or the greater the displacement across them.

Faults will usually have some effect on ground-water movement. Some faults act as barriers to ground water, whereas others provide pathways to ground water movement. Known faults should be avoided because of their possible deleterious effect on a site. A thorough investigation of location and types of faults within the general vicinity of a site is necessary to evaluate the effects on the integrity of the site. Highly faulted areas should be avoided due to the margin for error that they introduce into geologic investigations and subsequent interpretations.

Joints

Joints are fractures in rocks and are characterized by a lack of relative movement. Joints generally provide zones of higher permeability than that encountered in unjointed rocks with little or no opportunity for ion exchange. For this reason, areas of highly jointed rock should be avoided.

Colorado

Structural complexity throughout the State of Colorado varies greatly as a function of the actual tectonic history of the different parts of the state. The Rocky Mountains have undergone several stages of tectonic activity. The structure in these areas may be very complex. Generally, the structure of much of the western part of the state is also complex and highly variable. While the structural environment of much of the eastern plains is generally simpler, there are many small faults in the Denver Basin with local structures as complex as some parts of the Colorado Plateau. Due to the lower structural activity and greater ease of analysis and interpretation, the eastern plains are more suitable for the establishment of hazardous-waste-disposal sites from a structural standpoint. The general absence of faults, and the fact that fault-activity rates are lower in eastern Colorado, help to minimize earthquake potential. The extent of detailed structural investigations for a site will be controlled by the complexity of the general area. This will significantly affect the cost of the required investigations and probably the expense of developing the site as well.

General Structural Criteria

In general, the site should be:

- A minimum of 1 mile from any major fault.*
- Investigated thoroughly through all stages of site development to reveal the presence of faulting and jointing present within the general study area.
- In areas that have not undergone moderate-to-severe folding.
- A minimum of 1 mile from areas of igneous or geothermal activity.

Sources of Information

The U.S. Geological Survey, Colorado Geological Survey, and various professional and academic institutions have conducted general geologic and structural investigations and published reports on many regions of the state.

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GEOMORPHOLOGY*

Topography and slope characteristics should be carefully evaluated to insure long-term protection from excessive surface erosion and mass wasting. Areas which display significant erosion at the present or can be inferred to be subject to high erosion rates in the forseeable future should be avoided.

Slope

Natural slopes with low gradients less than 2 percent, generally do not provide good drainage and often experience surface-water retention, ponding, and high rates of infiltration. Slopes greater than 5 percent are subject to relatively high rates of erosion which can lead to eventual breaching of repository cells and subsequent escape of hazardous materials. These areas should be avoided.

The overall slope of the study area should be between 2 percent and 5 percent to provide for positive runoff control without excessive erosion. Detailed site grading and drainage should be developed to minimize the opportunity for surface water to come in contact with the waste materials. In general, areas of moderately low slope inclinations should have no stability problems other than those associated with construction, e.g., sides of trenches, and so forth.

Topography

Local topographic highs, such as the margins of buttes and escarpments, may locally be subject to erosion at a faster rate than surrounding areas. Streams tend to dissect these areas and provide a potential means of breaching containment and transporting hazardous wastes from the disposal site. The gentle flanks of drainage basins or broad, undissected divide areas should provide ideal locations for hazardous waste disposal, if other factors are favorable. The lower portions of the basin, should be avoided, as these areas are subjected to the highest flow rates during intense precipitation.

Erosional Processes

Erosion of the land surface is primarily caused by water and wind. Water-dominated (fluvial) processes vary in intensity among climatic regions, depending on variations in temperature, precipitation, altitude, and degree of variability of the climate. Geologic setting also strongly influences erosion.

Storm runoff accounts for the majority of surface erosion. The amount of runoff depends largely on the rate and amount of precipitation, vegetation, slope, and soil type.

The amounts and rates of precipitation and infiltration dictate the amount of water available for erosional processes. It is also affected by the amount and type of vegetation. Vegetation retards erosion by intercepting rain, increasing the infiltration rate, and the root system increases the cohesiveness of the soil. The degree of slope also affects the erosion process. Generally, the steeper the slope, the faster the rate of erosion. Soil type, depth, and structure affect erosion in many ways. Generally speaking, the soils subject to the high erosion are those which are fine grained and have low organic content. Soils most resistant to erosion are coarse grained; i.e., gravel, or clay with high organic content.

Sheet flow, overland flow which is not restricted to channels, occurs when precipitation exceeds the infiltration capacity of the soil. As sheet flow moves downslope, the water becomes concentrated into channels and small gullies, called rills, begin to form. As subsequent runoff and erosion continue, the rills advance headward, dissecting the slope. This type of erosion can be quite rapid and may occur naturally or after a slope has been altered. Activities such as construction, farming, or deforestation can bare the soil and render a slope much more susceptible to subsequent erosion.

Wind erosion involves two processes: abrasion and deflation. Abrasion of the surface by airborne silt and sand is very slow and should not present a significant problem in disposal siting. Deflation, however, can be a cause for concern. Deflation is the removal of sand or dust by wind. When natural vegetation is removed or disturbed, deflation hollows, or blowouts, can quickly develop. Deflation basins are common in many parts of the Eastern Plains and many have formed in the last few 100 to few 1,000 years, well within the time parameters set for this study.

Care must be taken when developing disposal sites. Mitigation procedures should be developed to avoid excessive erosion during excavation and after closure. Revegetation and protection of the cap by armoring should be integral parts of the development and closure plans for a site to protect against long-term erosion. Generally, the mitigation measures taken to protect a site from water erosion will be sufficient to protect it from wind erosion as well. This may not always be true, however, and both phenomena should be investigated thoroughly to insure proper mitigation of these problems.

General Geomorphologic Criteria

- Stable surface, such as low drainage divides, not subject to erosion greater than 0.5 $\frac{\text{acre ft}}{\text{mi}^2/\text{yr}}$
- Areas with base levels which are appreciably higher than surrounding areas should be avoided.
- Natural slope should be between 2 percent and 5 percent.
- Deflation potential should be evaluated and mitigation procedures developed for areas where the potential is significant.

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GEOCHEMISTRY OF SHALE - WASTE-MATERIAL RELATIONSHIPS

The chemical interactions between clays and inorganic* and organic* pollutants vary tremendously. Inorganic pollutants consist chiefly of metal cations*, some anions*, and gases. These include Pb^{+2}, Cr^{+6}, Cu^{+2}, Zn^{+2}, Co^{+2}, Mn^{+2}, Ni^{+2}, Hg^{+2}, Cd^{+2}, Cl^{-}, SO_2^{-}, CO, O_3, and oxides of nitrogen. Organic pollutants encompass a broad spectrum of compounds including pesticides, polychlorinated byphenyls (PCBs), aromatic* species of various kinds arising from industrial activity, fluorine compounds in aerosols, and so forth. The phenomena of ion exchange*, protonation*, coordination*, hydrogen bonding*, catalytic degradation*, polymerization*, and so forth, may be involved at one point or other in the interaction between clays and pollutants. In natural systems, it is likely that clays and clay complexes play an important role in absorbing and transporting some kinds of polluting species.

Clay - Inorganic-Pollutant Relationships

The interactions of metal ions with clays include adsorption by ion exchange, precipitation as hydroxides or hydrous oxides on clay surfaces, and adsorption as complex species. The pH* and Eh* are critical factors in determining the nature of the interaction between clays and some transition and heavy-metal ions. Recent investigations indicate that the cation exchange capacity is the principal chemical property of a clay for predicting its neutralization potential. Common clay minerals occurring in marine shales include montmorillonite*, illite* and kaolinite*. Montmorillonite tends to have the highest attenuation capability for inorganic pollutants, followed by illite and kaolinite.

Recent studies by Griffin and Shimp (1978) indicated that certain heavy-metal cations were attenuated primarily by ion exchange--an adsorption mechanism that is affected by pH and competition from other cations. These investigators found that at pH values between 5 and 6, a large increase in removal can be expected due to the increased adsorption of metal-complex ions and to formation of insoluble heavy metal hydroxide and carbonate compounds.

This leads to the conclusion that at highly acidic pH the primary mechanism of attenuation for these ions was precipitation. The effect of pH on the attenuation of the heavy metal anions is the opposite of the cations and that precipitation was not an important attenuation mechanism. The adsorption of the anions correlates well with the distribution of certain ionic species in solutions (Griffin and Shimp, 1978).

With respect to Cr(VI), for example, it was concluded that $HCrO_4^-$ was the adsorbed species, since its adsorption became zero as the pH was raised to 8.4, corresponding to its disappearance from solution in favor of the CrO_4^{-2} ion. They also found that the adsorption of Cr(VI) decreased as the pH was lowered past 2, corresponding to the decrease in $HCrO_4^-$ ion in favor of H_2CrO_4.

As(V) and Se(IV) adsorption was found to correspond to the distribution of $H_2AsO_4^-$ and $HSeO_3^-$ species in solution. Griffin and Shimp (1978) concluded that the principal attenuation mechanism for these heavy-metal anions was adsorption of the monovalent species from solution. Further, at higher pH values the heavy metal anions are significantly more mobile than the cations. The relative mobilities of the heavy metal cations, determined from equilibrium adsorption data from pure solutions of the metals at $pH^{=5}$ were: Cr^{+3} < Cu^{+2} < Pb^{+2} < Cd^{+2} <As^{+5} <As^{+3} < Se^{+5} r^{+6}. The heavy-metal cations are generally adsorbed to a greater degree than are the heavy metal anions depending on pH and ionic competition.

The results from various studies suggest that passage of leachate through Ca^{+2} saturated clay, i.e. montmorillonite, will result in high attenuation of the heavy metals, in moderate attenuation of K^{+1}, NH_4^{+1}, Mg^{+2}, and Si^{+4}, and in relatively low attenuation of C^{-1}, Na^{+1}, and water-soluble organic compounds.

The oxidation - reduction potential* (Eh) of the leachate controlled the attenuation of Fe^{+2} and Mn^{+2}. Under strongly anaerobic conditions, Fe^{+2} and Mn^{+2} will probably not be attenuated and may even elute in substantial concentrations due to the dissolution of oxide coatings on the clay surfaces. Under mildly anaerobic conditions, substantial attenuation can occur.

Organic-Clay Relationships

The adsorption of organic species by clay minerals depends upon the structural properties of the compound as well as the nature of the clay and its exchangable cations. Organic cations adsorb on clays by ion exchange and are usually preferred over the inorganic ions by the exchange complex because of their large size and high molecular weights. Certain hazardous organic compounds such as Paraquat and Diquat are strong bases and are completely ionized in water. Other organic compounds, while being neutral molecules at the ambient pH of the solution phase, may become protonated after adsorption at the clay surface. Another kind of organic-clay interaction is the coordination or ion-dipole type. Compounds which have nitrogen, oxygen, sulfur, or olefinic groups, have electron pairs which may be donated to electrophilic cations to form complexes on the clay surface. An important consideration here in natural systems is the competitive effect of water for these adsorption sites, such as is the case for organo-phosphorus pesticides. Still another kind of organic-clay interaction is hydrogen bonding. Other factors involved in clay-organic interactions include physical forces such as surface tension and entropy effects.

Recent studies of the adsorption, mobility, and microbiological degradation of Polychlorinated biphenyls (PCBs) in soil materials have proven to be fruitful. PCBs were found to be immobile in various soils consisting of clay and organic material when leached with aqueous solvents such as water and landfill leachates (Griffin and others, 1978). However, they became highly mobile when leached with organic solvents. The adsorption capacity and subsequent immobility of PCBs showed a high positive correlation with organic-carbon content and the amount of the respective soil.

Microbial degradation of PCBs was studied by Griffin and others (1978) using several mixed cultures of PCB-degrading microorganisms. Aerobic degradation of water soluble-Aroclor 1242 was 92 percent complete within 20 hours and as high as 98 percent within 10 days.

In order to achieve maximum stability/compatibility between the types of pollutants and the waste repository, it is essential that a careful study be conducted concerning the design of such a site. Important factors to consider include: the hydrologic system governing the direction of the migration of the pollutant, the geochemistry of the water-sediment system, and the release rate of labile pollutants to surface or ground waters. Current repository design and engineering practice are to construct thick clay liners, either natural or synthetic, that contain high percentages of clay minerals. The motive is to design relatively impermeable liners that will contain the leachate, thus preventing contamination of ground-water/surface-water resources. This approach can create difficulties in humid climates where infiltration exceeds the capacity of the liner to dissipate the leachate.

Griffin and Shimp (1975) studied the relative mobilities of chloride ion, heavy-metal cations, and ammonium ion as a function of the percentage of montmorillonite used in a clay liner (Figure 6). Chloride is extremely mobile where the containing medium is high in clay content (i.e., low attenuation number). However, the chloride ion is considered to be relatively nontoxic when compared with the heavy metals. Pb is almost completely removed by small percentages of clay (i.e., high attenuation number). For the case of NH_4^+ it is apparent that 18 to 20 percent montmorillonite would give nearly total removal from the leachate. Note the drastic reduction of the initial hydraulic conductivity with the increase of percentage of montmorillonite. Table 1 summarizes the relative mobilities of various chemical species.

General Discussion of Geochemistry

The clay-pollutant interaction within synthetic and natural systems must be well understood in order to accurately model and predict the behavior or compatibility of the various pollutants within different types of host rocks. Preliminary data indicates that the attenuation of heavy-metal cations is due to the precipitation of insoluble heavy-metal hydroxide and carbonate compounds at high pH values. The attenuation of heavy-metal anions is strongly dependent on the adsorption of monovalent species from solution. Further, heavy-metal anion attenuation is not dependent upon precipitation, which is the case for

TABLE 6

Summary of Relative Mobility of Chemical Species Through Clay-Mineral Columns

Modified from Griffin and Shimp, 1978; Yaron, 1977

	Chemical Constituent	Principal Attentuation Mechanism	Relative Mobility
1	OPP	adsorption-exchange	Low
	Pb	Precipitation/Exchange	Low
	Zn	Precipitation/Exchange	Low
	Cd	Precipitation/Exchange	Low
	Hg	Precipitation/Exchange	Low
2	PCB	adsorption/Microbial Degradation	Low
	Fe	Oxidation-Reduction	Moderate
	K	Cation Exchange	Moderate
	NH4	Cation Exchange	Moderate
	Mg	Cation Exchange	Moderate
3	WSOC (Dicamba)	Microbial Degradation	High
	Na	Cation Exchange	High
	Mn	Elution from clay	More eluted
	Ca	Exchange from Clay	than applied

1 Organophosphorus Pesticides (including parathion, pirimiphos-methyl and pirimiphos-ethyl)

2 PCB have low mobility when leached with aqueous solvents (water and landfill leachate). However, they are extremely mobile when leached with organic solvents.

3 WSOC Water soluble organic compounds

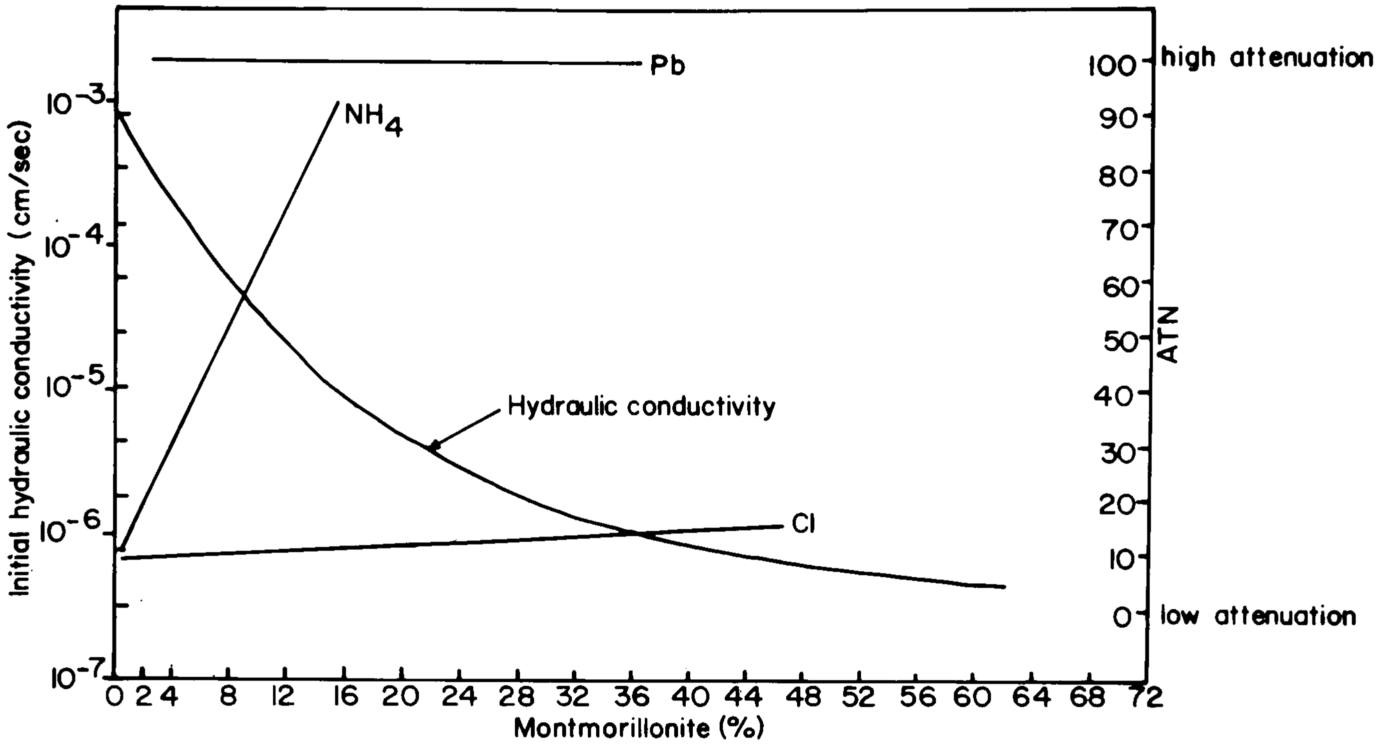

Figure 6. Effect of clay content on hydraulic conductivity and attenuation of Pb, NH_4, and Cl for a 40-cm. thick liner. (from Griffin and Shimp, 1978).

heavy metal cation attenuation. The heavy-metal cations are generally absorbed to a greater degree than are the heavy-metal anions, depending on pH and ionic competition.

The attenuation of organic species is primarily due to various adsorption mechanisms which are strongly dependent upon the structural properties of the compound as well as the nature of the clay and its exchangable cations (Figure 6). Within recent years numerous research projects have been conducted in order to quantitatively predict the suitability of the clay-pollutant system. The results of these various studies have proved to be helpful; however, a complete understanding of this critical aspect of the hazardous-waste-storage problem has not been achieved. Accordingly, continued and careful attention to this phenomenon is recommended in siting, operation, and monitoring of future hazardous-waste sites.

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CLIMATE

Climatic considerations for hazardous-waste-disposal siting include precipitation, evaporation, wind, and attendant erosion.

Precipitation and Evapotranspiration

Areas prone to frequent, severe thunderstorm activity and/or flooding should be avoided because of the serious adverse effects on a hazardous-waste-disposal site. Flooding of a site during operation can result in the immediate escape of pollutants. After closing of the site, flooding can cause severe erosion of the repository's protective cap or containing sides with attendant release of wastes and/or by-products. The 24-hour storm can be used as a gauge for determining areas prone to severe thunderstorms and flooding. Areas downstream of storm-prone areas should be evaluated for susceptibility to flooding. This situation is discussed in greater detail in the section on surface hydrology.

A major factor in climatic considerations is the relationship between evapotranspiration* (the total water loss from evaporation and transpiration from plants) and precipitation. If evapotranspiration exceeds precipitation by an appreciable amount, then percolation of water through most soils is restricted to shallow depths and meteoric or surficial water does not contact the waste material. Some highly porous soil or rock units will transmit water below the root zone more rapidly than it can be used by the vegetation resulting in vertical recharge to the aquifer. When precipitation exceeds evapotranspiration, water can percolate through a landfill and toxic materials may be carried off in solution as harmful leachate forms. This leachate can reach the ground water system and pollution may occur.

Wind

Wind velocity and duration should be considered in the analysis of potential hazardous-waste-disposal sites during routine operational handling or a breach of containment. The direction of prevailing winds in relationship to population centers should be considered in site selection because of the potential for airborne transport of hazardous materials. Severe winds (greater than 50 mph) can cause containment, personnel safety, and handling problems during operation of a landfill. Wind erosion can seriously reduce the long-term integrity of the facility after closure.

Colorado

Most of Colorado is semiarid. With the exception of the mountainous areas, the mean annual precipitation is less than 25 in./yr (Figure 7), and the mean-annual pan evaporation is approximately 40 to 90 in./yr (Figure 8). Pan evaporation is utilized as a close approximation of evapotranspiration (Veihmeyer, 1964). Historically, most severe thunderstorms have occurred along the Front Range and in an area between Castle Rock, Colorado Springs, Black Forest, and the forks of Bijou Creek (Hansen, 1978). However, all parts of the state have the potential for isolated intense cloudbursts and associated flooding and erosion.

Generally, wind patterns in Colorado are westerly. Local, small-scale variations can occur due to topography. Severe winds of long duration occur predominantly along the Front Range of Colorado, but can occur with lesser frequency everywhere in the state.

General Climatic Criteria

- The mean annual evaporation should exceed the mean annual precipitation by 20 in./yr.
- The maximum 24-hour storm should be evaluated and demonstrated to present no significant threat to the long-term integrity of the disposal facility.
- Sites should be located downwind from population centers with respect to prevailing wind patterns, and
- Away from recognized areas of frequent high winds.

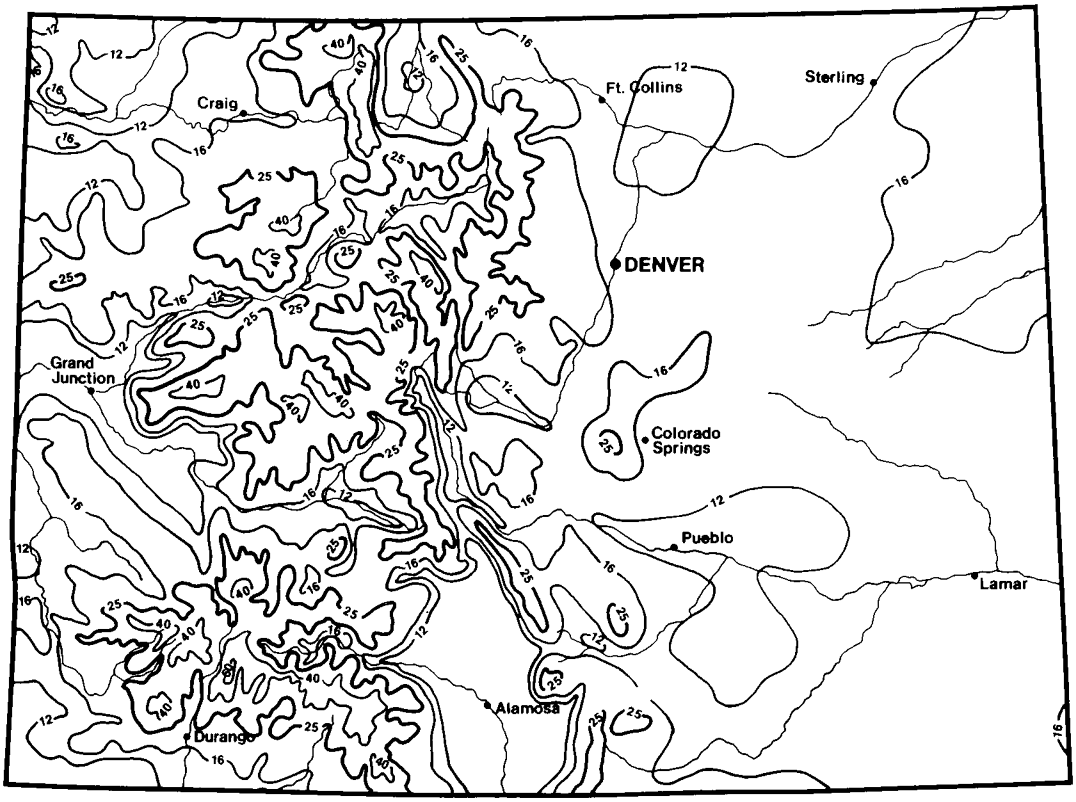

Figure 7. Mean annual precipitation in inches (U.S. Weather Bureau).

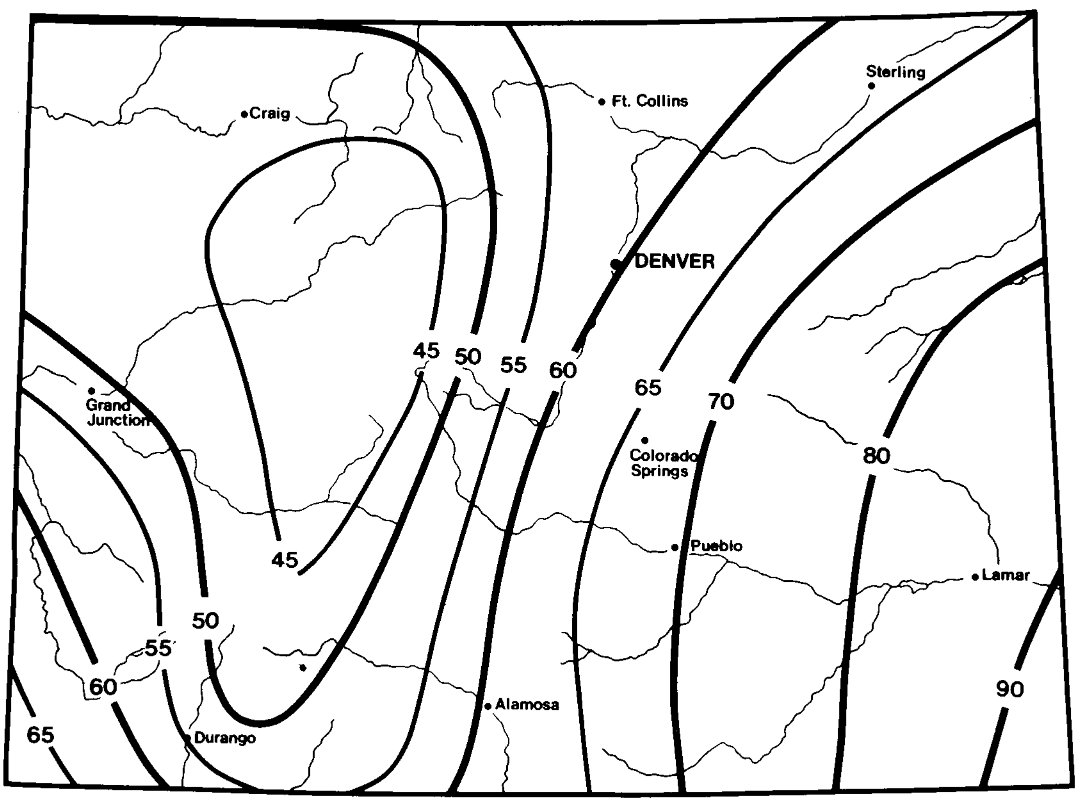

Figure 8. Normal annual Class A pan evaporation in inches (U.S. Weather Bureau).

Sources of Information

The National Weather Service has prepared precipitation-frequency analyses for Colorado. Information is also available from the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the U.S. Department of Agriculture Soil Conservation Service. It is important that the most recent information from these sources is used since they are revised periodically as additional data are acquired.

Winds in Colorado have been studied by the National Center for Atmospheric Research, the U.S. National Oceanographic and Atmospheric Administration, and the University of Colorado.

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APPENDIX B

GUIDELINES FOR THE CONDUCT OF SITE-SUITABILITY INVESTIGATIONS AND PREPARATION OF GEOLOGIC REPORTS FOR HAZARDOUS-WASTE-DISPOSAL SITES

A geotechnical report for hazardous-waste disposal must provide all necessary information relating to the engineering, geology, and environmental protection of the proposed disposal site. This information enables the applicant and reviewing agencies to make decisions relating to this activity with the full benefit of all relevant data and interpretations. In addition to normal parameters for any engineering-geologic investigation, the evaluation of site suitability for disposal of hazardous waste requires attention to certain special factors. These include the need for long term containment of the hazardous waste of concern, and continuing reconnaissance of the site after closure due to the serious nature of the health and environmental hazards associated with the leakage of the wastes to the environment. Investigation of these factors should conform to the relevent definitions, and criteria and regulations of the U.S. Environmental Protection Agency, the Colorado Department of Health, and the Colorado Geological Survey as cited in these guidelines.

Determination of geologic, hydrologic, and geotechnical parameters and the interrelations of these to the proposed activities constitute the principal contribution of the required report(s). These topics are usually presented as a separate section supported by specific geological data and explanation text. Relationships discussed should include (1) effects of the geological conditions on the proposed operation, and (2) effects of the proposed activity upon future geological processes and conditions in the area. These relationships are the key to determining the long-term safety of the project with regard to potential geologic hazards and constraints and the evaluation of pertinent parameters required for adequate containment of the hazardous wastes and their derived products.

To this end the following outline is presented as a general guide for preparation of engineering-geologic reports. This outline describes and recommends many specific investigations and studies. Some items may require particular emphasis because of the nature of the hazardous waste. Additional items not presented in this outline may be necessary for a particular site or other specific situations may render parts of the outline inapplicable. Judgements must be made by the professional geologist preparing the reports as to the geologic conditions that should be emphasized in the report. However, completeness of geotechnical reports and analyses are essential if delays in the review process are to be minimized. General guidelines not specifically related to hazardous wastes were adapted from Shelton and Prouty (1979) and Shelton and Junge (1979).

Reports should be prepared in accordance with the highest current standards of the profession, realizing that omissions of pertinent data are as serious an error as giving misinformation. The report must be prepared and signed by a Professional Geologist as defined by Colorado law (C.R.S. 1973, 34-1-120, et seq.).

GENERAL COMMENTS ON GEOLOGIC MAPPING AND REPORT PREPARATION

A. Each report must be the product of independent geologic study and mapping of the subject area at an appropriate scale and level of investigation to yield the required detail and kinds of relevant data. It will be necessary for the geologist to extend his mapping into adjacent areas to assure the ultimate suitability of the site.

B. All mapping should be done on a detailed topographic base map with satisfactory horizontal and vertical control. The base map should be the same scale as that used for the project plans so that the two can be easily compared.

C. Mapping by the geologist should reflect careful attention to the physical characteristics, lithology, structural elements, and three-dimensional distribution of the earth materials exposed or inferred within the area. In most areas these materials will include both bedrock and surficial deposits. Exploratory drill holes and test pits will be necessary in all cases to provide data and/or check interpretations.

D. Where three-dimensional relationships are significant but cannot be described satisfactorily in words alone, the report should be accompanied by appropriately positioned cross sections.

E. Locations and descriptions of test holes and other specific sources of subsurface information should be included in the report, on the geologic map, and on the cross sections.

GENERAL INFORMATION

A. Project Description

1. Present zoning, land use and status of the proposed site and surrounding area.

2. Indicate size and type of operation and relationship to adjoining areas.

B. Location

1. Specify site location in terms of section, township, range, and county.

2. Depict site location on an index map of appropriate scale, usually U.S. Geological Survey 7.5 minute quadrangle map or county maps at 1:50,000.

C. Scope

1. Make reference to any previous geologic investigations used in preparation of the report.

2. Indicate the commissioning person or organization.

3. Nature and source of information used, including geologic environmental and health impacts.

4. List all methods of investigations as well as professional firm(s) and individuals who participated.

5. If the level of investigation varies within the subject areas, describe in the text and show on the maps areas of concentration or exclusion

D. Regional Setting

1. Describe the general physiographic setting of the site and its relationship to local topographic features.

2. Describe general geologic setting of the site and indicate any lithologic, tectonic, geomorphic or soils problems specific to the area.

3. Describe general surface and ground water conditions and their relationship to the site.

4. Describe the known or probable mineral resources in the area.

5. Describe the climate in the area.

SPECIFIC GEOTECHNICAL INFORMATION

The report should contain specific descriptions of the hydrology and geology of the site and of the geotechnical aspects as they apply to hazardous waste disposal. The following section will be divided into these two categories. Where interpretations are involved the basis for such interpretations should be clearly stated. References should be given for all information submitted which is not a direct result of the specific investigations conducted for the particular site-suitability study.

GENERAL GEOLOGY DESCRIPTIONS

The following checklist should be used as a general guide but may not be a complete list of all relevant geologic parameters.

A. Bedrock units

   1. Rock type
   2. Age of and correlation with recognized formations.
   3. Dimensional characteristics such as thickness and extent.
   4. Distribution and surface expression of bedrock units.
   5. Physical and chemical characteristics.
   6. Distribution and extent of the weathered zone.
   7. Response of bedrock materials to natural processes.
   8. Regional and geohydrology of the bedrock units.

B. Surficial deposits

   1. Regional and local structural setting.

      Location and distribution of structure(s).
   2. Identification of material types.
   3. Dimensional characteristics such as thickness and extent.

4. Surface expression and relationships with present topography.

5. Physical and chemical characteristics.

6. Distribution and extent of altered zones.

7. Response of surficial materials to natural processes.

8. Geohydrology of the surficial units.

C. Structural features

1. Occurrence and distribution.

2. Dimensional characteristics.

3. Orientation and changes in orientation.

4. Special effects on the bedrock.

5. General seismo-tectonic environment.

6. Fault capability (e.g.: location, magnitude, and association with faults or fault systems).

D. Surface drainage

1. Distribution and occurrence.

2. Relations to topography (drainage density and patterns).

3. Relations to geologic features.

4. Source and permanence.

5. Variations in amounts of flow.

6. Evidence of earlier occurrence of water at localities now dry.

7. Estimated peak flows and physiographic flood plain of drainages (including flash flood and debris flood areas). Use probable maximum flood or 100-year flood, depending on land use and need for protection.

8. Water quality.

9. Use of surface waters.

E. Ground water

1. Distribution and occurrence (confined and unconfined).

2. Hydraulic gradients.

3. Recharge areas for aquifers.

4. Relations to topography.

5. Relations to geologic features.

6. Seasonal variations.

7. Water quality.

8. Use of ground waters.

F. Other features of special significance (Rogers and others, 1974).

1. Accelerated erosion and/or deposition.

2. Lateral spreading failures.

3. Subsidence or settlement (including hydrocompaction and piping).

4. Soil creep.

5. Slump and slide masses in bedrock and/or surficial deposits.

6. Deposits related to geologically recent flooding.

7. Rockfall areas.

8. Subsidence over underground mines or naturally created voids.

9. Seismic hazards (Kirkham and Rogers, 1978).

10. Expansive soil and rock.

11. Snow-avalanche areas.

12. Geomorphic processes.

13. Potential mineral resources (e.g., possible conflicts with other mineral resources).

ANALYSIS OF RELATIONSHIP OF GEOLOGIC FACTORS AND HAZARDOUS-WASTE DISPOSAL

This analysis is usually presented as a separate section supported by the above mentioned geologic descriptions and normally constitutes the principal findings of the report. The analysis should evaluate (1) the effects of geologic conditions upon the proposed construction and operation of the site and (2) the effects of these proposed modifications upon forseeable future geologic processes and conditions in the area. This evaluation ultimately should address site suitability, project feasibility, and evaluate whether or not it is reasonable to develop the subject property as planned. Special attention should be given to standards set by the State of Colorado and the U.S. Environmental Protection Agency.

The following checklist includes the items that ordinarily should be considered in preparing this section of the geologic report:

A. Climatology

1. A thorough examination of wind patterns with emphasis on severity of winds and proximity of population centers.

2. Precipitation and evaporation data and trends should be documented or ascertained.

3. The theoretical 24-hr, 50-yr, and maximum-anticipated storms should be calculated and their effects analyzed.

4. Deflation potential should be evaluated with respect to long term breach of containment due to loss of protective cover.

B. Surface Hydrology

1. Investigation of the potential for contamination of streams by overflow or spillage.

2. Potential for sheet erosion.

3. Location of all perenial and ephemeral streams with respect to potential loss of containment.

4. Proposed flood protection.

5. A complete investigation of flood potential in the area and its impact on the site should be performed.

C. Ground Water

1. Describe ground water quality.

2. Complete three dimensional representation of aquifers, surficial and bedrock, within 500 ft of the surface and their relationship to the site.

3. Describe hypothetical flow patterns from the waste site substantiated by on-site investigations.

4. Map and describe all aquifer-recharge areas.

5. Describe present flow patterns, depth to water table, and rate of ground-water movement.

6. Document all wells and exploratory borings within one mile of the site.

D. Lithology

1. Describe the lithology, including subsurface data, of the bedrock and surficial deposits in the area.

2. Describe subsurface relationship of permeable and impermeable units to the proposed site.

3. Determine in-situ permeability of host rock.

4. Provide well logs and cross sections of the site to a depth of at least 500 ft below the bedrock-soil interface.

E. Structure

1. Location, spacing, and proximity of faults, joints, and fractures.

2. Seismic history.

3. Description of folding.

F. Geomorphology

1. Describe landforms in the area.

2. Avoid areas of high relief, such as buttes and mesas, which are relatively sensitive to changes in the regional baseline of nearby streams.

3. Describe the type(s) of surface and its potential for erosion.

4. Avoid physiographic floodplains.

5. Determine slope stability.

G. Geochemistry

Recommendations

1. Perform detailed mineralogical, physical, and chemical studies of the selected clay mineral(s) in order to determine their exact suitability or compatibility with various types of pollutants (organic and/or inorganic).

2. Determine the chemical-physical relationships between the clay mineral(s) and the specific wastes to be disposed of by conducting laboratory studies coupled with in situ "in the field" observations. Various physical and chemical parameters to consider include: pH, Eh, ion exchange capacities, precipitation products, and so forth, of the clay mineral and the type(s) of pollutant.

3. Frequent field inspections, such as soil sampling, should take place in order to assure that a closed system between the waste-disposal site and the surrounding media is constantly maintained and to verify or modify the assumptions and interpretations utilized in the original suitability studies.

H. Special Recommendations

1. Describe any possible geologic barriers to the surface and subsurface movement of waste material.

2. Possible mitigation of any of the aforementioned problems.

3. Description and availability of liner materials for prevention of fluid migration.

4. Describe the nature and availability of the cover material proposed for site.

5. Describe the ongoing monitoring procedures and design conditions to be employed during operation of the site and after final closure.

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APPENDIX C

GLOSSARY

Absorption Taking up, assimilation, or incorporation within the structural lattice of solid bodies.

Actinide Series includes elements with atomic numbers 90 to 103 (includes Th, Pa, U, and transuranic elements).

Adsorption Adhesion of molecules of gases, or of ions or molecules in solutions, to the surfaces of solid bodies with which they are in contact.

Anion An atom or group of atoms that has a net negative charge resulting in an excess of valence (outermost) electrons. Examples include Cl^{-1}, O^{-2}, F^{-1}, SO_4^{-2}, HCO_3^{-1}, and so forth.

Aromatic Compounds Organic compounds that resemble benzene in chemical behavior.

Attenuation Number (ATN) A numerical rating system which quantitatively states the amount of immobility of a chemical compound or simple ion through each particular clay or clay-mixture column. ATN numbers are unique for each element/compound and each clay.

Aquifer A body of rock or unconsolidated earth material that contains saturated permeable material to conduct ground water/fluid which may or may not be utilized by man.

Aquitard A confining bed that retards but does not completely prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water. Cf: aquiclude.

Catalytic Degradation Degradation of a chemical species caused by an increase in the rate of a chemical reaction, induced by the presence of a substance that is not permanently altered by the reaction.

Cation Any element, atom, or group of atoms that has a net positve charge resulting in a lack of valence electrons. Examples included Ca^{+2}, Fe^{+2}, Mg^{+2}, Al^{+3}, Si^{+4}, etc.

Claystone An indurated clay having the texture and composition of shale however lacking the fine lamination or fissility characterized by a shale.

Capillary tension See moisture tension.

Coordination Refers to the number and arrangement of atoms attached to the central atom within a molecule.

Eh oxidation-reduction potential measured in a cell having the oxidized and reduced form of an element.

Electrophilic A property of a chemical substance, which by virtue of a deficiency of valence elections, tends to cause the acceptance of electrons from other atoms or molecules.

Evapotranspiration Loss of water from a land area through transpiration of plants and evaporation from the soil.

Fault A surface or zone of rock fracture along which there has been significant relative displacement ranging from a few centimeters to a few kilometers in scale.

Geologic hazard A geologic phenomenon which is so adverse to past, current, or foreseeable construction or land-use as to constitute a significant hazard to public health and safety or to property.

Geomorphology The science that treats the general configuration of the earth's surfaces, including the classification, description, nature, origin, and development of present land forms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

Ground Water That part of the subsurface water that is the zone of saturation (a subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere), including underground streams.

Heavy metal Any of the metals that react readily with dithizone, e.g., Zn, Cu, Co, Pb, Bi, Au, Cd, Fe, Mn, Ni, Ta, Te, Pt, Ag, and others.

Hydraulic Conductivity see permeability

Hydrogen bonding A type of Van der waals bond involving hydrogen and other atoms (i.e., O, F, C), resulting in a relative, weak chemical bond.

Hydrology The science that deals with the continental water (both liquid and solid), its properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the ocean.

Illite A general name for a group of three-layer, mica-like minerals lacking an expandable lattice, similar in chemical composition as to the montmorillonite group.

Inorganic Any chemical compound that does not contain the element carbon, with the exception of the oxides of carbon, compound, containing a carbonate group, carbon disulfide, phosgene, carbonyl sulfide, and metallic carbonyls.

Ion Exchange Capacity The reversible replacement of certain ions by others, without loss of crystal structure. It occurs in interlayer exchangeable ions or in channelways of weak bonding.

Joint A surface or zone of rock fracture in which there has been no relative displacement. However, fracturing is present.

Kaolinite A common clay mineral of two layer slightly expandable lattice of the general formula: $Al_2Si_2O_5(OH)_4$

Lithology The description of rocks; sedimentary, metamorphic, and igneous; on the basis of such characteristics as color, structures, mineralogic composition, and grain size.

Mineral Commodity: See Mineral Deposit

Mineral Deposit A mass of naturally occurring mineral material e.g. metal ores or nometellic minerals (elements) occurring in solid, liquid or gaseous state, usually of economic value.

Moisture tension In a soil, negative gage pressure of the water, equal to the equivalent pressure, necessary to bring the soil water to hydraulic equilibrium through a porous wall, with a pool of water of equivalent composition.

Montmorillonite A group of three layer expanding-lattice clay minerals of general formula: $R_{0.33}Al_2Si_4O_{10}(OH)_2 \cdot nH_2O$, where R includes one or more of the cations Na^+, K^+, Mg^{2+}, Ca^{2+}, and possibly others.

Oxidation-Reduction Potential See Eh

Permeability The property or capacity of a porous rock, sediment, or soil for transmitting a fluid without impairment of the structure of the medium; it is a measure of the relative ease of fluid flow under unequal pressure.

pH A symbol denoting the negative logarithm of the hydrogen ion concentration (usually expressed as moles/liter): used in expressing relative acidity (pH <7) and alkalinity (pH >7) neutrality = PH7; pH values range from 0 to 14.

Polychlorinated biphenyls (PCBs) A class of chlorinated organic compounds which are highly persistent in the environment and tend to bioaccumulate in food chains much the same way as DDT does. Studies involving human exposure have shown numerous adverse effects.

Polymerization The process of changing the molecular arrangement of a compound so as to form new compounds having the same percentage composition as the original, but of greater molecular weight and different properties.

Protonation The process by which a proton (hydrogen ion) is transferred from one chemical species (e.g., atom, molecule, ion) to another chemical species, the latter normally having a pair of electrons to share with the proton.

Radioactivity The spontaneous decay of unstable atoms of certain elements into new and different atoms. Example, U^{238} decays to Pb^{206} + 8 alpha particles.

Shale A fine-grained (<1/256 mm), indurated, detrital sedimentary rock formed by the consolidation of clay, silt, or mud.

Soil Moisture See Moisture Tension.

Tectonic Pertaining to the forces involved in, or the resulting structures or features resulting from the deformation of the earth's crust.

Transuranic element(s) Includes elements with atomic numbers (number of protons within the nucleus) greater than or equal to 92 up to 103. These include the following elements U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, and Lw. These elements have been produced by spontaneous radioactive decay of Uranium.

Unconfined aquifer Ground water that has a free water table; i.e., water not confined under pressure beneath relatively impermeable rocks. Unconfined aquifers are composed of granular materials, such as mixtures of clay, silt, sand, and gravel.

Unit Head The unit pressure of a fluid per unit area, at a given point caused by the height of the fluid surface above the point.

Zone of Saturation A subsurface zone that includes the water table and is under pressure greater than or equal to that of the atmosphere.

Zone of Unsaturation A subsurface zone that lies above the water table and is under pressure less than that of the atmosphere.

* Definitions were taken verbatim or modified from the Glossary of Geology 1972 by Margaret Gary, Robert McAfee Jr., and Carol L. Wolf published by American Geological Institute, Washington, D.C.

PART III

LEGAL RAMIFICATIONS OF EXCLUDING OUT-OF-STATE DISPOSAL

by

Janice L. Burnett

Office of the Colorado Attorney General

NOTE: Cases and opinions presented in this section are based upon the situation as of December, 1979. Many of these cases are under appeal to higher authority and, therefore, the legal status of this issue should be periodically reviewed in detail to determine the present legal status.

III. LEGAL RAMIFICATIONS OF EXCLUDING OUT-OF-STATE DISPOSAL

INTRODUCTION

The legislature required, in the context of S.B. 336, a study of the legal ramifications of legislation that would maintain hazardous-waste-disposal sites for the exclusive use of wastes originating in Colorado. C.R.S. 1973, 24-15-101(2)(d). There are three methods to prevent out-of-state use of hazardous-waste-disposal sites in Colorado that have been considered: 1) outright exclusion by legislation; 2) *de facto* exclusion by charging higher fees; and 3) selective exclusion of certain wastes. There are significant legal problems arising from each of these alternatives which are discussed herein.

OUTRIGHT EXCLUSION

The legislature has inquired as to whether it could legally prevent disposal of hazardous wastes originating outside of Colorado in Colorado sites. Similar legislation which attempted to exclude solid wastes originating outside of New Jersey from use of New Jersey landfills was recently struck down as unconstitutional by the United States Supreme Court in *Philadelphia v. N.J.*, 437 U.S. 617 (1978). In that case, which is closely analogous with the situation herein, New Jersey passed a statute which prohibited the importation of solid and liquid waste which originated or was collected outside of New Jersey. The Supreme Court held that the statute violated the Commerce Clause of the United States Constitution insofar as it operated to stop the flow of commerce for reasons of economic protectionism:

> The New Jersey law blocks the importation of waste in an obvious effort to saddle those outside the State with the entire burden of slowing the flow of refuse into New Jersey's remaining landfill sites. That legislative effort is clearly impermissible under the Commerce Clause of the Constitution.

Supra at 629. The Court isolated as a significant factor in its reasoning its conclusion that a state cannot discriminate against an article of commerce unless there is some reason, apart from its origin, to treat it differently. It should also be noted that Philadelphia v. N.J clearly specified that wastes are to be considered articles of commerce for purposes of the interstate commerce clause. Supra at 622-623.

The Tenth Circuit, following Philadelphia v. N.J., held that an Oklahoma statute which excluded industrial waste from out-of-state violated the Commerce Clause. Hardage v. Atkins, 582 F.2d 1264 (10th Cir. 1978). In that case, Oklahoma had enacted a statute which forbade the importation of controlled industrial waste from out-of-state unless the state of origin had enacted similar standards for controlled industrial waste disposal as Oklahoma. The court said that the statute was invalid as a form of economic protectionism. See also Oklahoma State Department of Health v. Lamberton, 582 F.2d 1267 (10th Cir. 1978); Dayton Power & Light Co. v. Lindley, 391 N.E. 2d 716 (Ohio 1979).

Philadelphia v. New Jersey, supra, which is strong authority against attempts to exclude out-of-state users from Colorado disposal sites, is not a radical departure from a long line of cases which have held, in essence, that legislation that discriminates against out-of-state articles of commerce, solely on the basis of their origin, is invalid whatever the motivation of the legislation may have been. See, e.g., Baldwin v. G.A.F. Seelig, Inc., 294 U.S. 511 (1935); Foster-Fountain Packing Co. v. Haydel, 278 U.S. 1 (1928); Johnson v. Haydel, 278 U.S. 16 (1928); Edwards v. California, 314 U.S. 160 (1941); Oklahoma v. Kansas Natural Gas Co., 221 U.S. 229 (1911); Pennsylvania v. West Virginia, 262 U.S. 553 (1923).

Thus, the weight of authority is contrary to any legislation which would seek to overtly prevent the use of Colorado hazardous-waste-disposal sites by citizens from out-of-state. It is significant to note, however, that the Supreme Court did not overturn or undermine the viability of a series of cases which upheld laws which banned the importation of articles because of their innate harmfulness. These so-called "quarantine cases" are exceptions to the rule that discrimination against out-of-state articles is unconstitutional insofar as they are not considered to be protectionist measures. Baldwin v. G.A.F. Seelig, Inc., supra; Bowman v. Chicago & Northwestern R. Co., 125 U.S. 465 (1888); Asbell v. Kansas, 209 U.S. 251 (1908); Reid v. Colorado, 187 U.S. 137 (1902). Thus, it is critical in Philadelphia v. N.J. that New Jersey demonstrated no facts to show that the movement of waste endangers health, or that the waste had to be disposed of as close to its point of generation as possible. In this sense, these facts would demonstrate why there is a reason, apart from their origin, to treat out-of-state articles differently from in-state articles. If the facts ascertained can show that the movement of hazardous waste over long distances, for example, endangers the health and safety of the citizens of Colorado, it is arguable that such discriminatory legislation could be upheld.[1]

LIMITATION OF USE BY DIFFERENTIAL FEES

Charging higher fees to out-of-state users to preclude disposal in Colorado sites is not expressly prohibited. Any fee charged by the State of Colorado to out-of-state users of a Colorado hazardous-waste-disposal site which is higher than that charged to in-state users, however, is subject to challenge under the Commerce Clause and must be scrutinized according to a balancing test which includes the following factors:

> 1) does the statute regulate evenhandedly with only "incidental' effects on interstate commerce or does it discriminate against interstate commerce either on its face or in practical effect;
>
> 2) does the statute serve a legitimate local purpose;
>
> 3) are there alternative means which could promote this local purpose as well without discriminating against interstate commerce.

See Hughes v. Oklahoma, ___ U.S. ___ (4/24/79); Pike v. Bruce Church, Inc., 397 U.S. 137 (1970); Winkler v. Colo. Dept. of Health, 564p.2d 107(1977).

Any significant difference in fees charged to residents and nonresidents will be determined by a court to be discriminatory on its face and will therefore subject the statute or regulation to a strict-scrutiny test.

A so-called "legitimate" local purpose, such as conserving the use of resource such as a hazardous-waste-disposal site will not be sufficient to overcome the presumption of unconstitutionality which arises from a facially-discriminatory fee scheme.

Moreover, if local use of the disposal site is basically unfettered or unrestricted, it will be determined that alternative means which are less offensive to the free flow of interstate commerce have not been adequately explored.

If it can be shown, however, that the fee differential is imposed to achieve partial cost equalization between those who do and those who do not contribute to the state's economy through payment of taxes, there is a better chance that the scheme will be upheld. Starns v. Malkerson, 326 F. Supp. 234 (D.Minn. 1970), aff'd per curiam 401 U.S. 985 (1971) Clark v. Redeker, 259 F. Supp. 117 (1966); Sturges V. Washington 368 F. Supp. 38 (1973). Or, if it can be shown that there are uniformly imposed graduated fees relating to the degree of use of the site, Toomer v. Witsell, 334 U.S. 34 (1947), or a fee differential to compensate the state for any added enforcement burden, Toomer v. Witsell, supra, the higher fees will probably be upheld . The courts have looked very strictly at these fee distinctions, however, and will look behind any purported legitimate reason to ascertain whether the impact on interstate commerce is too severe. For example, in Toomer v. Witsell, supra, which was actually a challenge under the privileges and immunities clause of the Constitution, South Carolina attempted to impose fees for shrimping in off-coast waters of $25 for residents and $2500 for nonresidents. Agreeing that the state can charge differential fees for cost equalization purposes or graduated fees according to the size of shrimping boats, the Supreme Court could find no reasonable relationship between the so-called dangers of noncitizens and the extensive discrimination practiced upon them. Clearly, it was the size of the differential that determined the outcome of that case. See also Mullane v. Anderson, 342 U.S. 415 (1951).

Any significant fee differential imposed by the state is also subject to challenge under article IV, section 2 of the United States Constitution (privileges and immunities clause). If the fee imposed by the state is determined to place an unreasonable burden on citizens of other states from pursuit of common callings (i.e. operation of a waste disposal or transportation business), it may be held to affect a fundmental right under the privileges and immunities clause. See Ward v. Maryland , 12 Wall. 418 (1871); Baldwin v. Fish and Game Commission of Montana, 436 U.S. 378 (1978). If a so-called fundamental right is affected, then the classification based on noncitizenship must be justified by a clear relationship between the discrimination imposed and the harm represented by the class of noncitizens. This is, in effect, the same kind of balancing test which is imposed in a commerce clause analysis (discrimination based on place of origin or noncitizenship is invalid "unless there is something to indicate that noncitizens constitute a particular source of the evil at which the statute is aimed." Toomer v. Witsell, supra at 398) and the same results will occur.

Allegations of the invalidity of differential fees under the equal protection clause presents a similar challenge to such legislation or regulations. It is clearly within the state's police power to protect the public from health hazards, Winkler v. Colo. Dept. of Health, supra. If, however, the right to engage in the occupation of disposal of hazardous wastes is classified as a fundamental right, then the "strict scrutiny" or "compelling state interest" test will be applied, subjecting the legislation to a similar analysis as set forth above.

Selective exclusion of certain wastes

If a statute regulates evenhandedly and has only incidental effects on interstate commerce, it will be held valid. Pike v. Bruce Church, Inc., supra; Tuscan Dairy Farms, Inc. v. Barber, 380 N.E.2d 179 (N.Y. 1978); Davis v. Md., 390 A.2d 1112 (1978). Thus, a viable alternative to either the restriction of Colorado hazardous waste disposal sites to in-state use or the charging of fee differentials may be the total exclusion from hazardous waste disposal sites of certain articles. Since in-state residents will be subject to the same restrictions as out-of-state residents, the commerce clause does not appear to be impacted.

Even such a facially neutral statute or regulation will not pass without close analysis if challenged in court. For example, in Mapco v. Grunder, 470 F. Supp. 401 (N.D. Ohio 1979), Ohio attempted to impose a graduated tax on coal which applied uniformly to out-of-state persons as well as to its residents. The tax was graduated according to the degree of sulphur in the coal; the lower the sulphur level the higher the tax. The court found that since all of the coal produced in Ohio was high-sulphur coal, and virtually all low-sulphur coal was produced outside of Ohio, that the tax in practical effect discriminated against out-of-state coal producers and violated the commerce clause. Similarly, if Colorado attempted to exclude from its hazardous-waste-disposal sites certain articles which in fact are not found in Colorado but only out-of-state, it may be subject to the same attack.

CONCLUSIONS AND RECOMMENDATIONS

The cases in which an attempt by a state to discriminate between its own citizens and citizens from other states in the area of commerce that have been struck down as unconstitutional are overwhelming in number. Philadelphia v. New Jersey, supra, which is closely analogous to the situation presented herein, is only one of a series of United States Supreme Court cases which have refused to allow a state to legislate to "conserve" its own resources to protect the health, safety or welfare of its citizens, if such legislation or regulation significantly interferes with interstate commerce. Therefore, any attempt by the state to either exclude outright the use of its hazardous waste disposal sites or to exclude the use de facto by charging exorbitant fees to out-of-state users will be clearly challenged, and most likely, successfully.

If it is ascertained that legislation excluding in some manner out-of-state use of Colorado hazardous waste disposal sites is critical to the interests of the state and that legislation should be passed despite the probability of a successful challenge being brought against it, any such legislation must contain specific facts justifying the circumstance in order to even attempt to meet constitutional scrutiny. It is recommended that the legislation include the following factors if such a course of action is taken.

Outright Exclusion

To posture the case for the best anticipated argument, it is recommended that any legislation which is written to exclude out-of-state use of Colorado hazardous-waste-disposal sites includes facts which demonstrate that the movement of hazardous wastes over long distances is inherently dangerous to the health and safety of the people. The Court in Philadelphia v. N.J., supra, noted the absence of any such claim from the record in that case.

Further, the extreme danger of hazardous wastes, per se, must be stressed. Philadelphia v. N.J., supra, appears to have involved solid wastes, not hazardous wastes.[2] The majority did not consider solid waste in and of itself as inherently harmful, at least not until it had been disposed of in landfill sites. (The dissent in Philadelphia v. N.J., supra, did note that the importation of solid wastes creates a serious health and safety problem to the residents of New Jersey which are analogous to the interests protected by the quarantine laws which have been consistently upheld by the Court. Philadelphia v. N.J., supra at 631.)

If it can be shown that out-of-state wastes can be distinguished from in-state waste by the latter's proximity to a disposal site and by the need to have such inherently toxic materials disposed of with as little movement as possible, then the chances of success are greatly improved.

Differential Fees

If the difference in fees charged for the use of a disposal site is so marked that it is obviously an attempt by the state to exclude out-of-state use, it will be struck down in a court challenge. Under these circumstances, it would be better to attempt outright exclusion under the preceding analysis.

Some fee differential can be justified, however. It is essential that facts be developed to conclusively show that the fee distinction is imposed as a partial cost equalization. Courts are approaching these fee differentials with tremendous skepticism and are quick to render their conclusions based on the practical effect of the discrimination. Obviously, the larger the differences in fees between in-state users and out-of-state users, the greater the burden imposed on the state to justify the differentiation.

[1] Although Hardage v. Atkins, supra, appears to be contrary to that position, that case can be distinguished as it turned on the existence of the reciprocity requirement in the statute. In fact, the Tenth Circuit stated that no argument that the reciprocity clause served to ensure health standards could be entertained because Oklahoma required a reciprocity clause even if another state had higher standards than Oklahoma.

[2] N. J. Admin Code 7:1-4.2 (Supp. 1977) specifically excepts from its scope "pesticides, hazardous wastes, chemical waste, bulk liquid, bulk semi-liquid" which is to be treated, processed or recovered other than by disposal on or in the land of New Jersey.

DEPARTMENT OF NATURAL RESOURCES
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

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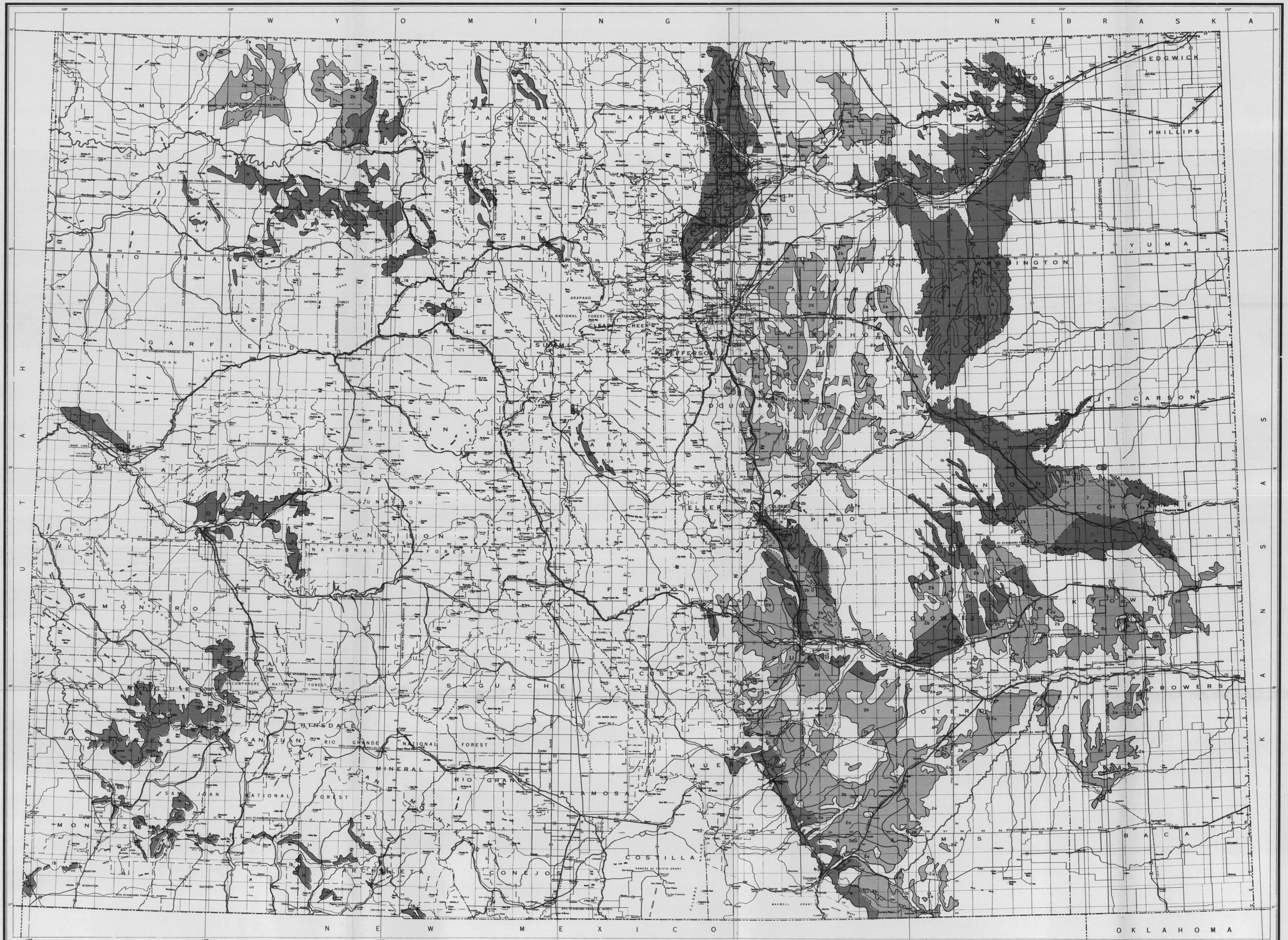

Base from U.S.G.S.

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COLORADO'S GEOLOGIC POTENTIAL FOR HAZARDOUS WASTE DISPOSAL

by

J. L. Hynes, P. A. Longmire, and T. Hatton

EXPLANATION

HOST ROCK SUITABILITY CLASSIFICATION SCHEME

The formations ranked below are divided into most suitable and marginally suitable host media for storage of hazardous waste. This selection is based on the following criteria (further discussed in the explanation and accompanying text):

- Contain a minimum thickness of 150 feet of impermeable shale or clay with in-place permeabilities less than 1×10^{-7} cm/sec. (0.1 ft/yr)
- Outside of ground water recharge/discharge areas.
- Outside of floodplain-Quaternary-Tertiary valley fill basins/drainage.
- Tectonically stable, structurally simple.
- Not within close proximity of igneous or geothermal activity.
- Areas with lowest sediment yield ranging from 0 < 0.2 acre ft/sq mi/yr are ranked "a" and those with sediment yield ranges from 0.2 to 0.5 acre ft/sq mi/yr are ranked "b" to reflect susceptibility to erosion. Covered areas are not ranked with respect to erosion susceptibility.

Group 1 Optimum conditions for potential storage of non-nuclear hazardous industrial waste, include the following argillaceous formations (except where highly fractured):

Pierre Shale of eastern Colorado (includes upper and lower sections)

Mancos Shale of western Colorado

Lewis Formation of northwestern and west central Colorado

San Jose Formation of southwestern Colorado

Group 2 Marginal suitability potential storage of non-nuclear hazardous industrial waste including the following argillaceous formations:

Pierre Formation - Middle Section of eastern Colorado.

Dawson Arkose, including Denver Formation of east-central Colorado.

Laramie Formation of east-central Colorado

Niobrara Formation of southeastern Colorado

Benton Shale, including Carlile and Graneros Shale members, of southeastern Colorado

Wasatch Formation of northwestern Colorado

Lance Formation of northwestern Colorado

——— Contact

- - - - Covered formation contact

DISCUSSION

Introduction

One of the more common methods employed to achieve long-term isolation of hazardous wastes from the environment is secure burial at a carefully selected and managed hazardous waste disposal site. The purpose of this map is to identify and rank generalized areas within the State of Colorado which, based upon reconnaissance studies, appear to be favorable for storage of non-nuclear, industrial wastes. This map has been generated from sources of information best characterized as regional in nature and therefore is not intended to provide site-specific information pertaining to the suitability of a particular locality for storage of such waste.

The suitability classifications presented here are based on evaluation of geologic, hydrologic, and physiographic conditions only. Other factors, such as access or population density were not considered. Many geologically suitable areas will be eliminated from final consideration on the basis of other such factors.

The map shows the areas where the physical conditions fall into a given category. Suitable sites can be found within these areas. However, detailed analysis may reveal local exceptions where conditions do not conform to the stated criteria. Conversely, there may be suitable locations outside the indicated areas. However, the likelihood of finding and developing such sites is much lower and the expense will probably be significantly greater than in the specified areas. In the great majority of cases, the map will prove accurate as determined by the stated criteria. This map is intended to be an effective tool for generalized hazardous waste planning and should serve as a guide for site selection. It should not be used as a substitute for detailed analysis of specific sites.

Numerous physical characteristics must be considered in the evaluation of potential hazardous waste disposal sites. These include hydrology, geology, geochemistry, structural geology, geomorphology, climatology, and mineral resources. Pertinent aspects of each of the above criteria and the areal classification scheme for suitable areas within Colorado are summarized here and are discussed in greater detail in the accompanying text.

HYDROLOGY

The single most important consideration in the development of suitability criteria for hazardous waste disposal sites is the protection of ground and surface water from contamination by leaking wastes or secondary byproducts. Surface water can be contaminated by runoff or introduction through recharge of ground water which has been polluted and vice versa. Protection of aquifers--geologic rock units which contain water and are, or can be utilized by man--is extremely important.

General Criteria

- A minimum thickness of 150 ft of impermeable material between the site and any aquifer (or potential aquifer).
- The actual disposal excavation should be below the interface between bedrock and the overlying surficial material. The landfilled waste material should lie entirely within the containing medium below the top of the bedrock.
- A thorough evaluation of specific sites should include:
  1. the direction and rate of groundwater flow,
  2. depth to the water table,
  3. presence of aquifers should be ascertained and their relationship to the site, the surrounding area, and its hydrology should be evaluated.
- A minimum distance of 100 ft of impermeable material must be maintained between the bottom of any proposed excavation and historical high water table.
- A minimum distance of one mile to any perennial stream channel or positive isolation from the stream by local topography.
- Avoidance of physiographic floodplain and low terraces.

GEOLOGY

Geologic conditions in the vicinity of a proposed waste disposal facility must be thoroughly analyzed. The lithology, permeability, thickness, and areal extent of the formation(s) present must be well understood and determined to be well suited for hazardous waste disposal.

Minimum permeability and thickness for suitability as a hostrock on this map are 10^{-7} cm/sec (10^{-3} gallons/day/ft^2-0.1 ft/year) and 150 feet of homogeneous shale or clay.

Geologic hazards such as avalanches, landslides, rockfalls, mudflows, debris fans, unstable slopes, excessive erosion, seismic activity, and ground subsidence must be avoided.

Suitable Host Rock Formations

Group I - Formations with highest potential for safe, long term containment of hazardous waste

1. Pierre Shale - (upper and lower sections) eastern plains area, eastern Colorado
2. Mancos Shale - northwestern, southwestern Colorado
3. Lewis Shale - northwestern Colorado
4. San Jose Formation - southwestern Colorado

Group II - Formations with marginal potential for safe storage of hazardous waste

1. Pierre Shale - (middle section) eastern plains area, eastern Colorado
2. Niobrara Fm.- eastern, southeastern Colorado
3. Wasatch-Lance Formations - northwestern Colorado
4. Benton Group - eastern Colorado
5. Laramie Formation - eastern plains area, eastern Colorado
6. Denver-Dawson Formation - eastern plains area, eastern Colorado

GEOCHEMISTRY

The chemical and physical compatibility of the host medium and waste material must be such that long term suitability within the closed system can be achieved and maintained. Detailed geochemical, mineralogical, and physical investigations must be conducted by empirical methods in order to precisely demonstrate the exact nature of the compatibility between the waste material and selected formations.

Recommendations

1. Perform detailed mineralogical, physical, and chemical studies on the selected clay mineral(s) in order to determine their exact suitability or compatibility with the various types of pollutants (organic and/or inorganic).
2. Determine the chemical-physical relationship between the clay mineral(s) and the specific wastes to be disposed of by conducting laboratory studies coupled with in situ (on the site) observations. Various physical and chemical parameters to consider include: pH, Eh ion exchange capacities, precipitation products, etc., of the clay mineral and the type(s) of pollutant.
3. Frequent field inspections, such as soil and water sampling, should take place during operation of the facility in order to assure that a closed system between the waste disposal site and the surrounding media is constantly maintained and to verify or modify the assumptions and interpretations utilized in the original suitability studies.

STRUCTURAL GEOLOGY

Structural geology is the study of the deformation of rocks, including folding and faulting. Structural or tectonic activity usually tends to modify the bulk characteristics of rock units in a manner that is deleterious to suitability of the rock as a hazardous waste disposal site.

Faults, joints, and fractures can serve as a conduit for the passage of fluids within a rock mass. Known faults should be avoided because of their possible deleterious affects on a site.

General Criteria

- The geologic structure of the area should be simple enough to be well understood and evaluated with respect to site suitability.
- Thorough site investigation to reveal the presence of faulting and jointing within the general study area.
- A minimum of one mile to any major fault/ tectonic feature.
- Select areas that are devoid of moderate to severe structural deformation.
- Avoid areas in close proximity to igneous or geothermal activity.
- Avoid areas of anomalous heat flow gradients.

GEOMORPHOLOGY

Topography and slope characteristics should be evaluated to insure long term protection from excessive surface erosion. Low slopes, less than 2%, generally do not provide positive drainage, resulting in surface retention, ponding, and possible high rates of infiltration. Slopes greater than 5% are subject to relatively high rates of erosion which can cause eventual breaching of the repository cells and escape of hazardous materials.

Local topographic highs, such as buttes and mesas, will erode at a faster rate than surrounding areas. Streams tend to dissect these areas and provide a means of transporting hazardous wastes from the disposal site.

Recommendations

- Stable surface, such as low drainage divides, not subject to erosion greater than 0.5 $\frac{\text{acre ft}}{\text{mi}^2/\text{yr}}$
- Areas with base levels which are appreciably higher than surrounding areas should be avoided.
- Natural slope should be between 2% and 5%.

CLIMATOLOGY

Climatic considerations for hazardous waste disposal sites include precipitation, evaporation, wind, and attendant erosion. Areas prone to frequent severe thunderstorm activity and flooding should be avoided because of the deleterious effects on a hazardous waste disposal site. Wind velocity and duration should be major factors involved in the analysis of a potential site. Severe winds (greater than 50 mph) can cause containment and handling problems during operation of a landfill, and wind erosion can seriously reduce the integrity of the facility after closure.

Recommendations

- The mean annual evaporation should exceed the mean annual precipitation by 20 in/yr.
- The maximum 24-hour storm should be no greater than 6 inches.

MINERAL RESOURCES

The potential burial site and vicinity should be evaluated for the presence of various potentially commercial or critical mineral commodities. These include uranium, thorium, other trace metals, coal, oil, oil shale, gas, precious and base metals, geothermal localities,

Presence of potentially commercial mineral resources are not necessarily preemptive, but should be carefully described so that it can be used in site-search evaluations at all stages.