REGIONALIZED FEASIBILITY STUDY
OF COLD WEATHER EARTHWORK

William S. Roberts

July 1976

Prepared for
DIRECTORATE OF MILITARY CONSTRUCTION
OFFICE, CHIEF OF ENGINEERS

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Approved for public release; distribution unlimited.
A regional approach is used to delineate areas in Canada, Alaska, and the conterminous United States, in which selected earthwork operations should receive careful consideration for winter execution. Soil texture and soil "form" or physical site environment are deemed important physical factors in the economic feasibility of cold weather earthwork. A compatible modern physiographic map of Canada, Alaska, and the conterminous United States compiled for this study is presented. The physiographic section is the basic areal unit used in the evaluation of winter earthwork feasibility. A generalized soil texture map for Canada, Alaska, and the conterminous United States is developed from geologic and pedologic information. Summary maps showing areally significant soil forms and
20. Abstract

related feasible earthwork operations are presented. A general discussion of the importance of the soil form in the economic feasibility of winter earthwork is included. A summary matrix is presented which shows, with respect to physiographic sections, the salient information and conclusions developed by this study. At least 94% of physiographic sections have two or more winter earthwork operations that are deemed feasible. Only 5 of 213 sections considered do not have any earthwork operations that appear feasibly implemented in the winter season. Inefficiency curves for manual labor, excavation, and hauling operations, as a function of season and geographic location, are shown. These curves are based on efficiency data published in a Swedish survey, and are calculated from the meteorological factors of temperature, lighting, and precipitation. Such curves can serve as a qualitative guide for those involved in scheduling earthwork in geographic areas where there is little or no previous experience.
This report was prepared by William Stephan Roberts, and was submitted in partial fulfillment for the degree of Master of Science, Purdue University, in May 1976.

The study was funded under DA Project 4K078012AAM1, *Engineering Criteria for Design and Construction (Cold Regions)*. It was performed under Contract DACA89-72-C-0011, with Purdue Research Foundation, Purdue University.

The writer would like to acknowledge the help of and thank the principal project advisor and committee co-chairman, Dr. C.W. Lovell, Professor of Civil Engineering.

Dr. T.R. West, Associate Professor of Geosciences, and committee co-chairman was very helpful in offering suggestions and guidance. The effort of Professor R.D. Miles, who served on the Graduate Advisory Committee and reviewed this manuscript, is also acknowledged.

An acknowledgement of special thanks and gratitude go to the U.S. Army Cold Regions Research and Engineering Laboratory and to the Project Officer, Mr. Francis H. Sayles, for providing funding for this study.

Mr. John H. Day, National Soils Correlator of the Soil Research Institute, Ottawa, Ontario, also deserves thanks for providing the writer with unpublished soil texture information for Canada.

The writer would also like to thank draftspersons Janet Reid and Yogesh Shah. Janet Schrodde, chemical technician, and James Lambrechts, graduate teaching assistant, deserve thanks for help with a computer program for the inefficiency curve calculations.

Virginia Ewing typed the manuscript. A special note of appreciation goes to my wife Kathy for providing support, encouragement and inspiration.
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>viii</td>
</tr>
<tr>
<td>1:0 ABSTRACT</td>
<td>ix</td>
</tr>
<tr>
<td>2:0 PURPOSE</td>
<td>1</td>
</tr>
<tr>
<td>3:0 GEOGRAPHIC LIMIT OF STUDY AREA</td>
<td>2</td>
</tr>
<tr>
<td>4:0 METHOD OF APPROACH TO PROBLEM</td>
<td>4</td>
</tr>
<tr>
<td>5:0 PHYSIOGRAPHIC MAPPING</td>
<td>7</td>
</tr>
<tr>
<td>5:1 The Physiographic Unit</td>
<td>7</td>
</tr>
<tr>
<td>5:2 Hierarchy of Physiographic Units</td>
<td>8</td>
</tr>
<tr>
<td>5:3 Usefulness of the Physiographic Section As a Basic Areal Unit</td>
<td>12</td>
</tr>
<tr>
<td>5:4 Complete List of Physiographic Units in Canada and the United States (excluding Hawaii)</td>
<td>13</td>
</tr>
<tr>
<td>5:5 Precision of Physiographic Maps</td>
<td>13</td>
</tr>
<tr>
<td>6:0 SOIL TEXTURE MAPPING</td>
<td>30</td>
</tr>
<tr>
<td>6:1 Usefulness of Soil Texture Mapping</td>
<td>30</td>
</tr>
<tr>
<td>6:2 Definitions of Soil</td>
<td>31</td>
</tr>
<tr>
<td>6:3 Definition of Soil Textures</td>
<td>32</td>
</tr>
<tr>
<td>6:4 Soil Texture Map Units</td>
<td>35</td>
</tr>
<tr>
<td>6:5 Method of Soil Texture Compilation</td>
<td>39</td>
</tr>
<tr>
<td>6:5:1 Conterminous United States</td>
<td>39</td>
</tr>
<tr>
<td>6:5:2 Canada</td>
<td>40</td>
</tr>
<tr>
<td>6:5:3 Alaska</td>
<td>41</td>
</tr>
<tr>
<td>6:6 Limitations of Generalized Soil Texture Mapping</td>
<td>41</td>
</tr>
</tbody>
</table>
7:0 EARTHWORK vs. COLD WEATHER

7:1 Technologically Feasible Cold Weather Earthwork Operations

7:2 Economically Feasible Cold Weather Earthwork

7:3 Working Efficiencies vs. Weather Factors

8:0 SOIL BEHAVIOR AT LOW TEMPERATURES

8:1 Frost Susceptibility

8:2 Compactibility

8:3 Frozen Soil Strengths

9:0 SOIL BEHAVIOR RELATED TO FEASIBLE COLD WEATHER EARTHWORK OPERATIONS

9:1 Fill and Compaction

9:2 Excavation and Hauling

9:3 Rock Blasting and Rock Crushing

9:4 Ditching and Pipe Laying

9:5 Culvert Work, Outflow Work, and Clearing and Grubbing

10:0 SITE SOIL FORMS AND THEIR AREAL DISTRIBUTION

10:1 No-Soil Areas

10:2 Organic and Wet Soil Areas

10:3 Plastic Soils

10:4 Clayey Soils

10:5 Coarse-Textured Soils

10:6 Permafrost Areas

11:0 SUMMARY

12:0 CONCLUSIONS

13:0 RECOMMENDATIONS FOR FURTHER EFFORT

14:0 REFERENCES

14:1 References Cited

14:2 General References

15:0 APPENDIX

15:1 Usefulness of Inefficiency Curves

15:2 Method of Calculating Inefficiency Curves

15:3 Data Input for Inefficiency Curve Calculation

15:4 Symbols Used in Inefficiency Curves

15:5 Inefficiency Curves

# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>A categorical breakdown of the physiographic units used in the base map compilation</td>
<td>9</td>
</tr>
<tr>
<td>2.</td>
<td>Approximate equivalence of physiographic units as used by different authors</td>
<td>11</td>
</tr>
<tr>
<td>3.</td>
<td>List of Divisions and Provinces of North America (excluding Mexico)</td>
<td>14</td>
</tr>
<tr>
<td>4.</td>
<td>Complete list of physiographic units for Canada and United States (excluding Hawaii)</td>
<td>16</td>
</tr>
<tr>
<td>5.</td>
<td>Textural classes as defined by size of primary soil particles</td>
<td>34</td>
</tr>
<tr>
<td>6.</td>
<td>Range of soil textural classes or soil textural class combinations as related to pedologic and report textural groups</td>
<td>38</td>
</tr>
<tr>
<td>7.</td>
<td>Rank ordering of technically advisable winter earthwork operations</td>
<td>44</td>
</tr>
<tr>
<td>8.</td>
<td>Rank ordering of economically advisable winter earthwork operations</td>
<td>48</td>
</tr>
<tr>
<td>9.</td>
<td>Manual labor efficiencies related to temperature, lighting, and precipitation</td>
<td>50</td>
</tr>
<tr>
<td>10.</td>
<td>Hauling and excavation efficiencies related to temperature, lighting, and precipitation</td>
<td>51</td>
</tr>
<tr>
<td>11.</td>
<td>Frost design soil classification</td>
<td>59</td>
</tr>
<tr>
<td>12.</td>
<td>Summary Matrix Relating Physiographic Sections to Soil Forms and Feasible Cold Weather Earthwork Operations</td>
<td>84</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Limit of study area and its relationship to Sourwine's freezing border</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>A comparison of the term &quot;soil&quot; in the engineering and pedologic sense</td>
<td>33</td>
</tr>
<tr>
<td>3.</td>
<td>Percentages of sand and clay in each textural class. Remainder of each class is silt</td>
<td>36</td>
</tr>
<tr>
<td>4.</td>
<td>Relationship of soil textural classes to verbal pedologic textural classes</td>
<td>37</td>
</tr>
<tr>
<td>5.</td>
<td>Comparison of climatic zones in Sweden as determined by different authors</td>
<td>53</td>
</tr>
<tr>
<td>6.</td>
<td>Trewartha's climatic classification of Alaska, Canada, and conterminous United States</td>
<td>54</td>
</tr>
<tr>
<td>7.</td>
<td>Example inefficiency curve based on monthly temperature, lighting, and precipitation</td>
<td>55</td>
</tr>
<tr>
<td>8.</td>
<td>Summary envelopes relating frost susceptibility to natural soil gradations</td>
<td>60</td>
</tr>
<tr>
<td>9.</td>
<td>Freezing soil temperatures and moisture content as related to soil compaction</td>
<td>62</td>
</tr>
<tr>
<td>10.</td>
<td>Generalized areas in which organic terrain (muskeg) presents engineering problems</td>
<td>76</td>
</tr>
<tr>
<td>11.</td>
<td>Wetlands of Canada expressed as percentages of grid area</td>
<td>78</td>
</tr>
<tr>
<td>12.</td>
<td>Mode of occurrence and distribution of permafrost in Alaska and Canada</td>
<td>80</td>
</tr>
</tbody>
</table>
LIST OF PLATES

Plate
1. Physiographic Divisions of Alaska, Canada and United States ..........
2. Physiographic Divisions and Provinces of Alaska, Canada and United States ....
3. Physiographic Provinces and Sections of Alaska, Canada and United States ....
4. Physiographic Sections and Subsections of Alaska, Canada and United States ....
5. Engineering Soil Texture Map of Alaska ....
6. Engineering Soil Texture Map of Canada
   a. Western ................
   b. Eastern ................
7. Engineering Soil Texture Map of the United States of America
   a. Western ................
   b. Eastern ................
8. Summary Map of Areally Significant No-Soil Occurrences and Potentially Economical Winter Earthwork Operations ...........
10. Summary Map of Areally Significant Plastic Soil Occurrences and Potentially Economical Winter Earthwork Operations .........
11. Summary Map of Areally Significant Coarse Textured Soil Occurrences and Potentially Economical Winter Earthwork Operations
2:0 PURPOSE

The overall purpose of this research is (1) to evaluate the state of the art for cold weather earthwork, and (2) to propose steps for the logical development and advancement of cold weather earthwork in North America.

The first objective was addressed in a report by Bieganousky in 1973 (5). The second objective was approached regionally; i.e., recommendations for an increased level of cold weather earthwork were related to physiographic units.

It is hoped that this report will provide some direction in research, planning and construction functions, particularly for those agencies and organizations with broad geographic interests and jurisdiction in North America.
3:0 GEOGRAPHIC LIMIT OF STUDY AREA

The study area includes the portion of North America which usually experiences significant ground freezing. Sourwine's freezing border, shown on Figure 1, approximates the southern boundary of significant frost potential based on climatic conditions in the conterminous U.S. (58). With the physiographic section being the basic areal unit in this report, the writer has defined the southern limit of study in the conterminous U.S. by the Witczak (70) physiographic boundaries that best approximate Sourwine's freezing border.

The boundary of potential frost in extreme southwestern Canada and Alaska was logically extended along mapped physiographic boundaries after reviewing monthly mean temperature data.
Figure 1. Limit of study area and its relationship to Sourwine's freezing border. (58)
4:0 METHOD OF APPROACH TO PROBLEM

This report is based on the general premise that cold weather earthwork can be shown to be technologically feasible. Previous studies have shown that cold weather earthwork operations can be economically justified if a cost-benefit analysis considers the economic advantages achieved by scheduling selected earthwork operations during cold weather (2,27,37,47). Certain operations in permafrost regions, organic soil, wet soil, and clay soil areas are commonly best accomplished in the winter season.

With the premise noted above, it has been attempted to match geographic areas with feasible cold weather earthwork operations. Since it has been clearly shown (2,27,47) that for cold weather earthwork to be of most benefit very careful planning and scheduling are required, the writer has attempted to delineate areas in which specific earthwork operations should receive careful attention in the planning stage.

The regional approach used in this report is necessarily a general one, based upon average or modal conditions (70). This approach allows an initial
prediction for a specific site, but detailed investigation is required to establish the degree of variance from the modal condition.

Specific location information is presented in the form of inefficiency curves for earthwork operations for 86 stations within the study area. These curves emphasize the importance of seasonal planning and can provide significant input for scheduling by regional agencies.

In summary, an assessment of the determination of the economic feasibility of cold weather earthwork necessitated the following steps:

1) a literature survey and review of the state-of-the-art of cold weather earthwork

2) determination of earthwork operations that can be economically feasible in winter

3) determination of factors which control the feasibility of cold weather earthwork

4) compilation of a soil texture map for the study area

5) evaluation of climatic conditions over the study area

6) determination of a basic areal unit upon which to base general predictions

7) a ranking of cold weather earthwork operations with respect to economic feasibility and soils conditions

8) relating of earthwork operations to study area units

Bieganousky's report (5) provided an overall summary of the state-of-the-art of cold weather earthwork. Many
references cited in his work were consulted to provide background information.
5:0 PHYSIOGRAPHIC MAPPING

5:1 The Physiographic Unit

A physiographic unit, as defined by Malott (14), is
"... an area or division of the land in which the
topographic elements of altitude, relief, and type
of land forms are characteristic throughout and
as such is set apart or contrasted with other areas
or units with different sets of characteristic
topographic elements."

Thus, a unique physiographic unit reflects an area of
similar structure which has undergone similar
geomorphic processes for a similar period of time. Rock
fabric, structure, and composition interrelate with the
landforms which exist today. It is not surprising that
in the preparation of the report maps, it was noted that
there is a coincidence in the distribution of soil origin
and/or texture and physiographic boundaries. For a concise
review of physiography and its application to engineering
problems, see Witczak's "Relationship Between Physiographic
Units and Highway Design Factors" (71).

The application of physiography to the areal distri-
bution of engineering soils problems in North America was
reported comprehensively by Woods and Lovell in
1960 (72). Subsequent works have demonstrated the useful-
ness of the approach (44,49,55,71).
5:2 Hierarchy of Physiographic Units

This study accepts Witczak's (70) report categories of: 1) division, 2) province, 3) section, and 4) subsection. The division level primarily contrasts physiography at a continental scale. Physiographic provinces reflect major differences in physiographic factors within the division unit. In the United States (exclusive of Hawaii) and Canada there are 39 provinces. Table 1 shows a categorical breakdown of the physiographic units used in this report.

It is apparent that provinces on the whole are vast areas of land which might not permit reliable prediction of engineering problems.

A further breakdown in physiographic units produces the section. This unit, of which there are 257 in Canada and the United States (excluding Hawaii), contains individual mountain ranges, limited soil and rock occurrences, and selective landform sequences. Witczak (70) noted that there was a high degree of correlativity of soil origin/texture distribution and section boundaries. This was also noted in the physiographic map compilation for this report.

The most detailed physiographic unit considered is the subsection, a term coined by Witczak (70). This unit reflects areas of least physiographic variance. Predictions of cold weather earthwork feasibility can undoubtedly be improved by use of the subsection, but the subsection
### Table 1

A categorical breakdown of the physiographic units used in the base map compilation.

<table>
<thead>
<tr>
<th>Category</th>
<th>Primary Source</th>
<th>Number of Units in North America**</th>
<th>Number of Units in Area Designated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>(L)</td>
<td>5</td>
<td>---</td>
</tr>
<tr>
<td>Province</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>(W)</td>
<td>39</td>
<td>11</td>
</tr>
<tr>
<td>Canada</td>
<td>(B)</td>
<td>---</td>
<td>22</td>
</tr>
<tr>
<td>Conterminous U.S.</td>
<td>(Z)</td>
<td>---</td>
<td>21</td>
</tr>
<tr>
<td>Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>(W)</td>
<td>257</td>
<td>60</td>
</tr>
<tr>
<td>Canada</td>
<td>(B)</td>
<td>---</td>
<td>114</td>
</tr>
<tr>
<td>Conterminous U.S.</td>
<td>(Z)</td>
<td>---</td>
<td>94</td>
</tr>
<tr>
<td>Subsection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska (named)</td>
<td>(W)</td>
<td>255</td>
<td>39 (incomplete)</td>
</tr>
<tr>
<td>Canada</td>
<td>(B)</td>
<td>---</td>
<td>13 (incomplete)</td>
</tr>
<tr>
<td>Conterminous U.S.</td>
<td>(Z)</td>
<td>---</td>
<td>211</td>
</tr>
</tbody>
</table>

**NOTE:** Total number of units compiled for North America does not include Mexico. Also, apparent discrepancy of numbers of unit breakdowns with area is due to units overlapping political boundaries.

(L) = Lobeck (34)
(W) = Wahrhaftig (68)
(B) = Bostock (10)
(Z) = Witczak (70)
has not been reliably mapped in Canada and Alaska.

As the mapping of physiography largely depends on the published literature and the mapper's experiences, there is a considerable variety among the available maps. In an attempt to reduce boundary conflicts, only four principal sources were used, which are listed in Table 1. It was assumed that the most complete and detailed source for each large political region was the principal one, i.e., the most authoritative one. The objective was a single, compatible and modern physiographic map for Canada, Alaska, and the conterminous United States.

Non-standardized terminology, as well as a variance in mapping scale, caused minor problems in extending mapped physiographic boundaries across major political borders. Table 2 shows the approximate equivalent of physiographic terms used by the principal authors referred to in Table 1.

When a particular physiographic unit had several name designations, the writer usually chose the name used by the principal source. No significant changes were made in the divisions of North America as determined by Lobeck (34). However, significant changes were made in province and section names and boundaries, as compared with original works such as Lobeck's "Physiographic Diagram of North America" (34). In addition, further work by
Table 2

Approximate equivalence of physiographic units as used by different authors.

<table>
<thead>
<tr>
<th>Unit as used in this report</th>
<th>Lobeck (34)</th>
<th>Wahrhaftig (68)</th>
<th>Bostock (10)</th>
<th>Witczak (70)</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division</td>
<td>Division</td>
<td>Division</td>
<td>Region</td>
<td>Division</td>
<td>Small</td>
</tr>
<tr>
<td>Province</td>
<td>Province</td>
<td>Province</td>
<td>Province</td>
<td>Province</td>
<td>to</td>
</tr>
<tr>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Sub-section</td>
<td>Section</td>
<td></td>
</tr>
<tr>
<td>Subsection</td>
<td>----</td>
<td>Subdivision</td>
<td>(un-named)</td>
<td>Subsection</td>
<td>Large</td>
</tr>
</tbody>
</table>

---- No appropriate equivalent, or does not apply.
several principal authors in their respective geographic areas has resulted in a large addition of new information and new physiographic units.

**5:3 Usefulness of the Physiographic Section as a Basic Areal Unit**

The physiographic section was chosen as the basic areal unit in this report for three reasons: 1) factors which contribute to physiographic boundary definition at this level relate well to factors considered pertinent in this study (soils, parent materials, stage of weathering, and climate), 2) the entire study area has been mapped by physiographers to the section level, and 3) Witczak (71) successfully demonstrated the use of physiographic units in a comprehensive regional report of highway design factors in the conterminous United States.

Engineering problems are reflected in the geographic area's soils, bedrock exposure, relief, structure, and climate, viz., all of the elements which help contribute to physiographic classification. Climate, soils, bedrock exposure, and topographic relief are important parameters in evaluating cold weather earthwork, as well. The physiographic section, with its unique topographic form, is a manifestation of many of the elements considered pertinent to this study.
Hopefully regional planning agencies will be able to use information at the physiographic section level in the decision making process.

5:4 Complete List of Physiographic Units in Canada and the United States (excluding Hawaii)

A list of physiographic units and alpha-numeric coding is presented in Plates 1 through 4 and Tables 3 and 4. The Roman numerals correspond to divisions, numbers indicate provinces, capital letters identify sections, and small letters represent subsections.

(The list of subsections is incomplete for Canada and Alaska.)

5:5 Precision of Physiographic Maps

A wall-mounted opaque projector, capable of enlarging or reducing by a factor of four, was used to transfer data to a common base map. Some difficulty was encountered when maps of different projections were not compatible. In these instances the writer used his judgment and "best fit" the information to the base map.

The base maps were photographically reduced to the report size (approximately 1/18 million). Some distortion was introduced in the reducing process. The four physiographic maps (Plates 1-4) were drawn to allow mutual superposition using a light table. The distortion cited
Table 3

List of Divisions and Provinces of North America (excluding Mexico)

Division I. North America Cordillera

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pacific Coast Ranges</td>
</tr>
<tr>
<td>2.</td>
<td>Pacific Troughs</td>
</tr>
<tr>
<td>3.</td>
<td>Sierra-Cascade Coast Mountains</td>
</tr>
<tr>
<td>4.</td>
<td>Seward Peninsula</td>
</tr>
<tr>
<td>5.</td>
<td>Bering Shelf</td>
</tr>
<tr>
<td>6.</td>
<td>Ahklun Mountains</td>
</tr>
<tr>
<td>7.</td>
<td>Western Alaska</td>
</tr>
<tr>
<td>8.</td>
<td>Northern Plateaus</td>
</tr>
<tr>
<td>9.</td>
<td>Central Plateaus</td>
</tr>
<tr>
<td>10.</td>
<td>Columbia Plateau</td>
</tr>
<tr>
<td>11.</td>
<td>Basin and Range</td>
</tr>
<tr>
<td>12.</td>
<td>Colorado Plateau</td>
</tr>
<tr>
<td>13.</td>
<td>Arctic Rockies</td>
</tr>
<tr>
<td>14.</td>
<td>Northern Rocky Mountains</td>
</tr>
<tr>
<td>15.</td>
<td>Middle Rocky Mountains</td>
</tr>
<tr>
<td>16.</td>
<td>Southern Rocky Mountains</td>
</tr>
</tbody>
</table>

Division II. Interior Plains

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17.</td>
<td>Arctic Foothills</td>
</tr>
<tr>
<td>18.</td>
<td>Arctic Coastal Plain</td>
</tr>
<tr>
<td>19.</td>
<td>Great Plains</td>
</tr>
<tr>
<td>20.</td>
<td>Central and Eastern Lowlands</td>
</tr>
<tr>
<td>21.</td>
<td>Ozark and Ouachita</td>
</tr>
<tr>
<td>22.</td>
<td>Interior Low Plateaus</td>
</tr>
</tbody>
</table>

Division III. Canadian Shield

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>Innuition</td>
</tr>
<tr>
<td>24.</td>
<td>Arctic Lowland</td>
</tr>
<tr>
<td>25.</td>
<td>Bear</td>
</tr>
<tr>
<td>26.</td>
<td>Slave</td>
</tr>
<tr>
<td>27.</td>
<td>Northern Churchill</td>
</tr>
<tr>
<td>28.</td>
<td>Western Churchill</td>
</tr>
<tr>
<td>29.</td>
<td>Eastern Churchill</td>
</tr>
<tr>
<td>30.</td>
<td>Hudson Bay</td>
</tr>
<tr>
<td>31.</td>
<td>Superior</td>
</tr>
</tbody>
</table>
Table 3, cont.

Division IV. Appalachian Highlands

32. Grenville
33. St. Lawrence
34. New England Maritime
35. Appalachian Plateau
36. Newer Appalachian (Ridge and Valley)
37. Older Appalachian
38. Triassic Lowland

Division V. Atlantic Plain

39. Atlantic and Gulf Coastal Plain
Table 4

Complete list of physiographic units for Canada and United States (excluding Hawaii)

Division I. North American Cordillera

1. Pacific Coast Ranges
   A. Kodiak Mountains
   B. Kenai-Chugach Mountains
   C. St. Elias Mountains
      (a) St. Elias Mountains
      (b) Fairweather Range
   D. Gulf of Alaska
   E. Chilkat-Baranof Mountains
      (a) Alsek Ranges
      (b) Glacier Bay
      (c) Chichagof Highland
      (d) Baranof Mountains
   F. Prince of Wales Mountains
   G. Skidegate Plateau
   H. Queen Charlotte Ranges
   I. Vancouver Island Ranges
   J. Pacific Coastal Plain
   K. Olympic Mountains
   L. Oregon Coast Ranges
      (a) Willapa Hills
      (b) Oregon Coast Range
      (c) Oregon Coastal Plain
   M. Klamath Mountains
   N. California Coast Ranges
      (a) Northern California Coast Ranges
      (b) Southern California Coast Ranges
   O. Los Angeles Ranges
      (a) Transverse Ranges
      (b) Los Angeles Basin
      (c) Faulted Peninsular Range

2. Pacific Troughs
   A. Cook Inlet-Susitna Lowland
   B. Broad Pass Depression
   C. Talkeetna Mountains
      (a) Chulitna Mountains
      (b) Fog Lakes Upland
      (c) Talkeetna Mountains
      (d) Clarence Lake Upland
      (e) Talkeetna Foothills

NOTE: Numbers correspond to provinces; capital letters correspond to sections; and small letters correspond to subsections.
Table 4, cont.

D. Upper Matanuska Valley
E. Clearwater Mountains
F. Gulkana Upland
G. Copper River Lowland
   (a) Copper River Lowland
   (b) Lake Louise Plateau
H. Wrangell Mountains
I. Duke Depression
J. Chatham Trough
K. Kupreanof Lowland
L. Queen Charlotte Lowland
M. Hecate Depression
N. Georgia Depression
O. Puget Sound
   (a) Puget Sound Basin
   (b) Basaltic Hills Area
P. Willamette Valley
Q. California Valley

3. Sierra-Cascade Coast Mountains
A. Aleutian Islands
B. Aleutian Range
C. Alaska Range (south part)
D. Alaska Range (central and eastern parts)
E. Northern Foothills of the Alaska Range
F. Coast Mountains (Canadian)
G. Coastal Foothills
H. Northern Cascade Mountains
I. Southern Cascade Mountains
J. Sierra Nevada
K. Lower California

4. Seward Peninsula
   (a) Bendeleben
   (b) Kiglvaik
   (c) York Mountains
   (d) Seward Peninsula

5. Bering Shelf
A. Yukon-Kuskokwim Coastal Lowland
   (a) Yukon-Kuskokwim Coastal Lowland
   (b) Norton Bay Lowland
B. Bering Platform
   (a) St. Lawrence Island
   (b) Pribilof Islands
   (c) St. Matthew Island
   (d) Nunivak Island

6. Ahklun Mountains
Table 4, cont.

7. Western Alaska
   A. Kanuti Flats
   B. Tozitna-Melozitna Lowland
   C. Indian River Upland
   D. Pah River
      (a) Lockwood Hills
      (b) Pah River Flats
      (c) Zane Hills
   E. Koyukuk Flats
   F. Kobuk-Selawik Lowland
      (a) Waring Mountains
      (b) Kobuk-Selawik Lowland
   G. Selawik Hills
   H. Buckland River Lowland
   I. Nulato Hills
   J. Tanana-Kuskokwim Lowland
   K. Nowitna Lowland
   L. Kuskokwim Mountains
   M. Innoko Lowlands
   N. Nushagak-Big River Hills
   O. Holitna Lowland
   P. Nushagak-Bristol Bay Lowland

8. Northern Plateaus
   A. Porcupine Plateau
      (a) Porcupine Plateau
      (b) Old Crow Plain
      (c) Keele Range
      (d) Thazzik Mountains
   B. Kokrine-Hodzana Highlands
      (a) Ray Mountains
      (b) Kokrine Hills
   C. Rampart Trough
   D. Yukon Flats
   E. Ogilvie Mountains
   F. Selwyn Mountains
   G. Yukon-Tanana Upland (Yukon Plateau)
      (a) Western Part
      (b) Yukon Plateau
      (c) Pelly Mountains
   H. Northway-Tanana Lowland (Shakwak Trench)
   I. Tintina Trench
   J. Hyland Plateau
   K. Liard Plain
Table 4, cont.

F. Datil
   (a) San Francisco Plateau (Eastern Portion)
   (b) Datil Volcanic Field
   (c) Zuni Uplift

13. Arctic Rockies
   A. DeLong Mountains
   B. Noatak Lowlands
      (a) Mission Lowland
      (b) Aniuk Lowland
      (c) Cutler River Upland
   C. Baird Mountains
   D. Ambler-Chandalar Ridge and Lowland
   E. Central and Eastern Brooks Range
   F. Richardson Mountains
   G. Peel Plateau
   H. Mackenzie Mountains
   I. Mackenzie Plain
   J. Franklin Mountains
   K. Liard Plateau

14. Northern Rocky Mountain Province
   A. Canadian Rockies
   B. Northern Rocky Mountain Trench
   C. Southern Rocky Mountain Trench
   D. Columbia Mountains
      (a) Columbia Mountains (Okanogan Highlands)
      (b) Selkirk Mountains
      (c) Purcell Mountains
   E. Bitterroot Mountains
   F. Salmon River
      (a) Salmon River (Idaho Batholith) Area
      (b) Salmon River Meta-Volcanic Area
   G. Montana
      (a) Northwest Montana
      (b) Southwest Montana
      (c) Big Belt Mountains
      (d) Little Belt Mountains

15. Middle Rocky Mountain Province
   A. Yellowstone
      (a) Gallatin Range
      (b) Beartooth Mountains
      (c) Yellowstone Lava Plateau
      (d) Absaroka Mountains
      (e) Teton Range
      (f) Jackson Hole
Table 4, cont.

B. Bighorn Mountains  
(a) Pryor Mountains  
(b) Bighorn Mountains  
(c) Owl Creek Range  
C. Wind River Mountains  
D. Wasatch  
E. Uinta Mountains  

16. Southern Rocky Mountain Province  
A. Front Range  
(a) Laramie Range  
(b) Colorado Front Range  
(c) Wet Mountain Range  
(d) Sangre de Cristo Range  
(e) Medicine Bow Range  
(f) North and Middle Parks  
B. Western  
(a) Sierra Madre Range  
(b) Park Range  
(c) Western Sedimentary  
(d) Gore Range  
(e) Elk Range  
(f) Sawatch Range  
(g) South Park  
(h) Northern San Luis Valley  
(i) San Luis Hills  
(j) Southern San Luis Valley  
C. San Juan Mountains  
(a) San Juan Plateau  
(b) San Juan Mountains  

Division II. Interior Plains  

17. Arctic Foothills Province  
A. Northern  
B. Southern  

18. Arctic Coastal Plain Province  
A. Teshekpuk  
B. White Hills  
C. Mackenzie Delta  
D. Banks Coastal Plain  
E. Sverdrup  

19. Great Plains Province  
A. Peel Plain  
B. Anderson Plain  
C. Brock Plain  
D. Horton Plain  
E. Colville Hills  
F. Great Bear Plain
Table 4, cont.

G. Great Slave Plain
H. Alberta Plateau
   (a) Alberta Plateau
   (b) Fort Nelson Lowland
   (c) Peace River Lowland
I. Alberta Plain (Glaciated Missouri Plateau)
   (a) Alberta Plain-Glaciated Missouri Plateau
   (b) Cypress Hills
   (c) Sweetgrass Hills
   (d) Bear Paw Mountains
J. Unglaciated Missouri Plateau
   (a) Little Rocky Mountains
   (b) Judith Mountains
   (c) Big Snowy Mountains
   (d) Crazy Mountains
   (e) Highwood Mountains
   (f) Missouri Plateau-Badland Complex
   (g) Pierre Hills
K. Bighorn Basin
L. Wyoming Basin
   (a) Wyoming Basins
   (b) Rock Springs-Leucite Hills
   (c) Sweetwater (Granite) Mountains
M. Black Hills
   (a) Black Hills Central Crystalline Area
   (b) Black Hills Volcanic Mountains
   (c) Black Hills Limestone Plateau
   (d) Black Hills Red Valley
   (e) Black Hills Hogback Ridges
N. High Plains
   (a) Arikaree Outwash Area
   (b) Nebraska Sandhills
   (c) Goshen Hole Lowland
   (d) Loess Hills Region
   (e) Ogallala Outwash Area
O. Colorado Piedmont
P. Raton Upland
   (a) Chataqua Plateau
   (b) Raton Mesa
   (c) Park Plateau
   (d) Las Vegas Plateau
Q. Pecos Valley
R. Plains Border
   (a) Blue Hills
   (b) Smokey Hills
   (c) Arkansas Lowland
Table 4, cont.

<table>
<thead>
<tr>
<th>Region</th>
<th>Map Regions</th>
</tr>
</thead>
</table>
| S. Edwards Plateau | (a) Stockton Plateau  
(b) Edwards Plateau  |
| T. Central Texas Mineral | (a) Grand Prairie  
(b) Llano Dissected Limestone Plateau  
(c) Llano Uplift  |
| U. Osage | (a) Flint Hills  
(b) Permian Rolling Plains  
(c) Wichita Mountains  
(d) Arbuckle Uplift  
(e) Limestone Scarped Plains  
(f) Cherokee Lowland  
(g) Sandstone Hills  
(h) Sandstone Scarped Plains  |
| 20. Central and Eastern Lowlands Province |  |
| A. Western Lakes and Lacustrine | (a) Lake Souris  
(b) Lake Dakota  
(c) Western Lakes Drift Area  |
| B. Manitoba Plain |  |
| C. Dissected Loessial and Till Plains | (a) Dissected Loess Covered Iowan Drift Area  
(b) Dissected Iowan Drift Area  
(c) Dissected Loess Covered Kansan Drift Area  
(d) Dissected Kansas Drift Area  |
| D. Driftless | (a) Loess Covered Southwest Cuestas  
(b) Central Sand Plain  |
| E. Eastern Lakes and Lacustrine | (a) Lake Saginaw  
(b) Lake Green Bay  
(c) Lake Maumee  
(d) Lake Chicago  
(e) Kankakee Sand Basin  
(f) Eastern Lakes Drift Area  
(g) Erie-Ontario Rolling Plains  
(h) Erie-Ontario Lacustrine Plains  |
| F. Central Till Plains | (a) Loess Plains of Western Illinois  
(b) Tipton Till Plain  
(c) Illinoian Drift  |
| G. Mohawk River Valley | (a) Tug Hill Cuesta  
(b) Black River Valley  
(c) Mohawk Lowland  |
Table 4, cont.

H. Hudson River Valley
   (a) Glaciated Ridge and Valley
   (b) Slate Hills Area

21. Ozark and Ouachita Province
   A. St. Francis Mountains
   B. Springfield-Salem Plateau
      (a) Salem Plateau
      (b) Springfield Plateau
   C. Boston Mountains
      (a) Boston Mountains
      (b) Arkansas Valley
      (c) Fourche Kiamichi Belt
      (d) Novaculite Uplift
      (e) Athens Piedmont Area

22. Interior Low Plateaus Province
   A. Blue Grass
      (a) Outer Blue Grass
      (b) Eden Shale
      (c) Inner Blue Grass
   B. Highland Rim
      (a) Western Pennyroyal Limestone Plain
      (b) Knob Hills
      (c) Kentucky Tennessee Eastern Pennyroyal
   C. Shawnee Hills
      (a) Southern Illinois Loessial Plain
      (b) Island Hills
      (c) Indiana-Kentucky Coal Fields
      (d) Mammoth Cave Plateau
   D. Nashville Basin

Division III. Canadian Shield

23. Innuition Province
   A. Sverdrup Lowland
   B. Parry Plateau
   C. Eureka Uplands
   D. Grant Land Mountains
   E. Victoria and Albert Mountains

24. Arctic Lowland Province
   A. Victoria Lowland
   B. Shaler Mountains
   C. Lancaster Plateau
   D. Boothia Plain
   E. Foxe Plain

25. Bear Province
   A. Coronation Hills
   B. Bear Upland

26. Slave Province
Table 4, cont.

27. Northern Churchill Province
   A. Davis Highlands
   B. Baffin Coastal Plain
   C. Baffin Upland
   D. Melville Plateau
   E. Frobisher Upland
   F. Hall Upland

28. Western Churchill Province
   A. Bathurst Hills
   B. Back Lowland
   C. East Arm Hills
   D. Boothia Plateau
   E. Wager Plateau
   F. Thelon Plain
   G. Kazan Upland
   H. Athabasca Plain

29. Eastern Churchill Province
   A. Belcher Islands
   B. Richmond Hills
   C. Povungnituk Hills
   D. Sugluk Upland
   E. Labrador Highlands
   F. George Plateau
   G. Whale Depression
   H. Labrador Trough
   I. Michigamau Plateau

30. Hudson Bay Province
   A. Southampton Lowland
   B. Hudson Bay Lowland

31. Superior Province
   A. Severn Upland
   B. Nipigon Plain
   C. Port Arthur Hills
   D. Superior Upland
      (a) Lake Duluth
      (b) Superior Upland
   E. Abitibi Upland
   F. Cobalt Plain
   G. Eastman Plain
   H. Larch Plateau
   I. Nichicum Plateau
   J. Kaniapiskau Plateau
   K. Mistassini Hills

Division IV. Appalachian Highlands

32. Grenville Province
   A. Pletipi Plateau
   B. Hamilton Upland
Table 4, cont.

C. Hamilton Plateau
D. Melville Depression
E. Mealy Mountains
F. Mecatina Plateau
G. Laurentian Highlands
H. Adirondack
  (a) Northwest Lowland
  (b) Central Highland Plateau
  (c) High Peaks Region

33. St. Lawrence Province
   A. St. Lawrence Lowland
   B. Champlain Lowland
   C. Anticosti Lowland

34. New England Maritime Province
   A. Newfoundland Coastal Upland
   B. Newfoundland Highlands
   C. Newfoundland Central Lowland
   D. Atlantic Uplands of Newfoundland
   E. Atlantic Upland of Nova Scotia
   F. Nova Scotia Highlands
   G. Annapolis Lowland
   H. Gulf of St. Lawrence Plain
   I. New Brunswick Highlands
   J. New England Upland
      (a) Northern New England Slate-Shale Area
      (b) Southern New England Upland
      (c) Reading Prong
   K. Notre Dame Mountains
   L. Eastern Quebec Uplands
   M. White Mountains
   N. Green Mountains
   O. Taconic
      (a) Taconic Mountains
      (b) Rensselaer Plateau
      (c) Limestone Valley of Vermont
   P. Connecticut Lowland
   Q. Seaboard Lowland
      (a) Seaboard Lowland
      (b) Cape Cod

35. Appalachian Plateau Province
   A. Catskill Mountains
   B. New York Glaciated
      (a) New York Glaciated Plateau
      (b) Pocono Mountains
   C. Allegheny Mountains
   D. Kanawha
   E. Cumberland
      (a) Cumberland Plateau
      (b) Sequatchie-Wills Creek Valley
Table 4, cont.

36. Newer Appalachian (Ridge and Valley)
   A. Pennsylvania-Maryland-Virginia
      (a) Parallel Folded Ridge and Valley Area
      (b) Great Valley
      (c) Zig-Zag Mountains
   B. Tennessee

37. Older Appalachian
   A. Blue Ridge
      (a) Northern Blue Ridge
      (b) Southern Blue Ridge
   B. Piedmont
      (a) Piedmont Plateau
      (b) Triassic Lowland Outlier

38. Triassic Lowland Province
   (a) Glaciated Triassic Lowland
   (b) Chester-Conestoga Valleys
   (c) Triassic Lowland
   (d) Piedmont Crystalline Inlier
   (e) Frederick Valley

Division V. Atlantic Plain

39. Atlantic and Gulf Coastal Plain Province
   A. Embayed
      (a) Long Island
      (b) Raritan Lowland
      (c) Eastern Atlantic and Gulf Terraced Coastal Plain
   B. Sea Island
      (a) Eastern Sand and Fall Line Hills
      (b) Eastern Red Hills
      (c) Eastern Tifton Uplands
      (d) Central Atlantic and Gulf Terraced Coastal Plain
   C. Florida
      (a) Florida Lime Sink Region
      (b) Southern Atlantic and Gulf Coastal Plain
Table 4, cont.

D. East Gulf
   (a) Western Sand and Fall Line Hills
   (b) Ripley Cuesta
   (c) Pontotac Ridge
   (d) Black Belt
   (e) Flatwoods
   (f) Western Red Hills
   (g) Buhrstone Cuesta
   (h) Jackson Prairie
   (i) Dougherty Plains
   (j) Western Tifton Uplands
   (k) Southern Pine Hills
   (l) Western Atlantic and Gulf Terraced Coastal Plain

E. Mississippi Loessial Upland

F. Mississippi Alluvial Plain
   (a) Mississippi Alluvial Plain
   (b) Crowley's Ridge

G. West Gulf
   (a) Blackland Prairie
   (b) West Gulf Terraced Coastal Plain
   (c) West Gulf Coastal Plain
above has caused some minor aberrations in the map boundaries.

The physiographic base maps are of the oblique conic conformal projection. With Canada and the United States extending over 55 degrees of latitude, there is some scale distortion, particularly along the margins of the maps (6).
6:0 SOIL TEXTURE MAPPING

6:1 Usefulness of Soil Texture Mapping

Soil texture maps are presented with the following objectives:

1) To assist in evaluating the economic feasibility of cold weather earthwork in a given geographic area.

2) To provide background information for the regional planner concerning the expected general soil textures.

3) To encourage improved general textural mapping in the future.

Mapping of soil textures at the regional level has definite limitations. Owing to the inherently small scale, the mapped units usually must include a significant variability in textures. For example, soils which are insignificant in areal extent cannot be mapped, even though they may be of paramount economic importance. Such soil texture maps do permit predictions with respect to geotechnical engineering problems; however, any such conclusions drawn from a generalized soil texture map will probably require verification by later detailed site or route investigations.
The importance of soil texture to the economic feasibility of cold weather earthwork will be discussed in Sections 7 and 8.

6:2 Definitions of Soil

The term "soil" has different meanings for different disciplines. For the geologist or engineer, soil may be defined as:

"The top layer of the surface of the earth, composed of finely divided disintegrated rock with an admixture of organic remains." (53)

The pedological definition may be:

"Soil is the collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter, acting upon parent material, as conditioned by relief, over periods of time." (56, p.8)

Or, as Joffe (14,p.3) has described soil, it may be:

"... described as a natural body consisting of layers of horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics."

Thus, pedologists and geologists map the loose mantle of earth termed "soil" with a different emphasis. Geologists map soils as an integral part of "surficial" geologic deposits, with an emphasis on deposit origin. Pedologists are concerned with the soil morphology, age, parent materials, texture, consistence, color, inorganic and
organic materials, mottling, thickness range, and reaction (60). The latter classification is directed more toward
thegenesis and recent change in the soils. The engineering geologist or engineer is concerned with the deposit
to the depth of potential excavation or significant
stressing in place; whereas pedologists are concerned with
the mantle of material to the depth which has undergone
the physical and/or chemical changes of weathering.

In this report "soil" shall include the unconsolidated material down to competent bedrock. See Figure 2.
The depth selected for two-dimensional mapping is usually
the upper portion of the "C" horizon, although the "B"
horizon texture may be used where this layer is thick.

6:3 Definition of Soil Textures

Soil texture classes are defined by the effective
diameter of the primary soil particles (60). Soil "parti-
cles" may range from 75mm (the upper limit of gravel
texture) to less than 0.0002mm in diameter. Table 5 lists
the texture classes and the corresponding range of soil
particle diameters. The soil texture classes cited in
Table 5 have been adopted by the United States Department
of Agriculture and the Canada Department of Agriculture
(56,60).
Figure 2. A comparison of the term "soil" in the engineering and pedological sense. (30)
Table 5

Textural classes as defined by size of primary soil particles.
(Agricultural texture classification)

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Diameter, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>75.0 - 2.0</td>
</tr>
<tr>
<td>Very coarse sand</td>
<td>2.0 - 1.0</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>1.0 - 0.5</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.5 - 0.25</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.25 - 0.10</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.10 - 0.05</td>
</tr>
<tr>
<td>Silt</td>
<td>0.05 - 0.002</td>
</tr>
<tr>
<td>Clay</td>
<td>0.002 - 0.0002</td>
</tr>
<tr>
<td>Heavy clay</td>
<td>&lt;0.0002</td>
</tr>
</tbody>
</table>
Soil textures are usually present in combinations, and additional texture classes are created by using combinations of the basic classes defined in Table 5. These soil texture class combinations are defined by the proportionate amounts of the various size components. Figures 3 and 4 define and illustrate the soil texture class combinations for sandy to clayey soils.

As indicated in Figure 4, a "sandy" soil may include a sufficient loam content to make subfreezing compaction impractical.

6:4 Soil Texture Map Units

Natural soils are mapped as single textures, combinations of textures, or as gradational textures, using the methods presented by Witczak(71). The writer has adopted Witczak's method, with only the slight modification that the predominate soil texture type is listed first, whereas the least areally significant soil texture is listed last. The method of reporting soil textures is detailed in the soil texture map legends.

Table 6 lists all the soil texture class combinations used on the report maps, and their relationship to the probable Unified Soil Classification.

Some map units do not represent textural classes, viz., 1) no-soil, 2) stoney phase, 3) organic, and 4) glacier. All of these map units are considered to have
Figure 3. Percentages of sand and clay in each textural class. Remainder of each class is silt. (60)
Figure 4. Relationship of soil textural classes to verbal pedologic textural classes. (74)
### Table 6

Range of soil textural classes or soil textural class combinations as related to pedologic and report textural groups.

<table>
<thead>
<tr>
<th>Textural class and class combinations</th>
<th>Symbol used on Report</th>
<th>Pedologic Texture Groups</th>
<th>Texture Groups as used in Report</th>
<th>Probable Unified Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>gravel</td>
<td>g</td>
<td>coarse</td>
<td>coarse</td>
<td>GP, GW</td>
</tr>
<tr>
<td>sand</td>
<td>s</td>
<td>coarse</td>
<td>coarse</td>
<td>GP, GW</td>
</tr>
<tr>
<td>loamy sand</td>
<td>ls</td>
<td>coarse</td>
<td>coarse</td>
<td>GP, GW</td>
</tr>
<tr>
<td>sandy loam</td>
<td>sl</td>
<td>medium</td>
<td>medium</td>
<td>SM, ML</td>
</tr>
<tr>
<td>loam</td>
<td>l</td>
<td>medium</td>
<td>medium</td>
<td>SM, ML</td>
</tr>
<tr>
<td>silt loam</td>
<td>ml</td>
<td>medium</td>
<td>medium</td>
<td>SM, ML</td>
</tr>
<tr>
<td>sandy clay loam</td>
<td>scl</td>
<td>medium</td>
<td>medium</td>
<td>SM, ML</td>
</tr>
<tr>
<td>silt</td>
<td>m</td>
<td>medium</td>
<td>medium</td>
<td>SM, ML</td>
</tr>
<tr>
<td>clay loam</td>
<td>cl</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>mcl</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>sandy clay</td>
<td>sc</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>silty clay</td>
<td>mc</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>clay</td>
<td>c</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>heavy clay</td>
<td>hc</td>
<td>fine</td>
<td>fine</td>
<td>CL</td>
</tr>
<tr>
<td>stoney</td>
<td>r</td>
<td>fine</td>
<td>fine</td>
<td>CH</td>
</tr>
<tr>
<td>no soil</td>
<td>br</td>
<td>fine</td>
<td>fine</td>
<td>CH</td>
</tr>
<tr>
<td>organic</td>
<td>o</td>
<td>fine</td>
<td>fine</td>
<td>CH</td>
</tr>
<tr>
<td>undifferentiated</td>
<td>qu</td>
<td>fine</td>
<td>fine</td>
<td>CH</td>
</tr>
</tbody>
</table>
a significance when cold weather earthwork is considered. The "stoney phase" map unit is a descriptive pedologic term, indicating the presence of numerous stones or rocks within the soil horizon.

Organic soils were not mapped regionally in Alaska, due to a lack of data.

6:5 Method of Soil Texture Compilation

Soil textural mapping of the conterminous United States, Canada and Alaska is presented in Wood's Highway Engineering Handbook (72). Largely exploratory in nature, this map has been outdated by the availability of new information.

Alaska was mapped in 1950 (16); however, additional information on the distribution of surficial materials has been supplied by the United States Geological Survey (28).

In view of the additional information available, it was felt that a new mapping of general soil textures would be of benefit to the study. The new texture maps required three different methods of compilation for the three distinct political areas, each of which is discussed below.

6:5:1 Conterminous United States

The conterminous United States mapping by Witczak (70) was consolidated into a single base map of considerably smaller scale. Some detail was lost because of the
significant scale reduction. Witczak's map was compiled from pedologic, geologic, and engineering sources.

6:5:2 Canada

Regional soil texture maps specifically for Canada have not been published as of this writing. However, many personal communications to soil scientists in Canada aided the writer in locating unpublished soil texture information. Mr. John Day, National Soils Correlator, provided the author with a copy of an unpublished manuscript of *The Inventory of The Soils of Canada* (26).

Mapping was accomplished by tracing the pedologic soil boundaries and extracting the probable soil textures from the unpublished manuscript. Much of the texture data is in the "exploratory" reliability category. This probably means that the mapping technique has relied on indirect methods with considerable conjecture. In many areas there is a wide range of soil textures indicated; this is probably due to the 1) small mapping scale, 2) natural soil variations, and 3) inadequate exploratory type information. Additional pedologic and geologic information was consulted to supplement the writer in developing a regional soil texture map (22,25,29,30,36, 37,40,42,43,57,67,72,73 ).
6:5:3 Alaska

Information for Alaska, like that for Canada, is exploratory in nature. A statewide surficial geologic map published by the United States Geological Survey (28) enabled the writer to deduce a soil texture map. The surficial geologic map had some textural information, but many of the soil textures had to be interpreted from the soil origin or topographic position. Available geologic reports for Alaska were consulted to aid in the interpretation (23, 24, 28, 41, 50, 54, 69, 72).

With these limited data, the Alaska soil texture map must be considered tentative. Although organic soils were not mapped in Alaska, the writer knows from personal experience that organic deposits are quite common in interior lowland areas. Detailed information on peat deposits is available for small portions of Alaska (15, 49, 50, 51, 52, 59).

6:6 Limitations of Generalized Soil Texture Mapping

Generalized soils texture mapping has some strong limitations; e.g., 1) the small scale precludes mapping of areally significant soil texture variants which may be very economically significant, and 2) the mapped units are those ordinarily encountered, but other textures may occur at a given site or along a particular route.

Both points are significant with respect to earthwork planning. An areally insignificant landform or
soil may be very important in the economic planning and execution of cold weather earthwork, e.g., the occurrence of dry and coarse sands and gravels in local terrace and alluvial deposits. Generalized mapping must nearly always be supplemented by more detailed information for the specific site or route.
7:0 EARTHWORK vs. COLD WEATHER

Cold weather earthwork can be discussed in terms of both technologic and economic feasibility. Cold weather earthwork efficiencies are reflected in technologic problems and low temperature effects on the physiology and psychology of the operators (1, 2, 27, 46, 47). A technologic and economic rank ordering of cold weather earthwork operations can provide a rational basis for encouraging operations which are most practically implemented. A discussion of the technical and economic feasibility of the various cold weather earthwork operations is presented below.

7:1 Technologically Feasible Cold Weather Earthwork Operations.

The technological feasibility of winter earthwork depends upon various factors, viz., 1) the type of equipment being used, 2) background experience of operators and planners, 3) climatic conditions, 4) site "soil form" (physical characteristics of soils at the site), 5) size of job, and 6) time span considered (2, 47). Using data published in a Swedish survey (2) as a base, the writer has developed a general rank order list of technically feasible cold weather earthwork operations. This is shown in Table 7.
Table 7
Rank ordering of technically advisable winter earthwork operations. (2)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Percent experts agreeing operations advisable: 1.0 = 100%</th>
<th>Cold Weather Earthwork Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>Excavation for waste</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
<td>Rock blasting</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>Rock crushing (Macadam)</td>
</tr>
<tr>
<td>4</td>
<td>0.7</td>
<td>Rock crushing</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>Clearing and grubbing; sub-base work</td>
</tr>
<tr>
<td>6</td>
<td>0.5</td>
<td>Large culvert, drainage work</td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>Small culvert; pipe; drainage work</td>
</tr>
<tr>
<td>8</td>
<td>0.2</td>
<td>Grading and compacting sand &amp; gravel; excavating and hauling clay and saturated sands and silts</td>
</tr>
<tr>
<td>9</td>
<td>0.1</td>
<td>Excavating moraine and sands &amp; gravels</td>
</tr>
<tr>
<td>10</td>
<td>0.0</td>
<td>Fine grading, spreading top soil</td>
</tr>
</tbody>
</table>

NOTE: earthwork in permafrost areas not considered.
The Swedish data are based on an extensive survey of experienced cold weather earthwork engineers and contractors. It was assumed by the writer that there is a direct relationship between an operation's technical feasibility and the reported agreement among the experts as to its technical advisability. For example, a high rating (agreement) probably indicates that the particular operation cited can be technically accomplished with certainty. A low rating would indicate a low level of confidence in the technical success of the cold weather earthwork operation.

Not considered in the Swedish survey is the effect of permafrost on cold weather earthwork technical feasibility (According to Flint (19), Sweden lies almost entirely south of any permafrost). The presence of permafrost would probably alter the rank ordering considerably; e.g., clearing and grubbing, sub-base work, and compaction and hauling of dry cohesionless sands and gravels would undoubtedly receive a higher ranking.

7:2 Economically Feasible Cold Weather Earthwork

The economic feasibility of winter earthwork operations depends on a large number of factors. The type of equipment, size of job, site soil form (including soil texture and moisture, location of water table, and permafrost), prevailing meteorologic conditions (temperature,
lighting, precipitation, humidity, wind), and availability of workers are some of the tangible economic determinants. Also important are a host of less tangible factors such as environmental laws, inflation and seasonal employment (33,47). A thorough treatment of all economic factors is beyond the scope of this study.

This study will consider only those earthwork operations which have been reported to be economically feasible in a specific environment. After the earthwork operations which can be economically feasible are identified, the geographic areas in which cold weather earthwork scheduling should be carefully considered will be outlined in a regional manner. As emphasized by Osborne (47) and Bieganousky (5), careful scheduling is of the utmost importance in winter earthwork.

Winter earthwork can often be justified with a thorough cost-benefit analysis. Osborne (47) showed in a sample calculation for an interstate highway project in northern Indiana that there could be a 58 percent saving, when a twelve-month construction season was considered rather than the conventional eight-month season.

From the factors listed as economic determinants, it is readily apparent that a rank ordering of economically feasible earthwork operations would depend greatly on the geographic locale and the specific type of job. A rank
ordering can be developed only in a general sort of way. As with the technological rank ordering, the writer has developed an economic feasibility list. The rank ordering is based on Swedish data, compiled from a survey of experienced cold weather earthwork engineers and contractors, and shown in Table 8.

It was assumed that a high degree of agreement among the experts considering the economic feasibility of an earthwork operation indicated a high degree of economic feasibility. For example, excavation for waste was considered to be economically feasible by 90 percent of the experts. This would indicate that excavation for waste should be seriously considered for winter scheduling. Conversely, ditching, fine grading, and spreading of top soil should be some of the least advisable winter operations, since no expert considered them to be economic.

It is important to mention that the rank order list is based on data from a non-permafrost area. Hauling of soils, clearing and grubbing, and placement and compaction of dry granular soils would probably receive a higher ranking with permafrost soils.

The earthwork operations receiving the highest ratings in the economic feasibility survey are excavation for waste, and rock blasting. Rock crushing, and the excavation and hauling of morainic deposits were next in the
Table 8

Rank ordering of economically advisable winter earthwork operations. (2)

<table>
<thead>
<tr>
<th>Rank; 1 = most economical; 8 = least economical</th>
<th>Percent experts agreeing operation is economic 1.0 = 100%</th>
<th>Winter Earthwork Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9</td>
<td>Excavation for waste</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>Rock blasting, rock crushing (Macadam)</td>
</tr>
<tr>
<td>3</td>
<td>0.7</td>
<td>Rock crushing</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>Excavating and hauling sands and gravels (deep excavations), large culverts, sub-base work</td>
</tr>
<tr>
<td>5</td>
<td>0.4</td>
<td>Clearing and grubbing</td>
</tr>
<tr>
<td>6</td>
<td>0.3</td>
<td>Excavating and hauling moraine (deep excavations), small culverts, pipes, water outflow work</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
<td>Excavating and hauling clay and saturated silts and sands (deep excavations)</td>
</tr>
<tr>
<td>8</td>
<td>0.0</td>
<td>Ditching, fine grading, spreading top soil, excavating and hauling (shallow excavations)</td>
</tr>
</tbody>
</table>

NOTE: Earthwork in permafrost areas not considered.
listing. Ditching, fine grading, spreading top soil, and shallow excavations ranked at the bottom of the economic feasibility list. An important exception to the above rank ordering would be the consideration of ditching in high water table areas.

Section 9 will deal further with the importance of the particular site conditions relative to the economic feasibility of winter earthwork operations.

7:3 Working Efficiencies vs. Weather Factors

Weather factors have a significant effect on the efficiencies of earthwork machinery and manual laborers. Machinery operational efficiencies are affected by 1) air temperature, 2) lighting condition, 3) precipitation, and 4) soil phase (frozen vs. unfrozen). Manual laborer efficiencies are also significantly affected by the above factors as well as by surface winds, humidity, and human acclimatization (1,5).

Efficiencies of manual laborers, excavation and hauling equipment are presented in the Swedish Vagbyggande Aret Runt (2). Tables 9 and 10 list these efficiencies with respect to temperature, lighting, and precipitation.

The efficiencies cited in Tables 9 and 10 were developed in Sweden by an extensive survey of experienced cold weather engineers and contractors. Changes in equipment and operational approaches may have altered the values since 1960, when they were published.
Table 9

Manual labor efficiencies related to temperature, lighting, and precipitation. (2)

<table>
<thead>
<tr>
<th>Weather Factor</th>
<th>Manual Efficiency (1.00 = 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>+30</td>
<td>.72</td>
</tr>
<tr>
<td>+20</td>
<td>.95</td>
</tr>
<tr>
<td>+10</td>
<td>1.00</td>
</tr>
<tr>
<td>+5</td>
<td>.98</td>
</tr>
<tr>
<td>±0</td>
<td>.97</td>
</tr>
<tr>
<td>-5</td>
<td>.95</td>
</tr>
<tr>
<td>-10</td>
<td>.88</td>
</tr>
<tr>
<td>-20</td>
<td>.73</td>
</tr>
<tr>
<td>-30 climatic zone Dcb*</td>
<td>.35</td>
</tr>
<tr>
<td>climatic zone E*</td>
<td>.53</td>
</tr>
<tr>
<td>Light Condition</td>
<td></td>
</tr>
<tr>
<td>Direct Sunlight</td>
<td>.97</td>
</tr>
<tr>
<td>Indirect Sunlight</td>
<td>1.00</td>
</tr>
<tr>
<td>Twilight</td>
<td>.92</td>
</tr>
<tr>
<td>Darkness</td>
<td>.56</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
</tr>
<tr>
<td>Heavy Rain</td>
<td>.36</td>
</tr>
<tr>
<td>Light Rain</td>
<td>.89</td>
</tr>
<tr>
<td>Heavy Snowfall</td>
<td>.41</td>
</tr>
<tr>
<td>Light Snowfall</td>
<td>.90</td>
</tr>
</tbody>
</table>

*See Figure 5.*
Table 10

Hauling and excavation efficiencies related to temperature, lighting, and precipitation. (2)

<table>
<thead>
<tr>
<th>Weather Factor</th>
<th>Hauling Machinery Efficiency (1.00 = 100%)</th>
<th>Excavation Machinery Efficiency (1.00 = 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+30</td>
<td>.89</td>
<td>.87</td>
</tr>
<tr>
<td>+20</td>
<td>1.00</td>
<td>.99</td>
</tr>
<tr>
<td>+10</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>+5</td>
<td>1.00</td>
<td>.99</td>
</tr>
<tr>
<td>±0</td>
<td>.97</td>
<td>.99</td>
</tr>
<tr>
<td>-5</td>
<td>1.00</td>
<td>.98</td>
</tr>
<tr>
<td>-10</td>
<td>.96</td>
<td>.92</td>
</tr>
<tr>
<td>-20</td>
<td>.88</td>
<td>.78</td>
</tr>
<tr>
<td>-30 climatic zone Dcb*</td>
<td>.66</td>
<td>.43</td>
</tr>
<tr>
<td>climatic zone E*</td>
<td>.82</td>
<td>.59</td>
</tr>
<tr>
<td>Light Condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Sunlight</td>
<td>.96</td>
<td>.96</td>
</tr>
<tr>
<td>Indirect Sunlight</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Twilight</td>
<td>.96</td>
<td>.88</td>
</tr>
<tr>
<td>Darkness</td>
<td>.82</td>
<td>.65</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Rain</td>
<td>.85</td>
<td>.81</td>
</tr>
<tr>
<td>Light Rain</td>
<td>.98</td>
<td>.97</td>
</tr>
<tr>
<td>Heavy Snowfall</td>
<td>.76</td>
<td>.73</td>
</tr>
<tr>
<td>Light Snowfall</td>
<td>.95</td>
<td>.97</td>
</tr>
</tbody>
</table>

*See Figure 5.
In applying the published efficiencies to North America, one must relate the climate of this continent to that of Sweden. Figure 5 illustrates two climatic classifications of Sweden. Trewartha's (63) climatic classification, which divides Sweden into only two categories, is preferred in this study, since it simplifies the correlation of North American (Fig. 6) and Swedish climates. For example, in Figure 5, Trewartha's E-Dcb boundary closely approximates the SN-M boundary determined by the Swedish survey. Of course, all climatic boundaries are convenient approximations representing broad zones of transition (63).

In applying the efficiency values listed in Tables 9 and 10, one must also recognize that the types of equipment, modes of operation, and experiences reflected in the Swedish survey are somewhat different from those found in North America.

However, the writer believes the efficiency data are at least qualitatively valid for North America. Figure 7 gives an example of calculated inefficiency values for manual factors at Kotzebue, Alaska. (Inefficiency data can be developed from the simple relationship \((1 - \text{efficiency} = \text{inefficiency})\). The method for developing inefficiency curves is presented in the Appendix, along with additional inefficiency curves. The
Climatic zones reported in
Vagbyggande Aret Runt (2)

Climatic zones determined
by G.T. Trewartha (63)

Figure 5. Comparison of climatic zones in Sweden as determined by different authors. (Note that the SN-H boundary depicted on the left and the E-Dcb boundary on the right are very similar.) (Ref. 63. Copyright, McGraw-Hill Book Company; reprinted by permission.)
Figure 6. Trewartha's climatic classification of Alaska, Canada, and conterminous United States. (63)

(Copyright authorization, McGraw Hill Book Company; reprinted by permission.)
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0-100 PERCENT

Figure 7. Example inefficiency curve based on monthly temperature, lighting, and precipitation.
developed data can be very useful in preliminary planning and scheduling.

The application of the inefficiency curves to the problem of scheduling selected earthwork operations is discussed in Section 15:6.
SOIL BEHAVIOR AT LOW TEMPERATURES

Certain earthwork operations in specific environments are greatly benefited by the presence of frozen soils, while with many other operations frozen soils are considered a detriment. An understanding of the general principles of soil behavior at low temperatures is essential to the definition of winter earthwork feasibility. Such earthwork must be designed and scheduled with a special consideration of factors pertinent to soil freezing and to frozen soil behavior, viz., frost heave potential, strength reduction on thaw, compactibility, and frozen soil strengths. A brief discussion of selected soil responses to low temperatures is presented below.

8:1 Frost Susceptibility

Frost susceptibility of a soil site is generally described in terms of: 1) soil texture, 2) soil grain-size distribution, 3) availability of free water, 4) rate and direction of freeze penetration, and 5) duration of freezing temperatures (35). The U.S. Army Corps of Engineers has developed a Frost Design Soil Classification (32) which categorizes soils with respect to frost
heave potential and reduced shear strength on thaw. Four groups of soils are recognized: F1, F2, F3, and F4 with the F1 soils having the least frost potential and F4 having the greatest frost susceptibility. See Table 11 for the Frost Design Soil Classification.

Note that the Frost Design Soil Classification is stated in terms of soil texture and the percentage of soil particles by weight finer than 0.02 mm. Actual frost heave testing, with controlled laboratory conditions, shows the range of response represented in Figure 8.

As further indicated by Table 11, poorly graded medium to coarse-grained sands and gravels should experience very little frost heaving and should retain a large portion of their bearing capacities on thaw. Thus, if soils are placed in a fill in the frozen state (with segregated ice being a potential factor) one should use the coarser, easily drained soils.

8:2 Compactibility

Laboratory research and field cold weather compaction studies provide evidence of the change in the compaction behavior of soils at low temperatures, viz., that as temperature decreases, the compactive effort required to reach a specified density increases. Above 0°C, this effect has been attributed to changes in the viscosity of the soil water (27). Below 0°C the necessary compaction
<table>
<thead>
<tr>
<th>Frost group</th>
<th>Kind of soil</th>
<th>Percentage finer than 0.02 mm by weight</th>
<th>Typical soil types under Unified Soil Classification System</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Gravelly soils</td>
<td>3 to 10</td>
<td>GW, GP, GW-GM, GP-GM</td>
</tr>
<tr>
<td></td>
<td>(a) Gravelly soils</td>
<td>10 to 20</td>
<td>GM, GW-GM, GP-GM</td>
</tr>
<tr>
<td></td>
<td>(b) Sands</td>
<td>3 to 15</td>
<td>SW, SP, SM, SW-SM, SP-SM</td>
</tr>
<tr>
<td>F2</td>
<td>(a) Gravelly soils</td>
<td>Over 20</td>
<td>GM, GC</td>
</tr>
<tr>
<td></td>
<td>(b) Sands, except very fine silty sands</td>
<td>Over 15</td>
<td>SM, SC</td>
</tr>
<tr>
<td></td>
<td>(c) Clays, PI&gt;12</td>
<td>-</td>
<td>GL, CH</td>
</tr>
<tr>
<td>F3</td>
<td>(a) All silts</td>
<td>-</td>
<td>ML, MH</td>
</tr>
<tr>
<td></td>
<td>(b) Very fine silty sands</td>
<td>Over 15</td>
<td>SM</td>
</tr>
<tr>
<td></td>
<td>(c) Clays, PI&lt;12</td>
<td>-</td>
<td>CL, CL-ML</td>
</tr>
<tr>
<td>F4</td>
<td>(d) Varved clays and other fine-grained banded sediments</td>
<td>-</td>
<td>CL and ML; CL and ML and SM; CL, CH and ML; CL, CH, ML and SM</td>
</tr>
</tbody>
</table>
Figure 8. Summary envelopes relating frost susceptibility to natural soil gradations. (32) (Copyright, Transportation Research Board, National Research Council; reprinted by permission.)
energy increases greatly. This is thought to be a result of both the increased water viscosity of absorbed and unfrozen water and the increased matrix rigidity due to the presence of interstitial ice (27).

The amount of total soils moisture present greatly affects the compactibility of soils at and below freezing temperatures (5,27). Figure 9 is a schematic representation of the effect of moisture and temperature on a fine sand with a constant compactive effort. As a soil's moisture is increased, or the soil temperature is lowered below freezing, the compactive effort required to produce a specified density will have to increase. On the other hand, Figure 9 shows that the compactibility of dry soils is little affected by low temperatures.

Additional evidence is summarized by Bieganousky (5). Field compaction studies by the New York State Highway Department utilizing relatively clean cohesionless soil found for soils with temperatures below -7°C (20°F) that it was difficult-to-impossible to attain specified densities (27). Highter (22), studying the effect of low but nonfreezing temperatures on the compaction and compacted strength of a clay, found that the low temperatures had about the same effect on density as a reduction in compactive effort. Accordingly, to achieve the same density as in warm weather compaction, the effort delivered at low temperatures had to be increased. Compacted soils
Figure 9. Freezing soil temperatures and moisture content as related to soil compaction. (27)
were somewhat stronger at low but unfrozen temperatures, other factors being equal.

8:3 Frozen Soil Strengths

A frozen soil's compressive and tensile strengths are directly affected by the soil temperature, provided soil moisture is present. As the temperature is lowered, the compressive and tensile strengths increase. In laboratory tests conducted by Lovell (35) a clay increased its compressive strength by almost 40% when the soil temperature was reduced from -6°C to -10°C (21°F to 14°F). According to Kaplar (27), the compressive strength of frozen soil at low temperature may exceed 3000 psi, comparable to the strength of some concretes. High moisture sands and silts increase in tensile strength by many orders of magnitude when the soil temperature is lowered below 0°C. A sand and silt tested by Kaplar (27) showed tensile strengths of slightly over 300 and 200 psi respectively at -4°C (25°F). Clays increase in tensile strengths with reduced soil temperatures, but at a lower rate than the sands and silts.

The compressive and tensile strength behavior of soils should reflect the degree of difficulty one would have in excavation. It is clear that deeply frozen moisture-bearing soils may prove uneconomical to excavate. "Moisture-free" soils, such as well-drained sands and
gravels, should be considered excavatable even in low temperatures (5).
9:0 SOIL BEHAVIOR RELATED TO FEASIBLE COLD WEATHER EARTHWORK OPERATIONS

Feasible winter earthwork operations are discussed in the following section with respect to 1) frozen soil behavior, and 2) reported successful winter operations. It will be shown that certain winter earthwork operations can be considered technologically and economically feasible in specific environments. Ultimately six categories of soil composition and condition will be recognized.

9:1 Fill and Compaction

Winter fill and compaction operations can be discussed relative to the two temperature-dependent soil phases: frozen and unfrozen. Winter operations with either soil phase are optimized in certain soil forms or physical environments. Soil forms for which winter filling and compaction may be feasible are discussed below.

Compaction of frozen soils involves the following restraints: 1) soil should be moisture free, or 2) if moisture is present the soil should be granular and its temperature should not be much below freezing. Soils which can be compacted dry include coarse sands and gravels. Moisture-free soils probably are rare in nature, thus stockpiling and air drying of sands and gravels prior
to the winter season is necessary; however, this is not an economic alternative except for small jobs. An alternative to dry sand and gravel as a low moisture fill material is crushed rock.

The use of frozen moisture-bearing granular soils requires additional limitations and restraints. First, the temperature in relatively clean cohesionless soils should not be less than -7 to -4°C (20 to 25°F). Secondly, extra compactive effort will probably be required. Hence, careful monitoring of soil temperature and compaction variables would have to be maintained.

Use of frozen granular material under conditions different from those specified above, or use of frozen cohesive soils as a fill material, is questionable. As stated previously, data collected by Bieganousky (5) indicate that of 28 state or provincial highway departments, 15 permit cohesive soils to be used as a winter fill material. Among these 15 departments, 7 report that they have encountered excessive fill settlements. Some of the above cases undoubtedly involve an inadvertent placement of frozen soils. Segregated ice masses within frozen cohesive soils, and related shear strength reduction on thaw, are some of the factors which make frozen cohesive soil a questionable fill material.

Winter compaction of unfrozen cohesive and cohesionless soil has been shown to be successful provided that
control measures are taken to ensure that the soil does not freeze prior to compaction, and that snow and ice are not incorporated into the fill material. Excavation, hauling, and compaction operations must be expedited to ensure against soil freezing. The cold but unfrozen soil has compaction characteristics only moderately different from those of warm soil (5, 27).

Major problems may be encountered when one attempts to alter the natural soil moisture to approximate the optimum for compaction. Lowering of the water content through spreading and drying of the soil is not practical when one considers the low evaporation rates and tendency to freeze. Raising the water content can become a problem if application, mixing, and compaction take too long. One possibility is raising the moisture content in situ by injecting an appropriate amount of water into bore holes. Kaplar (27) reports this method proved very successful when the fine grained core material for the Oahe Dam (N.D.) needed additional moisture.

In view of the potential problems of altering unfrozen soil moisture at freezing temperatures, two choices remain: 1) compact soils at natural moisture content, 2) compact soils whose water content can be raised in situ.

An embankment 15 to 16 m high was completed in the winter season near Oslo, Norway. The fill material was
a non-frozen silt. Subsequent performance was considered successful, even though 8 in. of settlement occurred. The Michigan State Highway Department reports satisfactory performance of unfrozen cohesive and cohesionless fills compacted at optimum moisture content at air temperatures as low as 

$-7^\circ C$ (20$^\circ F$) (27).

Thus, winter fill and compaction operations are enhanced in areas in which either relatively dry coarse-textured soils or crushed rock are readily available. If cohesive soils are to be used, rapid, continuous excavation, fill, and compaction operations with unfrozen materials are required. In addition, the cohesive soils must have an acceptable natural water content or be amenable to water content alteration.

### 9:2 Excavation and Hauling

Winter excavation and hauling operations must also be discussed relative to whether the soil is frozen or unfrozen. Small excavation jobs in frozen moisture-bearing soils may be technically feasible but are relatively very expensive when compared with non-frozen soil excavation. Large excavation jobs will be more expensive, but to a much lesser degree, since one would be handling only nonfrozen materials once the seasonally frozen soil layer is penetrated.
Excavation and hauling of moisture-free soils have no special winter problems, since dry soil behavior is unaffected by temperature \( (5,27,33) \). Coarse-textured natural soils probably contain the least moisture; however, even a little frozen moisture alters the cohesionless character of the soil.

High-water-table conditions found often in marsh and muskeg environments present another problem. It may prove highly beneficial to excavate muskeg soils during low temperature periods, since a frozen crust of significant bearing capacity helps mobility.

A stage method of excavation in high-water-table areas has been outlined by Kaplar \((27)\). The ground is allowed to freeze in 40-to 50-cm (16-to 20-inch) layers. Leaving frozen soil partitions, one would then partially excavate the frozen soil leaving a 15 to 20 cm (6 to 8 inch) frozen layer. As soon as freezing had again penetrated to a sufficient depth, one could repeat the process. Up to 2 ft of frozen soil can be broken up with a tractor-mounted ripper \((5)\).

The Corps of Engineers found in excavating dirty sands and gravels for the Moose Creek diversion project, that low winter temperatures reduced the need for de-watering, and allowed the use of equipment and personnel that may not have been as readily available as in the summer season \((48)\).
Winter hauling of excavated material can encounter two sorts of difficulties: 1) problems associated with low-temperature handling of soils, and 2) traffic-ability problems.

Handling of moisture-bearing soils is most severe at air temperatures between -9 and -10°C (33). Soil may freeze to any surface it touches, e.g., shovel buckets, railroad car bodies, and truck beds. Relatively dry materials do not demonstrate such temperature effects.

Trafficability in areas of organic, or plastic soils or with high water tables may be immensely improved by frozen crust of soil or water. Summer access costs may well prove to be prohibitive. For example, "Exploiting the Pembina oilfield required gravel access roads over muskeg costing about twice as much as over mineral terrain (37)". Another example of the high cost of summer access and transportation over muskeg is the $500,000 figure cited for a wildcat well site (36).

Thus, there is a need for careful scheduling in muskeg areas so that "... the work to be executed is of a type appropriate to the seasonal character of the muskeg..." (37). Winter access roads greatly reduce the need for gravel fill, and allow a great cost savings in temporary access.

Kaplar (27) has cited further benefits of winter work in muskeg areas, including, (a) the use of frozen...
soil as surcharge material, and (b) access on ice bridges over bodies of water.

Improved winter traffcibility can be taken advantage of in non-muskeg environments, as well. A significant portion of the subsurface soil exploration for the Garrison Dam (South Dakota) was done in the winter time when traffcibility over the river and river deposits was greatly facilitated (48).

In permafrost areas, trafficking on unprotected tundra may result in permanent damage to the insulating vegetative mat, and cause permafrost degradation and subsequently uncontrolled erosion. Land use regulations in Alaska control all surface travel north of 60 degrees latitude (32), and summer movements on the tundra are prohibited. In Canada similar laws are also in effect. Thus in the far north, winter earthwork is indirectly encouraged by law.

Winter excavation operations are often enhanced in high-water-table or muskeg areas. Excavation in well drained cohesionless soils is little affected by low temperatures, and so can be considered a feasible winter operation. Trafficability is enhanced in the winter season in clayey soils, permafrost, and muskeg or high-water-table areas.
9:3 Rock Blasting and Rock Crushing

Rock crushing can be an important phase of earthwork projects in areas where bedrock is abundant and there is a lack of suitable aggregate or fill material. Rock blasting takes on a special significance where rock cut is used to produce rock fill. Crushing and processing of rock can be accomplished at low temperatures if water is not a processing medium.

Blasting of frozen rock can be much more expensive than blasting of non-frozen rock. Linell and Johnston (33) reported for an iron ore mine in Quebec that blasting in frozen ore required three times as much powder and was twice as expensive as blasting operations in unfrozen ore. Blasting costs in an open pit mine in northern British Columbia increased considerably when blasting was in frozen ore. The low temperature effect on rock strength probably varies greatly. The competence of the rocks in the above two examples is not known to the writer.

The increased unit costs of frozen rock blasting notwithstanding, rock blasting and crushing are potentially feasible winter operations when viewed in a total context. See Sections 7:1 and 7:2.

9:4 Ditching and Pipe Laying

As was indicated in Sections 8 and 9:2, frozen soil behavior tends to make such shallow excavations as those required for ditching and pipe laying uneconomical. However, increased trafficability in high-water-table areas, in
clayey soils, and in permafrost areas can offset the increased costs of frozen soil excavation. According to MacFarlane (37), "Where most of the pipeline—or extensive sections at least—is to be built across muskeg and there is some freedom in the timing of the job, it has been found better from both an economic and technical standpoint to work in the winter". Thus, in poorly trafficable areas, ditching and pipelaying may prove to be best accomplished during the winter season.

9:5 Culvert Work, Outflow Work, and Clearing and Grubbing

Culvert and culvert outflow work (2) received a low economic ranking in Section 7. Winter execution of these operations may prove justified only where time is a critical factor. Winter outflow work can be enhanced in areas where trafficability is a problem, since ground water tables are generally lowered and precipitation runoff is greatly reduced.

Clearing and grubbing and clean-up can both be considered for winter operation, particularly in the case of permafrost soils, when damage to the surrounding vegetation would be at a minimum.
10:0 SITE SOIL FORMS AND THEIR AREAL DISTRIBUTION

This section discusses the areal distribution of six soil forms, viz., 1) no-soil areas, 2) organic and wet soil areas, 3) plastic soil areas, 4) clayey soil areas, 5) coarse-textured soil areas, and 6) permafrost areas. These six soil forms, used to facilitate the identification of feasible cold weather earthwork operations, are not mutually independent categories; e.g., many plastic soils are associated with organic or wet soil areas, and permafrost can be present in any of the five other soil forms.

As pointed out in Sections 7 and 9, the economic feasibility of a particular winter earthwork operation at a specific site depends on a number of tangible and intangible factors. Winter earthwork operations are listed on Plates 8 to 11 in economic ranking order as discussed in Section 7:2, i.e., the first operation listed is in general the most feasible winter operation.

10:1 No-Soil Areas

"No-soil" areas are those where there is little soil cover over the bedrock. No-soil areas are delineated in Plate 8. Such bedrock areas often reflect geologic
environments in which there has been active erosion either because of orogenic uplift or continental glacial scouring.

As noted in Section 9, rock blasting, rock crushing, and rock fill operations can be considered economically feasible in winter. No attempt was made to determine areas in which large rock cut and fill operations can be expected, or areas in which rock crushing is a necessary operation for aggregate production. At a larger scale one could map such areas delineating zones with large vs. small rock cut/fill, and areas where suitable sand and gravel aggregate deposits are lacking.

10:2 Organic and Wet Soil Areas

Organic and wet soil area environments are discussed together because they are usually directly associated with one another. Figure 10 presents a generalized map indicating organic terrains in Canada which present potential problems in earthwork operations.

Plate 9 is a summary map of areally significant organic soil occurrences in Canada and the conterminous United States. Alaska was not included because no information at the appropriate scale was available. Information on the size, depth, and structure characteristics of individual peat deposits in Alaska is presented by Dachnowski-Stokes (15). It has been estimated that
Figure 10. Generalized areas in which organic terrain (muskeg) presents engineering problems. (37)
there are more than 110 million acres of muskeg or organic terrain in Alaska (15). Additional references for detailed soil maps for portions of Alaska are listed in References Cited (15,49,50,51,52,59) (Section 14:1).

Wetlands of Canada are presented in Figure 11 (45). No information was available on a wetland classification of the conterminous United States or Alaska. From the writer's personal experience in Alaska, it may be said that wet areas are quite extensive in the lowland areas of the subarctic and arctic.

Earthwork operations which may be executed in the winter season in organic or wet soil terrains are listed on Plate 9. They are listed in decreasing order relative to their probable economic feasibility.

10:3 Plastic Soils

Areas in which definitely plastic soils are to be expected are mapped on Plate 10. It is not possible to differentiate at the small map scale between massive plastic soils and clayey soils interbedded or interfingered with other soil textures.

Winter earthwork operations which can show economic advantage in clay soils under certain conditions (which were indicated in Section 9:2) are listed in Plate 10. They are listed in order from the most economically feasible to the least economically feasible.
Note: Each grid equals 10,000 km². Wetland: refers to areas of land which are "inun­dated lands, seasonal marsh or swamp; alkali flats; string bog; and foreshore flats." (The National Atlas of Canada, plate 39-40.) These terms usually designate water saturated soil or vegetation associated with ponded water.

Figure 11. Wetlands of Canada expressed as percentages of grid area. (Copyright, Survey and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, Canada; reprinted by permission.)
10:4 Clayey Soils

This soil form, involving fine-grained soils of limited plasticity or clayeyness, was not mapped at the regional scale because the feasible winter earthwork operations for it cannot be readily summarized. Fill and compaction operations may be economically feasible in these materials provided the operation does not allow the fill material to freeze before the compaction operation is completed. See Plates 5 through 7 for the areal distribution of clayey soils.

10:5 Coarse Textured Soils

The areal occurrence of sandy and gravelly soils is presented in Plate 11. It is quite obvious that most of the study area has potential sources of coarse-textured soils. Even in areas where no coarse-textured soils are indicated, they are often locally present. The small map scale precludes the mapping of locally important soils such as kames, eskers, and valley trains.

Earthwork operations that are potentially economically feasible in the winter season are listed in Plate 11.

10:6 Permafrost Areas

Figure 12 presents the mode of occurrence and distribution of permafrost in Canada and Alaska (11,18). Regulations in permafrost areas have been developed which encourage winter earthwork (see Section 7:3).
Permafrost in Rocky Mountain Cordillera present south of mapped permafrost zones.

Figure 12. Mode of occurrence and distribution of permafrost in Alaska and Canada. (Reprinted by permission of National Academy of Science and U.S. Geological Survey.)
Feasible winter earthwork operations in permafrost environments depends greatly on the mode of permafrost and soil texture. In ice-rich, fine-grained soils, one tries to preserve the natural thermal regime (32,38). In well-drained, coarse-textured soils, thaw of the permafrost is not a physical detriment. Thus, in fine-grained permafrost soils surface activity over unprotected tundra is best accomplished in the winter season when a protective layer of snow overlies the vegetative mat. Surface activity on some coarse-grained permafrost may be carried out in any season. In ice-rich deposits thaw is deleterious to the soil stability.

Earthwork operations requiring mobility at an unimproved site may be best accomplished during the winter season. As was mentioned in Section 7:3 a layer of frozen ice and snow protects the insulative vegetative mat. Clearing and grubbing and temporary road access work should be considered for winter execution in permafrost areas.
11:0 SUMMARY

1. A compatible modern physiographic map of Alaska, Canada and the conterminous United States is presented. Physiographic units are mapped at the Division, Province, Section, and Subsection levels.

2. A generalized soil texture map is compiled for Alaska, Canada and the conterminous United States. Mapping of Canada is based in part on unpublished data supplied by the Soil Research Institute of the Canadian Department of Agriculture (26). Soil texture mapping of Alaska is based on surficial geologic reports and soils information (15,20,23,24,25,28,41,49,50,51,52, 54,59,69). Mapping of the conterminous U.S. is after Witczak (70).

3. A generalized economic feasibility rank ordering of winter earthwork operations based upon meteorological conditions, and based on data reported by a Swedish survey (2), is presented.

4. Seasonal earthwork inefficiency curves are presented for 86 selected stations in North America. They represent relative inefficiencies of manual labor, excavation, and hauling operations, with respect to
meteorologic factors such as temperature, lighting, and precipitation.

5. The importance of "site soil form" is recognized, in addition to the meteorological factors, and the areal distribution of five soil forms is presented in map form. Noted on each map are the general earthwork operations that are potentially feasible in the mapped soil form.

6. Potentially feasible cold weather operations and generalized soil forms are related to physiographic section units in the summary matrix of Table 12.

7. Evaluating potentially economical winter earthwork operations for a given site or region can be approached using the method developed by this study. Section 15:6 outlines the method of applying the report information to such practical problems.
Table 12
Summary Matrix Relating Physiographic Sections To Soil Forms and Feasible Cold Weather Earthwork Operations

Note: Code for soil form is as follows: s=coarse textural soils, e=plastic soils, b=no-soils, o=organic soils, q=permafrost soils, qu=undifferentiated soil form. Sections with none of the soil forms cited above are indicated with a (-).

<table>
<thead>
<tr>
<th>Physiographic Province</th>
<th>Significant soil forms (≥10% of area; see code refers to Table 4)</th>
<th>COCK BLASTING</th>
<th>FORGE ROLL</th>
<th>FILL &amp; CONNECTION</th>
<th>DECANTER PLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Coast Ranges</td>
<td>s,b,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pacific Troughs</td>
<td>s,c</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Sierra-Cascade</td>
<td>s,b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Coast Mountains</td>
<td>s,b,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Seward Peninsula</td>
<td>s,b,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bering Shelf</td>
<td>s,b,p,qu</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Anklun Mts.</td>
<td>s,b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Western Alaska</td>
<td>s,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Northern Plateaus</td>
<td>s,b,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Central Plateaus</td>
<td>s,b,p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Region</td>
<td>Table 12, cont.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td>-----------------</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbia Plateau</td>
<td>10A,D,E s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10C</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12B-D,F s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12C</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13A,A,H-J s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13B-D,F,G,K s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic Rockies</td>
<td>14A,D,E s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14B,C</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14D,F,G s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15B-E s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16A,C</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Rocky Mts.</td>
<td>16B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18A,D,F s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19A,B,E-G s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19C,D-I s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19M</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic Coastal Mts.</td>
<td>19R</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20A,D,E s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21C</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23C-D,E s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24A-C s,c,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24D,F s,b</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25A,B s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central and Eastern Lowlands</td>
<td>27A-F s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28A,B,D-G s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>29A,F,H s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>29B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Churchill</td>
<td>30A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western Churchill</td>
<td>28A,B,D-G s,b,p</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>29A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern Churchill</td>
<td>29B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hudson Bay</td>
<td>30A</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30B</td>
<td>x x x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 17, cont.

<table>
<thead>
<tr>
<th>Region</th>
<th>Sections</th>
<th>s, c, o, b</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
<td>31A, D, E</td>
<td>s, c, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>31B, F</td>
<td>s, c, o</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>31C</td>
<td>s, c</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>31G</td>
<td>s, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>31H, J, K</td>
<td>s, b, p</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Grenville</td>
<td>32A, C</td>
<td>s, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>32B, D, F</td>
<td>s, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>32E, G</td>
<td>s, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>32H</td>
<td>s, o</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>St. Lawrence</td>
<td>33A</td>
<td>s, c, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>33B</td>
<td>o</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>33C</td>
<td>b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>New England</td>
<td>34A, C, E, K, P</td>
<td>s, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Maritime</td>
<td>34A, Q, J</td>
<td>s, c, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>34B</td>
<td>s, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>34D, I, L-N</td>
<td>s, c</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Appalachian</td>
<td>34H</td>
<td>s, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Plateau</td>
<td>35A</td>
<td>s, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>35B</td>
<td>o</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>35C</td>
<td>s, c</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>35D</td>
<td>c, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Newer Appalachian</td>
<td>36A</td>
<td>s, o, b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Triassic Lowland</td>
<td>38</td>
<td>s, c</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
**CONCLUSIONS**

1. Soil form maps and potentially feasible earthwork operations for each soil form can be compiled.

2. Six categories of soil form can be recognized at the regional level.

3. One can estimate the relative effect of meteorological factors for any selected station.

4. One can predict areas which are potentially feasible for selected cold weather earthwork operations by relating soil forms and earthwork operations.

5. At least 94% of 213 physiographic sections considered have two or more earthwork operations that are potentially feasible if executed during the winter season.
13:0 RECOMMENDATIONS FOR FURTHER EFFORT

1. Mapping of physiographic subsections in Alaska and Canada will aid in regionalization of engineering problems and solutions in these areas.

2. Better input for generalized soil texture mapping is needed for Alaska and Canada.

3. The pertinent tangible factors which relate to earthwork seasonality, i.e., site soil form (including soil texture and moisture, location of water table, and permafrost), and prevailing meteorologic conditions (temperature, lighting, precipitation, humidity, and wind) should be studied and reported in detail for selected physiographic units.

4. Summarization in map form of any new information on the factors of (3) will help to further highlight geographic areas for cold weather earthwork activity or experimentation.

5. The social and economic benefits of cold weather earthwork should be made known to non-technical people, and to administrative persons who can influence the seasonality of earthwork scheduling.

6. Inefficiency information should be developed for the U.S. and Canada to refine Swedish data used.
14:0 REFERENCES

14:1 References Cited


2. Associated General Contractors and House Builders of Sweden, Vagbyggande Arbet Runt (Road Construction Year Around), Byggnadsindustrins Forlags AB, 1963, 187 pages.


37. MacFarlane, I.C., Muskeg Engineering Handbook, by Muskeg Subcommittee of the NRC Associate Committee on Geotechnical Research, University of Toronto Press, 1969.


47. Osborne, A.M., Feasibility of Cold Weather Earthwork in Indiana, MSCE Thesis, Purdue University, 1967, p. 84.


57. Soils of Canada, Soils Research Institute, Research Branch, Dept. of Agriculture, Ottawa, scale 1:5,000,000, 1972.


60. The System of Soil Classification for Canada, Revised, Publication 1455, Canada Dept. of Agriculture, 1974, p. 255.


64. Trewartha, G.T., Climate of the Earth, Simplified from Koppen, World Geography Series, 1:22,800,000, editor; E.B. Espenshade, Jr.


74. Zachary, A.L., Oral Communication, Professor of Agronomy, Purdue University, May, 1975.

14:2 General References


15:0 APPENDIX

15:1 Usefulness of Inefficiency Curves

While inefficiency curves are basically qualitative in nature, they may be useful to agencies planning earthwork operations in a specific area. They can also be helpful in predicting earthwork seasonalities in geographic areas where there is no previous experience. It has been shown by Bieganousky (5) that "tradition" is the main justification for earthwork seasonality in many areas. The inefficiency curves may encourage departures from past practice and indicate where cold weather operations could be initiated, at least on an experimental basis.

15:2 Method of Calculating Inefficiency Curves

The inefficiency curves are based on data developed by a Swedish study (2). Efficiency values, based on climatic factors, were developed for three categories of earthwork, viz., manual labor, excavation, and hauling operations. The developed efficiency values are presented in Section 7:3 of this report.

The climatic factors used in the calculation of inefficiency values include: 1) temperature (Et), 2) lighting condition (El), and 3) precipitation (Ep). The overall inefficiency value (Io), for a given climatic condition is determined by subtracting from a value of unity the product of a chain multiplication of the efficiency values for each climatic factor. The efficiency
values are expressed in percent. In mathematical form the equation is as follows:

\[ \text{Io}（\%） = \left[ 1 - (E_t)(E_l)(E_p) \right] \times 100 \]

A seasonal inefficiency curve can be generated by evaluating and plotting inefficiency values with time.

An example inefficiency calculation for manual labor operations at a temperature of 10°C (50°F), with indirect sunlight (overcast), and light rain would be as follows:

Manual Labor (From Table 9)

<table>
<thead>
<tr>
<th>Climatic Factor</th>
<th>Condition</th>
<th>Efficiency, ( E ) (1.0=100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>10°C</td>
<td>1.0</td>
</tr>
<tr>
<td>Lighting</td>
<td>Indirect Sunshine</td>
<td>1.0</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Light Rain</td>
<td>0.89</td>
</tr>
</tbody>
</table>

\[ \text{Io}（\%） = \left[ 1 - (E_t)(E_l)(E_p) \right] \times 100 \]
\[ = \left[ 1 - (1.0)(1.0)(0.89) \right] \times 100 = (1-0.89)(100) \]
\[ = 11\% \text{ inefficiency} \]

15.3 Data Input for Inefficiency Curve Calculation

The data used for input for the calculation of the inefficiency curves are based on published information issued by the U.S. Weather Bureau (65, 66), U.S. Naval Observatory (3, 61), and the Atmospheric Environment Department of Canada (13, 14). The input for the specific temperature, lighting and precipitation parameters is developed as indicated below.
The normal (mean) monthly temperature was used for determining the temperature efficiency value \((E_t)\). The temperature data for the United States are based on a ten year period (1951-1960), while Canadian temperature data are based on a thirty year period (1941-1970). Hence the value does not apply to those days within the period which are exceptionally warm or cold.

Lighting was based on a representative day, and was entered as three values: 1) hours of sunlight \((H_s)\), 2) hours of twilight \((H_t)\), and 3) hours of darkness \((H_d)\). These values were determined for 20 different latitudes for each representative day of each month. Lighting data were obtained from U.S. Naval Observatory Publications (3,61).

The lighting condition value \((E_l)\), was calculated for each month at 20 different latitudes with the following equation:

\[
E_l(\%) = \left[ \frac{H_s(E_s) + H_t(E_t) + H_d(E_d)}{24} \right] 100
\]

where \(E_s\), \(E_t\), and \(E_d\) are the efficiency values for the particular climatic conditions (given in Tables 9 and 10), and \(H_s\), \(H_t\), and \(H_d\) are the hours of sunlight, twilight, and darkness respectively in the representative day.

The precipitation value \((E_p)\), was determined in three categories: number of days per month with, 1) no precipitation \((P_n)\), 2) light precipitation \((P_l)\), and 3) heavy precipitation \((P_h)\). Heavy precipitation was
arbitrarily defined as equal to or greater than 0.5 inches per day. Light precipitation was defined as greater than 0.01 but less than 0.5 inches per day.

The number of days of precipitation for the United States is based on hourly summary data for a ten year period (1951-1960). Canadian precipitation data are based on a thirty year period (1941-1970). The precipitation values for Canadian stations were simply divided into number of days per month with light precipitation. No breakdown on precipitation amounts per day was available.

Ideally, precipitation values would be specific with respect to rain or snow. Unfortunately, the required information was not readily available.

Mathematically speaking, the efficiency value for precipitation was determined in the following manner:

$$E_p(\%) = \left[ \frac{D_h(E_h) + D_l(E_{lp}) + D_n(E_n)}{N} \right] \times 100$$

where $E_h$, $E_{lp}$, and $E_n$ are the efficiency values for the particular climatic condition (given in Tables 9 and 10), $D_h$, $D_l$ and $D_n$ are the number of days of heavy, light, and no precipitation per month respectively, and $N$ is the number of days in a given month.
15:4 Symbols Used In Inefficiency Curves

The states of the United States are abbreviated after the U.S. Postal Service state abbreviations. Canadian provinces and territories are abbreviated as follows:

Yukon = Yukon Territory
BC = British Columbia
ALB = Alberta
SA = Saskatchewan
MAN = Manitoba
ONT = Ontario
QUE = Quebec
NS = Nova Scotia
NB = New Brunswick
NEWF = Newfoundland
NWT = Northwest Territories

Other abbreviations include:

B = Bay
Lk = Lake
Br = Brook

The latitudes are given in degrees North, the longitudes are given as degrees West. When "99" appears in the latitude or longitude designation, it means that the exact coordinates are not known for that particular station.

The 86 inefficiency curves for the three major political areas (Alaska, conterminous United States, and Canada) are, in general, presented in a north to south, west to east pattern.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: BARROW AK
ELEVATION: 22
LATITUDE: 71.18
LONGITUDE: 156.47
PHYSIOGRAPHIC SECTION: 16A

LEGEND:
- --- Manual
- --- Excavation
- --- Hauling
1.0 - 100 PERCENT

INEFFICIENCY

0.8

0.6

0.4

0.2

0.0

JAN
FEB
MAR
APR
MAY
JUN MONTHS
JUL
AUG
SEP
OCT
NOV
DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: KOTZEBUE AK
ELEVATION: 10
LATITUDE: 66.52
LONGITUDE: 162.38
PHYSIOGRAPHIC SECTION: 7F

LEGEND
- - - - - - MANUAL
- - - - EXCAVATION
-- - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND

- - - - - MANUAL

--- --- EXCAVATION

-------- HAULING

1.0- 100 PERCENT

STATION NOME AK
ELEVATION 15
LATITUDE 64.5
LONGITUDE 165.26
PHYSIOGRAPHIC SECTION 4

INefficiency

JAN FEB MAR APR MAY JUN JUN AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
FAIRBANKS AK
ELEVATION 456
LATITUDE 64.49
LONGITUDE 147.52
PHYSIOGRAPHIC SECTION 7J

LEGEND
- - - - MANUAL
- - - - - EXCAVATION
- - - - Hauling
1.0 - 100 PERCENT

Months
JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC

INEFFICIENCY
0.  0.2  0.4  0.6  0.8
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: MC GRATH AK
ELEVATION: 534
LATITUDE: 62.58
LONGITUDE: 155.57
PHYSIOGRAPHIC SECTION: 7J

LEGEND:
- - - - - - - MANUAL
- - - - - - - EXCAVATION
- - - - - - - HAULING
1.0 - 100 PERCENT
EARTHWORK INEFEICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND

- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0 - 100 PERCENT

STATION ELEVATION
ANCHORAGE AK 90
LATITUDE 61.1
LONGITUDE 149.59
PHYSIOGRAPHIC SECTION 2A

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: BETHEL AK
ELEVATION: 10
LATITUDE: 66.47
LONGITUDE: 161.43
PHYSIOGRAPHIC SECTION: 5A

LEGEND
- - - - - - - - MANUAL
- - - - - - - - EXCAVATION
- - - - - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: CORDOVA AK
ELEVATION: 48
LATITUDE: 60.5
LONGITUDE: 145.5
PHYSIOGRAPHIC SECTION: 1B

LEGEND:
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: JUNEAU AK
ELEVATION: 15
LATITUDE: 58.22
LONGITUDE: 154.35
PHYSIOGRAPHIC SECTION: 3G

- --- MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0 - 100 PERCENT

MONTHS:
JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>COLD BAY AK</th>
<th>LEGEND</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>55.12</td>
<td>-</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>162.43</td>
<td>———</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC</td>
<td>7P</td>
<td>EXCAVATION</td>
</tr>
<tr>
<td>SECTION</td>
<td></td>
<td>HAULING</td>
</tr>
</tbody>
</table>

1.0 = 100 PERCENT

DECNOV

LEGEND
- MANUAL
- EXCAVATION
- HAULING

IN EFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: ANNETTE AK
ELEVATION: 110
LATITUDE: 55.02
LONGITUDE: 131.54
PHYSIOGRAPHIC SECTION: 2K

LEGEND:
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0 - 100 PERCENT

Month: JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INEFFICIENCY:
0.8
0.6
0.4
0.2
0.0
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION 4397
LATITUDE 59.29
LONGITUDE 119.46
PHYSIOGRAPHIC SECTION 11A

LEGEND
- - - - - MANUAI
- - - - - - - EXCAVATION
- - - - - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: GREAT FALLS MT
ELEVATION: 5664
LATITUDE: 47.29
LONGITUDE: 111.29
PHYSIOGRAPHIC SECTION: 19J

LEGEND:
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0 - 100 PERCENT

MONTHS:
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INEFFICIENCY:
0.8
0.6
0.4
0.2
0
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: SALT LK CITY UT
ELEVATION: 4222
LATITUDE: 40.46
LONGITUDE: 111.57
PHYSIOGRAPHIC SECTION: 11A

LEGEND:
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0-100 PERCENT

IN EFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: MURON SD
ELEVATION: 1282
LATITUDE: 44.25
LONGITUDE: 98.15
PHYSIOGRAPHIC SECTION: 20A

LEGEND:
- --- MANUAL
- - - - EXCAVATION
- --- HAULING
1.0 - 100 PERCENT

0.8
0.6
0.4
0.2
0.0

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>RAPID CITY SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>5165</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>44.05</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>103.04</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC</td>
<td>19M</td>
</tr>
<tr>
<td>SECTION</td>
<td></td>
</tr>
</tbody>
</table>

**Legend**
- --- MANUAL
- --- EXCAVATION
- --- HAULING
- 1.0 - 100 PERCENT

**Graph**
- X-axis: JAN to DEC
- Y-axis: 0 to 1
- Various lines representing inefficiency percentages over the months.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION.

STATION: TOPEKA KS
ELEVATION: 877
LATITUDE: 39.04
LONGITUDE: 95.30
PHYSIOGRAPHIC SECTION: 19U

LEGEND:
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

MONTHS: JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.8
0.6
0.4
0.2
0.0
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: WICHITA KS
ELEVATION: 1372
LATITUDE: 37.58
LONGITUDE: 97.16
PHYSIOGRAPHIC SECTION: 19U

LEGEND:
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
MANUAL
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
EXCAVATION
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
HAULING
1.0 - 100 PERCENT

INF\H\ENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: OMAHA NE
ELEVATION: 978
LATITUDE: 41.18
LONGITUDE: 95.55
PHYSIOGRAPHIC SECTION: 20C

LEGEND:
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

MONTHS
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND
- - - - - - - - - - - - - - - - MANUAL
- - - - - - - - - - - - - - - - EXCAVATION
- - - - - - - - - - - - - - - - HAULING
1.0 - 100 PERCENT

STATION
AMARILLO TX
ELEVATION 5570
LATITUDE 35.14
LONGITUDE 101.42
PHYSIOGRAPHIC SECTION 19M

INEFFICIENCY

0

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: DULUTH MN
ELEVATION: 1409
LATITUDE: 46.5
LONGITUDE: 92.11
PHYSIOGRAPHIC SECTION: 51C

LEGEND:
--- Manual
---------- Excavation
------------ Hauling
1.0 - 100 Percent
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION MINNEAPOLIS MN
ELEVATION 850
LATITUDE 44.55
LONGITUDE 95.15
PHYSIOGRAPHIC SECTION 20

LEGEND
- - - - - - - - MANUAY
- - - - - - - - EXCAVATION
- - - - - - - - HAULING
1.0- 100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: DES MOINES IA
ELEVATION: 940
LATITUDE: 41.52
LONGITUDE: 93.39
PHYSIOGRAPHIC SECTION: 20C

LEGEND:
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0 - 100 PERCENT

IN EFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: SIoux City IA
ELEVATION: 1095
LATITUDE: 42.25
LONGITUDE: 96.22
PHYSIOGRAPHIC SECTION: 20

LEGEND

- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: GREEN BAY WI
ELEVATION: 689
LATITUDE: 44.29
LONGITUDE: 88.08
PHYSIOGRAPHIC SECTION: 20E

LEGEND:--- MANUAL --- EXCAVATION --- HAULING
1.0 - 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEФICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>MADISON WI</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>858</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>45.8</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>89.19</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC SECTION</td>
<td>20E</td>
</tr>
</tbody>
</table>

LEGEND
- - - MANUAL
--- EXCAVATION
--------- HAULING
1.0- 100 PERCENT

0.8
0.6
0.4
0.2
0

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION 741
LATITUDE 39.07
LONGITUDE 94.55
PHYSIOGRAPHIC SECTION 20C

KANSAS CITY MO

LEGEND
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0- 100 PERCENT

INefficiency

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: ST LOUIS MO
ELEVATION: 552
LATITUDE: 38.45
LONGITUDE: 90.25
PHYSIOGRAPHIC SECTION: 20C

LEGEND
- - - - MANUAL
---- EXCAVATION
----- HAULING
1.0 - 100 PERCENT

IN EFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.6
0.4
0.2
0

EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

- MANUAL
- EXCAVATION
- HAULING

1.0 - 100 PERCENT

STATION: SPRINGFIELD MO
ELEVATION: 1265
LATITUDE: 37.14
LONGITUDE: 95.25
PHYSIOGRAPHIC SECTION: 21B

LEGEND

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: MOLINE, IL
ELEVATION: 599
LATITUDE: 41.27
LONGITUDE: 90.31
PHYSIOGRAPHIC SECTION: 20F

LEGEND:
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0-100 PERCENT

INeffICIENCY

MONTHS
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>SPRINGFIELD IL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>507</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>39.5</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>89.4</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC SECTION</td>
<td>20F</td>
</tr>
</tbody>
</table>

LEGEND
---
- --- MANUCAII
- --- EXCAVATION
- --- HAULING
1.0 - 100 PERCENT

The diagram shows the inefficiency of earthwork activities over the months of January to December for the station in Springfield, Illinois. The legend indicates the inefficiencies associated with manual, excavation, and hauling activities, with a scale ranging from 1.0 to 100 percent.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: FT WAYNE IN
ELEVATION: 801
LATITUDE: 41
LONGITUDE: 05.13
PHYSIOGRAPHIC SECTION: 20E

LEGEND:
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0-100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION: 795
LATITUDE: 39.44
LONGITUDE: 86.16
PHYSIOGRAPHIC SECTION: 20F

LEGEND:
- - - - - - MANUAL
--- --- EXCAVATION
--- --- HAULING
1.0% - 100% PERCENT

IN EFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: COLUMBUS OH
ELEVATION: 815
LATITUDE: 39.59
LONGITUDE: 82.52
PHYSIOGRAPHIC SECTION: 558

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0-100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: CINCINNATI OH
ELEVATION: 869
LATITUDE: 39.04
LONGITUDE: 84.26
PHYSIOGRAPHIC SECTION: 20F

LEGEND:
--- Manual
--- Excavation
--- Hauling
1.0 - 100 Percent

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

- **STATION:** SCRATON PA
- **ELEVATION:** 940
- **LATITUDE:** 41.2
- **LONGITUDE:** 75.44
- **PHYSIOGRAPHIC SECTION:** 358

**LEGEND:**
- - - - - MANIVAL
- - - - - EXCAVATION
- - - - - HAULING

1.0 - 100 PERCENT

MONTHS:
- DEC
- NOV
- OCT
- SEP
- AUG
- JUL
- JUN
- MAY
- APR
- MAR
- FEB
- JAN

INEFFICIENCY

0.8
0.6
0.4
0.2
0

MONTSES

139
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION  PITSBURG PA
ELEVATION  1151
LATITUDE  40.5
LONGITUDE  00.13
PHYSIOGRAPHIC SECTION  350

LEGEND
--- MANUAL
--- EXCAVATION
--- HAULING
1.0 - 100 PERCENT

IN EFFICIENCY

JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: HARRISBURG, PA
ELEVATION: 538
LATITUDE: 40.15
LONGITUDE: 76.51
PHYSIOGRAPHIC SECTION: 50

LEGEND
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY
0.8
0.6
0.4
0.2
0.0

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC MONTHS
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND

- - - - MANUAL
----- EXCAVATION
----- HAULING
1.0-100 PERCENT

STATION CHARLESTON WV
ELEVATION 950
LATITUDE 38.22
LONGITUDE 81.56
PHYSIOGRAPHIC SECTION 150

INefficiency

M O N T H S

1.0
0.6
0.4
0.2
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: SCRACUSE NY
ELEVATION: 424
LATITUDE: 43.07
LONGITUDE: 76.07
PHYSIOGRAPHIC SECTION: 20E

LEGEND:
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION: 695
LATITUDE: 42.56°
LONGITUDE: 78.44°
PHYSIOGRAPHIC SECTION: 20E

LEGEND:
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0 - 100 PERCENT

MONTHS:
- JAN
- FEB
- MAR
- APR
- MAY
- JUN
- JUL
- AUG
- SEP
- OCT
- NOV
- DEC

INEFFICIENCY
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: ALBANY NY
ELEVATION: 277
LATITUDE: 42.45
LONGITUDE: 73.48
PHYSIOGRAPHIC SECTION: 20H

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>PORTLAND ME</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>61</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>43.59</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>70.18</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC</td>
<td>340</td>
</tr>
<tr>
<td>SECTION</td>
<td></td>
</tr>
</tbody>
</table>

LEGEND
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0-100 PERCENT

IN EFFICIENCY

JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
DAWSON YUKON

ELEVATION
64.04

LATITUDE
64.04

LONGITUDE
159.22

PHYSIOGRAPHIC
SECTION
8G

LEGEND

MANUAL

EXCAVATION

HAULING

1.0 = 100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND

- - - - - - - MANUAL

--- EXCAVATION

--------- HAULING

1.0-100 PERCENT

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC SECTION
MAYO YUKON
63.4
155.51
8F

INEFFICIENCY

JAN MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFGIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION SNAG YUKON
LATITUDE 62.18
LONGITUDE 140.5
PHYSIOGRAPHIC SECTION 8H

LEGEND

MANUAL
EXCAVATION
HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

<table>
<thead>
<tr>
<th>STATION</th>
<th>HAINES JUN YUKON</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION</td>
<td>68.45</td>
</tr>
<tr>
<td>LATITUDE</td>
<td>68.45</td>
</tr>
<tr>
<td>LONGITUDE</td>
<td>137.21</td>
</tr>
<tr>
<td>PHYSIOGRAPHIC SECTION</td>
<td>8H</td>
</tr>
</tbody>
</table>

**LEGEND**
- --- --- MANUAL
- --- --- EXCAVATION
- --- --- HAULING
1.0-100 PERCENT

LINE GRAPH

- Inefficiency vs. Months
  - January to December
  - Station: Haines Jun Yukon
  - Elevation: 68.45
  - Latitude: 68.45
  - Longitude: 137.21
  - Physiographic Section: 8H
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION WHITEHORSE YUKON
LATITUDE 60.39
LONGITUDE 135.01
PHYSIOGRAPHIC SECTION 8G

LEGEND
-- - - - - - - - - - MANUAL
-- - - - - - - - - - - EXCAVATION
-- - - - - - - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION 58.57
LATITUDE 50.57
LONGITUDE 122.5
PHYSIOGRAPHIC SECTION 19H

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0-100 PERCENT

Graph showing inefficiency levels from January to December.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION  SMITH RIVER BC
ELEVATION  551
LATITUDE  55.1
LONGITUDE 114.02
PHYSIOGRAPHIC SECTION  8K

LEGEND
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0 - 100 PERCENT

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INEFFICIENCY
0.0 0.2 0.4 0.6 0.8
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION KITIMAT AC
LATITUDE 54.03
LONGITUDE 120.33
PHYSIOGRAPHIC SECTION 5F

LEGEND
- - - - - MANUAI
- - - - - EXCAVATION
- - - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC SECTION
PRINCE GEORGE BC
55.51
122.57
9F

LEGEND
MANUAL
EXCAVATION
HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.8
0.6
0.4
0.2
0
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION.

LEGEND:
- Manual
- Excavation
- Hauling

STATION:
- WILLIAMS LK BC

ELEVATION:
- 52.08

LATITUDE:
- 122.09

LONGITUDE:
- 9F

PHYSIOGRAPHIC SECTION:
- 1.0 - 100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION
JASPER ALB 62.55
LATITUDE 110.05
LONGITUDE 14A
PHYSIOGRAPHIC
SECTION

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0- 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.8
0.6
0.4
0.2
0

MANUAL
EXCAVATION
HAULING
1.0- 100 PERCENT

158
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION PEACE R ALB
ELEVATION 56.14
LATITUDE 117.17
LONGITUDE 19H
PHYSIOGRAPHIC SECTION

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0- 100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.8
0.6
0.4
0.2
0

159
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION JASPER ALB
LATITUDE 52.55
LONGITUDE 118.05
PHYSIOGRAPHIC SECTION 14A

LEGEND
- - - - - MANUAL
- - - EXCAVATION
- - - HAULING
1.0- 100 PERCENT

Month I: JAN
Month II: FEB
Month III: MAR
Month IV: APR
Month V: MAY
Month VI: JUN
Month VII: JUL
Month VIII: AUG
Month IX: SEP
Month X: OCT
Month XI: NOV
Month XII: DEC

INEFFICIENCY

0.0
0.2
0.4
0.6
0.8
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
EDMONTON, ALB

LATITUDE
55.55

LONGITUDE
115.20

PHYSIOGRAPHIC
SECTION
191

LEGEND

MANUAL

EXCAVATION

HAULING

1.0 - 100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: URANIUM CITY SA
ELEVATION: 59.54
LATITUDE: 50.59
LONGITUDE: 28.0
PHYSIOGRAPHIC SECTION: 28G

LEGEND:
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0 - 100 PERCENT

MONTHS: JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION SASKATOON SA
LATITUDE 52.07
LONGITUDE 106.38
PHYSIOGRAPHIC SECTION 20A

LEGEND
-- MANUCA1
--------- EXCAVATION
--------- HAULING
1.0- 100 PERCENT

INEFFICIENCY
0.8
0.6
0.4
0.2
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND
- --- Manual
--- --- Excavation
 --- --- Hauling
 1.0 - 100 Percent

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC
SECTION
KINDERSLEY SA
51.27
109.1
191

INEFFICIENCY

0.8
0.6
0.4
0.2
0

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION: YORKTOWN SA
ELEVATION: 51.15
LATITUDE: 102.20
LONGITUDE: 20A
PHYSIOGRAPHIC SECTION: 20A

LEGEND
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0 - 100 PERCENT

GRAPHIC CHART SHOWING INEFFICIENCY LEVELS FROM JANUARY TO DECEMBER.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION 58.47
LATITUDE 58.4
LONGITUDE 94.1
PHYSIOGRAPHIC SECTION 50B

LEGEND
- --- MANUAL
- - - EXCAVATION
- - - HAULING
1.0- 100 PERCENT
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION
LATITUDE 56.51
LONGITUDE 100.5
PHYSIOGRAPHIC SECTION 28G

LEGEND
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION: 55.5
LATITUDE: 50.15
LONGITUDE: 101.15
PHYSIOGRAPHIC SECTION: 208

LEGEND:
- - - - - MANUAL
----- - EXCAVATION
- - - - - HAULING
1.0-100 PERCENT

Graph showing the inefficiency distribution over the months of the year.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION
LATITUDE 51.2
LONGITUDE 80.44
PHYSIOGRAPHIC SECTION 50B

LEGEND
--- MANUAL
--- EXCAVATION
--- HAULING
1.0 - 100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
51.15
LATITUDE
95.2
LONGITUDE
PHYSIOGRAPHIC
SECTION
31A

LEGEND
- - - - - - - MANUAL
- - - - - - - EXCAVATION
- - - - - - - HAULING
1.0 - 100 PERCENT

INEFFICIENCY

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC
SECTION

NORTH BAY ONT
46.15
79.26
32G

LEGEND
----- MANUAL
------------- EXCAVATION
HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEффICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION  TORONTO, ONT
ELEVATION  43.4
LATITUDE  79.29
LONGITUDE  20E
PHYSIOGRAPHIC SECTION  20E

LEGEND
--- MANUAL
--- EXCAVATION
--- HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEfficIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION MONTREAL QUE.
LATITUDE 45.3
LONGITUDE 75.35
PHYSIOGRAPHIC SECTION 33A

LEGEND
- - - - - MANUAL
- - - - - EXCAVATION
- - - - - HAULING
1.0-100 PERCENT

MONTHS
FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INEFFICIENCY

0.0 0.2 0.4 0.6 0.8
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC SECTION
SYDNEY NS
46.09
60.11
34F

LEGEND
- ----- MANUAl
- - - - EXCAVATION
- - - - Hauling
1.0-100 PERCENT

INEFFICIENCY

JAN
FEB
MAR
APR
MAY
JUN
MONTHS
JUL
AUG
SEP
OCT
NOV
DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION
LATITUDE 70.29
LONGITUDE 127.41
PHYSIOGRAPHIC SECTION 198

LEGEND
- - - - MANUAL
- - - EXCAVATION
- - - HAULING
1.0-100 PERCENT

[Graph showing inefficiency levels over months with Cape Parry NWT station data]
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION          HALL BEACH, NWT  
ELEVATION        80.99  
LATITUDE         68.99  
LONGITUDE        81.99  
PHYSIOGRAPHIC    24E  
SECTION

LEGEND
- --- MANUAL
- --- EXCAVATION
- --- HAULING
1.0- 100 PERCENT

INEFFICIENCY
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING

1.0 - 100 PERCENT

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC
SECTION

INUVIK NWT
68.4
154.1
BC
Earthwork inefficiencies based on monthly temperature, lighting, and precipitation.

Station: Cape Dyer NWT
Elevation: 66.5
Latitude: 61.2
Longitude: 27A
Physiographic Section: 27A

Legend:
- - Manual
--- Excavation
----- Hauling
1.0-100 Percent

Inefficiency

Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

Graph shows inefficiency trends over the months with different line styles representing manual, excavation, and hauling activities.
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION PORT RADIUM NWT
LATITUDE 66.06
LONGITUDE 110.03
PHYSIOGRAPHIC SECTION 25B

LEGEND
--- MANUAL
------------- EXCAVATION
------------- HAULING
1.0-100 PERCENT

INefficiency

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INefficiency
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION NORMAN WELLS NWT
LATITUDE 65.26
LONGITUDE 127.
PHYSIOGRAPHIC SECTION 151

LEGEND
- - - - MANUAL
- - - - EXCAVATION
- - - - HAULING
1.0-100 PERCENT

GRAPHIC

INefficiency

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION FROBISHER B NWT
LATITUDE 65.48
LONGITUDE 68.51
PHYSIOGRAPHIC SECTION 27C

LEGEND
- - - - - - MANUAL
- - - - - - EXCAVATION
- - - - - - HAULING
1.0-100 PERCENT

MONTHS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

INEFFICIENCY
EARTHWORK INEFFECTIVENESS BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

LEGEND

- - - MANUAL
- - - EXCAVATION
- - - HAULING
1.0 - 100 PERCENT

STATION ELEVATION
LATITUDE 65.19
LONGITUDE 91.11
PHYSIOGRAPHIC SECTION 286

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION
ELEVATION
LATITUDE
LONGITUDE
PHYSIOGRAPHIC SECTION

YELLOW KNIFE NWT
62.29
114.30
26

LEGEND
- MANUAL
- EXCAVATION
- HAULING
1.0-100 PERCENT

INEFFICIENCY

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

0.8
0.6
0.4
0.2
0
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

STATION ELEVATION FT SIMPSON NWT 61.52
LATITUDE 61.52
LONGITUDE 121.48
PHYSIOGRAPHIC SECTION 19G

LEGEND
- - - - - - - - - - - - - MANUAL
----- ----- ----- EXCAVATION
---------- HAULING
1.0-100 PERCENT

INEFFICIENCY

0.

.2

.4

.6

.8

JAN FEB
MAR APR
MAY JUN
JUL AUG
SEP OCT
NOV DEC
MONTHS

581
EARTHWORK INEFFICIENCIES BASED ON MONTHLY TEMPERATURE, LIGHTING, AND PRECIPITATION

- Legend:
  - --- MANUAL
  - --- --- EXCAVATION
  - --- --- --- HAULING
  - 1.0-100 PERCENT

Station:
- Elevation: 61.5
- Latitude: 65.58
- Longitude: 63.58
- Physiographic Section: 27E

Graph shows inefficiency over months from January to December.
Earthwork inefficiencies based on monthly temperature, lighting, and precipitation.

Station: Clyde NWT
Elevation: 54.09
Latitude: 115.59
Longitude: 27A
Physiographic Section: 1.0–100 percent manual, excavation, hauling.

Chart shows inefficiency levels by month from January to December.
Potentially economic winter earthwork operations for a given area, either regional or specific, can be predicted with the method of approach developed by this study. The basic logic and procedural steps necessary are outlined below.

1) Use Plates 5 to 7b to estimate the predominate soil texture within the given area.

2) Identify the areal soil form in Plates 8 to 11. If the soil form is not mapped for the area, use the information from step (1) in further steps.

3) Review the information in Tables 7 and 8 on the technological and economic ordering of cold weather earthwork operations.

4) Review Section 9, "Soil Behavior Related to Feasible Cold Weather Earthwork Operations."

5) If the soil form is mapped for the area (step 2), the map legend will show the potentially economic operations. If the soil form is not mapped, the listing of potentially economic operations can be formulated from the information reviewed in steps (3) and (4).

6) Review climatic data for the area. See Section 15:3.

7) Review the efficiency of operations with meteorologic conditions, as presented in Section 7:3, and especially in Tables 9 and 10.

8) Identify the appropriate inefficiency curve in Section 15:5, or produce an inefficiency curve for the given area. To achieve the latter, use the information of steps (6) and (7), as described in Section 15:2.

Consider an application of the above procedure to an area in south-central Saskatchewan. It is determined in
step (1), that the predominate soils texture in the area is mapped as 1/c i.e., loams and clays are the predominate soil textures. The next step is to examine the soil form maps (Plates 8 to 11), to determine the appropriate soil form. In this case, the plastic soil form (Plate 10) applies and the map legend lists the potentially economic operations. Review steps (3) and (4) to determine if the listing should be modified based on engineering judgment. In the example considered, the following earthwork operations are considered potentially economically feasible:

1. excavation for waste
2. development of temporary access
3. borrow work
4. large culvert work
5. clearing and grubbing
6. water outflow work

The operations are listed in decreasing order of potential economy for winter execution. Thus, the first operations listed should be considered for the most severe, but acceptable, winter conditions.

Additional work would involve the development of an inefficiency curve for the particular south-central Saskatchewan area, such as that illustrated on page 163. Such curves predict the losses in efficiency with the season, and aid in scheduling particular operations at particular times.

Experiences in cold weather earthwork can probably be best organized and used with respect to the physiographic units (particularly Plate 3). In general, the
feasibility of operations is unique within the physiographic section, and differs significantly from section to section. In addition, a very general prediction can be effected by reference to a single table. viz., Table 12: "Summary Matrix Relating Physiographic Sections to Soil Forms and Feasible Cold Weather Earthwork Operations."

If specific site prediction is desired, one can input more specific and local data into steps (1), (2), (5), (6) and (8).
Plate 2. Physiographic Divisions and Provinces of Alaska, Canada and United States.
Plate 3. Physiographic Provinces and Sections of Alaska, Canada and United States.
Plate 4. Physiographic Sections and Subsections of Alaska, Canada and United States.
Primary Source: ref 28.
Primary Source: ref 26 and 32...

(Copyright, Transportation Research Board, National Research Council; reprinted by permission.) Primary Source: ref 71.
List of Cold Weather Earthwork Operations Which Are POTENTIALLY ECONOMICAL
1. Rock Blasting (deep and shallow cuts)
2. Rock Crushing
3. Rock Fill


Map Legend
- Area Mapped Exclusively as No Soil Area
- Area Mapped With No Soil as A Significant Occurrence
List of Cold Weather Earthwork Operations Which Are POTENTIALLY ECONOMICAL:
1. Excavation For Waste
2. Development of Temporary Access Roads
3. Surcharge Placement
4. Large Culvert Work
5. Clearing and Grubbing
6. Water Out Flow Work
7. Small Culvert Work
8. Pipe Work