TESTS TO DEFINE LEVELS OF TERRAIN DAMAGE BY TRACKED VEHICLES OPERATING ON TUNDRA

A Report submitted to
The Department of Indian Affairs
and Northern Development
Government of Canada

by

MUSKEG RESEARCH INSTITUTE
UNIVERSITY OF NEW BRUNSWICK

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FOREWORD

The project which is recorded in this report has been conducted by the Muskeg Research Institute, University of New Brunswick, under the auspices of the Government of Canada, Department of Indian Affairs and Northern Development, as part of its Arctic Land Use Research program.

In completing this work, the Institute is indebted to Imperial Oil Ltd., Shell Canada Ltd., Gulf Oil Canada Ltd., and the Inuvik Research Laboratory for provision of support facilities, test vehicles, and transportation in the field. The assistance of Bombardier Snowmobile Ltd. in obtaining aerial photographs of test sites and the interest and participation in the program of Foremost Developments Ltd. and Flextrack-Nodwell Ltd. are also gratefully acknowledged.

It is our earnest hope that this report will form a positive contribution to the concept of environmental conservation and that it will also provide a basis for fruitful discussion among the interested parties.

Norman W. Radforth
Director
Muskeg Research Institute

LIST OF ILLUSTRATIONS

Fig.

Introduction

Increased activity in the Canadian arctic and sub-arctic in recent years has given rise to a number of problems which attract efforts in applied scientific research in an attempt to find solutions. One of these problems has arisen from petroleum exploration involving the use of tracked vehicles for off-road transportation in support of seismic survey and supply operations. It has been widely publicized that these vehicles invariably leave trails behind them, and that these trails may be particularly significant in tundra regions.

It is the contention of some that such trails actually constitute physical damage to natural ecosystems and are therefore undesireable. It has not been known conclusively, however, whether or not all traffic results in ruin of ecological balances over a wide area, and if not what level or levels of disturbance could be considered acceptable.

Disturbance of plant life, permafrost melt, subsidence of the terrain surface, and erosion are all topics which have been commonly discussed, and yet there has been insufficient knowledge available about their relationship to vehicular traffic to enable recommendations to be made accurately concerning the planning of vehicular operations so that any terrain disturbance sustained would be within tolerable limits.

Vehicle activity associated with petroleum exploration has been and continues to be heavily concentrated in the vicinity of the Mackenzie River delta. A major portion of this activity occurs during the winter but some is also carried out during the summer. It is evident that terrain sensitivity to disturbance is higher in the summer when there is no protection from a layer of snow and the upper layer of the ground is thawed to a depth of several inches.

In order to relate known amounts of vehicle traffic to various aspects of terrain disturbance, an experimental program was established during the summer of 1970. This report is an account of the findings of that program. Also included are recommendations for the implementation of standards regarding off-road tracked vehicle traffic based on the results of the program.

Program Objectives

The overall aim of this work was "To assess the immediate and long term effects of tracked vehicles in current service by oil companies and operated under normal working conditions during summer months, on tundra vegetation and the thermal balance of permafrost soils, and to identify those vehicle and track designs which are capable of meeting industry transport requirements and are least detrimental to the tundra environment".

Approach and Procedure

In designing the test program, several variables had to be taken into account. These included characteristics of the terrain in the Mackenzie Delta area, seasonal climatic changes during the summer, types of vehicles commonly used by petroleum companies in exploration programs, and the nature of the operations in which these vehicles are normally involved.

Selection of test sites and vehicles used was controlled to some extent by availability of support facilities and suitable vehicles being located at these facilities.

The experimental program was divided into two sections or phases. Phase I was conducted during the latter half of June, 1970 and was designed to enable detailed selection of test sites, checking of test procedures, gathering of some preliminary data, and setting up contacts with various support facilities to be done. On the basis of the findings of Phase I the program for Phase II was designed. A summary report of Phase I is contained in Appendix I of this report.

Initially, test site centres were selected at Tuktoyaktuk and Tununuk, N.W.T. and at Shingle Point, Y.T.(Fig.1-4). At each centre several sites were chosen, each one considered to be representative of a particular terrain condition typical of the area.

Phase I tests were performed at Tununuk, in four sites. Vehicles used included a light tracked carrier (Fig.5), a light-medium four tracked carrier, a medium tracked carrier, and a

Fig. 1
Shingle Point Test Site
Locations
Scale Approx. 1:12000

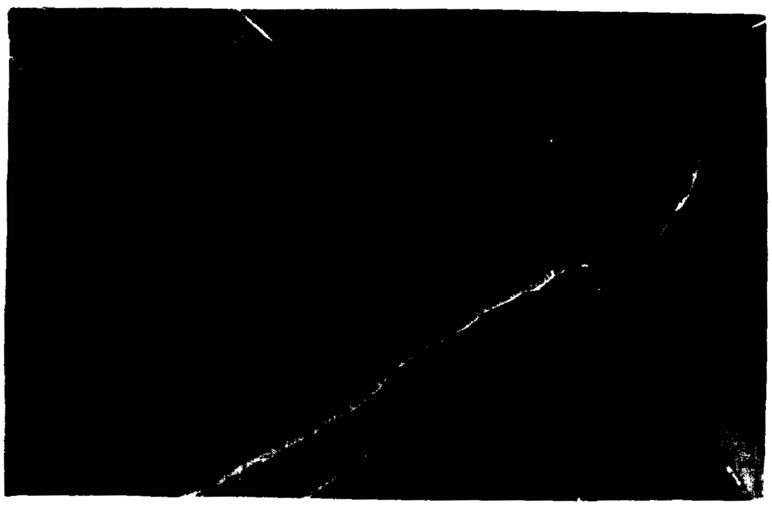


Fig. 2
Tununuk Test Site
Locations
Scale Approx. 1:12000

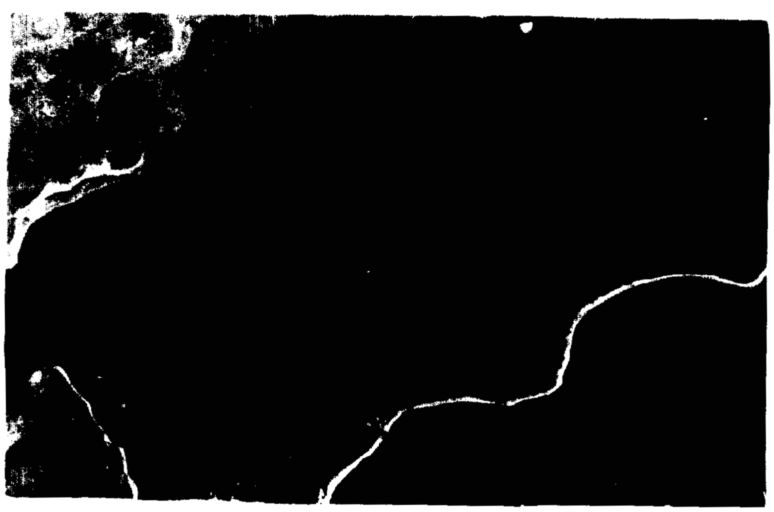
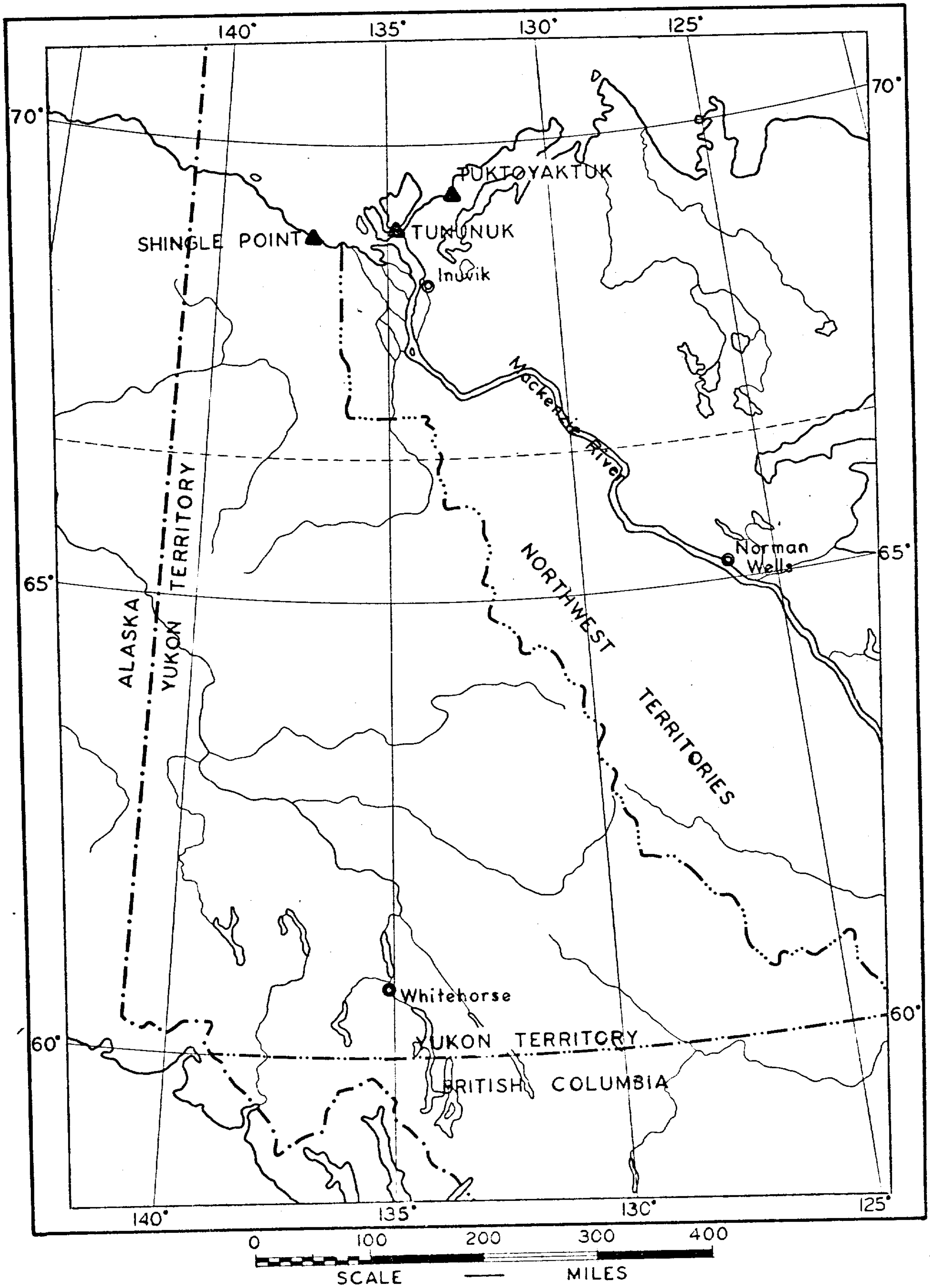


Fig. 3
Tuktoyaktuk Test Site
Locations
Scale Approx. 1:12000



140°
135°
130°
125°
70°
65°
60°
TUKTOYAKTUK
TUNUNUK
SHINGLE POINT
Inuvik
Mackenzie River
Norman Wells
NORTHWEST TERRITORIES
ALASKA
YUKON TERRITORY
Whitehorse
YUKON TERRITORY
BRITISH COLUMBIA
0
100
200
300
400
SCALE — MILES

Fig. 4

medium tracked bulldozer (Fig.6). At each site, test lanes at least 100 ft. in length were laid out and one vehicle was driven back and forth in each lane. Photographs of the tracks were taken after one, five, ten, twenty, forty, sixty, eighty and one hundred passes (it was previously determined that one hundred passes is a typical number in some vehicle operations). The vegetative cover, depth to frost, surface profile, slope and ground temperature were noted at each site, and soil and vegetation samples were taken for later analysis. An attempt was also made at one site to measure drawbar pull of some vehicles and simultaneously photograph the ground immediately behind the vehicle tracks during the test. In this way it was hoped that it would be possible to correlate vehicle weight and track design, drawbar pull and terrain surface disturbance.

Finally, during Phase I, a visual inspection of terrain conditions at Tuktoyaktuk and Shingle Point was carried out to ascertain the differences between conditions there and at Tununuk.

During Phase II several modifications were made in the test procedure based on experience in Phase I. Multipass tests were conducted on lanes 200 ft. in length and marked with a flag every 20 ft. The first pass was made along the entire length of the lane, the next four passes stopped 20 ft. short of the end, the next five 40 ft. from the end, and so on so that at the end of a test the lane showed the effects of one, five, ten, twenty,

Fig. 5. Light tracked carrier.

Fig. 6. Medium tracked bulldozer.

Fig. 7. Heavy 4 tracked carrier.

At Shingle Point, small streams and sometimes larger rivers flowing in gullies from the mountains across the coastal plain to the sea are a common feature of the landscape (Fig.1). Because of possible erosion developing in vehicle tracks up the sides of the gullies, it was thought that it may be useful to have an example of this condition which could be inspected at intervals in the future. Therefore, in one test at Shingle Point, a stream crossing was included. One hundred passes of a light tracked carrier were made through the stream.

Aerial photographs were taken at each of the test sites to aid in their description.

It was hoped that two types of flat tracks would be available for the tests, but in the end it was not possible to arrange this.

The final part of Phase II occupied the last week in September. It was originally intended that tests performed in August would be repeated at this time. There were, however, several circumstances which brought about a change in plans.

Freezing temperatures and light snow had prevailed at Tuktoyaktuk for several days, but three multipass tests with a medium tracked carrier loaded with a seismic drill were performed. Photographs and frost depths for each site were taken. At Tununuk, the living accommodations had been removed, and there were no vehicles available of the type tested earlier. There was a snow cover varying from one to six inches at Shingle Point and temperatures were near $0^{o}F$. This was judged to be a winter condition and therefore outside the scope of this work. Photographs and frost depths of the test sites were obtained.

At Shingle Point at the end of September, winter conditions also prevailed so that no tests were performed at this time. Photographs and frost depths were, however, taken at each test site where work had been performed in August.

Finally, as a supplement to the main program, similar tests in northern Alaska near Prudhoe Bay were observed. A four-tracked twenty-ton carrier (Fig. 8) and a two-tracked 8 ton carrier (Fig. 9) were operated over test lanes 1000 ft. in length (Fig. 10). After each pass was completed, the vehicle turned around outside the test lane and travelled back over the same path. This was repeated for a total of either 10 or 20 passes depending on the extent to which the terrain became disturbed.

Fig. 8. Four track 20 ton carrier - Prudhoe Bay

Fig. 9. Eight ton tracked carrier

Fig. 10. Test site in Alaska near Prudhoe Bay

Test Results and Observations

Test Sites

In selecting test sites at each of the three centres, an attempt was made to pick terrain conditions which appeared to be typical of each centre. For example, Shingle Point is situated at the edge of a gently rolling coastal plain in which numerous stream gullies are a prominent feature. At Tununuk, both macro- and microtopography are more rugged than at Shingle Point, and vegetal growth is somewhat heavier with larger woody shrubs in evidence. The characteristics of all the sites are presented in Table I below.

Vegetation classification in the first line of the table is according to the so-called Radforth muskeg vegetation classification system described in Appendix II. Surface temperatures and temperatures at the bottom of the thawed soil layer were measured with a thermistor probe and depths to frost as well as frozen surface crust thickness were determined by inserting a calibrated steel rod in the ground. A surveyor's level was used to obtain slope measurements, and at some sites surface soil samples were taken for moisture content analysis. When no samples were taken, a visual estimate of moisture conditions was made. Figure numbers of photographs in this report depicting each of the sites are also listed.

Each site has a characteristic feature which accounts for its presence in the set of sites. These features are presented in table II.

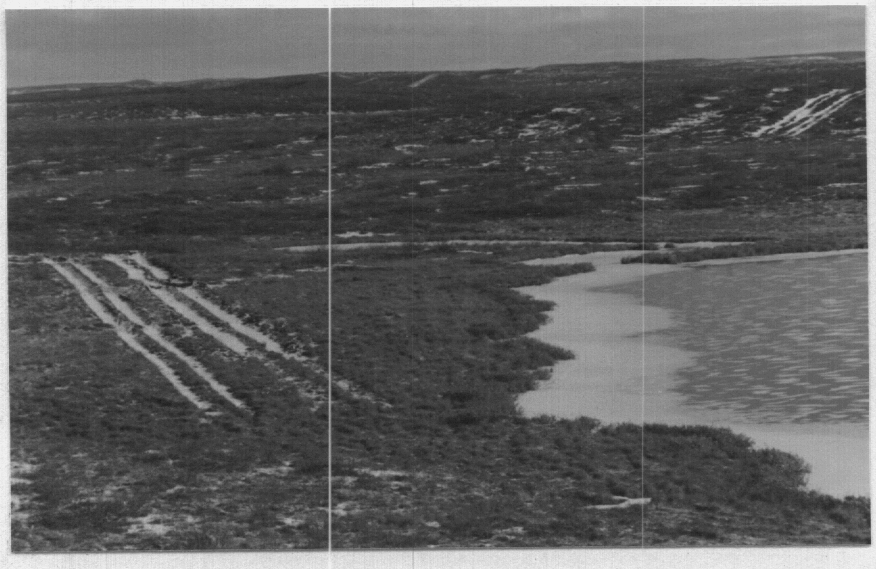


Fig. 17. Tununuk Test Sites 3 and 4

Fig. 18. Tuktoyaktuk Test Sites 1 and 2

forty, sixty, eighty and one hundred passes.

Drawbar pull tests were carried out with the camera which was used to photograph the ground behind the test vehicle linked to the strip chart recorder used to measure drawbar pull and slip. In this way pull and slip measurements could be accurately correlated with photographs of terrain disturbance.

The tests carried out at each site depended on the vehicles available at the particular location. Phase II was carried out during two different periods of time as a part of an attempt to assess the effects of seasonal climatic variations on terrain conditions. The first series of tests was performed during the latter half of August. At Tuktoyaktuk, test vehicles included a medium tracked carrier fitted with a seismic drill, a light tracked carrier loaded with a magazine and cement, and a heavy four tracked carrier loaded with 30 tons of cement(Fig.7).

Turn tests were also performed by laying out test lanes in concentric 90 degree arcs having inside radii of 20, 40 and 60 ft. and having the medium tracked carrier, fitted with the seismic drill, run four or five passes around each arc. Photographs of the ground disturbance were taken after each pass for later analysis.

A heavy tracked bulldozer was run in a multipass test at Tununuk in one test site. At Shingle Point, a light tracked carrier was operated in four sites and a heavy bulldozer in one site.

CENTRE TEST SITE DATE	SP 1 AUG	SP 1 SEPT	SP 2 AUG	SP 2 SEPT	SP 3 AUG	SP 3 SEPT	SP 4 AUG	SP 4 SEPT	TUN 1 JUNE	TUN 1 AUG	TUN 1 SEPT	TUN 2 JUNE	TUN 2 AUG
VEGETATION (RADFORTH)	FI		FI		EFI		FEI		EFI			EFI	
SURFACE TEMP. °C	6.25		6.33		8.9		9.5		11.8	7.5		11.7	13.3
TEMP. AT BOTTOM OF THAWED LAYER	2.4		2.15		3.5		1.65		6.08	1.5		5.1	2.03
DEPTH TO PERMAFROST CM	39.1	76.1	32.2	45.6	48.5	43.3	45.7	40.6	8.44	35.2	63.5	10.7	36.4
SLOPE %	0		0		12		0		0			1	
MOISTURE (% WET WEIGHT)	very wet		wet		varies wet or dry		moist		69.5			85.7	
NUMBER OF VEHICLES TESTED	1		1		1		2		4	1		2	
THICKNESS OF FROZEN SURFACE CRUST CM	0	2.5	0	2.5	0	2.5	0	2.5	0	0	5	0	0
PHOTOGRAPH SEE FIG.	11		12		13		14		15			16	

CENTRE TEST SITE DATE	TUN 2 SEPT	TUN 3 JUNE	TUN 3 AUG	TUN 3 SEPT	TUN 4 JUNE	TUN 4 AUG	TUN 4 SEPT	TUK 1 AUG	TUK 1 SEPT	TUK 2 AUG	TUK 2 SEPT	TUK 3 AUG	TUK 3 SEPT
VEGETATION (RADFORTH)		FI			EFI			FEI		EI		EFI	
SURFACE TEMP. °C		11.03	14.5		16.7	15.8		10.4		11.5		11.6	
TEMP. AT BOTTOM OF THAWED LAYER		5.57	2.1		5.27	1.8		2.4		1.8		2.0	
DEPTH TO PERMAFROST CM	57.1	12.4	34.1	55.9	11.3	48.3	57.1	27.9	25.4	53.4	53.4	40.1	30.4
SLOPE %		0			12.6			1.0		10.0		0.5	
MOISTURE (% WET WEIGHT)		86.3	—	—	71.2		-	MOIST WET		DRY		MOIST WET	
NUMBER OF VEHICLES TESTED		2			2			3	1	3	1	3	1
THICKNESS OF FROZEN SURFACE CRUST CM	0-2.5	0	0	6.5	0	0	5-10	0	5-10	0	5	0	5-10
PHOTOGRAPH SEE FIG.				17			17	18		18		57	

TABLE I - DESCRIPTION OF TUNDRA DISTURBANCE TEST SITES

Table II

Test Site	Characteristic Features
Shingle Point 1	Very wet, predominant sedge cover, adjacent to small lake.
Shingle Point 2	An area of depressed centre polygons in a large shallow depression.
Shingle Point 3	A south-facing well-drained hillside with a stream crossing at its base. Possibility of erosion after traffic.
Shingle Point 4	An upland, almost level area, moist, with mixed sedge, shrub and moss cover.
Tununuk 1	High, dry, level plateau with moderately abundant woody shrubs.
Tununuk 2	Moist, sedge, and shrub covered depressed centre polygons adjacent to a small lake, merging into a south-facing hillside at one end of the test lanes.
Tununuk 3	Wet to very wet (June), becoming much drier by August, depressed centre polygons, sedge covered adjacent to a thaw lake.
Tununuk 4	Southwest facing shrub covered slope, possible thermokarst by high exposure to sunlight, slope encourages runoff erosion.
Tuktoyaktuk 1	Low-lying moist depressed centre polygons covered by a mixture of sedges and shrubs.
Tuktoyaktuk 2	South-facing, dry, rough slope covered with heavy shrub growth.
Tuktoyaktuk 3	Sedge and shrub covered plateau with good drainage only at edges. Otherwise drainage poor and moisture content described by "moist to wet".

TABLE II Description of Characteristic Features of Tundra Disturbance Test Sites

It may appear from an inspection of Table II that there is some duplication of characteristics. It was felt however that following traffic by vehicles, the variations in climate among the three test centres could lead to different rates of response in the form of vegetative regrowth, thermokarst and runoff erosion. Also a complete set of test vehicles was not available at each centre. Therefore all three centres (11 test sites) were studied in order to make the investigation as comprehensive as possible.

As compared with the Mackenzie Delta sites, the test area in Alaska near Prudhoe Bay was unique. Viewed at ground level the flatness of the landscape was striking, and from the air the boundaries of the depressed centre polygons were clearly defined. Vegetation consisted of sedges and a very few shrubs all of very low stature, as well as moss cover (Fig. 10).

Results of Multipass Tests

During observation of numerous tests it became apparent that with increase in traffic by any given vehicle, the vegetation and ground surface structure (microtopography) responded in various ways. These were identifiable as stages in a process, and the action of the vehicle tracks which produced these stages could be accounted for.

In general, the vehicle tracks would commence by breaking branches on woody shrubs and knocking leaves off if these were present. The grouser bars on the tracks then gradually chopped vegetation, flattening it into the ground surface, scuffed the tops of mounds exposing mineral soil, and then flattened the mounds noticeably. This was accompanied by chopping and scattering of vegetation, displacement of soil by the vehicle's weight, and was followed by the grouser bars picking up chunks of peat and scattering them. If traffic was continued, ruts formed along the vehicle's path and deepened until the permafrost table was reached.

The prevalent terrain conditions and the characteristics of the particular vehicle involved could definitely be related to the response of the terrain to traffic. For the terrain, the moisture content, vegetation composition, and depth to permafrost appeared to be the major controlling factors. High moisture content, often accompanied by vegetation consisting mostly of sedges and depth to permafrost exceeding 10 cm. encouraged rapid rut development. On the other hand, dry hillsides were commonly covered with woody shrubs having a rugged root structure, and although the shrub stems and branches suffered rapidly, ruts were slower to form under these conditions. In very wet areas the tracks running in open water produced a washing action which splashed peat outside the immediate path of the vehicle and on to the sides or "banks" of the ruts.

Vehicle weight appeared to be the most significant single variable affecting disturbance rate, heavier vehicles forming ruts more quickly than light ones. Grouser bar design on tracks is also important, but mostly in the early stages of disturbance when the number of passes is low. The detent which acts as a wheel guide along the centre of some tracks is responsible for creating an initial shallow rut often within one or two passes. Differential velocities of the detent and side portions of the track as it is picked up around the rear idler wheel cause a shearing force in the centre of the rut. This force produces localized vegetation tearing in the rut surface. So-called "flat tracks" (Fig. 19) avoid this problem by having straight grouser bars, but the U-shaped cross-section of these bars has a noticeable chopping action. They also tend to trap and pick up chunks of peat and thereby disturb the ground surface.

Analysis of a total of thirty multipass tests has resulted in formulation of a disturbance classification system which describes the various stages of vegetation and microtopography response to increasing amounts of traffic. The system is described here in table III.

Fig. 19. Flat track on eight ton carrier in Alaska

DISTURBANCE LEVEL	STRUCTURE	VEGETATION
1	Undamaged	Undamaged
2	Slight damage	Shrubs broken, leaves knocked off
3	Mound top scuffing/ flattening	Cutting and/or flattening of all vegetation
4	Mound top destruction	Tearing and scattering of vegetation - 10% destroyed
5	Ruts start to form, less than 50% structure destroyed	25% destroyed
6	Ruts slightly deeper, more than 50% structu-re destroyed	50% destroyed
7	Ruts half bare	90% destroyed
8	Ruts entirely bare	100% destroyed
9	Ruts to permafrost	

TABLE III Vegetation and structure disturbance classification system

To illustrate some of the points suggested above, reference is made to several photographs taken during the traffic tests. Figures 20 to 32 show a comparison of a heavy (120,000 lb.G.V.W. vehicle and a light (9000 lb. G.V.W.) vehicle operating in Site I at Tuktoyaktuk. The more rapid progress of disturbance under the heavy vehicle is obvious.

Figures 33 to 40 show ruts from a similar light vehicle in a very wet area (Shingle Point Site I). If a comparison is made between figures 21 and 33, 23 and 34, 25 and 35, 27 and 36, 29 and 37, 30 and 38, 31 and 39, and 32 and 40, it will be seen that the high ground moisture content at the Shingle Point site has a profound effect on rate of terrain disturbance.

By conducting tests at three different times during the summer it was possible to assess, to a certain extent, the effect of season on terrain sensitivity. As one example, a bulldozer was operated (blade up) at Tununuk, site 1 at the end of June and again at the end of August. From Table I, average depth to permafrost at this site in June was 8.44 cm while by the end of August it had reached to 35.2 cm. The effect of this recession appears in a comparison of bulldozer ruts formed at each of these times as shown in figures 41 to 56. In June the permafrost near the surface combined with the deep grouser bars on the bulldozer tracks to carry most of the vehicle's weight. Rut depth could not grow to a very large value. In August, however, the soft ground surface allowed the vehicle to sink rapidly until it reached the permafrost after about 60 passes.

Fig. 20. Tuktoyaktuk, site 1, heavy vehicle 1 pass

Fig. 21. Tuktoyaktuk, site 1, light vehicle 1 pass

Fig. 22. Heavy vehicle 5 pass

Fig. 23. Light vehicle 5 pass

Fig. 24. Heavy Vehicle 10 pass

Fig. 25. Light Vehicle 10 pass

Fig. 26. Heavy Vehicle 20 pass

Fig. 27. Light Vehicle 20 pass

Fig. 29. Light Vehicle 40 pass

Fig. 32. Light Vehicle 100 pass

Fig. 33. Shingle Point, site 1,
Light Vehicle 1 pass

Fig. 34. 5 pass

Fig. 35. 10 pass

Fig. 36. 20 pass

Fig. 37. 40 pass

Fig. 38. 60 pass

Fig. 39. 80 pass

Fig. 40.100 pass

Fig. 41. Tununuk, site 1, June,
Bullodozer 1 pass

Fig. 42. Tununuk, Site 1, August,
Bulldozer 1 pass

Fig. 43. June, 5 pass

Fig. 44. August, 5 pass

Fig. 45. June, 10 pass

Fig. 46. August, 10 pass

Fig. 47. June, 20 pass

Fig. 48. August, 20 pass

Fig. 49. June, 40 pass

Fig. 50. August, 40 pass

Fig. 51. June, 60 pass

Fig. 52. August, 60 pass

Fig. 53. June, 80 pass

Fig. 54. August, 80 pass

Fig. 55. June. 100 pass

Fig. 56. August, 100 pass

The next set of photographs demonstrates another thermal effect of seasonal change on terrain response. Tests were run with a seismic drill vehicle weighing about 46,000 lb. at Tuktoyaktuk site 3 at the end of August and again at the end of September. Depth to permafrost was about 40 cm. in August and 30 cm. in September, but in September there was also a frozen surface crust varying in thickness from 5 to 10 cm. This crust inhibited the September disturbance until about 30 passes had been completed. Once this point was reached, the disturbance rate proceeded at about the same rate as it had in August. Figures 57 to 72 illustrate this phenomenon.

The effect of local changes in microtopography and ground water relations were most evident at the test site in northern Alaska. When vehicles were driven through the narrow depressions between adjacent polygons, free water in the depressions was displaced with a washing action which spilled peat up on the banks of the depressions. Observation of test sites in the area where this had been done one year before showed that this peat is a deterrent to growth of vegetation which it covers.

An attempt has been made to quantify the relationship between the weight of a tracked vehicle and the number of passes it completes in creating a given level of terrain disturbance as defined in Table III. It is suggested that level 4 be temporarily accepted as an acceptable maximum level for purposes of discussion.

Fig. 57. 46,000 lb. vehicle
Tuktoyaktuk site 3, August 1 pass

Fig. 58. 46,000 lb. vehicle
Tuktoyaktuk site 3, September 1 pass

Fig. 59. August 5 pass

Fig. 60. September 5 pass

Fig. 61. August, 10 pass

Fig. 62. September, 10 pass

Fig. 63. August, 20 pass

Fig. 64. September, 20 pass

Fig. 65. August, 40 pass

Fig. 66. September, 40 pass

Fig. 67. August, 60 pass

Fig. 68. September, 60 pass

Fig. 69. August, 80 pass

Fig. 70. September, 80 pass

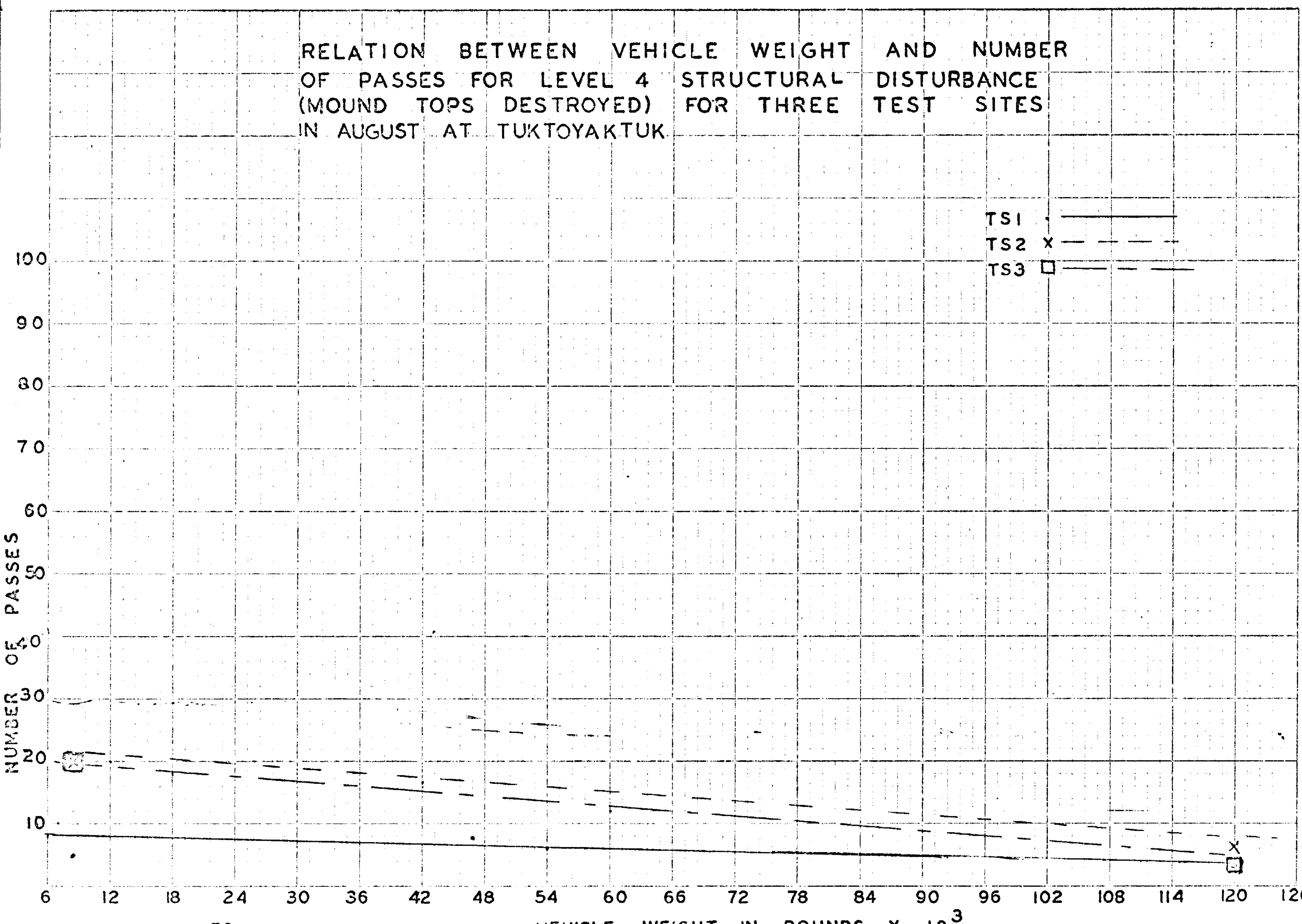
Fig. 71. August, 100 pass

Fig. 72. September, 100 pass

The relationships between weight and number of passes for level 4 structural disturbance for three test sites at Tuktoyaktuk in August are shown in figure 73. Figure 74 shows similar information based on vegetation disturbance while in Figure 75 the response of structure and vegetation are averaged to give a composite picture.

Several features emerge from this analysis, especially figure 75. Site 1, appears to be the most delicate of the three sites, followed by sites 3 and 2 in that order. In site 1, the microtopography was fairly smooth initially and the vegetation composition contained a large proportion of sedges. Moisture content here was comparatively high. In site 2, on the other hand, the ground was relatively dry, rough, hard and covered with robust woody shrubs. It would seem that conditions of this type will tolerate more traffic than those found in site 1. Both the characteristics and the response of site 3 lie between those of sites 1 and 2.

Also, quite predictably, as the weight of the vehicle increases, the number of passes that can be tolerated diminishes. Over the range of weights tested there appears to be a roughly linear relationship between these variables. This allows prediction of the tolerable number of passes for a wide-tracked vehicle of any given weight in the range treated here. In deciding on a limit to number of passes for any proposed tundra crossing, it should be possible to use this type of information to plan operations effectively and predictably.


RELATION BETWEEN VEHICLE WEIGHT AND NUMBER OF PASSES FOR LEVEL 4 STRUCTURAL DISTURBANCE (MOUND TOPS DESTROYED) FOR THREE TEST SITES IN AUGUST AT TUKTOYAKTUK
TS1
TS2
TS3
100
90
80
70
60
50
40
30
20
10
NUMBER OF PASSES
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
126

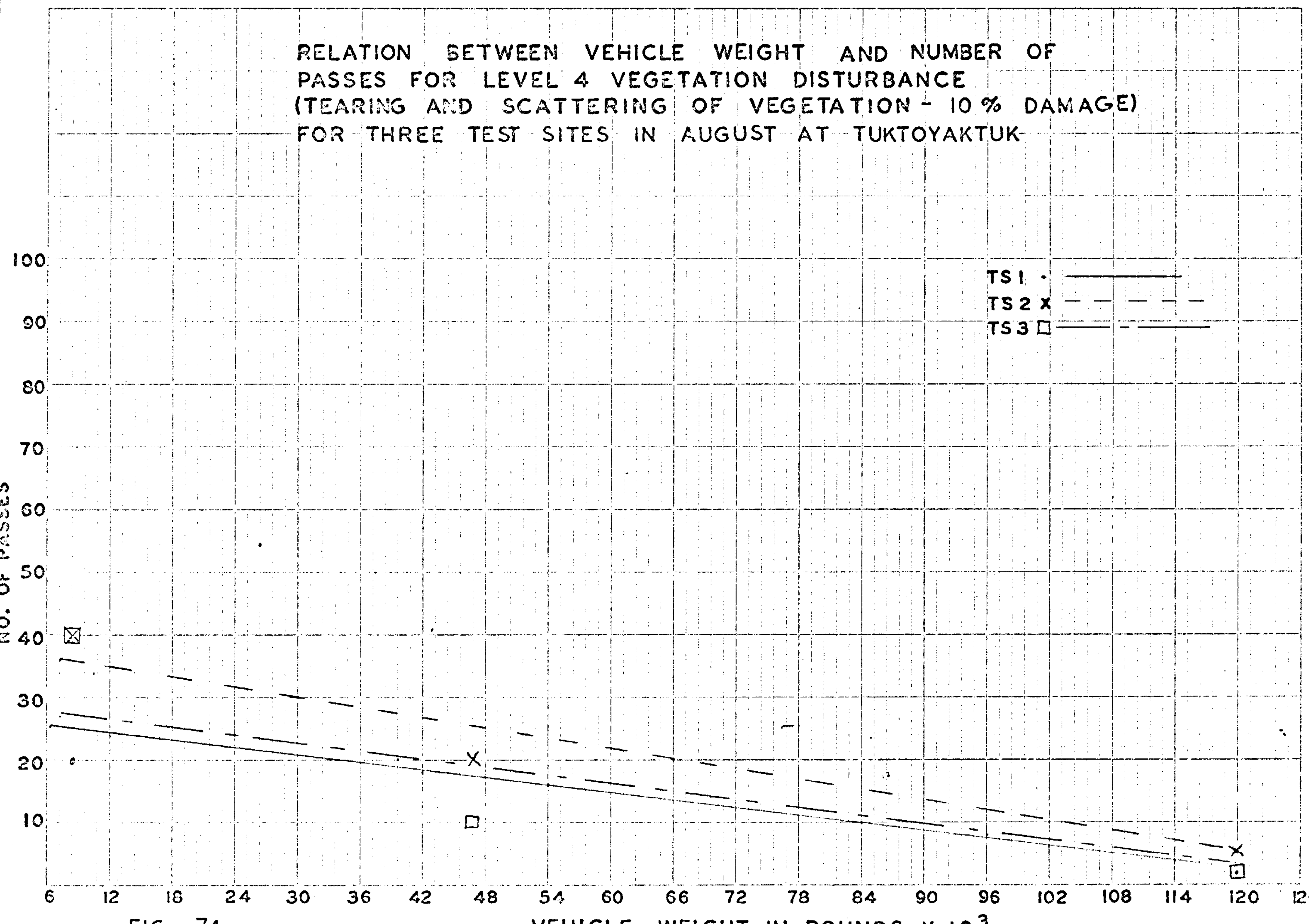
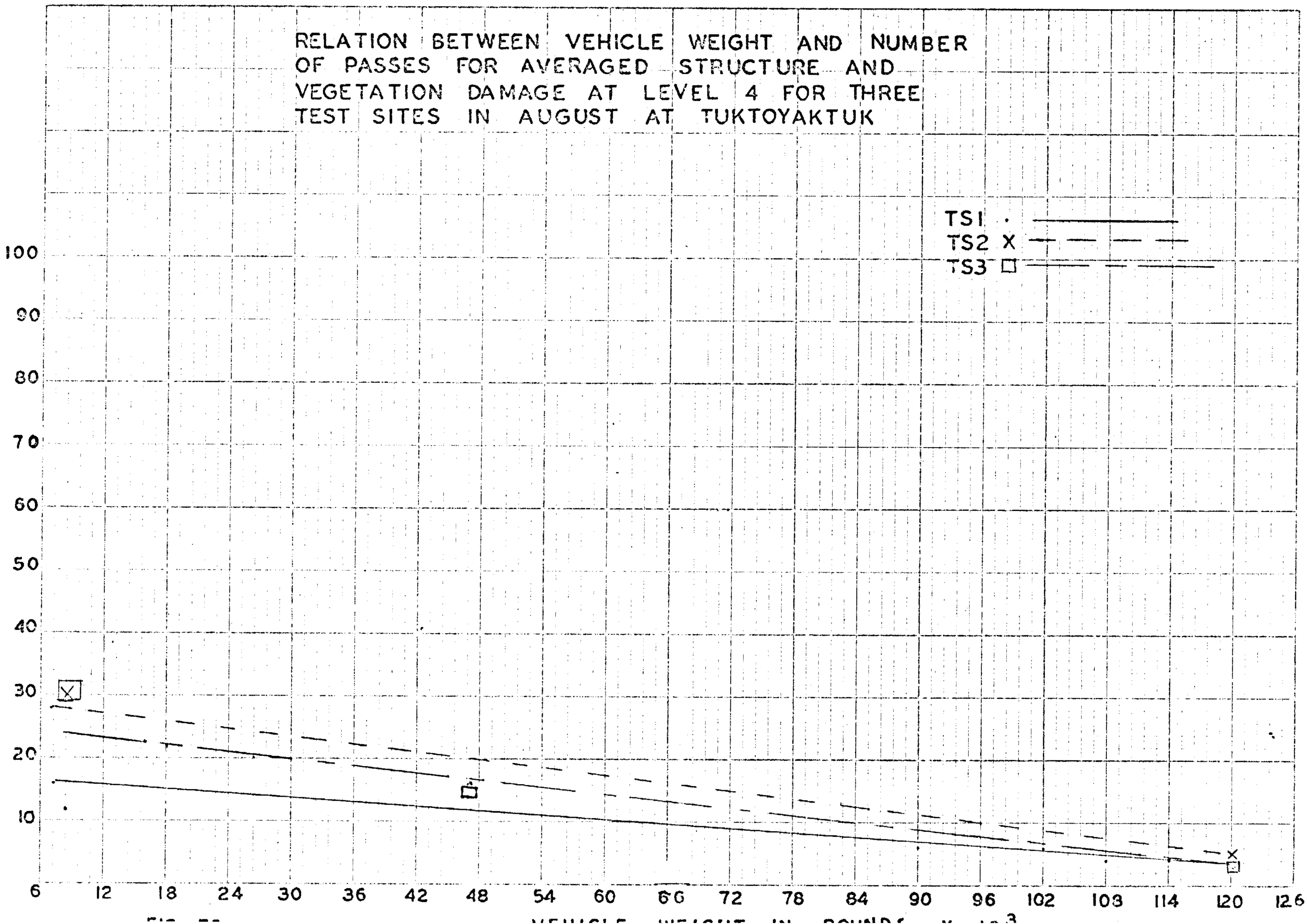

RELATION BETWEEN VEHICLE WEIGHT AND NUMBER OF PASSES FOR LEVEL 4 VEGETATION DISTURBANCE (TEARING AND SCATTERING OF VEGETATION - 10 % DAMAGE) FOR THREE TEST SITES IN AUGUST AT TUKTOYAKTUK
TS 1 ·
TS 2 X
TS 3 □
NO. OF PASSES
100
90
80
70
60
50
40
30
20
10
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
126
VEHICLE WEIGHT IN POUNDS x 10³

FIG. 74


RELATION BETWEEN VEHICLE WEIGHT AND NUMBER OF PASSES FOR AVERAGED STRUCTURE AND VEGETATION DAMAGE AT LEVEL 4 FOR THREE TEST SITES IN AUGUST AT TUKTOYAKTUK
TS1 ·
TS2 X
TS3 □
100
90
80
70
60
50
40
30
20
10
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
126

While the information in figures 73, 74 and 75 is of limited use, the principle is believed to be sound and wider successful application of the principle only requires additional data for other terrain conditions. Although in this project more data were accumulated for various other test sites, there are as yet not enough data to enable further relationships of the type shown in figures 73, 74 and 75 to be defined.

It may be helpful to consider Table IV which describes the response of all the test sites to the same type of vehicle. There are probably considerable errors because the three vehicles used although of the same type, were likely not all exactly the same weight. However, these are the best data available at this time.

CENTRE	SP	TUN	SP	SP	TUK	TUK	SP	TUN	TUN	TUK	TUN
TEST SITE	1	3	2	4	1	3	3	2	4	2	1
DATE	AUG	JUN	AUG	AUG	AUG	AUG	AUG	JUN	JUN	AUG	JUN
1 pass	7.6	1.1	2.1	2.3	1.1	1.1	2.5	1.1	1.4	1.1	---
5	7.7	3.1	2.2	3.3	4.2	2.2	2.5	2.2	3.3	2.2	---
10	8.7	4.2	2.3	4.3	5.3	2.3	3.6	3.3	4.4	3.3	---
20	8.8	5.3	6.5	5.4	6.4	4.3	4.7	3.4	4.5	4.3	---
40	8.8	6.4	7.7	6.5	6.5	5.4	7.7	5.6	5.7	5.4	5.6
60	8.8	7.6	8.7	7.7	7.7	6.5	8.5	7.7	7.8	5.5	6.7
80	8.8	8.6	8.7	8.7	7.7	6.6	8.8	7.7	8.8	6.7	8.7
100	8.8	8.6	8.8	8.8	8.7	7.7	8.8	8.7	8.8	6.7	8.8

SP -SHINGLE POINT
TUN -TUNUNUK
TUK -TUKTOYAKTUK

1ST DIGIT - STRUCTURE DAMAGE LEVEL
2ND DIGIT - VEGETATION DAMAGE LEVEL

TABLE IV - STRUCTURE AND VEGETATION DISTURBANCE AT ALL TEST SITES AFTER TRAFFIC BY LIGHT TRACKED CARRIERS WEIGHING APPROXIMATELY 9000 LB.

It would appear that with one exception level 4 disturbance appears between ten and twenty passes for a tracked vehicle weighing approximately 4.5 tons. The exception is Shingle Point test site 1 which was easily recognizable by its very high soil moisture content - (free water was visible on the ground surface). Pending acquisition of further data, it would seem practical to extend the application of results displayed in figures 73, 74, and 75 to areas remote from Tuktoyaktuk, except for very wet regions.

Turning Radius

Results of the turn tests appear in figures 76, 77 and 78 which show the effects of 5 passes of a 46,000 lb. vehicle at radii of 20, 40 and 60 ft. respectively. The tests were performed at Tuktoyaktuk, site 1.

The test vehicle excecuted the 40 ft. and 60 ft. radius turns without difficulty. On the 20 ft. radius turn, the inside track frequently slipped on its sprocket, steering effort by the vehicle operator was high, and tussocks were torn from the ground surface.

Terrain surface disturbance appeared to be at or below level 4 in a turn with a 60 ft. radius. This is suggested to be a reasonable minimum turning radius for a vehicle of this size and weight. Operations with smaller vehicles would probably not be inconvenienced by restricting turns to a minimum radius of 60 ft., and larger vehicles normally probably have their minimum turning radius mechanically limited to a value greater than 60 ft. In areas more sensitive than site 1, Tuktoyaktuk, it is perhaps possible that this 60 ft. minimum is too generous. In the writer's judgement, however, such sensitive areas would tolerate almost no traffic before level 4 disturbance was produced (c.f. Shingle Point Site 1). Analysis of Table IV has shown this to be a reasonable tentative assumption.

Fig. 76. Turn test, 20 ft. radius

Fig. 77. Turn test, 40 ft. radius

Fig. 78. Turn test, 60 ft. radius

Stream Crossing Test

Figure 13 shows a light tracked carrier passing through the small stream used in this test at Shingle Point. As traffic progressed, sediment lying on the stream bottom was disturbed and carried downstream in the current as might be expected. Following the test the water in the stream cleared within an hour. Shallow ruts at right angles to the stream emerged from it on both sloping banks, and sediment carried out of the stream bottom by the vehicle tracks was spread on the banks near the ruts.

It is suggested that assessment of the long term effects of this test will depend on repeated inspection of the site in the future. Immediate effects of the test appeared to be confined to the shallow ruts formation. Stream flow rate and water quality as observed visually did not seem to be altered in any way after the disturbed sediment had flowed downstream.

Drawbar Pull Tests

It is quite well known that in order for a vehicle to propel its weight up a slope, overcome rolling resistance of the ground and tow a trailer, the vehicle must exert tractive effort. This effort is sustained by shear stresses in the vegetation and soil near the ground surface. The maximum shear stress, and therefore tractive effort, that can be sustained by the ground depends on its shear strength which in turn depends on a number of other properties.

If the shear strength is exceeded in applying tractive effort, the ground surface fails and the vehicle tracks or wheels slip. In the process, vegetation is torn up and soil is displaced. In other words, the terrain surface becomes disturbed. Failure of the ground surface does not signify complete loss of tractive effort. In fact maximum tractive effort is usually accompanied by a slight amount of slip.

For the purposes of these tests, an attempt has been made to relate terrain disturbance level to various values of slip in order to suggest a slip value that might correspond to a maximum tolerable terrain disturbance level. Given this value it is a matter of mathematical calculation and vehicle performance testing outside the scope of this project to determine slope and load-towing limits which might be imposed on vehicles to enable them to stay within terrain disturbance limits.

The type of results derived from the drawbar pull tests conducted at Tuktoyaktuk in August is shown in figures 79 and 80. These photographs were taken in Test Site 3 and show the effects of 19.7% slip and 100% slip (100% slip being the condition in which the vehicle is not moving but its tracks are spinning). Analysis of this and other tests has shown that maximum tractive effort was developed at close to 20% slip and that this effort was virtually sustained up to 100% slip. Terrain disturbance was well within level 4 at 20% slip and in site 1 at Tuktoyaktuk approached level 5 in places (permanent ruts just starting to form). This level of disturbance was reached in one pass under drawbar load conditions whereas it had been reached in between 5 and 15 passes in the multipass tests. Drawbar pulls at 20% slip varied between 30% and 45% of the vehicle's weight.

It would appear that in operating tracked vehicles as tractors towing loads or as carriers climbing slopes, slip should be less than 20% to limit terrain disturbance to level 4. This amount of slip is consistent with net tractive effort amounting to 30% to 45% of the vehicle's gross weight.

As is the case for the other tests this should be regarded as a tentative conclusion until regeneration of vegetation in the test sites can be observed for several years and level 4 can be confirmed as a tolerable disturbance limit.

Fig. 79. Drawbar pull test
19.7% slip

Fig. 80. Drawbar pull test
100% slip

Vegetative Regeneration

During the course of the summer there were a few opportunities to visit and inspect test sites which had had some time to recover following traffic. One area near Prudhoe Bay in northern Alaska had had almost a year for recovery following traffic amounting to ten or twenty passes of medium and heavy vehicles. When viewed from the air, the tracks were certainly visible and noticeable in contrast to the surrounding terrain. The vegetation in some tracks was a darker green.

Closer inspection at ground level revealed that vegetation in the tracks was not only a darker green but also slightly larger in stature with more plant material in a given area than in adjacent undisturbed areas. There did not appear to be any subsidence of the permafrost table in such locations.

Where traffic through puddles had splashed dark peat up on the sides of depressions, covering the vegetation, plant growth appeared to have been retarded and the covered plants were yellow in colour as compared with undisturbed vegetation.

At Tununuk it was possible to inspect in August the sites where multipass tests had been conducted two months previously. Figure 81 shows test site 2 following completion of 60 passes by two light vehicles in June. Figure 82 is the same view of this area in August. Considerable growth of vegetation in the ruts is visible. Figures 83 and 84 show Tununuk site 4 in June and August respectively. One hundred passes of the same vehicle were completed in this site.

Fig. 81. Tununuk test site 2
June, 60 passes

Fig. 82. Tununuk test site 2
August

Fig. 83. Tununuk test site 4
June, 100 passes

Fig. 84. Tununuk test site 4
August

Sites at Tuktoyaktuk where tests were performed at the end of August displayed virtually no noticeable regrowth by the end of September.

There was some recession of the permafrost table but measurements showed the recession to be highly irregular and variable. It was not possible to account for the variations, except to suggest that the recession process was not complete when the measurements were taken. If additional measurements are taken in the future, they may show more uniform response of the permafrost to the surface disturbance.

Significance of Test Results

There is one major obstacle to establishing the relevance of the test results in this report to future regulation of off-road vehicle operations. That obstacle is the absence of an established criterion which would allow an "instant" decision to be made regarding an acceptable level of terrain disturbance. It is probable that there will be conflicting opinions as to what constitutes acceptable terrain disturbance, and disagreement as to whether all disturbance can be called damage.

In many tundra areas even the slightest amount of vehicle traffic will leave a permanent or at least a very persistent mark on the surface of the terrain. Some will contend that such a mark is intolerable because an undisturbed natural system has been interfered with, even though vegetative growth may actually have been enhanced. There will also undoubtedly be a few advocates of unrestricted traffic on the grounds that there is no evidence that such traffic causes any more than very localized damage over an area that is miniscule in comparison with the total area of countryside with which we are concerned.

Either of these alternatives would make the decision simple and would preclude the need for the type of study reported here. Neither seems realistic. The needs of industry and society in general should be met without abusing the environment by needless destruction. If this can be accepted as a working principle it is possible to suggest a level of disturbance from which the terrain will probably recover within two to three years.

This, it must be admitted, is a prediction based on scanty factual evidence. There now exist, however, documented test sites which can be monitored during the next few years to confirm or disprove the prediction.

It was suggested earlier that level 4 disturbance is an amount which can be tolerated. At this level there is slight tearing and scattering of vegetation with an estimated 10% of the vegetation totally destroyed. The tops of mounds are scuffed and packed down, but ruts have not started to form in the vehicle tracks. In suggesting that this level should be accepted, it is predicted that on terrain disturbed to this extent there will be total recovery of all species of vegetation originally found there, there will be no permanent subsidence of the permafrost table to bring about slumping of the surface known as thermokarst, and the absence of ruts will avoid the problems of artificial channels on slopes leading to erosion by surface runoff.

Because of the need to observe recovery of the disturbed test sites during the next few years, any attempt at this time to classify terrain sensitivity to disturbance must be regarded as a first approximation. In responding to damage at the time it is inflicted rough, dry, shrub-covered slopes are the least sensitive, followed by flat, moist, shrub and sedge covered areas, then sedge, moss, and lichen covered depressed centre polygons, and finally the most sensitive very wet sedge covered areas adjacent to small lakes. It may prove through time that the wet areas will recover more quickly than the dry regions. If this is so it will have to be taken into account in the final definition of tundra sensitivity.

The regulation of vehicle traffic to conform to terrain disturbance limits will ultimately depend on an ability to recognize terrain types and know their sensitivities. This information could be converted into useable form by mapping the sensitivities of areas where traffic is likely to be concentrated. The effects of the seasons on response of terrain to traffic would have to be taken into account.

The design of the vehicle also has an effect on terrain response as has been revealed to some extent in this report. Vehicle weight is an especially important parameter. Track design which incorporates sharp cutting edges and/or a detent in the centre of each grouser appears to promote rapid disturbance. There is a need for additional investigation of the disturbing influence of track designs other than those used in these tests and also of wheels and low pressure rollers.

It has also been learned that vehicle operations can be designed to minimize disturbance. In Alaska, it has been found that making one or two final passes with the vehicle tracks overlapping the original path blends the shallow ruts with the adjacent ground surface and the vehicle path then becomes less noticeable.

No mention has been made here of the effects of winter traffic on the tundra surface. This would be required for a truly complete analysis of vehicular tundra disturbance.

Conclusions

1. Moisture content, vegetation composition and depth to permafrost appear to be the primary factors controlling terrain sensitivity to disturbance.
2. Traffic should be avoided in areas where open water is visible on the ground surface.
3. The most influential factor of tracked vehicle design affecting terrain disturbance is weight.
4. Flat tracks having no detent in the centre are beneficial in reducing terrain disturbance.
5. Based on the terrain disturbance classification system described earlier, disturbance level 4 has been selected tentatively as a tolerable maximum disturbance level. Level 4 consists of 10% damage to vegetation and scuffing and flattening of mounds.
6. The effect of season on terrain sensitivity cannot be neglected. Sensitivity appears to be directly related to proximity of frost to the ground surface.
7. A minimum turning radius of 60 ft. for 5 passes of any tracked vehicle of the types tested results in terrain surface disturbance equal to or less than level 4.
8. Conclusions concerning stream crossings cannot be drawn until long-term observations of test sites have been completed.
9. In operating tracked vehicles as tractors towing loads or as carriers climbing slopes, slip should be less than 20% to

limit terrain disturbance to level 4. This amount of slip is consistent with net tractive effort amounting to 30% to 45% of the vehicle's gross weight.

10. Even for disturbance exceeding level 4, considerable vegetative regrowth of all species present is possible immediately following the disturbance provided the disturbance occurs early in the growing season. Disturbance occurring during the latter third of the growing season results in no significant appearance of vegetative regeneration.
11. A final decision on tundra sensitivity classification must await observation of test sites over a two to three year period.
12. Effective use of a tundra disturbance and sensitivity classification system will depend on effective mapping procedures.

Recommendations

It is suggested that, as a result of the conclusions reported here, attempts should be made to:

1. Observe the changes occurring in each of the test sites and prepare a suitable report.
2. Study and report on the response of the terrain to traffic by new track designs and by wheeled vehicles.
3. Observe and document winter vehicle operations and record their effect on the terrain as determined by inspection during the summer season.
4. Document descriptions of typical summer vehicle operations for use in assessing relevance of possible tundra traffic limits.
5. Survey terrain and climatic conditions in other arctic exploration areas to determine suitability of disturbance criteria developed in this report.
6. Develop and test route selection and mapping methodology which will take into account vehicle design, terrain sensitivity, climate and season.

APPENDIX I

SUMMARY REPORT OF

PHASE I

TRIALS TO ASSESS TUNDRA

DISTURBANCE BY TRACKED VEHICLES

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July 3, 1970

Mr. John Grant
Water, Forests and Land Division
Water Resources Section
Northern Economic Development Branch
Canada Department of Indian Affairs
and Northern Development
Ottawa 4, Ontario

Dear Mr. Grant:

In accordance with the terms of our agreement between the crown and the Muskeg Research Institute, this letter is respectfully submitted as a summary report describing Phase One trials of Arctic Terrain Disturbance by Tracked Vehicles. This program was carried out between June 16 and June 24, 1970 in the Mackenzie Delta area by a field party of four from the Muskeg Research Institute, University of New Brunswick.

Objectives of the program were to:

1. Become acquainted with normal operating practices involving tracked vehicles in the Mackenzie Delta area.

2. Establish test sites at a location offering typical terrain conditions and a selection of tracked vehicles suitable for test purposes.

3. Conduct vehicle tests to enable terrain disturbance to be observed and correlated with vehicle activity.

4. Obtain data and samples from the terrain to facilitate its description for future reference.

5. Conduct a preliminary survey of other possible trials locations to determine the necessity of incorporating additional sites in subsequent vehicle trials.

In accordance with these objectives, the field party established test sites at Tununuk Point at the south end of Richards Island in the Mackenzie Delta, and selected four test sites which appeared to be representative of typical terrain conditions to be found in the area.

A light tracked carrier, a light-medium four-tracked carrier, a medium tracked carrier and a medium tracked bulldozer were incorporated in the tests.

At each test site, data consisting of vegetation cover, depth to frost, ground temperature and elevations were obtained to facilitate description of the sites. Soil and vegetation samples were also taken from each site.

Test vehicles were operated at each site in several different ways. At the first site, all vehicles took part and tests were conducted with all vehicles unloaded. Then the light carrier and light-medium carrier were provided with payloads and the tests were repeated.

One test consisted of driving the vehicles back and forth along a test line at least 100 feet long and photographing the ruts after 1, 5, 10, 20, 40, 60, 80, and 100 passes to determine and record the extent of the terrain disturbance.

Another test involved measuring the recording drawbar pull and slip of a vehicle while photographs were taken at intervals vehind the test vehicle to record the extent of terrain disturbance corresponding to various amounts of track slip.

The drawbar tests were conducted in one site only while the multipass traffic tests were conducted in all four test sites.

As indicated earlier, the test sites were located on terrain conditions judged to be typical of the area. Low hilltops covered with short woody shrubs, grasses, sedges, mosses and lichens, slopes covered with similar vegetation or predominantly with sedges and mosses, low-lying areas of depressed centre polygons with sedge and moss cover, and still lower polygons adjacent to small lakes and covered with tussocks of sedge were the main typical terrain conditions found both in the general area and in the test sites.

It was observed that frost depths varied from 2 to 12 inches, but were usually in the neighbourhood of 3 to 7 inches.

With respect to the degree of terrain disturbance observed, there was some variation in the rate of disturbance develeopement from traffic depending on the weight of the vehicle, type of track, and ground moisture content.

Terrain disturbance was most noticeable and developed most quickly beneath the prominent "D" wheel guide sections in the tracks.

The bulldozer tracks had fairly deep cleats which penetrated immediately to the frost which supported the vehicle. There was no apparent change in terrain disturbance after about 20 passes with this vehicle.

While the drawbar pull tests conducted were successful in that good measurements were obtained, it was difficult to establish any meaningful relationship between these measurements and the corresponding terrain disturbance. Continuation of these tests in Phase Two trials will depend on whether a method can be developed to correlate exactly terrain disturbance photographs with other recorded measurements.

Detailed records of all quantitative data will be maintained and incorporated into any report emerging from Phase Two of this program.

Members of the field party visited Tuktoyaktuk and Shingle Point to inspect terrain conditions and to determine probable availability of vehicles and accommodation which could possibly be used in Phase Two of the program.

The differences in climate, sub-surface mineral soil, topography, vegetation, and ground water content between these two areas and Tununuk suggest that all three locations should, if possible, be incorporated in Phase Two trials if results truly applicable to those areas are desired.

Consultation with petroleum company personnel has revealed that operations involving summer activity of tracked vehicles consist mainly of seismic exploration and some drill moving and supply operations. In travelling around the Mackenzie Delta area by aircraft, it was possible to observe the general extent of off-road tracks. Many were winter trails not used during the summer. A minority appeared to be summer trails. It was also observed that while seismic lines ran in straight lines across country, supply lines tended to follow level ground as much as possible, and avoided climbing over hills. Very few supply lines observed were summer trails, and all winter trails travelled across the numerous small frozen laken in the Tuktoyaktuk peninsula at every opportunity.

It is estimated that in a normal summer exploration or supply operation, thirty to forty passes of tracked vehicles over a given track would be required.

On the basis of the results described above, we have been able to reach several conclusions which will have some bearing on the content of Phase Two of this program.

1. The multipass test employed in Phase One yields terrain disturbance information which is useful because it can be related to vehicle operational practice and is in a descriptive and repeatable form.

2. Drawbar pull tests may yield useful supplementary information if data acquisition methods can be improved somewhat.

3. It will be necessary to employ a wider range of terrain and vehicle types in Phase Two in order to arrive at accurate conclusions concerning terrain disturbance generated by all types of tracked vehicle operations in the Mackenzie Delta area.

Several recommendations are offered concerning planning for Phase Two.

1. Further vehicle trials similar to those described above should be conducted in early August and late September.

2. Phase Two test sites should include Tununuk and other locations selected on the basis of probable future operations an air photo inspection study of terrain conditions. Tests in Tuktoyaktuk and Shingle Point would be highly desirable.

3. Phase Two trials should incorporate a wider range of vehicle types and sizes as well as various designs of flat track.

4. Analysis of the quantitative results of Phase One should be included in the detailed report for Phase Two.

5. Phase Two trials should include:

    a. Multipass tests with loaded vehicles and test site survey as in Phase One.

    b. Multipass tests with run length decreasing as pass number increases.

c. Multispectral aerial photography of test lanes completed in Phase Two.

d. Drawbar pull tests with precise correlation of terrain disturbance with vehicle slip.

e. Stream crossings feature of Phase Two tests.

f. Turning tests

g. Martin and flat tracks.

Suitability of these tests for assessing terrain disturbance will be reviewed by Muskeg Research Institute prior to the commencement of Phase Two.

We trust you will find this account of Phase One satisfactory and look forward to receiving any comments concerning either Phase One or Phase Two.

Sincerely yours,

John R. Radforth, P. Eng.
Development Engineer

JRR/gn

APPENDIX II

RADFORTH MUSKEG VEGETATION

CLASSIFICATION SYSTEM

APPENDIX II

RADFORTH MUSKEG COVER CLASSIFICATION SYSTEM

An important feature of muskeg is that it is characterized by a finite number of vegetation structural types. These types consist of nine basic cover classes, each designated by one of the first nine letters of the alphabet, listed in table I in combinations called cover formulae.

cover class	Description
A	Trees over 15 ft. high
B	Trees up to 15 ft. high
C	Non-woody, grass-like 2-5 ft. high
D	Woody, tall shrubs or dwarf trees 2-5 ft. high
E	Woody shrubs up to 2 ft. high
F	Sedges and grasses up to 2 ft. high
G	Non-woody broad-leaf plants up to 2 ft. high
H	Leathery to crisp mats of lichen up to 4 in. high
I	Soft mats of moss up to 4 in. high

TABLE I - MUSKEG COVER CLASSES

The cover classification does not depend on the naming of plant species, and since these classes can be used to describe any muskeg, the system has worldwide application.

On any given muskeg area, certain of these cover classes are found in combination, and the cover formula used to describe that muskeg area is derived by listing in descending order of prominence the cover classes which can be observed to be growing there. To be included in the cover formula, any cover class must represent at least 25% of the total cover, based on estimate from visual observation. This estimate may seem to be a rather subjective type of evaluation, but in practice there is rarely any doubt that a given cover class represents more or less than 25% of the total cover.

As an example of the application of this classification system, a muskeg area covered by tall spruce trees over 15 ft. high, woody shrubs from 2-5 ft. high, and woody shrubs up to 2 ft. high would be referred to as ADE. A muskeg area covered by grasses and sedges up to 2 ft. high and a carpet of moss would be called FI and so on.

It might appear that all the combinations of the nine cover classes in groups of two or three would lead to an unwieldy number of possible cover formulae. In reality many possible combinations, such as GAD, and BGC, do not occur. The most common include: ADE, ADF, ADI, AEH, AEI, AFI, BDE, BDF, BEF, BEH, BEI, BFI, C, CI, DEF, DFI, DI, EFI, EH, EI, FI, FEI, FIE, G, HE.

The fact that muskeg vegetal cover can be classified depends on the recurrence of cover formulae on a worldwide scale and this in turn reflects the orderliness and predictability of conditions such as peat depth, water content and climate which prevail in areas where muskeg occurs. The significance of this fact is that results obtained from tests on one muskeg area of a given cover type are applicable to all other muskeg areas with the same cover type.

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