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Terrain, Land Use and Waste Drilling Fluid Disposal Problems, Arctic Canada

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ABSTRACT. A survey of over 60 abandoned wellsites in the Mackenzie Delta, the Arctic Islands and the interior Yukon Territory indicated that approximately 25% of the sites experienced terrain problems related either directly or indirectly to sumps and/or the containment of waste drilling fluids. These problems are classified as follows: (A) non-containment during drilling, (B) melt-out problems during summer operations, and (C) restoration problems. Fewest problems are associated with one-season winter drilling operations. Two-season winter drilling, in which the sump is left open during the summer, and one-season summer drilling operations present more problems.

RÉSUMÉ. Une étude des problèmes de terrain et d'utilisation des terres pour 60 emplacements de forage abandonnés dans le delta du Mackenzie, les îles de l'Arctique et le nord intérieur du Territoire du Yukon indique qu'environ 25 p. 100 des emplacements observés ont révélé des problèmes reliés directement ou indirectement aux bassins à boue ou à la retenue des déchets liquides de forage. Ces derniers ont été classés de la façon suivante: (1) type A - problèmes de fuite au cours du forage, (2) type B - problèmes de fonte pendant les travaux d'été et (3) type C - problèmes de rétablissement de la végétation. Il semblerait que les travaux de forage achevés en un seul hiver permettent de réduire les difficultés. Par contre, des forages faits en deux hivers, et au cours desquels le bassin à boue est laissé à l'air libre, ainsi que les travaux de forage réalisés en un seul été, seraient habituellement à l'origine de plus grandes complications.
Traduit par l'auteur.

INTRODUCTION

Companies wishing to conduct exploratory drilling for hydrocarbons in the Northwest Territories and the Yukon require land use permits which are issued under the Territorial Arctic Land Use Regulations. Various conditions are attached to these permits. One condition requires that waste drilling fluids be contained completely in below-ground sumps and that these sumps be filled upon completion of the well. A second condition restricts, wherever possible, landbased drilling and the associated movement of heavy equipment to winter months when the tundra surface is frozen.

This paper focuses upon the effectiveness of the Arctic Land Use Regulations in Canada as they relate to the drilling operation and the disposal of waste drilling fluids.

DRILLING FLUID TOXICITY

The rationale behind the policy of containment of waste drilling fluids in below-ground sumps is linked to the apparent toxicity of many drilling fluids used in Arctic Canada (e.g. Falk and Lawrence, 1973; Lawrence and Scherer, 1974; Wright, 1974; Hrudey *et al.*, 1974). Since current regulatory policy discour-

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ages the use of drilling fluid additives of known high specific toxicity, the major constituents of drilling fluids pose a threat to vegetation and aquatic animals primarily because of their salinity and high suspended matter. It is assumed that, upon burial in the permafrost, the drilling fluids freeze *in situ* and in this way are prevented from escaping and poisoning plants and animals.

Disposal of drilling fluids has proven to be one of the more difficult environmental problems presented by arctic drilling (e.g. Dames & Moore, 1974; Beak Consultants, 1974; APOA/Environment Canada, 1976). The use of 'southern' techniques such as flocculation, detoxification and spraying upon the adjacent parts of the lease have not been adopted since treatment techniques have not been shown to be particularly useful, especially to remote northern areas where extra costs are involved. In addition, the construction of a sump in permafrost terrain which may contain ice poses unique terrain disturbance and thermokarst problems not encountered in non-permafrost regions. Third, the delicate ecological balance of many arctic regions leads to a low 'stress' threshold. A final complication is that, since drilling fluids commonly contain salts, sump fluids do not necessarily freeze at 0° C. It seems reasonable to assume, therefore, that at some critical range of mud and salt/chloride concentrations, sump fluids may remain buried but not frozen in the permafrost. This raises the possibility of their escape at some future date, and the slow movement of water and ions within the overburden so that they may eventually reach the surface.

THE DRILLING OPERATION

The terrain and land use problems associated with waste drilling fluid disposal can best be examined within the logistical and operational constraints of modern arctic well drilling operations, particularly in the Arctic Islands. Two factors make drilling increasingly more difficult from the point of view of environmental conservation.

First, many arctic wells are drilled to greater depths than ever before as deeper geologic structures are explored, and wells which exceed 4000 m in depth are increasingly more common. In general, the time required to drill a well is directly proportional to depth. As a rough guideline, a period of 120 days is necessary to complete a 4000 m hole (e.g. Argument, 1973; Strang, 1975). When approximately 30 additional days are required to prepare the site prior to drilling together with a similar time to terminate operations, it is clear that more and more drilling operations are extending into the critical summer months. The movement of heavy equipment and supplies around the site may lead to considerable terrain disturbance.

Second, the larger volumes of drilling muds used in these deep drilling operations results in the construction of larger sumps. For example, a 3000 m well requires approximately 40 000 m^3 of drilling fluid (e.g. Canadian Petroleum Association, 1977, Fig. 11). To contain this volume, a sump with dimensions of approximately 50 m x 25 m x 5 m deep is required. In practise, however, the sump must be larger than this since drilling fluids are periodically changed or modified depending upon the lithology being drilled, and 'rigwash' (soapy water which hoses down the drilling platform for safety reasons) also drains into the sump. Furthermore, Arctic Land Use Regulations require a minimum of 1.3 m (4.0 feet) of freeboard at all times to prevent seepage of sump fluids through the active layer.

The very large sumps currently being constructed not only represent a significant increase in the overall drilling costs but also constitute the most terrain disturbance which is officially sanctioned under the Arctic Land Use Regulations. Hence, the use of sumps and their effectiveness in containing waste drilling fluids must be carefully assessed.

THE ALUR SUMP PROJECT

In direct response to the terrain and toxicity concerns indentified above, a reasearch program was initiated in 1976 by the Arctic Land Use Research (ALUR) Program of the Department of Indian Affairs and Northern Development, Ottawa, in close association with the Arctic Petroleum Operators' Association (APOA), Calgary. A primary objective was to provide environmental and geotechnical information related to the construction, use and subsequent restoration of sumps in different permafrost and terrain situations. A second objective was to assess the impact of direct spillage of waste drilling fluids upon the tundra and boreal forest vegetation. A third, more long-term, objective was to assess alternate methods of waste drilling fluid disposal.

A first phase, reported here, consisted of a survey of over 60 abandoned wellsites in the Mackenzie Delta and the high Arctic Islands during the summers of 1976 and 1977 (French, 1978). In 1979 a further survey was undertaken in the northern Yukon. These wellsites were of varying ages and were located in a variety of terrain and permafrost environments. The objective was to document the performance of sumps, to develop case histories of sump problems where these were evident and to identify localities where drilling without a sump might have been preferable. A second phase, initiated during the winter of 1976-1977, consisted of the instrumentation of two sumps in order that the thermal, permafrost and geomorphic changes associated with sump use could be monitored over a 24-month period (French and Smith, 1980). A third phase, still in progress, involves an investigation into the toxicity of waste drilling fluids to plants (Smith and James, 1979).

SUMP PROBLEMS

Approximately 25% of the wellsites investigated displayed problems of terrain disturbance of varying magnitudes related either directly or indirectly to the sump and the containment of waste drilling fluids. No trend was discernible as to whether problems with stabilization of the abandoned sumps had increased or decreased since the inception of the Arctic Land Use Regulations in 1970. More important than age in determining problems with sumps are general site conditions and the timing and nature of the drilling operation.

An analysis of problems with the sumps is presented in Table 1. Basically, problems can be of three types: (A) non-containment during drilling; (B) melt-

Table 1. Analysis of problems related directly or indirectly to sumps and the containment of waste drilling fluids in the North West Territories and the Yukon[1]

PROBLEMS	EXAMPLES	COMMENTS
A. Non-containment problems during drilling.	Bent Horn I-01, Cameron Island	Two sumps constructed.
	Chads Creek B-64, Melville Island	Three sumps constructed.
	Parsons Lake N-10, Mackenzie Delta	Spill into lake; gully erosion; legal action.
B. Melt-out problems during summer drilling.	Bent Horn A-02, Cameron Island	Undermining of rig.
	Parsons Lake D-20, Mackenzie Delta	Leakage of fluids.
	Parsons Lake A-44, Mackenzie Delta	Thermokarst/enlargement of sump.
	Caribou N-25, Peel Plateau, northern Yukon	Leakage of fluids and slope failure.
C. Restoration problems:		
(a) sump infilling and volcano-effect;	Parsons Lake A-44	
(b) sump subsidence and collapse	Drake D-68; Beaverhouse Creek N-13	
(c) lack of infill	Niglintgak M-19; H-30; Taglu D-55	
(d) leakage of fluids	Parsons Lake D-20	
(e) poor geographic locations	Drake B-44; Castel Bay C-68; Hecla J-60; Kumac J-06	
(f) excessive terrain disturbance	Bent Horn A-02; Orksut I-44	

[1]Examples not mentioned in the text are described in French (1978).

out during summer operations; and (C) restoration problems occurring either during restoration or in subsequent years. Many of these problems are interrelated. For example, non-containment during summer drilling may be caused by melt-out problems, and certain restoration problems are clearly related to problems encountered earlier during drilling.

Problems related to sumps are often caused by the various drilling schedules employed. Within this context, drilling operations in Arctic Canada can be grouped into one of three time frames; (a) one-season winter drilling, (b) two-season winter drilling (i.e. sump is left open during summer and site restoration is accomplished during the second winter), and (c) one-season summer drilling. By far the majority of arctic drilling operations are either one - or two-season winter operations. Field observations indicate that the fewest problems with sumps occur in one-season winter drilling programs, in which commencement and restoration are completed during the winter months. The fluids freeze quickly upon entering the sump (Fig. 1) and terrain damage is minimal (Fig. 2). Winter

FIG. 1. A sump in use at the Panarctic Charles Point G-07 wellsite, southeast Cameron Island, November 1976. Waste fluids entering the sump freeze quickly in temperatures as low as −40° C. Photo: courtesy of A.G. Lewkowicz, University of Ottawa.

FIG. 2. Oblique air view of the Elf Dyer Bay I-59 wellsite, Prince Patrick Island, following site restoration, August 1976. The well was a one-season winter operation drilled the previous winter. Minimal terrain damage occurred and waste fluids were contained and buried within the sump.

drilling in two seasons poses more problems because these operations are usually deep holes which become extended for one reason or another, thus continuing into the critical summer season. Finally, limited data suggest that summer drilling has the highest probability of occurrence of problems related to sumps, as discussed below.

A. Non-containment during drilling

Non-containment can be the result of either too small a sump for a given operation or a given operation assuming larger dimensions (i.e. deeper drilling) than planned. As such, problems with sumps are the result of either bad planning in the initial phase of sump construction, or drilling problems. In the case of the former, permafrost is sometimes a factor. The presence of massive icy bodies, which possess different elastic properties to mineral soil, may reduce the effectiveness of the explosive blast used to excavate the sump. Such conditions are sometimes extremely difficult to predict without detailed site investigations. Thus, the initial sump may not be as large as planned and additional sumps, with associated terrain disturbances, may be required at a later stage.

The probability of non-containment is highest in exploratory drilling in areas where deep and complex geologic structures are being tested. Drilling is unpredictable and sometimes extended, leading to excessive production of waste drilling fluids. For example, the Chads Creek B-64 well, drilled on the Sabine Peninsula of Eastern Melville Island in 1975, is reasonably typical of these problems. Originally planned to be 4000 m deep, the well ended up being in excess of 5000 m deep. Two additional sumps had to be constructed to accommodate all the waste drilling fluids and a considerable area adjacent to the well-head was disturbed. Similar problems were encountered in the Bent Horn area of southwest Cameron Island. There, complex faulting of limestone reef formations led to the creation of small pockets of high-grade oil which were extremely difficult to locate. Exploratory drilling turned out to be unpredictable, in terms of both depths drilled and structures encountered. At the Bent Horn I-01 wellsite, for example, a second sump had to be constructed during the latter period of drilling and frozen fluids were periodically removed from the main sump and transported to the auxiliary sump 300 m distant. Inevitably, lumps of frozen drilling fluid became scattered on the tundra, to melt the following summer.

The effective containment volume of a sump is reduced if it is constructed on sloping terrain. In this case, overflow may occur at the downslope end while the upslope end is only partially full. One such example was the Parsons Lake N-10 wellsite, drilled in the Mackenzie delta region in the spring of 1973 (Fig. 3). The hilly nature of the site, surrounded by deep depressions containing lakes on three sides, precluded the possibility of sump construction on level terrain. When it was realized that the sump was too small, the lower end of the sump was extended by the construction of a dyke placed upon approximately 1.0 m of snow which had fallen that winter. In May, as air temperatures rose, this snow melted and fluids escaped beneath the dyke. This thaw was probably accelerated

FIG. 3. Oblique air view of the Gulf Parsons Lake N-10 wellsite, Mackenzie Delta, September 1976. In the summer of 1973, fluids escaped from the sump (centre) and entered a lake (bottom right) via a system of ice wedges (lower left). Gullies eroded at the time are still visible.

by the temperature of the drilling effluent in the sump, which may have been between 35-50°C at the time of deposition. Further difficulties were encountered later that summer when the thawing of large ice wedges, exposed in the walls of the sump, enabled a further release of fluids and the erosion of gullies several meters deep down from the sump.

Remedial measures for non-containment problems include (a) the construction of additional sumps, (b) the modification of the existing sump, and (c) the trucking of fluids to other dispersal sites. The experience from both the Chads Creek and Bent Horn wellsites indicates that the construction of an additional sump results in considerable terrain disturbance and, almost inevitably, a mixing of sump fluids with overburden and the surface soils. In areas where several wells are being drilled, the trucking of fluids in winter to other sumps, or to a central sump constructed in a approved area, might be considered.

B. Melt-out during summer operations

The thermal influence of sump fluids upon the enclosing permafrost and the effect of positive ambient air temperatures upon permafrost exposed in the sump walls can lead to degradation around the sump. Clearly, these are not problems if the well is drilled during the winter months. During a summer operation however, or when a sump is left open during the summer, the possibility exists for substantial enlargement of the sump if the permafrost is ice-rich. This has led to problems in the Parsons Lake area of the Mackenzie Delta. For example, at the

Parsons Lake A-44 wellsite, the sump walls melted during the summer of 1975 which led to a substantial enlargement of the sump. Filling and site restoration was only accomplished by the placement of a large gravel cap, or mound, approximately 6 m high, over the sump (Fig. 4). In other cases, melting along ice

FIG. 4. Oblique air view of the Gulf Parsons Lake A-44 wellsite, September 1976. Following melt-out and enlargement of the sump during the summer of 1975, sump infilling was accomplished by placing a large gravel cap, over 6 m high, over the sump. A revegetation program was also initiated.

wedges has allowed sump fluids to escape from the sump. For example, the Parsons Lake D-20 well was drilled in the winter of 1975-76 and restored during the following winter. Because of substantial melting around the sump during the summer of 1976, a large gravel cap was installed, similar to that at the A-44 wellsite. Subsequently fluids seeped to the surface approximately 30 m below the edge of the sump. Probably, the hydrostatic head induced by the weight of the gravel cap aided the slow movement of unfrozen fluids along the lines of ice wedges. In March 1978, a small icing mound, composed of frozen sump fluids and approximately 1 m high and 3 m in diameter, had formed at the site of the seepage (Fig. 5).

One of the most severe examples of terrain damage caused by melting and leakage of fluids occured at the Caribou N-25 wellsite in the northern Yukon in 1975. The well was drilled between May and August 1974 on a flat narrow interfluve separating two deeply incised stream valleys. The sump, by necessity, was constructed too close to the western edge of the interfluve such that a large containment dyke had to be constructed on the downstream end. During the late summer, when this dyke thawed out, fluids escaped through the dyke (Fig. 6).

FIG. 5. A small icing mound formed in winter downslope from the Gulf Parsons Lake D-20 sump from the seepage of sump fluids through the active layer and along ice wedges. Photo taken March 1978.

FIG. 6. Gulf Caribou N-25 wellsite, Peel Plateau, Yukon Territory, September 1974, showing leakage of fluids through the sump wall. Note how close the sump was located to the edge of the valley slope. Photo: courtesy of W. Robson, Fisheries and Environment Canada, Whitehorse.

The next summer, following site restoration that winter, substantial slumping and instability occurred at the site of the leak (Fig. 7). Clearly, the fluids had not frozen *in situ* in the permafrost and the weight of the sump overburden led to the seepage which triggered the mass wasting. By 1979 a program of revegetation, undertaken to stabilise the slope, had met with some success (Fig. 8).

FIG. 7. Gulf Caribou N-25 wellsite, September 1975, following site restoration. Slumping and mass wasting occurred at the site of the initial leak of sump fluids. Photo: courtesy of W. Robson, Fisheries and Environment Canada, Whitehorse.

FIG. 8. Gulf Caribou N-25 wellsite, July 1979, showing slope stabilisation and effects of revegetation. Compare with Figure 7. Seepage from the disturbed area is still occurring.

C. Restoration problems

A number of restoration problems can be recognised (see Table 1). They are frequently associated with operations in which the sump has remained open during the summer. The more important are described here. First, during sump filling when fluids are not completely frozen, the surface of the sump may break under the weight of the overburden, allowing fluids to squeeze to the surface. This is referred to as the 'volcano' effect (French, 1978: 36). Second, waterlogging and sump subsidence is a frequent occurrence (Fig. 9) resulting from either

FIG. 9. **Oblique air view of the Panarctic Drake N-67 wellsite, Sabine Peninsula, Eastern Melville Island, August 1976. The sump overburden shows signs of collapse and subsidence. Snow is present within the overburden.**

(a) excessive snow and ice incorporated in the sump infill or (b) a slope location where seepage through the active layer in summer causes a build-up of pore water pressures in the overburden. Third, the melting of ice during summer from material excavated from the sump may result in a significant decrease in volume of material available for sump filling. If aggregate is unavailable, a depression is created over the restored sump and promotes the accumulation of a body of standing water. This acts as a heat 'sink' and increases the possibility of the eventual thaw of the frozen sump fluids buried beneath. Finally, certain sumps have been excavated in poorly-chosen sites, these having been chosen in winter when snow obliterates the details of the landscape. For example, the Hecla J-60 sump, on the Sabine Peninsula of Eastern Melville Island, was located in the middle of a water course (Fig. 10). This raises the possibility of the fluvial dissection of the sump and the release of the sump fluids into the stream. In a number of other cases of poor geographic locations, a pre-inspection during summer together with air photo interpretation would have prevented similar problems.

FIG. 10. Oblique air view of the Panarctic Hecla J-60 wellsite, Sabine Peninsula, Eastern Melville Island, August 1976. The sump, located in a permanent watercourse, has collapsed and a body of standing water has collected over the sump.

CONCLUSIONS

The policy of containment of waste drilling fluids in below-ground sumps as required under the Territorial Arctic Land Use Regulations appears to have worked satisfactorily in the majority of wells drilled in arctic Canada. A significant minority have experienced terrain disturbance problems related to sumps. It would appear that the deep drilling, which is increasingly typical of much Canadian exploration, the complex geology of potential oil and gas reserves and the high probability of an operation extending into critical summer months are important factors which limit the effectiveness of present Arctic Land Use Regulations.

It is clear that certain sump-related problems can be resolved by more rigorous planning, careful operating techniques, and strict application of present regulations. In other areas of high potential terrain and toxicity damage, however, alternate methods of disposal must be considered, notably direct spillage of fluids upon tundra following detoxification procedures and overland trucking of toxic fluids to official disposal sites. A compromise solution involving one or more of these options may be required in certain instances, in which terrain disturbance, cost, and the effects of uncontrolled release of fluids are minimised. In addition, the substitution of non-toxic components in the drilling mud systems, already pursued in granting drilling approvals, must be continued.

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