Occurrence and Growth of Gullies on Mine Disturbed Land

OCCURRENCE AND GROWTH OF GULLIES ON MINE DISTURBED LAND*

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SUMMARY

Gullies are erosional features found in both natural and reconstructed landscape. They are indicators of geomorphic maturity and therefore represent a valuable tool for assessing the performance and sustainability of mine disturbed land following reclamation. Some types of gullies are associated with instability, rapid erosion, and accelerated landform deterioration. Other types are inactive, self-healing and/or subject to gradual change, consistent with the aims of sustainable reclamation. Both types of gullies occur on mine disturbed land following reclamation or premature abandonment. An inventory of gullies at a sand disposal area near Fort McMurray was conducted to identify the types of gullies, their size, associated erosion rates, and self healing tendency. The results of this analysis lend support to the current method of reclamation and provide guidance for future modifications to closure plans. The data can be used to develop a strategy for mine closure to minimize the risk of rapid landscape evolution by gullying. A system of annual monitoring of gully shapes and sizes is being conducted to confirm long term sustainability.

BACKGROUND

Suncor Inc. has built numerous tailings storage facilities at their oilsands mine in Northern Alberta, 30 km north of Fort McMurray. The facilities are composed of sand dykes which presently contain a combination of fine tailings, other mine waste materials and water. Ultimately, upon mine closure, the fine tailings will be replaced with Consolidated Tailings (CT) which is a solid mixture of sand and fine tailings, to enable development of mainly dry landscape.

The oldest sand dykes on the Suncor mine site are located at Pond No. 1 which is contained by a sand perimeter dyke known as the Tar Island Dyke (TID). Construction of the TID began in the late 1960's and is presently close to completion. The sand dyke has been progressively reclaimed and therefore vegetation at the lower reaches of the dyke have reached a 25 year maturity.

The TID is composed mainly of sand and is presently about 100 metres high at an overall slope of 3H:1V. The sand is highly permeable with an effective infiltration rate of over 70 mm/hour. The near surface soil permeability was measured by Guelph Permeameter to be about 1 to $6x10^{-3}$ cm/sec. The D_{50} of the sand ranges from 0.20 to 0.25 mm. The sand contains 2 percent to 8 percent fines (minus #200 sieve).

Reclamation of the sand dykes includes a 15 to 20 cm cover of topsoil composed mainly of peat. Formerly, revegetation involved planting of agronomic grasses as well as trees but the present method of reclamation involves growth of natural species enabled by direct placement of peat. Most of the dyke area is covered by topsoil and supports vigorous growth of grasses, natural species and trees. Some areas have little or no topsoil cover as a result of erosion during construction and covering by windblown sand.

In 1995, Suncor Inc. commissioned a study to examine the erosional sustainability of their reclaimed areas. The study was commissioned to provide a sound basis for reclamation planning and ultimately to provide evidence that the reclamation system is sustainable over the long term.

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As part of this study, Suncor Inc. commissioned an inventory of the occurrence, character, frequency and stability of gullies on the TID. The inventory included classification of the gullies and an assessment of any self-healing characteristics. Suncor Inc. also commissioned the selection, survey and monitoring of fifteen gullies to provide a long term assessment of their growth or stabilization. The monitoring data is intended to provide a basis for acceptance of the sustainability of the TID by government regulators.

METHODOLOGY

Tar Island Dyke (TID) has been subject to a range of environmental conditions since reclamation began 25 years ago. These have resulted in some gullying, particularly at unreclaimed areas and freshly reclaimed areas. A survey was conducted to provide a basis for assessing the frequency and stability of the gullies. The survey included the number, density, location, size, type, cause and growth/stability of gullies. An inventory of gully data was developed to determine the prevalence, severity and long term continuation of gullying. It was configured to provide a basis for assessing the self-healing character and progressive growth of gullies.

A representative sample of gullies was selected to provide a sound statistical basis for developing an inventory of gullies. The inventory was based on an area of 23 hectares which represents about 19 percent of the total surface area on the outside face of TID. The total area was divided into eight strips, each approximately 100 metres wide, located at 500 metre intervals. They extended from the crest of the dyke, down to the toe of the dyke. Each strip was divided into blocks from the toe to the crest of the dyke.

In addition to the inventory of gullies in the representative strips, fifteen gullies were selected for more detailed investigation and future monitoring. The fifteen gullies were selected to represent a range of gully sizes (five small, five medium and five large) and a variety of gully types (self-healed, no growth and active growth). Detailed investigation included a survey of gully cross sections with local benchmarks installed along each cross section so that gully growth may be tracked over time.

SURVEY, INVENTORY AND MAPPING

A detailed inventory of all gullies identified during the study was presented on a spreadsheet which indicated the following characteristics of each gully:

- Gully location;
- Gully length, width and depth;
- Volume of eroded material;
- Existing vegetation cover;
- Assessment of possible causes;
- Assessment of erosion activity (self-healed, growth, etc.;
- Repair efforts and effectiveness;
- Photograph record;
- Commentary.

A statistical summary of the gully inventory assessment was also prepared. The number of gullies in each block were summarized by cause of erosion and by level of erosion activity. The number of gullies in each category of cause, type and eroded volume was summarized for each block. This provided a spacial analysis of gullying on the TID. The character and cause of gullying was summarized by location, from the earliest reclamation at the base of the TID to the most recent reclamation near the crest of the dyke.

The locations of the 15 gullies selected for detailed assessment were mapped. The surveyed cross sections, photographs and details of each gully were presented on separate drawings. Future surveys may be carried out using the benchmark information provided on the drawings.

CAUSES OF GULLYING

The spacial distribution of gully density indicated a greater number of gullies within Strips A, B and C, located on the south end of the TID, than at other locations. This may be indicative of improved soil moisture availability to support vegetation on the north end of TID, where aspect is more favourable to water conservation. The south end of TID has a southerly exposure resulting in greater solar radiation, more drying, and possibly more loosening of surfical soil by freeze-thaw.

The three most common causes of gully development observed at the TID are as follows: no vegetation present when the gully first developed (29 percent of gullies identified); no existing vegetation (39 percent of gullies identified); and terrace ponding (22 percent of gullies identified).

There were other minor causes of gullying. A high phreatic surface and groundwater seepage discharge at the toe of TID caused 6.5 percent of the gullies. Such gullies are characterized by a cirque-shaped head. The channel formation process for this type of gully has been described by Schumm, *et al* (1995). One gully was caused by a pipe outfall and two gullies were caused by uneven grading of the TID slope.

Gullies exhibiting the greatest growth were found near the top of TID, where very little or no reclamation existed. This area of the TID was built most recently and the extensive gullying reflects immature vegetation and pre-reclamation conditions. Many large gullies and rills formed on the exposed sand surface as a result of the absence of a protection cover and root mass. Sand dunes caused by wind erosion on the unreclaimed sand surfaces near the crest have formed on the lower berm. These dunes have caused flow obstructions and ponding on the lower berms and this may have caused many of the gullies on the lower slope.

Active gullies exhibiting progressive growth occur at various locations on TID. Active gullies on the recently reclaimed area are attributed to the absence of an effective vegetative cover, reflecting pre-reclamation conditions. Most other active gullies are attributed to terrace ponding (i.e., flow concentrations created on the TID berms).

A self-healed gully is one in which there is no active erosion or growth as a result of an armour layer or the growth of vegetation in and alongside the gully. The concept of self-healing has been described by Ireland, *et al.*, (1939) in a description of the stages of gully development. "Stage 3 is a period of healing. Slopes of the gully walls are reduced by weathering, slope-wash and mass movement; plants are established on the lowered slopes, and vegetation gradually brings about a healing of the gully. Stage 4 is a period of stabilization, and it is characterized by the slow development and accumulation of new soil over the old scarred surface." More recent discussion of this phenomenon is provided by Schumm, *et al.*, (1984). Self-healed gullies are predominantly located near the bottom of the TID. Self-healed gullies comprised 37 percent of all gullies identified.

Self-healed gullies were analyzed to identify the cause of the self-healing mechanism. Self-healing is often associated with the development of a gravel armour layer as a result of the removal of fines by erosional forces which are insufficient to remove the larger size material. However, the self-healing process on TID is different. Vegetation develops in the gully to reduce erosion. Vegetation develops naturally in gullies, probably as a result of improved moisture conditions inside the gully The gullies collect more water than adjacent areas because of their larger collection area and because wind blown snow deposition in depressional areas. At many locations, the vegetation in the gullies was observed to be thicker than the vegetation adjacent to the gully.

RATES OF EROSION AND GULLYING

The total volume of gully erosion on the 100 metre strips is approximately 5900 m^3, based on the calculated volume of measured gullies. This equates to an erosion per unit area of 26 mm, or an average of 1.3 mm per year over the average 20 year life of TID.

Assuming this erosion rate is representative of long term conditions, the total erosion over the entire dyke in 1000 years would be 3.1×10^6 m^3, which is equivalent to a total depth of erosion of 1.3 metres over the entire surface of the TID. This erosion volume and depth shows that TID has been subject to moderate to high rates of erosion. However, most of the gullying is representative of immature reclamation conditions during the early years immediately after construction. Gullying at the more mature reclaimed areas is much smaller than calculated above.

A useful follow-up to this gully mapping study is monitoring the selected fifteen gullies whose cross sections have been surveyed. It is very likely that future erosion will be far less, especially at well reclaimed areas. Such data may provide a sound basis for confirming the sustainability of TID and also for regulatory certification.