Methodology for Geomorphic Assessment of Alluvial Channels in Oil Sands Region - A Case Study

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Abstract

This paper explains procedure devised and used for the design of dynamic system for geomorphic studies in the Oil Sand Regions (northern Alberta, Canada), comprising Muskeg, and deals with geomorphic investigation, scientific issues and technical complexities, approach and methodology. Conventional approaches for design of reclamation drainage systems often provide rigid, non- erodible drainage facilities that are designed to handle specific extreme flood events. The alternative to rigid systems designed for specific extreme events is a dynamic system capable of accommodating evolutionary changes without accelerated erosion or unacceptable environmental impacts, a geomorphic approach. Development of this approach requires a comprehensive field investigation, afterward analysis and development of design equations for the design of streams to restore them back into pre-excavation form - this study provides a systematic procedure to the solution.

Key Words: Muskeg; geomorphic; assessment; oil sands region; mine closer; dynamic system; channels; muskeg soils.

1. Introduction

The development of credible mine closure plans is being increasingly scrutinized by regulators, stakeholders and mining companies. This development becomes more difficult when working in areas comprising of Muskeg (a soil type consists of dead plants in various states of decomposition i.e. peat). It can hold 15 to 30 times its own weight in water and common in Canadian arctic [12, 13] e.g. oil sands regions of Northern Alberta (shown in Figures 1 & 2). Mine closure plans that are conceived many years before mine closure are normally based on many assumptions and future technological developments. This introduces a level of uncertainty that is best remedied by continuous research, pilot trials and monitoring of reclaimed land. The sustainability of mine closure drainage systems represents a significant uncertainty, risks long term liability and compliance with commitments to develop suitable levels of aquatic productivity. Previous closure drainage designs have been based on geomorphic data of other environments. Development of appropriate geomorphic relationships to suit local conditions is necessary [8,9] to minimize long term liabilities and maximize aquatic productivity. A few Calgary based organizations had, for several years, encouraged the development of locally-based geomorphic relationships and natural analogues for replication in the mine closure environment. Recognizing the need for a much larger efforts required for such kind of investigations a Calgary based company played a significant role.

2. Background

1.1 *Need for Geomorphic Study*

Oil sands mines excavate large areas mostly covered with Muskeg and create new topography involving lakes, wetlands, upland areas, lowland areas and hills. For each mine development, the disturbed areas typically exceed 60 km^2 and require new drainage systems to provide for effective drainage, erosion control and development of sustainable landscape. The entire Oil Sands Region is over 10,000 km^2.

Figure 1: Arial view of Muskeg soil region (surrounding area of West Jackpine Creek), Northern Alberta

Figure 2: More than a meter thick layer of Muskeg (left bank of Asphalt Creek), Northern Alberta

The challenges of recreating sustainable watercourses have recently, focused on vegetated waterways since these may form a large majority of drainage works. However, larger watersheds will need to be drained by defined watercourses that cannot be protected by vegetation due to their sustained flow and higher flow velocities. Although fewer in number, reconstructed streams draining larger watersheds represent greater vulnerability and long term liability because of their larger and continuous flows. The conventional remedy for such conditions is to design armored channels with rip rap sized for design recurrence intervals ranging from the 10 years flood to the PMF. This conventional remedy is incompatible with the design criteria of maintenance free sustainability because armored channels normally require maintenance. In contrast to the conventional approach of providing armored channels for large watersheds, most of the mine closure plans for existing and new mines are based on developing sustainable alluvial channels that replicate natural streams. This approach is based on the assumption that natural channels represent the optimum end-state and are sustainable in the long term.

Natural channels are normally considered to be maintenance free even though they are subject to erosion, sedimentation, beaver dams, debris blockage, icing, etc. Natural channels are dynamic and yet they demonstrate superior longevity relative to man-made channels. The proposed approach is termed the "geomorphic approach".

Channel design based on geomorphic approach involves the use of regime equations which relate channel width, depth, width-depth ratio, sinuosity and meander wave length [7], [10], [11]. These parameters are normally a function of the bank full discharge, soil type and slope [7], [10]. In the oil sands region, the landscape is generally characterized by fen soils (muskeg), which are highly absorbent, typically 0.5 to 2 m thick and generally poorly drained. Beaver activity is also significant especially in the lowland areas. Such an activity in the form of Beaver dam is shown in Figure 3. Likewise special features of this area e.g. submerged vegetation, in-stream debris, fallen trees are depicted in Figure 4. The hydrology of this area is unique and channel design of reclaimed drainage systems will require a sound understanding of the local natural fluvial geomorphic processes and

Figure 3: Muskeg area natural stream with a Beaver dam (Beaver River, site 26), Northern Alberta

Figure 4: Muskeg area natural stream with debris and submerged vegetation (Site N4), Northern Alberta

adaptation of existing regime equations. The application of existing regime equations to design of reclaimed channels in the oil sands region has not been successful ([2]-[4]).

The current regime relationships are based on climates and geography ([5] & [6]) that are distinctly different from the muskeg and peat lands of the oil sands regions. Natural streams of this region exhibit different conditions e.g. their velocity profiles are of different shapes as compared to the ordinary natural streams as depicted in Figures 5 & 6. The proposed work will derive regime relationships based on local conditions so that local natural streams can be emulated. Considering the shortcomings in applying the existing regime equations in designing reclaimed channels in the oil sands region, it was the goal to develop a new but simple design method for channel design.

2.2 *Scientific Issues and Technical Complexities*

The science of geomorphology is well established and much research has been done to develop regime relationships that describe natural channels that are in equilibrium (not subject to rapid erosion). However, most of the research on natural channels is focused on temperate, arid and tropical climates. The conditions in Canada's northland are quite different from those areas that were used in previous channel regime studies.

The thick layers of peat and muskeg in northern Canada and the oil sands region in particular, result in unique hydrologic conditions involving relatively small peak flood flows and high low flows. People are currently applying channel regime relationships to the design of reclamation drainage systems for oil sands mine closures. They know that the natural streams in this region of Canada behave quite differently from the predictions of channel regime equations. People have long recognized the difference between the channel hydraulics predicted by commonly used regime relationships and local natural channels. It has also been strongly criticized by a noted Canadian geomorphologist, Dr. Robert Newbury [8], who frequently represents the Federal Department of Fisheries and Oceans (DFO) as specialist reviewer of project applications.

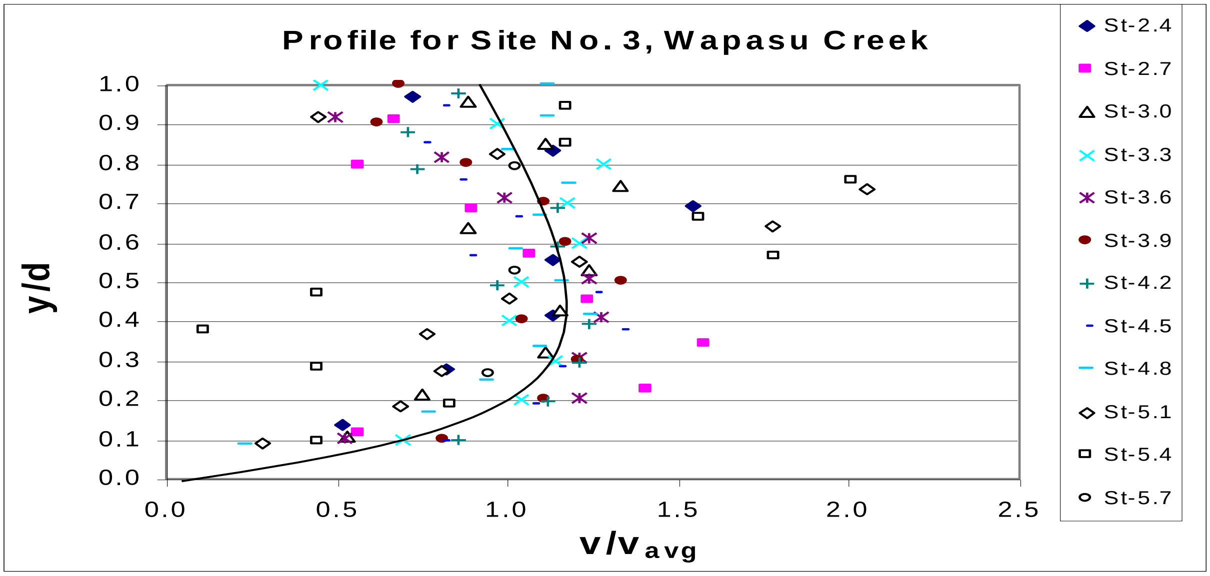

Figure 5: Muskeg area stream (Wapasu Creek) having an abnormal velocity profile, Northern Alberta (adopted from [1]).

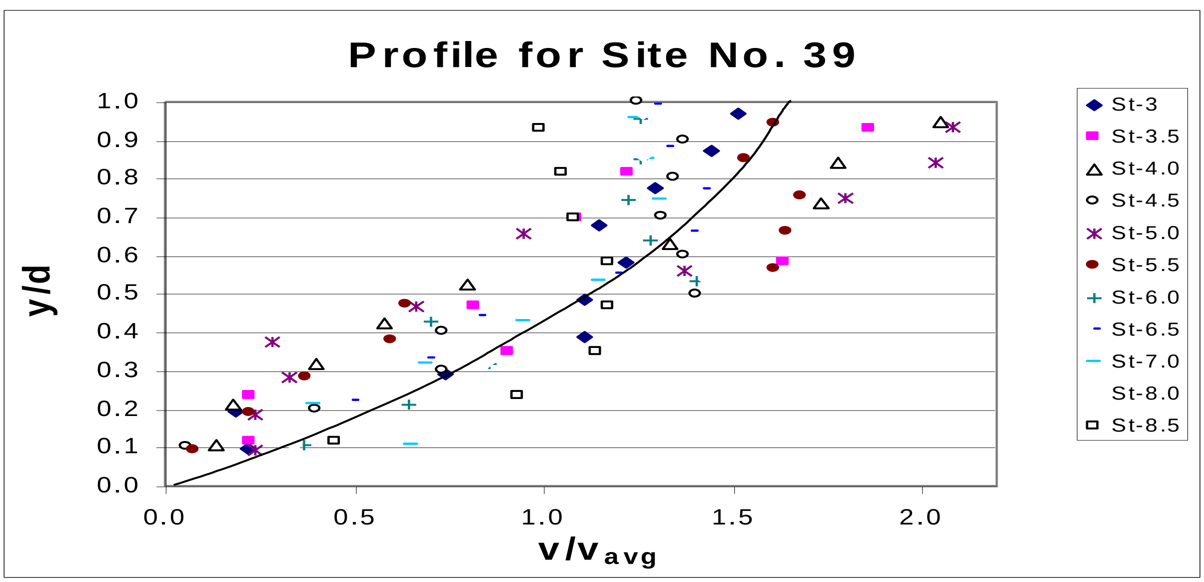

Figure 6: . **Figure 6:** Muskeg area stream (Site No 39) having an abnormal velocity profile, Northern Alberta (adopted from [1]).

[Where y = flow depth, d = channel depth, v = flow velocity at depth y, v_{avg} = average flow velocity]

Dr. Newbury [8] advised oil sands organizations to conduct research on natural channel regime conditions in the oil sands region to redress the discrepancy between actual conditions and standard design procedures that are based on available regime equation predictions and actual conditions.

The scientific issues and research problems that may pose some challenges in geomorphic studies, but are resolvable include the following:

- Developing a cost-effective system of collecting additional local geomorphic data in the Oil Sands Region;
- Collection and review (quality check) of available field data, in particular, local field data;
- Determining the validity of existing regime design equations, some of which are not reported;
- Developing a process of screening existing regime equations to a few equations for validation test;

3. Adopted Approach

Conventional approaches for design of reclamation drainage systems often provide rigid, non-erodible drainage facilities that are designed to handle specific extreme flood events. This results in uniformity of design and construction but does not necessarily accomplish the performance objectives of the closure drainage systems to minimize erosion and to achieve long-term sustainability.

A major deficiency of the conventional approaches is the absence of a self-healing mechanism. Man-made channels may fail because of overtopping, washout of erosion protection or channel degradation. Such failures often lead to accelerated erosion and/or channel relocation, conditions that typically cause high sediment yields resulting in alterations of aquatic habitats.

The alternative to rigid systems designed for specific extreme events is a dynamic system capable of accommodating evolutionary changes without accelerated erosion or unacceptable environmental impacts. Such a dynamic system must have robust drainage facilities with several lines of defense and self-healing capability that can be built into reclamation drainage systems by design.

The geomorphic approach to design of closure drainage systems for mine reclamation is novel. The oil sand industry welcomes the approach because government regulators and stakeholders are highly supportive of this approach. However, the application of this innovative technology is constrained by deficient applied research.

4. Study Methodology

The methodology followed is summarized as follows:

Task 1: Literature Review

Literature review of all available public domain reports on existing and pre-disturbance streams from baseline data compiled by companies to support their Environmental Impact Assessment (EIA) reports on oil sands projects was completed. Existing regime equations and published geomorphic data in northern climates have also been reviewed and complied.

Task 2: Field Investigations

- Selected candidate channels covering a broad range of conditions and areas. The stream cross-sections varied in size from 1 m to over 20 m in width. Sixty candidate streams were investigated. The sampling strategy was to obtain at least five stream sites for each class of stream. Twenty stream classes represented a range of watershed slopes, channel slopes, surface geology, sizes of watershed, etc were developed.
- Measured watershed parameters including aspects; size of watershed, vegetation cover, elevation, slope, topography, surficial geology and depth of peat.
- Measured watershed parameters including bed material, bank material, plan-form, meander wave length, channel width, channel depth and channel slope.
- Described channel evolutionary stage including bank stability, bank erosion, degradation, aggradation.
- Measured stage discharge curve that reflects channel bed roughness and form roughness.
- Photo inventory at all sites was done.

Task 3: Office Investigations

- Plotted the field data on graphs that typically are used to examine regime relationships.
- Conducted multi-dimensional statistical analyses to derive regime relationships for the oils sands areas in Northern Alberta.
- Prepared reports.
- Analyzed the channel regime and sustainability, rates of erosion, sediment transport, and rate of evolution of natural streams in the Oil Sands Region;
- Identified natural processes that govern sustainability;
- Developed design concepts including regime equations that may be used in closure schemes to achieve robust drainage systems comparable to natural systems. Screening and validation test of existing regime equations to determine the form of a new regime equation based on local data.
- Validated the new or modified channel design equations.
- Developed prescriptions for design of mine closure drainage systems.
- Applied the design concepts to a real closure drainage design.
- Analyzed the long term sustainability of the example design by model simulation of a long period of flow data generated by stochastic methods.

5. Professional Expertise Required

A Ph.D. qualification individual was the project engineer. He was responsible for most of the work including literature review, field data collection, data analysis, developing a new design concept and regime equation, application of the new design concept and reporting. This engineer worked independently as much as possible in collaboration with one of the senior fluvial geomorphologists/ hydrologists who provided support and direction to him.

The project engineer's knowledge and experience in the field of fluvial geomorphology; hydrology; river hydraulics; erosion and sediment transport was extensive and impressive. For example he conducted field investigations during using four different field sites located in the Northern England (UK). These investigations lasted for three years and field data were collected during various field visits. In addition to this, he worked in the Rocky Mountain area of Colorado, USA. For this study, two filed sites located in the Estes Park area (i. e. downstream of the Lawn Lake dam) were used and field data were collected. He had also worked on other field sites under different projects. He gained sufficient experience in field site selection, data collection and analysis. He had the qualifications to undertake experiments related to the proposed project.

A senior level professional engineer served as Project Director. This senior person was a water resources engineer with over 25 years of experience in erosion control, reclamation drainage, fluvial geomorphology and landform design for long term sustainability. His experience during the past ten years included shaping of mine waste dumps to minimize erosion potential. He pioneered non-structural erosion control measures that replicate natural analogues. He had extensive experience in applying these techniques to mine disturbed land and presented workshops and short courses on this technology. Recent projects include landform shaping and drainage of waste dumps at TransAlta's Centralia Mine; reclamation drainage design of Syncrude's W1 dump, W2 dump, S4 dump and S5 dump; evaluation of drainage of Syncrude's SWSS area, and drainage of Syncrude's 30 dump.

Beside the above mentioned professionals, two more experts needed to be involved in this project including a Project Manager and Stream Restoration specialist.

6 Specific Milestones

Under the milestones, first field season investigation was completed in November 2005, while data from the available literature was compiled until March 2006.

Preliminary analysis of 1st season data and compiled data was finished during the month of September of 2006. Based upon this preliminary analysis, the program was briefly modified and accordingly data for the second field investigation was collected in October-November 2006. By using the earlier mentioned collected and complied data, analysis was completed in March 2007 and regime relationships were developed. These developed relationships and concepts were tested to real closure drainage and final report was issued.

7 Conclusions

A geomorphic approach for the rehabilitation of natural streams and for the design of closure drainage systems for mine reclamation has been devised for the northern regions of Canada, in particular and other regions (with similar characteristics) in general. This approach was prepared in consultation with the oil sand industry who appreciated the approach because government regulators and stakeholders are highly supportive of this approach. Nonetheless, the application of this innovative approach is constrained by deficient applied research, therefore further research and development in this regard would be helpful to generalize it further.

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