An Abbreviated History of Development of the "Insitu Seepage Treatment" (Bioremediation) Concept at the Abandoned South Bay Property.

Introduction:

- The South Bay mine, a copper/zinc producer, was operated by Selco Inc. during the period 1971-1981.
- Surface facilities were decommissioned/removed in 1987-88.
- Boojum Research began "ecological engineering" work at the site in 1986, with a principal focus on minesite contamination and Boomerang Lake.
- This summary is provided in support of Talisman's plan to "scale-up" insitu seepage treatment (bioremediation) in order to control contaminated groundwater seepage emanating from the South Bay tailing deposit. The bioremediation activity proposed would be confined to the existing "waste management area" at South Bay.
- This summary focuses on insitu bioremediation of contaminated groundwater from the tailings area, and does not address the many other aspects of "ecological engineering" ongoing at the site. For a fuller discussion of ecological engineering at South Bay, see update reports provided earlier by Talisman entitled "South Bay Discussion (1998)" and "South Bay Progress Report (1998-2000)".

The Concept of Insitu Seepage Treatment (Bioremediation) at South Bay:

- In 1994, breakthrough of contaminated groundwater became evident "downstream" of the South Bay tailing deposit, in Mud Lake (see Map 1).
- Key indicators of the breakthrough of contaminated groundwater seepage were elevated iron and zinc and depressed pH, recorded in water samples collected in Mud Lake.
- Sixty tonnes of phosphate rock was batch-applied in Mud Lake to boost pH, precipitate iron and zinc, and generally slow-down water quality deterioration.
- In order to understand the critical dimensions of this contaminated groundwater seepage from the tailings (i.e. location, pathways, depth, geochemistry, etc.), we completed approximately 40 km of EM surveys in the vicinity of the tailing deposit and drilled and installed an additional 50 piezometers in and around the tailings area. This brought the total number of piezometers onsite to approximately 100+.

- At about the same time, we began to develop a 3D groundwater model to better understand the hydrology in and around the tailing deposit, to support future tailings area "intervention", and to confirm results of earlier hydrological studies initiated at the site in 1987.

- Through this work it was determined that the bulk of the contaminated seepage (groundwater flow) from the tailings is confined to a well-defined buried bedrock channel (i.e. the so-called Kalin Canyon) located West of the tailing deposit.

- Contaminated groundwater from the tailing deposit spills westward into the Kalin Canyon, travels north along the length of the Canyon, and then discharges via upwelling into Mud Lake. The contaminated groundwater mixes with Mud Lake surface water and discharges as surface water into the tip of Armanda Lake and on into Confederation Lake at long term monitoring station C11 (Map 1).

- Since the contaminated groundwater flow is confined in the Kalin Canyon, we saw this area as a logical focus for "intervention".

- The "intervention" of choice is the development of insitu bioremediation capacity based on ARUM principles (i.e. Acid Reduction Using Microbiology) implemented and under development elsewhere at the South Bay site. Site constraints limit the applicability of more-conventional treatment approaches, and bioremediation offers the possibility of long term sustainability with fewer inputs.

- The bioremediation strategy initially conceptualized was very simple, and built on research underway at the time at the University of Toronto. The concept involves controlled, localized introduction of urea into the groundwater, to stimulate the activity of naturally occurring urea-degrading bacteria. Bacterially mediated urea hydrolysis generates alkalinity which increases pH and brings about the precipitation of iron and zinc, the contaminants of greatest concern;

- Thus the concept of insitu seepage treatment (bioremediation) in the Kalin Canyon was "born". However, considerable subsequent effort was then required in order to demonstrate the practical utility of this approach. This work was focused along two main avenues:

    1. Modeling and lab-scale experimentation conducted in collaboration with the University of Toronto.

    2. Small-scale field trials conducted at the South Bay site in the vicinity of the "sandpit" area, wholly within the South Bay "waste management area".

These two avenues of investigation are discussed in more detail following.

Research at the University of Toronto:

- Well-known U of T geochemist and microbiologist Dr. Grant Ferris had been working for some time on microbial intervention in oilfield reservoirs. We approached him to discuss the possibility of treating metal-contaminated groundwater through microbial mediated urea hydrolysis. Dr. Ferris was keen to partner with Talisman and Boojum Research to further develop these concepts, with an eye to practical application at South Bay.

- A two-year research program was implemented with Dr. Ferris, the U of T, the NRC, and Boojum/Talisman. The research included microbial evaluation and culturing, molecular-typing of bacteria from the South Bay site, geochemical modeling, column studies (hydraulic conductivity), and evaluation of microbial nutrient requirements.

- In summary, this work has demonstrated the practical utility of the insitu treatment and bioremediation concept for application South Bay. Key results from this work were as follows:

    - Appropriate urea-degrading bacteria occur naturally in the groundwater and subsurface matrix at South Bay.

    - Geochemical simulations, accounting for microbially generated carbon dioxide and ammonia as neutralizing agents, confirm that pH can be increased and metals precipitated inset by urea-degrading bacterial activity within the contaminated groundwater at South Bay.

    - Supplemental carbon may be critical to stimulating microbial activity to the level necessary to mediate the desired water quality effects.

Sandpit Experiments:

- In order to test practical applicability in the field in parallel with the U of T lab work, field trials were established in the sand pit area. The sandpit overlies the Kalin Canyon immediately West of the tailing deposit, and is confined within the broader "waste management area" at South Bay (see Map 1).

- This sandpit was chosen as the site for the field trials because it overlies Kalin Canyon, is subject to contaminated groundwater flow, it offers a relatively porous subsurface matrix underlain by an impermeable clay layer, and was thought to have a relatively predictable groundwater flow rate and direction.

- “Initially, shallow piezometers were installed down-gradient and small, measured volumes of urea were trenched into the substrate "upstream" of the piezometers.

- Groundwater samples were collected regularly from the piezometers in order to monitor the affect of the urea dissolution and microbial hydrolysis on water quality "downstream" at the piezometers.

- Fluctuations in groundwater flow and direction complicated interpretation of the sandpit experimental results. Notwithstanding, the anticipated increase in pH and reduction in groundwater acidity was observed at several of the "down-gradient" piezometers and in the saturated soil matrix "down-gradient".

- Carbon additions (sugar and yeast) resulted in measurably enhanced urea degradation rates, and attendant water quality improvement, in the sandpit trials.

- The sandpit data supported the results of the U of T work and suggested that there was utility in "scaling-up" to bioremediation metal-contaminated groundwater flowing through the Kalin Canyon. However, the hydrological complexity of the sandpit experiments (i.e. flow in porous sand) confounded our initial efforts to quantify the amount of urea (i.e. dosing rate) required for scale-up.

- Therefore, a second sandpit trial, using a different (i.e. radial) layout, was set up in 4Q 2000 in order to better quantify reaction rates and quantify the amount of urea and carbon required for scale-up. Increases in pH have already been observed in several of these new piezometers. Dosing rate calculations are in progress.

Scale-Up Plan:

- Based on the success of the U of T and early sandpit trials, we began to work on the details of a scale-up plan for bioremediating contaminated groundwater in the Kalin Canyon.

- Key practical concerns arose early on with regard to urea delivery mechanisms. Initially, we had envisioned trenching the urea into the substrate and allowing fresh meteoric water (precipitation and runoff) to passively carry the urea (and the attendant bacterially mediated high-pH “plume”) down into the deeper contaminated groundwater flow. However, we soon became concerned that proper mixing of the reactive high-pH plume and the deeper contaminated groundwater would not occur because of their significant density differences. Poor mixing would limit the effectiveness of the bioremediation.

- As an alternative, we briefly considered injection of urea solution directly into the deeper contaminated groundwater. While the “drive” associated with direct injection overcomes the mixing problem, direct injection is not without problems. First of all, from the U of T work, we know that urea degradation and attendant pH increase occurs much less efficiently in metal-contaminated water. Second, direct injection increases the chance of “plugging” the subsurface matrix as a result of oxygen introduction.

- The delivery concept ultimately devised more-or-less gets around the shortcomings previously described, and is based on introducing contaminated groundwater into a larger microbially mediated high-pH environment or “reaction zone”. The basic concept is as follows:

  - Inject urea into a saturated, uncontaminated subsurface matrix immediately adjacent the Kalin Canyon that drains towards and into Mud Lake, thus creating a localized microbially mediated high-pH environment or subsurface "reaction zone".

  - Using subsurface water pressure to advantage, passively slipstream a significant portion of the contaminated groundwater flow and discharge it through the same injection infrastructure into the localized zone of microbially mediated high pH (i.e. the "reaction zone” above).

  - The seepage treatment per se relies on alternating cycles of urea injection and contaminated groundwater injection into the "reaction zone”.

  - Delivery of contaminated groundwater to the “reaction zone” occurs within a closed system to prevent entrainment of oxygen.

  - Microbial activity is initiated in “clean” water, raising pH at maximum efficiency.

  - Injection provides a drive to assist with mixing in the “reaction zone”.

- A suitable site for this delivery concept was identified on the Southwest shore of Mud Lake. This site has the following critical characteristics:

  - Immediately adjacent the Kalin Canyon groundwater pathway.

  - Homogeneous shallow subsurface "matrix" (gytta) provides the required "reaction zone".

  - Shallow groundwater in the "reaction zone" is currently not metal contaminated.

  - Adjacent piezometer M60A is completed within the deeper contaminated groundwater flow.

  - Piezometer M60A has a pressure gradient that can be exploited so as to deliver deep contaminated groundwater upwards through the piezometer into the shallower gytta “reaction zone”.

  - The site drains naturally towards Mud Lake.

  - The gytta “matrix” in the “reaction zone” is naturally rich in carbon. Recall the carbon source is an important stimulant for the required microbially mediated urea hydrolysis. It is unlikely given the abundant natural carbon that we will need to add supplemental carbon (sugar or yeast) during scale-up at this site.

- A delivery system was designed and installed onsite the Southwest shore of Mud Lake in 4Q 2000. This system has remained non-operational pending consent of the appropriate Ministries. A schematic of the delivery system is shown in Schematic 1. The delivery system includes the following main components:

    - A series of parallel injection wells (injection gallery), to inject either urea or contaminated groundwater into the shallow gytta "reaction zone".

    - A gravity feed system to deliver urea slurry into the injection gallery.

    - A metered flow line from piezometer M60A to the injection gallery, to passively deliver deep contaminated groundwater into the injection gallery.

    - Two series of parallel monitoring wells (monitoring galleries) completed in the shallow "reaction zone"

- The delivery system will be operated as described above, alternating cycles of urea injection followed up with contaminated groundwater injection into the high-pH "reaction zone" so created. Further description of the delivery system is included in the previously submitted NRC report, pages 21-23.

- We expect that piezometer M60A will deliver approximately 0.3 litres/second during the contaminated groundwater injection cycle. This represents approximately 30% of the total contaminated groundwater flow in the Kalin Canyon according to our 3D groundwater model.

- As mentioned earlier, urea dosing rates are currently being calculated and this work should be completed by the end of May 2001. Similarly, the duration of the alternating injection cycles will be roughly calculated by end May 2001. Conceptually, it is expected that urea injection cycles will occur approximately once annually for a period of several weeks, with contaminated groundwater injection occurring more or less continuously in between urea injection cycles. In practice, groundwater quality response, monitored through the monitoring well galleries, will influence the duration of individual injection cycles.

- We will attempt to run this system year round.

Monitoring and Reporting of Scale-Up Performance:

- The effectiveness of the scale-up operation will be determined on the basis of samples collected from the two monitoring well galleries. During initial operations, samples will be collected weekly, or more frequently as necessary based on operational performance. Sampling frequency will be adjusted over time as we develop an understanding of the system dynamics insitu. Parameters monitored will include pH, acidity, urea derivatives, and metals.

- In addition, we will continue to monitor water quality in Mud Lake, looking for water quality improvements attributable to the scale-up operation. We expect that we will monitor the Mud Lake system on at least a quarterly basis. Parameters monitored will include pH, acidity, and metals.

- Assuming we are allowed to proceed, performance of the scale-up operation will be discussed with the Ministries at a South Bay update meeting to be convened in Kenora in late 2001 or early 2002. More-informal reporting can be provided on an ongoing basis.

Contingency and Parallel Plans:

- Contingency and "parallel plans" for Mud Lake and "downstream" include the following. By "parallel plans" we mean other ecological engineering initiatives that complement the objectives of seepage treatment (bioremediation) scale-up, and that we will most likely be doing at the site in any case.

    - **Wood Ash Treatment:** We are currently investigating the utility of waste wood ash application in Mud Lake as a means to precipitate and stabilize metals accumulated in the concentration gradient above the Mud Lake sediments. This approach derives from wood ash experiments completed over the last year. We may also wish to further explore the possibility of direct treatment of Armanda Lake, although we recognize the sensitivity and additional issues associated with working outside of the defined South Bay "waste management area".

    - **Mud Lake Outflow Wetland Restoration (Biopolishing)**: We are investigating methods to enhance and "restore" (post-beaver activity) the muskeg in the vicinity of the Mud Lake outflow. If we can create conditions similar to those at the Boomerang Lake outflow, then we will greatly improve on biological polishing capacity in the Mud Lake system.

    - **Introduction of Brush Cuttings (Biopolishing):** We will be making arrangements to introduce brush cuttings (for periphyton colonization) into Mud Lake, to further augment biological polishing in that system. This has proven to be effective in Boomerang Lake.

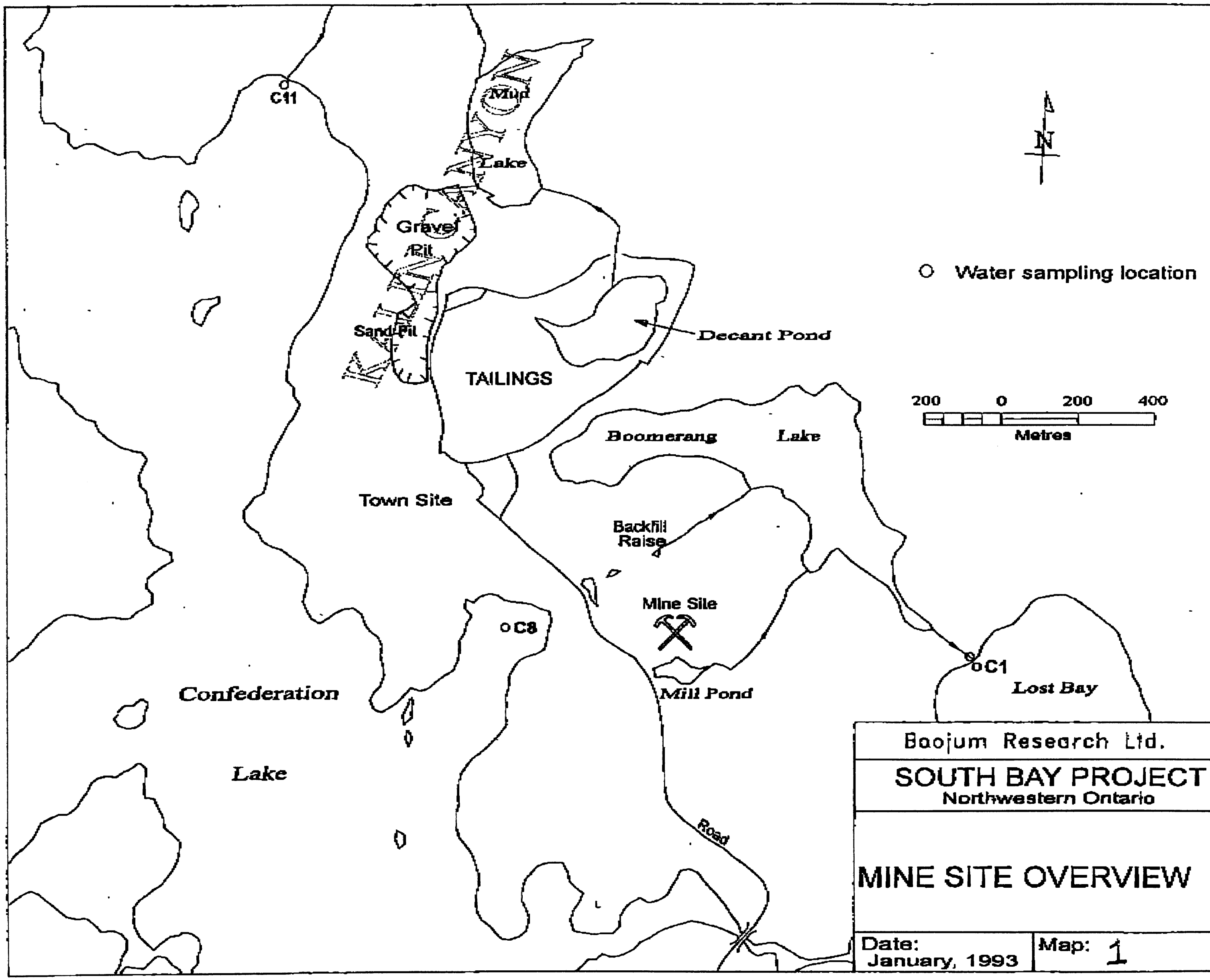
- **Reduction in Tailing Permeability:** Twenty-one tonnes of phosphate rock were recently applied to the tailing surface in areas having the highest infiltration rates (based on the 3D model). This should precipitate iron in these high-infiltration areas. Over time, this should "seal" the tailing surface locally and, significantly reduce infiltration. The 3D model suggests that sealing the tailings surface would result in a 40% reduction in contaminated groundwater flow in the Kalin Canyon.

- **Conventional "Treatment" in Kalin Canyon:** Worst case, we could opt for more-conventional treatment of part or all of the contaminated flow in the Kalin Canyon. In the short term, this could involve caustic injection directly into the Kalin Canyon. Optimal locations would be in the vicinity of piezometers M73, M79, M81, and M34. Equipment and "experience" with this technique is readily available commercially and could be mobilized on relatively short notice. This would "buy time" to address the feasibility and relative cost of other conventional options.

Conclusion and Request for Support:

- We feel that “insitu seepage treatment” (bioremediation) as described is a viable concept, and we are looking for the Ministries’ consent to proceed with scale-up at the South Bay site as soon as possible. All activity would be confined to the defined “waste management area” unless otherwise sanctioned by the Ministries.

DFP: 16-05-2001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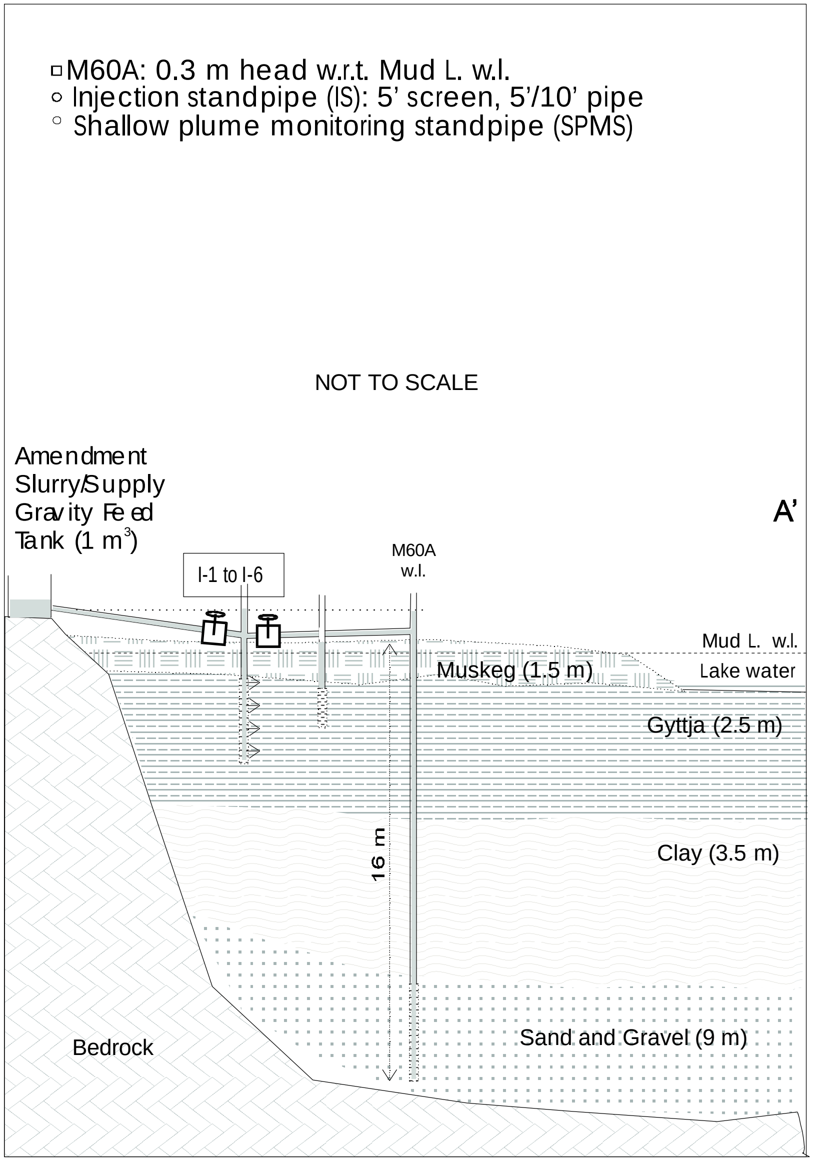

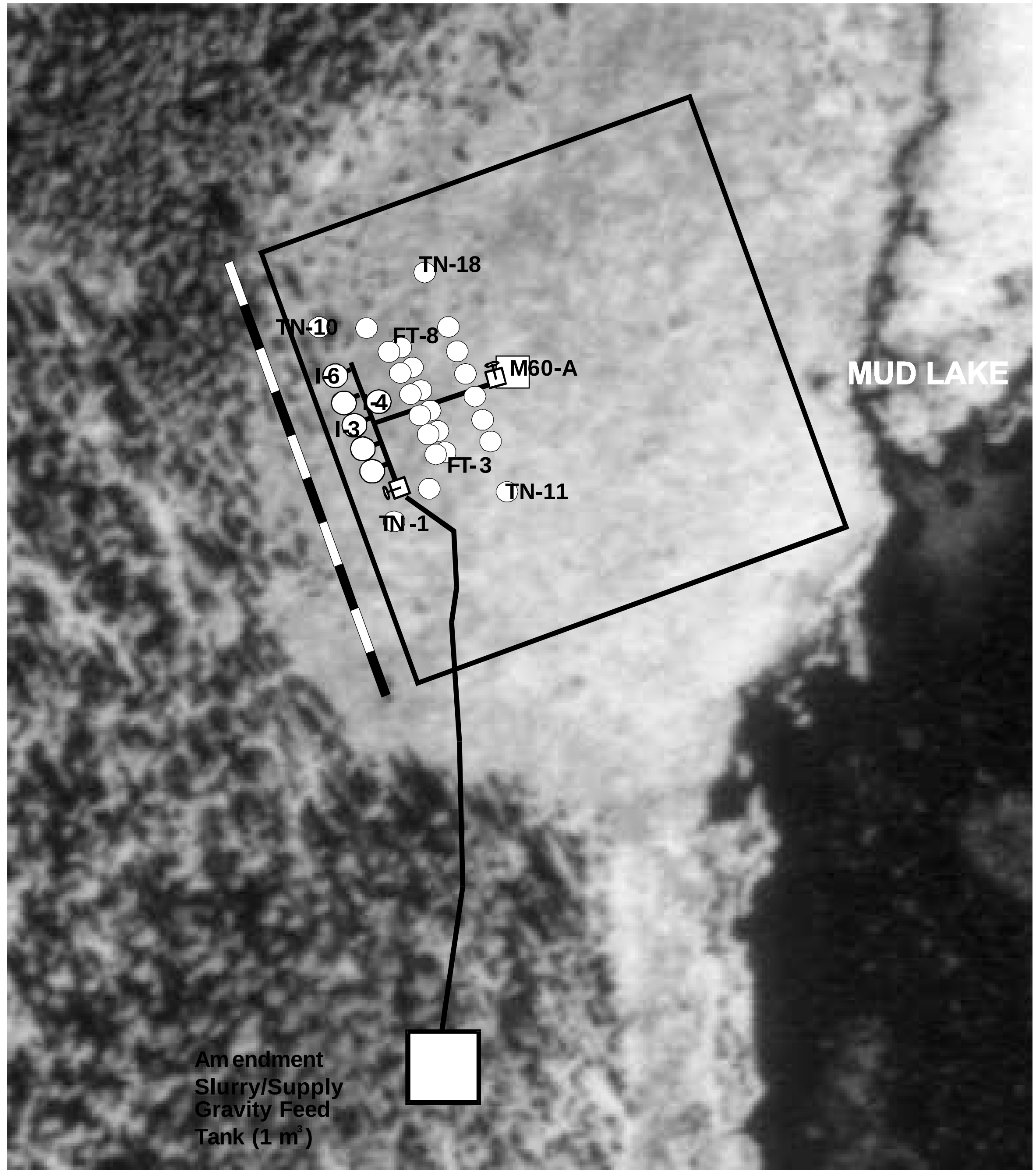

Schematic 1: Lay-out of M60A passive injection system installed in July, 2000 on region of floating muskeg adjacent to Mud Lake.