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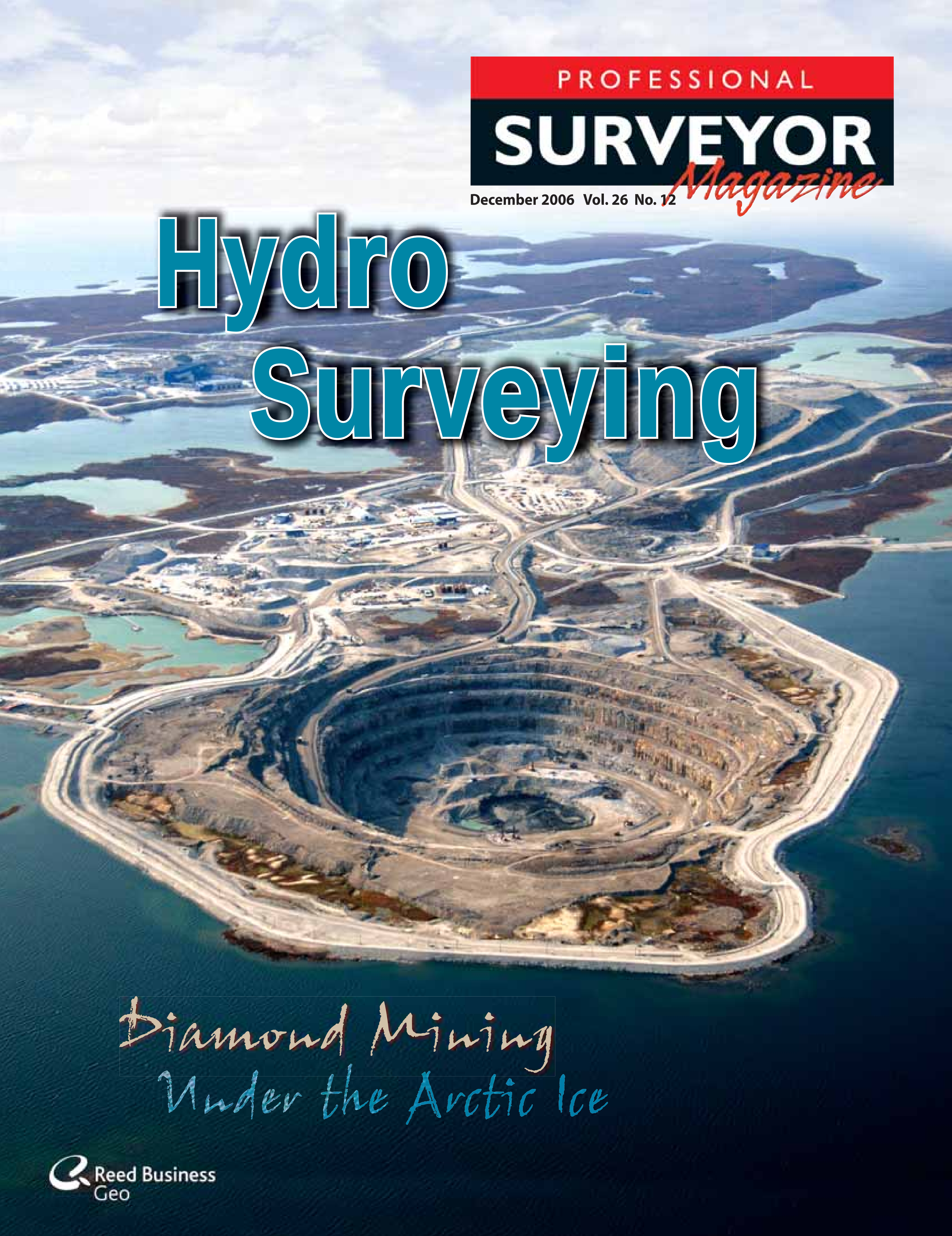
Hydro Surveying



Diamond Mining Under the Arctic Ice

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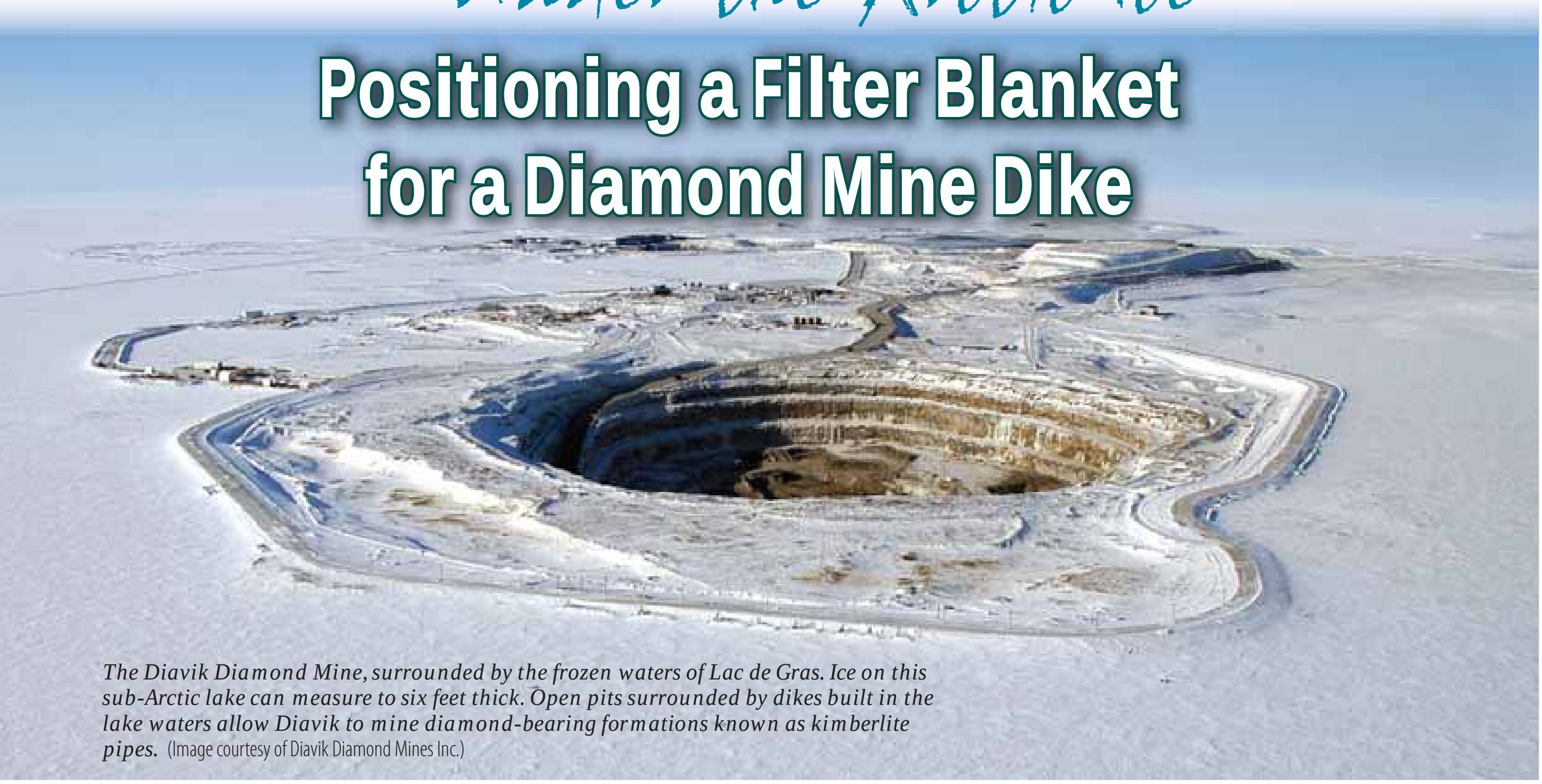
FEATURE

Mining for Diamonds Under the Arctic Ice

Positioning a Filter Blanket for a Diamond Mine Dike



The Diavik Diamond Mine, surrounded by the frozen waters of Lac de Gras. Ice on this sub-Arctic lake can measure to six feet thick. Open pits surrounded by dikes built in the lake waters allow Diavik to mine diamond-bearing formations known as kimberlite pipes. (Image courtesy of Diavik Diamond Mines Inc.)

Tim Cawood, PLS

It was snowing the day I arrived at the Diavik Diamond Mine… on June 23, 2001. I was tired and cold after a 3,500-mile, 36-hour trip that started in Wilmington, North Carolina, and for me ended 300 kilometers northeast of Yellowknife, the capital of Canada's Northwest Territories. For my luggage, the trip ended in Toronto.

The Diavik Diamond Mine sits on a 20-square-kilometer island in Lac de Gras (French for Fat Lake). The diamonds are located in kimberlite pipes found beneath the bottom of Lac de Gras, which is 90 feet deep in some areas. Diamond production began at Diavik in January 2003, and the estimated mine life is 16 to 22 years. Approximately eight million carats of diamonds are produced annually.

The gently rolling tundra surrounding the mine is called the Barren Lands. Year round, the mine is accessible only by air. In winter, ice roads are built across the island's tundra to transport supplies and equipment.

Water diversion structures called dikes temporarily hold back the waters of Lac de Gras to allow mining. The dikes surround the kimberlite pipes, and the water is pumped out. The dike design calls for a two-meter thick filter blanket of small-diameter rock to be placed on the lake bed; the dike is then built upon this filter blanket. The rock must be distributed 1) uniformly, to assure proper functionality, 2) accurately, due to the high cost of producing the small rock on-site, and 3) expeditiously, before the lake becomes covered with ice. Ice forms in mid-October and doesn't thaw until July.

I arrived at the Diavik Diamond Mine on that snowy "summer" day five years ago to work with Lac de Gras Excavation Inc., the company hired by Diavik Diamond Mine Inc. to build the dikes. The excavation company was charged with placing the filter blanket and having it approved before the lake froze over in October. As a consultant to Lac de Gras Excavation, McKim & Creed, P.A., was responsible for three primary tasks:

1) Install and configure a DGPS positioning system on a crane to help the crane operator place the blanket material on the bottom of the lake quickly and accurately while also tracking when, where and how much material was placed.

2) Set up a hydrographic survey launch to be used by Lac de Gras Excavation and Diavik to inspect the placement of the blanket during operations,

so the crane/barge could complete the project with only one pass. There would be no time to go back to fill any voids.

3) Train the excavation company's surveyors to operate both systems. This included processing, analyzing, and recording the data as well as backup, maintenance, and troubleshooting.

My first day at the mine was spent in an intense and comprehensive safety and orientation program. When I finally lied down that evening around 11:00 p.m. (2:00 a.m. North Carolina time), I wondered, "What in the world have I gotten myself into?" Three weeks later, Lac de Gras Excavation placed the first bucketful of gravel on the bottom of the lake, and I was on my way home. The following October, the filter blanket for the A154 dike was completed, thanks to a lot of hard work from many people working both on- and off-site and 24/7 operations for three straight months.

▲ *This image illustrates how the mine is expected to look at full development in 2015.*
(Image courtesy of Diavik Diamond Mines Inc.)

Task 1: Develop a Positioning System for the Crane

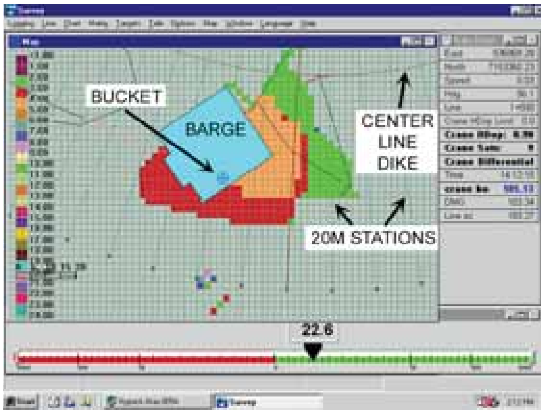
The mechanical system used to place the gravel filter blanket at the bottom of the lake consisted of a Manitowoc 2250 crane centered on a 90- x 90-foot flexi-float barge. The bucket used to place the material on the lake bottom held eight cubic yards of material. On the back of the barge, a modular office housed the computer, radios, three GPS processor/receivers, and a survey technician. From this venue, the technician monitored the work of the crane and tracked material placement and location, as well as quantities placed. A real-time heads-up display in the crane house consisted of a ruggidized color monitor with a Sunbrite display mounted above the crane's controls at about eye level. A simple thumb toggle switch was attached to the operator's dump level.

Since there are no continuously operating reference stations (CORS) or GPS beacons available for differential corrections in the Northwest Territories, we had to establish our own base station: a semi-permanent setup powered on-shore from the island's main power generating system. A NovAtel RT-20 receiver was set up on a known point centrally located to the project area, and a Freewave 900 MHz radio was used to transmit differential corrections to the barge and the survey launch. The GPS receiver was housed in a large shipping container. The base station ran 24/7 for the duration of the project. A RTK float solution was used for positioning to provide submeter to decimeter accuracy.

Three additional GPS units were placed on the crane/barge. Two units were mounted at opposite ends of the module office, one to provide the XY position of the crane/barge while the second to provide the rotational orientation of the barge. This was done by referencing the second GPS unit to the first using HYPACK software and the kinematicgyro device setup. The barge was then measured, using the location GPS unit No. 1 antenna as the origin. Each corner of the barge was then referenced to the origin by x and y offsets using HYPACK Shape Editor. Then the barge could be shown on the operator's monitor in real time and be accurate, to scale, and at the correct rotation.

Configured to be independent of the other two units on the barge, the third GPS unit was mounted on top of the crane boom with a weighted custom gimbaled mount. This allowed the crane operator to see the precise location of his bucket at all times. Maxstream data modems were used on all three GPS units in lieu of cables.

Once the system was configured and operational, the contractor's land-based survey crews, who were responsible for the construction layout for the mine site, were brought aboard the barge for training. With the barge spudded down in place, we had them locate the corners of the barge and the bucket as it hung straight down from the boom. This was done with a totally separate RTKGPS system, which included an independent base station and allowed us to check the accuracy and quality of our system.



◀ ***Shown is the crane operator's display with a 2.6-meter bucket pattern. Here, the bucket is resting on the barge. The different colored squares represent the number of loads of material dropped inside each individual square. The crane operator can zoom in or out as needed.***

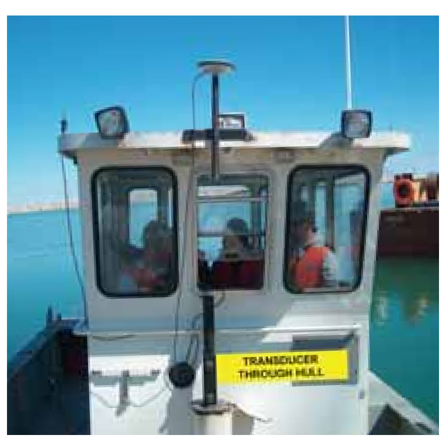
To help the crane operators place the gravel, we loaded background files, line files, and bucket patterns into HYPACK and displayed them on the crane operator's and survey technician's monitors. The background files included the limits of the filter blanket, the center line alignment of the dike, 20 meter x-sectional lines across the dike, and a bucket pattern. In 2001, Jerry Knisley of HYPACK created the "bucket" device for the construction of dike A154. At that time, the device worked with a standard HYPACK matrix. When the A418 dike was built in 2005, HYPACK improved the bucket device by using bucket patterns instead of matrix files. The new and improved version allowed for automatic logging of daily production files and allowable overlap and proved to be more user-friendly.

Task 2: Implement a Hydrographic Surveying System

The simple hydrographic system consisted of DGPS with a float RTK solution, a 200 kHz Odom Echotrac echosounder, and HYPACK Version 4.3 Gold. An Odom Digabar was used to measure the speed of sound through water and was verified periodically with the old reliable bar check. Although the float RTK solution provided us with a z value, we did not use it; instead, we read water levels from a staff before and after each survey. Because the area was fairly protected from wind and waves, the system did not include a motion sensor to measure roll and pitch.

The survey vessel was a 30-foot Steel-hulled craft with twin outboards. The transducer was mounted through a circular shaft located amidships and could be retracted into the hull to protect it against boulders when not in use. When the transducer was lowered, it was pinned in place to ensure the draft (the distance between the transducer and the water surface) remained constant for each survey.

The GPS antenna was mounted directly above the transducer. This was the optimal installation and eliminated the need to compensate for horizontal offsets between the soundings at the transducer and the position from the GPS.



Kevin Shaver *of McKim & Creed trained Lac de Gras Excavation Surveyor Ed Knox and his team to steer survey lines.*

Minimizing Environmental Impact

According to officials at Diavik Diamond Mines, Inc., the company is taking extensive measures to minimize environmental impact at the Diavik Diamond Mine. This all comes as part of their ISO-certified environmental monitoring system.

When the dikes are closed, all the fish are captured and relocated into the main lake. When the mining is complete, the open pits will be flooded, and there will be no net loss of fish habitat. To protect the waters of Lac de Gras during dike construction, a silt curtain was suspended in the lake to redirect silt to the lake bed and ensure Diavik stayed within total suspended solids limits. For dewatering one of the pools, clean clear water was pumped over the dike to the lake, while silty water was pumped to on-land sedimentation areas, then through the mine's water treatment plant, and then returned to the lake.

Even the scupper and bilge discharge on the survey boat were welded closed so there could be no accidental discharge of bilge water into the lake. Rainwater that accumulated in the boat was periodically pumped into a container and disposed of on land.

—Tom Gibson, Editor

Task 3: Pre-Placement Hydrographic Surveying and Training

Prior to the filter blanket placement, the entire dike alignment had to be surveyed so the blanket limits could be determined using the design cross-section template. The deeper the water, the wider the blanket footprint would be. Twenty meter lines were surveyed radial to the dike center line. The data was processed and given to Diavik engineers.

Without the intense pressures of meeting production goals, this pre-construction conditions survey was the opportune time to train the construction crew. Specifications called for a two-meter maximum offline distance from the survey line allowed for verification surveys, so a considerable amount of time was spent learning to steer the survey lines using HYPACK. Data processing and data reduction were also taught during the pre-construction survey.

When laying the filter blanket, the crane/barge was positioned by a

▲ *In operation, the crane/barge setup (inset) has material barges flanking it and an eight-cubic-yard bucket (right) for placing gravel to form the dikes.* (Image courtesy of Diavik Diamond Mines Inc.)

tugboat that received instructions from the surveyor in the modular office as he monitored his graphical display of the barge and project area. Once in position, the barge spudded down and the crane operator went to work.

Material barges, each with a large front loader, were located on either side of the crane barge. The crane operator swung the empty bucket onto one of the material barges. Two scoops of material from the front end loader were dumped into the bucket. Then, using the graphical display on the heads-up monitor, the crane operator swung the bucket into one of the 2.6-meter bucket pattern squares and released the load, at the same time pushing the thumb toggle button attached to the dump lever.

The square in which the bucket was located at the moment the operator pushed the button turned a color on the operator's display. The time of the drop and the drop number in each square were recorded. The procedure was repeated until all the squares were colored.

When the operator dropped a second load into a square, the square changed to a different color, and again the time was recorded on the computer. It usually took two buckets dropped into each square to achieve the required two-meter filter blanket depth. When the crane operator filled all the squares he could reach from his current position, he called the survey boat to perform the inspection/verification surveys.

The size of the bucket pattern used for placing the gravel was 2.6 x 2.6 meters. This was not randomly decided; rather, it was determined after days of testing on dry ground. Prior to the construction of the A154 dike in 2001, load after load of blanket material was dropped on dry land from the eight-cubic-yard bucket. Each time, the spread pattern of the dropped load was measured. Then the load was scooped up and dropped again. Drops were performed from different heights and using slightly different methods, over and over, until the Lac de Gras engineers determined which combination of procedures produced the most consistent distribution of material. This procedure was well documented and used for both the A154 and A418 blanket placements. Each bucket load contained the same amount of gravel, and the load was dropped from the same height.

When a section of the blanket was complete, the crane/barge operator called the survey launch, which ran survey lines across the area to inspect and verify that the blanket had been satisfactorily placed. The computer display on the survey launch compared the newly-placed blanket material with the designed two-meter blanket template, which was determined from the pre-placement survey. This allowed for real time verification.

Onboard with the surveyors was an independent owner representative who signed off on each line that completely filled the design template. When an area was found to be lacking material, the surveyors identified these areas and radioed the coordinates to the survey technician in the crane/barge modular office. The technician entered the coordinates in the crane operator's system as targets, and the operator would place additional material in the target area. Then the survey launch ran the line again for inspection and verification. The whole process usually took less than 30 minutes. Over time, as the operators grew accustomed to what was needed to completely fill the template, very few areas required additional material after the first placement.

In the spring of 2005, McKim & Creed received the call that Diavik was ready to start construction on the second dike, A418, and wanted our assistance. For this trip, I brought some help: Kevin Shaver, our hydrographic survey supervisor. Kevin stayed on the site for three weeks after the system was up and running to provide training and support. As for me, I'm beginning to enjoy snowball fights in the summer.

Tim Cawood, *PLS, is vice president and survey manager in the Wilmington, North Carolina, office of McKim & Creed, P.A., an engineering and surveying firm. He is an ACSM-certified Hydrographer and oversees McKim & Creed's geomatics operations throughout North Carolina, South Carolina, and Virginia.*