MANAGING THE LARGE-SCALE RECLAMATION MONITORING NETWORK AT SYNCRUDE CANADA LTD.[1]

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Abstract. Syncrude Canada Ltd. (Syncrude) operates the Mildred Lake mine, one of the world's largest operating mines, situated in the Athabasca Oil Sands Region of northeastern Alberta. This region will produce more than 50% of Canada's oil supply within the next ten years with Syncrude alone supplying 20% of the nation's oil. It is estimated that more than 21,000 ha of boreal forest will require reclamation as a result of large tracts of land disturbed during operations. Oil sand operators receive operating licenses from the provincial government based on achievable closure and reclamation plans, and the ability to demonstrate successful reclamation is a competitive advantage in a region where limits on development due to cumulative environmental impacts are a reality.

Monitoring the performance of field trials is commonly performed at mine sites to guide development of, and build support for, final reclamation closure. The objective of this paper is to allow mine operators to understand "real" costs associated with reclamation monitoring. Once reclamation has been completed, monitoring may be continued to document success in an effort to gain bond release. Mine sites typically utilize automated data acquisition systems to the greatest extent because of reduced labor requirement. However, due to the variety of data collected, the differences in cover and waste materials, and the inevitable need for manual intervention and monitoring, the effort required to install and maintain a network of data acquisition systems can be significant. At the beginning of the 2005 field season, Syncrude operated a network of 27 automated data acquisition systems that collect surface runoff, meteorological, and *in situ* soil data to track the water and salt balance of reclaimed areas. This paper describes the development of Syncrude's integrated watershed reclamation monitoring system, and the effort, time, and costs associated with maintaining the system.

Additional Key Words: Mine Closure, Monitoring Cost.

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Introduction

Site Description

Syncrude Canada Ltd. (Syncrude) operates one of the largest mines in the world, the Mildred Lake mine. Located north of Fort McMurray, Alberta (see Fig. 1) in the Athabasca Oil Sands Region of the boreal forest, the Mildred Lake mine had a total footprint of 17,162 ha at the end of 2004. The "ore" is oil sand, a mixture of sand and bitumen. A generalized stratigraphy working up from the oil sand is: saline sodic shale, clay till, and muskeg or peat supporting the forest. Till and peat are the primary reclamation materials. Syncrude performs contemporaneous reclamation and has reclaimed 5,271 ha through 2004. The major structures that are reclaimed are made of shale and tailings sand.

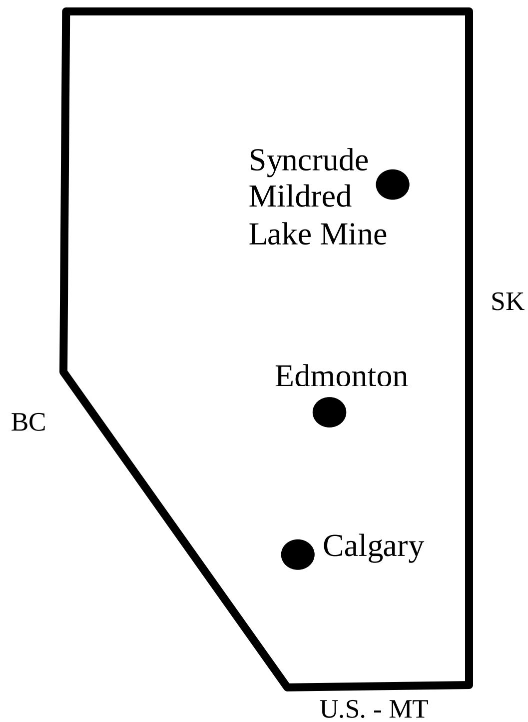

Figure 1. The Syncrude Mildred Lake Mine location in Alberta, Canada.

Reclamation History

Intensive reclamation research began at Syncrude in 1999 with the instrumentation of the reclaimed 30 Dump, now known as the South Bison Hills, a former shale overburden pile. Four soil moisture monitoring stations, four weirs, a meteorological station and a Bowen Ratio evapotranspiration station were installed. The weirs allowed for the measurement of individual runoff from each of three main reclamation trials. The four soil moisture stations allow for the comparison of varying cover thicknesses, as well as the number of layers in the cover system.

Syncrude has developed reclamation research, as well as their monitoring approach, with a focus on constructing one complete watershed within each of the reclaimed landforms at the site. The rationale for a "watershed" research and monitoring approach is: (i) watersheds are the major building block of landscapes; (ii) the majority of questions asked about landscape performance can be addressed at the watershed scale (iii), the watershed can encompass the range of target ecosites desired for the particular cover material; (iv) a watershed monitoring approach allows for "real" measurement of essential fluxes, balances, and patterns (e.g. water, gas, contaminants of concern); (v) a watershed approach demands thought regarding the interactions between all aspects influencing reclamation performance and design; and (vi) watersheds are manageable in size, while still being able to use the results to scale up to the macro or landscape scale required for final cover system design, and include sufficient complexity so that the complex interactions between fluxes are represented (Qualizza, 2004 and Barbour *et al.*, 2004).

Since 1999, the research has accelerated. Syncrude is now partnered with at least five major Canadian universities in its research effort; over 15 students have completed advanced degrees with the research they have conducted with Syncrude. At the end of 2003, Syncrude had 20 automated field stations; as students graduated, some of the stations, while still supporting research, were no longer the primary focus of a thesis or dissertation. With additional stations planned and a need to continue data collection from existing stations, Syncrude created an on-site contractor position to manage the automated field stations. This position would maintain and install stations, and download, reduce, manage and perform quality control (QC) checks on the data.

Reclamation monitoring is not unique to Syncrude and is done for a variety of reasons. Monitoring may be required by regulators (Phillip and Myers, 2003). Monitoring can provide the basis to choose a reclamation prescription and also supplies data for calibration of modeling. Monitoring also allows for the demonstration of final reclamation success, which is likely a requirement of bond and/or regulatory release. This paper discusses the experience of installing and maintaining a large network of automated field stations at Syncrude.

Syncrude obtains its monitoring equipment from Canadian distributors; however, due to conference venue, all equipment costs presented are in U.S. currency, from U.S. sourced 2007 quotes. Costs exclude labor, shipping and tax.

Monitoring Equipment Installation

Numerous instruments have been installed at various Syncrude study areas to better understand each site's water balance. Instrumentation may be manual, or automated with the use of a data acquisition system, or datalogger. Below is a summary of the most common instrumentation found in the Syncrude reclaimed areas: three classes of automated instrumentation stations, and two types of manual instruments. Installation assumes two workers.

Meteorological Station

The meteorological (met) station is used to measure precipitation, wind speed, net radiation, air temperature and relative humidity. The last four parameters can be used in the Penman Equation to calculate potential evaporation (Penman, 1948). The standard met station installation requires approximately 12 hours. All of the sensors are located on a station tripod except the tipping bucket, which is installed on its own post approximately 7 m from the tripod. See Table 1 for met station equipment and costs.

TABLE 1. Syncrude Meteorological Station Instruments, Costs, and Installation Time

Parameter	Instrument[1]	Cost
Wind Speed & Direction	RMY 05103	$954
Net Radiation	NR Lite	$1,635
Air Temperature & Relative Humidity	HMP45C Series	$551
Precipitation	TE525WS	$400
	Total Equipment Install Cost[2]	$7,000
	Total Install Time	12 hrs

1 All instruments and station equipment supplied by Campbell Scientific Canada.
2 Includes datalogger, solar panel, battery, enclosure box, tripod and miscellaneous items.

Precipitation as snowfall is not monitored during the winter months. Snowfall monitoring was attempted with the use of snow adapters for the tipping buckets; however, the effort to keep the eight adapters across the site full of antifreeze was judged to be too intensive and was discontinued. In addition, the magnitude of an individual snowfall is not important for a water balance analysis in northeastern Alberta. Wind and sublimation will reduce the snow pack before spring melt; therefore, snow surveys are performed on the watersheds immediately prior to spring melt to determine the water equivalent that will be released into the system.

Syncrude maintains a network of eight met stations. Only two of the met stations are stand alone units; more commonly a met station is pared with a soil moisture monitoring station, which eliminates duplicate equipment such as a data logger, solar panel and battery. Combining the two stations reduces equipment costs by approximately $2,500.

Soil Moisture Monitoring Station

Soil moisture monitoring stations are used to track the change in water storage within the various evapotranspirative covers. In this paper the term "soil" is used loosely and includes both reclamation and waste material. The stations typically consist of eight, paired volumetric water content and matric suction sensors at various depths in the cover and waste material. Installation of a soil station requires approximately 16 hours. A backhoe and operator is needed for approximately 8 hours, although much of this time is standby. During installation individual soil samples are collected from the profile to determine *in situ* water content, dry density, paste pH, and paste conductivity. Bulk soil samples of the reclamation materials are also collected for development (in the laboratory) of material specific calibration curves for the *in situ* volumetric water content sensors.

Eight soil suction and volumetric water content sensors are paired to provide a detailed study of the processes affecting the water balance. Laboratory and field conditions are typically quite different, and the pairing of the two sensor types allows for development of field soil-water characteristic curves for each of the different reclamation materials, which are essential for developing field calibrated predictive models.

Permanent partially walled "access boxes" that could be sealed from atmospheric conditions were built into the ground when the original soil moisture monitoring stations were installed in 1999, allowing access to the soil profile during installation, but also in the future. These boxes provided the advantage of collecting a soil sample to determine volumetric water content as a check on sensor readings over time; in addition, if a sensor failed it could be easily removed and replaced. However, special effort was required to conduct these activities and maintain the access boxes due to confined space issues. As the sensors demonstrated their robustness, these boxes were discontinued. Currently, the soil sensors are installed by excavating a trench with a backhoe, using a mobile access box to address confined spaces issues when required, installing the sensors, removing the mobile access box, and backfilling the trench.

The volumetric water content and matric suction sensors must be calibrated, the former to field conditions. The water content sensors are calibrated to *in situ* conditions (reclamation material, density, pore-water conductivity, etc.) Each matric suction sensor requires individual calibration due to the manner in which they are manufactured. Calibration of the matric suction sensors is completed in the laboratory using modified pressure plate apparatus, and do not require material specific relationships because matric suction is a stress state variable. Sensor calibration costs for eight 229 soil suction sensors and three soil types are approximately $3,500. See Table 2 for soil station costs.

TABLE 2. Syncrude Soil Station Instruments, Costs, and Install Time

Parameter	Instrument[1]	Cost
Soil Suction and Temperature	229 (eight)	$1,104
Soil Volumetric Water Content	CS616 (eight)	$1,496
	Total Equipment Install Cost[2]	$10,500
	Total Install Time	16 hrs

1 All instruments and station equipment supplied by Campbell Scientific Canada.

2 Includes datalogger, solar panel, battery, enclosure box, sensor calibration, two multiplexers, and miscellaneous items.

Weir Station

Runoff is measured at several locations using 60 and 90-degree zero-height v-notch weirs. After large precipitation events during the summer (usually greater than 25 mm) some weirs will flow, but usually only for a few days. The main runoff event occurs during the spring melt and lasts for approximately 2 weeks. Because spring melt nighttime temperatures can drop back to well below freezing, the weirs are enclosed within insulated huts that are outfitted with propane heaters in an effort to minimize development of ice within and around the weir.

Calculating the flow through the weir requires the measurement of the water height behind the v-notch; this measurement is conducted using a Campbell Scientific SR50 Sonic Ranger, an instrument that measures distance with an ultrasonic pulse. The air temperature within the weir hut is measured to correct the sensor response and provide a representative water level measurement. The electrical conductivity (EC) and temperature of the runoff water is also measured. The EC reading will become negative when water freezes; therefore, the EC and temperature data also helps to reveal whether the water level measurement is flowing water or ice.

Weir instrumentation costs are shown in Table 3. The size of a weir, or other flow measurement devices, is dependent on predicted flow. The materials used to construct a weir are dependent on water chemistry and available resources. Because of this site-specific variability the cost of the weir itself is excluded, focusing instead on only the installed automated data acquisition system cost.

TABLE 3. Syncrude Weir Station Instruments, Costs, and Install Time

Parameter	Instrument[1]	Cost
Water height	SR50 Sonic Ranger	$1,109
Air temperature	107 temperature probe	$ 96
Water Temperature and Electrical Conductivity	CS547A probe	$357
	Total Equipment Install Cost[2]	$3,700
	Total Install Time[3]	8 hrs

1 All instruments and station equipment supplied by Campbell Scientific Canada.
2 Includes datalogger, solar panel, battery, CS547A interface, enclosure box, and miscellaneous items. The weir capital cost is excluded.
3 Time to install the weir structure itself is excluded.

Diviner 2000 Portable Moisture Probe

The Diviner 2000 volumetric water content measurement system, manufactured by Sentek, is used extensively to provide an understanding of spatial soil moisture characteristics. The Diviner 2000 system consists of a mobile volumetric water content capacitance sensor positioned on the end of a rod; a portable datalogger / display unit is connected to the opposite end of the rod. The datalogger will store profile data for up to 99 access tubes. The sensor is inserted into specially designed access tubes installed in the ground. In the time it takes to move the sensor down the length of the tube and back out, the unit has collected volumetric water content data at 10 cm intervals.

While a soil station provides a detailed view of conditions at one location, the Diviner 2000 system provides a broad view of conditions across a site when the access tubes are installed at key locations across the watershed. The Diviner 2000 allows for the investigation or confirmation of water content differences caused by slope length, slope aspect, microtopography, in situ density, vegetation, slope aspect, among a variety of other factors. A limitation of the Diviner 2000 is the depth constraint of a 1.6 m rod length; however, a modified and portable Sentek sensor capable of measuring in situ water content at depths up to 50 m has been field tested.

The access tubes required for the Diviner 2000 are installed with a Sentek-supplied kit of augering equipment and sealed at either end with a plug and cap. Depending on cover or waste material rockiness, installation of one access tube takes up to one hour. Costs associated with installing a simple Diviner 2000 system are shown in Table 4.

TABLE 4. Diviner Instruments, Costs, and Install Time

Component[1]	Cost
Set of 4 Access Tubes with caps and bungs	$246
Diviner probe and display	$3,300
Total Equipment Install Cost[2]	$3,546
Total Install Time[3]	4 hrs

1 Manufactured by Sentek, supplied by O'Kane Consultants.
2 Includes miscellaneous items. The cost of installation kit, $2,240 is excluded. The install kit is usually contractor equipment.
3 Assumes install of all 4 access tubes.

Vacuum Lysimeters

Vacuum lysimeter soil water samplers are used to measure soil pore-water chemistry. The vacuum lysimeters, manufactured by Soil Moisture, are PVC tubes with a ceramic tip. The top is sealed, and hoses exit the tube. One hose extends to the bottom of the lysimeter, the other to just inside the tube. A vacuum is created within the lysimeter that is greater than the negative pore-water pressure of the surrounding reclamation material, causing pore-water to migrate into the tube for subsequent collection and analysis.

Pore-water chemistry can provide key information on such issues as nutrient levels and the upward migration of salts from the underlying waste material into the reclamation material. Vacuum lysimeter nests are utilized, with samples collected from depths approximately 30 and 60 cm, and 90 or 120 cm. The deepest lysimeter usually terminates in the waste material. For statistical purposes, nests are installed in triplicate. Nests have been installed to compare different cover types or to investigate the differences on one cover type along a slope.

Installation of the vacuum lysimeters is completed by augering a hole to the required depth. A small amount of silica flour slurry is added to the bottom of the hole to support a strong seal between the ceramic tip and the soil. The installation costs of vacuum lysimeters are shown in Table 5. The lysimeters are modified with a permanent cap, hose fittings, and inline valves to ensure that the vacuum created is maintained for a sufficient time frame to allow for migration of soil pore-water into the tube.

TABLE 5. Vacuum Lysimeter Instruments, Costs, and Install Time

Component[1]	Cost
1900L12-B02M2 (30 cm)	$233 [2]
1900L24-B02M2 (60 cm)	$236 [2]
1900L36-B02M2 (90 cm)	$240 [2]
1900L48-B02M2 (120 cm)	$261 [2]
2005G2 Hand vacuum pump	$150
Total Equipment Install Cost[3]	$2,340
Total Install Time[4]	8 hrs

1 Manufactured by Soil Moisture, modified by O'Kane Consultants.
2 Base component cost plus modification time and materials.
3 Includes lysimeter modification, miscellaneous items and hand pump. Assumes installation of three nests of three vacuum lysimeters each (30, 60, and 120 cm depths).
4 Assumes installation of nine vacuum lysimeters.

Data Collection and Management

Once installed, data or samples must be collected from the stations or instruments. The collection frequency may be dependent on several conditions (study requirements, regulatory requirements, weather conditions, the status of the monitoring site, season of the year, or age of the instruments). Depending on a station's configuration, the datalogger is capable of storing over one year of data, both from a memory and reliability standpoint. However, if an error is to occur, either with a datalogger, sensor or system component, it is beneficial to know as soon as possible. The longer the time between downloading a datalogger, the more risk is assumed.

At Syncrude, the automated data acquisition systems (met, soil and weir stations) are downloaded twice per month from May through September (a typical field season), and once per month the remainder. Regardless of the time of year, downloading the 27 automated systems require approximately 20 hours per month. The main cluster of 14 automated stations, located within approximately 57 hectares of the South Hills research area, can be downloaded in 2 – 2.5 hours if there are minimal maintenance issues.

The majority of automated stations are downloaded with a storage module and keypad/display. While a laptop computer or PDA can be used, the storage module is preferred for its small size and rugged construction. Battery failure in freezing conditions is not a concern because the storage module and keypad/display use the datalogger's power supply. The keypad/display allows a user to view current sensor readings, set the datalogger clock, and view and change the datalogger program.

Met and soil stations require minimum time to download, approximately five minutes per station. During this time the data logger clock is checked and modified if necessary. As a first check on the sensors, the current readings are evaluated. The humidity level of the enclosure is noted and desiccant packs are changed as required. The solar panel is cleaned if necessary. At a met station the tipping bucket rain gauge is checked for any obstruction, and dust may be cleaned off the net radiometer.

Downloading of a weir's automated data acquisition system is similar to a met or soil station; however, depending on field conditions the time spent at a weir station ranges from five to 45 minutes. Any ice is chipped out from underneath the SR50 and the weir v-notch. The automated water level reading is compared to a manual measurement; if there is a significant difference between the two, the SR50's datum is changed in the data logger program. A water sample may be collected if there is flow.

Syncrude's weir monitoring occurs almost exclusively during the spring melt. During the 2005 spring melt Syncrude maintained 8 weirs in the reclaimed areas. During this four-week period, the weirs were visited twice a day, Monday through Friday. Weekend coverage of once per day was conducted on the first two weekends. The weirs are also checked after significant rain events, but runoff flow occurs infrequently during the summer as a result of the high moisture holding capacity of the most common top layer cover material, peat.

The Diviner 2000 system is designed for easy downloads. From start to finish an access tube can be read within two minutes. The Diviner access tubes are downloaded once a week from May to October.

Putting a vacuum on nine vacuum lysimeters requires approximately 60 minutes. Collecting pore water samples from the nine lysimeters requires approximately one hour. By mid-summer the number of lysimeters that produce a sample decreases as the cover material dries out. At this point, collection of a pore-water sample is attempted only after significant rainfall.

Once downloaded from a datalogger, data must be transferred from the storage module to a personal computer. Each data file is opened, renamed, and cursory data review is performed to look for any readings that may indicate a problem sensor.

Quarterly data QC requires 80 to 120 hours. Stations with active field involvement, such as weirs, require comparisons and adjustments with field notes and are the most time consuming to QC. Finalized data is entered into a database and distributed to researchers.

Equipment Maintenance

Station maintenance and instrument calibration are performed at the frequency recommended by Campbell Scientific Canada (CSC). Because Syncrude maintains a large number of meteorological stations, instruments that may more commonly be shipped away for maintenance and calibration are instead largely serviced on site. While this has required the purchase of special equipment (to calibrate the 05103 wind monitors and the HMP45 series T/RH probes), it minimizes instrument downtime and increases the repairs that can be made in the event of a malfunction.

It is recommended that NR Lites (net radiation) be calibrated every 2 years. To calibrate the NR Lite net radiometers (approximately $500), one NR Lite is sent away to Kipp & Zonen, in the Netherlands for a total of eight weeks. Once returned, this NR Lite becomes the standard to calibrate others on site. NR Lites requiring calibration are co-located with the standard over a period of two days and nights with calm, clear skies. The calibration factor, or multiplier, can then be adjusted so the resulting net radiation equals that of the standard.

During field visits, the NR Lite sensor should be checked for dust and debris and cleaned if necessary. Once a year, a check can be made on the top and bottom sensors during stable atmospheric conditions. The absolute value of the sensor reading with the sensor upside down and right side up should be within 15% of each other (Dolce, 2005).

CSC recommends that the HMP45 series of temperature and relative humidity probes receive annual calibration. The sensor and its radiation shield can be checked occasionally for dirt and cleaned. Campbell Scientific will recalibrate a HMP45 series sensor for $90.

The RM Young 05103 wind monitor has three main components that will eventually need to be replaced. Two of the components (bearings and potentiometer) affect wind direction, while the third (propeller shaft bearings) affects wind speed. At every 1 – 2 years, replacement of the latter costs less than $20.

Precipitation tipping buckets should be calibrated annually. The tipping bucket should be cleaned as needed, leveled, and then made to tip with the addition of 473 ml over a period of at least 45 minutes. The number of tips recorded must match the acceptable amount expected for the given volume.

The recommended calibration period for dataloggers is 3 years and costs $200. For this service the electronics are recertified and internal battery and desiccant pack are replaced.

Most maintenance for the Diviner 2000 access tubes occurs in the spring following snowmelt. Once the ground has thawed and prior to any readings, the access tubes are checked for any internal moisture and dried out if necessary. Small desiccant packs are kept under the cap to avoid condensation of humidity. When measurements are obtained throughout the field season, the probe tip is examined after removal and checked for any moisture; if present, the probe and tube are dried, and the measurement redone.

The vacuum lysimeters require minimal maintenance. Winterizing is the main maintenance activity; to avoid freezing and cracking of the ceramic tip, water and vacuum are removed in the fall.

Equipment Reliability

The purchase and installation of monitoring equipment can be a sizable investment, and as such equipment should be robust and reliable. Caution is required before procuring and installing seemingly less expensive equipment because it can prove to be less robust and thus data capture rates significantly reduced. Syncrude has installed a large number of automated sensors as part of its reclamation research; of those shown in Table 6, 37% are at least seven years old. Examining the success of these sensors provides an indication of the overall robust nature of the automated systems. Table 6 summarizes both the number of common sensors installed each year and the number of those sensors still operational. Of the nine sensor failures, four were a result of environmental damage or human activity.

Out of all the Campbell Scientific data loggers installed for Syncrude reclamation research (23 at the start of the 2005 field season), only one has malfunctioned. A CR10X became unresponsive 3 ½ years after installation; reloading the operating system solved the problem.

Conclusion

Syncrude has implemented a watershed level research approach to reclamation. Due to the large number of automated data acquisition systems and the projected increase in their number, a position was created to manage the systems on site. This position supports the joint research efforts of Syncrude and leading universities by maintaining existing systems, installing new robust systems, calibrating sensors with minimal downtime, and managing the data. The information developed from these systems as critical to closure planning and eventual reclamation certification.

Table 6. Success/failure data on common sensors at Syncrude automated field stations.

Year	229		CS615/616		107	
	Installed	Operating	Installed	Operating	Installed	Operating
1999	32	32	32	32	33	32 [5]
2001	16	15 [1]	16	15 [3]	1	1
2002	8	8	12	9 [4]	2	2
2003	-	-	-	-	1	1
2004	32	31 [2]	32	32	7	7
2005	-	-	5	5	5	5
Total	88	86	97	93	49	48

Year	NR Lite		05103		HMP45 Series	
	Installed	Operating	Installed	Operating	Installed	Operating
1999	-	-	1	1	1	1
2001	2	2	2	2	2	2
2002	1	1	1	1	1	1
2003	1	1	1	1	1	1
2004	3	3 [6]	2	2	2	2
2005	1	1	1	1	1	1
Total	8	8	7	7	7	7

Year	TE525WS		CS247/547		SR50	
	Installed	Operating	Installed	Operating	Installed	Operating
1999	1	1	1	1 [7]	4	4 [7]
2001	2	2	1	1	1	1
2002	1	1	3	3	2	2
2003	2	2	2	2 [8]	1	1
2004	2	2	-	-	2	2
2005	1	1	-	-	-	-
Total	9	9	7	7	10	10

1 Sensor's ceramic tip may have been cracked during installation.
2 Shallowest sensor failed; possibly post-install surface activity cracked sensor.
3 Sensor disconnected; appeared to not switch off, draining the battery.
4 Three sensors provide only intermittent readings in unison. Readings appear correct when present. Source of problem (sensors, multiplexer, or data logger) unknown.
5 Cause of failure unknown.
6 NR Lite deployed over pond replaced after ice heaving over-stressed cable.
7 The CS247 and three of the SR50s were operational when stations were recently decommissioned.
8 Sensor replaced after animal chewed through conduit and cable.

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