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7.7 10160 Part 2
CR-153045 II

HYDROLOGIC DATA RELAY BY SATELLITE
FROM REMOTE AREAS

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(E77-10160) HYDROLOGIC DATA RELAY BY SATELLITE FROM REMOTE AREAS (Department of the Environment, Ottawa) 22 p HC A02/MF A01 CSCL 08H
N77-24555
Unclas
G3/43 00160

Prepared for:

Technical and Scientific Sessions
on Water Resources
World Water Conference
Mar del Plata, Argentina

March 14 to 25, 1977

28190

RECEIVED
MAY 23 1977
SIS/902.6

HYDROLOGIC DATA RELAY BY SATELLITE FROM REMOTE AREAS

R.A. Halliday*

ABSTRACT

Since the launch of Landsat-1 in 1972, experiments have been conducted using satellites to relay hydrologic data from remote areas of Canada. Several satellite systems that could be used for this purpose are now available or will be available soon. All have desirable features and some drawbacks. The potential user must evaluate each system to select the one that best meets local requirements. This paper describes the operation of several systems.

As an example of the types of data that can be relayed and the conditions under which this can take place, the program of one agency, the Water Survey of Canada, is described in some detail. The future plans for satellite data relay are also discussed.

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INTRODUCTION

The collection of hydrologic data in Canada presents many challenges since the country is large (10 000 000 km^2), has a sparce population (23 000 000) and has a severe winter climate. These factors make it difficult to supply data to users on an immediate or "real time" basis as in most parts of the country it is not economically feasible to install conventional telephone or radio telemetry systems. Furthermore, the Water Survey of Canada as the operator of about 80% of Canadian gauging stations is faced with rapidly increasing costs of collecting data in the field. The launching of Landsat-1 (formerly ERTS-1) in 1972 therefore aroused considerable interest.

Landsat-1 carried a data collection system that enabled many users to collect data from any site in North America on a near real time basis. Experiments with satellite data collection at about 200 sites, mainly in the United States of America and Canada, demonstrated the suitability of this technology. Since that time the network has been expanded significantly and other satellite data collection systems have been put into service.

This paper will discuss and compare several satellite systems and will give examples of results obtained in Canada.

SATELLITE DATA COLLECTION SYSTEMS

A satellite data collection system is made up of three elements: a battery operated radio known as a Data Collection Platform (DCP) that is installed at a field site and connected to hydrologic sensors, second, a satellite-carried transponder that receives and retransmits data from DCPs and, third a satellite ground-station that receives, processes and distributes the data. The Landsat and GOES data collection systems are now in operation while the Tiros-N system will be available in 1978. In addition a test of the feasibility of using commercial communications satellites for collection of hydrologic data will be conducted in 1977. These systems are compared in Table one.

The satellites used in data collection are in one of two kinds of orbit: geostationary equatorial or low near polar. (A geostationary orbit is achieved by inserting a satellite into a circular orbit 36 000 km above the equator such that the speed of the spacecraft on its orbital path matches that of the earth's rotation. The satellite then appears to be stationary with respect to a point on the earth's surface. Such orbits are also known as geosynchronous or synchronous orbits.)

Low orbiting spacecraft (at altitudes of 800 to 1200 km) provide global, but intermittent, coverage while geostationary satellites provide continuous coverage of 2/3 of a hemisphere. A disadvantage of geostationary satellites is that in polar or mountainous regions it is not possible to "see" the satellite from the gauging station. For example at latitude 60^{o} the antenna elevation angle must be 22^{o} or less while at Mar del Plata the elevation angle must be about 45^{o}.

Landsat

The Landsat spacecraft that were launched on July 23, 1972 and January 22, 1975 are in sun synchronous, near polar orbits. Both spacecraft orbit the earth at an altitude of 900 km every 103 minutes, crossing the equator southbound at 0942 local solar time. The two orbits, however, are 9 days out of phase. These precise orbits are a requirement of the imaging systems carried by the spacecraft and are not necessary for the data collection system.

The Landsat DCP transmits 64 bits of data along with a platform identification number in a 38 ms burst every 180 s regardless of the position of the satellite. Whenever the satellite is in mutual view of a DCP and a ground-station the message is relayed instantaneously to the ground-station over distances as great as 5000 km. At other times data cannot be relayed. The Landsat system operates on a random access basis using one satellite frequency channel. This means that it is possible for two DCPs to interfere with each other's transmissions. In practice this seldom occurs - it has been computed that over 1000 DCPs could use the same channel without significant data loss.

Because the satellite is sun synchronous, as explained above, it crosses Canada from north to south in the daylight hours but south to north during the night hours. Data may be relayed during the southbound passes of the satellite in the morning and the northbound passes in the evening. Generally data are obtained on 3 or 4 orbits a day although, since the orbits converge at the poles, data from northern Canada have been received on as many as 11 orbits. Usually 10 to 25 transmissions are received, some of which are only 180 s apart.

The USA's National Aeronautics and Space Administration operates ground-stations in Alaska, California and Maryland for receipt of Landsat data. The data are transmitted by landline to a data handling facility at Greenbelt, Md. where they are punched onto computer cards along with the time of receipt and the identification code. These cards along with computer printouts can be mailed to the DCP operator. In addition, data can be made available to users on a near real time basis (within 20 minutes of receipt) by means of teletype lines.

Some users in the USA have installed their own antennas so that they can receive data directly from the satellite. A similar capability is now being added to the Prince Albert Satellite Station which is presently operated by the Canada Centre for Remote Sensing for receipt of Landsat and NOAA imagery. The Landsat ground-stations now in operation or proposed for several countries including Argentina could similarly be upgraded to receive DCP data.

GOES

The Geostationary Operational Environmental Satellite (GOES) system was developed by the USA as its contribution to the World Weather Watch System of geostationary satellites. The GOES system consists of two satellites stationed over the equator at 75^{0} and 135^{0} west longitude and an in-orbit spare midway between these two. SMS-1 and SMS-2, the NASA prototypes of the GOES spacecraft were launched on May 17, 1974 and February 6, 1975 while GOES-1 was launched on October 16, 1975. SMS-1 is now used as the spare. As their contribution to the World Weather Watch, the European Space Agency, the Soviet Union and Japan will operate similar satellites at 0^{0}, 70^{0} east and 140^{0} east longitude by 1978. The satellites will be known as Meteosat, GOMS and GMS respectively.

The GOES data collection system is significantly different than that carried by Landsat. Instead of one frequency channel, the satellite has 183 channels. One hundred of these are for use with satellite interrogated DCPs, 50 for ordered self-timed DCPs and 33 international channels for use during the first international GARP project, an atmospheric research project. Each satellite can relay messages from over 20 000 DCPs.

The DCPs used with the interrogate channels consist of both a receiver and a transmitter. On command from the ground-station, the GOES spacecraft commands the DCP to transmit its data on a specific channel. Each DCP therefore has a unique receive and transmit identification. The DCPs are polled on a schedule but under emergency conditions can be polled much more frequently.

In the case of ordered self-timed channels, the DCP initiates its own transmissions on a predetermined schedule, say a one minute time slot every three hours, on an assigned channel. To meet the scheduling requirements so that no interference with another DCPs transmissions will occur, each DCP must contain a timer accurate to about 1 in 10^6.

Unlike the Landsat data collection system the GOES system can handle messages having various lengths, say up to 2000 bits. By using DCPs having built-in memories it is possible to store data at frequent intervals for transmittal later. Memory units have also been used with Landsat DCPs, but the operation of such memories is a little more complex because of the 64 bit message length.

The USA's National Environmental Satellite Service operates a ground-station at Wallops Island, Va. for receipt of GOES data. The data are then sent by land line to Suitland, Md. where they can be distributed over dial-in 110 baud or 1200 baud circuits or on direct dedicated computer to computer circuits having speeds up to 9600 baud.

As is the case for Landsat, some data users in the US and Canada have installed passive GOES receive sites. These are less complicated than those required for Landsat since there is no need for a tracking antenna. A fixed dish antenna 4 to 5 m in diameter is all that is required.

Tiros-N

Tiros-N is a NASA prototype of a series of operational polar orbiting satellites that will, like GOES, be part of the World Weather Watch. The first satellite will be launched in early 1978 with the second following a few months later. Two spacecraft will be operational at all times. The satellite orbits will be orthogonal near the poles and sun synchronous and will have altitudes of 830 km and 870 km.

The satellites will carry the Argos data collection system designed by the French Centre National d'Etudes Spatiales. The Argos system is similar to that carried by Landsat since it is used with self-timed DCPs on a random access basis. However there are some significant differences.

First, the DCPs transmit at much lower speeds. This enables the computation of the DCP position to an accuracy of 3 to 5 km based on the doppler shift of the incoming message. Thus it will be possible to track the course of buoys, balloons and ice floes.

The Argos system can handle messages varying in length from 32 to 256 bits and these messages can be transmitted at intervals of 60 to 200 s at a rate of 400 baud. Argos is a four channel system and system capacity with low probability of interference should be in the order of 2000 DCPs in view at any one time. A large number of position location platforms in view at the same time will significantly increase interference problems.

It has been calculated that each day data will be retransmitted on about 7 orbits at latitude 0^{o}, 11 orbits at 45^{o} and 28 orbits at 75^{o}. This schedule should meet many requirements of the hydrologic community especially for those nations beyond the equatorial zones. In equatorial nations it would probably be preferable to use geostationary satellites.

The data transmitted by Tiros-N will be tape recorded on the spacecraft and played back when in view of ground-stations operated by NESS at Wallops Island, Va. and Gilmore Creek, Alaska. Data for North America will be distributed by NESS while that for the rest of the world will be distributed by CNES in Toulouse, France. A time delay in data distribution of 2 to 3 hours is expected.

If this delay is unsatisfactory, users may establish their own receive sites to receive the data on a real time basis directly from the satellite via a vhf beacon operating at 136.770 MHz and 137.770 MHz. Such a ground-station would be inexpensive.

Communications Satellites

The three systems described so far all use DCPs that transmit at uhf frequencies of about 401 MHz. Another possibility for hydrologic data relay is the use of existing geostationary commercial communications satellites. Many such satellites, either domestic or international, are now in orbit and their use in the telecommunications industry is steadily expanding. These satellites operate at much higher frequencies (6 GHz) and therefore present some technical problems. For this reason the USA's Comsat General Corporation, the US Geological Survey and Telesat Canada will conduct an experiment in 1977 using the Canadian Anik to relay data from 15 DCPs.

These DCPs will operate on a random access self-timed mode transmitting up to 64 bits of data at the same time at which the data are acquired, that is, as often as every 15 minutes. Since one satellite transponder may handle up to 300 000 DCPs, the chance of two DCP's transmissions interfering is remote. However in an operational system each message would be repeated thereby decreasing the probability of a clash even more.

During the course of the experiment data will be received by Comsat at Southbury, Connecticut and transmitted by a high speed line to the US Geological Survey on a near real time basis. A back-up receive site will be operated in Ottawa, Canada.

COSTS OF SATELLITE DATA RELAY

There are both capital and operating costs associated with a satellite data relay system. These may be divided into sensor costs, DCP costs, space segment costs and data reception and distribution costs. In order to make conversion into other currencies easy, all figures in the following discussion are in USA dollars.

Sensors

Most data collection platforms are designed so that they will accept sensor data in several formats or combinations of formats. Typically, a DCP will accept data in parallel digital, serial digital and analogue forms. The analogue signals from sensors generally must be scaled to a range of 0 to 5 volts although 0 to 1 and -2.5 to +2.5 volt ranges have also been used.

Because of the versatility of the DCPs the additional costs of connecting a DCP to hydrologic sensors is relatively small. The costs generally are costs for cabling and connectors, say $100, and, in the case of analogue sensors, amplifiers to scale the sensor output voltages to the correct level. If an organization operates graphical rather than digital recorders for water level, there is a problem since the levels must be encoded in digital fashion for transmission. The cost of water level encoder may run to $1000.

No additional sensor operating costs are incurred when satellite telemetry is used.

Data Collection Platforms

Data collection platforms have been constructed by several companies but they all consist of a small electronics unit (about 0.01 to 0.02 m^3 volume, 5 kg mass) and a small antenna. (The DCPs that will be used with commercial communications satellites are somewhat larger.) All DCPs are manufactured to exacting specifications and use up-to-date electronic technology. The transmitter characteristics, the length of the message transmitted and the rate at which it is transmitted must all conform to the satellite system requirements. Platforms that can store several hundred bits of data have been constructed. Also, DCPs that can transmit to either of two satellites are in use.

The cost of a DCP varies widely depending on the user's needs and the satellite data collection system used. These costs, which may run from $2000 to over $10 000, have decreased steadily in recent years because of decreased cost of electronic parts. Self-timed, random access DCPs such as those used with Landsat or Tiros-N are the cheapest, self-timed, ordered DCPs are next lowest in cost, interrogatable DCPs are next and finally the DCPs used with communications satellites are most expensive.

The DCPs are easy to install and to connect to sensors.

Typically two persons can install a DCP in an existing gauge house in about two hours. Much of this time is taken up in installing the 50 mm diameter antenna mast. Some agencies have installed masts at several gauging stations where real time data may be required. In this way one person can install a DCP in minutes should the need arise, for example, during a flood.

Data collection platforms will operate in a wide range of environmental conditions and have proved to be trouble-free. Most of the original Landsat DCPs used in Canada have operated for over 4 years without a failure. All units that have failed, with one exception, have been easily repairable by electronic technicians. The only operating cost is that of replacing or recharging the DCP battery. More recently solar battery chargers, which cost less than $200 for a 3.5 W panel, have been used.

Satellite Costs

The satellite data collection systems now in use and those that will be operational in the near future are all carried by multipurpose spacecraft. This means that the characteristics of the satellite may not be ideal for data relay purposes. However, it also means that the persons engaged in collecting hydrologic data have not had to bear any costs associated with the satellite. (In the case of using commercial communications satellites, this is not exactly correct but the cost would be very small in any event.)

As a point of interest, the cost of a system of three dedicated data relay satellites complete with launching costs and ground-station costs has been estimated to be in the order of $20 to $25 million. Such a system could handle data from several thousand DCPs.

Data Reception and Distribution

All operators of satellites having data collection systems operate ground-stations for data reception and distribution. In some cases data users are requested to pay a portion of the data distribution costs. This may consist of teletype or telex charges, costs of computer interfaces and so on. These data distribution costs are small, usually in the order of a few hundred dollars for each DCP for each year.

When users choose to construct and operate their own ground stations, costs become much higher. The cost of constructing a receive site can range from \$40 000 to over \$200 000 depending on the satellite system and the degree of complexity in the ground-station. Since the satellite operator's ground-station can be used for back-up in the event of a malfunction, it is not really necessary to spend a lot of money on redundant components. Some agencies operating less than 30 DCPs have installed their own ground-stations. Others operating several hundred DCPs have not.

Before a user has established a ground-station, the operating costs of the station should also be considered. Persons will be needed to operate the station. Maintenance of mini-computers and related equipment usually is in the order of 10% of the original cost each year.

CANADIAN RESULTS

There are about 3000 sites in Canada at which water quantity data are collected. The uses of the data are myriad including hydroelectric power generation, water transportation, irrigation, flood control, domestic water supply and sanitation, fisheries, design of structures and interprovincial or international division of flow.

Many data users need archival data, for example in design of hydraulic structures; others need real time data, for example, in division of flow; while others need forecast data, for example in forecasting low flows for navigation. To meet the latter two requirements, some gauging stations are equipped with telephone systems for telemetry of water level data. In most cases it is prohibitively expensive to install conventional telemetry systems; fewer than 5 per cent of the gauging stations have been equipped. Instead, data needs are fulfilled to some extent by hiring a local observer to read a gauge and to report the readings by telephone or by mail on a daily, or even weekly basis. In sparcely populated areas even this procedure cannot be used.

Thus when the Landsat data collection system became available in the early 1970s, a proposal for the use of the system in relaying hydrologic data from remote parts of Canada was made to NASA and was accepted. Initially 9 DCPs were installed at Water Survey of Canada gauging stations in northern and western Canada. It was hoped that the Landsat system would provide one water level reading from each site every day. These data would then be used for flow and flood forecasting and in planning hydrometric field operations. The project proved so successful that the network was eventually expanded to include the 23 sites shown in Figure one. The GOES system has also been used and Canada will take part in the experimental use of commercial communications satellites. Because of the multiparameter capability of the DCPs, sensors other than water level were installed as well. These are summarized in Table two and discussed in detail in the following section.

Sensors

Water level is transmitted from all DCP sites. The most common sensor is a float and pulley system cperating in a stilling well. When it is not feasible to construct or operate a stilling well, a nitrogen purge system is used to sense the head of water above a fixed orifice near the streambed. This head is converted to a shaft rotation by means of a servomanometer. As graphical recorders are used by the Water Survey of Canada, it is also necessary to install a water level encoder that encodes levels as 4 or 5 Binary Coded Decimal (BCD) digits. This encoder is connected directly to a DCP. No significant problems have been encountered with the system.

Two different water velocity sensors have been used with the DCPs as a means of providing velocity data for interpretation of stage and discharge interactions. One of these is an electromagnetic point velocity meter that was installed in a river bed. The analogue output of the meter was integrated by a specially designed interface and transmitted as 3 BCD digits. This experiment was not successful as, even though it had no moving parts, the meter was easily fouled by water-borne debris, thus providing inaccurate data.

The other water velocity sensor is an acoustic flow meter that measures the integrated velocity on a line between two transducers, one on either side of the river, every 10 minutes. This instrument also has no moving parts. The water velocity is available for telemetry in the instrument as 3 BCD digits or as an analogue voltage (scaled 0 to 10 V). Both outputs are connected to the DCP but the analogue signal was reduced to a maximum level of 5 V so as to prevent possible damage to the DCP. This instrument has operated perfectly since it was installed in 1976.

As Canada is a northern country the presence or absence of ice on a river is important. In order to detect the break-up of ice in the spring so that personnel will know that it is safe to fly into a site using float equipped aircraft, a simple ice condition indicator was devised. The indicator uses a parallel digital bit in the DCP message.

Another sensor was devised to indicate that the clock on the standard graphical water level recorder was operating. If the DCP data indicates that there is no reason to visit a site, visits can be postponed thereby saving operating costs. The sensor is a simple cam and switch arrangement that uses two parallel digital bits.

When DCP data are used in flow and flood forecasting, meteorological conditions are also of interest. Data from weighing-type precipitation gauges have been transmitted as three BCD digits. Air temperature from platinum resistance bulbs or thermistors and snow water equivalent from a snow pillow have been transmitted on analogue channels. No serious problems have been encountered with these sensors.

Finally, in order to monitor DCP battery voltage, a battery voltage sensor was devised. The DCP battery voltage is scaled to a range of 0 to 5 volts and transmitted on an analogue channel.

Data Reception and Distribution

All Canadian data retransmitted by Landsat are sent by teletype to the Canada Centre for Remote Sensing (CCRS) in Ottawa, usually within 15 to 20 minutes after each Landsat pass. At CCRS the data are recorded simultaneously on a Teletype hard copier and magnetic tape. A software data retrieval system sorts the user DCPs, reformats the data into engineering units and stores individual user files on disk. A user may then access the file, usually daily, using a Teletype or Telex remote terminal.

In addition to this near real time operation, NASA also provides the data as punched cards and uncalibrated computer listings. These data are delivered to the Canadian Embassy in Washington, D.C. then carried by diplomatic bag to Ottawa for distribution. This process usually takes 10 to 14 days. The cards are run on a computer to sort the data and perform conversions to engineering units. This process is used to produce archival water resources data and also to generate statistics on DCP performance.

The Canadian data retransmitted by GOES originally were sent to the Canadian Atmospheric Environment Service in Toronto on a high speed line, usually once daily. From Toronto, the data are distributed to Canadian users by Telex. More recently the National Environmental Satellite Service has instituted a dial-up service that enables users to obtain data at will.

Starting in May, 1977 Canadian users of both the Landsat and the GOES data collection systems will be able to obtain their data on a dial-up basis by Teletype or Telex from the Prince Albert Satellite Station which is operated by CCRS. This will give Canada first hand experience in operating a complete data distribution system.

Plans for the Future

The use of satellites in relaying hydrologic data from remote areas has proved very successful and has gained wide acceptance. It is apparent that, not only can this technology be used in acquiring real time data, but also it may be economically feasible to use satellite data relay as the primary means of collecting data. This could result in the elimination of on-site recording of data at many gauging stations and could also result in improved data quality or decreased operating costs since sites would be visited only as required.

There are several hundred sites where satellite data relay techniques could prove cost effective in Canada. However, before such a large network were implemented, it would be necessary to have an absolute certainty that the satellites used would be in existence for many years. Because of the difficulty of having a line of sight to geostationary satellites from the north, an operational polar orbiting system such as Tiros-N would probably prove most satisfactory for Canada.

Some studies for a Canadian data collection satellite capability have been conducted. Such a system could be a satisfactory alternative to the World Weather Watch systems. A decision concerning future use of satellite data relay systems will likely be made in the near future.

CONCLUSIONS

Experimental use of the Landsat data collection system and, more recently, the GOES system has demonstrated the feasibility of using this technology to relay hydrologic data from remote areas on a near real time basis. The system has proved to be accurate, reliable and cost effective. Further expansion based on systems now being implemented is warranted.

If a satisfactory operational system were placed in service, data acquisition costs could be reduced by reducing field travel and reducing dependence on on-site recorders. Such a system would have to have back-up satellites and ground-stations so that system wide data losses would not occur.

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TABLE 1 - INTERCOMPARISON OF DATA RELAY SATEL'ITES

	LANDSAT	GOES	TIROS-N et seq.	COMMUNICATIONS
OPERATOR	USA-NASA	USA-WWW	USA/FRANCE - WWW	COMSAT CORP/DOMESTIC
STATUS	EXPERIMENTAL	OPERATIONAL	OPERATIONAL	DEMONSTRATION/OPERATIONAL
ORBIT	NEAR POLAR	GEOSTATIONARY	NEAR POLAR	GEOSTATIONARY
SATELLITES	TWO	TWO PLUS SPARE	TWO IN ORBIT	SEVERAL
GROUNDSTATIONS	SEVERAL	SEVERAL	SEVERAL	SEVERAL
NO. OF DCPs IN VIEW	1000	20 000	2000	300 000
TYPE OF TRANSMISSIONS	RANDOM SELF-TIMED	INTERROGATE, ORDERED SELF-TIMED	SELF-TIMED	SELF-TIMED
NUMBER OF TIMES	3 or 4 + PER DAY	ON DEMAND OR 3 TO 6 HRS	6 or 8 + PER DAY	EVERY 15 MIN. OR AS REQUIRED
DATA RATE	2400 BAUD	100 BAUD	400 BAUD	1200 BAUD
MESSAGE LENGTH	64 3ITS	UP TO 2000	32 TO 256	64 BITS
FREQUENCY	401.55 MHZ	401.7 to 402 MHZ	401.65 ± 0.002 MHZ	5.925 to 6.425 GHZ
DATA INPUTS	PARALLEL DIGITAL, SERIAL DIGITAL, ANALOGUE	PARALLEL DIGITAL, SERIAL DIGITAL, ANALOGUE	PARALLEL DIGITAL, SERIAL DIGITAL, ANALOGUE	PARALLEL DIGITAL, ANALOGUE

FIGURE 1

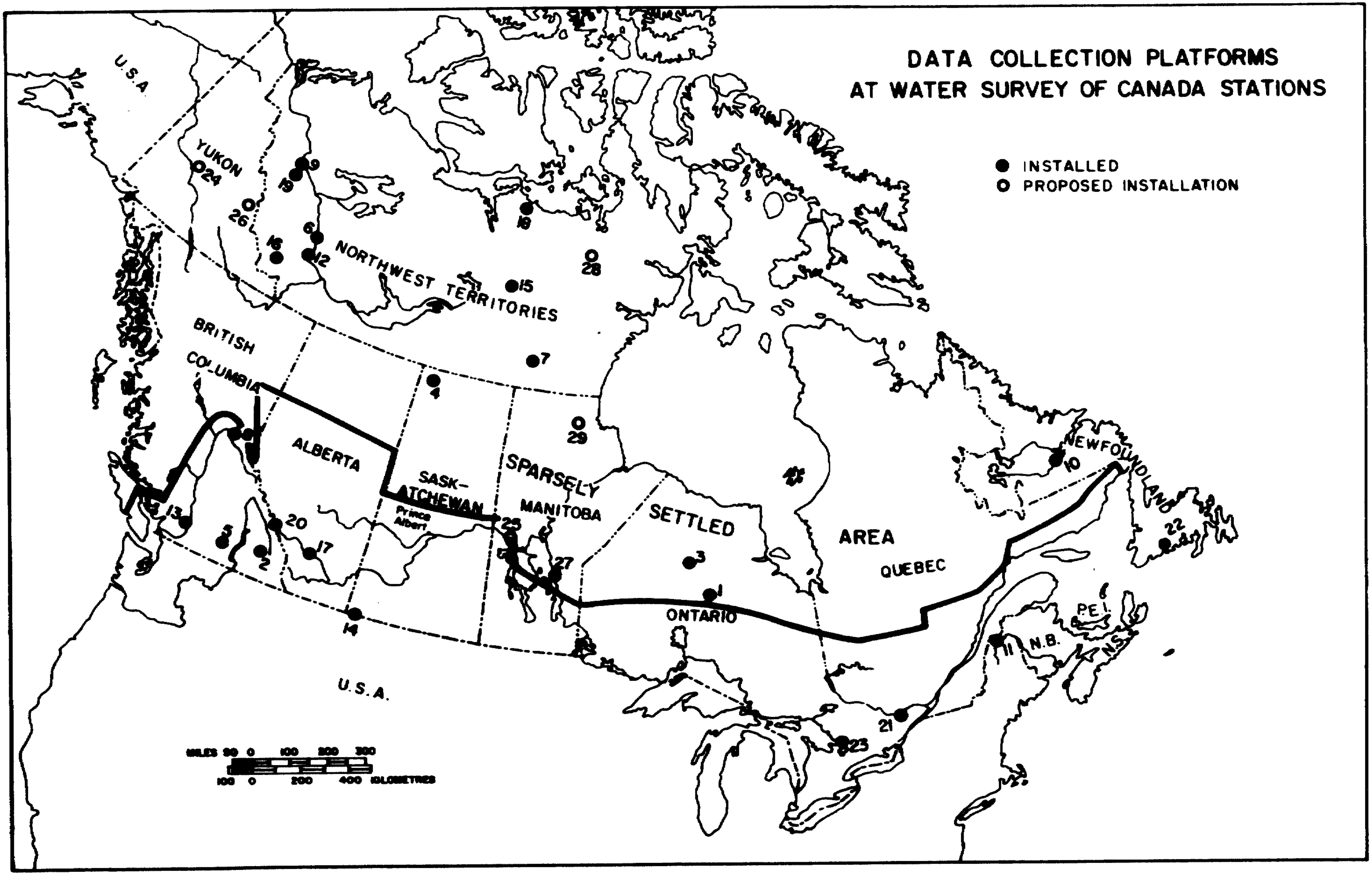
DATA COLLECTION PLATFORMS
AT WATER SURVEY OF CANADA STATIONS
INSTALLED
PROPOSED INSTALLATION
U.S.A.
YUKON
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASK-ATCHEWAN
Prince Albert
SPARSELY
MANITOBA
SETTLED
AREA
ONTARIO
QUEBEC
NEWFOUNDLAND
P.E.I.
N.B.
N.S.
U.S.A.
MILES 50 0 100 200 300
100 0 200 400 KILOMETRES

TABLE 2 - SENSORS USED WITH WATER SURVEY OF CANADA LANDSAT DCPs

PARAMETER	SENSOR	INSTRUMENT	INTERFACE
WATER LEVEL	FLOAT	STEVENS MEMOMARK II	CONTAINED IN MEMOMARK
	PRESSURE	CAE SERVOMANOMETER	STEVENS MEMOMARK II
WATER VELOCITY	ELECTROMAGNETIC	MARSH-MCBIRNEY	ANALOGUE INTEGRATOR
	ACOUSTIC	ATLAS FLORA 10	NONE REQUIRED
ICE CONDITION	ELECTRO-MECHANICAL	NOT APPLICABLE	NONE REQUIRED
RECORDER OPERATION	ELECTRO-MECHANICAL	NOT APPLICABLE	NONE REQUIRED
PRECIPITATION	WEIGHING TYPE	FISCHER & PORTER	HARTS UNIT
TEMPERATURE	PLATINUM RESISTANCE BULB		HARTS UNIT
	TERMISTER	YSI 44033	MINOR
SNOW WATER CONTENT	SNOW PILLOW	PRESSURE TRANSDUCER	NONE REQUIRED
DCP BATTERY VOLTAGE	ELECTRONIC	NOT APPLICABLE	NONE REQUIRED