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THE DEVELOPMENT AND EVALUATION OF ALTERNATIVE BLEEDER CONTROLS

by

ALLAN YEE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE DEVELOPMENT AND EVALUATION OF ALTERNATIVE BLEEDER CONTROLS submitted by ALLAN YEE in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in ENVIRONMENTAL ENGINEERING.

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Date 22 April 1982

ABSTRACT

The prevention of freezing in northern water distribution and wastewater collection systems requires that the heat losses from the system not exceed the heat available before ice formation. In areas with sufficient quantities of potable water, one of the easiest methods of accomplishing this is to continuously discharge water from distribution system to the sewers. This practice of bleeding water during the win spring results in high water consumption rates and energy costs and also high and operational difficulties associated with pumping and treating large quantiti and dilute wastewater.

The present project has examined various methods of alleviating the associated with existing water distribution systems that rely on bleeding as freeze protection. It has involved developing a data base on the exis installation in Whitehorse, Y.T., reviewing and evaluating those bleeder alte have been identified thus far, testing the most feasible alternatives in a laborat and using a computer simulation to attempt to determine the effects of reduce bleede flows on the Whitehorse bleeder system.

Laboratory testing consisted of pumping water through a series of parallel recirculating pipes in a cold room at an ambient temperature of -25 °C. A different bleeder control device was then mounted on each of the recirculating pipes. The devices tested in this manner were a temperature control device, a metal orifice plate, a timer, a storage tank that filled with water and discharged it, and a pressure tank that, in theory, would fill with water during periods of high system presure, and drain it back to the distribution system whenever network pressures drop.

Four tests of from five to nine days duration with the first four devices and two ten day tests with the last device suggest that only the orifice plate and a variable set timer are technically feasible for further development. Employing a present worth comparison based on a twenty year expected life, the timer appears to be the more economic of the two devices based largely on the volume of water that would be bled.

For the computer modelling work, a piping network of downtown Whitehorse was derived from as built drawings. A steady state thermal package was then added to the hydraulic portion of a proprietary piping analyis model developed by Associated

Engineering Services Limited and used to determine the thermal effects of reductions in flow and ambient temperature upon the network. The results suggest that pipe freezing will occur at exterior soil temperatures below 0 °C. The results also suggest that varying the network flow rate will have a negligible effect on whether or not thermal failures occur in the system. Due to uncertainties about the assumptions made and the steady state equations used in the computer analysis, these results are considered to be conservative and network thermal failures will probably not occur as readily as predicted.

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I. INTRODUCTION

Water quantities permitting, one of the more traditional approaches used to protect buried water lines in the north from freezing has been to maintain a continuous flow of water in the supply mains and service lines. These flows have largely been sustained through the practice of bleeding water directly from off line hydrants, dead end mains, and building drawoffs into the sewer system.

The practice of bleeding water has had a number of impacts on those communities using it. On the positive side, this method of freeze protection has allowed distribution lines to be installed with a minimum of insulation and, in some cases, with shallower placement. This method also allows water utility lines to be laid out in a conventional manner and thus, as in more temporate climates, vehicular traffic patterns could be used as the primary criteria when planning communities.

However, water bleeding leads to large water consumption rates, higher treatment and pumping costs, and the high costs associated with the handling of large quantities of highly diluted wastewater.

The work presented in this thesis has been aimed at developing and evaluating some alternative methods for reducing the amount of freeze protective water that must be bled from a distribution network. The project has involved studying an existing water bleeder system, conducting laboratory tests on various bleeder control alternatives, and running computer simulations to determine the effects of bleeder flow reductions on an existing system.

II. LITERATURE REVIEW

A. HISTORICAL DEVELOPMENT

In North America, cold region utility systems (water and sewer) have evolved largely in response to the interaction of two factors:

1. the demand for a safe and adequate water supply and waste disposal facilities; and
2. the constraints placed on the provision of the above by the environmental conditions prevalent in the north.

The original methods of utility servicing used in the north were those developed by the aboriginal peoples – the Indians, Inuit, and Aleut (Murphy and Hartman, 1969). These methods largely conformed with individual preference modified somewhat by concern for the group welfare (Alter, 1977).

The transport of water and sewage in the north was first accomplished through the use of self-haul systems. The average water consumption rates tended to be low, on the order of 5-25 L/person/day (Smith *et al.*, 1979; Murphy and Hartman, 1969; Grainge, 1968), nevertheless, because manual labour was used, water collection was a time consuming process. Sources included ice and snow melt, warm springs, wells, holes drilled through ice covered lakes and streams, and, during the summer, rain water as well as the normal surface sources (Grainge, 1959; Alter, 1950).

Waste disposal methods also tended to be primitive. The use of chamber pots that were emptied periodically was common, as was the construction of latrine holes and privies (Alter, 1969).

For various reasons such as exploration, economic development, resource development, and perceived military need, non-indigenous people have been migrating into the north since the early nineteenth century (Alter, 1977). At first, their living conditions were only slightly less primitive than the native population (Grainge, 1968). Gradually, however, water and waste transmission works, mostly gravity flow systems, were constructed. The large quantities of water required for mining and fishing activities brought about the first water supply and transmission works in Alaska (Alter, 1977), while in the Canadian arctic, the first running water and sewer systems were constructed for schools and hospitals by Christian missionaries with the aid of the Federal government (Grainge, 1968). In Dawson City, a buried wood stave water and sewer system was installed in 1903 – 1904 (Stanley Associates Engineering Limited, 1977; Stanley, 1965; Murphy and Hartman, 1969; Grainge, 1969b)). Larger municipal utility projects in Alaska were developed in the period 1916 – 1930, and the first municipally own public utilities system (at Ketchikan) was established in 1930 (Alter, 1977).

Historically, in northern North American communities, the municipal water supply and waste disposal services were first established as haulage systems (Dawson and Cronin, 1977). As populations grew and/or government subsidies became available, on grade or shallow burial summer distribution and collection systems were constructed. Continuous piped utility services similiar to those available in more temperate climates have generally been the goal of most northern communities thus far (Alter, 1974; Yates and Stanley, 1963; Stanley, 1965; Raniga, 1980).

With the advent of piped water and sewage transmission works in the north, a number of problems arising from their ambient operating conditions became evident. Chief amongst these were line freeze-ups (Dickens, 1959; Grainge, 1958; Alter, 1963; Dawson and Cronin, 1977), and, in the case of permafrost areas, soil instability (Alter, 1950; Yates And Stanley, 1963; Grainge, 1959).

There are many reasons for preferring piped utility systems to haulage ones. Grainge (1969a, 1969b) has suggested that piped water and wastewater systems are superior because:

1. the water supply that reaches the consumer will generally be less contaminated;
2. the cost of water is less and thus, freer use of it is made for washing; and
3. there is no accidental spillage of sewage.

B. PIPE FREEZING MECHANISMS

The properties of water on freezing were investigated and compiled by Dorsey (1940, 1948), while the freezing mechanism in a closed pipeline has been well documented by Gilpin (1977a, 1977b, 1979).

Water free from any contamination can normally be supercooled to −20 °C before freezing, however, depending on environmental conditions, only a moderate amount of supercooling can be tolerated before ice will nucleate in ordinary water (Dorsey, 1940). In natural bodies of fresh water for example, the nucleation temperature for frazil ice is only slightly less than 0 °C (Riddick, Lindsay and Tomassi, 1950), while in a pipe, ice will typically nucleate at −4° to −6 °C (Gilpin, 1977a; Zarling, 1979).

In a quiescent pipe, supercooling will initially produce dendritic ice growth − thin 'feathery' crystals intermingled with the water. The amount of the dendritic growth is directly proportional to the amount of supercooling required to produce nucleation (Gilpin, 1977a). In turn, the nucleation temperature is dependent upon the amount of active nucleation particles or 'motes' of foreign matter present in the water (Dorsey, 1948).

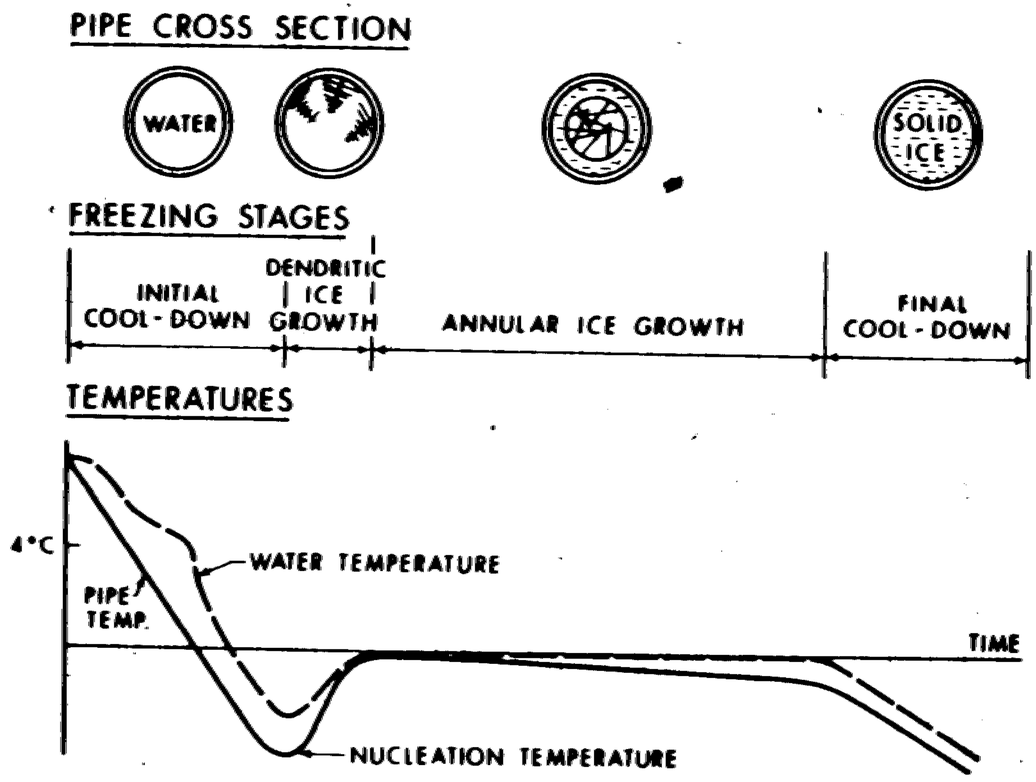
The heat of fusion liberated by the growth of the dendritic ice (sufficient to block off the entire cross−section of a small diameter pipe in a short period of time) will raise the temperature in the pipe back to 0 °C. Further cooling will then produce an annulus of solid ice growing inwards from the pipe wall, with the dendritic ice being transformed into thin continuous sheets imbedded in the annulus (Gilpin, 1977a, 1977b). See Figure 1.

The prescence of dendritic ice will increase the pressure required to reestablish flow in the pipe. These start up pressures will further increase by a factor of ten or more with the initial formation of annular ice. Also, with a relatively small temperature gradient between the pipe wall and the pipe axis such as would be the case with a small diameter pipe and/or a slow cooling rate, dendritic ice formation can effectively block off the pipe in much less time than required for the pipe to freeze solid (Gilpin, 1977a, 1977b).

Low temperature failures in a pipe occur not because of ice expansion on the walls, but rather, because of hydrostatic pressure (Rice, 1970). Ice expansion places an increasing pressure on that water in the pipe that is still unfrozen. This pressure will then be transmitted to the pipe walls and bursting will occur if the elastic limit of the wall material is exceeded.

One cause of a pipe bursting that has been suggested has been that of non−uniform cooling along its length (McFadden, 1977a, 1977b). This non−uniform

FIGURE I



THE VARIOUS STAGES DURING THE FREEZING HISTORY OF A STAGNANT WATER PIPE

SOURCE: GILPIN, R.R. (1977B)

cooling will lead to trapping isolated pockets between frozen pipe sections.

For flowing pipes under sub-zero conditions, Gilpin (1979) observed that ice will form as a series of cyclical ice bands tapered downstream from an expansion (see Figure 2). Given sufficient time, the expansions will migrate upstream until an equilibrium point is reached and presumably, the change in convective heat transfer between the upstream and downstream sides of the separation balances the change in conduction through the ice layer. Subsequent cooling will result in the closing off of the narrow separation. Pockets of unfrozen water will then be isolated and pipe failures, if they occur, will occur between the ice bands. It was found that a pipe wall temperature below -3° to -4 °C was required before ice growth could be initiated (Gilpin, 1979).

For pipes with water flow in them, there is an increase in the viscosity of the water as the temperature is decreased (CRC Handbook, 1973). The increase in viscosity causes the friction factor to increase (Daugherty and Franzini, 1977), thereby resulting in a lower Reynolds number and a smaller discharge. Quraishi (1978) found that by keeping the head loss per unit length constant in smooth (i.e., plastic) pipes in the 5° to 30 °C temperature range, there is about a 2% reduction in flow for every 5 °C reduction in temperature. For rough pipes, the variations in flow with temperature appear to be neglible (Alter, 1979).

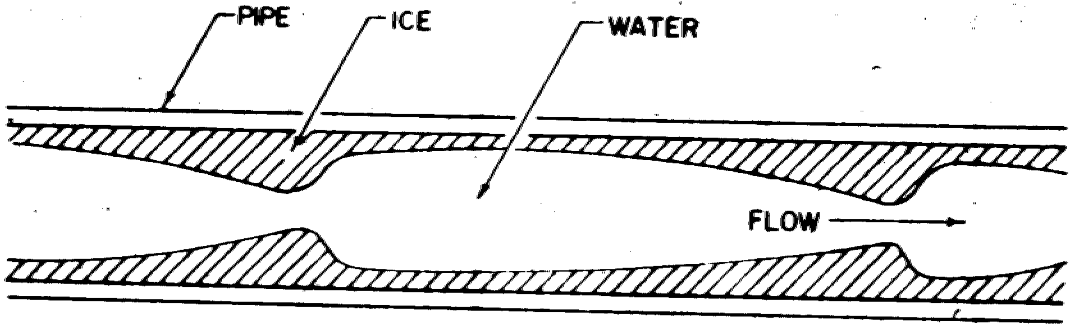
C. FREEZE PROTECTIVE STRATEGIES

In an entire community or installation water supply concept, the most critical phase of the system with respect to frost damage is the distribution component (Sargent, 1963, Alter, 1969, Grainge, 1969).

To effect distribution of a safe and reliable supply of water to consumers in the arctic regions of North America, a number of types of piping systems have been used over the years. Various schemes for classifying these systems have been proposed by a number of authors (Stanley and Yates, 1963; Stanley, 1965; Alter, 1963, 1972, Grainge, 1969; Murphy and Hartman, 1969; Dawson and Cronin, 1977). A simple listing of the types of systems that, singly or in combination, have been successfully operated, would include the following:

1. an intermittent system with the distribution lines being filled only on a periodic

FIGURE 2



ICE BANDS FORMED DURING THE
COOLING OF A FLOWING WATER PIPE

ADAPTED FROM: GILPIN, R.R. [1979]

or a seasonal basis;

2. an encapsulated pressure system supplied from storage tanks which are filled by hauled water;
3. a heat cable system with electrically heated supply mains and service connections;
4. recirculating systems employing either a single main or dual mains;
5. a conventional non-recirculation system with heavy users located at the ends of the supply mains;
6. a utilidor system either placed below, on, or above grade;and
7. a conventional non-circulatory system with bleeding at dead ends to maintain the flow.

Further discussion of these types of piping systems is given in the following sections.

D. INTERMITTENT SYSTEMS

In a number of small communities, seasonal distribution with pipelines is practiced (Alter, 1969). The overall costs for water supply are reduced by eliminating the trucking of water for four months and relying instead on inexpensive, above grade lines (Smith *et al.*, 1979). Reservoirs may also be filled for winter use at this time. The lines are operated by either gravity flow or with pumps and drainage is accomplished by gravity flow, or by blowing compressed air through the system (Murphy and Hartman, 1969). As noted by Alter (1950, 1969), some of the problems associated with this type of seasonal distribution are as follows:

1. the complete collection, storage, and relaying of the pipe each year is a costly procedure;
2. the pipes, when disjointed, are left open and exposed on the ground to accumulate whatever contamination is around; and
3. hasty assembly and the use of worn and damaged joints and piping make the system susceptible to contamination whenever negative heads occur.

A variation on this type of distribution system is to use a conventionally laid, below grade piping network (Hubbs, 1963; Murphy and Hartman, 1969; Smith *et al.*, 1979). Summer time operation would be similiar to systems in more temperate climates During the winter however, the water would be distributed through the lines only on a pre-determined schedule or on demand. Each consumer would be hooked up to the supply main through a continuous looped service line (Smith *et al.*, 1979) and would be responsible for filling his own holding tank. So that individual consumers would have water pressure, the holding tank could be located in the attic (Murphy and Hartman, 1969).

Advantages to this type of intermittent system are as follows:

1. water use is higher than would be the case with a haulage system (Smith and Heinke, 1980). Presumably, larger quantities of water would therefore be used for washing,
2. the possibilities for contamination of the water supply are considerably less than with a haulage system (Grainge, 1969a, 1969b, Smith *et al.*, 1979); and
3. water usage is not as high as would be the case with a fully piped system. The chances are therefore greatly reduced of depleting a village's water supply or requiring the construction of a very large reservoir (Murphy and Hartman, 1969).

Some disadvantages of an intermittent pumping system are its lack of fire protection (Alter, 1969, Murphy and Hartman, 1969), the requirement for large storage facilities, and its unsuitability for larger size communities (Alter, 1969).

Grainge (1969a) has proposed that it might be economical to operate a permanently laid distribution system only during the summer. An electrical heat tape could be used to preheat the supply lines prior to spring start up while every fall, the same lines would be drained and sealed again. Such a system has been operated successfully in such communities as Fort Franklin, Old Yellowknife, and Aklavik.

Alter (1969) has documented the use of an intermittent system in Point Barrow, Alaska and at some DEW Line stations. In some communities in Greenland, seasonal surface distribution is practiced by connecting small summer lines to the existing year round supply mains (Rosendahl, 1980a, 1980b).

E. ENCAPSULATED SYSTEMS

Encapsulated water systems are ones in which all or some of the components of the water supply system are protected from freezing by being enclosed in heated buildings or other structures. Complete encapsulation of both water and wastewater systems, as Alter (1963, 1972) has pointed out, implies the concept of full water re-use. For various aesthetic, technical, and financial reasons however, re-use applications to date have been limited to demonstration projects and specific aerospace and military applications (Cameron and Armstrong, 1979).

Encapsulated water systems that have been attempted under arctic conditions have generally been modified ones in which some components of the system, such as the initial water supply, have been located outside of the encapsulated area. Locations where encapsulation has been practiced include some DEW Line stations (Alter, 1969, 1977, McConnell, 1958) and some stations in the Antarctic (Esser, 1981a, 1981b).

Other projects with some aspect of encapsulation are the Alaska Village Demonstration Projects at Emmonak and Wainwright where, in addition to the truck hauling of water to individual consumers, central facilities for showers and saunas, and laundry machines for community use were also constructed (Reid, 1974, 1977; Puchtler *et al.*, 1976). Such an arrangement had the following advantages:

1. because it contained much less infrastructure, the central facility was cheaper to construct and maintain than a fully piped and pressurized distribution system; and
2. efficient use of the water was practiced because control of water for bathing and laundry, estimated to comprise 35% of total water needs, was maintained at a central facility which employed energy and water conservative systems. The facility was also close enough that use of water for washing was not unduly discouraged, yet it was far enough away that more frivolous water uses were kept under control. The success of the projects at Emmonak and Wainwright have prompted the construction of central facilities for other Alaskan villages under the Village Safe Water Program (Sargent and Scribner, 1977; Sargent, 1977, 1980).

F. HEAT TRACING

Tracing of water lines with steam pipes or electric cables has long been a recognized technique of freeze protection (Alter, 1977). Electric heat tracing is, in fact, currently the standard backup freeze protection system used in most northern piped distribution systems in North America (Smith *et al.*, 1979). Practices related to these, such as electrical resistance thaw wires, or thawing with steam or hot water, are not protective techniques in themselves, but are instead, after the fact procedures which are used to restart the flow if a pipe has already frozen.

In locations where central heating with steam is available, the placing of water lines adjacent to them in a common utilidor has been successfully practiced (Alter, 1950, 1953; Grainge, 1959; Cameron, 1977). Instances of problems that have occured with steam tracing include overheating of the water line in the summer (Cameron, 1977; Alter, 1977), and the attendant costs and problems incurred with producing steam and collecting the condensate (Hubbs, 1963). In the former case, the problem can be attributed to poor utilidor design, while the latter problem deals more with the economics of central heating with steam.

Other fluid mixtures for heat tracing have also been used, such as ethylene glycol and propylene glycol. These antifreeze mixtures are easier to use than steam or hot water because they have low freezing points and, therefore, they protect the heat trace piping and allow winter startups. However, these fluids are also corrosive, more viscous, and have poorer heat transfer characteristics than water. Friction losses will consequently be greater and pumping costs will be higher (Smith *et al.*, 1979). Fluid tracing as a whole has other drawbacks such as the reliance on leak free plumbing and the inability to provide a given amount of heat at a specific point (Whyman, 1980).

In locations where water lines have been traced with electric cables, the technique has generally been employed only as a backup protective measure. Primary protection of mains with electric heat tracing is no longer a popular concept, although the practice is still fairly common in Newfoundland and Labrador (Whyman, 1979). There, although the cost of electricity to heat the mains is high, no major expenses for pumping and recirculation are required, and a conventional distribution system layout can be used

The main types of electric heat tracing systems in use are:

3. series and parallel resistance cables and tapes;
4. induction heating; and
5. Skin Effect Current Tracing or SECT©.

The series resistance method employs a looped cable used to heat up the water line. The heat output per unit length will vary with the length of the cable. Parallel resistance heating cables and strips, on the other hand, carry both the conductor and resistance buss wires in the same casing and therefore, can be cut to any length without affecting the output or watt density (Johnson *et al.*, 1980). The SECT© system employs a carbon steel heat tube attached to a water line to transmit the heat generated when an AC current is passed through the copper cable located in the tube. The main uses of SECT© have been with metal pipes, however, claims have been made for its applicability to plastic pipes as well. To improve heat transfer to the water in this situation, a metallic foil, aluminum or mild steel, would be wrapped abound both the heat tube and the main carrier pipe (Tracey, 1980). Finally, induction heating consists of wrapping an alternating current carrying wire around a pipe. The water is heated by inducing eddy currents within the pipe.

For maximum energy efficiency, research and experience has shown that a resistance cable should be placed inside a pipeline (Kardymon and Stegantsev, 1972; Cheriton, 1966). There are a number of problems attendant with this arrangement however. These include:

1. maintaining hermetic seals at leads in and out of the pipe;
2. Maintaining the dielectric properties of the cable insulation;
3. the structural requirements for the cable to withstand the pressure and vibration loads inside the pipe;
4. the need for special arrangements for bypassing valves and other fittings; and
5. the need to remove the cable whenever individual pipe sections are repaired.

For these reasons, heat cables are usually placed outside of a water pipe.

For supply mains, the capital and O & M costs associated with heat tracing are very high (Hubbs, 1963; Smith *et al.*, 1979; James, 1980b). Major problems include the high cost of electricity and attempts to find a safe and reliable heat cable and thermostat system (Ryan, 1977). Thermostatic controls are often a major source of wasted energy and malfunction. James (1980b) reported that in a heat traced Rankin Inlet installation, many burnouts and faulty circuits were found after one year of operation. Mechanical, liquid filled thermostats generally have a wide tolerance range and are only accurate to within a few degrees (Smith *et al.*, 1979). Much greater sensitivity and control can be attained with solid state thermostats employing thermocouples, resistance temperature detectors (RTDs), or thermistors as sensors, however, their cost is considerably higher than mechanical thermostats (Whyman, 1980).

In thermostatically controlled systems, placement of the sensors can also be critical. Under high moisture conditions, they may become faulty and either lead to excessive heating and high electrical wastage, or to freezeups and possible line damage. Alter (1969) has noted that utilidor fires have resulted from the overheating of electric cables. Plastic pipe and insulation can also be damaged by overheating (Whyman, 1980). Efforts to alleviate overheating problems include high limit thermostats and the use of 'self limiting' or modulating heating cables that lower heat output with an increase in pipe temperature.

In some northern installations, prefabricated and preinsulated piping systems have been introduced which have incorporated heat cable channels or tubes attached or suspended underneath the main pipe. These piping systems are only a recent phenomenom to the north (O'Brien and Whyman, 1977), although research into their use were conducted in the middle to late 1960s (Yates and Stanley, 1963; Hoffman, 1968).

With these prefabricated and preinsulated piping packages, there can be problems with sealing the joints in the exterior heating cable channel. Cases of water intrusion into the channel have occured at installations such as Resolute and Rankin Inlet (Whyman, 1980). Because of this, and because of the fact that the high density polyethylene pipe used in these piping packages is capable of sustaining liquid freeze ups without damage, heat trace cables have been eliminated altogether in some supply main systems. The experience from Frobisher Bay has shown that given a continuously flowing water main with backup power and pumps and in line heaters, heat trace cables were not required along the supply mains (James, 1980b; Whyman, 1980). Subsequently, heat tracing of the sewer system in Frobisher Bay was abandoned as were the electric heaters in each manhole (James, 1980a). In the supply mains, the heating cables are being replaced in new construction with after the fact thaw tubes attached to the pipe with heat transfer cement. These thaw tubes are joined at each pipe connection with a watertight coupling (Whyman, 1980) and in the event of freeze ups, hot water or steam can be injected into them.

Because of the smaller pipe sizes involved, the lesser flow velocities, and the possibilities of long periods of stagnant flow, individual service connections are usually considered the critical points in a piped water system. The tracing of service connections with electric cables is a very common practice in arctic and subarctic regions and many of the problems associated with the electric cable tracing of supply mains are eliminated when service lines are considered. Service connections are usually not very long, typically 15 to 30 meters, and hence, the operation of electric cables can be site specific. Operating costs can also be billed directly to the consumer. Service line heating cables are also frequently installed without thermostat controls and are manually operated. They are then left on during the entire period when freezing may occur. This is, however, a very wasteful practice. In Frobisher Bay, service line heating cables without thermostats have been installed which are activated by flow switches only under stagnant flow conditions (James, 1980a).

G. RECIRCULATING SYSTEMS

Recirculating systems rely on the continuous movement of water within the lines to prevent the occurence of freezeups. The method works because, under design conditions, the water temperature in the supply mains does not drop below freezing before it returns to the main pumps and is reheated again. At any given cross section therefore, the net heat losses are not enough to allow the formation of ice. Heat can also be added to the system at other points along the circuit.

There are basically two types of recirculating systems, the single main system and the dual main system.

The dual main recirculating system consists of two water mains laid adjacent to each other. One line is operated at high pressure and is used to distribute water to consumers. Each service connection comes off the high pressure line into the building, goes through a pressure reducing mechanism (orifice, valve, etc.), and then discharges the unused water to the second, lower pressure return line. The consumed water is taken off the end of the service loop in the building.

Meanwhile, the lower pressure line returns the unconsumed water back to the main pumphouse or to an intermediate facility where, if necessary, it is reheated and returned to the high pressure distribution network.

The dual main system has been used in a number of government installations and mining camps in Alaska (Alter, 1977), in Flin Flon, Manitoba (Grainge, 1969b), and in Yellowknife in the Northwest Territories (Grainge, 1959; Yates and Stanley, 1963; Alter, 1969). In Yellowknife, the dual main system was constructed between 1947 and 1949 and flow in the copper service loops between the distribution and return lines was maintained by the use of an orifice plate in each building and at every hydrant (Grainge, 1959). The dual main consisted of two cast iron lines, one a 15.2 cm (6") supply main, the other a 10.2 cm (4") return line. In areas of permafrost and ice lenses, 25.4 cm (1 ft) of compacted moss was used as insulation in the top and sides of the pipe trench, with 0 - 5.1 cm (2") of the same as bedding (Copp, 1954; Yates and Stanley, 1963; Stanley, 1965). The Yellowknife system was expanded at various times over the years as the population increased. The original dual main system now only serves the Central Business District of the City. In 1972 - 1973, after freezing problems, an investigation revealed that the holes in a number of the original copper orifice plates had worn away, thereby causing a loss of differential pressure and hence, flow, between the dual mains. These were subsequently replaced with steel plates (Prentice and Srouji, 1980). Recent additions to the system have been installed as recirculating loops with service connections thermostatically heat traced and bled (Dawson and Cronin, 1977).

Some features of a dual main recirculating system are as follows:

1. the system layout can be similiar to conventional shallow buried systems;
2. with double the amount of pipe required, the installation costs would approach twice that of a conventional system (Murphy and Hartman, 1969), even though smaller capacity pipe can be used for the return line and both lines may be laid in the same trench;
3. due to a larger total surface area with two sets of mains, energy consumption

would be higher than with a conventional system (Smith *et al.*, 1979); and

4. the control mechanisms for this type of system are elaborate and careful control must be maintained over line pressures (Murphy and Hartman, 1969). Because varying consumptions would lead to stagnant flows occuring in certain locations at certain times, thermostatically controlled solenoid valves between the two mains are required at regular intervals to short circuit the system (Smith *et al.*, 1979).

The second type of recirculating system in use is the single main distribution system. This consists of one pipeline through which water is continuously circulating. The system is laid out in loops originating at a pumping/ heating facility and the return portion of each loop is also used to service consumers.

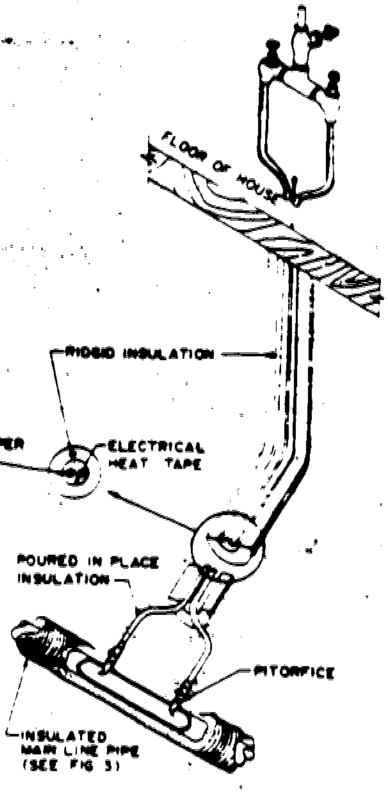
The single main recirculating system was developed just after the dual main system, in the early 1950s. In certain single main systems, flows sufficient to prevent freezing in the services connections are maintained by the use of pitorifices, devices developed as a result of research conducted by Captain W.B. Page of the Arctic Health Research Center, U.S. Public Health Service (Page, 1952, 1954) from an idea initially presented by A.J. Alter (Alter, 1950, 1979).

Each pitorifice consists of a piece of pipe shaped into a scooplike lip at one end (see Figure 3). These are located at each end of a service loop running between the building and the supply main and are inserted into the main as corporation stops, with one pitorifice opening being oriented upstream and one downstream. Flows in the service loop are maintained by utilizing the velocity head present in the main pipeline.

There are limitations on the length of service lines that can be successfully operated with a pitorifice as well as minimum velocities that must be maintained in the supply main. Since the pioneer work by Page, further research and calibration of pitorifices has been carried out by the U.S. Army Corps of Engineers (Johnson, 1978).

The first installation of a full scale community single main recirculating system occured at Fairbanks, Alaska in 1952 - 1954 (Grainge, 1969b; Alter, 1977). Prior to this, in 1944, a recirculating system for Fairbanks was designed by the firm of Black & Veatch. This system relied heavily on bleeding to maintain flows however, and was never constructed (Black & Veatch, 1944). Another recirculating system was subsequently

FIGURE 3



TYPICAL PITORIFICE SERVICE LINE INSTALLATION

SOURCE RYAN, W.L. [1973]

designed for Fairbanks after the war by the firm of R.W. Beck & Associates. After the initial cost estimates on four types of systems (including a dual main recirculating system, a steam tracing system, and a system of utilidors), the single main system using pitorifices was selected. This system was estimated to cost $900,000.00 U.S. less for installation than the comparable dual main system (Hubbs, 1963; Wallace and Westfall, 1954; R.W. Beck & Associates, 1953; Westfall, 1956).

The single main recirculating system is currently recommended as the best non-institutional piping system for arctic conditions (Murphy and Hartman, 1969; Smith *et al.*, 1979). Its features include the following:

1. the system must be laid out in one or more loops. For maximum efficiency of pumping and line lengths, a dense circular pattern of development around a central pumping/heating facility is preferred. This would tend to place constraints on town planning by eliminating such features as cul-de-sacs (Grainge, 1969a). One possible way to get around this limitation is to employ dual main subsystems taken off from the main loop to service areas for which it would be otherwise impractical to extend the main circuit (Smith *et al.*, 1979);
2. system controls are simpler than those required for a dual main recirculating installation. Flow and temperature measurements at the main station or at booster stations are all that are required (Murphy and Hartman, 1969; Smith *et al.*, 1979);
3. in a pitorifice installation, in order to achieve protective flows in the service loop, certain velocities are required in the main. Because the service connection is laid out in a loop, the actual length of pipe exposed to soil ambient conditions is twice the distance from the serviced building to the supply main. Assuming certain steady state temperature and soil conditions for Fairbanks, Page calculated that a service flow velocity of 0.05 m/sec (0.17 fps) as produced by a main velocity of 0.61 m/sec (2 fps) would be sufficient to prevent water freezing in a 30.5 m (100 ft) length of pipe (intake and return) (Page, 1954); and
4. because the system is laid out in loops, if problems occur anywhere in the line

and a shutdown is required, loss of service might occur along the entire loop. In practice however, temporary connecting sections are constructed as a loop is extended and these normally closed sections could be used to bypass problem areas (Smith *et al.*, 1979).

Because the single and dual main recirculating systems were developed during the same time period and because the former has several distinct advantages over the latter, recirculating systems that have been installed in the arctic have generally been of the single main type. The pitorifice has been used fairly extensively in Alaska with this system. In Canada however, other methods, such as recirculating pumps, are preferred with the service loop (Whyman, 1979).

H. CONVENTIONAL SYSTEM WITH HEAVY END LINE USERS

For a conventionally laid distribution system located in a frost susceptible soil, some degree of protection can be maintained if there is a continual flow of water in the lines such that the net flow of heat into the system is at least equal to the net flow of heat out. In order to sustain a continual flow of water without recirculation, dead ends must be eliminated. This may be accomplished by placing high volume users at the terminals of the main distribution lines (Smith *et al.*, 1979).

Such a system has been extensively used for many years in Greenland. Its success there can be attributed to a number of factors, chief of which is that in Greenland, the responsibility for all fields of technical development work lies with only one organization, the Greenland Technical Organization (GTO). As such, therefore, it has been possible to coordinate all aspects of utility servicing with town planning (Grainge, 1969b, 1969c, Grainge *et al.*, 1980).

The sixteen towns in Greenland have all been supplied with piped water distribution systems, but in each case, only the heavy consumers such as hospitals, industrial plants and apartment buildings are directly connected to the line. All other water users are supplied by summer lines and a haulage system (Rosendahl, 1980b).

This servicing arrangement is facilitated by the fact that unlike comparible population centers in the Canadian north and Alaska (Godthaab, the capitol of Greenland has a population of 8500 people – Grainge *et al.*, 1980), the majority of the urban

Greenland population are housed in multi-story apartment blocks of 350 - 400 persons/hectare density. According to Grainge (1969b, 1969c), acceptance of this typically northern Scandinavian philosophy of housing by the indigenous population has been good. In part, this has been due to good community planning, the attractiveness of having piped water distribution and sewage collection, and the high apartment building standards that afford some degree of privacy to the occupants (Grainge *et al.*, 1980; Rosendahl, 1980a, 1981). Lately however, a rash of social problems has led to the GTO policy of constructing some lower density multiple housing (Grainge *et al.*, 1980; Rosendahl, 1981).

The practice for water distribution lines in Greenland is to lay them below the depth of frost penetration (approximately 2 meters) in areas where this is possible, and to insulate and protect the lines in areas of permafrost. Typically, ductile cast iron pipe is used, and if it is required, it is insulated with polyurethane foam and covered with a high density extruded polyethylene pipe jacket. Where additional freeze protection is needed, a single heat trace cable is embedded in the insulation. The heating cable is controlled by sensitive electronic thermostats which allow the system to operate at temperatures very close to freezing. Placement of the sensors at strategic locations is very critical (Smith *et al.*, 1979). For non-insulated pipe, some protection from frost penetration is achieved by placing a five cm. thick layer of polystyrene insulation spanning the pipe trench about fifteen cm. above the water main (Grainge *et al.*, 1980; Rosendahl, 1980b).

The water distribution lines in Greenland are generally smaller than in North America and therefore have a smaller fireflow capacity. This is because of a different fire protection philosophy which stresses containment by isolation rather than extinguishment. Adjacent units in apartment buildings in Greenland are separated on all sides by concrete firewalls and individual buildings are separated from each other by relatively long distances (Rosendahl, 1980a; Grainge *et al.*, 1980).

I. THE UTILIDOR

A utilidor is a duct in which various utility services, such as water and sewer pipes, central heating pipes, electrical and telephone lines, and fuel lines, are carried. One of its purposes may, in fact, be to consolidate utilities such as those listed.

Utilidors have been constructed in a wide variety of shapes, configurations, and sizes. They may be located below, on, or above grade, in both permafrost and nonpermafrost areas. Service connections with utilidors are accomplished by extending the utilidor to each building serviced (a utilidette), or through a common service bundle (James, 1977).

Regardless of design, all utilidors are made up of the following components:

1. a foundation;
2. a frame;
3. an outer casing;
4. inner insulation; and
5. internal piping systems (Leitch and Heinke, 1970; Gamble and Lukomskyj, 1975; Carefoot, 1977; Smith *et al.*, 1979).

Alter (1977) reported that the first utilidor system in Alaska was built at Fairbanks in the early 1900s. This was a small buried system constructed of wood, steam traced, and used to service commercial concerns in the downtown business section of the City. A more elaborate utilidor system containing steam, sewer and water, and wiring, was started at Ladd Field near Fairbanks in the late 1930s. This was a walk through affair, with a large internal cross section (2.13 m X 2.74 m, or 7' X 9'), buried, and contructed with steel and reinforced concrete.

In Canada, elaborate above ground utilidors have been constructed at Inuvik, N.W.T., which has become known as the test bed for utilidors (Gamble, 1977). Accounts from 1977 (Carefoot, 1977; Dawson and Cronin, 1977) list eight different utilidor designs designs in use there. Even more systems have been added on since (Smith *et al.*, 1979; James, 1980a).

Utilidor systems have a number of adverse features. The costs for construction and maintenance are generally high. Gamble and Lukomskyj (1975) analyzed the utilidors in Inuvik and arrived at capital cost estimates for the eight systems thatranged from $144.36 to $997.38/m ($44.00 to $304.00/foot) in 1974 dollars. The utilidors at the bottom end of the spectrum however, were so-called 'low cost' systems that had the highest maintenance costs and did not exceed their short intended lifespans. A subsequent utilidor constructed in Inuvik in 1976 had capital costs of $600.00/meter not including the cost of vaults and roadway crossings. In 1977, a small on grade utilidor constructed in Noorvik, Alaska cost $230.00/meter (Smith *et al.*, 1979).

In the past, one of the reasons for the high cost of utilidors (and to a lesser extent, other northern utility systems) has been the lack of uniform design standards. The lack of information dispersal has led to independent solutions being worked out for essentially similiar problems in different regions, areas, and countries (Murphy and Hartman, 1969; Gamble, 1977; James, 1980a). Engineering costs are therefore inflated because designers must design from scratch instead of utilizing suitable standard off-the-shelf components.

To minimize heat losses, utilidors would ideally be buried. In a series of pipeline tests in the late 1960s, Grainge (1968, 1969a) reported a reduction in heat losses of 43% over an exposed pipe when the same pipe was buried to a depth of one foot. Buried utilidors would also have a longer lifespan, be less costly to maintain, and would not be subject to vandalism or accidents (Cameron, 1977). Two basic problems exist however, with underground utilidors. The early underground utilidors, unless they were specially constructed to be watertight, served as infiltration galleries and collected groundwater (Alter, 1950). The water then destroyed the thermal properties of the interior insulation. Lukomskyj and Thornton (Cameron, 1977) have even suggested that the lack of a hydrophobic insulation was one of the chief reasons for the development of above ground utilidors.

In permafrost regions, other reasons may have been the difficulties of excavation. Equipment (bucket teeth) may wear excessively and groundwater in the active layer would continually fill trenches and excavations (James, 1977).

Also in regions of permafrost, another, more serious problem with underground utilidors is the destruction of the permafrost areas immediately adjacent to them. In fine grained soils, with high moisture contents, thawing would produce a slurry like unstable material, very plastic, with little or no strength (Ryan, 1980). Differential settlement will therefore occur throughout the utilidor structure and pipes and joints can break or become misaligned.

Methods that have been suggested for minimizing the damage done to underground utilidors from permafrost degradation include installing a system of refrigerated brine tracer lines to maintain the thermal balance between the permafrost and the utility piping (Giles, 1956), installing thermal piles with surface cooling fins that remove heat from the ground by natural convection (Jahns *et al.*, 1973), designing the system to tolerate a large degree of deformation (Rice, 1979), prethawing the soil, placing insulation around the utilidors (Alter, 1969), replacing the soil around the utilidor with non-frost susceptible materials, and ventilating the utilidor. The latter two methods have been used extensively in underground utilidors in Northern Russia (Krasnoyarsk Design and Research Institute for Heavy Construction, 1967). In Nome, Alaska, the underground utilidors are located in an ice rich soil, but they have been designed with enough system flexibility to withstand a large amount of displacement whenever the ground thaws (Leman *et al.*, 1979).

Installing utilidors on grade, or above grade on piles also presents a number of problems. Surface utilidors impede traffic flows and tend to unnaturally segment the community (Cameron, 1977). Vaults and road crossings, thrust blocks at deflections and special anchors for valves and hydrants must be constructed (Cameron, 1977). Heat losses are greater and the costs for maintenance are also higher since vandalism or accidents may occur as well as excessive surface wear from people using the utilidors as walkways. Elevated utilidors also require that buildings be constructed higher than normal to allow for gravity drainage of sewer flows. Finally, in fine grained, high moisture content soils, frost heaving will also occur as the active layer freezes and thaws (Ryan, 1980). In Greenland, the planning disadvantages of above ground utilidors were such that they were discontinued in the early 1950s (Rosendahl, 1980a, 1980b).

On the other hand, construction of on or above grade utilidors is easier, as is access for their maintenance. Thermal influence on the ground is also minimal (Cameron, 1977).

There are several methods in use for the freeze protection of water lines in utilidors. The most common is to trace them with central heating lines. Heat tracing of utility lines is not the primary concern however, when installing central heating (Smith *et al.*, 1979). In Inuvik, central heating was originally installed because it allowed the elimination of less efficient and fire hazardous individual building furnaces and fuel tanks, and because it also allowed a cheaper grade of fuel to be used. Waste heat for the protection of the water and sewer mains was only considered an attractive byproduct of the system (Leitch and Heinke, 1970).

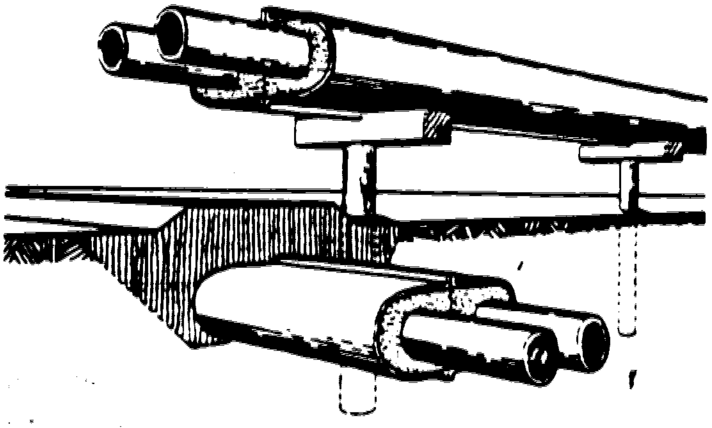
Temperature control of the water lines is difficult to achieve with constant central heating. During the summer months, the ambient temperatures will increase inside the utilidor and it may be difficult to obtain anything other than hot water from the service taps. In such situations, cold water may be eventually obtained by bleeding the taps. To counteract this high temperature water problem, an attempt was made at a U.S. Army Cold Regions Research and Engineering Laboratory facility in Alaska to heat and protect a utilidor using a recirculating domestic hot water line. The experiment failed and such an arrangement was not recommended (Reed, 1977).

Freeze protection of utility lines in utilidors have also been accomplished through such means as heat cable tracing and recirculation. At Canadian Forces Station Alert on Ellesmere Island, a single main recirculating line was placed inside an insulated, on grade, wooden box utilidor. Two emergency heating cables were also located inside the utilidor (Chong and Mattes, 1980a, 1980b).

In large open utilidors, thermal stratification can become a problem (Cooper, 1968; Smith *et al.*, 1979). Even if average temperatures inside the utilidor are adequate, instances of pipe freezing can occur in lines located too far from the heat source. Convective flows of hot air upwards along sloping sections of utilidors have also been recorded (Cooper, 1968). In such instances, baffles or spacers may be used.

Attempts have been made to correct some of the faults evident in many past and present utilidor systems through the design of prefabricated utilidors. One of these, the U-Dore system developed by Gamble and Lukomskyj, has done away with the frame or support structure of the typical utilidor. It consists of fibreglass reinforced plastic (FRP) pipe anchored or bonded in rigid polyurethane foam insulation and covered with an FRP casing. It comes in longitudinally segmented modules (see Figure 4) with system appurtenance modules for valves, hydrants, junction boxes, and service connections. A sewer and water line can be clamped together to form a utility conduit and the system can be buried or installed above ground on piles. Claims by the developer for the system are a 2/3 reduction in engineering design time and costs, a 2/3 reduction in on site contruction time and costs, plus significant heat loss reductions over a conventional

FIGURE 4



TYPICAL U-DOR CONFIGURATIONS

SOURCE: LUKOMSKYJ, P. AND GAMBLE, D. J. [1973]

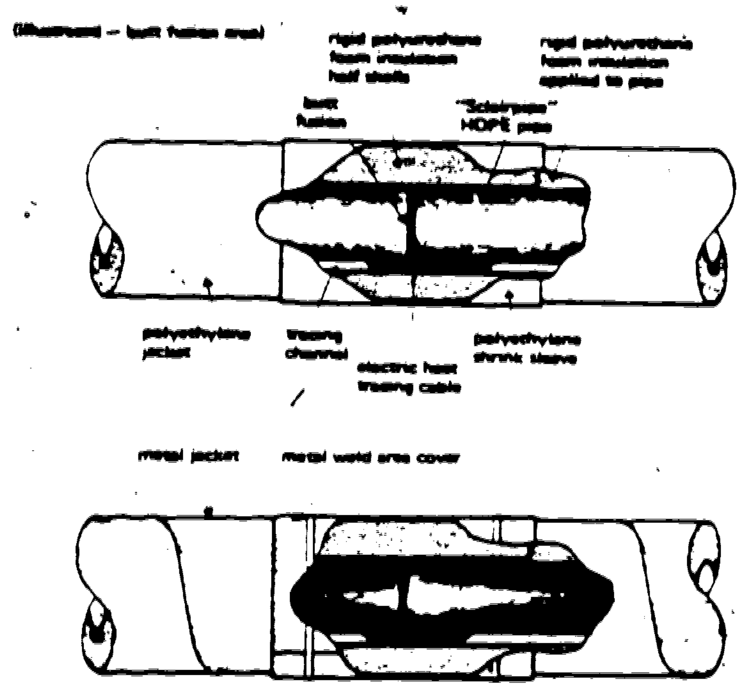
utilidor (Lukomskyj and Gamble, 1973; Gamble and Lukomskyj, 1975; Gamble, 1977; Fiberlite Products Co. Ltd., 1976). The first installation of a U-Dor® system was for a small trailer court in Inuvik.

The U-Dor® concept is similiar to that of another system which some feel may eventually replace many of the utilidor systems in the north (James, 1980a). This is the shallow buried pipe system using rigid polyurethane factory insulated high density polyethylene pipe. The major proponent of this type of installation is the Dupont Corporation with their Sclaircor® piping system (see Figure 5). Dupont's claims for Sclaircor® include 304,800 m (one million feet) of installation at over 150 northern locations by 1979 (Whyman, 1980), and 383,000 m (1-1/4 million feet) by 1981 (Fiala *et al.*, 1981). Other claims for the system are low thermal conductivity, unit flexibility to conform in unstable soils, light weight, water tightness, and the ability to withstand full and repeated fluid freezeup without damage (Dupont Canada, Inc., n.d.). Freeze protection for this type of shallow buried system is usually single main recirculation with either single service lines electrically traced, or dual service lines operated with pitorifices or recirculation pumps in each building. Backup freeze protection or thaw capability on the supply mains is provided by either heat cable tracing or with thaw tubes.

Currently, in the Northwest Territories, virtually all new water and sewer systems commissioned by the Department of Public Works employ shallow burial using Sclaircor® (Whyman, 1979b). The system is also increasingly being used in Greenland (Rosendahl, 1980a, 1980b) and the Yukon (Shillington, 1981), while acceptance in Alaska has been slower (Fiala *et al.*, 1981).

In certain instances, such as extremely rocky terrain, very unstable soils, or for military installations, utilidors may still be economic. A large, high cost utilidor employing both above ground and walk-through underground sections, for example, has been designed for Barrow, Alaska (Leman, 1980). In comparisons made in the late 1960s and early 1970s for U.S. naval installations, the utilidor was found to be an economic proposition for 4 to 6 line utility systems if waste heat or cheap heat were available or, if it were desired for esthetic reasons. For one to six line systems, single lines employing pre-insulated and heat traced piping was found to be more cost effective (Hoffman, 1968, 1971). Since that time, the weight of opinion has seemed to increasingly lean

FIGURE 5



BASIC COMPONENTS OF THE
SCLAIRCOR PRE-INSULATED PIPING SYSTEM
SOURCE: O'BRIEN, E.T. AND WHYMAN, A. [1977]

towards the latter option.

J. WATER BLEEDING

The practice of bleeding to prevent water pipes from freezing is perhaps the simplest method of protection for piped distribution systems. In its crudest form, it consists of wasting water directly from the building service taps into the sewer outlets. Alternatively, special bleeder takeoffs can be arranged from the service line to a sewer drain. The ends of supply mains and off line fire hydrants are also usually bled in order to avoid stagnant flow conditions.

The principle of operation of a bleeder system is similiar to that of a recirculation system. As water exits any given pipe section, it is continuously being replaced with more water with a higher heat content. Under equilibrium conditions, water entering a pipe section will exit with a slightly lower heat content, with the net heat losses at any pipe section not being enough to allow freezing to occur in that section. The continual influx of water and hence, heat, through the system is assured by bleeding at dead ends and service connections.

Characteristics of bleeder systems include the following:

1. a very high per capita water consumption (see Table 1). Hanson (1974), in looking at the water usage in a number of Alaskan municipalities, found average flows ranging from a textbook figure of 378 L/person/day (100 USgpcd)in Fairbanks, to 4163 L/person/day (1100 USgpcd) in Seward. He attributed the main cause for the high flows at the upper end of the scale to bleeding of water lines to avoid freezing. Figures reported by Armstrong and Given (1979) from a number of sources on communities that practice water bleeding also indicate high per capita water consumption rates (up to 9080 L/person/day);
2. because of the higher water consumption, larger water and sewer systems are required. For water distribution, larger pipe, pump, and reservoir sizes are required, and larger water treatment facilities may also be needed. Larger pumps, pipes, and wastewater treatment facilities would also be required to handle the higher sewage flows generated. Capital and O & M costs for these

TABLE 1

Water Consumption In Some Northern Communities Which Practice Water Bleeding*

Location	Consumption L/person.d	Percent of Reference Consumption	Comments	Reference
Northwest Territories				
Yellowknife	485	115	piped portion of community	Smith *et al.* 1979
Pine Point	590	140	Average daily Jan.-Nov., 1975	Reid Crowther & Partners, Ltd., 1977; also King, 1979
	1160	276	peak daily	
Yukon Territory				
Clinton Creek	1185	285	average annual	Stanley Assoc. Engineering Ltd., 1974
	680-2270	162-540	range	
Whitehorse	1680	400	average annual	
	1135-2500	270-595	range	
Dawson City	3630-9080	865-2162	range	
Dawson City	3890	2120	average daily Sept.-Apr., 1976	Stanley Assoc. Engineering Ltd., 1977
	2410	574	average daily May-Aug., 1976	
Faro	790	188	average annual	Cormie, 1979
Haines Junction	570	136	average annual	
Mayo	2730	650	average annual	
Watson Lake	820	195	average annual	
Alaska				
Anchorage	890	212	average annual	Smith *et al.*, 1979
Dillingham	1630	388	average annual	
Fairbanks	650	155	average annual	
Homer	1630	388	average annual	
Palmer	760	181	average annual	
Seldoria	680	162	average annual	
Ketchikan	1135	270	average annual	Martin, 1978
	660	157	bleeder portion	
Seward	985	235	average annual	
	345	85	bleeder portion	
Sitka	1600	381	average annual	
	285-380	68-90	bleeder portion	
Wrangell	740	176	average annual	
	195	46	bleeder portion	
Reference consumption	420		design community consumption rate	Hammer, 1977

* The water consumption rates noted are most likely due to water bleeding. However, defects in the distribution system piping or other large consumers may be responsible for the high use rate.

systems would consequently be greater;

3. the practice of bleeding on a community wide scale presupposes that a large source of potable water must be readily available to the municipality involved;
4. the practice of water bleeding allows northern communities to layout a water distribution system in a conventional manner (Smith *et al.*, 1979). There are no special restrictions on town planning, pipe burial depths can be minimal, and in localities where permafrost and its destruction is not a factor, line insulation can also be minimized;
5. large quantities of wastewater are generated as a result of bleeding. This wastewater will be cold and dilute and consequently, will be harder to treat. Physical, biological, and chemical processes (such as precipitation), are all adversely affected under these conditions (Alter, 1950, 1979; Smith *et al.*, 1979; Given and Smith, 1979; Smith and Given, 1979; Smith and Given, 1980; Balmer, 1980.) Martin (1979) has pointed out that U.S. federal requirements for treatment plants specify 85% removal of BOD and suspended solids and that whereas this would pose no difficulties for a normal strength sewage of 200 mg/L BOD, problems would arise with a dilute sewage of 100 mg/L BOD. In the former case, the effluent would be required to be reduced to 30 mg/L, while in the latter case, a reduction to 15 mg/L would be needed. Hanson (1974) has also speculated that the lower temperature wastewater would also make the sewer lines more susceptible to freezing; and
6. in communities which practice bleeding, the extravagant use of water tends to be taken for granted. Bleeders which are turned on to prevent service line failures are then frequently, out of habit or neglect, left on during the summer months when bleeding is not required. Such a practice is true in Dawson City, Y.T. (Stanley Associates Engineering Limited, 1977), and is also felt to be true of Seward, Alaska (Hanson, 1974). A factor contributing to this practice is that, in many of these communities, water is billed to consumers not on a consumptive use basis, but on a set monthly rate structure. In localities where heat traced service lines are installed, and where set water rates are prevalent, it makes more economic sense to an owner to keep his taps running rather

than operating his heat cable whenever freeze protection is required.

The water distribution systems in many of the communities that practice bleeding were installed at a time when their municipal water supplies were abundant and relatively cheap to develop. Due to community growth and water system expansion however, substantial quantities of potable water are now being required to keep these systems (such as those at Mayo, Whitehorse, and Dawson City in the Yukon) operational (Armstrong and Given, 1979). Economic considerations also did not take into account wastewater treatment costs because, in many cases, wastewater treatment was not practiced.

In Whitehorse, supply main bleeding is practiced along with service line bleeding in the older sections of the City. In newer areas, heat tracing of the service lines is the norm. In 1974, Stanley Associates Engineering Limited (SAEL, 1974) reported per capita consumptions of 1680 L/person/day (370 igpcd) on an annual average, and peak daily flows of 2500 L/person/day (550 igpcd). Together with infiltration into the sewer system in some parts of the City (Mar-Tech Municipal Pipe Services Ltd., 1978), the large volumes of generated wastewater have become expensive to handle and treat. Water bleeding is also practiced in more southern areas of North America such as Jasper and Lake Louise in Alberta (Reid, Crowther & Partners Limited, 1978). Wright and Fricke (1963) have reported on the practice in a number of mountain communities in Colorado. There, water system freezing problems exist because of the high elevation, low air temperatures, and the generally extreme winter conditions.

In some localities, bleeding is still considered an economic method of freeze protection. A complete new water distribution system has recently been installed in Dawson City, Yukon Territory. It uses recirculating, shallow buried, pre-insulated, and heat traced high density polyethylene pipe for the supply mains, but water bleeding has been retained as a system feature for the freeze protection of service lines. The dilute sewage effluent is discharged, untreated, into the Yukon River (Shillington *et al.*, 1981; Shillington, 1981).

Various calculations of the bleeder flows required in a pipeline to prevent it from freezing have been presented over the years. All of these calculations have been made using standard heat transfer equations available from such sources as the ASHRAE

Handbook of Fundamentals (1972). Because of their ammenability to providing closed form numerical solutions, steady state conditions of initial water, air, and ground temperatures and soil thermal conductivities have generally been assumed. Anderson (1959) and Constance (1964) have presented their mass flow rate calculations in the form of easy to use graphs. Stephenson (1977) went further by also presenting formulae for pipe inlet and outlet fluid temperatures. Zarling (1979) modified the standard fluid freeze-up and temperature drop time formulas given by ASHRAE by taking into account the thermal resistances of the pipe wall and air film and incorporating a Log Mean Temperature Difference (LMTD) term. The majority of the steady state heat transfer equations for fluid flow in pipes have been summarized within a common terminology framework by Thornton (1977). Derivations of these are given in Appendix 1.

III. PROJECT OBJECTIVES

Up to the present time, there has been little detailed information available on what can be done to alleviate the problems associated with existing water distribution systems that rely on bleeding as a means of freeze protection. The current project has been an attempt at remedying this situation. Its overall objective has been to identify and develop the most technically and economically viable service line/bleeder flow reduction alternatives and to determine the effects of these upon an existing bleeder system. In order to achieve this, sub-objectives were set for the project as follows:

1. using an existing bleeder installation as a study area, to develop an up to date data base on the system's development and characteristics;
2. to review and evaluate those water bleeder control alternatives that have been identified;
3. to test the most feasible alternatives in a laboratory setting; and
4. to determine, with the aid of a computer simulation model, the effects of reduced bleeder flows on the existing bleeder system studied in sub-objective 1.

Further discussion of the methodology used to achieve each sub-objective is given in the following chapter.

IV. PROJECT COMPONENTS

A. FIELD MONITORING

The existing water bleeder system chosen for study was that of Whitehorse in the Yukon Territory.

Whitehorse is the capitol city of the Yukon Territory, and as such, is the headquarters for the Territorial and Federal governments, and most large businesses in the Yukon. The Whitehorse Metropolitan Area consists of the City of Whitehorse, the adjacent subdivisions of Riverdale, Hillcrest, Valleyview, Camp Takhini, the Marwell Industrial Area, and the Alaska Highway subdivisions of McRae, Porter Creek, and Crestview (SAEL, 1974). See Figure 6.

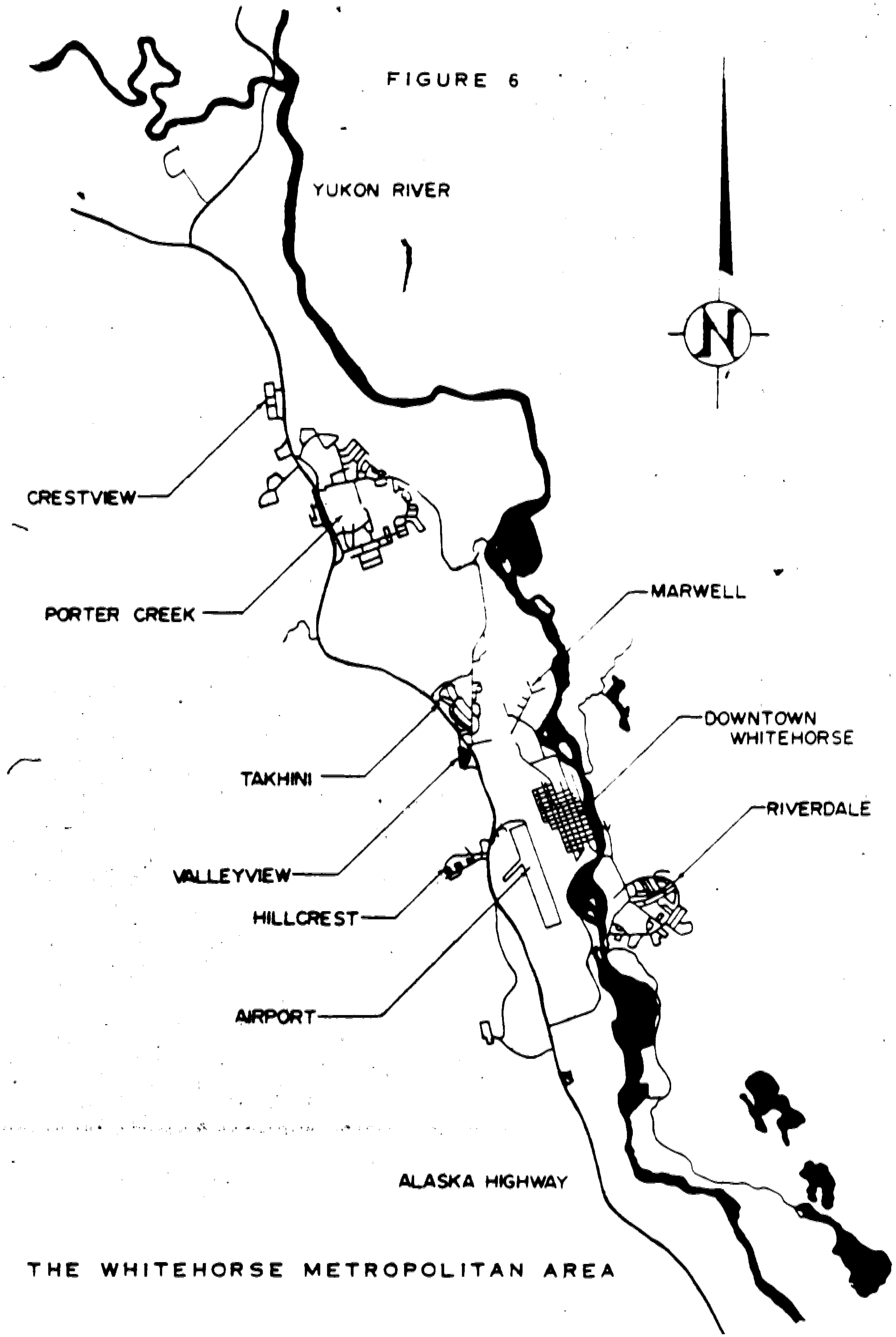
The City of Whitehorse proper (downtown Whitehorse) is situated approximately 640 m (2100 feet) above sea level on a gravel plain 3.0 - 6.1 m (10 - 20 ft) above the Yukon River which flows east of the City. The airport serving the area is located on a plateau southwest of the downtown area and has a mean altitude of 702 m (2303 feet). The yearly average temperature of downtown Whitehorse is 1.7 °C (35 °F) with a mean January temperature of -7.8 °C (18 °F). Total average annual precipitation is 26 cm (10.24"), 14.2 cm (5.6") of which is rainfall, with 127.7 cm (50.3") of snow. There is a frost free period of 78 days in the City proper and 45 days in the subdivisions located on the plateaus. The City itself is located in a permafrost free area, however, islands of permafrost have been encountered in the surrounding area (City of Whitehorse and Whitehorse Chamber of Commerce, n.d., Lotz, 1961).

The Whitehorse Metropolitan Area is serviced year round with chlorinated and fluoridated piped water from the Yukon River. In the winter, to maintain water temperatures in the system, warm groundwater, constituting 40 - 50% of the total flow, is mixed with the river water.

Bleeding is practiced throughout the system except for the subdivisions of Porter Creek and the Takhini Trailer Court which have a network of heated and recirculating mains.

From the 1971 Federal Census, the population of the Whitehorse Metropolitan Area was 11,217, while estimates in 1978 derived from ongoing tallies of public health

FIGURE 6



THE WHITEHORSE METROPOLITAN AREA

records placed the population at 15,394. 1981 census figures were not available at the time of writing.

The existing data gathering portion of the project was carried out during a field trip to Whitehorse from 19 to 23 November, 1979. A subsequent follow-up trip was made to Whitehorse from 17 to 19 December, 1980, and additional information was also subsequently obtained from City of Whitehorse Engineering Department technicians.

Work conducted during the field trips included:

1. making a survey of some representative water bleeders in municipal, domestic, and commercial locations;
2. obtaining seven and a half years of water pumping records from the City of Whitehorse Engineering Department library; and
3. examining reports, documents, and records in the Engineering Department library for information pertaining to the historical development and the current state of the Whitehorse water distribution and sewage collection system.

Data collected during this portion of the project was refined and analyzed back in Edmonton.

B. BLEEDER ALTERNATIVES - INITIAL REVIEW

From an analysis of data obtained about the Whitehorse bleeder system and a review of the technical and economic requirements for preventing system freeze ups while at the same time reducing water wastage, various alternatives to conventional bleeders were identified for further study. Criteria for evaluating these alternatives were also established. These were as follows:

1. compatibility with existing infrastructure. Implementing a given alternative should not involve any major construction modifications to the existing water distribution system;
2. public health considerations. Safeguards should exist with any alternative to prevent the possibility of contaminating public water supplies;
3. ease of installation, operation and maintenance. Ideally, installation should be quick and easy, and operation of any alternative should be either automatic or under central control. Given that separate bleeders exist for each service

connection in a water distribution system however, this may not be possible without large capital expenditures. In any event, owner involvement once a bleeder control is installed, should not extend beyond turning a valve or flicking a switch on or off twice a year Maintenance intervals should also be on the order of years, and

4. ease and cost of manufacture.

Only one previous consideration of bleeder alternatives exists in the literature. In 1979, after discussions with various individuals and using a slightly different set of criteria, Armstrong and Given (1979) identified various alternatives to existing service line bleeding. These are listed in Table 2.

As a starting point, the Armstrong and Given alternatives were evaluated Discounting the do nothing alternative of continued full bleeding, several problems can be seen with attempting to conduct a laboratory study on some of the options listed

The spot check with penalty option for bleeder operators who bleed too much water or when it is not required, was discounted because it is a practice that must be instituted in an actual situation in the field.

Similiarly, while installing water meters along with instituting a consumptive use water rate structure would undoubtedly provide an economic incentive to conserve water (Cameron and Armstrong, 1979), this alternative was deemed outside the scope of the present project. Testing the hypothesis would also require an actual field situation and there would be political overtones associated with attempting to institute water metering in an area used to paying a flat rate for water use and in which it is therefore viewed as an inviolable right. The standard municipal engineering literature (Fair, Geyer and Okun, 1966; Clark, Viessman and Hammer, 1971) all state, however, that the institution of metering will tend to reduce water use

Due to the expense involved in excavation, exterior heat tracing of an existing service line would probably only be feasible if the service line were in need of repair or replacement. In any event, no laboratory testing of already service proven heat trace cables was deemed necessary.

No excavation would be required if a heat trace cable were installed inside an existing service line Thermal efficiency would also be maximized by this placement

TABLE 2

ALTERNATIVES FOR REDUCTION AND ELIMINATION OF SERVICE LINE WATER BLEEDERS

Alternate Number	Description
	Continued Bleeding
1A	Continue Full Bleeding
1B	Spot Checks with penalties
1C	Meter Installation
1D	Bleeder Flow Restrictor
1E	Thermostatically controlled bleeder value
1F	Timer bleeder value
	No Bleeding
2A	Heating cable in service line
2B	Plastic tube recirculation
2C	Adjacent dwelling recirculation
2D	In-house tank and recirculation
2E	Service line replacement

Source: Armstrong, B.C. and Given, P.W.
Preliminary Analysis of Alternatives for Upgrading Service Line Water Bleeders May 1979.

There are a number of adverse problems with this alternative however. In 1979, no commercially available constant watt/foot heat tracing cable was CSA approved for use while immersed in water (Whyman, 1979). Perhaps this was due to the permeability of the jacket and the vulnerability of the end caps and splices. A problem would also exist with obtaining water tight seals whenever valves and other fittings have to be bypassed. Mineral insulant resistance cables are available for use under submerged, in-pipe conditions, but the specifications for their use require the return loop to be placed outside the pipe (Armstrong and Given, 1979). To do this, excavation is again required and if this is done, it would then be easier to apply an exterior heating cable.

The adjacent dwelling recirculation alternative would consist of establishing a pump operated recirculation loop between adjacent buildings and then returning the water to the main. This option was rejected for laboratory study because service line recirculation technology has already been proven. Another problem with this alternative is that of the split cost and control dilemma that would arise from the usual situation of different ownership between two adjoining properties. Again, this was regarded as a largely political problem outside of the scope of the present project.

The plastic tube recirculation option would consist of installing a small plastic or copper tube into the service line and using individual pumps to recirculate the water back to the supply main. Problems with this option were foreseen with possible vibration loads inside the pipe, the need for fittings or some other means of bypassing valves such as curb stops, and the cost of installing the system plus a backup solenoid valve.

From this initial evaluation then, the service line bleeder alternatives, modified slightly, chosen for laboratory study, were:

1. a temperature control device;
2. a timer device;
3. an orifice or flow restricter; and
4. a storage tank that would fill from an existing bleeder line before discharging to a sewer drain.

Of the four devices, three of them rely on the principle of intermittent bleeding while the orifice can be used to restrict bleeder flows to a desired minimum figure.

A fifth bleeder alternative was later chosen that might have industrial or large commercial applications Basically, this would consist of a large pressurized storage tank that would fill with water during periods of high water distribution system pressures; and discharge it back to the supply main whenever the system pressures drop

C. LABORATORY FACILITIES

The laboratory testing phase of the project as conducted using a 1.65 m wide by 2.25 m long by 2.13 m high insulated cold room The refrigeration controls on the cold room were rated at −40 °C, but as was determined during testing, were incapable of dropping interior temperatures below approximately −26 °C.

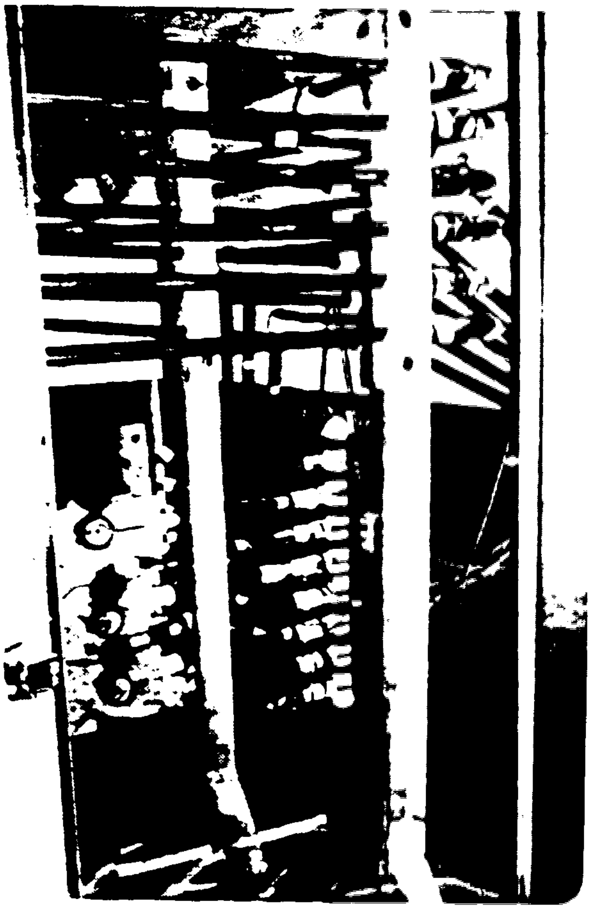
Inside the cold room, a set of parallel recirculating copper pipes mounted on timber supports were set up (see Figures 7 and 8) Arrangements were made such that parts of the pipe network resided outside the cold room In theory, the temperatures inside the cold room were set to simulate in-ground service conditions, while the piping outside the cold room represented the service conditions inside a heated building.

All interior piping was covered with a 9.5 mm (3/8") thick layer of closed foam cell plastic pipe insulation with two layers of the same being applied at every elbow and union. All seams were closed with either contact cement or weatherstripping tape

In initial testing, a recirculation cycle started with water from a constant temperature bath being pumped through a 25.4 mm (1") i.d. copper feeder pipe leading to the cold room Once inside, the water was distributed by a copper manifold to six 12.7 mm (1/2") i.d. copper lines. These pipes were looped in parallel through the cold room before exiting Gate valves on the pipe manifold controlled the flow into each pipe Outside the cold room, a different bleeder control device was mounted on each of four of the pipes while a fifth pipe was used as a bleeder control (i.e. constantly bleeding), and a sixth one was retained as a spare

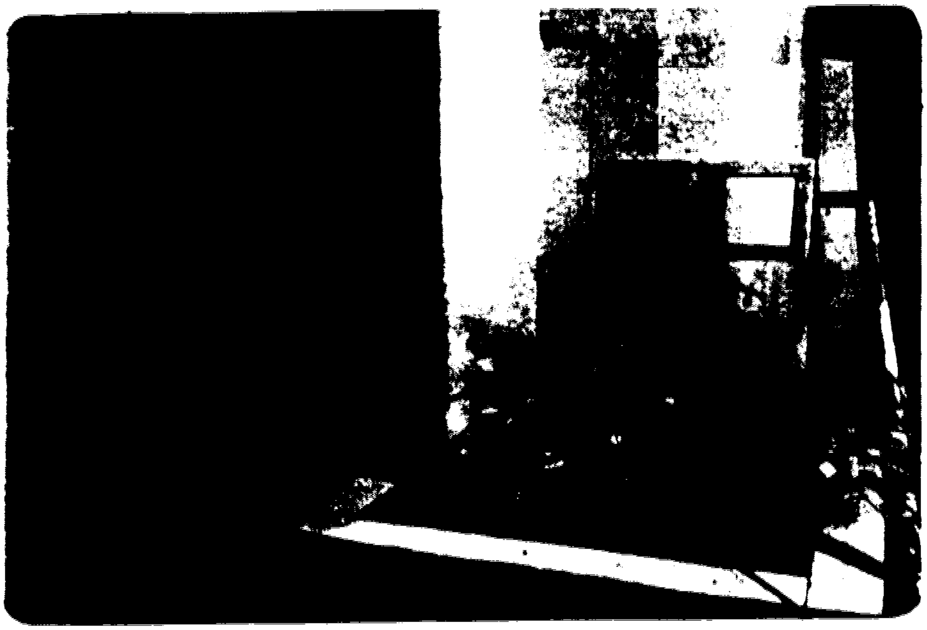
Outside the cold room, all six pipes were reduced to 6.4 mm (1/4") copper tubing (3.2 mm or 1/8" i.d.) which freely discharged into an insulated partly covered stainless steel holding tank From this the water was pumped into the constant temperature bath where the cycle started again

FIGURE 7



COLD ROOM INTERIOR PIPING

FIGURE 8



COLD ROOM EXTERIOR PIPING

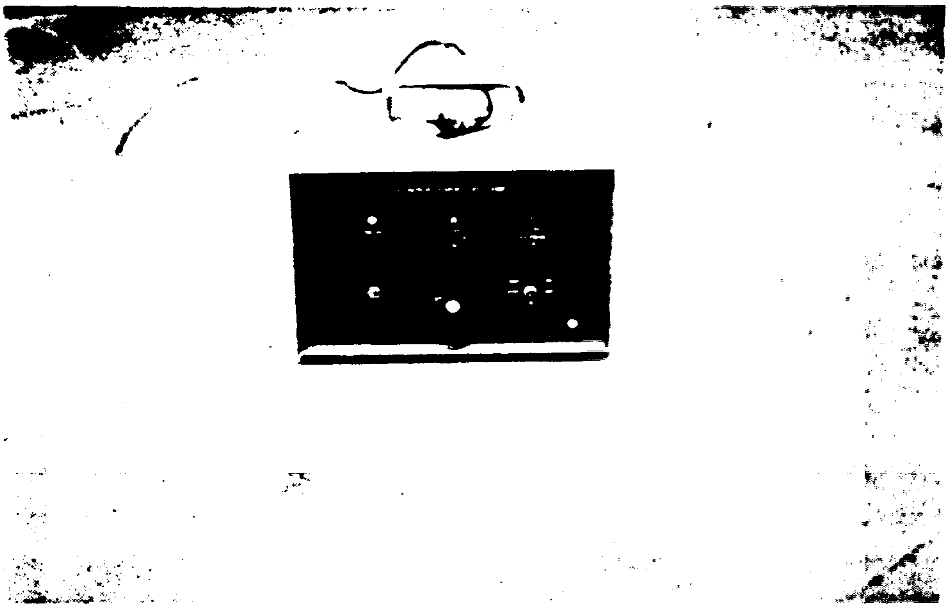
In the first four cold room test runs, four different bleeder control devices were placed on the system. These were the temperature controller, a timer device, an orifice plate, and a holding tank.

The temperature control device was a device designed to allow water bleeding whenever the service line temperature fell below a specified minimum. The device consisted of a temperature sensor (thermistor) and a solenoid valve connected together via a circuit board. See Figure 9. The solenoid valve was set to stay open in the event of a power failure. In an actual situation, placement of the solenoid valve would be at the end of the existing bleeder line, while the temperature sensor would be positioned somewhere on the service line. The ideal (i.e., the coldest) location for the thermistor would be where the service line runs underneath a sidewalk or some other place with little or no snow cover. In the laboratory situation, the thermistor was placed inside one of the bleeder lines just at the point where it exited the cold room, while the solenoid valve was located at the discharge end of the same line. The device was operated by the circuit board which was calibrated to trigger open the solenoid valve at a preset input signal (temperature) sent to it from the thermistor. Calibration of the device was achieved by placing the temperature sensor in a beaker of ice and water. The temperature of the ice/water mixture was raised or lowered by stirring with a glass thermometer.

The timer option was a device aimed at allowing bleeding on an intermittent or timed basis. In the lab, it consisted of a solenoid valve placed on the end of one of the bleeder lines exiting the cold room and triggered by a timer which alternated equal periods of bleeding and non-bleeding. Two timers were used during the testing period, one a commercial model and one a custom made unit built from standard modular components. See Figure 10.

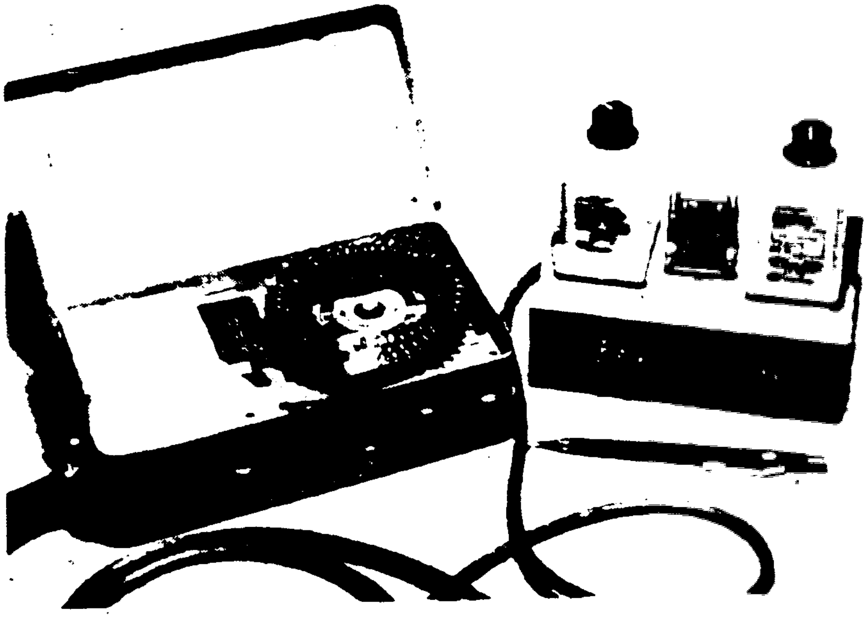
In theory, the time interval set between periods of bleeding would only depend on the amount of time taken for the temperature inside a service line to drop to 0 °C under no flow conditions, while the bleeding period need only be as long as would be required to replace the cold water in the service line with warmer water from the supply main (see the calculations in Appendix 1). In actual fact, with the limitations of inexpensive, off-the-shelf timers, it is more practical to set periods of non-bleeding equal in length to periods of bleeding. If such were the case, bleeder flows from each service

FIGURE 9



TEMPERATURE CONTROL DEVICE AND SENSOR

FIGURE 10



THE TWO TIMERS USED IN LABORATORY TESTING connection would still be reduced by 50%.

Again, as a safety precaution, the solenoid valve used with the timer device was set to allow continuous bleeding in the event of a power failure.

The orifice plate was the simplest device tested in the laboratory and consisted solely of a metal plate machined to fit into a 12.7 mm (1/2") i.d. brass union set into a bleeder line and used to obstruct the flow (See Figure 11). Dependent on line pressures, the size of orifice drilled into the plate can be varied to regulate the amount of water bled. Sample calculations on determing orifice sizes are given in Appendix 2. In the dual main recirculating system in Yellowknife, flows in the service loop are maintained by the insertion of an orifice plate into the line to create differential pressures.

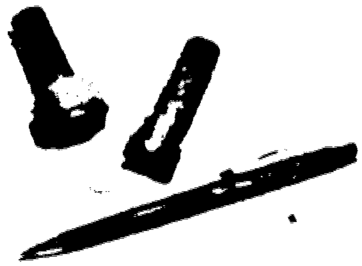
The drainage tank option consisted of a small, insulated steel tank connected to a three way solenoid valve attached to another of the bleeder lines exiting the cold room (See Figure 12). Two variable set level detectors were placed inside the the tank and these were connected to a circuit board. Below the first level detector, the circuit board triggered the valve to allow water from the bleeder line into the tank. When the water level in the tank reached the second detector, the valve was triggered to shut off the incoming water and allow the tank to drain.

In this case again, in a field situation, the critical variable is the time taken for a service line to freeze under stagnant flow conditions.

After simultaneous testing of the four bleeder alternatives was carried out, the cold room set up was modified to test a fifth alternative. This was done because testing of the fifth device required an extensive amount of counter space and its operation was incompatible with the other four alternatives.

In a field situation, this alternative would consist of a large pressure tank which would fill with water from the bleeder line during periods of high distribution system pressures (say during the day), and release it back to the supply main during periods of low system pressure (say at night). Operation of the tank would be with a pressure switch connected to two solenoid valves (see Figure 13). At high system heads, the normally open valve on one line would allow flow into the tank at the normal bleeder rate. When the tank pressures reached a certain specified amount, the pressure switch would close the first valve and open the second, normally closed valve to allow the tank to drain

FIGURE II

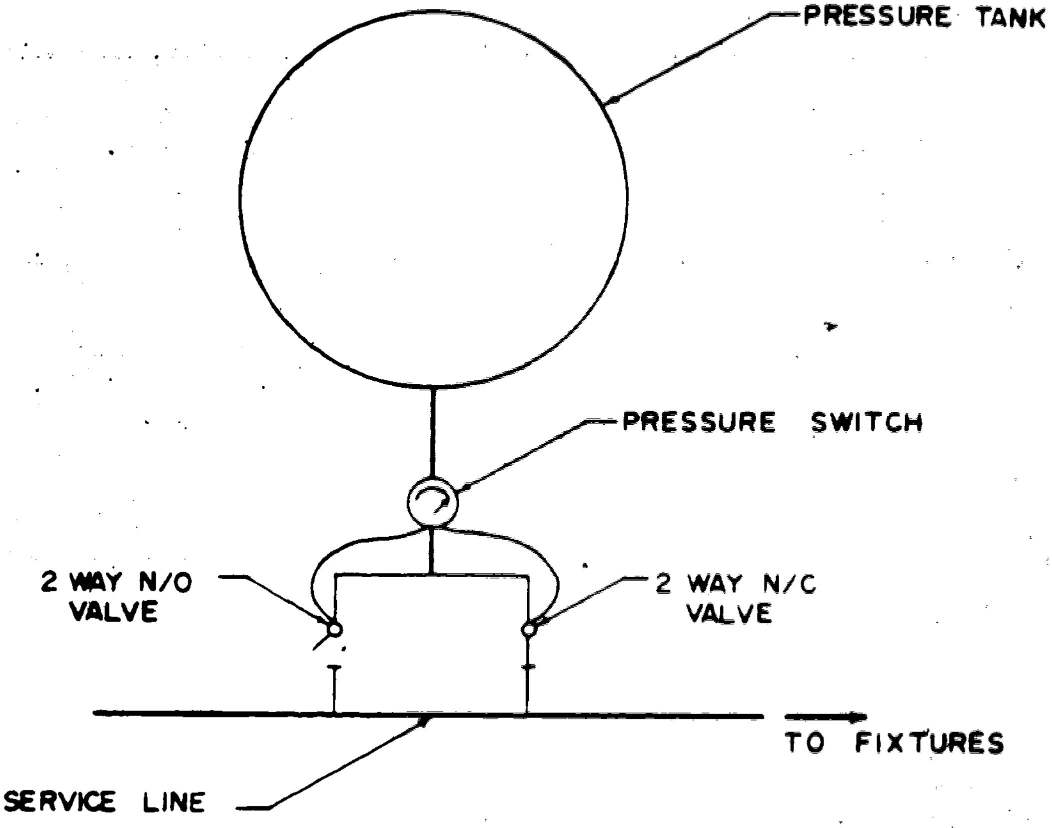


ORIFICE PLATE AND 1/2" BRASS UNION

FIGURE 12

DRAINAGE TANK WITH LEVEL SENSORS

FIGURE 13



THE PRESSURE TANK OPTION

FIELD SET-UP

back through the return line into the service pipe to the supply main.

A slightly different set up was adopted in the laboratory to test this concept. Because the circulation pump operated continuously, it was decided to allow the pressure tank during drain periods to empty outside the cold room into the steel holding tank rather than attempting to operate against the pump. See Figure 14.

Another modification in the cold room set up was made when it was decided to obtain information on the performance of other sizes of pipe. Accordingly, a number of the 12.7 mm (1/2") i.d. interior pipes were replaced with 19.1 mm (3/4") and 25.4 mm (1") i.d. lines.

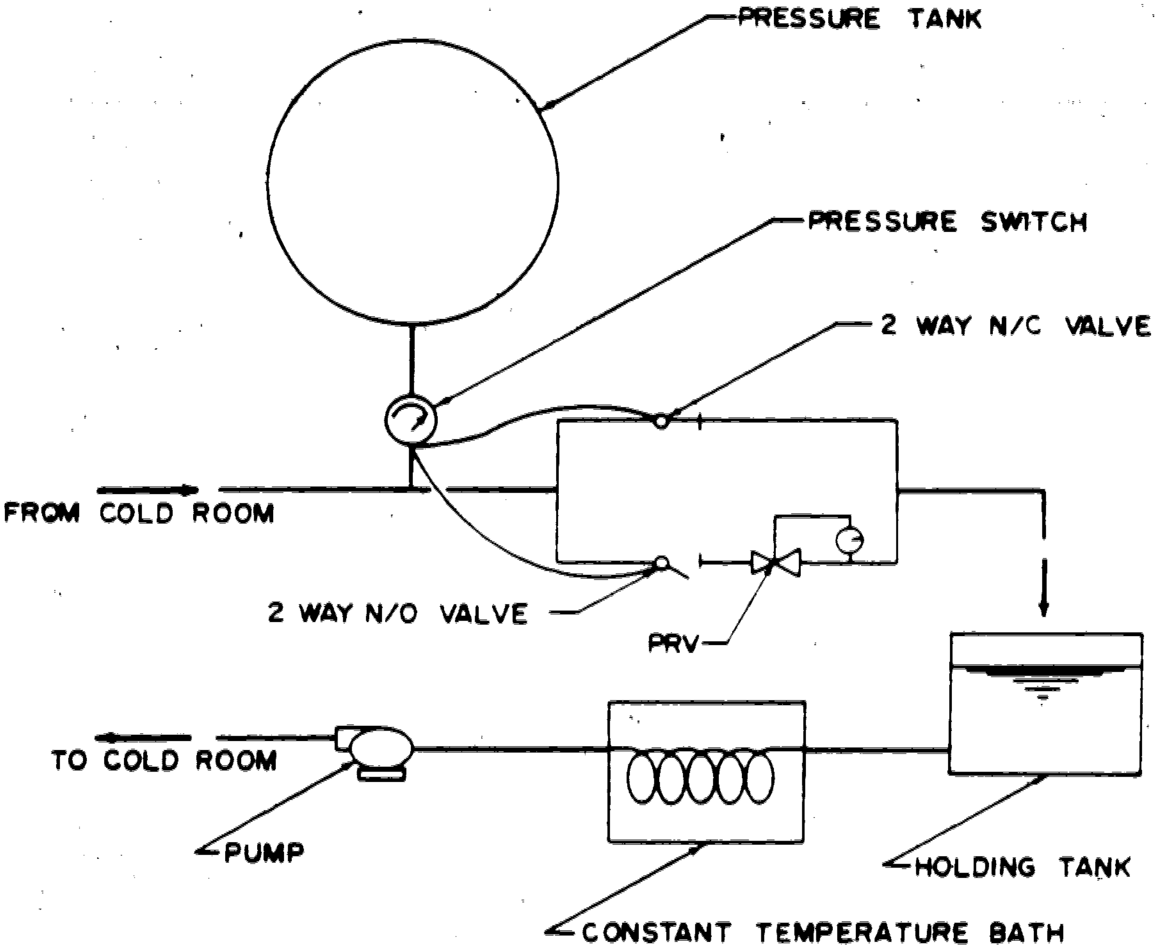
The data collected during laboratory testing consisted of temperature, pressure, and flow recordings. Temperature information was collected using Type T thermocouples (copper and constantin). Using a T junction hydraulic fitting, one thermocouple was placed in each pipe near its discharging end, just inside the cold room. For water tightness, the sensing end of each thermocouple was covered with self fusing butyl rubber pressure tape and sealed with a layer of silicone caulking and a layer of epoxy cement. This had the effect of causing a slight time delay in the temperature readings, but the effect was considered unavoidable for the sake of maintaining a water tight seal. In later testing, the T junction hydraulic fittings were replaced with a 1/4" tube X 1/8" (6.4 mm X 3.2 mm) NPT male connector threaded and soldered directly into the pipe.

In addition to measuring the water temperature in each pipe, a number of thermocouples were placed on the pipe insulation outside of where an interior pipe thermocouple was situated. By using the paired temperatures thus obtained, it was hoped to calculate heat flux values. Unfortunately, the low degree of refinement of the temperature readings (0.1 °C) did not allow the calculations to be made.

Pressure values in each pipe were obtained using pressure transducers connected to each line via 6.4 mm (1/4") copper takeoffs. These were placed just outside the cold room and were uninsulated. Each transducer was attached to a carrier demodulator used to convert the AC output into a usable DC voltage.

Flows in the system were measured using modified household water meters. The modifications consisted of adding a device attached to the face of each flow meter which picked up the magnetic pulses generated by each turn of the reading dial. A signal

FIGURE 14



THE PRESSURE TANK OPTION

LABORATORY SET-UP

conditioner was then used to convert the magnetic pulses to voltages A mechanical flow accumulator display counter was also present on the face of each dial.

Due to space constraints, a flow meter was placed on each line inside the cold room. These were then initially covered with a two inch layer of fibreglass insulation. After initial testing, a layer of foam pipe insulation was attached to each meter before a blanket of fibreglass was wrapped around it. The flow meters were not susceptible to damage by freezing. Each meter was equipped with a replacable bottom plate with preformed stress lines in it which would crack open if the water in the meter froze and expanded.

All the information generated by the various types of instrumentation was inputted into a Fluke 2240B data logger which could be programmed to print out readings at any one second time interval up to 24 hours (see Figure 15). The flow and pressure readings were outputted as voltages which then had to be manually converted into their representative units, while a special option on the data logger permitted temperatures to be printed out directly in degrees Celcius. Calibration of the pressure transducers was accomplished using a pressure gauge set in psig as a standard while calibration curves for the flow meters (in igpm) were developed following a series of timed flow tests on each meter.

D. COMPUTER MODELLING

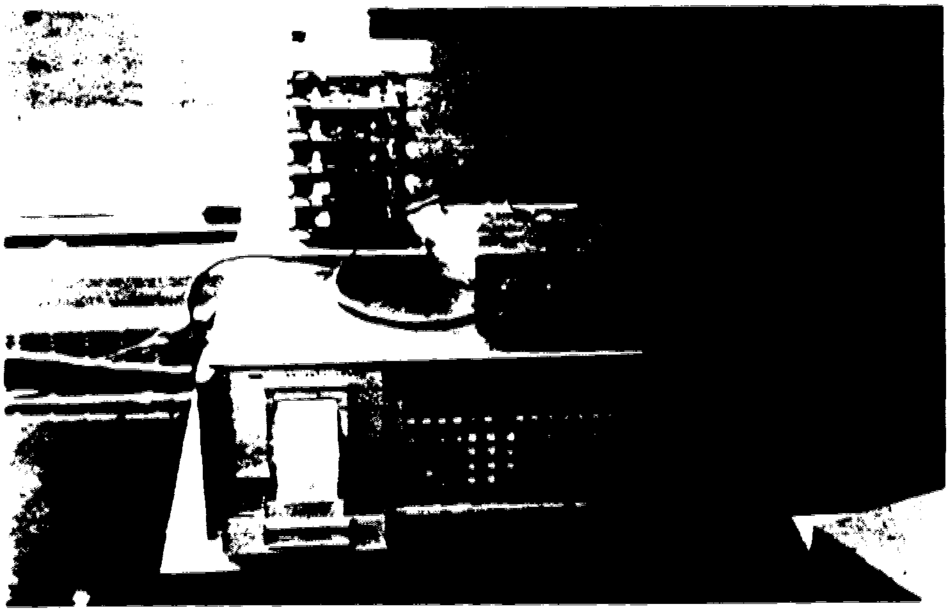
During this phase of the project, an attempt was made to determine the effect that reducing bleeder flows would have on the Whitehorse water distribution system.

For this work, rather than attempting to develop a new hydraulic and thermal computer model, a thermal package employing steady state heat transfer theory was added to the hydraulic portion of an existing propietary piping analysis model. This was done because of time constraints and the limited programming experience of the author.

The model chosen for use in the project was Hydrotherm, a computer program series developed by J. Stewart for Associated Engineering Services Limited (AESL) in Edmonton. Hydrotherm was chosen for a number of reasons, among which were:

1. accessibility. The model was preloaded on to AESL's in-house computer in Edmonton ready for use. The model developer was also in Edmonton and

FIGURE 15



FLUKE 2240B DATA LOGGER

available for consultation;

2. prior northern thermal application. AESL had previously used Hydrotherm to determine the heat loss rates of the utilidor systems in Inuvik, N.W.T. (Hull, 1980). The program results there had been checked against actual on site conditions and had compared very favourably (Stewart, 1981);
3. applicability to Whitehorse conditions. AESL had recently completed a waterworks, sewerage, and roadways engineering analysis for the City of Whitehorse (AESL, 1979), in which Hydrotherm had been used to conduct hydraulic analyses of a skeletonized version of the water distribution network.

Hydrotherm consisted of nine active programs which ran in an automatic, self-generating order. It was claimed by the developer to be capable of simulating all hydraulic and thermal aspects of a piping network (Stewart, 1981), although prior to the present project, all thermal analyses done with it had been on utilidor systems.

In general, the program ran in an iterative mode where pressures, flows, and temperatures were calculated and corrected from one iteration to the next. The program set up a system of simultaneous linear equations for each piping network analyzed, assumed initial values (either specified or default), and solved the set of linear equations. The initial values were then corrected and the linear equations resolved. Reiteration terminated when the corrections all fell within a set tolerance.

Hydraulic parameters were simulated using the Darcy-Weisbach and Colebrook equations. A set of nodal pressure correction equations was set up using the first and second terms of the Taylor Expansion Series and mass flow rates were solved as a function of the pressure differentials. Network equipment such as pumps, check valves, reservoirs, and hydrants could also be simulated. Network loads were simulated by setting drawoff rates at the desired nodes. Flow calculations were all done using mass flow rates (lbs/min) to account for descrepancies due to temperature and pressure sensitive fluid viscosities and densities. All values were then converted to USgpm and feet of head.

Thermal calculations for a piping network were carried out after a hydraulic balance had been obtained. Once a hydraulic balance was achieved, hydraulic corrections were made using the temperature corrected values for fluid densities and viscosities. The process was then repeated until the model was balanced both thermally and hydraulically. Heating equipment such as boilers could also be simulated.

Originally, Hydrotherm was only set up to thermally analyze above surface pipes using the steady stateheat loss equations summarized by Thornton (1977). The four types of networks that could be handled were bare and insulated pipes in air, and single and multiple pipe utilidors.

For project purposes, a thermal package was added to Hydrotherm to handle the situation of uninsulated pipes buried in thawed or frozen ground. In order to obtain closed form explicit solutions amenable to numerical computations, use was made of the steady state heat transfer equations for flow in pipes (see Appendix 1). Direct calculations of the longitudinal pipeline temperature drops rather than the cross sectional heat loss rates were also made.

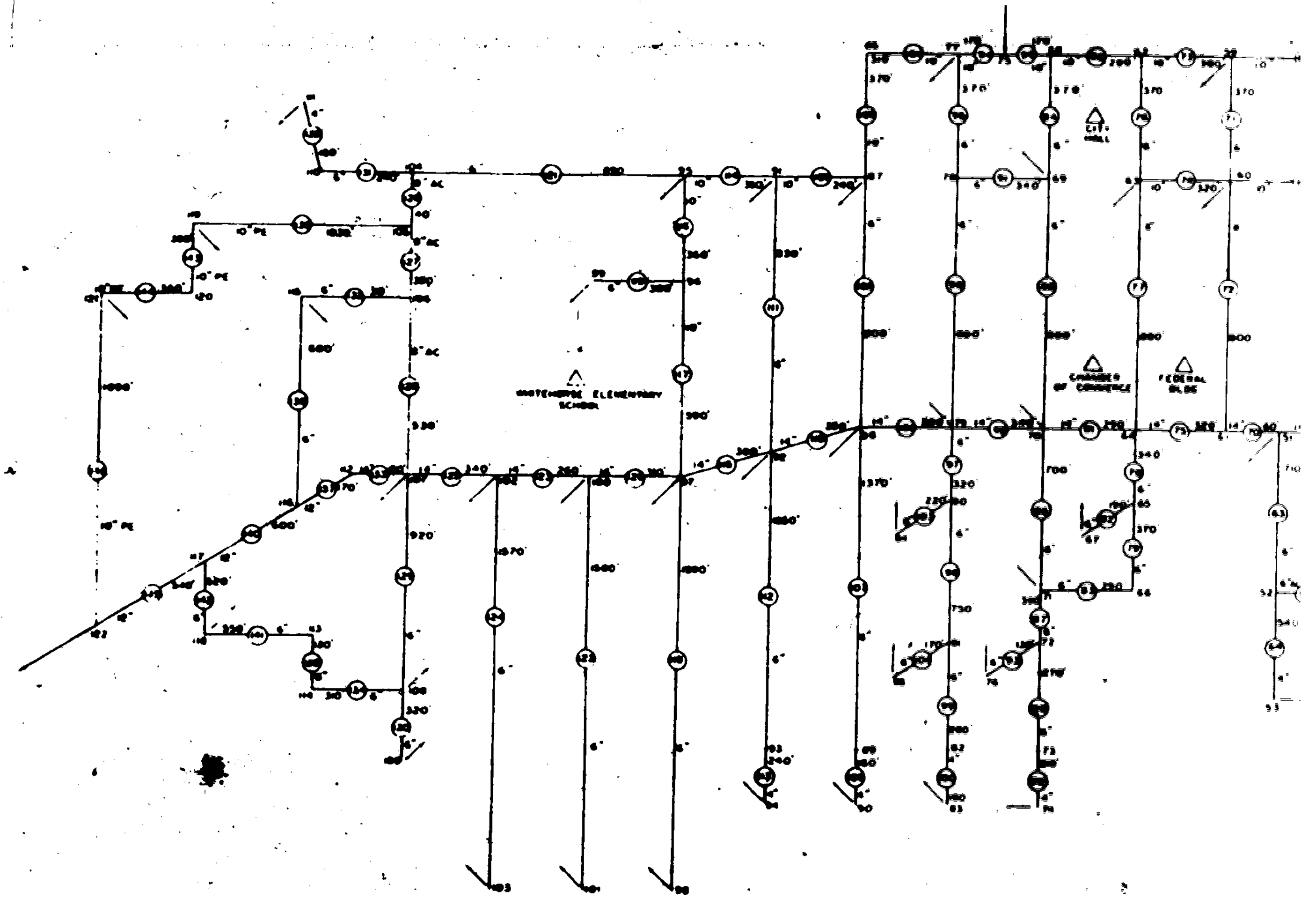
Downtown Whitehorse was the section of the City chosen for computer analysis. It was chosen for a number of reasons, among which were:

1. this was the oldest section of the City with the most established water distribution system. It had the best mix of land uses and included residential, commercial, institutional, and system water bleeders;
2. information was more readily available on this section of the water distribution system eg., detailed contour maps of the City were not available from the City of Whitehorse Engineering Department, however, hydrant elevation records were found for the downtown portion of the City from which the elevation heads necessary as input information for Hydrotherm could be deduced. Similiarly, recent soil temperature records were available from the City. To that point in time however, thermocouples had only been installed at locations in the downtown and Riverdale areas;
3. for network analysis purposes, downtown Whitehorse was a well defined and easily separated area, with only two inflow lines and one outflow pipe.

The piping network was formulated from the City of Whitehorse water and sewer as-built drawings. Rather than skeletonizing the system by replacing a series of smaller pipes with one larger equivalent line, as is prevalent in most hydraulic analyses, the entire network of pipes was retained down to the service connection level (see

Figure 16). This resulted in a network of 146 pipes and 124 nodes. Pipe lengths were measured from the water and sewer plans, and inside diameters were determined using the given nominal sizes in the plans and the appropriate pipe size tables for the given material. Only a few figures for pipe burial depths were available, and it was therefore decided to use a single conservative estimate of 1.5 m (5 ft) for the entire network.

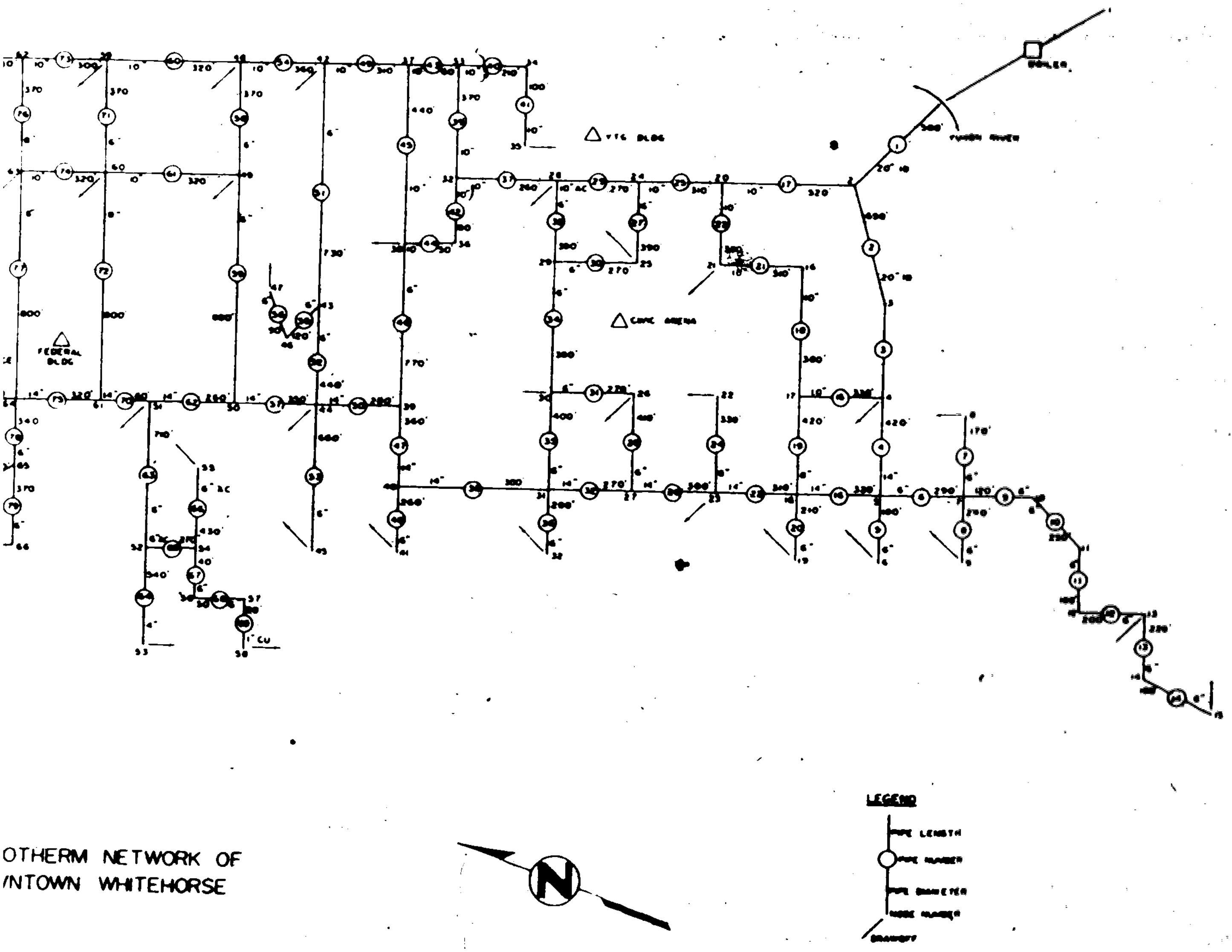
FIGURE 16



HYDROTHERM NETW
DOWNTOWN WHITE

1 of

FIGURE 16



OTHERM NETWORK OF
NTOWN WHITEHORSE

2 of 2

V. RESULTS

A. BLEEDER SURVEY

During the first field trip, a survey was conducted of 18 representative service line and supply main water bleeders in commercial, civic, and domestic locations. Six more bleeders were sampled on the following field trip, and a further 13 were surveyed by City of Whitehorse Engineering Department staff and the results obtained in early 1981.

Information obtained on each bleeder installation examined included its location, the type of bleeder (i.e., how it was set up and controlled), and a brief description of the physical conditions. A picture was taken of each installation, and where possible, temperatures (both water and ambient), flows, and line pressures were also taken. This data is given in Appendix 3.

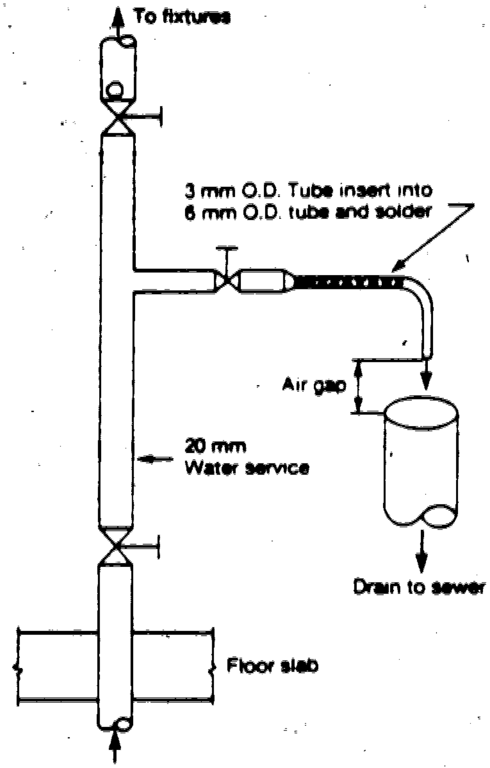
The survey, as conducted, did not represent a statistically valid sampling; in domestic and commercial locations where owner permission had to be obtained for access, this became the governing criteria for examination. Nevertheless, it was felt by the City engineering staff who took part in the survey that examples of most of the existing bleeder variations were included.

From the survey photographs and descriptions, it can be seen that there are many variations in the types of bleeder set ups. A 'typical' domestic one will consist of a 12.7 mm (1/2") i.d. copper takeoff from the service line in the building. This will be reduced to a 6.4 mm (1/4") o.d. copper line leading to the sewer drain. There may or may not be an air gap between the drain and the bleeder. Flow control is usually maintained via a petcock or gate valve. See Figure 17.

System bleeders will typically consist of 12.7 mm (1/2") takeoffs from the supply main or a hydrant. This will run to the sewer main in a manhole and will be controlled by a curb cock type valve with a vacuum breaker.

Whitehorse has a City bylaw (No. 180) which states that bleeder flows are to be limited to 1/3 igpm (1.5 L/min), however, since the bleeder controls are usually set by hand based on past practice or 'whatever sounds good' to the owner, large variations exist in the bleeder flows. The use of only a simple petcock or gate valve to control the

FIGURE 17



SCHEMATIC OF TYPICAL WHITEHORSE HOUSEHOLD BLEEDER flow also does not facilitate bleeder setting to a given rate, since it would require the owner to somehow obtain an accurate measurement of his bleeder flows. This could easily be done with a watch and a measured container, but for many people, the procedure would be too bothersome. The difficulty of setting bleeder flows accurately can also be extended to the system bleeders on the supply mains.

The quality of plumbing and bleeder set ups varied considerably in the survey. Some were obviously home rigged affairs, or set ups modified by persons ignorant or uncaring about plumbing or public health standards. In some instances (see tests No. 28, 30, 31, 33, 35), the controls were non-servicable. Several instances of cross connections (tests No. 11, 24, 26, 31) were also found. In some cases, there were no air gaps between the discharge end of the bleeder and the drain, or where a bleeder led to a pipe drain, the owner had attempted to seal the end into place. Conceivably then, in reverse flow situations, public water supplies could become contaminated. Similiar situations were even observed in the manholes examined.

The flow data from the bleeder survey has been summarized by type in Table 3. Given that water line freeze ups were not mentioned as being a problem in the set ups examined, even in those with the bleeder not turned on, or with flow rates set below 1.5 L/min (1/3 igpm), it can be surmised that flows in excess of those required for freeze protection were being maintained in a sizable number of locations. If such were the case, with the entire water bleeder system, the implications on system water wastage become enormous.

B. WATER FLOW RECORDS

The daily City of Whitehorse water pumping records were obtained for the years 1973 to 1980. These have been refined and reduced to daily averages by week and are presented numerically and in graphical form in Appendix 4.

At the present time, the Whitehorse water supply is taken from two sources, Schwatka Lake and a series of six warm water wells, only four of which are normally used. Schwatka Lake is an impoundment lake formed by the placing of a dam across the Yukon River in Whitehorse by the Northern Canada Power Commission in 1955-56 (Sack, n.d.). In 1979, the Schwatka Lake 55.9 cm (22") diameter intake and transmission

TABLE 3

Bleeder Survey Summary

Type of Location	Water Bleeder Rate L/min		Number of Locations	
	Range	Mean	Examined	Flow Tested
municipal government buildings	.32-5.23	2.02	5	4
manholes	15-40	28.3	3	3
commercial buildings	.50-4.54	2.43	6	5
domestic dwellings	.82-7.50	3.07	16	14
institutional buildings	.25-20	6.75	7	4
		mean = 5.84	Σ = 37	Σ = 30

line was rated at 27,240 L/min (6000 igpm - AESL, 1979) This was considered to be sufficient to meet the City's peak day demand until 1983 (AESL, 1979).

No treatment other than chlorination and fluoridation is done on either the well water or the lake water. The temperature of the incoming Schwatka Lake water is monitored daily and whenever it falls below approximately 4 °C (38° - 40 °F), warmer well water at 5 °C (41 °F) is added to it to maintain the temperature of the resulting mix at about 3° to 4 °C. Reheating of the water in the system is also carried out at various points.

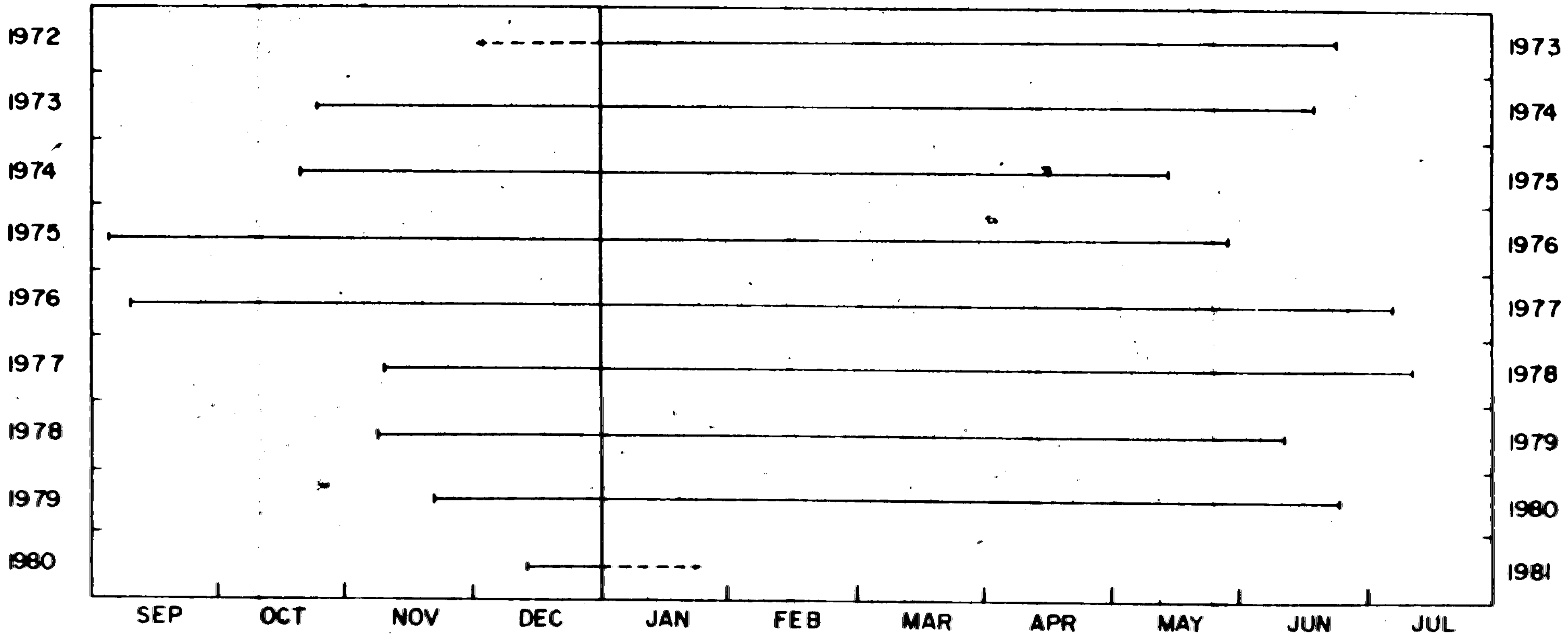
During the summer, to lower the water table for construction purposes, water is also periodically pumped from the wells. In 1979, the wells were rated at 7877 L/min (1735 igpm - AESL, 1979).

During the years 1973 - 1980, depending on weather conditions, the pumping of well water for pretempering was initiated from as early as September 3, in 1975, to as late as December 12, in 1980. Periods of pretempering have lasted from as little as 7 1/4 months to as long as 9 1/2 months (see Figure 18 and Table 4). The total quantities and rates of well water pumped have also fluctuated considerably from year to year, with 1978 – 1979 being the lowest on record.

Some general trends are evident from examining the flow graphs. Unlike typical urban communities in more temporate climates, Whitehorse displays a reverse annual flow variation, with high flows being exhibited during December and the first six months of the calendar year and the low flow period occurring from August to November. This cycle roughly coincides with the cycle of water bleeding in the City and also is consistent with the soil temperature records compiled by the City Engineering Department which show the deepest frost penetration occurring in mid to late spring. Transition periods in the cycle occur due to tardiness in turning off bleeders in the summer and the cycle is also complicated somewhat due to the practice of summer well pumping.

As can be expected from an increasing population, overall water usage has increased in Whitehorse during the last eight years. This is evidenced by overall increases in consumption during the low flow periods when it is expected that the majority of water bleeders would be turned off. The overall increases in water consumption have not been as great as the general population increase however (11,217 in 1971 to 15,394 in

FIGURE 18



CITY OF WHITEHORSE WATER SUPPLY

PRETEMPERING PERIODS 1973 - 1980

TABLE 4

CITY OF WHITEHORSE - WATER SYSTEM PRETEMPERING DATA

Year	Well Turn-Off Date	Well Turn-On Date	Length of Pretempering Period (months)
1973	23 June	18 October	
1974	18 June	20 October	7 3/4
1975	12 May	3 September	7 3/4
1976	26 May	25 September	8 3/4
1977	6 July	9 November	9 1/2
1978	10 July	7 November	8
1979	12 July	19 November	7 1/4
1980	24 June	13 December	7 1/2

1978 – a 37% increase). This can partially be attributed to the fact that new subdivisions are being constructed with heat traced service lines rather than water bleeders.

Estimates for 1978 obtained from the City Engineering Department and derived from flow records and public health population tallies place the average annual daily per capita water consumption at about 1090 liters. If a typical southern design figure of 450 liters per person per day is assumed for actual consumptive use (a high estimate as Whitehorse has only a small industrial base – Reid, Crowther & Partners Limited, 1970), then 640 L/person/day, or 59% of the total flow can be attributed to wastage (i.e., bleeding and system leakages). If a more realistic consumption figure of 227 L/person/day or 50 igpcd is assumed (AESL, 1967), then 79% of the total flow can be attributed to wastage.

C. LITERATURE REVIEW

Historical Development

From investigations in the City of Whitehorse Engineering Department library, copies of a number of reports, blueprints, and documents were obtained that related to the development of the present waterworks and sewerage system.

Until its incorporation, Whitehorse consisted of a number of isolated developments, each of which operated its own separate water distribution and sewage collection systems. Growth in the area was spurred on by the construction of the Alaska Highway during the Second World War; a large proportion of the present buildings in the City were constructed for or by the Canadian and U.S. Armies working on the highway.

Historical documents on the construction of water and sewer facilities in the area have largely been destroyed, but evidence from a number of sources (Main, Rensaa & Minsos, 1953; Sack, n.d.) suggest that these systems were generally brought to the area in the years 1954 – 55.

As required, these systems were expanded and improved at various times over the space of the next 25 years. The City of Whitehorse took over the operation of the Canadian Army water and sewer system in Whitehorse proper in October of 1957 (Yates, 1960). These had been left in an incomplete state and extensions to the downtown distribution network were required in 1960 (Haddin, Davis & Brown Limited, 1960). Further extensions to Riverdale were carried out in the middle to late 1960s. The water supply for the Whitehorse system was obtained from an intake structure in the Yukon River. In the meantime, the Department of National Defence retained control of their separate systems in Camp Takhini. Water for all of the federal installations in the area including Camp Takhini, the RCAF Base (the airport) and housing area (Hillcrest), Valleyview, and the Department of Transport facilities was obtained from McIntyre Creek (T.H. Newton Engineering Ltd., 1964). In the mid to late 1960s, additional service connections to the federal system were made to the Kopper King and Takhini Trailer Camps, and to a Yukon Territorial Government school and correctional institution (Department of Public Works, 1969).

Porter Creek was established as a residential subdivision sponsored by the Yukon Territorial Government and, until the installation of piped services in 1967 - 68, subsisted on trucked water delivery from a well (AESL, 1969). The well supply was initially retained for the piped distribution network, but was later replaced by a pumphouse at McIntyre Creek (AESL, 1979).

In 1969, consideration was being given to abandoning the federally operated McIntyre Creek supply due to increasing evidence of contamination from Alaska Highway construction and the Yukon Electric hydro installation upstream (Department of Public Works, 1969). Upgrading of the treatment facilities was considered uneconomic because of the liklihood at that time of certain federal lands being incorporated into the Whitehorse municipal area and resulting in an integrated water system.

In the Whitehorse system in the mid 1960s, a number of problems became evident with the water supply from the Yukon River. These included frazil ice problems at the intake, bank erosion problems adjacent to the intake, and high pumping heads (AESL, 1967). Accordingly, a new 55.9 cm (22") diameter supply main was constructed to the Northern Canada Power Commision power dam at Schwatka Lake. Additional pumping facilities and a new pumphouse was also added at this time at the site of the original Selkirk Street Pumphouse (AESL, 1967).

Studies on the feasibility of consolidating all the various water systems in the region had been conducted as early as the mid 1960s (AESL, 1963b; T.H. Newton Engineering Ltd., 1964) and had been accepted in principle (Reid, Crowther & Partners

Ltd., 1970), however, it was not until 1971 that these networks were all integrated into an elongated three pressure zone system. At the present time, the sewerage facilities continue to consist of a number of independent collection and treatment systems.

Currently, the water distribution system still consists of three interconnected networks. The first and original Whitehorse network serves downtown Whitehorse and Marwell on the west side of the Yukon River, and the subdivision of Riverdale on the east side. The main pumphouse (Selkirk) for the entire metropolitan system and the warm water wells are also situated in Riverdale.

The second waterworks network serves the subdivisions of Hillcrest, Takhini, and Valleyview, as well as the Whitehorse Airport. Essentially, it consists of the old federal government network with some extended services to Hillcrest. Use of the old McIntyre Creek Intake Pumphouse has been discontinued.

The third water distribution network services the subdivisions of Porter Creek and Crestview. It consists of the original Porter Creek network with extensions and a booster pumphouse and heater added for servicing Crestview.

All three networks have their own reservoir. In unifying the various systems, reservoirs were added at Valleyview and Porter Creek, a booster pumphouse was installed at Two Mile Hill, and additional feeder lines between the networks were added (AESL, 1979).

Using Hydrotherm, AESL conducted hydraulic analyses for the entire water distribution network in 1979 and estimated that under existing peak hour flows, the line pressures in all three networks would vary from 207 - 621 kPa (30 - 90 psi). Under fireflow conditions, the minimum pressures would drop by a further 69 kPa (10 psi).

Historically, wastage (bleeding and leakage) has played a significant role in the operation of the Whitehorse distribution networks. Estimates of the consumption rates have varied over the years. In 1963, AESL estimated bleeder flows of 1362 L/person/day (300 igpcd) for the City of Whitehorse and up to 2724 L/person/day (600 igpcd) in Camp Takhini. T.H. Newton Engineering Ltd. (1964) revised these figures to a normal domestic flow range of 890 - 1339 L/person/day (196 - 295 igpcd) and a winter time flow of 1362 - 3795 L/day (300 - 836 igpd) per service connection. Internal City of Whitehorse estimates have placed the average annual consumption at

1312 L/person/day (289 igpcd - 1973), and 999 L/person/day (220 igpcd - 1978). There has been a noticable downward trend in overall consumption over the years, and with better controls and a ban on the construction of new bleeders, this trend is expected to continue. One area where the reverse has been true is the subdivision of Porter Creek where consumption from 1972 - 73 to 1977 - 78 increased from 400 L/person/day to 1049 L/person/day (88 to 231 igpcd - AESL, 1979). This increase may be attributed to the installation of a piped sewage collection system in the latter half of the decade.

The seemingly excessive water consumption rate in Whitehorse has been a point of concern since the middle 1960s. In 1964, T.H. Newton Engineering Ltd. recommended that means be taken to drastically curtail the usage of water. The same recommendation has been echoed in various other consultants' reports since then (AESL, 1967, 1969, 1979). These reports have generally conceded that with the existing system, bleeding is the most feasible means of freeze protection, and have instead focussed on maintaining the bleeding rates for domestic service connections at a given level, usually 1.1 L/min (0.25 igpm- T.H. Newton Engineering Ltd., 1964) or 1.5 L/min (0.33 igpm - AESL, 1967).

Internal documents and bleeder surveys conducted by the City Engineering Department have also conceded the necessity of bleeding. An internal memorandum from the Assistant City Manager to the City Manager (Byron, 1970) recommended that meters be installed on all service lines in the City and that a usage rate structure be established for excessive water use above that required for bleeding at 1.5 L/min (0.33 igpm) (68,100 L or 15,000 ig/month), plus domestic consumption, during the months when bleeding is required. Since that time, sporadic metering has been done, but a Citywide usage rate structure is still not in place.

Bleeder surveys conducted by the City in 1974 and 1975 focussed on obtaining an accurate record of the existing meters and bleeders. Particular attention was paid to determining the number of oversized bleeders. For residential services, this was determined to be anything over 3.2 mm (1/8") o.d. (1.6 mm or 1/16" i.d.) of copper tubing bleeding over 1.5 L/min (0.33 igpm). Hydrant and dead end bleeders were found in the surveys to be bleeding at the respective average rates of 3.4 and 6.8 L/min (0.75 and 1.5 igpm).

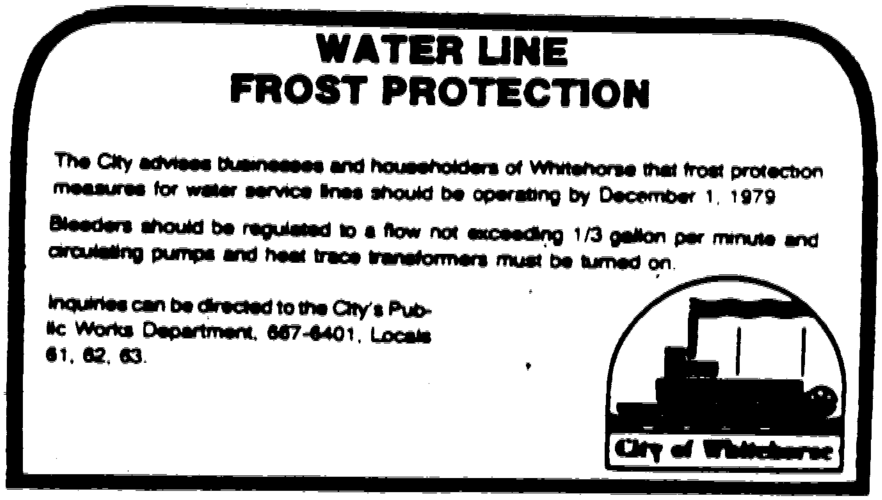
The total water usage rates for Whitehorse can be easily determined, but separation of the bleeder flows from system leakages has not been an easy matter. Leakage is known to be a major problem in the Whitehorse distribution system, but to date, due to the highly permeable nature of the soil (T.H. Newton Engineering Ltd., 1964), the exact extent of it has not been documented. Byron (1970) has recorded that in 1969, a supply main repair by the City in Riverdale resulted in a daily consumption reduction of 681,000 L (150,000 gallons). A leak survey using sonic techniques was conducted in 1976 which resulted in 18 possible system leaks being detected, however, difficulties in distinguishing between leakage sounds and bleeder generated sounds hampered the survey considerably (Heath Survey Consultants, 1976). AESL, in 1979, also recommended that leakage surveys be conducted, but considered that no successful survey could be conducted unless the entire distribution system were metered. Their summary of supply main examinations done over the years spotlighted some of the more corroded sections of pipe found. A large amount of sediment and grit in the lines was also found to be characteristic of the system.

The current practice for operators of water bleeders has the City advising them via newspaper and other media ads when to turn on their bleeders each year and again, when to turn them off. Due to carelessness, or the lack of an economic incentive, some bleeders are turned off late or left on year round. Because of less visibility, this would probably be more true of those operators with direct connections from their service line to the sewer drain. The City bleeder surveys previously mentioned also found a large number of leaking faucets wasting a continual stream of water.

A sample ad in the Yukon News of November 14, 1979, has been included as Figure 19. The 1/3 igpm figure referred to in the advertisement is incorporated into Bylaw 180 of the City of Whitehorse (see Appendix 5).

Water bleeding results in large quantities of cold and dilute wastewater in the Whitehorse sanitary sewage flows. There is some evidence that a sizable portion of this can be attributed not only to bleeding, but to groundwater infiltration into the sewer mains as well. A 1977 - 78 study on the Riverdale sewer system concluded that on an average annual basis, 6,819,100 L/day (1,502,000 igpd) flowed from the Riverdale system, 2,024,800 L/day (446,000 igpd - 30%) of which came from infiltration,

FIGURE 19



WATER LINE FROST PROTECTION

The City advises businesses and householders of Whitehorse that frost protection measures for water service lines should be operating by December 1, 1979.

Bleeders should be regulated to a flow not exceeding 1/3 gallon per minute and circulating pumps and heat trace transformers must be turned on.

Inquiries can be directed to the City's Public Works Department, 667-6401, Locals 61, 62, 63.

City of Whitehorse

CITY OF WHITEHORSE BLEEDER ADVERTISEMENT

YUKON NEWS 14 NOVEMBER 1979

1,262,100 L/day (278,000 igpd - 18%) from domestic sewage, and 3,529,600 L/day (777,454igpd - 52%)from bleeder flows (Mar-Tec Municipal Pipe Services, 1978). Similiar analyses have not been done on the rest of the Whitehorse system, although in certain areas such as downtown, the problem is believed to be substantial (AESL, 1979).

Problems arising from the large sewage flows have been the surcharging of lines resulting in residential basement flooding (T.H. Newton Engineering Ltd., 1964; AESL, 1967), and the high costs associated with pumping sewage (AESL, 1979; Foster, 1980). The latter problem has been accentuated with the construction in 1978 of sewage lagoon facilities for the Whitehorse Metropolitan area. Whereas raw effluent was once discharged, untreated, directly into the Yukon River, sewage from downtown, Marwell, Takhini, Valleyview, the airport, and Riverdale must now be pumped through a force main to the central sewage lagoon located on the east side of the Yukon River 1-1/2 miles downstream of Marwell. Separate lagoon facilites also exist for Porter Creek and Crestview.

Some performance data has been collected from the Central Lagoon (see Table 5), but as yet, not enough of a data base has been established to verify the effects of sewage dilution on treatment performance.

Soil Data

Subsoil investigations in the Whitehorse area have generally been for construction or groundwater exploration purposes. The areas of investigation have varied considerably (See Figure 20). A brief summary of the types of soil encountered at shallow depths by various investigators is as follows.

SAEL's 1978 groundwater exploration program in Hillcrest, an area directly east of the airport, found that the materials near the surface consisted of either glacial till, or glacial outwash sand and gravel ranging from clean to silty in composition. Further exploration (SAEL, 1979) located gravel and silty gravel deposits near the surface in the area. Underwood McLellan (UMA) and EPEC Consulting's investigations (1978c, 1978) in Hillcrest for a subdivision expansion largely confirmed these findings: the surficial materials largely consisted of cobbly sand, sands and gravels, and some silty tills found in a frozen state with moisture contents of approximately 5%.

Table 5

Whitehorse Wastewater Lagoon Performance*
Summary of Data
Grab Samples
March 1979 to January 1980

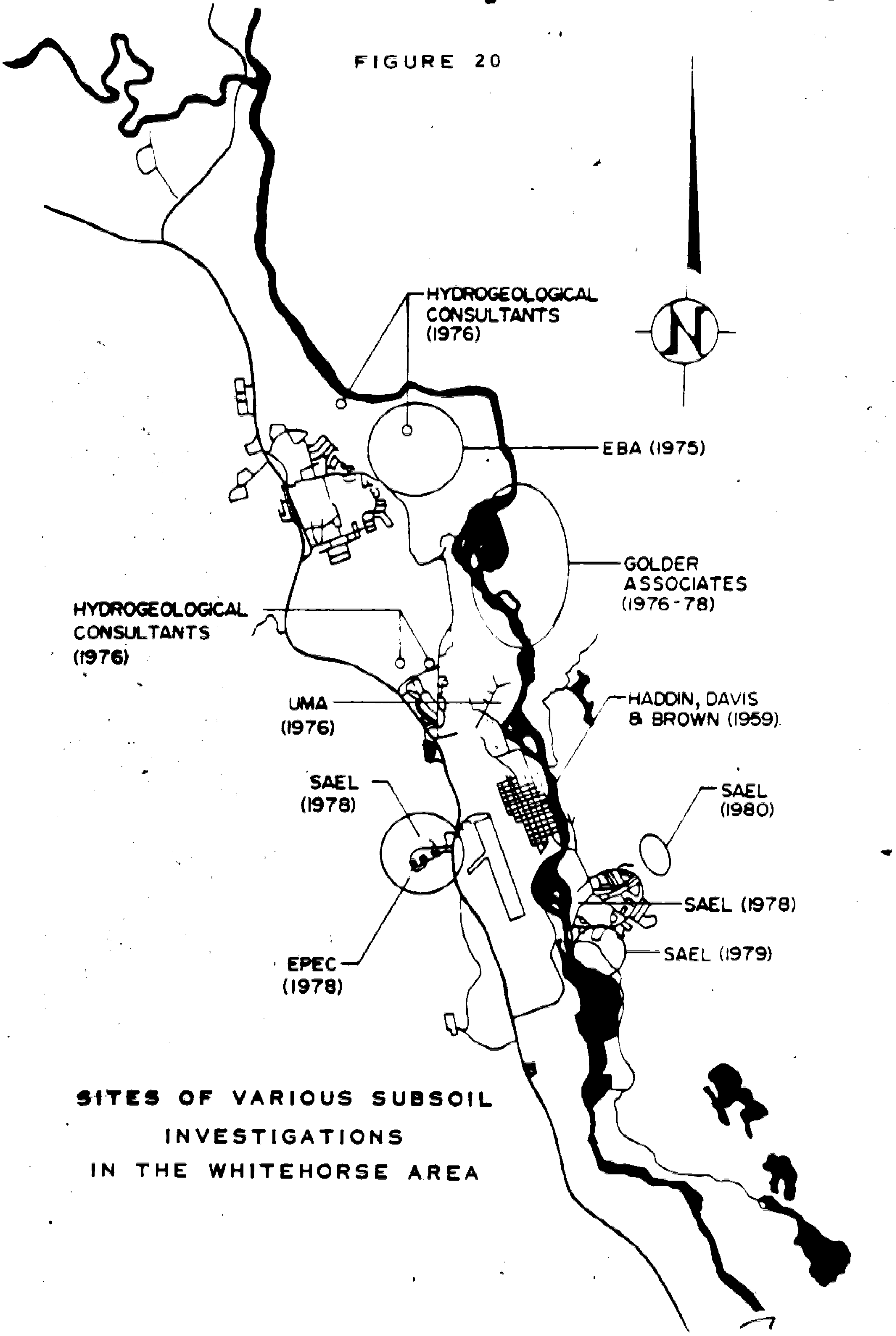
Parameter	Location	Means and Geometric Means for Data	Range	Number of Samples	Percent Reductions
Temperature, °C	Infl.	8.4	4.0 to 13.0	7	
	Effl.	6.1	0.0 to 13.0	7	
BOD_5, mg/L	Infl.	36	12. to 70.	11	
	Effl.	22	11. to 29.	11	39
Suspended solids, mg/L	Infl.	38	7. to 94.	12	
	Effl.	18	11. to 25.	13	53
Total Coliform per 100 mL	Infl.	2.7×10^6 (G)	0.13 to 5.8×10^6	11	
	Effl.	6.2×10^5 (G)	0.8 to $24. \times 10^5$	10	77
Fecal Coliform per 100 mL	Infl.	5.8×10^5 (G)	1.3 to $20. \times 10^5$	11	
	Effl.	1.7×10^5 (G)	0.1 to 5.0×10^5	11	71
Flow rate ML/d		12.2	8.2 to 16.0	9 (months)	
Pumping Energy from city to Lagoon ** KWH		121050. ($5474/month)	88125 to 142125	9 (months)	

* Lagoon size, 4 cells of 68200. m^3 each, liquid depth 6.1 m, average detention time 17.2 d.

** Average Cost of Energy $0.0452/KWH

Data Sources: Chemical and biological data, Environmental Protection Service, Whitehorse, Yukon.
Pumping and flowrate data, City of Whitehorse, Engineers Office.

FIGURE 20



SITES OF VARIOUS SUBSOIL INVESTIGATIONS IN THE WHITEHORSE AREA

Groundwater test holes in Selkirk, the area where the current wells for the City are located, contained poorly sorted sands and gravels near the surface (SAEL, 1978).

UMA (1978a) investigations in the Marwell land area directly north of downtown Whitehorse found mostly saturated alluvial sands and gravels to the 3 meter depth. In another investigation in Takhini, UMA (1978b) found mainly loose, dry sand beneath a thin topsoil layer.

In 1976, Golder Associates's geotechnical investigation at the site of the Whitehorse sewage lagoons found, in general, a 1.2 - 2.4 m (4 - 8 ft) thick intermittent stratum of brown fine to medium sand in the area. These findings were confirmed in their final report in 1977 (Golder Associates, 1977).

Hydrogeological Consultants' groundwater exploration program in 1976, in an area north of the City, encountered mainly sand and/or gravel deposits in all their test holes.

The only formal soil investigations in the downtown area appear to be by Haddin, Davis & Brown Limited in 1959. Their 0.9 m (3 ft) testhole borings throughout downtown Whitehorse revealed mainly sand and gravel layers with some silt mixed in. Other, undated test drillings on old plans in the City Engineering Department Library support these findings.

D. LABORATORY RESULTS

After a long period of initial difficulties in obtaining equipment, setting it up, testing and calibrating it, and constructing a water tight pipe recirculation network, testing of laboratory alternatives was started in October of 1980. The immediate objectives of the testing were:

1. to determine which of the alternatives would fail under simulated severe service conditions; and
2. to determine the net water savings, if any, gained by using a particular device as opposed to using a conventional service line bleeder.

The insulating effects of conventional depth burial in the ground were simulated by applying foam insulation to the pipes. The insulation also helped to dampen out the temperature cycle of the refrigeration equipment in the cold room. With the amount of insulation that could be practically applied however, the temperature inertia effect of conventional depth burial (i.e., it takes a number of months for frost to penetrate a given depth of soil) could not be simulated. This effect was also not desired due to the amount of time that would be required to run a lab test.

The cold room controls were placed at their maximum setting because it was felt that this would provide a safety factor in applying the laboratory results to a field situation. It is unlikely that soil temperatures at conventional burial depths would reach −25 °C for long periods of time.

Each test run was started by turning on the pump that ran the water recirculating system while simultaneously lowering the temperature controls in the cold room. Printouts of the data logger readings were usually programmed for 5 minutes initially for one or two hours, and then for every 10, 15, or 20 minutes.

The devices operated in Test #1 consisted of the temperature controller, the commercial timer, the drainage tank, and the orifice plate. The cold room temperature controls were set for −30 °C.

As testing continued, and after the cold room temperature stabilized, some operating characteristics of the recirculation system became apparent. One was that the opening and closing of the valves in the intermittent bleeder devices would cause fluctuations in flows and pressures throughout the rest of the lines in the system. The cyclic nature of the Jacuzzi 0.373 kW (1/2 HP) jet pump also contributed to flow and pressure fluctuations. Another problem was that the closing of the three way solenoid valve on the drainage tank was so sudden that a water hammer effect with its accompanying pipe vibrations was created. These problems had some effect on overall system performance, but were considered acceptible.

Yet another problem was that the cold room compressor, while being rated at −40 °C, was incapable of lowering ambient temperatures below approximately −25° to −26 °C. In test #1, the room temperature stabilized at −19 °C in five hours after being set for −30 °C, so after 73 hours, the controls were set for the maximum temperature drop. This resulted in −25° to −26 °C ambient temperatures.

In Test #1, the first device that failed was the temperature controller. The triggering temperature for its sensor was set at about 0.5° C and at that setting, the solenoid valve failed to operate before a blockage occured in the pipe.

The next device that froze was the drainage tank. For this test, the tank level sensors were set to allow a flow of 2.8 liters (over 3 times the amount of water in the line) into the tank. The drainage time for this amount of water was 5 minutes, with a tank refill time of 8 seconds between drainage intervals. Evidence that the tank would eventually fail came in the form of successively greater water hammer effects (indicating increasing ice blockage in the line) as the test run progressed. This device failed some 103 hours after test initiation, 31 hours after the ambient temperature was lowered to -25 °C.

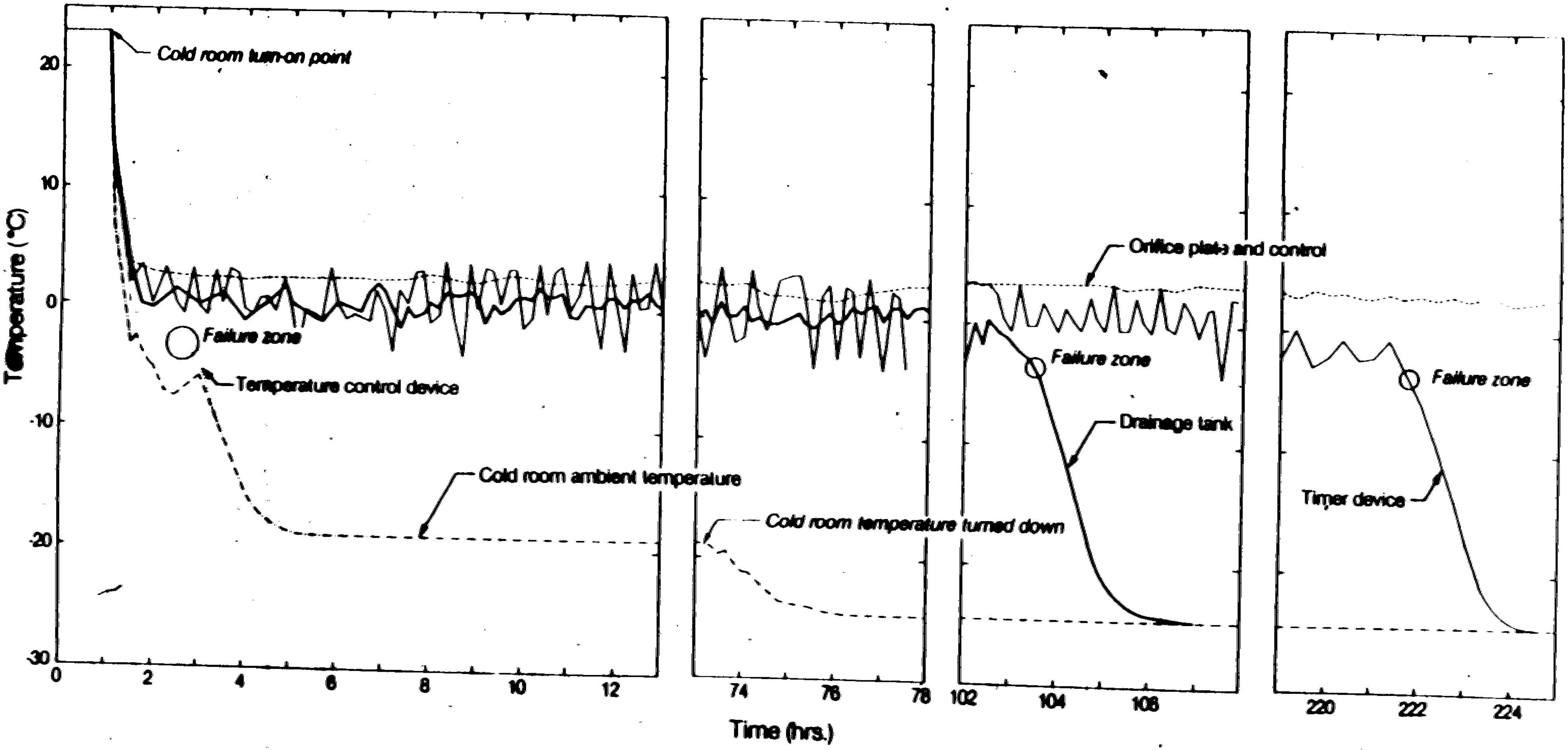
The final device to freeze in Test #1 was the timer. The timer used for this test was the most sensitive one commercially available and was operated by the pushing in and out of metal key tabs on a 24 hour cycle clock, each key tab controlled 15 minutes of time. The timer failed after 221 hours of operation. The progress of ice growth in the pipe was deduced from observing the increasing time delays taken for full bleeder flows to be achieved after the solenoid valve was opened.

The orifice plate therefore, was the only device that had not failed by the time the test run was concluded after 224 hours. It was also the only device in which flows and pressures did not vary significantly from their means, respectively, of 1.8 L/min and 415 kPa (0.39 igpm and 60 psi). The results of Test #1 are summarized in Figures 21 and 22 and in Table 6.

After test termination, the recirculation system was thawed out and repairs initiated. This resulted in a long down period during which leaks were detected, pipe insulation stripped off, and fittings and pipe sections replaced.

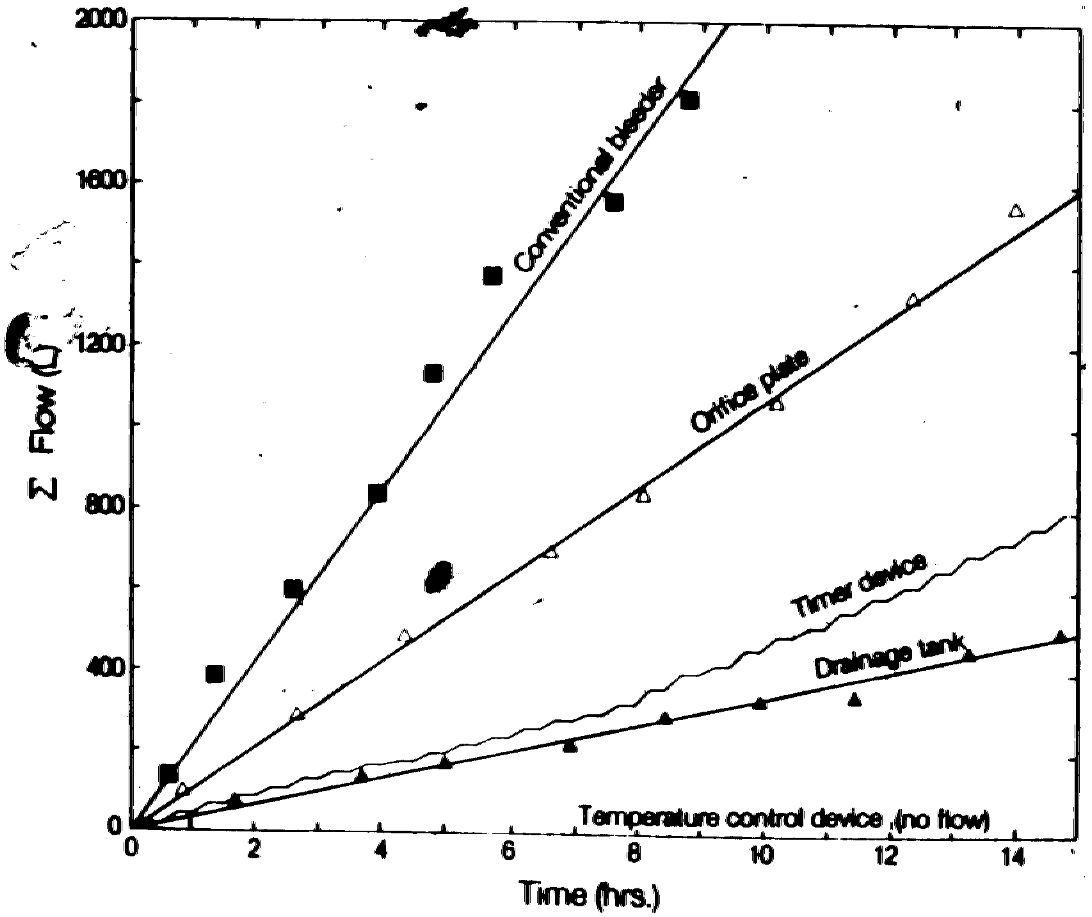
It was found throughout laboratory testing that all the pipe failures occurred only at elbows and other pipe fittings (see Figure 23), however, entire straight pipe sections would have to be replaced because taking off a split fitting necessitated cutting off some straight tubing with it and sometimes not enough of the straight tubing remained which could be joined together with new fittings. Another problem was that of solder cracks and leaks developing where a frozen pipe jutted out of the pipe manifold. These were difficult to repair because of the impossibility of draining all the water out of the manifold.

FIGURE 21



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 1

FIGURE 22



WATER CONSUMPTION RATES DURING LABORATORY TEST NUMBER 1

TABLE 6

WATER WASTAGE DATA FROM LABORATORY TEST #1

Device	Water Bled Net Rate (L/hr)	Water Bled Test Total (L)
Drainage Tank	34	3,500 L @ failure
Orifice Plate	106	23,400 L @ 224 hr
Temperature Control Device	0	0 L @ failure
Timer Device	46	13,100 L @ failure
Conventional Bleeder	212	47,600 L @ 224 hr

FIGURE 23

TYPICAL PIPE FAILURE AT AN ELBOW

Other problems that developed were attempting to solder in cramped and difficult to reach places, and the difficulty of maintaining water tight seals for the thermocouples inserted into a pipe. Long down times therefore became characteristic of the laboratory testing phase of the project.

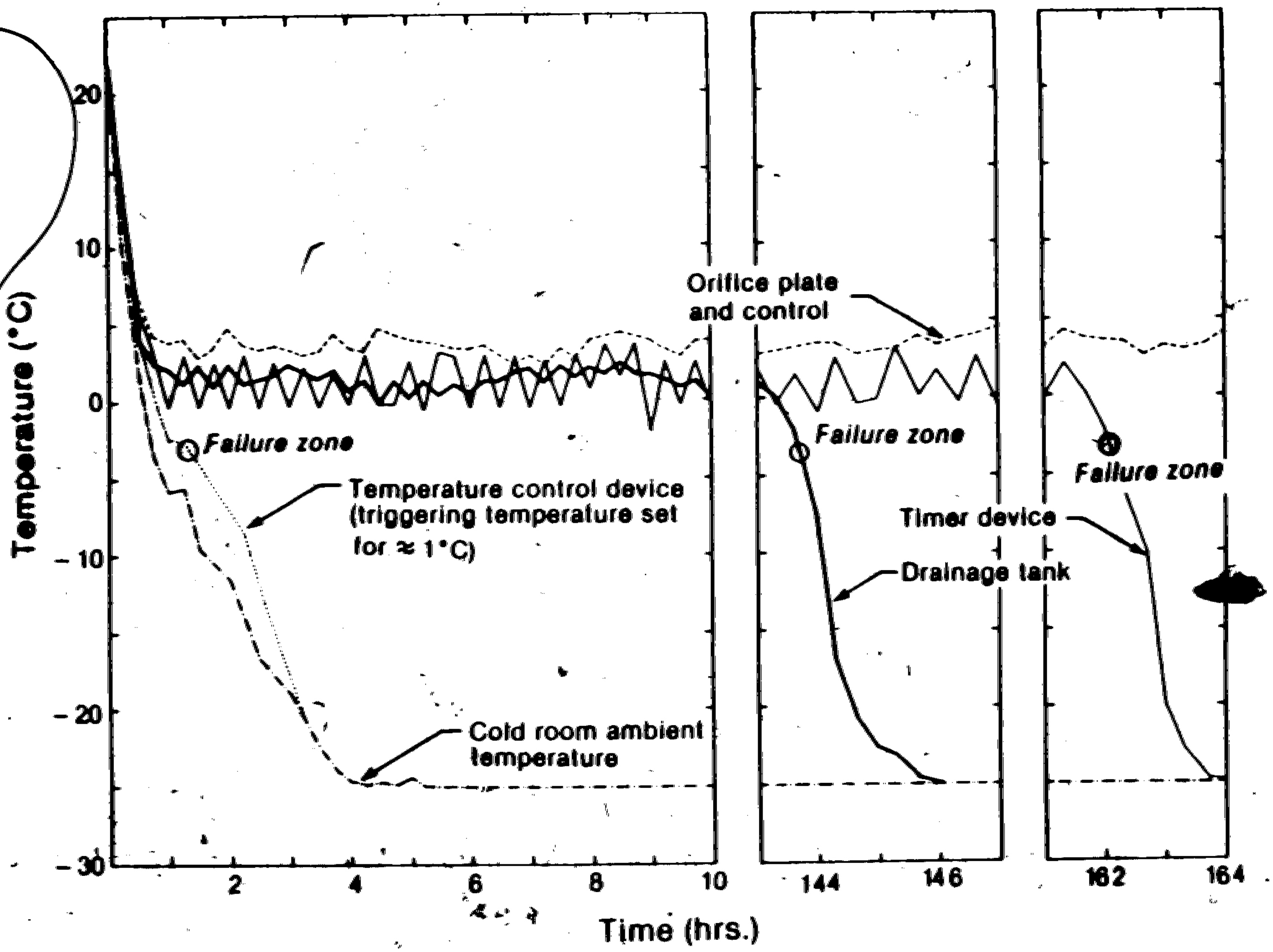
Test #2 was essentially a repeat of Test #1 with some modifications made to some of the failed devices. The circuit board on the temperature controller was recalibrated to trigger open its attached solenoid valve when its temperature sensor registered 1 °C, and the level sensors in the drainage tank were set to allow a drainage and fill cycle of 4-3/4 minutes and 7 seconds, respectively. The same timer from Test #1 was retained.

The results of Test #2 are summarized in Figures 24 and 25, and Table 7. The maximum cold-room temperature setting was retained throughout the test. Again, the temperature controller failed immediately in that its attached solenoid valve did not open before blockages occured in the pipe. The drainage tank failed again, this time after 143 hours of operation, while the timer failed after 162 hours. The effects observed in Test #1, i.e., increasingly severe water hammer effects with the drainage tank, and increasingly longer delays taken to achieve full bleeder flow with the timer, were again observed in Test #2. No perceivable difference in the operation of the orifice plate device was observed throughout the test and Test #2 was terminated after 164 hours.

More device modifications were made for Test #3. The temperature controller was recalibrated again for a 2 °C triggering temperature. The drainage tank cycle was readjusted to a 4-1/2 minute drainage and 6 second fill up cycle. Finally, the commercial timer was replaced with a custom constructed unit built with modular components. This timer contained a variable control feature for separate setting (0 - 5 minutes) of both the bleeding and non-bleeding periods. For test purposes, both were set at three minutes.

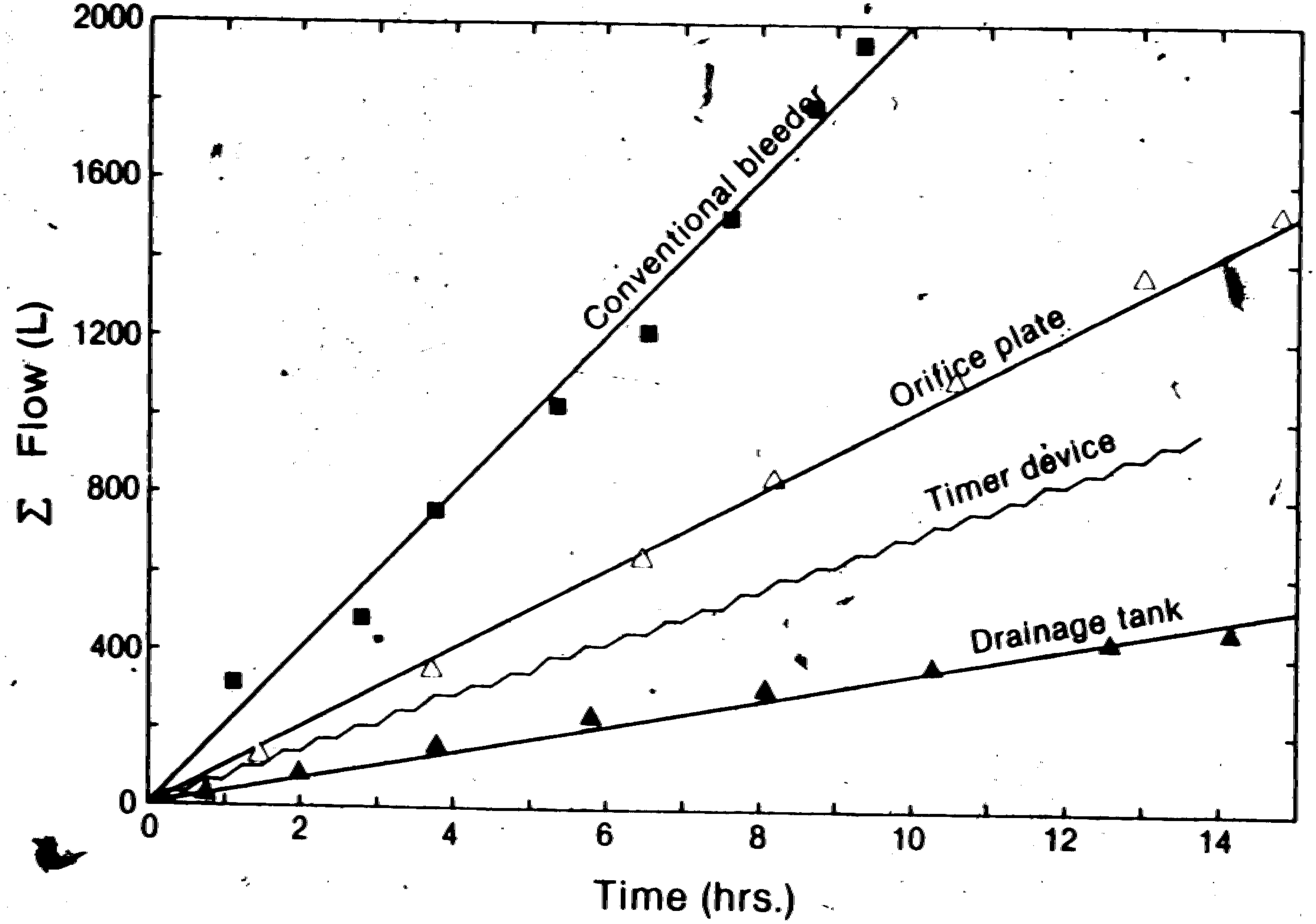
The results of Test #3 are summarized in Figures 26 and 27 and in Table 8. The temperature controller triggered open its solenoid valve after some 25 minutes of operation. Only the water in the immediate vicinity of the thermistor drained however; by the time the valve opened, blockages had already occured elsewhere in the line. The drainage tank also failed, this time after 131 hours of operation. The increasing severity of water hammer effects was again observed.

FIGURE 24



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 2

FIGURE 25



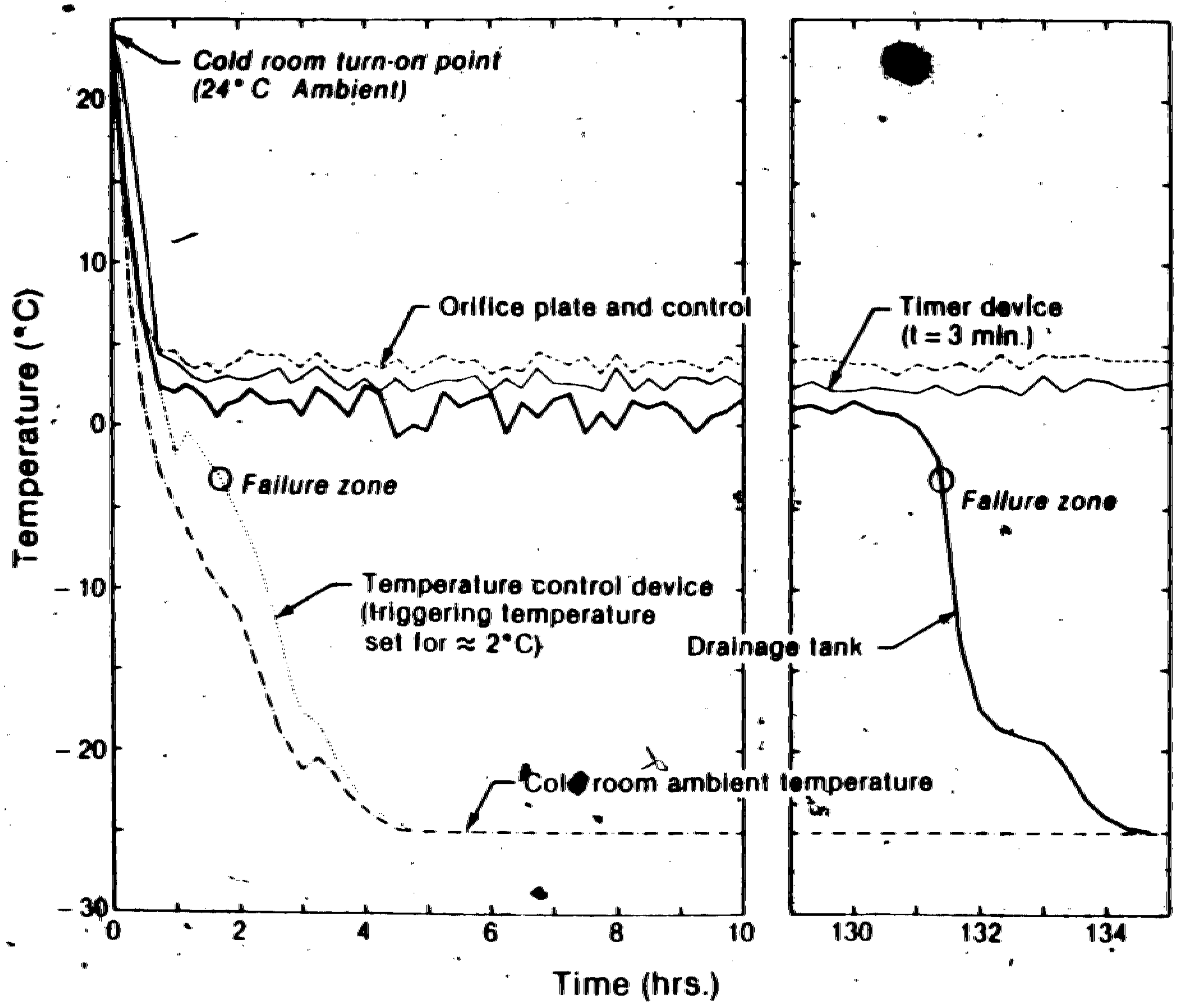
WATER CONSUMPTION RATES DURING LABORATORY TEST NUMBER 2

TABLE 7

WATER WASTAGE DATA FROM LABORATORY TEST #2

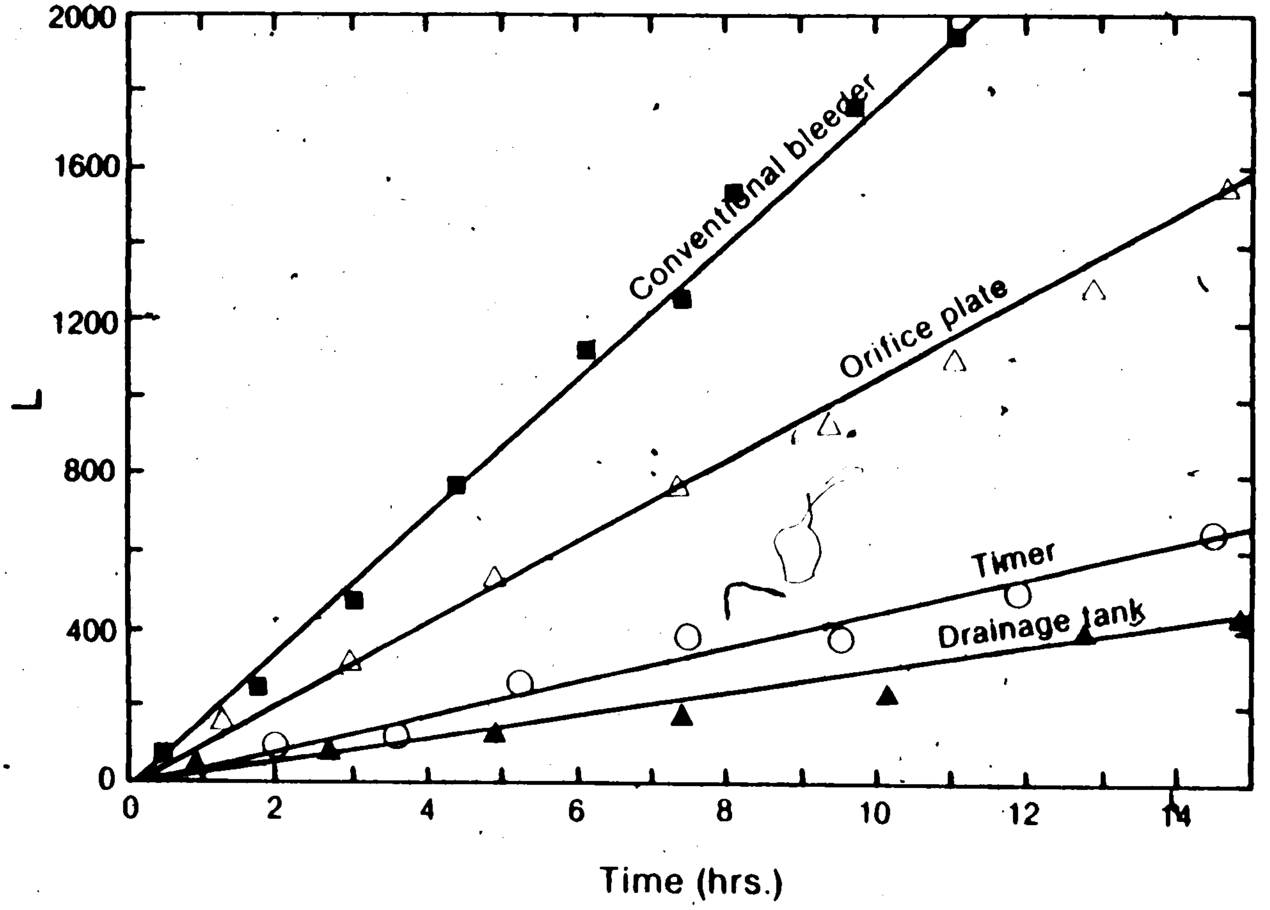
Device	Water Bled	
	Net Rate (L/hr)	Test Total (L)
Drainage Tank	35	5,000 L @ failure
Orifice Plate	106	17,400 L @ 164 hr
Temperature Control Device	0	0 L @ failure
Timer Device	69	11,250 L @ failure
Conventional Bleeder	203	33,300 L @ 104 hr

FIGURE 26



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 3

FIGURE 27



WATER CONSUMPTION RATES DURING LABORATORY TEST NUMBER 3

TABLE 8

WATER WASTAGE DATA FROM LABORATORY TEST #3

Device	Water Bled Net Rate (L/hr)	Water Bled Test Total (L)
Drainage Tank	30	3,950 L @ failure
Orifice Plate	106	17,700 L @ 167 hr
Temperature Control Device	0	0 L @ failure
Timer Device	45	7,500 L @ 167 hr
Conventional Bleeder	177	29,600 L @ 167 hr

The new timer device did not fail during Test #3. Full bleeder flows appeared immediately after the opening of the solenoid valve on the line. The observed line temperatures also did not fall below 2 °C.

As the orifice plate also operated continuously throughout, Test #3 was terminated after 167 hours of operation.

In test #4, some more device modifications were made. The drainage tar drain times were readjusted to five seconds and 4 minutes, respective recalibration of the temperature controller was made, this time t temperature of 3 °C. Finally, in an attempt to reduce the bleeding rate of th without reducing the size of the orifice, a variable control pressure red purchased from a local plumbing distributor. This was installed on the 12 immediately in front of the orifice plate (see Figure 28).

The results of Test #4 are summarized in Figures 29 and 30 an before, both the timer and the orifice plate functioned throughout the addition of the pressure reducing valve, the rate of bleeding of the or [illegible] was reduced further. The temperature control device also operated this time around after 20 minutes, it triggered open its solenoid valve and full bleeder flows were maintained continuously thereafter. Finally, as in the previous test runs, the drainage tank failed again, this time after 153 hours of operation.

After Test #4, two of the pipes in the recirculation system were replaced with 25.4 mm (1") i.d. pipe and two with 19.1 mm (3/4") i.d. pipe. All four of the control devices previously tested were taken out and the jet pump was also replaced with a more powerful centrifugal pump. A fifth bleeder alternative was then set up as per Figure 31. It consisted of a large steel pressure tank equipped with an internal air bladder. A pressure switch was mounted on the copper line leading into the tank. It was connected to two 2-way solenoid valves, one normally open and one normally closed. A pressure reducing valve set for 103 kPa (15 psi) was also placed on the line after the normally open valve.

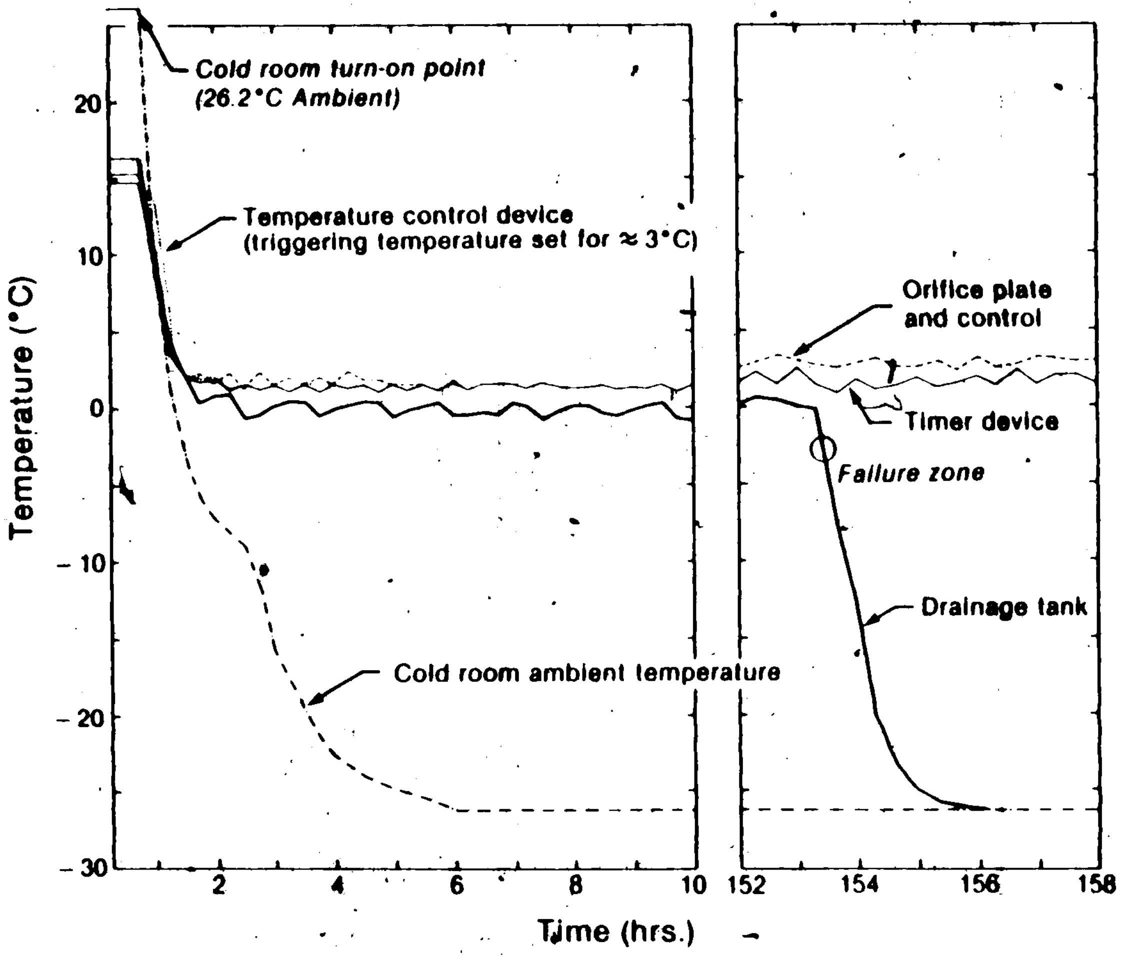
For Test #5, the pressure switch was set for a high/low pressure cycle of 103 - 276 kPa (15 - 40 psi). Because of the use of larger diameter pipe, it was determined that the recirculation pump was incapable of sustaining system line pressures above 276 kPa

FIGURE 28

PRESSURE REDUCING VALVE AND

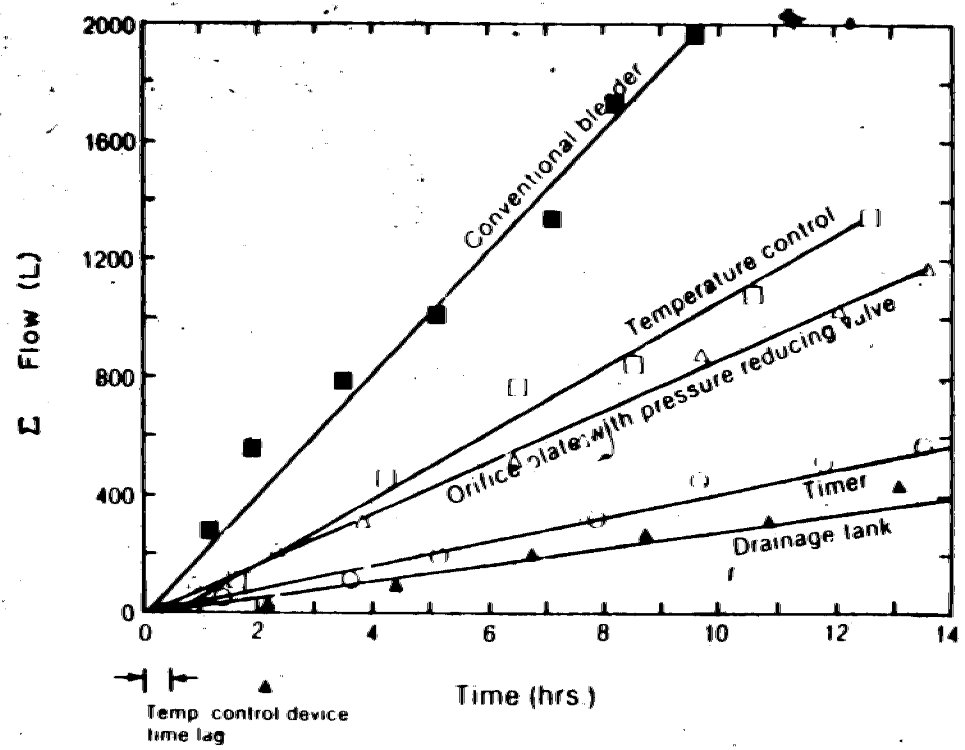
ORIFICE PLATE INSTALLATION

FIGURE 29



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 4

FIGURE 30



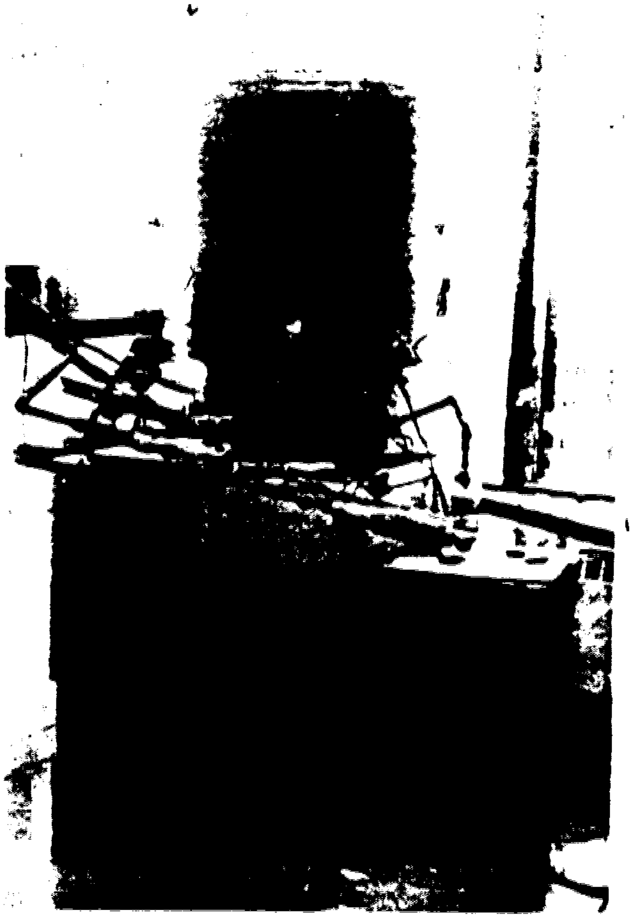
WATER CONSUMPTION RATES DURING LABORATORY TEST NUMBER 4

TABLE 9

WATER WASTAGE DATA FROM LABORATORY TEST #4

Device	Water Bled	
	Net Rate (L/hr)	Test Total (L)
Drainage Tank	28	4,300 L @ failure
Orifice Plate	87	14,600 L @ 168 hr
Temperature Control Device	111	18,650 L @ 168 hr
Timer Device	41	6,900 L @ 168 hr
Conventional Bleeder	197	33,100 L @ 168 hr

FIGURE 31



PRESSURE TANK SET-UP

(40 psi).

Operation of the pressure tank proceeded as follows: after the system was switched on, water would recirculate through the system, with some being diverted into the pressure tank. The water being recirculated would flow through the normally open solenoid and the pressure reducing valve. After the pressure in the tank reached 276 kPa (40 psi), the pressure switch would trigger open the normally closed valve and shut the normally open one. The tank would then drain along with the recirculating water until its internal pressure dropped to 103 kPa (15 psi). The cycle would then start again.

Using 25.4 mm (1") i.d. pipe, this alternative was operated in Test #5 for some 240 hours. No failures occured during this period. The fill times averaged approximately 13 minutes, with a two minute drain time. This was equal to a drawdown of some 64 L (14 ig) during each cycle. A temperature record of Test #5 is given in Figure 32.

In Test #6, the 25.4 mm (1") i.d. pipe was replaced with a 19.1 mm (3/4")line. The system was tested for 240 hours and again, no failures were observed. Fill and drain times were on the order of 14 and 2-1/4 minutes, respectively. The system temperatures for Test #6 are given in Figure 33.

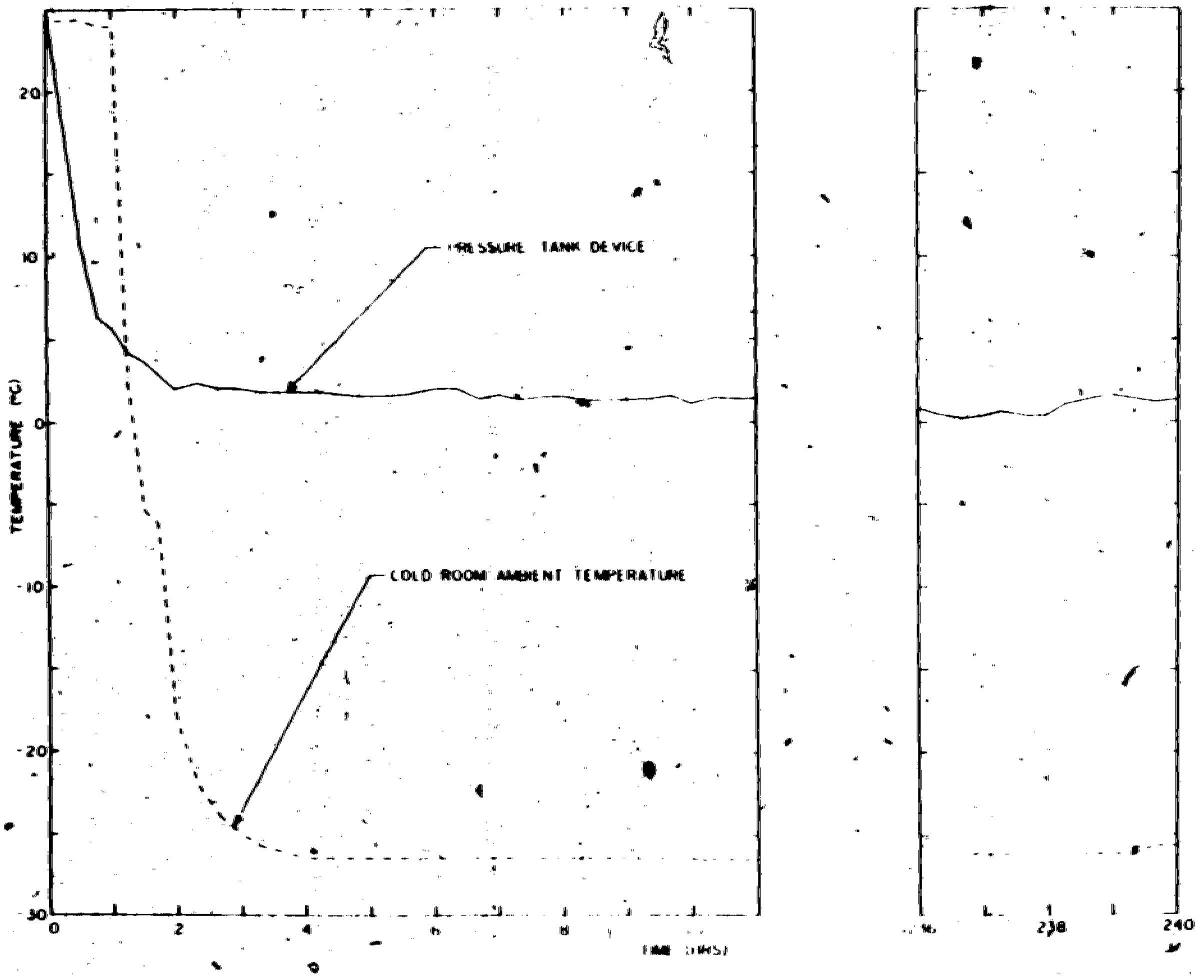
E. COMPUTER MODELLING

A copy of one of the basic input files for Hydrotherm is given in Appendix 6. The majority of terms are self explanatory; a brief discussion of those that are not is given in the following paragraphs. Note that because of model characteristics, all data is first given in Imperial or U.S. units.

In the general data, the default value for the pipe roughness coefficient, RC, of 0.01 is applicable to old bare steel, cast iron, and ductile iron pipe. Other roughness coefficient values used were 0.001 for asbestos cement pipe, and 0.0002 for polyethylene pipe.

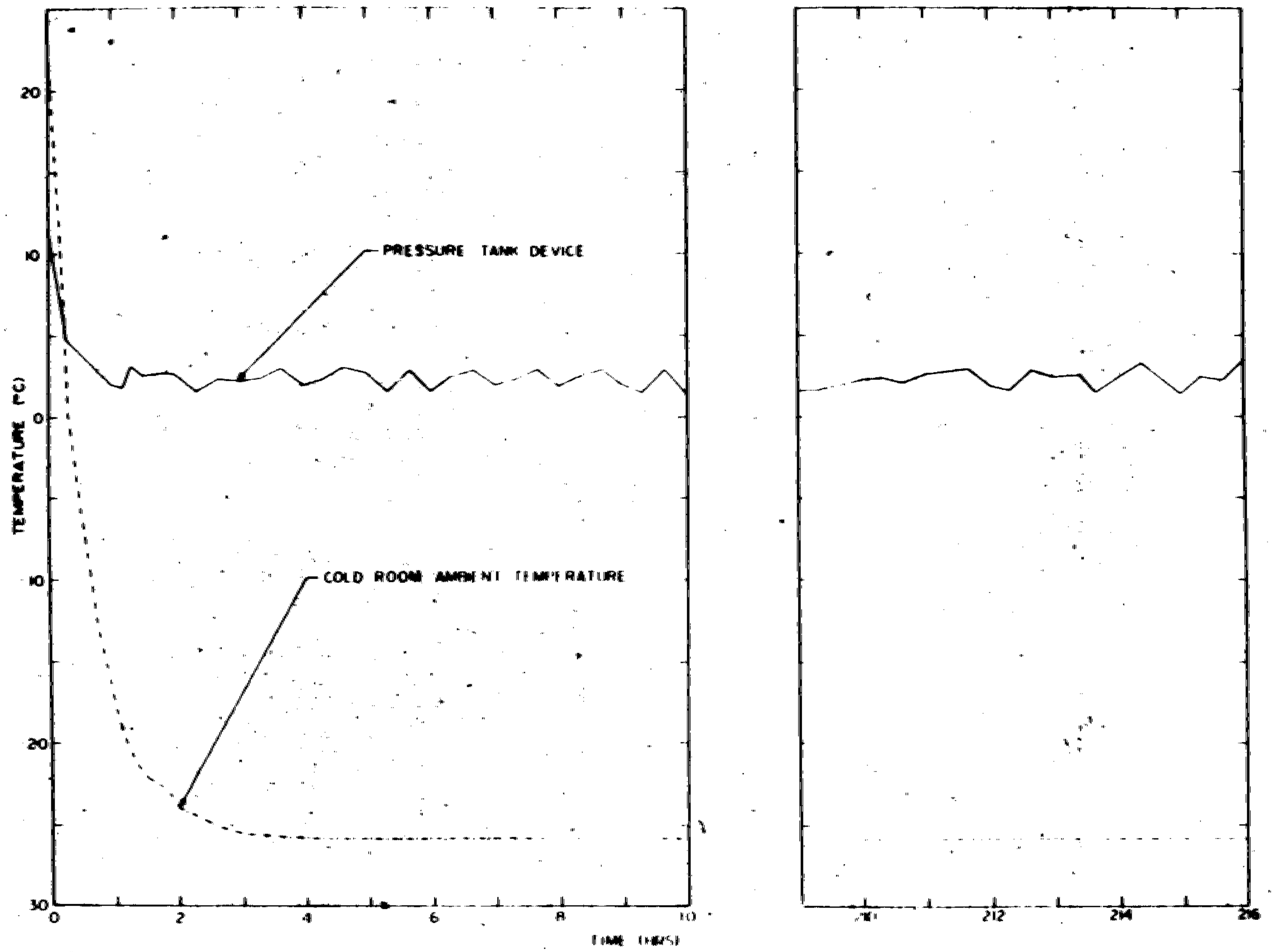
The constant head node, CH, in the input file was required as a reference starting point for Hydrotherm. This was taken as the elevation head of the Riverdale reservoir minus an estimate for head losses as taken at the start of the downtown Whitehorse system.

FIGURE 32



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 5

FIGURE 33



TEMPERATURE PROFILE OF LABORATORY TEST NUMBER 6

The consumer drawoff factor, CD, is a factor by which all the specified drawoff flow rates are multiplied. Overall increases or decreases in flow (as in peak or low demand periods) are thus considered to be the result of the same percentage increase or decrease throughout all parts of the system.

The temperature constants, DT and OT, are extraneous figures not required for a Hydrotherm thermal analysis and random values were arbitrarily assigned to them. CT, the constant water temperature, is that input temperature assumed at the start of the network. For project purposes, from the City of Whitehorse pumping records, this was taken to be 38 °F (about 3.3 °C).

Finally, the type 4 temperature analysis was that designated for the case of uninsulated pipes in frozen and thawed ground.

In the supply pipe data, the equivalent pipe length, LE, was taken as equal to the actual pipe length, LA, as measured from the City's as-built drawings. In actual fact, LE is the actual pipe length plus enough pipe to account for head losses at fittings, valves, etc. The losses are taken as a multiple of the velocity head in the Bernoulli equation. In the pipe lengths, the drawing scales, and the flow velocities being dealt with, these head losses were disregrded as being relatively insignificant.

Modifications to Hydrotherm were made for the next two constants, R1 and R2. The R1 constant was modified to represent the ratio of thawed and frozen ground thermal conductivities. From evidence derived from subsoil investigations in the Whitehorse area, it was decided to use the thermal conductivities for sand, 10% saturated throughout the modelling area. Silt and clay soils are also known to be present in downtown Whitehorse and most soils, in any case, are not homogeneous, isotropic mediums, but the assumption of sand, with its greater thermal conductivities (Harlan and Nixon, 1978), throughout the area, provided a more conservative estimate of ground thermal conditions. The values used therefore, were 1.9 and 2.4 BTU/ft-hr-°F (3.2 and 4.1 W/m-°K), respectively, for thawed and frozen ground.

The constant R2 represented the pipe longitudinal thermal resistance in terms of hr-ft-°F/BTU as used in the Hydrotherm steady state equations for heat transfer. The values used for the calculation of R2 included the outside radius of the pipe and an assumed five foot burial depth throughout the system. With regard to the latter, the

Engineering Design Standards for Whitehorse specify that the minimum depth of bury for water mains must be 10 ft (3 m) or an equivalent depth when rigid insulation is used in the pipe trench (City of Whitehorse, 1975). Older undated Yukon Territorial Government drawings from the City Engineering Department library of the downtown area state a minimum burial depth of 9 ft (2.7 m), and this is confirmed in an internal memorandum from 1970 (Byron, 1970). Some records obtained from the City Works trailer for one section of the downtown area however, show actual burial depths varying from 1.5 m to 2.9 m (5 – 9.5 ft), with the average being around 2.1 m (6.9 ft). In any event, the assumption of 5 ft (1.5 m) burial is a conservative estimate.

The final figure of concern in the supply data is that of the pipe ambient temperature, PA. For the Hydrotherm steady state heat transfer equations, these were taken either as the undisturbed soil temperature at the depth of burial of the pipe, or as an equivalent temperature for the thaw zone surrounding the pipe.

In the consumer data, various demand drawoffs were assigned to various nodes to simulate the consumption from various sections of the downtown area. All the service connections in a particular section were lumped together as a 100 ft (30.5 m) equivalent length (LE) of asbestos concrete pipe of 1.5" (38.1 mm) i.d. The member status, MS, assigned to each drawoff designated it as a fixed flow drawoff. Other MS designations possible with Hydrotherm included pumps, boilers, check valves, etc.

The average flow rates assigned to the various sections were obtained from the hydraulic analyses that AESL had previously done for the City. Due to the lack of complete metering on the Whitehorse system, AESL had obtained their flows by the basic technique of using bulk flows and assigning drawoffs to various sections of the City according to land use. After discussion with the AESL personnel who had done this, for project purposes, the flows from their skeletonized downtown network were de-skeletonized and reassigned. For the one outflow pipe from the downtown area, the downstream skeletonized flows were summarized and used as the drawoff.

The boiler data for Hydrotherm was required in order to set an incoming water temperature into the downtown network of 38 °F (3.3 °C).

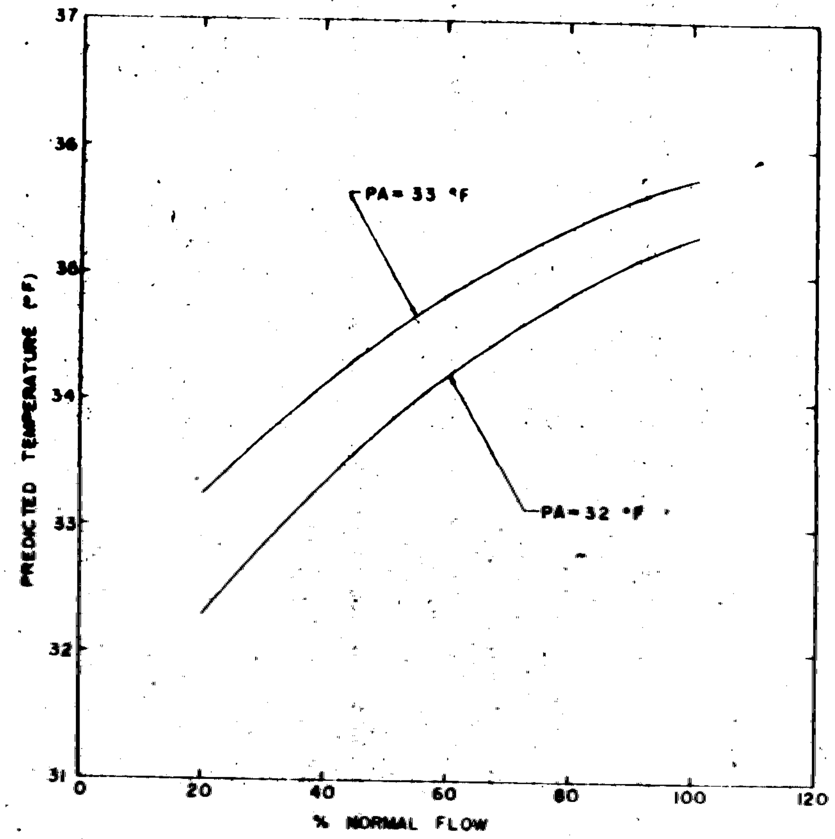
Finally, the node elevations, or static heads, were taken from hydrant elevation records for the downtown area minus a figure of 8 ft (2.4 m) to allow for the assumed height of the hydrant and a 5 ft (1.5 m) burial depth.

After some initial difficulties in modifying Hydrotherm, putting together and correcting the data file for the model of downtown Whitehorse, and calibrating the output results with a few isolated test runs, a matrix of twenty test runs was conducted. The consumer drawoff factors, CD, were varied from 1.0 to 0.2 by 0.2 increments, while at the same time, the pipe ambient temperatures, PA, were varied from 32 °F to 20 °F (0 °C to −6.7 °C) by 4 °F (2.2 °C) increments. It was thus hoped to obtain an idea of the network thermal responses to reductions in flow and soil temperature.

The results of the Hydrotherm analysis showed frozen pipe members occuring in the network at all flow rates at 28°, 24° and 20 °F (−2.2°, −4.4° and −6.7 °C). In an attempt to define the failure temperatures further, additional runs were made at pipe ambient temperatures of 30° and 31 °F (−0.6° and −1.1°C). Here again, at all flow variations, the results showed frozen pipes occuring in the network. A final series of computer runs were then made at PA = 33 °F (0.6 °C).

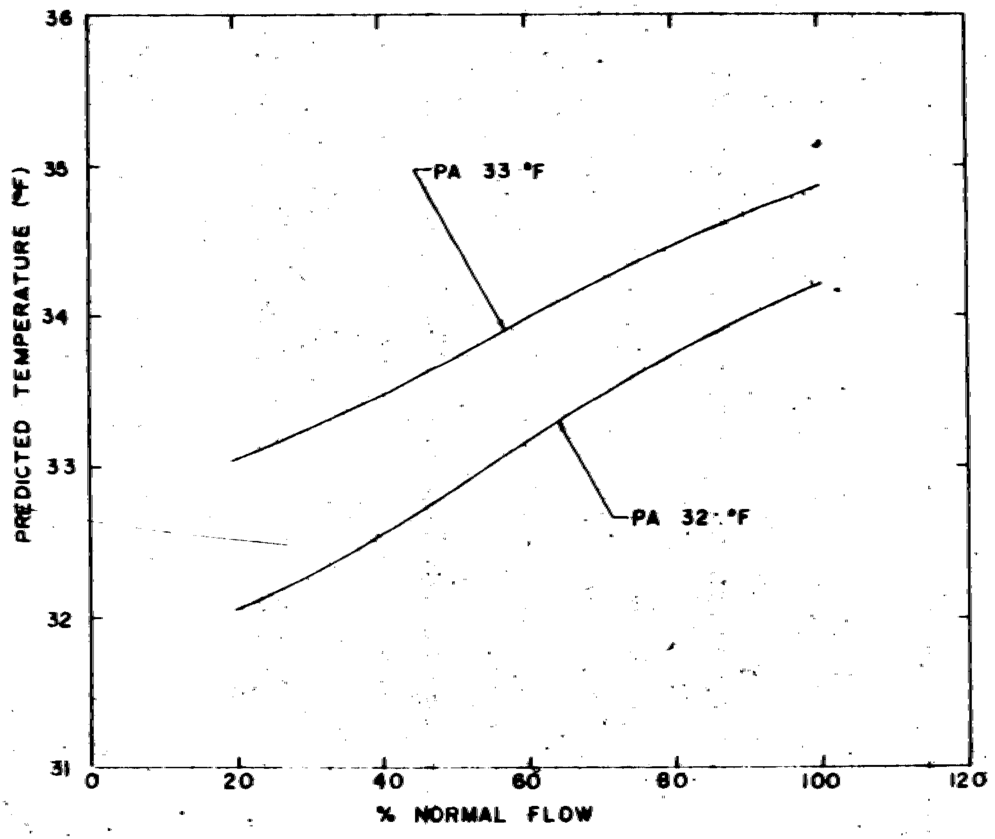
Information from some of the test runs for some representative pipes in the network are plotted in Figures 34 through 38. These show the variations in temperature in the pipe as a function of flow.

FIGURE 34



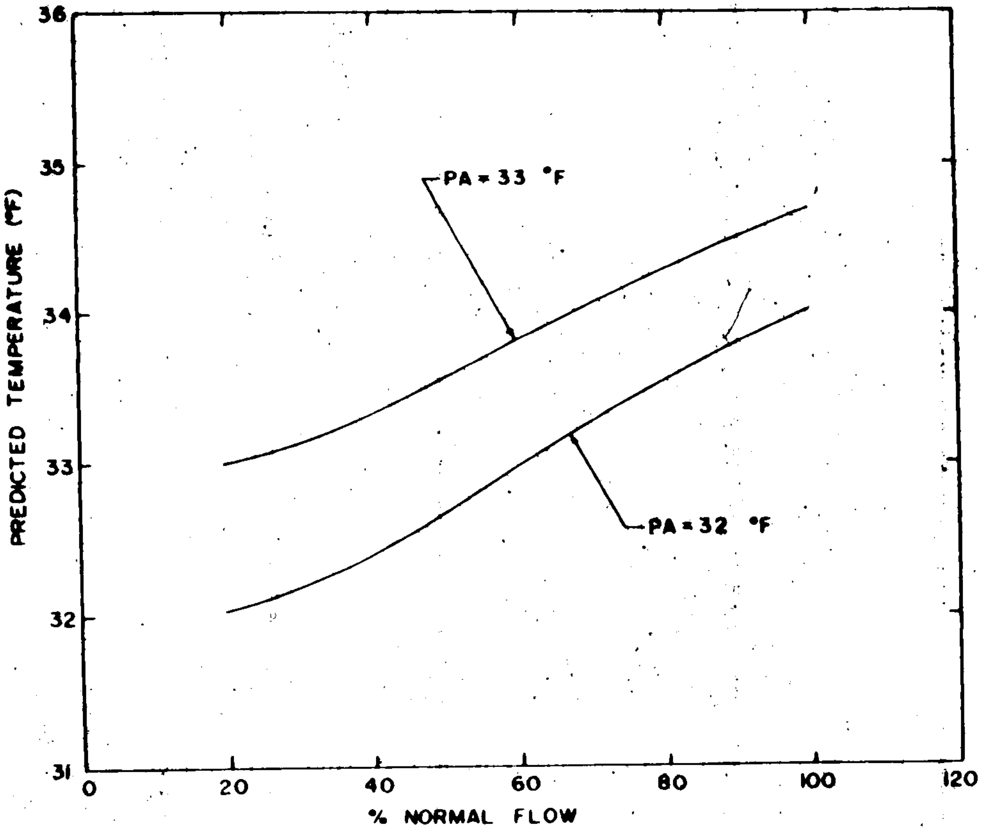
CONSUMER NUMBER 15
PREDICTED UPSTREAM TEMPERATURE
AS A FUNCTION OF FLOW

FIGURE 35



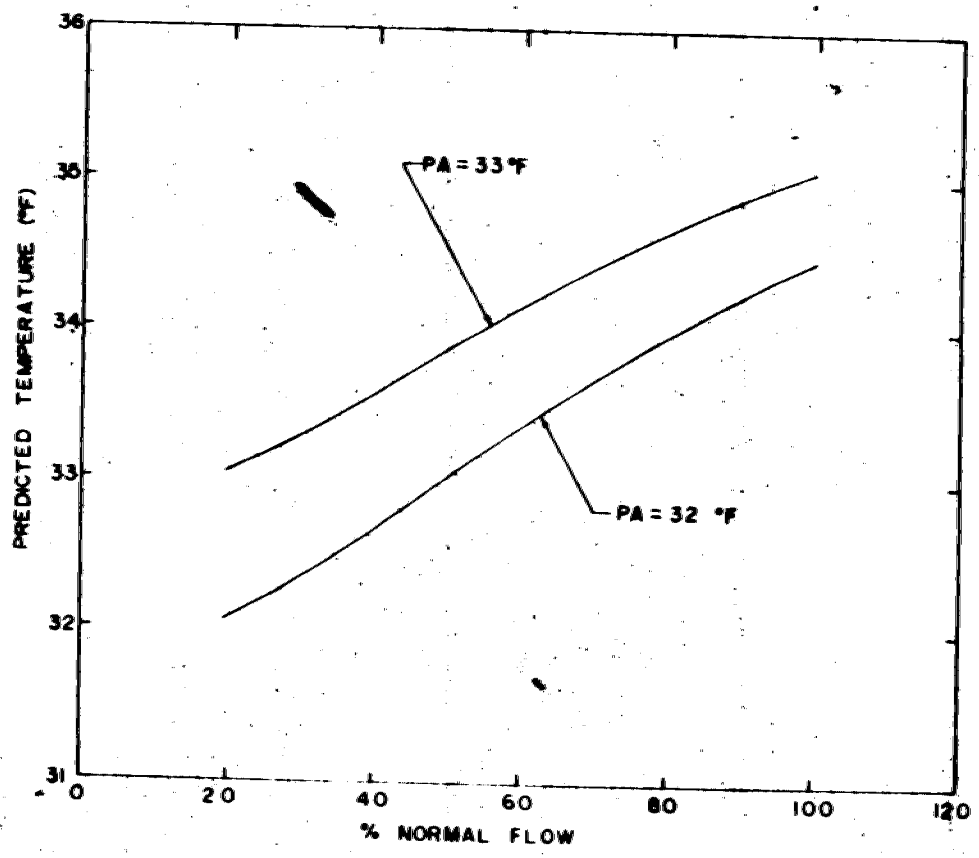
CONSUMER NUMBER 58
PREDICTED UPSTREAM TEMPERATURE
AS A FUNCTION OF FLOW

FIGURE 36



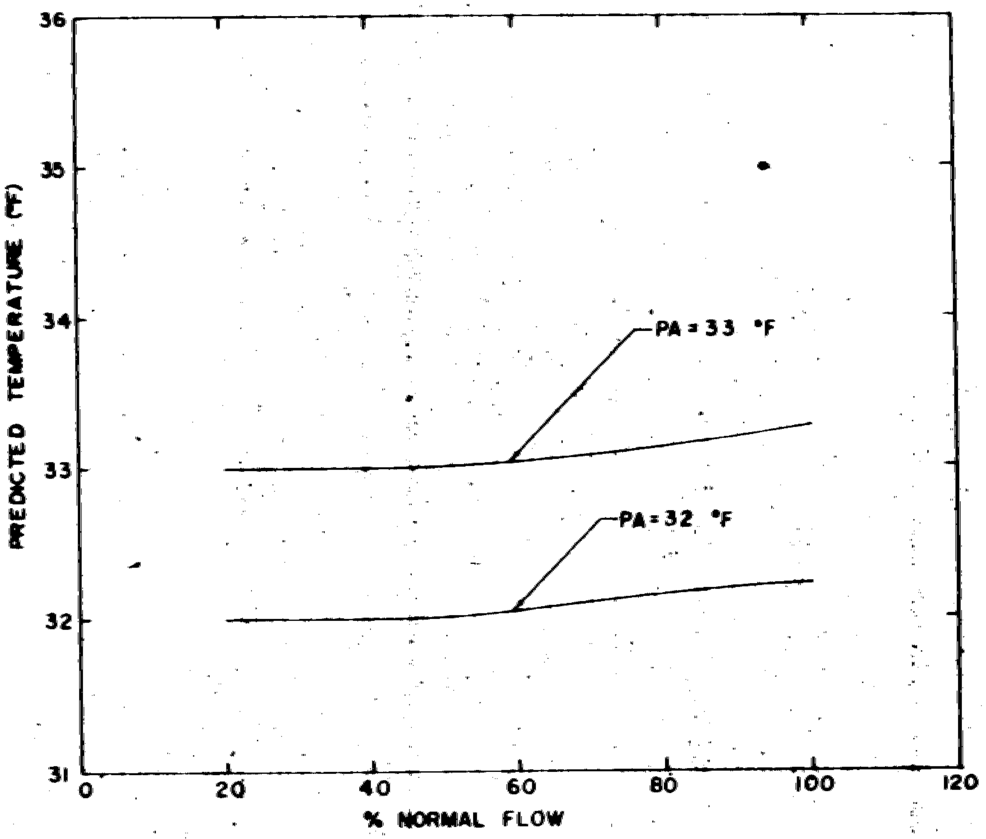
CONSUMER NUMBER 90
PREDICTED UPSTREAM TEMPERATURE
AS A FUNCTION OF FLOW

FIGURE 37



CONSUMER NUMBER III
PREDICTED UPSTREAM TEMPERATURE
AS A FUNCTION OF FLOW

FIGURE 38



CONSUMER NUMBER 103
PREDICTED UPSTREAM TEMPERATURE
AS A FUNCTION OF FLOW

VI. DISCUSSION

A. LABORATORY RESULTS

In terms of each tested device, the following observations can be made.

The temperature control device failed in three of the four times it was tested. Only at the triggering temperatures of 2 °C and 3 °C did the solenoid valve open, and only at 3 °C did any bleeder flows develop from the line. It is speculated that the failure cases occurred because, in a full pipe under stagnant flow conditions, ice formation sufficient to close off the pipe occured inside the cold room before the water temperature at the sensor had dropped low enough to trigger open the valve. In the one test where the valve opened to allow bleeding, the flow was maintained at a continuous rate for the duration of the test.

The major problem with the device seems to be the location of the temperature sensor on the service line. If the location of the thermistor at the coldest spot on the line could be ensured, proper freeze protection could probably be achieved by setting the triggering temperature within half a degree Celcius, or less, of the freezing point. On a service line where the critical location could either not be determined exactly , or where placing the sensor there would not be practical, however, it appears that the triggering temperature would have to be increased in order to make the temperature control device function properly. For exterior placement, the sensor could be either taped to the outside wall of the pipe, or set inside the line itself. The latter arrangement would require a fitting of some sort and/or a means of maintaining a water tight seal. The cable for the sensor would then have to be run inside the building and connected to the temperature controller for operating the solenoid valve. Running the sensor through the service line from the interior of a heated building to a critical location would present the problem of obtaining a cable suitable for operating under submerged conditions.

If the cable were placed on the service line inside the building, the triggering temperature would again have to be increased in order to provide adequate freeze protection. The critical period for the device would be during periods of stagnant flow when no water is being drawn from the supply main. If the triggering temperature were not set high enough, freezing could conceivably occur at a critical location during this period before the temperature at the sensor dropped low enough to initiate bleeding. This is because, under stagnant flow conditions, the heat pick up (or loss) in the building interior at the sensor location would be greater (or less) than the convective/conductive heat loss transmitted to the sensor from an exterior location along the service line. This would be especially true with longer and smaller diameter service lines. Probably the only way in which the temperature drop would be picked up by the sensor under such an arrangement would be if there were a sudden drawoff from the service line from inside the building.

If, in order to trigger open the solenoid valve, it were required to raise the triggering temperature to near the normal water temperature at a service tap, bleeding, once initiated, would be continuous and the temperature control device, during winter time operation, would be reduced to a conventional bleeder similiar to what occured during test #4.

The failure of the drainage tank in each of its four test runs can be attributed to the fact that, under the near steady state temperature conditions exhibited in the cold room, the stagnant flow periods were sufficient in length to allow the nucleation of dendritic ice. As evidenced by the increasing severity of the water hammer effects each time the flow was stopped, each flow period was not long enough to completely clear the pipe of ice, and eventually, the buildup became sufficient to block off the flow entirely.

The critical requirement for this device is that after a stagnant flow period, all the water in the pipe must be replaced by more water as the tank is being filled. If ice has nucleated in the line, the total heat imparted to the pipe by the incoming water must be sufficient to melt the ice and prevent further nucleation during the period of stagnant flow. Further to this, the pressure in the supply main also must be enough to restart the flow when the valve is reopened, especially if sufficient cooling has occured to allow the growth of annular ice.

The time period during which the tank drains and flow is arrested in the service line must also not exceed the time period required for dendritic ice to form in the line. In the laboratory test runs, these time periods were maximized because the tank was not pressurized and therefore, drainage occured by gravity flow alone.

The timer failed in two of the four tests because of the model used. A fifteen minute period of stagnant flow was sufficient under the test conditions to allow the formation of ice in the pipe. This was borne out by the amount of time taken for full bleeder flows to develop after the opening of the solenoid. No slush or ice particles were observed issuing from the line, but this can probably be accounted for by the smallness of the bleeder opening.

With the constructed timer, the amount of cooling in the pipe during the stagnant flow period was insufficient to allow dendritic ice to nucleate. The steady state equations bear this out (see Appendix 1), as did the fact that the full bleeder flows developed immediately after the opening of the valve in tests #3 and #4.

For maximum operating efficiency, the stagnant flow period should be long enough for the temperature at a critical point inside the pipe to drop to just above freezing. The bleeding period should then be just sufficient to replace all the water inside the line with higher temperature water from the supply main. Setting the solenoid to operate on such a cycle is possible with a variable set timer such as the one used in tests #3 and #4.

With all three of the devices that operate through intermittent bleeding, the critical period occurs when the flow in the line is stagnant. The net heat loss is greatest during this period because no heat input is provided into the line. With the orifice plate, a continuous input of water and hence, heat, is going into the service line and it only remains for the flow rate to be sufficient to prevent an ice nucleating temperature drop at a critical point in the line (See Appendix 1). From the orifice equation (Appendix 2), the flow through a line can be controlled by manipulating two factors. One is the size of the orifice opening, and the other is the line pressure prior to the orifice. A third factor, the size of the line can also be manipulated, but this may not be as accomplished as easily as the other two. A table giving the variations in flow with different line pressures and orifice sizes is given in Appendix 2.

In a field situation, installation of an orifice plate would allow the regulation of bleeder flows without relying on the owner, with his gate valve, to attempt to set his flows to a specified rate like 1.5 L/min (1/3 igpm). He could simply turn his valve or petcock completely open every season and turn it off every summer. In areas where grit in the lines is a problem, the size of the orifice opening could be increased if a preset pressure reducing valve were installed in the line upstream. Possible clogging of the bleeder line could thus be avoided and only a periodic cleaning of the strainer screens in the pressure reducing valve would be required. The use of a pressure reducing valve would also result in additional water savings because of the fact that the orifice plate, if used alone, would have to be set to pass minimum flows during the low pressure periods and would consequently discharge greater flows during high pressure periods.

Finally, the pressure tank device, although operated successfully in the laboratory, would appear to have a number of problems associated with it if set up as per Figure 13 (i.e., draining back through the service line to the supply main) in a field situation. One of these is the sheer size of the tank that would be required. For a release rate of, say, 1.5 L/min, operating for roughly 14 hours (say from 6 p.m. to 8 a.m.), a tank drawdown of 1271 L would be required. Additional tank space would also be required for an air bladder or some other driving mechanism. An operating air bladder would, in fact, take up the majority of the tank space. And even more storage room would be required because not all the water in the tank would drain; discharge would only continue until the internal tank and supply main pressures equalized.

At the present time, no pressure tank above 545 L (120 ig) is commercially available. Such a tank (depending on the storage/drainage ratio) releasing water at 1.5 L/min would probably be sufficient for a drain period of some 4 to 5 hours. Tanks larger than 545 L must be manufactured to order (Westburne, 1981; Bartle & Gibson, 1981).

Another problem with the field set up as originally envisioned, is the control mechanism required. With a pressure switch monitoring internal tank pressures, inflows into the tank would have to be carefully regulated to ensure that the tank operates during the times required. If tank pressures build up to the amount required for discharge prematurely, stagnant flows may occur at a critical time during the night unless an allowance is made for this with a larger size tank. If the pressure switch were mounted on the service line, there would still be a problem because the diurnal pressure cycle in the supply main system is not totally reliable. Drops in line pressure, eg. during fire flow situations, may also prematurely discharge the tank and result in stagnant flows during critical times.

To totally eliminate bleeding, the ideal arrangement for this device would be for the tank to fill up with, say, 1271 L during the daylight hours when normal demands plus tank inflows would provide frost protection for the service line, and release the same amount back to the supply main during the night. Utilizing a pressure switch as a control mechanism would not appear to be very feasible, since the device depends heavily on a constant diurnal pressure cycle.

One possible way around this would be to substitute a timer for the controlling mechanism, but this option would still require maintaining careful control over the incoming flow rate into the tank. If the fill period set were set higher than required to fill the tank during the day, a continuous night time release back to the supply main would be ensured, but periods of no flow in the service line may occur during the fill up period if the tank is already at capacity and there is no demand in the building. A larger capacity tank would therefore have to be provided in this case, and a greater tank release rate set. Some backup freeze protection method for power failures would also have to be arranged.

A more feasible pressure tank set up would be to apply the laboratory arrangement to the field situation. Rather than attempting to operate as a diurnal cycle recirculating system, the pressure tank could be run as an intermittent bleeder. This arrangement would overcome the slow discharge limitation of the original holding tank tested because of the air bladder discharging mechanism. Some sort of flow regulating device must still be used however, due to the high net bleeding rate (64 L on a 13 and 2 minute fill/ drain cycle).

A rough economic analysis of the successful laboratory alternatives is given in Tables 10 and 11. All costs have been calculated on a present worth basis for a comparison period of 20 years at a 10% rate of return. For comparative purposes, technical considerations aside, the pressure tank has been analyzed on the basis of its operation in either of two configurations: either as an intermittent bleeder, or as a holding tank discharging back to the supply main. As a bleeder, it has been assumed that its discharge can be controlled to a flow of 1.5 L/min.

Actual equipment costs were used as the basis of the capital estimates where applicable. For the variable set timer, the actual component costs of the one tested in the

TABLE 10

ESTIMATED COST

OF

SERVICE LINE BLEEDER ALTERNATIVES

Alternative	Components	Initial Cost (Capital + Installation) ($)	Water Bled (L/yr)	Power Used (kWh/yr)
1. Orifice Plate:	orifice plate & union	$ 5.00	262,080	0
	PRV	$ 50.00		
	installation	$ 20.00		
		Σ = $ 75.00		
2. Timer:	timer	$100.00	201,131	54.5
	solenoid valve	$ 50.00		
	installation	$ 20.00		
		Σ = $170.00		
3. Pressure Tank	tank	$150.00	262,080	132.8
	solenoid valve	$150.00		
	pressure switch/timer	$100.00		
	installation	$ 50.00		
		Σ = $450.0		
4. Pressure Tank (Non-bleeding)	tank	$500.00	0	132.8
	solenoid valve	$150.00		
	pressure switch/timer	$100.00		
	installation	$ 50.00		
		Σ = $800.00		

Assumptions:

1. For installation, assume a $20.00/hr rate
2. For continuous bleedings assume 182 days @ 1.5 L/min (1/3 igpm)
3. For intermittent bleeding (timer) assume a 2.2 min. bleeding and 2.1 min. non-bleeding cycle. this is derived from:
   a) the steady state calculation for the temperature drop in a 22.9 m (75 ft.), uninsulated service line, 15.9 mm (5/8") o.d., buried 1.8 m (6') underground @ -1° C pipe exterior temperature and a flow of 1.5 L/m (1/3 igpm);
   b) the steady state calculation for the time taken for a stagnant pipe with an initial temperature of 3° C to drop to the temperature calculated above;
   c) the time taken for water to flow through 22.9 m (75') of 15.9 mm (5/8") of pipe @ 1.5 L/min (1/3 igpm) and
   d) a 15% safety factor on the calculated bleeding period required.

TABLE 11

ECONOMIC COMPARISON OF SERVICE LINE BLEEDER ALTERNATIVES

Alternatives Compared	Breakeven Point: Water Delivery and Removal Cost (\$/m^3)	Conclusion
1. Timer vs. Orific Plate	\$1.73	at more than \$1.73/m^3 the timer will be more economic than the orifice plate.
2. Timer vs. Pressure Tank (Bleeding)	N/A	a bleeding pressure tank is not economical when compared to the timer.
3. Timer vs. Pressure Tank (Non-bleeding)	\$8.35	at \$\$8.35/m^3 ig or greater a non-bleeding pressure tank would be more economical than a timer.
4. Orific Plate vs. Pressure Tank (Bleeding)	N/A	a bleeding pressure tank is not economical vs the orifice plate.
5. Orifice Plate vs. Pressure Tank (Non-bleeding)	\$5.08	at \$5.08/m^3 ig or greater a non-bleeding pressure tank would be more economical than an orifice plate.

Assumptions:

1. cost/alternative = initial cost (capital + installation) + present value of annual costs (power + water bled).
2. power rate = 10¢/kwh
3. 10% rate of return for 20 years

$$\text{Present Worth Factor} = \frac{(1+i)^n - 1}{i(1+i)^n}$$

$$= 8.5136$$

laboratory were $140.00, but it was felt by the technical staff who constructed it, that comparable ones could be built for 1/2 to 2/3 that price. The cost for a 1360 L (300 ig) pressure tank is not actually available because no tank of that size is available. The $500.00 cost used in the calculation is therefore only a rough estimate, but based on the quoted net cost of a 545 L (120 ig) tank ($220.00 – Westburne, 1981), this may be low.

Finally, the power consumption for each device was calculated from equipment ratings or actual current measurements. Other assumptions and conditions are as stated in the table.

For the purposes of the present study, each device was compared and equalized on the basis of break even water delivery and sewage disposal costs to the consumer. For situations such as in Whitehorse, this may not be what he is actually billed for water and sewer, but what he will eventually have to pay (either in higher municipal taxes, or in higher costs for other municipal services) in order to keep the system operational.

The analysis has been done on this basis due to the difficulties of assessing some of the more indirect water distribution system and sewage collection system costs. Nevertheless, it is believed that these calculations provide an indication of the relative costs of each alternative.

For the Whitehorse situation, a further comparison of each alternative to the continued full bleeding option was also considered in order to obtain some net water and/or cost savings. This comparison was discarded because of the lack of water metering data on all service line bleeders and the difficulty of separating the bleeder flows from the system leakage flows.

From the internal comparison then, it can be seen that due to higher capital costs, bleeding pressure tank option is not an economic proposition when compared to the timer or the orifice plate. Technical problems aside, the non bleeding pressure tank will be viable versus the timer and orifice plate at water delivery/disposal costs of $5.08 and $8.35 per m^3 ($1.12 and $1.84 per 1000 ig), respectively. The timer option becomes a feasible alternative to the orifice plate at a delivery/disposal rate of $1.73/m^3 ($0.38/1000 ig). For approximate comparison purposes, the City of Edmonton, at roughly the same water usage rate being considered (68,100 L or 15,000 ig/month), charged $7.26/m^3 ($1.60/1000 ig) to its municipal residential customers in 1981 (City of

Edmonton, 1981).

The rate of return will have a significant effect on these calculations. Low interest rates will favor altern[illegible] high capital investments and low annual costs, whereas high interest rates will favour reverse combinations.

B. MODELLING RESULTS

The results of the computer simulation runs predict thermal failures in the downtown Whitehorse system whenever the exterior soil temperatures surrounding the pipe drop below 32 °F (0 °C). They also show the relative insignificance of the given flow rates in determining system failures. This is evidenced by the predicted pipe temperatures charted in Figures 34 through 38. The minimal importance of the flow rate relative to the pipe ambient (PA) temperature becomes increasingly evident as the water in the system moves further downstream from the start of the system and/or reaches a critical flow section. At Consumer #15, a flow decrease of approximately 22% is required before the predicted inflow temperature at PA = 33 °F (0.6 °C) will equal the same predicted temperature at PA = 32 °F (0°C). At Consumers #90 and #58, however, a flow decrease of 32% is required before the predicted temperatures at the two PA values will equal each other; and at Consumer #103, the flow independent variation in predicted temperatures is minor in comparison to the PA dependent variation.

In analyzing the computer modelling work, the validity of the predicted results can be questioned because of a number of factors.

Some of these are associated with shortcomings in the Hydrotherm model. The program, as it exists, will stop at the end of a current iteration if any of the predicted temperatures fall below 32 °F (0 °C). This is then interpreted as a system failure; in actual fact, ice growth in a flowing line will not be initiated until some supercooling has occured. This model feature does, however, provide a degree of safety for the distribution system, since not all the latent heat in the water must be lost before ice formation will start somewhere in the network, particularly on metal valves and fittings (Carefoot *et al.*, 1981).

More serious shortcomings in the model exist because of the equations used and the assumptions made. In dealing with the latter, the rationale for using a 5 ft (1.5 m) burial depth and the thermal conductivities for sand throughout the network have been discussed in Chapter 5. Lacking actual burial depths and soil data for the entire system, conservative estimates leading to conservative predictions were made.

Most soil materials will actually have a range of thermal conductivities. According to Kersten, who conducted the pioneer work in this area in the late 1940s, correct values for thermal conductivities are difficult to determine and can be up to 25% in error (Johnston *et al.*, 1981). Nixon and McRoberts (1973) have shown however, that for Neumann and Stephan type thaw calculations, neither the absolute magnitude nor the temperature dependence of the frozen conductivity will have a significant effect on the predicted rate of thaw.

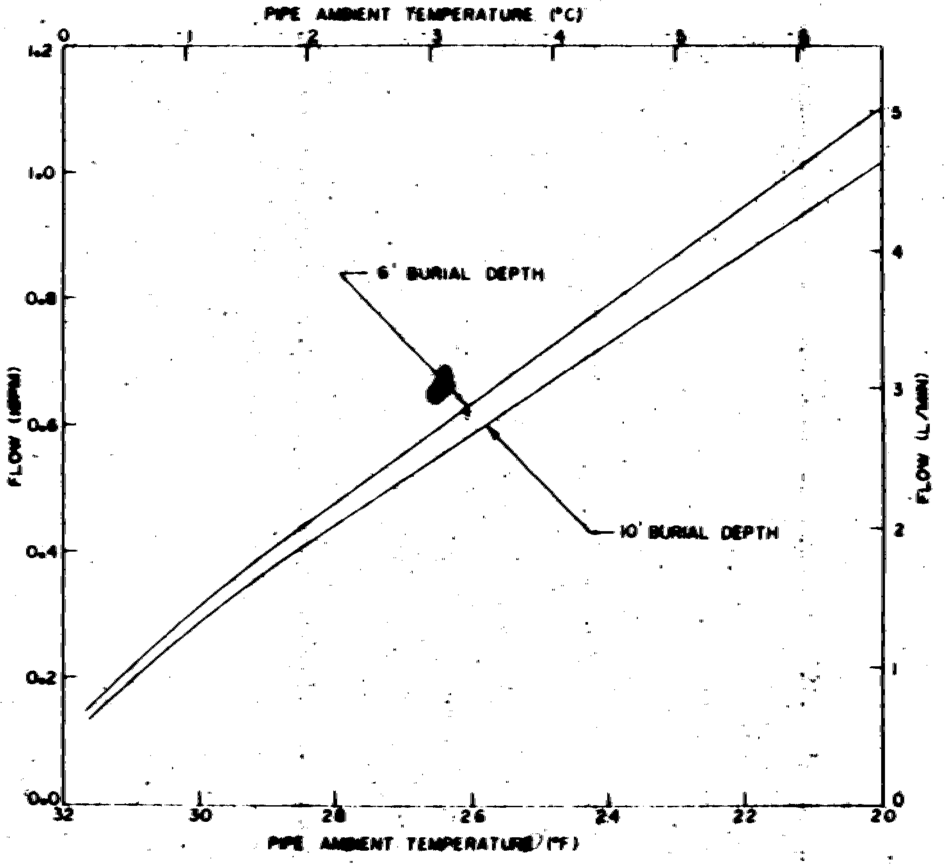
Some estimate of the effect of depth of pipe burial can be obtained from Figure 39, where freeze preventive flows for various PA temperatures have been plotted for two burial depths for a 30.5 m (100 ft) section of 12.7 mm (1/2") i.d. uninsulated pipe. The graph is deceptive in certain respects because the PA temperature is in itself dependent upon the soil depth considered i.e., there is a temperature gradient in the soil and for non permafrost soils during the freezing season, the temperature at 3.0 m (10 ft) will be higher than the temperature at 1.8 m (6 ft).

There is also some uncertainty regarding the assigning of the flow rates for the network. The sum total of the downtown Whitehorse flows were obtained from actual pumping records; lacking complete metering on the network however, the quantity and distribution of the flows in the subsidiary pipes could only be roughly estimated by indirect means. Possibly less conservative predictions would have then been obtained if the actual subsidiary flows had been known and substituted into the model. The dominance of the PA temperature variable in the actual results do not support this premise however.

In calculating interior water temperatures, conservative estimates for PA were also made. The coupling of the time independent steady state equations with exterior soil temperatures below 0 °C essentially presumes non-thawing permafrost conditions. The actual ground thermal conditions for Whitehorse are less severe than this.

T.H. Newton Engineering Ltd. (1964) has recorded that localized frost penetrations to 4.3 m (14 ft) have been known to occur in the Whitehorse area, and Byron (1970) has

FIGURE 39



STEADY STATE FREEZE PROTECTIVE FLOWS

ASSUMPTIONS

1. 100 FEET OF 1/2" ID (5/8" OD) UNINSULATED PIPE.
2. ALL THERMAL RESISTANCES OTHER THAN THE SOIL ARE IGNORED.

stated that during periods of intense cold, frost has been known to penetrate below 2.7 m (9 ft). For the ground and temperature conditions assumed in the present study, the modified Berggren equation (see Appendix 7) predicts a frost penetration, or active layer, of 4.0 meters (13.1 feet). All of these figures are for undisturbed areas however, and do not take into account the thermal influence of a warm pipe upon its surrounding soil mass. The modified Bergreen equation assumes, for example, that all the soil material is initially isothermal at some temperature greater than 0 °C. Other assumptions such as a step decrease in temperature, and the liberation of all the latent heat at 0 °C, will tend to overestimate the maximum freezing isotherm (Nixon and McRoberts, 1973; Smith *et al.*, 1979; Goodrich and Gold, 1981).

Some soil temperature data obtained from the City of Whitehorse Engineering Department for 1979 – 1980 is given in Appendix 8. Wherever possible, the City placed their sensors close (0.1 meters) to the water main and the temperatures thus obtained are for areas under the thermal influence of the pipe. These show that the minimum ground temperatures (occurring in the late winter/early spring period) at the depth of bury do not drop below the freezing mark. In the case of the two temperature sensors (#s 4 and 5) not located near a water main, at the time the data was obtained from Whitehorse, not enough time had elapsed for natural ground conditions to reassert themselves, or for the sensors to record an entire annual temperature cycle.

The thermal influence of the pipe upon its surrounding soil mass is of importance because of the soil temperature term, PA, used in determining the interior fluid temperature at the end of a given pipe section. The majority of work conducted in this area has focussed on the extent and nature of permafrost beneath an engineering structure and the resultant thaw settlement and loss of soil stability. A number of geothermal models using computerized numerical techniques have been developed that are capable of accounting for latent heat effects, temperature dependent soil thermal properties, and various surface temperature fluctuations and heat source inputs (Goodrich, 1973; Jahns *et al.*, 1973; Kent and Hwang, 1980). Nevertheless, the most sophisticated of these models still employ severe idealizations, and all of them are limited by the quantity and reliability of input data (Thornton, 1976, 1977). Goodrich (1973) has pointed out the uncertainties associated with relating air thawing or freezing indices to ground temperatures which are usually unavailable – and notes that such uncertainties may negate any additional benefits to be gained by further refining a model.

In permafrost soils, a simple analytical solution to obtaining the temperatures below the active layer has been given by a number of authors (Thornton, 1977, Cameron, 1977; Smith *et al.*, 1979, Carefoot *et al.*, 1981). The principle of superposition is used to add the calculated steady state ground temperatures when a pipeline is considered, to the maximum ground temperature that would occur in the permafrost beneath the active layer without a pipe present. Because of the idealizations employed, this solution will overestimate the depth of thaw. When fluctuating surface temperatures and latent heat effects must be considered however, there is no analytical solution, and numerical techniques must be applied.

Relatively little consideration has been given to the reverse problem of soil/pipe thermal interactions upon the fluid temperatures inside the pipe. Steady state equations have usually been used, although in the strict sense, these heat transfer approximations are only appropriate for situations with constant, or relatively constant, boundary conditions. For pipes buried beneath the influence of fluctuating air temperatures, Porkhayev (Cameron, 1975) has stated that the soil temperatures around the pipe will resemble a slowly changing series of steady state conditions. Some early work on using steady state theory to calculate heat losses for pipes buried at conventional depths has been done by Page (1955, 1956) and Day (1956) for Fairbanks, Alaska. The results there were calibrated using measured temperatures in and around the pipeline and calculated values for the soil conductivities.

Refinements to the simple case steady state heat loss equations for buried pipes have been made by a number of researchers. Janson (1963) used superposition to add a partial differential term to the equation for use in calculating the heat loss when there is a temperature gradient in the ground. He suggested that the term is insignificant except for pipes buried just below the ground surface and under the influence of air temperature fluctuations. Further steady state refinements and experiments by a number of Russian authors have also been made. These have involved substituting the ground surface temperature with the undisturbed soil temperature at the depth of the pipe axis, and in the case of a thaw zone around the pipe, an equivalent thaw bulb temperature. Cameron

(1975) has reported good to erratic results in the Russian verification of these equations. The majority of the steady state refinements for various pipe burial conditions have been summarized by Thornton (1977) and are given in Appendix 1.

Use of the steady state approximations have focussed on calculating heat loss rates at given pipe cross sections in order to determine the requirements, such as insulation thicknesses or heat tape capacities, for pipe freeze prevention and/or protection of the permafrost.

When conducting a network thermal analysis such as Hydrotherm, a more useful indication of heat adequacy can be obtained by working with temperatures rather than with heat losses. A different steady state equation must therefore be used which employs a Log Mean Temperature Difference to account for the fluid convective effects inside the pipe (See Appendix 1). This equation is generally applicable to pipes in air, but has been applied to buried pipes as well (Smith *et al.*, 1979). The PA temperature term that must be used in this case is that of the undisturbed soil mass at the pipe axis depth. A drawback to this temperature equation appears to be the lack of a term to account for the latent heat present in the water. At the freezing point and slightly below therefore, predicted temperatures using the equation will be lower than what will actually occur. The latent heat effect will offer some additional degree of protection to the system, but exactly how much, is difficult to ascertain. At valves and fittings, the safety factor time will certainly be less than that required for the cross section to freeze solid.

Finally, a third ambiguity relates back to the mechanism of heat transfer between the pipeline and the soil. One of the more common assumptions used in these kind of heat transfer problems is that the process will occur through conduction alone. This approximation is useful when dealing strictly with frozen soils, but when water, water vapour, and air are present in the soil pores, heat will actually be transfered simultaneously through a number of processes: conduction through the structural soil skeleton, convection (internal pore circulation, migration, and filtration), evaporation and condensation, and radiation. In such cases, it might be prudent to determine an effective soil "conductivity" for the soil as a system rather than as a substance.

In 1974, Lock and Thierman attempted to reconcile the predictions of a mathematical steady state thermal model (similiar to that used in Hydrotherm) with measured observations from the Yellowknife dual main recirculation system. They speculated that the observed temperature difference of only 0.27 °C (0.5 °F) between the supply and return at the pumphouse might be due to a much lower effective soil conductivity than that usually associated with a saturated material.

VII. SUMMARY AND CONCLUSIONS

Bleeding of service lines, and dead end mains and hydrants is the simplest method of freeze protection for a conventional piped water system in northern areas. Adverse characteristics of bleeding systems are high per capita water usage, high system operating costs, and the generation of large quantities of cold and dilute wastewater.

The aim of the present study has been to develop some viable alternative service line bleeder controls for use with an existing bleeder system. Towards this end, the initial development and current characteristics of an existing bleeder system have been summarized, a number of service line bleeder controls have been tested in a laboratory setting, and an attempt has been made to determine, with the aid of a computer model, an existing network thermal response to reductions in bleeder flows.

Five types of bleeder control devices were tested in the laboratory: a temperature controller, a timer, a gravity flow drainage tank, an orifice plate, and a storage pressure tank. The results suggest the following:

The temperature control device, in theory, holds the most promise for control of bleeding because of its reliance on the most direct indicator of thermal failure in a pipe. But because of triggering temperature problems and anticipated sensor placement difficulties on an existing service line, it cannot be considered a feasible bleeder alternative.

The use of a pressure tank cycling water back to the supply main during low system pressure periods also cannot be considered a feasible bleeder alternative. Such a device, if operated successfully, would eliminate service line bleeding altogether, but besides the size of the tank that would be required, this alternative places too great a reliance on a regular diurnal pressure cycle in the supply main network.

For a different reason, the use of an ordinary holding tank that would fill up, and then waste water to a sewer drain, also cannot be considered a viable bleeder alternative. The main problem here is that gravity flow is too slow a method for discharging the accumulated water. Attempting to alleviate the problem by accumulating smaller amounts of water would also entail decreasing the fill period, with the result that the latter may not be long enough to completely clear the supply pipe of any nucleated ice. This problem would be solved if a pressure tank with an internal air bladder, or other driving mechanism to drain away the water, were substituted instead. Notwithstanding this, careful control over the tank inflow and discharge rates would still be required, as would a reliable control mechanism. This version of the holding tank alternative is therefore also not considered to be feasible.

The two tested alternatives considered technically feasible for further development are the orifice plate and the variable set timer. Used alone, the former device would regulate continuous bleeder flows to a specified minimum and relieve the bleeder operator of the responsibility of attempting to set his own flows. Line grit problems could be avoided and further water savings would also be possible if the orifice plate were installed in conjunction with a pressure reducing valve on a vertical service line bleeder take off.

The variable set timer device, on the other hand, has the greater water saving potential because bleeding would only be intermittent. Assuming certain Whitehorse conditions, the total amount of water bled with this device would be only half of that allowed by the orifice plate.

Employing a present worth comparison based on a 20 year expected life, the timer appears to be the more economic of the two options, based largely on the amount of water that would be bled.

The results of the computer modelling work are not as definite or as clear cut as those from the laboratory. With a developed thermal model employing basically steady state heat transfer theory, the results for downtown Whitehorse suggest that pipe freezing will occur at exterior soil temperatures below 0 °C. The results also suggest that the network flow rates will only have a minor effect on whether or not thermal failures occur in the system.

These results cannot be regarded as conclusive due to uncertainties about the assumptions made and the equations used in the analysis. Uncertainties with the former include the average flow rates, the depth of pipe burial, and the effective soil thermal conductivities. Uncertainties about the latter are the applicability of steady state approximations for non steady state conditions, the ignoring of latent heat effects in the water, and the exterior soil temperature term used in calculating incoming and outgoing fluid temperatures.

It is concluded that the computer modelling results are conservative and that the actual water temperatures will be somewhat higher than predicted. At the flow rates considered, it also appears that reductions in bleeder flow will not affect the thermal response of the system to any significant degree.

VIII. RECOMMENDATIONS

1. Verification of the laboratory results should be carried out in a field situation before any large scale application of the tested alternatives is made to an existing bleeder system. It is therefore recommended that interested parties set up a field monitoring program to test out the timer and orifice plate devices (and variations thereof) in a variety of service line bleeder settings. Testing should be carried over a minimum of one winter bleeding period. Data collected should include bleeder flows, supply main and service line water temperatures, and ground surface temperatures.

2. If further information is desired on distribution network thermal responses to reductions in bleeder flow, it is also recommended that additional computer modeling work be carried out. An attempt should then be made to calibrate the chosen model with actual site conditions. This would entail obtaining actual pipe burial depths, data from actual representative soil samples, supply main flow data, and air and soil temperature data. The latter could be gathered by burying strings of thermocouples at various depths both near and away from buried pipelines. Some thought should also be given to using a geothermal model to predict the exterior soil temperatures at the pipe axis depth. Verification of the distribution network model could then be carried out by comparing the predicted and actual system temperatures.

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APPENDIX 1

STEADY STATE HEAT TRANSFER EQUATIONS APPLICABLE FOR FLUID FLOW IN PIPES

Appendix 1

References:
1. Andrews, R.V. (1955)
2. Gebhart, B. (1971)
3. Thornton, D.E. (1977)
4. Stephanson, D.G. (1977)
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6. Smith et.al. (1979)
7. Thomas, L.C. (1980)

Heat Conduction

The general equation for heat conduction is

$$\frac{\partial T}{\partial t} = \alpha\left[\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2} + \frac{\partial^2 T}{\partial Z^2}\right] \qquad (1.1)$$

where T = temperature
t = time
α = thermal diffusivity
= k/c, k = thermal conductivity
c = volumetric heat capacity

Under steady state conditions, $\frac{\partial T}{\partial t} = 0$ and the equation reduces to α times the Laplacian of T

$$\text{i.e.,} \quad \alpha \nabla^2 T = 0 \qquad (1.2)$$

In cylindrical coordinates (see Figure 1A)

$r = (x^2 + y^2)^{1/2}$

$\theta = \arctan \frac{y}{x}$

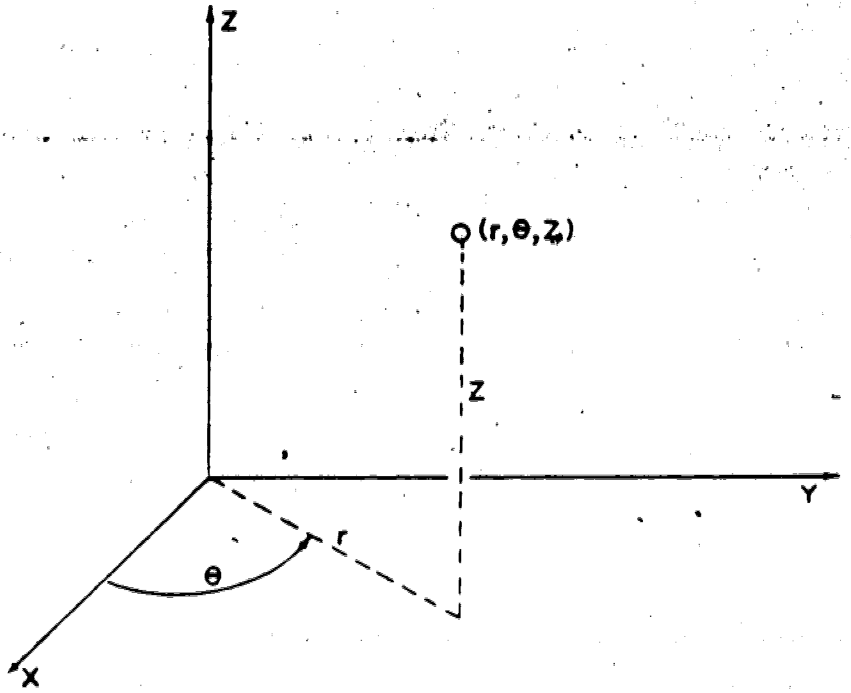
$x = r \cos\theta$

$y = r \sin\theta$

$z = z$

and $T = f(r,\theta,z)$ where $r = f(x,y)$
$\theta = f(x,y)$

FIGURE 1A



RADIAL COORDINATES

by the chain rule,

$$\frac{\partial T}{\partial X} = \left(\frac{\partial T}{\partial r} \cdot \frac{\partial r}{\partial x}\right) + \left(\frac{\partial T}{\partial \theta} \cdot \frac{\partial \theta}{\partial x}\right)$$

and

$$\frac{\partial^2 T}{\partial x^2} = \underbrace{\frac{\partial}{\partial x}\left[\frac{\partial T}{\partial r}\right.}_{a} \cdot \underbrace{\left.\frac{\partial r}{\partial x}\right]}_{b} + \underbrace{\frac{\partial}{\partial x}\left[\frac{\partial T}{\partial \theta}\right.}_{c} \cdot \underbrace{\left.\frac{\partial \theta}{\partial x}\right]}_{d}$$

a. $$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial r}\right) = \left[\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial r}\right) \cdot \frac{\partial r}{\partial x}\right] + \left[\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial \theta}\right) \cdot \frac{\partial \theta}{\partial x}\right]$$

$$= \left[\frac{\partial^2 T}{\partial r^2} \cdot \frac{\partial r}{\partial x}\right] + \left[\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial \theta}\right) \cdot \frac{\partial \theta}{\partial x}\right]$$

b. $$\frac{\partial r}{\partial x} = \frac{\partial}{\partial x}\left[\left(x^2 + y^2\right)^{\frac{1}{2}}\right]$$

$$= \frac{x}{(x^2+y^2)^{\frac{1}{2}}}$$

$$= \frac{x}{r}$$

$$\therefore \frac{\partial^2 r}{\partial x^2} = \frac{r - x\left(\frac{\partial r}{\partial x}\right)}{r^2}$$

$$= \frac{1}{r} - \frac{x^2}{r^3}$$

$$= \frac{y^2}{r^3}$$

c. $\frac{\partial}{\partial x}\left[\frac{\partial T}{\partial \theta}\right] = \left[\frac{\partial}{\partial r}\left(\frac{\partial}{\partial \theta}\right)\cdot\frac{\partial r}{\partial x}\right] + \left[\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial \theta}\right)\cdot\frac{\partial \theta}{\partial x}\right]$

$$= \left[\frac{\partial}{\partial r}\left(\frac{\partial T}{\partial \theta}\right)\cdot\frac{\partial r}{\partial x}\right] + \left[\frac{\partial^2 T}{\partial \theta}\cdot\frac{\partial \theta}{\partial x}\right]$$

d. $\frac{\partial \theta}{\partial x} = \frac{\partial}{\partial x}\ (\text{arc tan } \frac{y}{x}\ )$

$$= \frac{1}{1 + (\frac{y}{x})^2} \cdot \left(\frac{-y}{x^2}\right)$$

$$= \frac{-y}{r^2}$$

$$\therefore \frac{\partial^2 \theta}{\partial x^2} = -y\left(\frac{-2}{3r^3}\right)\frac{\partial r}{\partial x}$$

$$= \frac{2xy}{r^4}$$

by substituting all of the above and assuming continuity of first and second partial derivatives such that

$$\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial r}\right) = \frac{\partial}{\partial r}\left(\frac{\partial T}{\partial \theta}\right) .$$

$$\frac{\partial^2 T}{\partial x^2} = \left[\frac{x^2}{r^2}\left(\frac{\partial^2 T}{\partial r^2}\right)\right] - \left[\frac{2xy}{r^3}\cdot\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial r}\right)\right] + \left[\frac{y^2}{r^4}\left(\frac{\partial^2 T}{\partial \theta^2}\right)\right] + \left[\frac{y^2}{r^3}\left(\frac{\partial T}{\partial r}\right)\right] + \left[\frac{2xy}{r^4}\left(\frac{\partial T}{\partial \theta}\right)\right]$$

similiarly,

$$\frac{\partial^2 T}{\partial y^2} = \left[\frac{y^2}{r^2}\left(\frac{\partial^2 T}{\partial r^2}\right)\right] + \left[\frac{2xy}{r^3}\cdot\frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial r}\right)\right] + \left[\frac{x^2}{r^4}\left(\frac{\partial^2 T}{\partial \theta^2}\right)\right] + \left[\frac{x^2}{r^3}\left(\frac{\partial T}{\partial r}\right)\right] - \left[\frac{2xy}{r^4}\left(\frac{\partial T}{\partial \theta}\right)\right]$$

substituting into the Laplacian and reducing:

$$\alpha\left[\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\left(\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\left(\frac{\partial^2 T}{\partial \theta^2}\right) + \frac{\partial^2 T}{\partial z^2}\right] = 0 \qquad (1.3)$$

In considering only 1 dimensional heat conduction (radial) from a cylindrical region (see Figure 1B),

$$\frac{\partial^2 T}{\partial y^2} = 0$$

$$\frac{\partial^2 T}{\partial z^2} = 0$$

and equation 1.3 reduces to

$$\alpha \left[\frac{\partial^2 T}{\partial r} + \frac{1}{r}\frac{\partial T}{\partial r}\right] = 0 \qquad (1.4)$$

$$\longleftrightarrow \alpha \left[\frac{d^2 T}{dr} + \frac{1}{r}\frac{dT}{dr}\right] = 0 \qquad (1.5)$$

solving $\frac{d^2 T}{dr} + \frac{1}{r}\frac{dT}{dr} = 0$,

let $p = \frac{dT}{dr}$

$$\therefore \frac{dp}{dr} + \frac{p}{r} = 0$$

$$\longleftrightarrow r(dp) + p(dr) = 0$$

and $d(p \cdot r) = 0$ by the chain rule

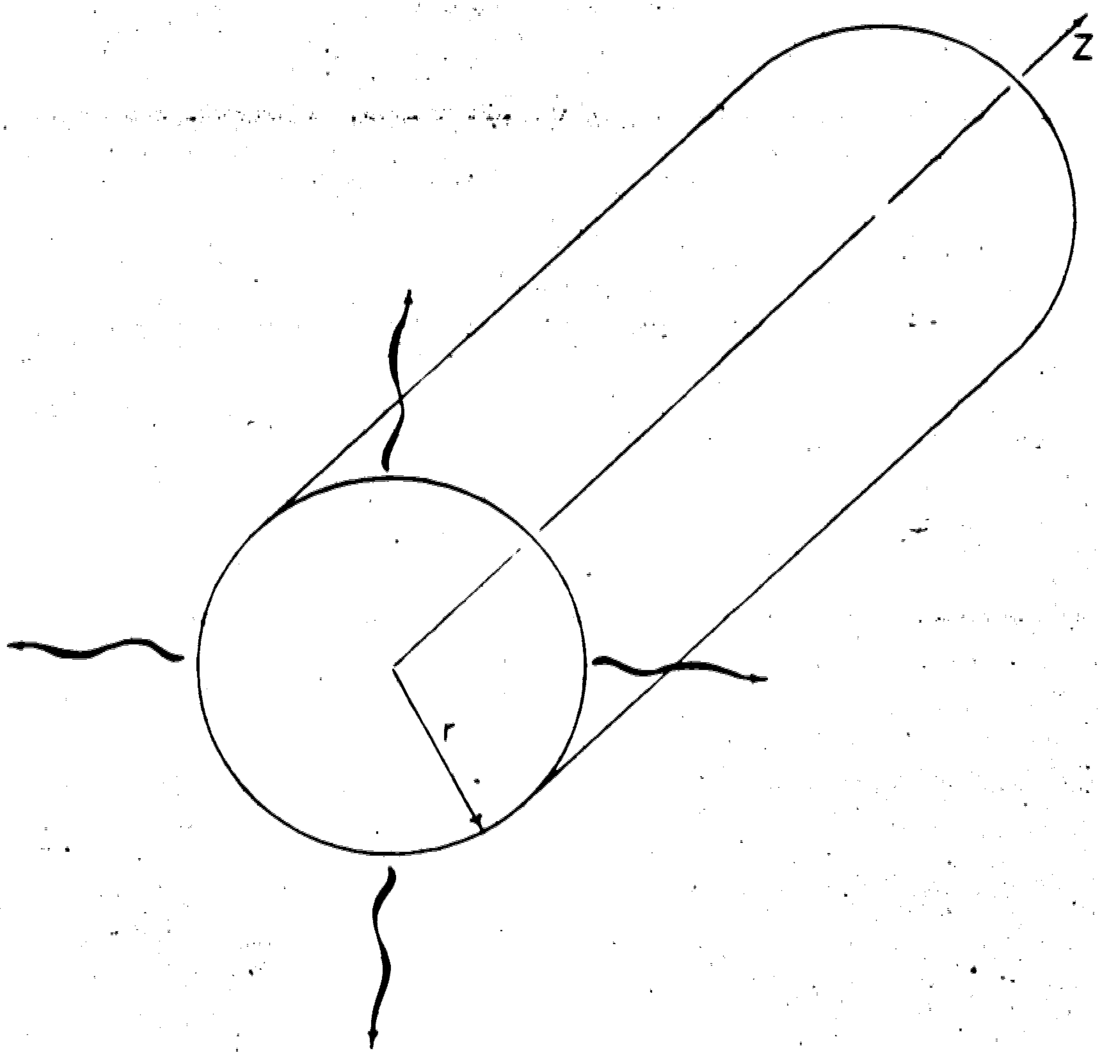
$$\int d(p \cdot r) = \int 0$$

$$\longleftrightarrow \frac{dT}{dr} \cdot r = A_1$$

$$\longleftrightarrow \int dT = A_1 \int \frac{dr}{r}$$

$$\longleftrightarrow T = A_1 \ln r + A_2 \qquad (1.6)$$

FIGURE 1B



ONE DIMENSIONAL [RADIAL] HEAT CONDUCTION

In the case of a hollow cylinder like a pipe (see Figure 1c),

$$@ \quad r_1, \quad T = T_1$$

$$@ \quad r_2, \quad T = T_2$$

and equation 1.6 becomes,

$$T_1 = A_1 \ln r_1 + A_2$$

$$T_2 = A_1 \ln r_2 + A_2$$

solving,

$$A_1 = \frac{T_2 - T_1}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$A_2 = T_1 - \left[\frac{T_2 - T_1}{\ln\left(\frac{r_2}{r_1}\right)}\right] \ln r_1$$

and ∴ the distribution of heat, $T(r)$, in the region $r_1 < r < r_2$ becomes

$$T = \left[\frac{T_2 - T_1}{\ln\left(\frac{r_2}{r_1}\right)}\right] \ln r + T_1 - \left[\frac{T_2 - T_1}{\ln\left(\frac{r_2}{r_1}\right)}\right] \ln r_1$$

$$\longrightarrow T = \frac{\left[T_1 \ln\left(\frac{r_2}{r}\right)\right] + \left[T_2 \ln\left(\frac{r}{r_1}\right)\right]}{\ln\left(\frac{r_2}{r_1}\right)} \qquad (1.7)$$

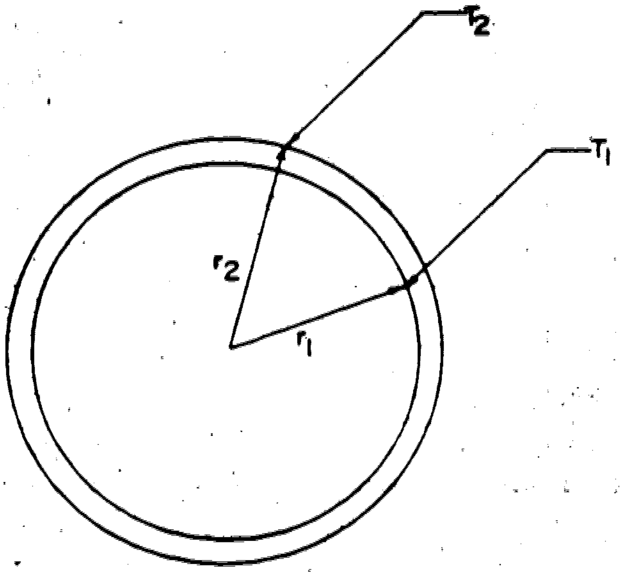
By Fourier's Law of Conduction, the rate of heat q_x transferred in a direction x through a finite area A_x is

$$q_x = -k\, A_x \frac{\partial T}{\partial x}$$

or, in cylindrical coördinates,

$$q = -k\, A \frac{\partial T}{\partial r}$$

FIGURE 1C



HOLLOW CYLINDER

For a hollow cylinder of surface area $2\pi r$, therefore .

$$q = -k(2\pi r)\frac{\partial}{\partial r}\left[\frac{\left[T_1 \ln\left(\frac{r_2}{r}\right)\right] + \left[T_2 \ln\left(\frac{r}{r_1}\right)\right]}{\ln\left(\frac{r_2}{r_1}\right)}\right]$$

which eventually reduces to

$$q = \frac{2\pi k\,(T_1 - T_2)}{\ln\left(\frac{r_2}{r_1}\right)}$$

$$= \frac{T_1 - T_2}{R} \qquad (1.8)$$

where

$$R = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k} \qquad (1.9)$$

In general, R may be defined as a thermal resistance and is equal to the difference in temperature between two surfaces divided by the rate of heat flow between them.

Equation 1.8 can therefore be taken as the radial conductive heat flow rate for a bare or insulated pipe in air. In the former case,

r_1 = inside pipe radius

r_2 = outside pipe radius

T_1 = interior pipe temperature

T_2 = ambient temperature

For an insulated pipe where all thermal resistances other than the insulation are ignored,

r_2 = outside radius of pipe insulation

r_1 = inside radius of pipe insulation

T_1 = temperature inside the pipe

T_2 = ambient temperature

Equation 1.8 can be rewritten as

$$q = k\ (S.F.)\ \Delta T \qquad (1.10)$$

where S.F. can be defined as a Shape Factor equal to the inverse of the thermal resistance divided by the thermal conductivity, i.e.,

$$\left[\frac{1}{R}\right] \div k$$

The shape factor is thus independent of the material involved and is solely dependent on the geometric properties of the body through which heat is being conducted.

For a hollow cylinder,

$$S.F. = \frac{2\pi}{\ln\left(\frac{r_2}{r_1}\right)}$$

and for a cylinder near an infinite plane (see Figure 1D),

$$S.F. = \frac{2\pi}{\ln\left[\frac{H_p}{r} + \sqrt{\frac{H_p^2}{r^2} - 1}\right]}$$

$$= \frac{2\pi}{\text{arc cosh}\ (\frac{H}{r})}$$

and the rate of heat flow is ∴

$$q = \frac{T_1 - T_2}{\left[\text{arc cosh}\left(\frac{H_p}{r}\right) / \ 2\pi k\right]} \qquad (1.11)$$

This can therefore be taken as the equation for the radial conductive heat flow for a bare pipe buried H distance below the ground in a one phase soil, where

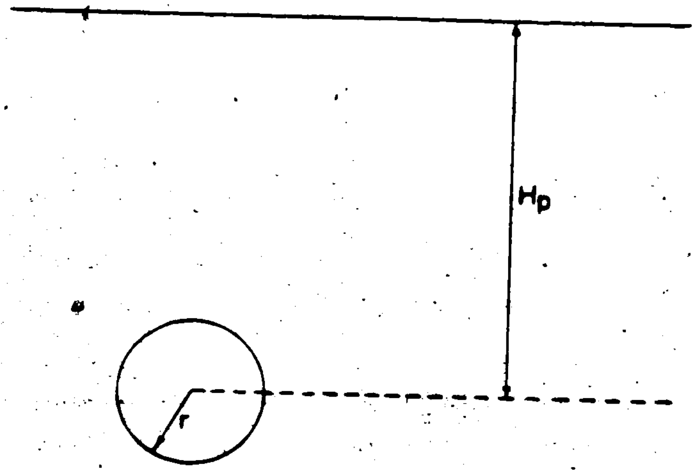
T_1 = interior pipe temperature

T_2 = ground surface temperature

Where the depth of burial is greater than one pipe diameter, the ground surface temperature may be replaced by the undisturbed soil temperature at the depth of bury.

All thermal resistances other than the soil are ignored in Equation 1.11. For insulated pipes, a net thermal resistance is obtained through the addition of Equation 1.9.

FIGURE 1D



CYLINDER NEAR A PLANE

INTERIOR PIPE TEMPERATURES

In general, the convective heat flow q from an object of surface area A is given by

$$q = h\ A\ \Delta T_m \qquad (1.12)$$

where h = a convection conductive/convective coefficient
ΔT_m = temperature difference in terms of average values

For a pipe flowing full, at any given pipe section dA (see Figure 1E) therefore,

$$dq = h\ dA\ (T - T_A)$$

where T = the average temperature of the fluid at dA
T_A = exterior pipe temperature

The heat transfer rate is also equal to the time rate of change of the fluid energy content when passing over dA

i.e., $dq = m\ Cp\ dT$

where m = fluid mass flow rate
Cp = specific heat of the fluid
dT = change in average fluid temperature across dA
$= d\ (T - T_A)$

$$\therefore h\ dA\ (T - T_A) = m\ Cp\ d\ (T - T_A)$$

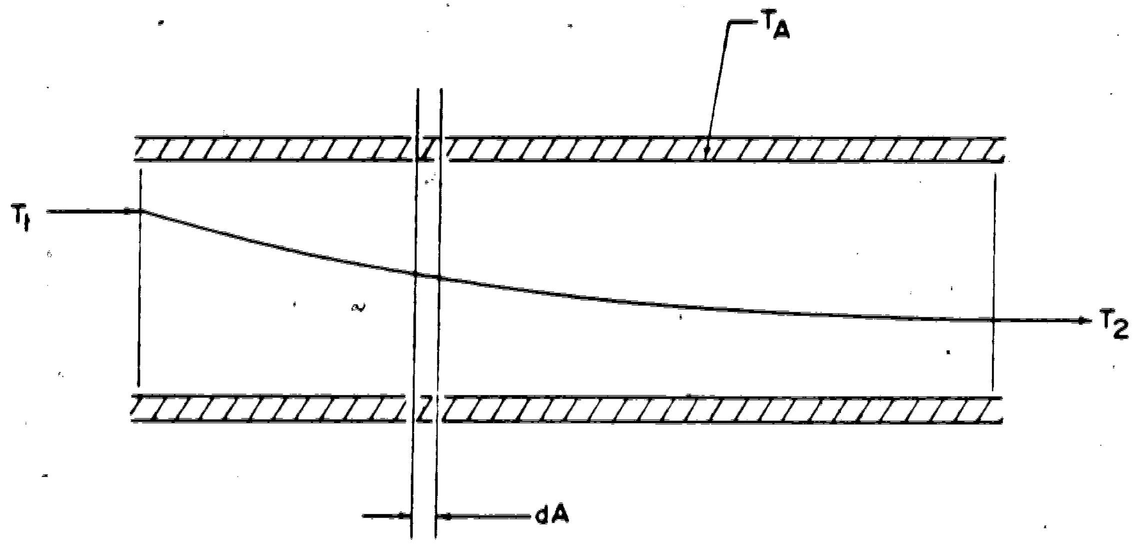
$$\longleftrightarrow \quad \frac{h\ dA}{m\ Cp} = \frac{d(T-T_A)}{(T-T_A)}$$

$$\longleftrightarrow \quad \int_0^A \frac{h\ dA}{m\ Cp} = \int_{T_2}^{T_1} \frac{d(T-T_A)}{(T-T_A)} \quad , \quad T_1 > T_2$$

$$\longleftrightarrow \quad \frac{h\ A}{m\ Cp} = \ln\ (T-T_A)\Big]_{T_2}^{T_1}$$

$$= \ln \left[\frac{T_1 - T_2}{T_2 - T_A}\right]$$

FIGURE 1E



THE TEMPERATURE DISTRIBUTION

ALONG A PIPE

Since the total heat transfer rate q across A is also equal to the rate of fluid energy loss,

$$h\ A\ \Delta T_m = m\ Cp\ (T_1 - T_2)$$

$$\longleftrightarrow \left[\frac{h\ A}{m\ Cp}\right] \Delta T_m = T_1 - T_2$$

It therefore follows that

$$\Delta T_m = \frac{T_1 - T_2}{\ln\left[\frac{T_1 - T_A}{T_2 - T_A}\right]} \qquad (1.13)$$

$$= \text{Log Mean Temperature Difference (LMTD)}$$

and $$q = h\ A \left[\frac{T_1 - T_2}{\ln\left(\frac{T_1 - T_A}{T_2 - T_A}\right)}\right] \qquad (1.14)$$

In electrical analog terms, h can be thought of as

$$h = \frac{1}{RW}$$

where R = thermal resistance
W = an area dimension

For a pipe of length L therefore, equation 1.14 can be rewritten as

$$q = \frac{A\ \Delta T_m}{RW}$$

$$= \frac{L\ \Delta T_m}{R} \qquad (1.15)$$

In a pipe, the heat loss rate q can also be related to the fluid flow rate and the temperature drop between inlet and outlet (see Figure 1F)

$$q = \pi r_w^2 \, V \, C \, (T_1 - T_2) \tag{1.16}$$

where r_w = interior pipe radius
V = fluid velocity
C = volumetric heat capacity of the fluid

Equating equations 1.15 and 1.16,

$$\pi r_w^2 \, V \, C \, (T_1 - T_2) = \frac{L \, (T_1 - T_2)}{\ln\left(\frac{T_1 - T_A}{T_2 - T_A}\right) R}$$

$$\longleftarrow \ln \left[\frac{T_1 - T_A}{T_2 - T_A}\right] = \frac{L}{\pi r_w^2 \, V \, C}$$

from which

$$T_1 = T_A + (T_2 - T_A) \, e^{\left(\frac{L}{\pi r_w^2 VCR}\right)} \tag{1.17}$$

$$T_2 = T_A + (T_1 - T_A) \, e^{\left(\frac{-L}{\pi r_w^2 VCR}\right)} \tag{1.18}$$

Further, if we set

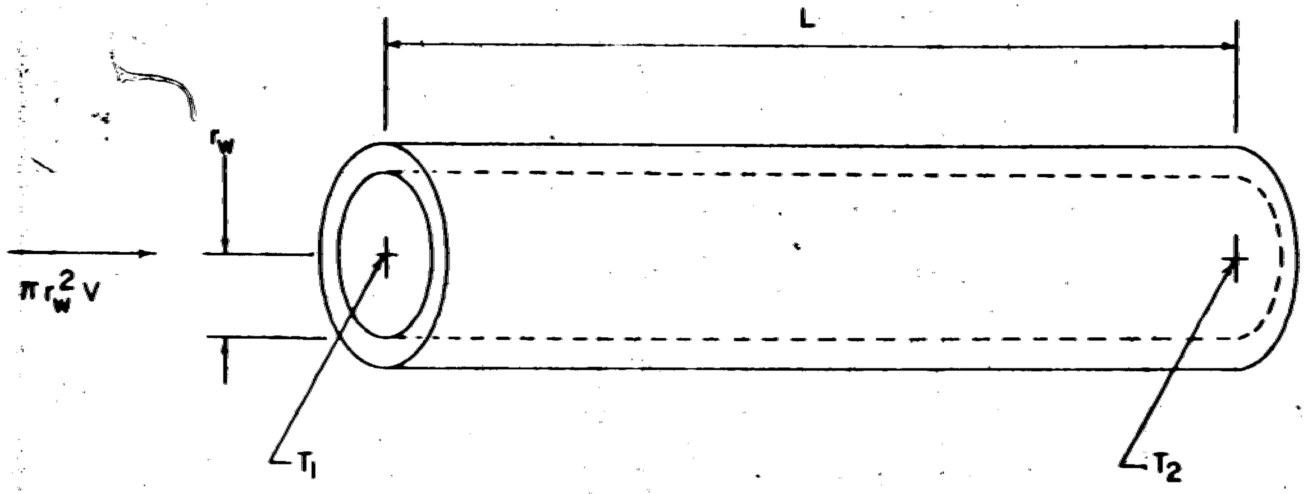
$$D = \pi r_w^2 VCR,$$

then

$$q = \frac{D}{R} \left[(T_1 - T_A) \, (1 - e^{\left(\frac{-L}{D}\right)})\right] \tag{1.19}$$

For uninsulated buried pipes, the thermal resistance R will be that of the soil plus the pipe material. Where the latter is insignificant, the soil resistance alone may be used.

FIGURE 1F



PIPE FLUID FLOW RATE

FREEZE PROTECTIVE FLOWS

From equation 1.16,

$$q = \pi r_w^2 \; V \; C \; (T_1 - T_2)$$

$$= m \; Cp \; (T_1 - T_2) \qquad (1.20)$$

where $m = \pi r_w^2 \; V \; P$

P = specific weight of the fluid

Equating equations 1.15 and 1.20

$$m \; Cp \; (T_1 - T_2) = \frac{L \, \Delta T_m}{R}$$

From which

$$m = \frac{L}{\ln\left(\frac{T_1 - T_A}{T_2 - T_A}\right) R \; Cp} \qquad (1.21)$$

For a buried service line of length L, the fluid mass flow rate necessary to keep the interior temperatures from dropping to 0°C (see Figure 1 G) at the fluid exiting end of the pipe becomes

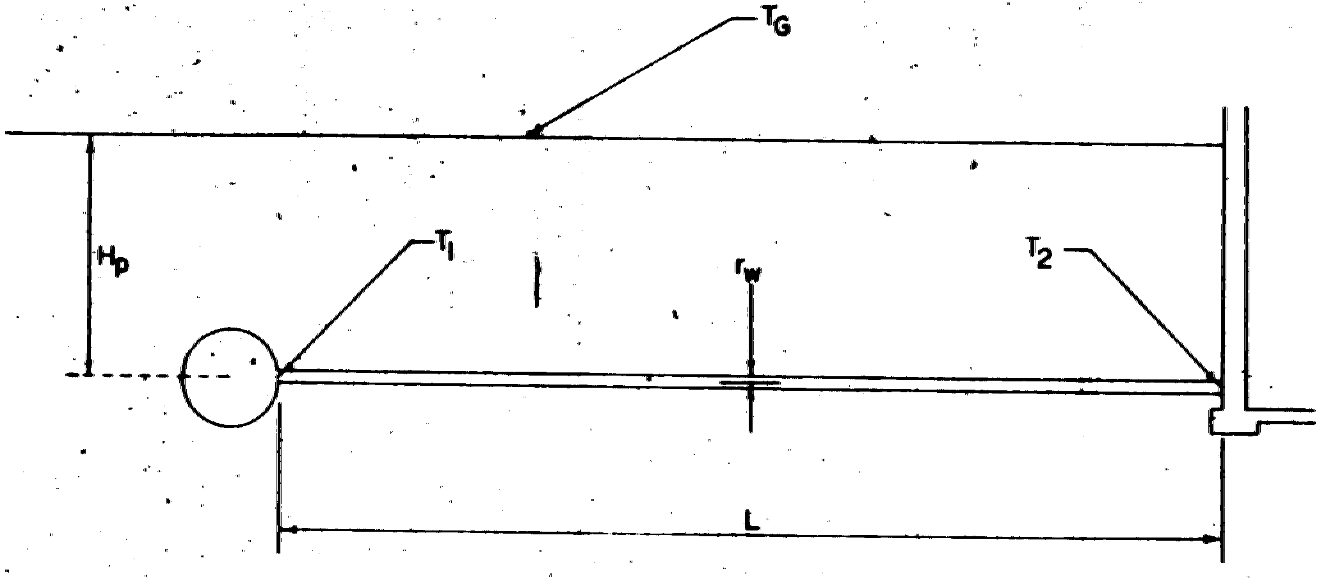
$$m = \frac{2 \, L \, \pi \, k}{\ln\left[\frac{T_1 - T_G}{T_o - T_G}\right] \text{arc cosh}\left(\frac{H_p}{r}\right) Cp} \qquad (1.22)$$

where $T_o = 32^oF \;\; (0^oC)$

$T_G < T_o$

As before, T_G may be replaced by the undisturbed soil temperature at the pipe axis. Equation 1.22 will overestimate m since steady state T_G temperatures are assumed; the exiting end of the service line will, in all liklihood, be within the thaw bulb of the building.

FIGURE 1G



TEMPERATURE DROP ALONG A SERVICE LINE

STAGNANT FREEZE-UP TIMES

Ignoring latent head effects, the rate of heat loss in a stagnant pipe multiplied by the time taken for the fluid temperature to drop to the freezing point will equal the total fluid heat content (see Figure 1H)

i.e.,

$$q\ t_D = \pi r_w^2\ L\ C\ (T_1 - T_o) \qquad (1.23)$$

where t_D = time taken for the fluid to drop to the freezing point

T_1 = initial fluid temperature

T_A = exterior pipe wall temperature for pipes in air or undisturbed soil temperature for buried pipes

As the interior pipe temperature drops, the core temperature T_1 drops towards T_o. Using equation 1.15,

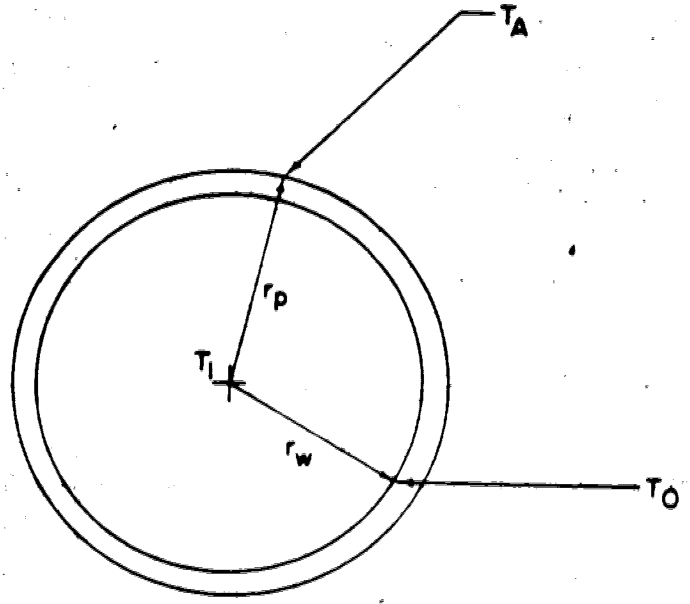
$$\frac{L\ (T_1 - T_A)}{\ln\left[\frac{T_1 - T_A}{T_o - T_A}\right] R} \cdot t_D = \pi r_w^2\ L\ C\ (T_1 - T_o)$$

from which

$$t_D = \pi r_w^2\ R\ C\ \ln\left[\frac{T_1 - T_A}{T_o - T_A}\right] \qquad (1.24)$$

For pipes in air, R will be the resistance of the pipe material. For buried pipes, the thermal resistance of the soil will be included in a composite R term. Where the buried pipe is uninsulated, the thermal resistance of the pipe material can usually be ignored.

FIGURE 1H



TEMPERATURE VARIATION WITHIN
A PIPE CROSS SECTION

SAMPLE CALCULATIONS

1. Freeze preventive flows. Assume the following:

   a. an uninsulated ½" i.d. service line (5/8" o.d.), 100 ft. long buried 6 ft. below the ground surface in frozen, saturated sand

   r_w = 0.0208 ft.
   r_p = 0.0260 ft.
   H_p = 6 ft.
   k_s = 2.4 BTU/ft.h. °F

   b. T_G = mean ground surface temperature
   = -20°C (-4°F)
   T_A = mean undisturbed soil temperature at burial depth
   = -1°C (30.2°F)
   T_1 = water temperature at the service to main connection
   = 3°C (37.4°F)
   C = 62.42 BTU/ft.^{3} °F
   Cp = 1.0 BTU/lb°F

$$\therefore \dot{m} = \frac{2 \pi L k}{\ln \left[\frac{T_1 - T_A}{T_0 - T_A}\right] Cp \cdot \ln \left[\left(\frac{H_p}{r_p}\right) + \sqrt{\left(\frac{H_p}{r_p}\right)^2 - 1}\right]}$$

$$= \frac{2 \pi (100)(2.4)}{\ln \left[\frac{37.4 - 30.2}{32.0 - 30.2}\right] 1.0 \ln \left[\left(\frac{6}{0.026}\right) + \sqrt{\left(\frac{6}{0.026}\right)^2 - 1}\right]}$$

= 177.3 lb/hr

= 0.30 igpm

2. Freeze-up time for the same conditions.

$$tD = \pi r_w^2 R C \ln \left[\frac{T_1 - T_A}{T_0 - T_A}\right]$$

$$= \pi (0.0208)^2 \left[\frac{\ln \left[\left(\frac{6}{0.026}\right) + \sqrt{\left(\frac{6}{0.026}\right)^2 - 1}\right]}{2 \pi (2.4)}\right] (62.42) \ln \left[\frac{37.4 - 30.2}{32.0 - 30.2}\right]$$

= 0.048 hrs.

= 2.9 min.

3. Freeze-up time. Assume the following:

   a. 35 ft. of ½" i.d. copper pipe (5/8" o.d.) insulated with a 3/8" thick layer of pipe insulation and placed inside a cold room.

      r_w = 0.0208 ft.
      r_p = 0.0260 ft.
      r_I = 0.0573 ft.
      k_I = 0.021 BTU/h·ft. °F

   b. Cold room temperature $T_A = -25^oC$ (-13^oF)

$$\therefore \quad R = \frac{\ln\left(\frac{r_I}{r_p}\right)}{2\pi k_I}$$

$$= \frac{\ln \frac{0.0573}{0.0260}}{2\pi\,(0.021)}$$

$$= 6.00 \text{ hft } ^oF/BTU$$

$$tD = \pi r_w^2 \, RC \ln\left[\frac{T_1 - T_A}{T_o - T_A}\right]$$

$$= \pi(0.0208)^2\,(6.00)\,(62.42)\,.\ \ln\left[\frac{37.4 - (-13)}{32.0 - (-13)}\right]$$

$$= 0.057 \text{ hr}$$

$$= 3.5 \text{ min.}$$

RATES OF HEAT LOSS - SCALING FACTORS

For insulated pipes in air, from equations 1.8 and 1.9, the radial rates of heat loss at a cross section will vary as $\left[1/\ln\left(\frac{r_2}{r_1}\right)\right]$ while for buried bare pipes, from equation 1.11, these rates will vary as $\left[1/\text{arc cosh}\left(\frac{H_p}{r_p}\right)\right]$. An indication of the predicted increases in heat loss with increases in pipe size is given in Tables 1A and 1B.

TABLE 1A

RELATIVE HEAT LOSS RATES - INSULATED PIPE IN AIR

Pipe ID (inches)	Pipe OD (inches)	Radius (pipe + insulation) (inches)	$\frac{1}{\ln\left(\frac{r_2}{r_1}\right)}$	Ratio of Heat Loss	Ratio of Outside Radii
1/2	5/8	11/16	1.26	1.00	1.00
3/4	7/8	13/16	1.62	1.27	1.18
1	1-1/8	15/16	1.96	1.54	1.36

Assumptions: 1. 3/8 " thick pipe insulation
2. copper pipe

TABLE 1B

RELATIVE HEAT LOSS RATE - BURIED BARE PIPE

Pipe ID (inches)	Pipe OD (inches)	Radius (inches)	$\dfrac{1}{\text{arc cosh}\left(\dfrac{H_p}{r_p}\right)}$	Ratio of Heat Loss	Ratio of Outside Radii
1/2	5/8	5/16	0.168	1.00	1.00
3/4	7/8	7/16	0.178	1.06	1.40
1	1 1/8	9/16	0.186	1.11	1.80

Assumptions: 1. burial depth = 5 ft.
2. copper pipe

APPENDIX 2

THE ORIFICE EQUATION

Appendix 2

References:
1. Handbook for Monitoring Industrial Wastes (1973)
2. Vennard, J.K. and Street, R.L. (1975)
3. Flow Meter Engineering Handbook (1977)

The liquid flow in a straight section of undisturbed pipe can be obstructed by the placement of a plate with a limited orifice. The resulting discharge can be determined by using the following form of the orifice equation:

$$Q = C\,A\left[\frac{2gH}{1-\left(\frac{d_2}{d_1}\right)^4}\right]^{\frac{1}{2}} \qquad (2.1)$$

where Q = discharge in cfs
C = dimensionless orifice coefficient
A = orifice area in ft^2
g = acceleration of gravity
= 32.2 ft/sec^2
H = pressure differential between both sides of the orifice in ft
d_2 = orifice diameter in ft
d_1 = inside pipe diameter in ft

The quantity of the pipe discharge can be controlled by controlling the differential pressure, the orifice size, or the pipe size. The size of the orifice coefficient is dependent upon the geometry of the orifice. For a freely discharging pipe, H simply becomes the line pressure upstream of the orifice.

For a desired free discharge rate through a given pipe, trial values of d_2 and H must be assumed. The resultant discharges for various orifice sizes and line pressures are given in Table 2A. In calculating this table, the following have been assumed:

1. a 5/8" o.d. pipe with i.d. of 1/2" (0.0417 ft)
2. a sharp edged orifice giving a C value of 0.61
3. water at 40^oF with a mass density of 62.42 lb/ft^3

TABLE 2A

RATES OF FREE DISCHARGE (IGPM)					
H (psi) / d_2 (inches)	40	45	50	55	60
0.125 (1.8)	1.50	1.60	1.68	1.76	1.84
0.094 (3/32)	0.84	0.90	0.94	0.99	1.03
0.063 (1/16)	0.38	0.40	0.42	0.44	0.46
0.047 (3/64)	0.21	0.22	0.24	0.25	0.26
0.031 (1/32)	0.09	0.10	0.10	0.11	0.11

For a sharp edged orifice plate set in a 1/2" i.d. pipe with a line pressure of 40 psi, an orifice size of 0.060" will result in a free discharge of 0.35 igpm

$$\text{i.e.,} \quad Q = (0.61)\left[\frac{\pi\left(\frac{0.06}{12}\right)^2}{4}\right]\left[\frac{2(32.2)\left(\frac{40 \times 144}{62.42}\right)}{1-\left[\left(\frac{0.06}{12}\right)\Big/\left(\frac{0.5}{12}\right)\right]^4}\right]^{1/2}(60)\quad(6.242)$$

$$= 0.35 \text{ igpm}$$

APPENDIX 3

BLEEDER SURVEY RESULTS

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 1
DATE 22 Nov 79
TIME OF DAY 0905 hours

1. ADDRESS: 2030 Quartz Road
City Works Department Warehouse

2. OWNER City of Whitehorse

3. LOCATION OF BLEEDER: above sink
inside city warehouse

4. BLEEDER TYPE: household gate valve

5. DESCRIPTION: 1/8" i.d. bleeder from
1/2" i.d. service line draining
to sink

a. main pressure approximately 78 psi (estimated)
b. bleeder already on at time of inspection
c. copper service line exposed for 3 ft beneath trailer

6. TEMPERATURE:
WATER: 7.8 °C
ROOM AIR: 19.5 °C
OUTSIDE AIR: 0 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 1.0 l	52 sec	1.15 L/M = 0.25 igpm
b. 1.0 l	52 sec	1.15 L/M = 0.25 igpm
c. 1.0 l	52 sec	1.15 L/M = 0.25 igpm

$\bar{x}$ = 1.15 L/M
σ = 0.0

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 2
DATE 22 Nov 79
TIME OF DAY 1000 hours

1. ADDRESS: Rosewood Crescent

2. OWNER: City of Whitehorse

3. LOCATION OF BLEEDER: manhole

4. BLEEDER TYPE: control valves with vacuum breaker

5. DESCRIPTION: ½" reduced bleeders from 2 mains on crescent. Drainage to sewer main in manhole.

6. TEMPERATURE
WATER: 46 °C
ROOM AIR: -
OUTSIDE AIR: 1.0 °C

a. bleeder set in winter @ 5 igpm by watch and bucket. Valve turned on full for flow test.
b. estimated pressure = 65 psig

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 l	4 sec	1.5 L/M = 3.30 igpm
1 l	4 sec	1.5 L/M = 3.30 igpm

$\bar{x}$ = 3.30 igpm
σ = 0.0

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 3
DATE 22 Nov 79
TIME OF DAY 1045

ADDRESS 2246 2nd Avenue
City Works Dept. Trailer
OWNER: City of Whitehorse

LOCATION OF BLEEDER: on ½" heat traced service line in washroom
4. BLEEDER TYPE: household gate valve

DESCRIPTION: ¼" line with 1/8" internal restrictor leading to sink drain

6. TEMPERATURE:
WATER: 149 °C
ROOM AIR: 19.5 °C
OUTSIDE AIR: approx. 1.0 °C

a. copper service line exposed for 3 ft underneath trailer
b. bleeder already on at time of inspection

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 0.5 l	1.36 min	0.31 L/M = 0.07 igpm
b. 0.25 l	0.46 min	0.33 L/M = 0.07 igpm
c. 0.25 l	0.46 min	0.33 L/M = 0.07 igpm

$\bar{x}$ = 0.32 L/M
σ = 0.01 L/M

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 4
DATE 22 Nov 79
TIME OF DAY 1115

ADDRESS Bell Crescent
OWNER City of Whitehorse
LOCATION OF BLEEDER: manhole
BLEEDER TYPE control valve with vacuum breaker
DESCRIPTION ½" bleeders from 2 mains draining to sewer main in manhole

6. TEMPERATURE:
WATER: 45 °C
ROOM AIR: n/a
OUTSIDE AIR: 1.5 °C

a. bleeders set at 1-2 igpm in the winter. Valve turned on full for flow test.

7. FLOW DATA:

VOLUME	TIME	FLOW RATE
a. 1.0 l	2 sec	30 L/M = 6.60 igpm
b. 1.0 l	2 sec	30 L/M = 6.60 igpm

$\bar{x}$ = 30 L/M
σ = 0.0

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 5
DATE 22 Nov 79
TIME OF DAY 1130 hours

1. ADDRESS: Teslin Avenue
2. OWNER: City of Whitehorse
3. LOCATION OF BLEEDER: manhole
4. BLEEDER TYPE: hydrate bleeder with control valve and vacuum breaker
5. DESCRIPTION: ½" bleeder from hydrants draining to sewer main in manhole

6. TEMPERATURE
   WATER: 4.8 °C
   ROOM AIR: n/a
   OUTSIDE AIR: 1.4 °C

a. estimated line pressure = 62 psi

b. bleeder flow set at 1 1/2 igpm in winter

7. FLOW DATA:

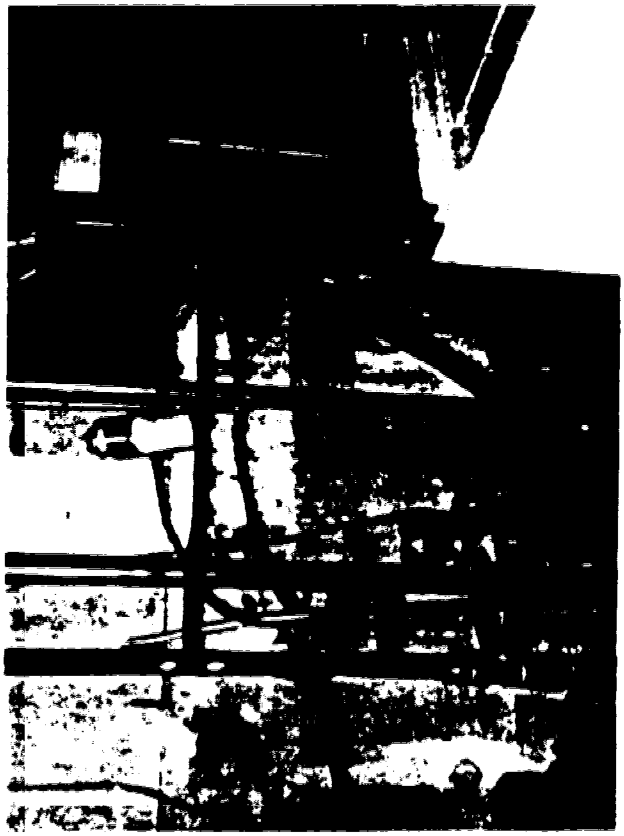
VOLUME	TIME	FLOW RATE, L/M
		a. at full flow, rate approx. 40 L/M (8.8 igpm)

$\bar{x}$ =
σ =

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 6
DATE 22 November 79
TIME OF DAY 1150



1. ADDRESS: 405 Hage Street

2. OWNER: Al Dibbs

3. LOCATION OF BLEEDER: basement

4. BLEEDER TYPE: petcock control

5. DESCRIPTION: 1/4" line with 1/8" internal restrictor from 1/2" service line to laundry drain. Air gap between bleeder line and drain.

a. pressure = 58 psig

b. bleeder set by owner of normal flow for test

6. TEMPERATURE: WATER: 6.4°C
ROOM AIR: 18.3°C
OUTSIDE AIR: 1.6°C

7. FLOW DATA:

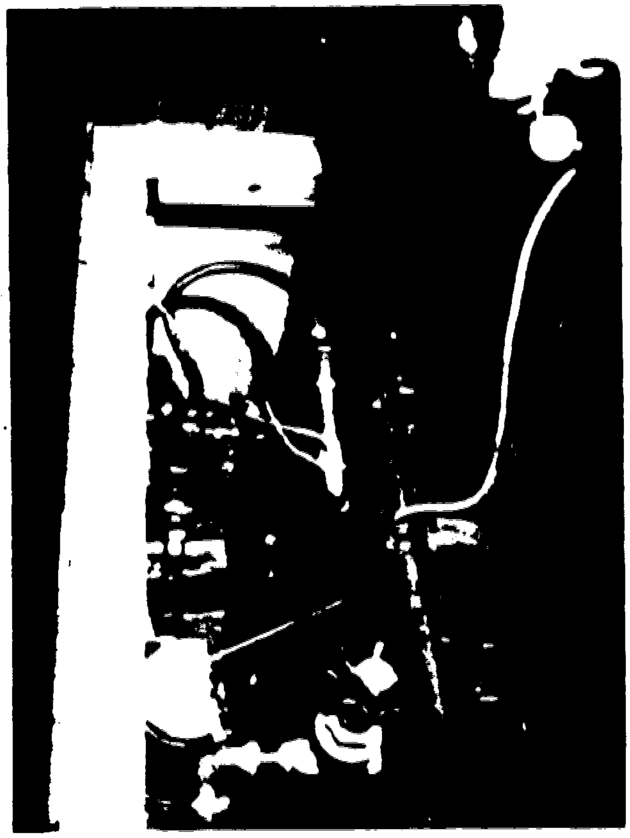
VOLUME	TIME	FLOW RATE, L/M
1 liter	33 sec	1.81 L/M = 0.40 igpm
1 liter	33 sec	1.81 L/M = 0.40 igpm

TESTS CONDUCTED BY ~~Bryan Armstrong/Allan~~ Yee

$\bar{x}$ = 1.81 L/M
σ = 0.0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 7
DATE 22 Nov 79
TIME OF DAY 1555 hours



1. ADDRESS: 2nd Avenue and Wood Street
2. OWNER: City of Whitehorse
3. LOCATION OF BLEEDER: City Hall Basement
4. BLEEDER TYPE: household gate valve
5. DESCRIPTION: ¼" bleeder from ½" service line to pipe drain. Air gap between bleeder line and drain.

6. TEMPERATURE: WATER: 9.2 °C
ROOM AIR: 20.0 °C
OUTSIDE AIR: approx. 0°C

a. estimated pressure ≠ 45-50 psig
b. bleeder set at normal flow for test

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 1 litre	42 sec	1.43 L/M = 0.31 igpm
b. 1 litre	42 sec	1.30 L/M = 0.29 igpm

$\bar{x}$ = 1.37 L/M
σ = 0.09

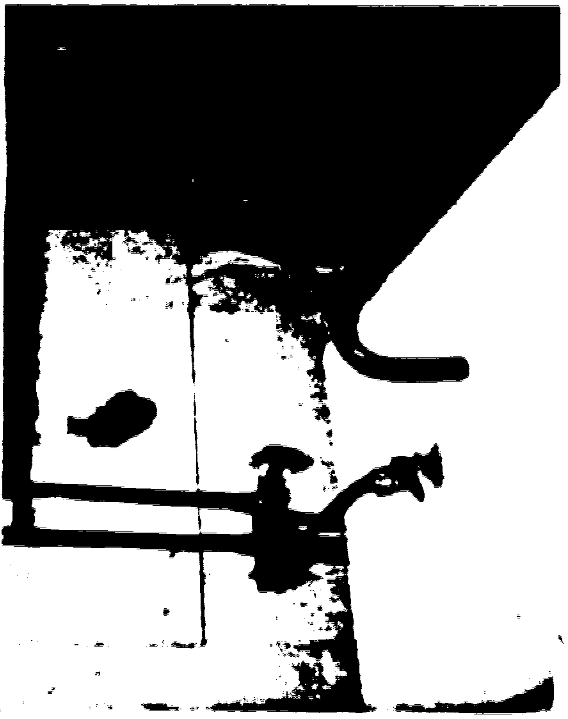
TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 8

DATE 22 Nov 79

TIME OF DAY 1420 hours



1. ADDRESS: 62 Alsak Road

2. OWNER: Fred Blaker

3. LOCATION OF BLEEDER: Basement

4. BLEEDER TYPE: household gate valve

5. DESCRIPTION: ½" bleeder reduced to 1/8" bleeder from ½" service line to laundry drain. Air gap between bleeder line and drain.

6. TEMPERATURE:
WATER: 8.8 °C
ROOM AIR: 21.0 °C
OUTSIDE AIR: approx 0 °C

a. pressure = 51 psi

b. bleeder alrady on at time of inspection

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 1.0 litre	1.13 min	0.82 L/M = 0.18 igpm
b. 1.0 litre	1.13 min	0.82 L/M = 0.18 igpm

$\bar{x}$ = 0.82 L/M

σ = 0.0

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 9
DATE 22 Nov 79
TIME OF DAY 1640 hours

1. ADDRESS: 40 Alsak Road

2. OWNER: Doug Row

3. LOCATION OF BLEEDER: basement laundry room

4. BLEEDER TYPE: household gate valve

5. DESCRIPTION: 1/8" id bleeder from ½" id service line to laundry drain. Air gap between bleeder line and drain.

6. TEMPERATURE WATER: 7.3 °C
ROOM AIR: 21.0 °C
OUTSIDE AIR: approx. 0°C

a. pressure = 50 psig

b. bleeder set at normal flow by owner for flow test

7. FLOW DATA:

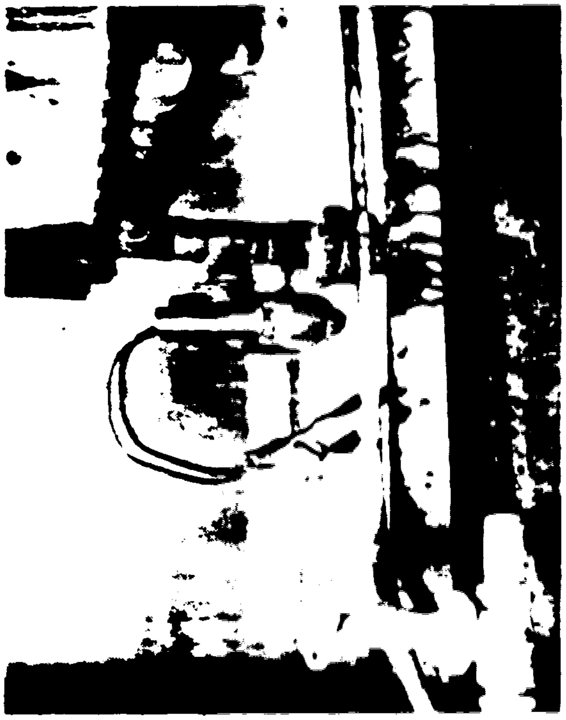
VOLUME	TIME	FLOW RATE, L/M
a. 1.0 litre	19 sec	3.15 L/M = 0.70 igpm
b. 1.0 litre	19 sec	3.15 L/M = 0.70 igpm

$\bar{x}$ = 3.15 L/M
σ = 0.0

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 10
DATE 22 Nov 79
TIME OF DAY 1715 hours



1. ADDRESS: Takhini Firehall
2. OWNER: City of Whitehorse
3. LOCATION OF BLEEDER: underneath sink
4. BLEEDER TYPE: petcock and household gate valve
5. DESCRIPTION: 1/8" id bleeder from ½" id service line to sink drain. Air gap between bleeder line and drain.

a. pressure = 68 psig

6. TEMPERATURE
WATER: 24.0 °C
ROOM AIR: 19.8 °C
OUTSIDE AIR: approx 0 °C

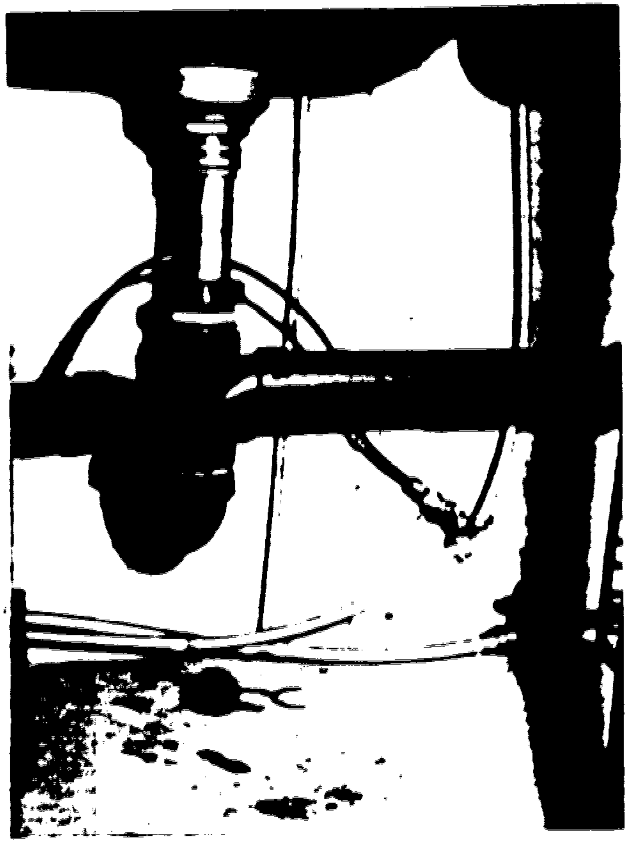
7. FLOW DATA:

VOLUME	TIME	FLOW RATE, [illegible]
a. 0.5 litre	1.11 min	trial results discarded due to leaking service line
b. 0.5 litre	0.18 sec	

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 11
DATE 22 Nov 79
TIME OF DAY 1730 hours



1. ADDRESS: Trailer #22 Northland
Trailer Park

2. OWNER: Vicki Blaker

3. LOCATION OF BLEEDER: underneath
kitchen sink

4. BLEEDER TYPE: petcock control

5. DESCRIPTION: 1/8" cross connection
between service line and sink drain

6. TEMPERATURE WATER 7.0 °C

a. pressure approx. 40 psig

ROOM AIR approx 20 °C
OUTSIDE AIR: approx 0 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 1.0 litre	26 sec	2.31 L/M = 0.51 igpm
b. 1.0 litre	35 sec	1.71 L/M = 0.38 igpm
c. 1.0 litre	36 sec	1.67 L/M = 0.37 igpm
		initial trial result discarded

$\bar{x}$ = 1.69 L/M
σ : 0.03 L/M

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 12
DATE 22 Nov 79
TIME OF DAY 1945 hours

1. ADDRESS 115 Alsek Road

2. OWNER Al Castequar

3. LOCATION OF BLEEDER: basement laundry room

4. BLEEDER TYPE: household gate valve

5. DESCRIPTION: 1/8" id bleeder from service line to laundry drain. Air gap between bleeder line and drain.

6. TEMPERATURE
WATER 6.8 °C
ROOM AIR: approx 20 °C
OUTSIDE AIR: approx 0 °C

a. pressure = 50 psig

b. bleeder set at normal flow by owner for test

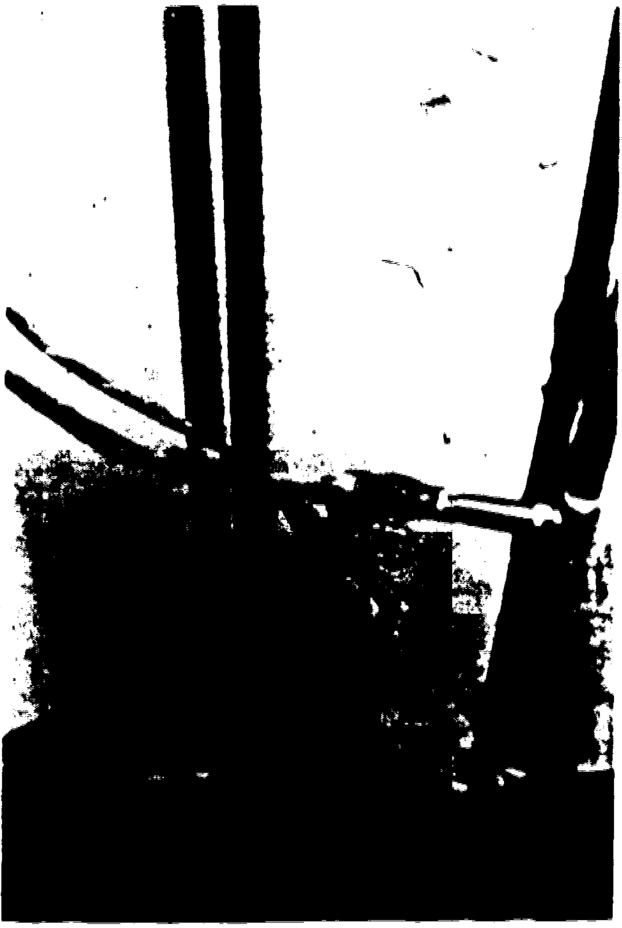
7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 1.0 litre	56 sec	1.07 L/M = 0.24 igpm
b. 1.0 litre	55 sec	1.09 L/M = 0.24 igpm

$\bar{x}$ = 1.08 L/M
σ = 0.01 L/M

TESTS CONDUCTED BY Bryan Armstrong/ Allan Yee

WATER BLEEDER MONITORING
DATA SHEET



TEST NO. 13
DATE 22 Nov 79
TIME OF DAY 2010 hours

1. ADDRESS: 21 Hyland Crescent

2. OWNER Dave Hodgeson

3. LOCATION OF BLEEDER: basement laundry room

4. BLEEDER TYPE household gate valve

5. DESCRIPTION: ¼" bleeder from ½" service line to laundry drain. Air gap between bleeder line and drain.

a. pressure = 46 psig

6. TEMPERATURE:
WATER: 7.1 °C
ROOM AIR: approx 20.0 °C
OUTSIDE AIR: approx 0.0 °C

b. bleeder set by owner for test

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1.0 litre	52 sec	1.15 L/M = 0.25 igpm
1.0 litre	52 sec	1.15 L/M = 0.25 igpm

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

$\bar{x}$ = 1.15 L/M
σ = 0.0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 14
DATE 23 Nov 79
TIME OF DAY 1030 hours

1. ADDRESS: 6118 - 6th Ave

2. OWNER: Crossroads Alcoholic Treatment Center

3. LOCATION OF BLEEDER: basement furnace room

4. BLEEDER TYPE: household gate valve

5. DESCRIPTION: ¼" bleeder from 5/8" service line to floor drain. Air gap between bleeder line and drain.

6. TEMPERATURE: WATER 6.5 °C
ROOM AIR 22 °C
OUTSIDE AIR: 0 °C

a. pressure = 45 psig
b. valve turned on full for test

7. FLOW DATA:

VOLUME	TIME	FLOW RATE L/M
a. 1.0 l	3 sec	20 L/M = 4.41 igpm
b. 1.0 l	3 sec	20 L/M = 4.41 igpm

TEST CONDUCTED BY: Bryan Armstrong/Allan Yee

$\bar{x}$ = 20 L/M
σ = 0.0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 15
DATE 23 Nov 79
TIME OF DAY 1100 hours

1. ADDRESS: 2098 - 2nd Avenue
2. OWNER: Diary Queen
3. LOCATION OF BLEEDER: basement adjacent to furnace
4. BLEEDER TYPE: household gate valve
5. DESCRIPTION: 3/4" bleeder from 1" service line to pipe drain. Air gap between bleeder line and drain. Bleeder reduced to ¼" line.

a. pressure = 56 psig

b. bleeder set at normal flow for test

6. TEMPERATURE:
WATER 6.3 °C
ROOM AIR: approx 20 °C
OUTSIDE AIR: approx 0 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE
a. 1.0 litre	1.01 min	0.98 L/M = 0.22 igpm
b. 1.0 litre	1.02 min	0.97 L/M = 0.21 igpm

$\bar{x}$ = 0.98 L/M
σ = 0.01

TESTS CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 16
DATE 23 Nov 79
TIME of DAY 1115 hours

1 ADDRESS 302 Steele Street

2 OWNER Whitehorse Chamber of Commerce

LOCATION OF BLEEDER separate room in basement

BLEEDER TYPE household gate valve

DESCRIPTION ½" bleeder from 1" service line to pipe drain. Air gap between bleeder line and drain. Pinched end.

TEMPERATURE WATER 10.2 ^{o}C
ROOM AIR approx 20^{o}C
OUTSIDE AIR approx 0^{o}C

a. pressure = 58 psig

b. bleeder already on at time of inspection

FLOW DATA

VOLUME	TIME	FLOW RATE L/M
a. 0.25 litre	1.00 min	0.25 L/M = 0.06 igpm
b. 0.25 litre	1.00 min	0.25 L/M = 0.06 igpm

$\bar{x}$ 0.25 L/M
σ 0.0

TEST CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING
DATA SHEET

TEST NO 17
DATE 23 Nov 79
TIME OF DAY 1140 hours

ADDRESS 402 - 4th Avenue

OWNER Yukon Auto Rentals

LOCATION OF BLEEDER corner of basement

BLEEDER TYPE petcock control

DESCRIPTION: ¼" bleeder from 1" service line to tape sealed pipe drain.

6. TEMPERATURE WATER 8.0 °C
ROOM AIR approx 20 °C
OUTSIDE AIR approx 0 °C

a. pressure = 56 psig

7. FLOW DATA

VOLUME	TIME	FLOW RATE L/M
a. 1.0 gallon	1.00	1.0 igpm reading taken off from water meter when bleeder turned on

$\bar{x}$ = 1.0 igpm
σ = 0.0

TEST CONDUCTED BY Bryan Armstrong/Allan Yee

WATER BLEEDER MONITORING DATA SHEET

TEST NO. 18

DATE 23 Nov 79

TIME OF DAY 1150 hours

1. ADDRESS 4th Avenue

2. OWNER A&W Drive Inn

3. LOCATION OF BLEEDER basement to washroo

4. BLEEDER TYPE petcock control

5. DESCRIPTION 1/8" bleeder from 1" service line to pipe drain. Air gap between bleeder line and drain. Pinched end.

a. pressure = 54 psig

6. TEMPERATURE WATER 8.3 °C

ROOM AIR: approx 20 °C

OUTSIDE AIR: approx 0 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
a. 0.5 litre	1.00 min	0.5 L/M = 0.11 igpm
b. 0.5 litre	1.00 min	0.5 L/M = 0.11 igpm

TESTS CONDUCTED BY: Bryan Armstrong/Allan Yee

$\bar{x}$ = 2 L/M

σ = 0.0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 191
DATE 18 Dec 80
TIME OF DAY 0930

1. ADDRESS 404 Jackell Street
(Fourplex walk-up apartment)

2. OWNER B. Pratt

3. LOCATION OF BLEEDER: basement laundary room

4. BLEEDER TYPE gate valve

5. DESCRIPTION ¼" copper tubing from service line into pipe drain Air gap.

6. TEMPERATURE
WATER 4.6 °C
ROOM AIR: 18 °C
OUTSIDE AIR: -38 °C

estimated pressure = 55-60 psi

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	8 sec	7.5 L/min = 1.65 igpm
1 L	8 sec	7.5 L/min = 1.65 igpm

TESTS CONDUCTED BY Allan Yee / Rom Kirschner

$\bar{x}$ = 7.5 L/min
σ = 0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 20

DATE 18 Dec 80

TIME OF DAY 0945

ADDRESS 502 Hanson Street
(502 Lowe Street)

OWNER YTG Children's Group Home

LOCATION OF BLEEDER Basement
furnace room

BLEEDER TYPE gate valve

DESCRIPTION ¼" copper tubing take off from the service line into the sink.

F. TEMPERATURE

WATER 5.6 °C
ROOM AIR 22.0 °C
OUTSIDE AIR -38.0 °C

estimated pressure = 55-60 psi

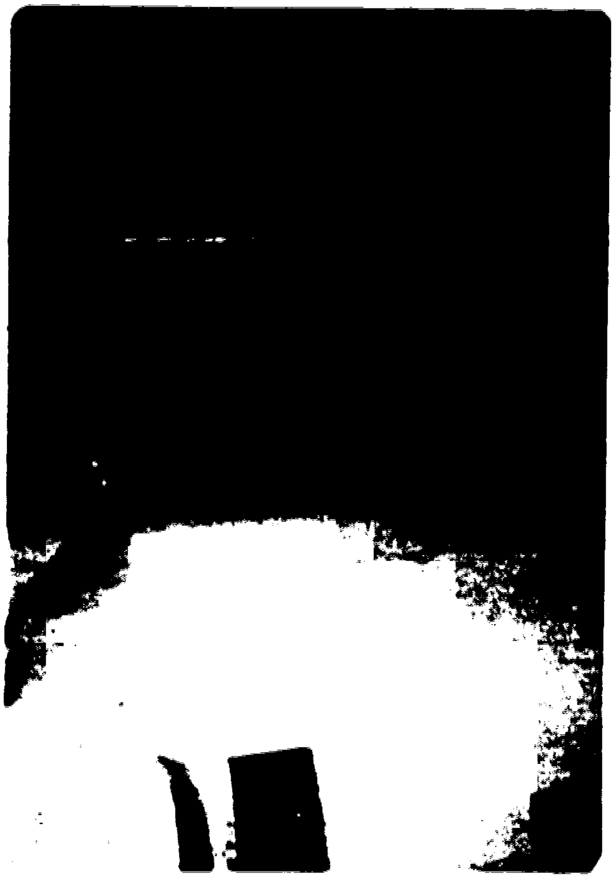
G. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	18 sec	3.3 L/min = 0.73 igpm
1 L	18 sec	3.3 L/min = 0.73 igpm

3.3 L/min

TESTS CONDUCTED BY Allan Yee / Ron Kirschner

WATER BLEEDER MONITORING
DATA SHEET



TEST NO. 21
DATE 18 Dec 80
TIME OF DAY 1005

1. ADDRESS: 2157 2nd Avenue

2. OWNER: Bus terminal

3. LOCATION OF BLEEDER: main floor furnace room

4. BLEEDER TYPE gate valve

5. DESCRIPTION: ¼" copper take off from the service line into a standing pipe drain.

6. TEMPERATURE
WATER: 4.2 °C
ROOM AIR: 23.0 °C
OUTSIDE AIR: -38.0 °C

7. FLOW DATA:

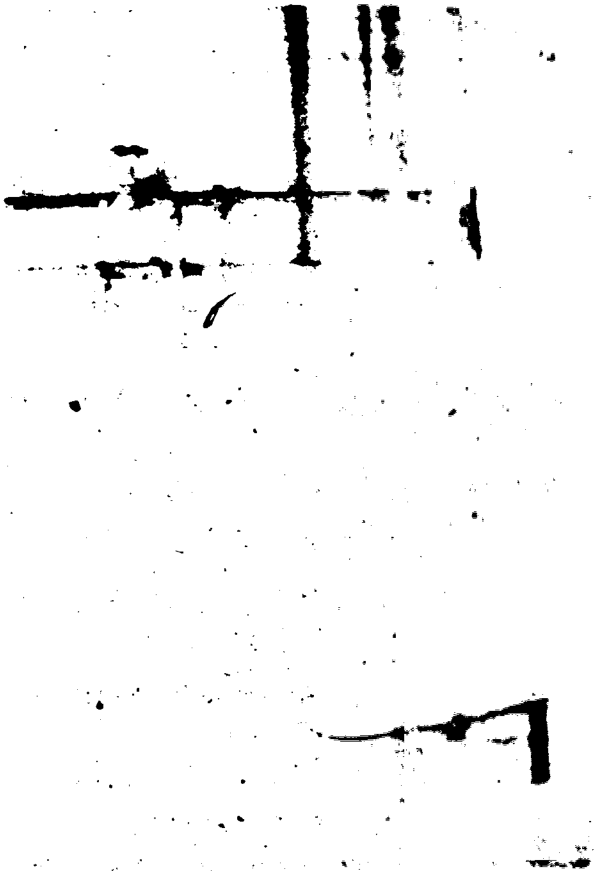
VOLUME	TIME	FLOW RATE, L/M
1 L	23 sec.	2.61 L/min = 0.57 igpm
1 L	23 sec	2.61 L/min = 0.57 igpm

$\bar{x}$ = 2.61 L/min
σ = 0

TESTS CONDUCTED BY Allan Yee / Ron Kirschner

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 22
DATE 18 Dec 80
TIME OF DAY 1030



1. ADDRESS: 180 Valleyview
duplex (former PMO)
2. OWNER: M.A. Thompson
(leased from DPW)
3. LOCATION OF BLEEDER: basement
4. BLEEDER TYPE: petcock control
5. DESCRIPTION: ½" copper takeoff from the service line to the floor drain.

5. TEMPERATURE: WATER: 7.8 °C
ROOM AIR: 18.2 °C
OUTSIDE AIR: -38.0 °C

line pressure = 55 psi

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	18 sec	3.33 L/min = 0.73 igpm
1 L	18 sec	3.33 L/min = 0.73 igpm

$\bar{x}$ = 3.33 L/min
σ = 0

TESTS CONDUCTED BY Allan Yee / Ron Kirschner

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 23
DATE 18 Dec 80
TIME OF DAY 1100

1. ADDRESS: 35 Tutshi

2. OWNER: Andrew Balla

3. LOCATION OF BLEEDER basement furnace room

4. BLEEDER TYPE gate valve

5. DESCRIPTION ½" takeoff from service line reduce to 3/8" reduced to ¼" leading to pipe drain

6. TEMPERATURE: WATER: 5 °C
ROOM AIR: 19 °C
OUTSIDE AIR: -38 °C

a. bleeder set by owner to normal rate during time of inspection

7. FLOW DATA:

VOLUME	TIME	FLOW RATE,
1 L	8 sec	7.5 L/min = 1.65 igpm
1 L	8 sec	7.5 L/min = 1.65 igpm

TESTS CONDUCTED BY Allan Yee / Ron Kirschner

$\bar{x}$ = 7.5 L/min
σ_x = 0

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 24
DATE 12 Dec 80
TIME OF DAY 1110

1. ADDRESS 9 Tutshi

2. OWNER Eiko Stenzig

3. LOCATION OF BLEEDER: basement

4. BLEEDER TYPE gate valve

5. DESCRIPTION ½" copper takeoff from service line soldered directly into main house drain

6. TEMPERATURE WATER: N/A
ROOM AIR: 19 °C
OUTSIDE AIR: -38 °C

7. FLOW DATA: **N/A**

VOLUME	TIME	FLOW RATE, L/M

TEST CONDUCTED BY Allan Yee / Ron Kirschner

$\bar{x}$ =
σ =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 25
DATE 19 Jan 81
TIME OF DAY 0928

1. ADDRESS: 2102 2nd Ave & Elliot Street
2. OWNER: Nelson's Hardware
3. LOCATION OF BLEEDER: Storage room
4. BLEEDER TYPE: Gate valve
5. DESCRIPTION: ½" copper reduced to ¼" copper draining openly into sink

6. TEMPERATURE

WATER: 6 °C
ROOM AIR: 20 °C
OUTSIDE AIR: 5 °C

62 psi

7. FLOW DATA:

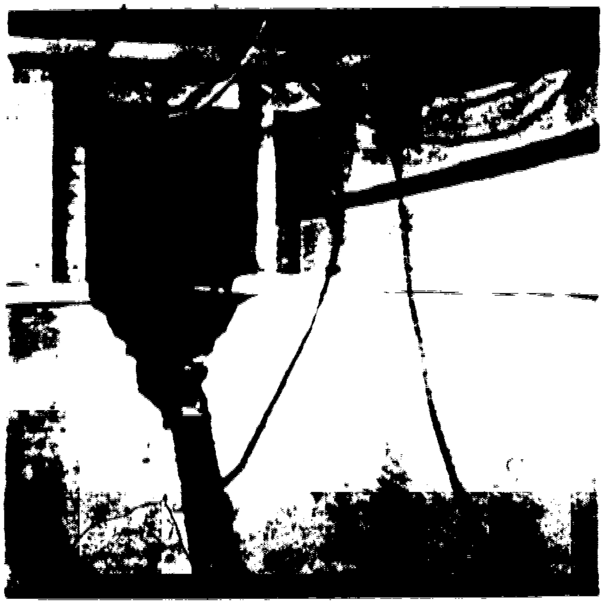
VOLUME	TIME	FLOW RATE
1 L	17 sec	3.53 L/min = 0.78 igpm
1 L	17 sec	3.53 L/min = 0.78 igpm

TESTS CONDUCTED BY Dave Parfitt

$\bar{x}$ =
σ =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 26
DATE 19 Jan 81
TIME OF DAY 0955



1. ADDRESS: 207 Elliot Street

2. OWNER: Family Services

3. LOCATION OF BLEEDER: furnace room

4. BLEEDER TYPE: gate valve

5. DESCRIPTION: ½" copper reduced to 3/8" copper soldered directly into 3" copper sanitary drain pipe

6. TEMPERATURE:
WATER: 5 °C
ROOM AIR: 18 °C
OUTSIDE AIR: 5 °C

7. FLOW DATA: N/A

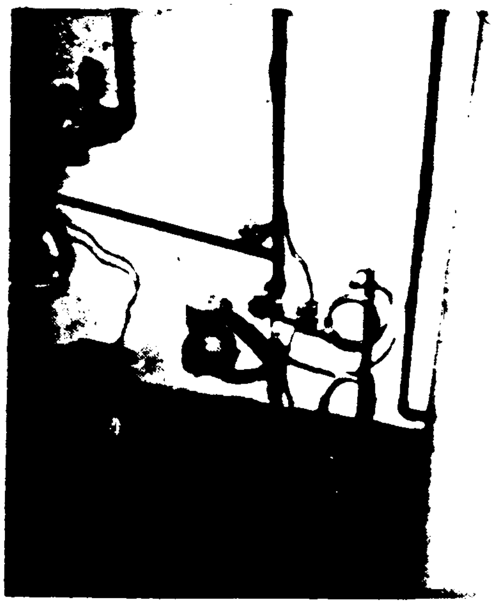
VOLUME	TIME	FLOW RATE, L/M

TESTS CONDUCTED BY Dave Parfitt

$\bar{x}$ =
σ =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 27
DATE 19 Jan 81
TIME OF DAY 1005



1. ADDRESS: 502 Hoge St.

2. OWNER: Detox Center (YTG)

3. LOCATION OF BLEEDER: furnace room

4. BLEEDER TYPE: gate valve

5. DESCRIPTION: ½" copper reduced to ¼" copper running into 3/4" copper drain. No air gap.

6. TEMPERATURE:

WATER: 6 °C
ROOM AIR: 26 °C
OUTSIDE AIR: 5 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	17 sec	3.53 L/min = 0.78 igpm
1 L	18 sec	3.33 L/min = 0,73 igpm

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 28
DATE 19 Jan 81
TIME OF DAY 1045 .

1. ADDRESS: 4th Ave & Ogilvie St.
2. OWNER: Budget Rent-A-Car
3. LOCATION OF BLEEDER: basement storage room
4. BLEEDER TYPE: saddle-petcock
5. DESCRIPTION: 3/4"ϕ reduced to 1/4"ϕ running into 1 1/4"ϕ waste drain. No air gap, petcock not operational.

6. TEMPERATURE:
WATER: 5 °C
ROOM AIR: 18 °C
OUTSIDE AIR: 5 °C

60 psi

7. FLOW DATA: N/A

VOLUME	TIME	FLOW RATE, L/M

$\bar{x}$ =
σ =

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 29
DATE 19 Jan 81
TIME OF DAY 1115

1. ADDRESS: 121 Hillcrest Drive

2. OWNER: Neil Groves

3. LOCATION OF BLEEDER: furnace room

4. BLEEDER TYPE: petcock

5. DESCRIPTION: 3/4"ϕ reduced to 1/4" copper running into waste drain. No air gap, petcock non-operational.

6. TEMPERATURE:
WATER: 5 °C
ROOM AIR: 22 °C
OUTSIDE AIR: 5 °C

60 psi

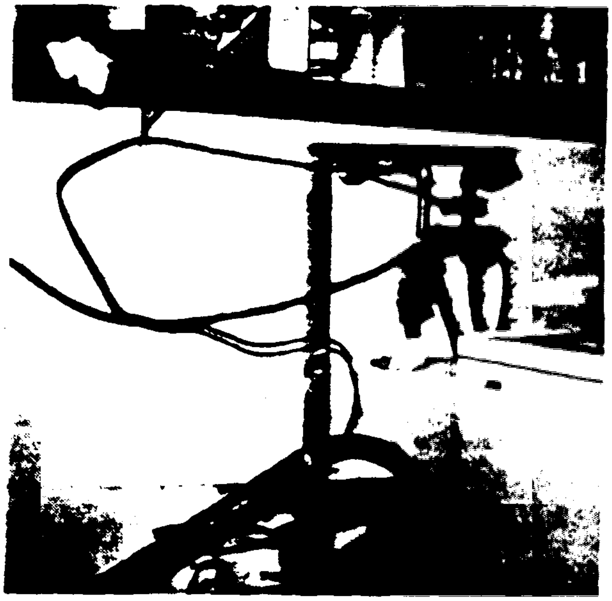
7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	21 sec	2.86 L/min = 0.63 igpm
1 L	20 sec	3.0 L/min = 0.66 igmp

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 30
DATE 19 Jan 81
TIME OF DAY 1130



1. ADDRESS: 104 Parklane

2. OWNER Chip Chase

3. LOCATION OF BLEEDER: furnace room

4. BLEEDER TYPE petcock

5. DESCRIPTION: 3/4" galvanized reduced to 1/4" copper running into 1 1/2" galvanized waste drain; no air gap, petcock not operational.

6. TEMPERATURE
WATER: 5 °C
ROOM AIR: 18 °C
OUTSIDE AIR: 5 °C

60 psi

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	25 sec	2.4 L/min = 0.53 igpm
1 L	24 sec	2.5 L/min = 0.55 igpm

TESTS CONDUCTED BY Dave Parfitt

x̄ =
y =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 31
DATE 19 Jan 81
TIME OF DAY 1145

1. ADDRESS. 199 Valley View

2. OWNER

3. LOCATION OF BLEEDER. basement storage room

4. BLEEDER TYPE gate valve

5. DESCRIPTION. 1/2" copper reduced to 3/8" copper welded to waste drain, (main stock); gate valve non operational.

6. TEMPERATURE:
WATER: 5 OC
ROOM AIR: 14 OC
OUTSIDE AIR: 5 OC

7. FLOW DATA: N/A

VOLUME	TIME	FLOW RATE, L/M

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 32
DATE 19 Jan 81
TIME OF DAY 1400

1. ADDRESS: 507 Jeckel St.
2. OWNER Anglican Church
3. LOCATION OF BLEEDER laundry room
4. BLEEDER TYPE gate valve
5. DESCRIPTION: 1/2" reduced to 1/4" running into 1 1/2" copper waste drain. No air gap. Bleeder not running at time of inspection.

6. TEMPERATURE:
WATER: 7 °C
ROOM AIR: 23 °C
OUTSIDE AIR: 6 °C

7. FLOW DATA: N/A

VOLUME	TIME	FLOW RATE

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 33
DATE 19 Jan 81
TIME OF DAY

1. ADDRESS: 5039 Hugh St.

2. OWNER: Walter Tchis

3. LOCATION OF BLEEDER: utility room

4. BLEEDER TYPE petcock

5. DESCRIPTION: 1/2" reduced to 1/4" running into 1 1/4". PVC waste drain. Petcock non operational.

6. TEMPERATURE:

WATER:	7 °C
ROOM AIR:	19 °C
OUTSIDE AIR:	6 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	12 sec	5 L/min = 1.1 igpm
1 L	12 sec	5 L/min = 1.1 igpm

TESTS CONDUCTED BY Dave Parfitt

$\bar{x}$ =
σ =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 34
DATE 19 Jan 81
TIME OF DAY 1500

1. ADDRESS:

2. OWNER: Elks Hall

3. LOCATION OF BLEEDER: furnace room

4. BLEEDER TYPE: gate valve-hose bib

5. DESCRIPTION: ½" rubber hose attached to a hose bib running into floor drain. No air gap. Bleeder not running at time of inspection.

6. TEMPERATURE:

	WATER:	6 °C
	ROOM AIR:	24 °C
	OUTSIDE AIR:	6 °C

7. FLOW DATA: N/A

VOLUME	TIME	FLOW RATE, L/M

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 35
DATE 19 Jan 81
TIME OF DAY 1500

1. ADDRESS: 18 Lewes Blvd.
2. OWNER
3. LOCATION OF BLEEDER: furnace room
4. BLEEDER TYPE: gate valve
5. DESCRIPTION: ½" reduced to ¼" copper running into 1 ¼" PVC drain. No air gap. Valve non operational.

6. TEMPERATURE:
WATER: 5 °C
ROOM AIR: 26 °C
OUTSIDE AIR: 6 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	45 sec	1.33 L/min = 0.29 igpm
1 L	44 sec	1.36 L/min = 0.30 igpm

TESTS CONDUCTED BY Dave Parfitt

$\bar{x}$ =
σ =

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 36
DATE 19 Jan 81
TIME OF DAY 1600

1. ADDRESS: #3 Tatchum
2. OWNER: DPW
3. LOCATION OF BLEEDER: basement
4. BLEEDER TYPE: petcock
5. DESCRIPTION: ½" reduced to ¼" running into 1 ½" PVC waste drain. No air gap.

6. TEMPERATURE:

WATER:	6 °C
ROOM AIR:	15 °C
OUTSIDE AIR:	6 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	12 sec	5 L/min = 1.1 igpm
1 L	11 sec	5.45 L/min = 1.2 igpm

TESTS CONDUCTED BY Dave Parfitt

WATER BLEEDER MONITORING
DATA SHEET

TEST NO. 37
DATE 19 Jan 81
TIME OF DAY 1610

1. ADDRESS: 37 Takhini

2. OWNER: Bev Combs

3. LOCATION OF BLEEDER: basement laundry room

4. BLEEDER TYPE: petcock

5. DESCRIPTION: ½" reduced to ¼" running into 1 ¼" waste drain. No air gap.

6. TEMPERATURE:
WATER: 6 °C
ROOM AIR: 18 °C
OUTSIDE AIR: 6 °C

7. FLOW DATA:

VOLUME	TIME	FLOW RATE, L/M
1 L	19 sec	3.16 L/min = 0.69 igpm
1 L	19 sec	3.16 L/min = 0.69 igpm

TESTS CONDUCTED BY Dave Parfitt

$\bar{x}$ =
σ =

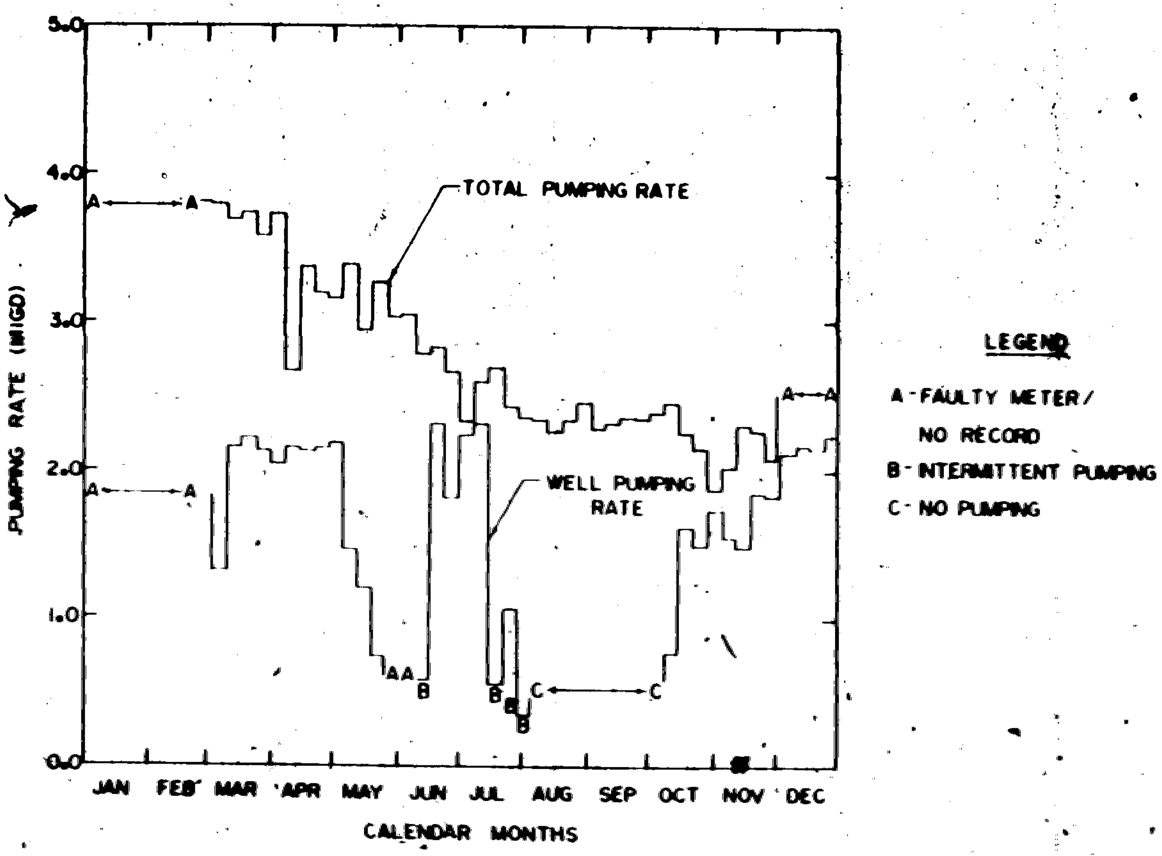
APPENDIX 4

CITY OF WHITEHORSE

WATER PUMPING RECORDS

1973 - 1980

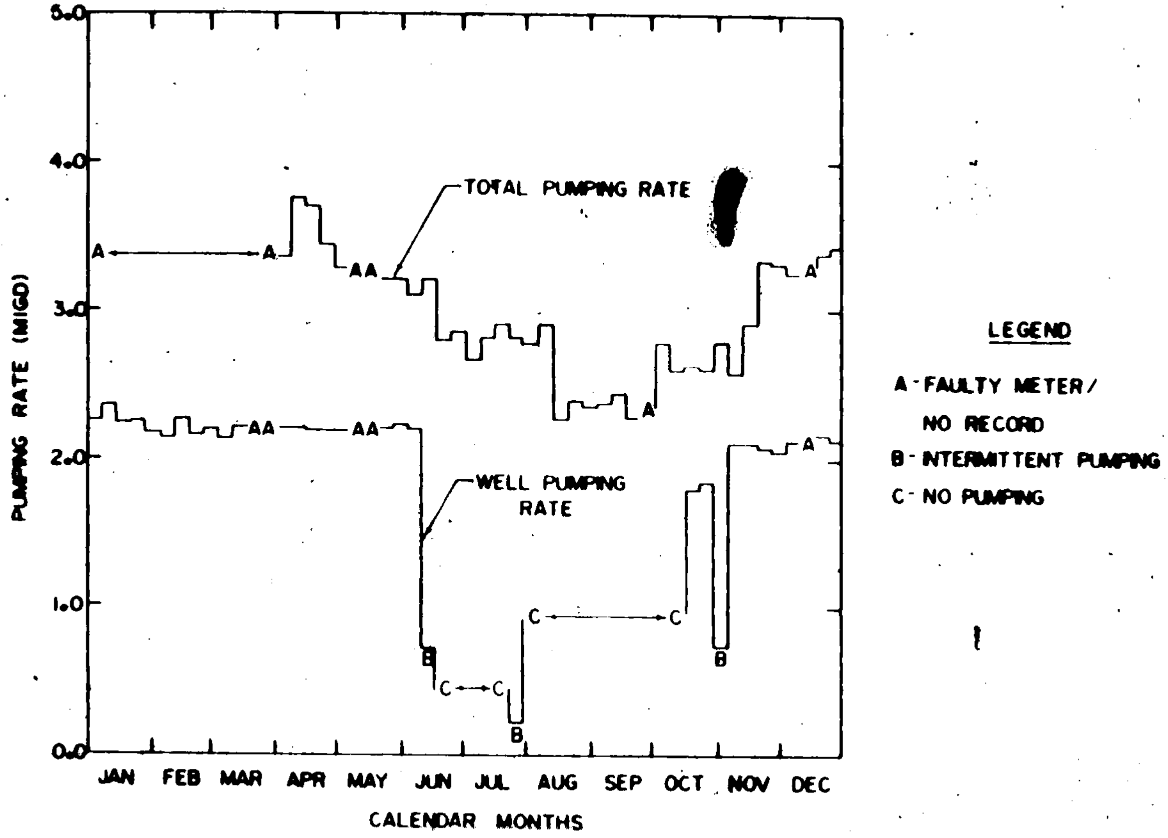
FIGURE 4A



CITY OF WHITEHORSE

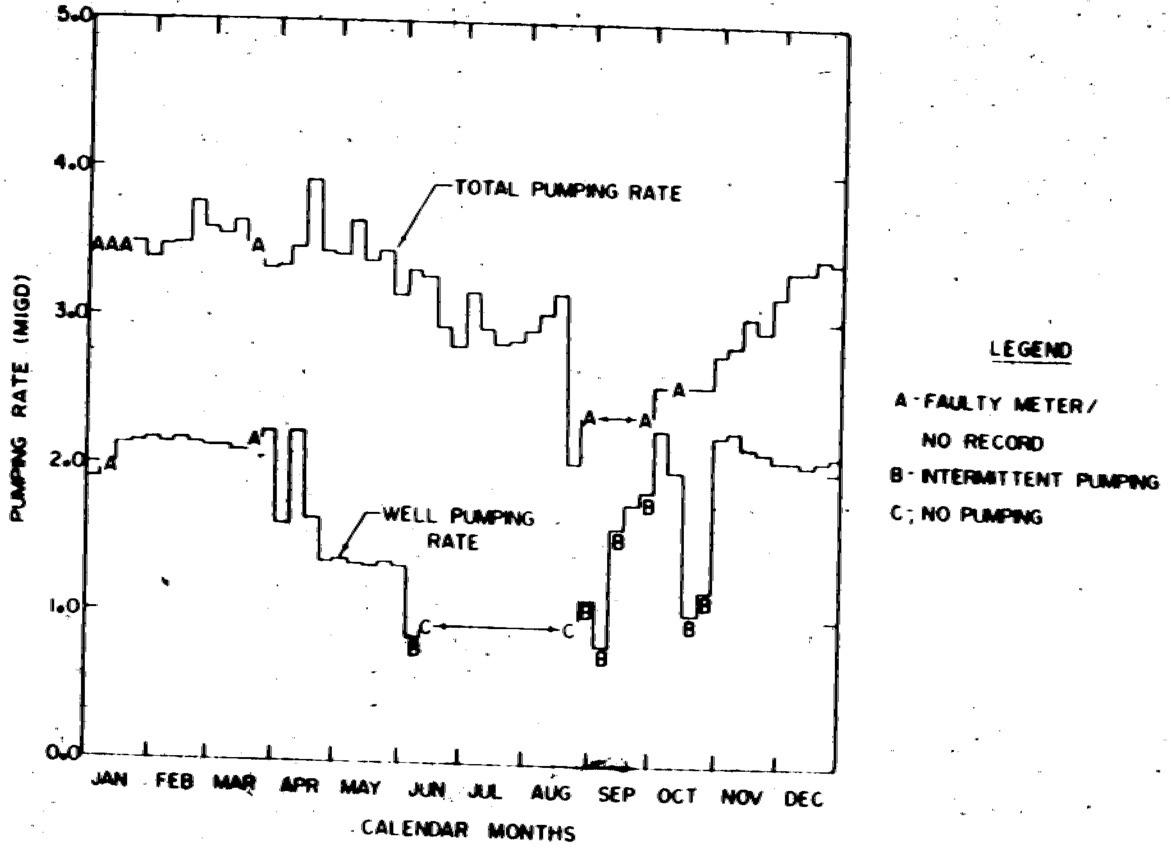
AVERAGE DAILY WATER PUMPING RATES 1973

FIGURE 4B



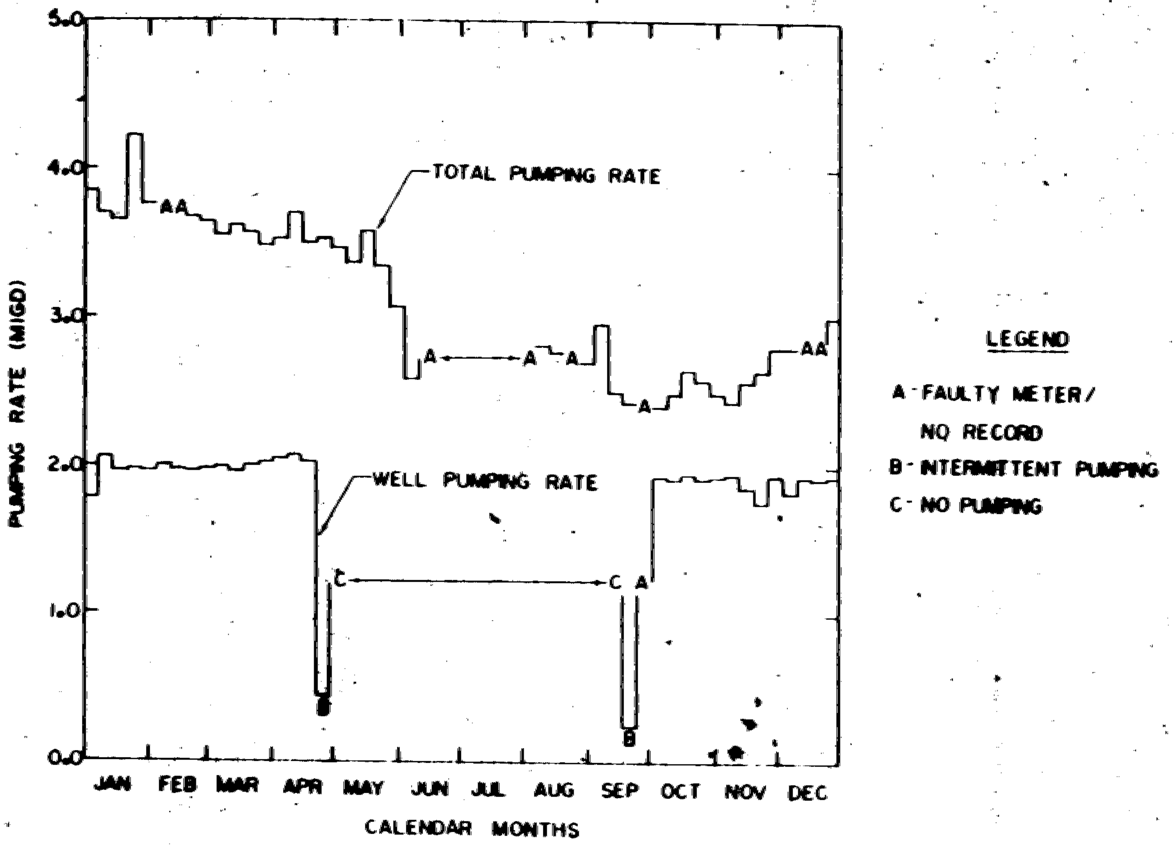
CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1974

FIGURE 4C



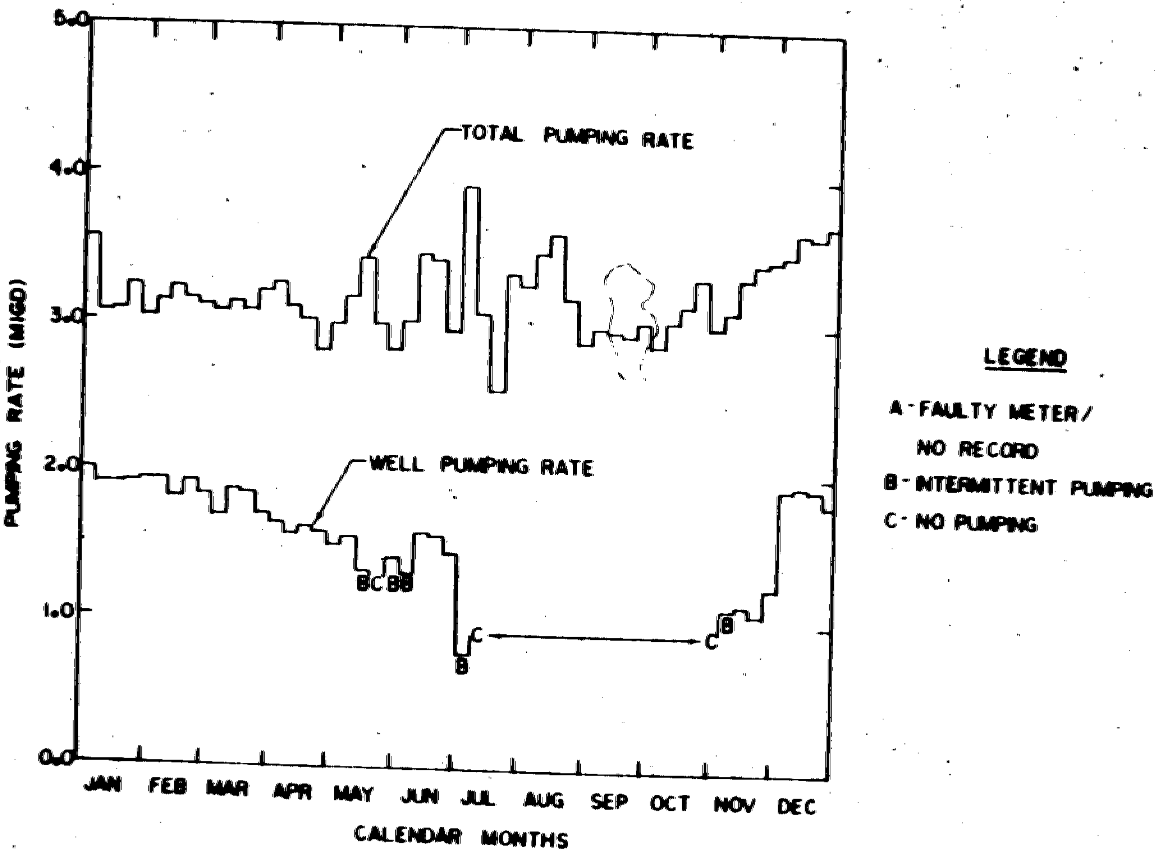
CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1975

FIGURE 4D



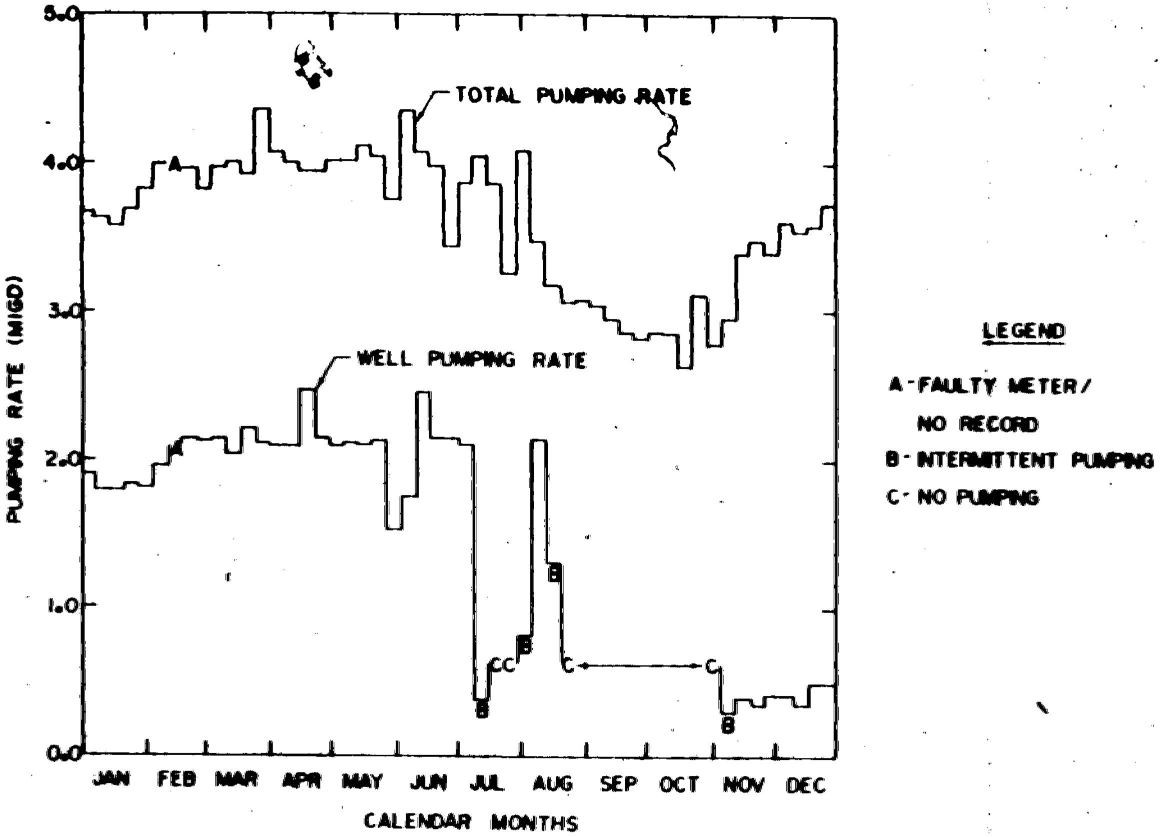
CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1976

FIGURE 4E



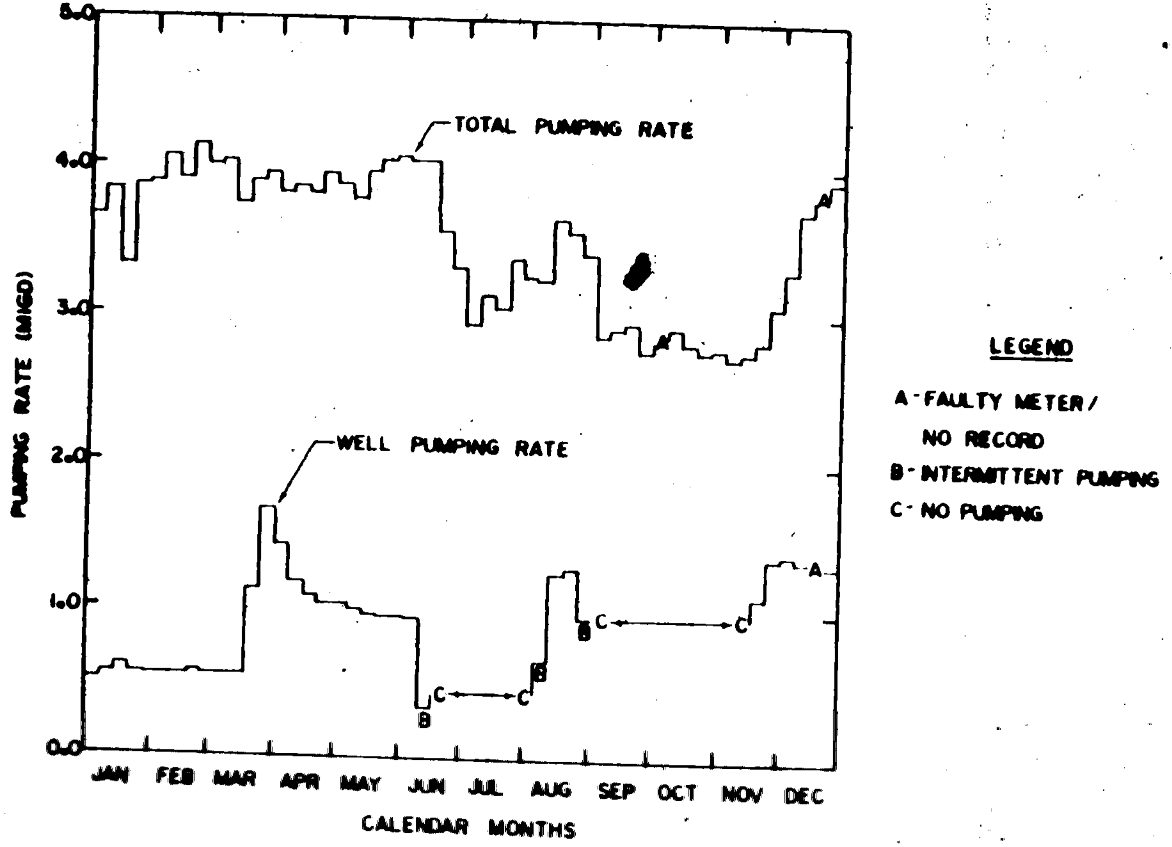
CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1977

FIGURE 4F



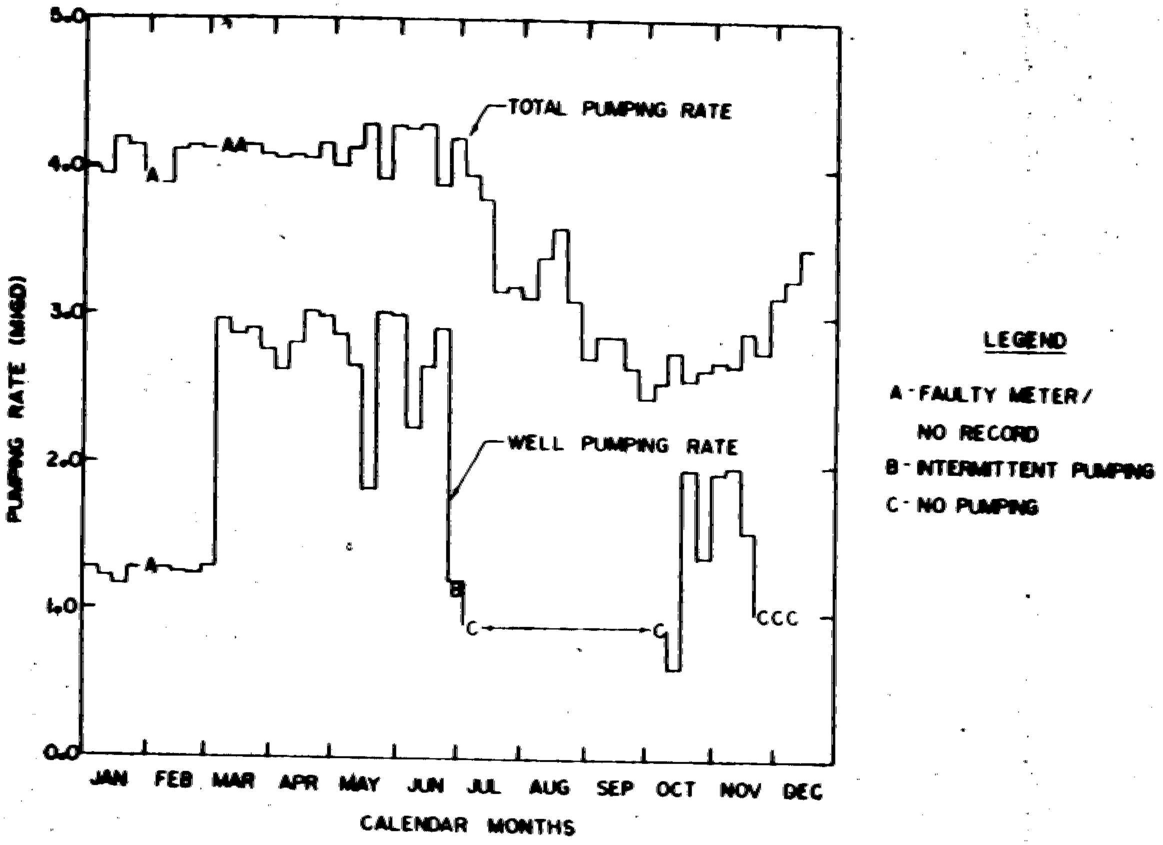
CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1978

FIGURE 4G



CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1979

FIGURE 4H



CITY OF WHITEHORSE
AVERAGE DAILY WATER PUMPING RATES 1980

1973

Average Daily Water Pumping Rates*

Dates	Total ($\times 10^3$ ig)	Wells ($\times 10^3$ ig)	Lake ($\times 10^3$ ig)
9. 4/3-10/3	3,784	1,809	1,975
10. 11/3-17/3	3,765	1,311	2,454
11. 18/3-24/3	3,661	2,159	1,502
12. 25/3-31/3	3,705	2,214	1,491
13. 1/4- 7/4	3,556	2,131	1,425
14. 8/4-14/4	3,707	2,050	1,657
15. 15/4-21/4	2,665	2,155	510
16. 22/4-28/4	3,346	2,135	1,211
17. 29/4- 5/5	3,189	2,154	1,035
18. 6/5-12/5	3,166	2,184	982
19. 13/5-19/5	3,396	1,472	1,924
20. 20/5-26/5	2,931	1,204	1,727
21. 27/5- 2/6	3,249	759	2,490
22. 3/6- 9/6	3,020	-no pumping	3,020
23. 10/6-16/6	3,020	-no pumping	3,029
24. 17/6-23/6	2,779	586(22,23 June)	2,193
25. 24/6-30/6	2,819	2,322	497
26. 1/7- 7/7	2,666	1,808	858
27. 8/7-14/7	2,304	2,248	56
28. 15/7-21/7	2,594	2,314	280
29. 22/7-28/7	2,701	557(22,23 July)	2,144
30. 29/7- 4/8	2,418	1,075(31 July,1-4 Aug)	1,343
31. 5/8-11/8	2,355	335(5,6 Aug)	2,020
32. 12/8-18/8	2,347	-no pumping	2,347
33. 19/8-25/8	2,262	-no pumping	2,262
34. 26/8- 1/9	2,343	-no pumping	2,343
35. 2/9- 8/9	2,463	-no pumping	2,463
36. 9/9-15/9	2,281	-no pumping	2,281
37. 16/9-22/9	2,312	-no pumping	2,312

1973

Average Daily Water Pumping*Rates (cont'd)

Dates	Total (x10³ ig)	Wells (x10³ ig)	Lake (x10³ ig)
38.23/9-29/9	2,360	-no pumping	2,360
39.30/9-6/10	2,350	-no pumping	2,350
40.7/10-13/10	2,396	-no pumping	2,396
41.14/10-20/10	2,457	779(18, 19, 20 Oct)	1,678
42.21/10-27/10	2,250	1,611	639
43.28/10-3/11	2,151	1,491	660
44.4/11-10/11	1,875	1,730	145
45.11/11-17/11	2,026	1,543	483
46.18/11-24/11	2,321	1,488	833
47.25/11-1/12	2,270	1,845	425
48.2/12-8/12	2,591	1,821	770
49.9/12-15/12	faulty meter	2,120	-
50.16/12-22/12	"	2,172	-
51.23/12-29/12	"	2,156	-
52.30/12-5/1	"	2,238	-

*multiply imperial gallon values by 4.546 to get litres

1974

Average Daily Water Pumping Rates

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1. 6/1-12/1	(faulty	2,230	-
2.13/1-19/1	meter,	2,327	-
3.20/1-26/1	no	2,214	-
4.27/1- 2/2	record)	2,226	-
5. 3/2- 9/2	"	2,157	-
6.10/2-16/2	"	2,121	-
7.17/2-23/2	"	2,231	-
8.24/2- 2/3	"	2,124	-
9. 3/3- 9/3	"	2,176	-
10.10/3-16/3	"	2,108	-
11.17/3-23/3	"	2,197	-
12.24/3-30/3	"	(faulty meter)	-
13.31/3- 6/4	"	"	-
14. 7/4-13/4	3,322	2,180	1,142
15.14/4-20/4	3,703	2,181	1,522
16.21/4-27/4	3,664	2,171	1,4[illegible]
17.28/4- 4/5	3,406	2,177	1,229
18. 5/5-11/5	3,248	2,171	1,077
19.12/5-18/5	(faulty meter, no record)		-
20.19/5-25/5	"	"	-
21.26/5- 1/6	3,176	2,191	985
22. 2/6- 8/6	3,175	2,214	961
23. 9/6-15/6	3,074	2,179	895
24.16/6-22/6	3,176	716 (16,17,18 June)	2,460
25.23/6-29/6	2,777	-no pumping	2,777
26.30/6- 6/7	2,840	-no pumping	2,840
27. 7/7-13/7	2,643	-no pumping	2,643

1974

Average Daily Water Pumping Rates (cont'd)

Dates	Total ($x10^3$ ig)	Wells ($x10^3$ ig)	Lake ($x10^3$ ig)
28.14/7-20/7	2,294	-no pumping	2,294
29.21/7-27/7	2,392	-no pumping	2,392
30.28/7- 3/8	2,301	228 (30 July)	2,073
31. 4/8-10/8	2,748	-no pumping	2,748
32.11/8-17/8	2,384	-no pumping	2,384
33.18/8-24/8	2,245	-no pumping	2,245
34.25/8-31/8	2,375	-no pumping	2,375
35. 1/9- 7/9	2,334	-no pumping	2,334
36. 8/9-14/9	2,342	-no pumping	2,342
37.15/9-21/9	2,433	-no pumping	2,432
38.22/9-28/9	2.256	-no pumping	2,256
39.29/9- 5/10	(faulty meter)	no pumping	-
40. 6/10-12/10	2,768	-no pumping	2,768
41.13/10-19/10	2,577	-no pumping	2,577
42.20/10-26/10	2,591	1,794	797
43.27/10- 2/11	2,580	1,837	743
44. 3/11- 9/11	2,775	742 (7, 8, 9 Nov)	2,033
45.10/11-16/11	2,554	2,085	469
46.17/11-23/11	2,898	2,090	807
47.24/11-30/11	3,305	2,067	1,238
48. 1/12- 7/12	3,291	2,036	1,255
49. 8/12-14/12	3,220	2,114	1,106
50.15/12-21/12	(faulty meter, no record)		-
51.22/12-28/12	3,348	2,148	1,200
52.29/12- 4/1	3,510	2,110	1,400

1975

Average Daily Water Pumping Rates

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1. 5/1-11/1	(faulty	1,900	-
2. 12/1-18/1	meter	(faulty meter record)	-
3. 19/1-25/1	no record)	2,137	-
4. 26/1- 1/2	3,480	2,148	1,332
5. 2/2- 8/2	3,384	2,179	1,205
6. 9/2-15/2	3.468	2,147	1,321
7. 16/2-22/2	3,484	2,172	1,312
8. 23/2- 1/3	3,751	2,153	1,598
9. 2/3- 8/3	3,585	2,124	1,460
10. 9/3-15/3	3,541	2,122	1,419
11. 16/3-22/3	3,629	2,104	1,525
12. 23/3-29/3	(faulty meter, no record)		-
13. 30/3- 5/4	3,318	2,219	1,099
14. 6/4-12/4	3,329	1,615	1,715
15. 13/4-19/4	3,463	2,221	1,242
16. 20/4-26/4	3,908	1,649	2,259
17. 27/4- 3/5	3,427	1,376	2,051
18. 4/5-10/5	3,412	1,385	2,027
19. 11/5-17/5	3,650	1,366	2,284
20. 18/5-24/5	3,378	1,347	2,032
21. 25/5-31/5	3,435	1,369	3,065
22. 1/6- 7/6	3,154	1,335	1,819
23. 8/6-14/6	3,309	857 (8-12 June)	2,453
24. 15/6-21/6	3,275	-no pumping	3,275
25. 22/6-28/6	2,936	-no pumping	2,936
26. 29/6- 5/7	2,804	-no pumping	2,804
27. 6/7-12/7	3,173	-no pumping	3,173
28. 13/7-19/7	2,913	-no pumping	2,913
29. 20/7-26/7	2,817	-no pumping	2,817

1975

Average Daily Water Pumping Rates (cont'd)

Dates	Total ($\times 10^3$ ig)	Wells ($\times 10^3$ ig)	Lake ($\times 10^3$ ig)
30.27/7- 2/8	2,841	-no pumping	2,841
31. 3/8- 9/8	2,929	-no pumping	2,929
32.10/8-16/8	3,018	-no pumping	3,018
33.17/8-23/8	2,669	-no pumping	2,669
34.24/8-30/8	2,026	-no pumping	2,026
35.31/8- 6/9	(faulty meter)	1,117(3-6 Sept)	-
36. 7/9-13/9	"	811(7-9 Sept)	-
37.14/9-20/9	"	1,598(15-10 Sept)	-
38.21/9-27/9	"	1,750	-
39.28/9- 4/10	"	1,834(28,30 Sept, 14 Oct)	-
40. 5/10-11/10	2,552	2,257	295
41.12/10-18/10	(faulty meter)	1,979	-
42.19/10-25/10	2,539	1,025(19-23 Oct)	1,514
43.26/10- 1/11	2,538	1,197(29 Oct, 1 Nov)	1,341
44. 2/11- 8/11	2,778	2,213	565
45. 9/11-15/11	2,817	2,238	579
46.16/11-22/11	3,004	2,134	870
47.23/11-29/11	2,915	2,118	798
48.30/11- 6/11	3,153	2,062	1,091
49. 7/12-13/12	3,316	2,066	1,250
50.14/12-20/12	3,314	2,027	1,287
51.21/12-27/12	3,408	2,069	1,339
52.28/12- 3/1	3,383	2,082	1,301

1976

Average Daily Water Pumping Rates

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1. 4/1-10/1	3,838	1,783	2,055
2. 11/1-17/1	3,690	2,059	1,631
3. 18/1-24/1	3,656	1,980	1,676
4. 25/1-31/1	4,218	1,993	2,225
5. 1/2-7/2	3,757	1,989	1,768
6. 8/2-14/2	(faulty meter)	2,006	-
7. 15/2-21/2	(faulty meter)	1,991	-
8. 22/2-28/2	3,669	1,985	1,684
9. 29/2- 6/3	3,635	1,983	1,652
10. 7/3-13/3	3,543	2,001	1,542
11. 14/3-20/3	3,617	1,986	1,631
12. 21/3-27/3	3,570	2,011	1,559
13. 28/3- 3/4	3,484	2,021	1,463
14. 4/4-10/4	3,529	2,055	1,474
15. 11/4-17/4	3,705	2,081	1,624
16. 18/4-24/4	3,499	2,033	1,466
17. 25/4- 1/5	3,531	477 (25,26 May)	3,054
18. 2/5- 8/5	3,473	-no pumping	3,473
19. 9/5-15/5	3,367	-no pumping	3,367
20. 16/5-22/5	3,573	-no pumping	3,573
21. 23/5-29/5	3,332	-no pumping	3,332
22. 30/5- 5/6	3,084	-no pumping	3,084
23. 6/6-12/6	2,600	-no pumping	2,600
24. 13/6-19/6	(faulty meter)	-no pumping	-
25. 20/6-26/6	(faulty meter)	-no pumping	-
26. 27/6- 3/7	(faulty meter)	-no pumping	-
27. 4/7-10/7	(faulty meter)	-no pumping	-
28. 11/7-17/7	(faulty meter)	-no pumping	-
29. 18/7-24/7	(faulty meter)	-no pumping	-

1976

Average Daily Water Pumping Rates (cont'd)

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
30.25/7-31/7	(faulty meter)	-no pumping	-
31. 1/8- 7/8	(faulty meter)	-no pumping	-
32. 8/8-14/8	2,813	-no pumping	2,813
33.15/8-21/8	2,772	-no pumping	2,772
34.22/8-28/8	(faulty meter)	-no pumping	-
35.29/8- 4/9	2,700	-no pumping	2,700
36. 5/9-11/9	2,760	-no pumping	2,960
37.12/9-18/9	2,506	-no pumping	2,506
38.19/9-25/9	2,435	279 (25 Sept)	2,156
39.26/9-2/10	(faulty meter, no record)		-
40.3/10-9/10	2,415	1,930	485
41.10/10-16/10	2,491	1,926	565
42.17/10-23/10	2,654	1,951	703
43.24/10-30/10	2,585	1,927	658
44.31/10-6/11	2,500	1,929	571
45.7/11-13/11	2,443	1,945	498
46.14/11-20/11	2,574	1,874	700
47.21/11-27/11	2,645	1,746	899
48.28/11-4/12	2,801	1,930	871
49.5/12-11/12	2,800	1,834	966
50.12/12-18/12	(faulty meter)	1,922	-
51.19/12-25/12	(faulty meter)	1,911	-
52.26/12- 1/1	3,000	1,915	1,085

1977

Average Daily Water Pumping Rates

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1. 2/1- 8/1	3,555	2,009	1,546
2. 9/1-15/1	3,077	1,916	1,161
3. 16/1-22/1	3,088	1,917	1,171
4. 23/1-29/1	3,254	1,927	1,327
5. 30/1- 5/2	3,040	1,943	1,097
6. 6/2-12/2	3,141	1,940	1,201
7. 13/2-19/2	3,231	1,830	1,401
8. 20/2-26/2	3,154	1,941	1,213
9. 27/2- 5/3	3,124	1,848	1,276
10. 6/3-12/3	3,076	1,715	1,361
11. 13/3-19/3	3,141	1,886	1,255
12. 20/3-26/3	3,094	1,837	1,257
13. 27/3- 2/4	3,202	1,721	1,481
14. 3/4- 9/4	3,277	1,675	1,602
15. 10/4-16/4	3,102	1,598	1,504
16. 17/4-23/4	3,021	1,656	1,365
17. 24/4-30/4	2,812	1,608	1,204
18. 1/5- 7/5	3,005	1,516	1,489
19. 8/5-14/5	3,178	1,589	1,589
20. 15/5-21/5	3,435	1,345 (15-20 May)	2,090
21. 22/5-28/5	3,007	-no pumping	3,007
22. 29/5- 4/6	2,827	1,450 (30 May - 2 June)	1,377
23. 5/6-11/6	3,018	1,337 (7-11 June)	1,681
24. 12/6-18/6	3,471	1,606	1,865
25. 19/6-25/6	3,435	1,593	1,842
26. 26/6-2/7	2,964	1,478	1,486
27. 3/7-9/7	3,907	790 (3-6 July)	3,907
28. 10/7-16/7	3,078	-no pumping	3,078
29. 17/7-23/7	2,559	-no pumping	2,559

1977

Average Daily Water Pumping Rates (cont'd)

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
30.24/7-30/7	3,341	-no pumping	3,341
31.31/7-6/8	3,265	-no pumping	3,265
32. 7/8-13/8	3,489	-no pumping	3,489
33.14/8-20/8	3,618	-no pumping	3,618
34.21/8-27/8	3,177	-no pumping	3,177
35.28/8-3/9	2,889	-no pumping	2,889
36. 4/9-10/9	2,994	-no pumping	2,994
37.11/9-17/9	2,969	-no pumping	2,969
38.18/9-24/9	2,963	-no pumping	2,963
39.25/9-1/10	3,024	-no pumping	3,024
40.2/10-8/10	2,859	-no pumping	2,859
41.9/10-15/10	3,028	-no pumping	3,028
42.16/10-22/10	2,136	-no pumping	2,136
43.23/10-29/10	3,308	-no pumping	3,308
44.30/10-5/11	2,996	-no pumping	2,996
45.6/11-12/11	3,100	1,132 (9,11,12 Nov)	1,968
46.13/11-19/11	3,317	1,160	2,157
47.20/11-26/11	3,417	1,100	2,317
48.27/11-3/12	3,438	1,276	2,162
49.4/11-10/12	3,486	1,919	1,567
50.11/12-17/12	3,626	1,928	1,698
51.18/12-24/12	3,607	1,917	1,690
52.25/12-31/12	3,677	1,820	1,857

1978

Average Daily Water Pumping Rates

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1. 1/1- 7/1	3,647	1,973	1,724
2. 8/1-14/1	3,619	1,803	1,816
3.15/1-21/1	3,574	1,801	1,773
4.22/1-28/1	3,680	1,849	1,831
5.29/1-4/2	3,814	1,826	1,988
6. 5/2-11/2	3,987	1,984	2,003
7.12/2-18/2	faulty meter-no record		-
8.19/2-25/2	3,964	2,159	1,805
9.26/2- 4/3	3,811	2,139	1,672
10. 5/3-11/3	3,960	2,150	1,810
11.12/3-13/3	3,989	2,068	1,921
12.19/3-25/3	3,907	2,216	1,691
13.26/3- 1/4	4,349	2,122	2,227
14. 2/4- 8/4	4,055	2,116	1,939
15. 9/4-15/4	3,998	2,112	1,886
16.16/4-22/4	3,928	2,482	1,446
17.23/4-29/4	3,924	2,164	1,763
18.30/4- 6/5	4,002	2,117	1,885
19. 7/5-13/5	4,002	2,125	1,877
20.14/5-20/5	4,106	2,116	1,990
21.21/5-27/5	4,021	2,137	1,884
22.28/5- 3/6	3,745	1,543	2,202
23. 4/6-10/6	4,332	1,756	2,576
24.11/6-17/6	4,074	2,472	1,602
25.18/6-24/6	5,972	2,151	1,821
26.25/6- 1/7	3,416	2,151	1,265
27. 2/7- 8/7	3,850	2,117	1,733
28. 9/7-15/7	4,039	409 (9, 10 July)	3,630
29.16/7-22/7	3,844	-no pumping	3,844

1978

Average Daily Water Pumping Rates (cont'd)

Dates	Total ($\times 10^3$ ig)	Wells ($\times 10^3$ ig)	Lake ($\times 10^3$ ig)
30.23/7-29/7	3,253	-no pumping	3,253
31.30/7- 5/8	4,087	832 (3,4,5 Aug)	3,255
32. 6/8-12/8	3,457	2,150	1,307
33.13/8-19/8	3,172	1,323 (13-17 Aug)	1,849
34.20/8-26/8	3,065	-no pumping	3,065
35.27/ - 2/9	3,072	-no pumping	3,072
36. 3/9- 9/9	3,029	-no pumping	3,029
37.10/9-16/9	2,944	-no pumping	2,944
38.17/9-23/9	2,854	-no pumping	2,854
39.24/9-30/9	2,813	-no pumping	2,813
40.1/10-7/10	2,856	-no pumping	2,856
41.8/10-14/10	2,848	-no pumping	2,848
42.15/10-21/10	2,630	-no pumping	2,630
43.22/10-28/10	3,112	-no pumping	3,112
44.29/10-4/11	2,782	-no pumping	2,782
45.5/11-11/11	2,965	330 (7-11 Nov)	2,635
46.12/11-18/11	3,375	427	2,948
47.19/11-25/11	3,486	388	3,098
48.26/11-1/12	3,385	450	2,935
49.3/12-9/12	3,596	449	3,147
50.10/12-16/12	3,532	392	3,140
51.17/12-23/12	3,569	512	3,057
52.24/12-30/12	3,716	516	3,200

1979

Average Daily Water Pumping Rates -

Dates	Total (x10^3 ig)	Wells (x10^3 ig)	Lake (x10^3 ig)
1.31/12- 6/1	3,667	514	3,153
2. 7/1-13/1	3,825	566	3,259
3.14/1-20/1	3,315	605	2,710
4.21/1-27/1	3,857	558	3,299
5.28/1- 3/2	3,883	555	3,328
6. 4/2-10/2	4,065	557	3,508
7.11/2-17/2	3,908	561	3,347
8.18/2-24/2	4,134	558	3,576
9.25/2-3/3	4,000	570	3,430
10.4/3-10/3	4,035	559	3,476
11.11/3-17/3	3,839	564	3,275
12.18/3-24/3	3,908	1,133	2,775
13.25/3-31/3	3,956	1,692	2,264
14.1/4-7/4	3,808	1,424	2,384
15.8/4-14/4	3,853	1,195	2,658
16.15/4-21/4	3,812	1,092	2,720
17.22/4-28/4	3,943	1,027	2,916
18.20/4-5/5	3,878	1,032	2,846
19.6/5-12/5	3,777	1,000	2,777
20.13/5-19/5	3,970	970	3,000
21.20/5-26/5	4,043	958	3,085
22.27/5-2/6	4,064	963	3,101
23.3/6-9/5	4,033	943	3,090
24.10/6-16/6	4,035	333 (10,11,12 June)	3,702
25.17/6-23/6	3,537	-no pumping	3,537
26.24/6-30/6	3,308	-no pumping	3,308
27.1/7-7/7	2,928	-no pumping	2,928
28.8/7-14/7	3,128	-no pumping	3,128
29.15/7-21/7	3,049	-no pumping	3,049

1979

Average Daily Water Pumping Rates (cont'd)

Dates	Total ($\times 10^3$ ig)	Wells ($\times 10^3$ ig)	Lake ($\times 10^3$ ig)
30.22/7-28/7	3,383	-no pumping	3,383
31.29/7-4/8	3.245	-no pumping	3,245
32.5/8-11/8	3,221	665 (8-11 Aug)	2,556
33.12/8-18/8	3,653	1,255	2,398
34.19/8-25/8	3,558	1,285	2,273
35.26/8-1/9	3,411	953 (26-31 Aug)	2,458
36.2/9-8/9	2,863	-no pumping	2,863
37.9/9-15/9	2,907	-no pumping	2,907
38.16/9-22/9	2,945	-no pumping	2,945
39.23/9-29/9	2,775	-no pumping	2,775
40.30/9-6/10	faulty meter, no record		-
41.7/10-13/10	2,927	-no pumping	2,927
42.14/10-20/10	2,811	-no pumping	2,811
43.21/10-22/10	2,738	-no pumping	2,758
44.23/10-3/11	2,785	-no pumping	2,785
45.4/11-10/11	2,720	-no pumping	2,720
46.11/11-17/11	2,751	-no pumping	2,751
47.18/11-24/11	2,839	1,112(19-24)	1,727
48.25/11-1/12	3,074	1,375	1,699
49.2/12-8/12	3,340	1,396	1,944
50.9/12-15/12	3,722	1,367	2,356
51.16/12-22/12	faulty meter, no record		-
52.23/12-29/12	3,923	1,319	2,604

1980

Average Daily Water Pumping Rates

Dates	Total ($x10^3$ ig)	Wells ($x10^3$ ig)	Lake ($x10^3$ ig)
1.30/12-5/1	3,984	1,323 (records for 1-5 only)	2,661
2.6/1-12/1	3,940	1,272	2,668
3.13/1-19/1	4,181	1,207	2,973
4.20/1-26/1	4,133	2,376	2,817
5.27/1-2/2	no record		
6.3/2-9/2	3,885	1,309	2,576
7.10/2-16/2	4,105	1,300	2,805
8.17/2-23/2	4,125	1,285	2,839
9.24/2-1/3	4,108	1,324	2,784
10.2/3-8/3	(faulty meter)	2,972	-
11.9/3-15/3	(faulty meter)	2,892	-
12.16/3-22/3	4,133	2,917	1,216
13.23/3-29/3	4,074	2,786	1,288
14.30/3-5/4	4,052	2,651	1,401
15.6/4-12/4	4,061	2,813	1,248
16.13/4-19/4	4,053	3,027	1,026
17.20/4-26/4	4,150	3,003	1,147
18.27/4-3/5	3,998	2,887	1,111
19.4/5-10/5	4,118	2,694	1,424
20.11/5-17/5	4,289	1,849	2,440
21.18/5-24/5	3,911	3,022	889
22.25/5-31/5	4,274	3,008	1,266
23.1/6-7/6	4,252	2,269(well mechanical breakdown)	1,983
24.8/6-14/6	4,296	2,677	1,619
25.15/6-21/6	3,878	2,993	885
26.22/6-28/6	4,196	1,225 (22, 23, 24)	2,971
27.29/6-5/7	3,943	-	3,943
28.6/7-12/7	3,779	-	3,779
29.13/7-19/7	3,178	-	3,178

1980

Average Daily Water Pumping Rates (con't)

Dates	Total ($\times 10^3$ ig)	Wells ($\times 10^3$ ig)	Lake ($\times 10^3$ ig)
30.20/7-26/7	3,202	-	3,202
31.27/7-2/8	3,131	-	3,131
32.3/8-9/8	3,403	-	3,403
33.10/8-16/8	3,595	-	3,595
34.17/8-23/8	3,121	-	3,121
35.24/8-30/8	2,739	-	2,739
36.31/8-6/9	2,882	-	2,882
37.7/9-13/9	2,886	-	2,886
38.14/9-20/9	2,667	-	2,667
39.21/9-27/9	2,468	-	2,468
40.28/9-4/10	2,585	-	2,585
41.5/10-11/10	2,782	667 (9,10,11)	2,115
42.12/10-18/10	2,583	1,999	584
43.19/10-25/10	2,666	1,401	1,265
44.26/10-1/11	2,711	1,989	722
45.2/11-8/11	2,692	2,019	673
46.9/11-15/11	2,909	1,577 (9,10,11,12,13,14)	1,332
47.16/11-22/11	2,786	-	2,786
48.23/11-29/11	3,144	-	3,144
49.30/11-6/12	3,257	-	3,257
50.7/12-13/12	3,469	293 (13 Dec)	3,176

APPENDIX 5

BYLAW 180

CITY OF WHITEHORSE

"Each water service shall be equipped with a device, known as a bleeder, which will permit a pre-determined quantity of water to be drained from the service pipe.

The size of each bleeder shall be, unless otherwise instructed by the Inspector, of sufficient size to pass a maximum of 1/3 gallon of water per minute and shall not be connected directly to the sanitary sewer.

Bleeders shall be installed on the consumer side of the main shut-off valve and sufficient space shall be left between the main valve and the point where the bleeder is connected, to permit the future installation of the water meter."

APPENDIX 6

A HYDROTHERM INPUT FILE

```
                    ***************
                    * HYDROTHERM *
                    ***************

                  INPUT FILE [illegible]
                        [illegible]
        ****************************************************


                     GENERAL DATA FILE
                     -----------------

AT- TYPE OF ANALYSIS(1=TEMP,HYDRAULIC, 2=HYDRAULIC ON[illegible]) ------  [illegible]
NT- TYPE OF NETWORK(1=IGNOR NODE ELEVATIONS, 2=CONSID. [illegible])---  [illegible]
UN- TEMP., PRES.&FLOW UNITS(1=ENGLISH, 2=METRIC)-- --------  [illegible]
NS- NUMBER OF SUPPLY PIPES------------------------------------  [illegible]
NR- NUMBER OF RETURN PIPES------------------------------------  [illegible]
NC- NUMBER OF CONSUMERS(INCLUDING PUMPS&HEATERS)--------------  [illegible]
TN- NUMBER OF NODES-------------------------------------------  [illegible]
RC- PIPE ROUGHNESS COEFFICIENT (DEFAULT VALUE)----------------  [illegible]
CH- NUMBER OF CONSTANT HEAD NODES-----------------------------  [illegible]
CD- CONSUMER DRAWOFF FACTOR(TYPE 2 NETWORK ONLY)--------------  [illegible]
DT- DESIGN OUTDOOR TEMPERATURE(TYPE 1 ANALYSIS ONLY)----------  4
OT- AMBIENT OUTDOOR TEMPERATURE(TYPE 1 ANALYSIS ONLY)---------  4
CT- CONSTANT WATER TEMPERATURE(TYPE 1 ANALYSIS ONLY)----------  55
TT- TYPE OF TEMPERATURE ANALYSIS([illegible])-----------------  4

    ****************************************************************


                     SUPPLY PIPE DATA
                     ----------------

MEM    UPSTREAM     DOWNSTREAM        SIZE          LENGTH OF PIPE   ROUGHNESS
NUM    NODE-UP      NODE-DOWN    INSIDE DIAM.       [illegible]      COEFFICIENT
----  ------------  ------------ ---------------  ---------------  -------------
 1          1000           2             20             [illegible]   [illegible]
 2             2           3             20             600        [illegible]
 3             3           4             20             [illegible]   .01
 4             4           5           13.5             [illegible]   [illegible]
 5             5           6            8.1             150        [illegible]
 6             5           7            8.1             290           .01
 7             7           8            8.1             1[illegible]  .01
 8             7           9            8.1             240        [illegible]
 9   [illegible]          10            8.1              20           .01
10            10          11            8.1             250           .01
11            11          12            9.1             200           .01
12            12          13            8.1             200           .01
13            13          14            8.1             220           .01
14            14          15            8.1             180           .01
15             4          17           10.1             330           .01
16             5          18           13.5             320           .01
17             2          20           13.5             520           .01
18            17          16           10.1             380           .01
19            17          18            8.1             420           .01
20            18          19      [illegible]           310           .01
21            16          21           10.1             510           .01
22             8          23           13.5             510           .01
23            21          20           10.1             380           .01
24            13          22            8.1             330           .01
25            20          24           10.1             510           .01
26             7          2[illegible]  8.1             300        [illegible]
```

27	25	26	10.1	390	.01
28	27	26	6.1	416	.01
29	26	28	9.6	270	.001
30	29	25	6.1	276	.01
31	26	30	6.1	270	.01
32	27	31	13.5	270	.01
33	29	28	6.1	390	.01
34	30	29	6.1	300	.01
35	31	30	6.1	400	.01
36	31	320	6.1	266	.01
37	28	32	10.1	260	.01
38	31	40	13.5	300	.01
39	32	33	10.1	370	.01
40	33	34	10.1	210	.01
41	34	35	10.1	100	.01
42	32	36	10.1	66	.01
43	33	37	10.1	60	.01
44	36	38	10.1	30	.01
45	38	37	10.1	440	.01
46	38	39	6.1	770	.01
47	39	40	13.5	360	.01
48	40	41	6.1	260	.01
49	37	42	1000	310	.01
50	39	44	13.5	290	.01
51	43	42	6.1	730	.01
52	44	43	6.1	440	.01
53	44	45	5.7	400	.01
54	42	48	10.1	360	.01
55	43	46	6.1	120	.01
56	46	47	6.1	96	.01
57	46	50	13.5	350	.01
58	49	48	6.1	370	.01
59	50	49	6.1	800	.01
60	48	59	10.1	320	.01
61	49	60	10.1	320	.01
62	50	51	13.5	360	.01
63	51	52	6.1	710	.01
64	52	53	4	540	.01
65	52	54	5.7	270	.001
66	54	55	5.7	430	.001
67	54	56	6.1	40	.01
68	56	57	6.1	50	.01
69	57	58	1	90	.001
70	51	61	13.5	60	.01
71	60	59	6.1	370	.01
72	61	60	6.1	800	.01
73	59	62	10.1	300	.01
74	60	63	10.1	300	.01
75	61	64	13.5	220	.001
76	63	62	6.1	370	.01
77	64	63	5.1	300	.01
78	64	65	10.1	340	.01
79	65	66	10.1	370	.01
80	62	68	13.5	250	.01
81	64	70	13.5	290	.01
82	65	67	6.1	190	.01
83	66	71	6.1	290	.01
84	69	68	6.1	370	.01
85	70	69	6.1	800	.01
86	70	71	6.1	700	.01
87	71	72	6.1	390	.01
88	72	73	6.1	270	.01
89	73	74	4	210	.01
90	66	75	10.1	170	.01
91	59	78	6.1	350	.01
92	70	79	13.5	340	.01

POOR COPY
COPIE DE QUALITEE INFERIEURE

93	77	76	6.1	130	.01
94	75	77	10.1	170	.01
95	77	78	6.1	370	.01
96	79	78	6.1	600	.01
97	79	80	6.1	320	.01
98	80	81	9.1	750	.01
99	81	82	6.1	200	.01
100	82	83	4	100	.01
101	77	86	10.1	310	.01
102	79	88	13.5	300	.01
103	80	84	6.1	220	.01
104	81	85	6.1	170	.01
105	86	87	10.1	370	.01
106	88	87	6.1	800	.01
107	88	89	6.1	1370	.01
108	89	90	4	160	.01
109	87	91	10.1	240	.01
110	88	92	13.5	240	.01
111	92	91	6.1	830	.01
112	92	93	6.1	1350	.01
113	93	94	4	240	.01
114	91	95	10.1	350	.01
115	92	97	13.5	380	.01
116	96	95	10.1	360	.01
117	97	96	10.1	590	.01
118	97	98	6.1	1590	.01
119	96	99	3.1	380	.01
120	97	100	13.5	310	.01
121	95	104	6.1	890	.01
122	100	101	6.1	1580	.01
123	100	102	14.1	260	.01
124	102	103	6.1	1570	.01
125	102	107	13.5	340	.01
126	105	104	7.6	40	.001
127	106	105	7.6	380	.001
128	107	106	7.6	530	.001
129	107	108	6.1	970	.01
130	108	109	6.1	320	.01
131	104	110	6.1	240	.01
132	106	115	6.1	150	.01
133	107	112	13.5	180	.01
134	114	108	6.1	310	.01
135	105	119	10.3	1030	.0002
136	115	116	6.1	600	.01
137	112	116	12.1	170	.01
138	113	114	6.1	130	.01
139	110	111	4	150	.01
140	116	117	12.1	600	.01
141	118	113	6.1	550	.01
142	117	118	6.1	720	.01
143	119	120	10.3	360	.0002
144	120	121	10.3	340	.0002
145	117	122	12.1	540	.01
146	121	122	10.3	1090	.0002

SUPPLY PIPE DATA (CONTINUED)

MEM NUM	ACTUAL PIPE LENGTH-LA	HEAT.SUP/RET CONST.#1-R1	HEAT.SUP/RET CONST.#2-R2	PIPE GRD.TEMP.-TA
1	500	.8	.135	32
2	570	.8	.1135	32
3	330	.8	.1135	32
4	470	.8	.1416	32
5	180	.8	.1921	[illegible]

6	290	.8	[illegible]	32
7	[illegible]	.8	.1921	32
8	240	.8	.1921	32
9	120	.8	.1921	32
10	250	.8	.1591	32
11	130	.8	.1921	32
12	200	.8	.1921	32
13	220	.8	.1921	32
14	180	.8	.1921	32
15	330	.8	.1591	32
16	320	.8	.1416	32
17	320	.8	.1416	32
18	380	.8	.1591	32
19	420	.8	.1744	32
20	210	.8	.1921	32
21	310	.8	.1591	32
22	310	.8	.1416	32
23	380	.8	.1591	32
24	330	.8	.1921	32
25	310	.8	.1591	32
26	300	.8	.1921	32
27	390	.8	.1591	32
28	410	.8	.1921	32
29	270	.8	.843	32
30	270	.8	.19	32
31	370	.8	.1921	32
32	270	.8	.1416	32
33	390	.8	.1921	32
34	380	.8	.1921	32
35	400	.8	.1921	32
36	280	.8	.1921	32
37	280	.8	.1591	32
38	300	.8	.1416	32
39	370	.8	.1591	32
40	210	.8	[illegible]	[illegible] 32
41	100	.8	.1591	32
42	80	.8	.1591	32
43	50	.8	.1591	32
44	50	.8	.1591	32
45	440	.8	.1591	32
46	[illegible]	.8	.1921	32
47	360	.8	.1416	32
48	280	.8	.1921	32
49	310	.8	.1591	32
50	[illegible]	.8	.1416	[illegible]
51	730	.8	.1921	32
52	440	.8	.1921	32
53	360	.8	.1921	32
54	300	.8	.1591	32
55	120	.8	.1921	32
56	90	.8	[illegible]	32
57	350	.8	.1416	32
58	370	.8	.1921	32
59	800	.8	.1921	32
60	320	.8	.1591	32
61	320	.8	.1591	32
62	200	.7	.1416	32
63	710	.8	.1921	32
64	540	.8	.2176	32
65	270	.8	.1985	32
66	430	.8	.1985	32
67	40	.8	.1921	32
68	30	.8	.1921	32
69	90	.8	[illegible]	32
70	60	.7	.1916	32
71	400	.8	.1921	32

72	[illegible]	.8	[illegible]	32
73	400	.8	[illegible]	32
74	300	.8	.1591	32
75	320	.8	.1416	32
76	370	.8	.1744	32
77	400	.8	.1744	32
78	340	.8	.1591	32
79	270	.8	[illegible]	32
80	380	.8	.1416	32
81	390	.8	.1416	32
82	390	.8	.1921	32
83	390	.8	.1921	32
84	370	.8	.1921	32
85	[illegible]	.8	.1921	32
86	[illegible]	.8	.1921	32
87	390	.8	.1921	32
88	270	.8	.1921	32
89	210	.8	.2176	32
90	170	.8	.1591	32
91	350	.8	.1921	32
92	340	.8	.1416	32
93	150	.8	.1921	32
94	170	.8	.1591	32
95	370	.8	.1921	32
96	300	.8	.1921	32
97	320	.8	.1921	32
98	750	.8	.1921	32
99	280	.8	.1721	32
100	180	.8	.2176	32
101	310	.8	.1591	32
102	300	.8	.1416	32
103	220	.8	.1921	32
104	170	.8	.1921	32
105	370	.8	.1591	32
106	300	.8	.1921	32
107	370	.8	.1721	32
108	180	.8	.2176	32
109	240	.8	.1591	32
110	240	.8	.1416	32
111	330	.8	[illegible]	32
112	[illegible]	.8	[illegible]	32
113	240	.8	.2176	32
114	350	.8	.1591	32
115	780	.8	.1416	[illegible]
116	380	.8	.1591	32
117	590	.8	.1591	32
118	1590	.8	.1921	32
119	380	.8	.1921	32
120	310	.8	.1416	32
121	390	.8	[illegible]	32
122	[illegible]	.8	.1921	32
123	260	.8	.1416	32
124	1570	.8	.1921	32
125	340	.8	.1416	32
126	40	.8	.1793	32
127	380	.8	.1793	32
128	330	.8	.1793	32
129	720	.8	.1921	32
130	370	.8	.1921	32
131	240	.8	.1921	32
132	150	.8	.1921	32
133	180	.8	.1416	32
134	[illegible]	.8	[illegible]	
135	1030	.8	.1591	32
136	300	.8	.1921	32
137	[illegible]	.8	.1416	32

```
138          130          .8          .1471          32
139           50          .8          .1176          32
140          500          .8          .1418          32
141          550          .8          .1214          32
142          520          .8          .1121          32
143          560          .8          .1791          32
144          340          .8          .1791          32
145          340          .8          .1418          32
146         1090          .8          .1391          32
     ************************************************************


     ************************************************************




                          CONSUMER DATA
                          -------------

MEM   UPSTREAM     DOWNSTREAM      METER         PIPE        EQUIVALENTE
NUM   NODE#-UN     NODE#-DN      STAT#-MS   INSIDE DIA IN    LENGTH-FT
---  ------------ ------------ ------------ --- ----- ---  ------------
  4            4            0            7          1.5           100
  5            5            0            7          1.5           100
  6            6            0            7          1.5           100
  9            9            0            7          1.5
 13           13            0            7          1.5           100
 15           15            0            7          1.5           100
 19           19            0            7          1.5           100
 21           21            0            7          1.5           100
 22           22            0            7          1.5            50
 23           23            0            7          1.5            60
 25           25            0            7          1.5           100
 26           26            0            7          1.5           100
 28           28            0            7          1.5           100
 30           30            0            7          1.5           100
320          320            0            7          1.5           100
 35           35            0            7          1.5           100
 37           37            0            7          1.5           100
 38           38            0            7          1.5           100
 41           41            0            7          1.5           100
 42           42            0            7          1.5           100
 44           44            0            7          1.5           100
 45           45            0            7          1.5           100
 47           47            0            7          1.5           100
 48           48            0            7          1.5            50
 49           49            0            7          1.5           100
 51           51            0            7          1.5           100
 53           53            0            7          1.5           100
 55           55            0            7          1.5           100
 58           58            0            7          1.5           100
 59           59            0            7          1.5           100
 60           60            0            7          1.5           100
 63           63            0            7          1.5           100
 67           67            0            7          1.5           100
 69           69            0            7          1.5           100
 70           70            0            7          1.5           100
 71           71            0            7          1.5           100
 74           74            0            7          1.5           100
 76           76            0            7          1.5           100
[illegible]  [illegible]    0            7          1.5            50
 79           79            0            7          1.5           100
 83           83            0            7          1.5           100
 84           84            0            7          1.5           100
```

85	85	0	-	1.5	100
87	87	0	-	1.5	100
89	89	0	-	1.5	100
90	90	0	-	1.5	100
91	91	0	-	1.5	100
92	92	0	-	1.5	100
94	94	0	-	1.5	100
95	95	0	-	1.5	100
97	97	0	-	1.5	100
98	98	0	-	1.5	100
99	99	0	-	1.5	100
100	100	0	-	1.5	100
101	101	0	-	1.5	100
102	102	0	-	1.5	100
103	103	0	-	1.5	100
107	107	0	-	1.5	100
108	108	0	-	1.5	100
109	109	0	-	1.5	100
111	111	0	-	1.5	100
115	115	0	-	1.5	100
118	118	0	-	1.5	100
119	119	0	-	1.5	100
121	121	0	-	1.5	100
123	123	0	-	1.5	100

CONSUMER DATA (CONTINUED)

MEM NUM	ROUGHNESS COEFFICIENT	ACTUAL PIPE LENGTH-LA	HEAT.SUB.NET CONST.K1-K1	HEAT.SUB.NET CONST.K2-K2	PIPE AMB.TEMP.-FA
4	.001	100	.8	.2853	32
6	.001	100	.8	.2853	32
8	.001	100	.8	.2853	32
9	.001	100	.8	.2853	32
13	.001	100	.8	.2853	32
15	.001	100	.8	.2853	32
19	.001	100	.8	.2853	32
21	.001	100	.8	.2853	32
22	.001	100	.8	.2853	32
23	.001	100	.8	.2853	32
24	.001	100	.8	.2853	32
25	.001	100	.8	.2853	32
26	.001	100	.8	.2853	32
31	.001	100	.8	.2853	32
32	.001	100	.8	.2853	32
35	.001	100	.8	.2853	32
37	.001	100	.8	.2853	32
38	.001	100	.8	.2853	32
41	.001	100	.8	.2853	32
42	.001	100	.8	.2853	32
44	.001	100	.8	.2853	32
45	.001	100	.8	.2853	32
47	.001	100	.8	.2853	32
48	.001	100	.8	.2853	32
49	.001	100	.8	.2853	32
51	.001	100	.8	.2853	32
53	.001	100	.8	.2853	32
55	.001	100	.8	.2853	32
56	.001	100	.8	.2853	32
59	.001	100	.8	.2853	32
60	.001	100	.8	.2853	32
63	.001	100	.8	.2853	32
67	.001	100	.8	.2853	32
69	.001	100	.8	.2853	32
[illegible]	.001	100	.8	.2853	32

```
[illegible]      .001        100        .8      .2853      32
[illegible]      .001        100        .8      .2853      32
[illegible]      .001        100        .8      .2853      32
[illegible]      .001        100        .8      .2853      32
 79      .001        100        .8      .2853      32
 83      .001        100        .8      .2853      32
 84      .001        100        .8      .2853      32
 85      .001        100        .8      .2853      32
 87      .001        100        .8      .2853      32
 88      .001        100        .8      .2853      32
 90      .001        100        .8      .2853      32
 91      .001        100        .8      .2853      32
 92      .001        100        .8      .2853      32
 94      .001        100        .8      .2853      32
 95      .001        100        .8      .2853      32
 97      .001        100        .8      .2853      32
 98      .001        100        .8      .2853      32
 99      .001        100        .8      .2853      32
100      .001        100        .8      .2853      32
101      .001        100        .8      .2853      32
102      .001        100        .8      .2853      32
103      .001        100        .8      .2853      32
107      .001        100        .8      .2853      32
108      .001        100        .8      .2853      32
109      .001        100        .8      .2853      32
111      .001        100        .8      .2853      32
113      .001        100        .8      .2853      32
114      .001        100        .8      .2853      32
117      .001        100        .8      .2853      32
121      .001        100        .8      .2853      32
122      .001        100        .8      .1476      32

                    CONSUMER DATA (CONTINUED)
                    -------------------------

CON   TOTAL HEAT     % DEM LD    MAX.HEAT CO.  HEAT EQUIP     MAX. SND
NUM  HEAT LD.-TL   OF DT.LD-FR  TEMP DIFF-FR  EQUIV.LEN-M   TEMP DIFF-SD
---  ------------  -----------  ------------  ------------  ------------
  4       -99          -99          -99          -99           -99
  5       -99          -99          -99          -99           -99
  6       -99          -99          -99          -99           -99
  9       -99          -99          -99          -99           -99
 13       -99          -99          -99          -99           -99
 15       -99          -99          -99          -99           -99
 17       -99          -99          -99          -99           -99
 21       -99          -99          -99          -99           -99
 22       -99          -99          -99          -99           -99
 23       -99          -99          -99          -99           -99
 25       -99          -99          -99          -99           -99
 26       -99          -99          -99          -99           -99
 28       -99          -99          -99          -99           -99
 30       -99          -99          -99          -99           -99
 32       -99          -99          -99          -99           -99
 33       -99          -99          -99          -99           -99
 37       -99          -99          -99          -99           -99
 38       -99          -99          -99          -99           -99
 41       -99          -99          -99          -99           -99
 42       -99          -99          -99          -99           -99
 44       -99          -99          -99          -99           -99
 45       -99          -99          -99          -99           -99
 47       -99          -99          -99          -99           -99
 48       -99          -99          -99          -99           -99
 49       -99          -99          -99          -99           -99
 51       -99          -99          -99          -99           -99
 53       -99          -99          -99          -99           -99
 57       -99          -99          -99          -99           -99
```

```
72   [illegible] [illegible] [illegible] [illegible] [illegible]
57   [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
83   [illegible] [illegible] [illegible] [illegible] [illegible]
84   [illegible] [illegible] [illegible] [illegible] [illegible]
85   [illegible] [illegible] [illegible] [illegible] [illegible]
87   [illegible] [illegible] [illegible] [illegible] [illegible]
88   [illegible] [illegible] [illegible] [illegible] [illegible]
90   [illegible] [illegible] [illegible] [illegible] [illegible]
91   [illegible] [illegible] [illegible] [illegible] [illegible]
92   [illegible] [illegible] [illegible] [illegible] [illegible]
94   [illegible] [illegible] [illegible] [illegible] [illegible]
95   [illegible] [illegible] [illegible] [illegible] [illegible]
97   [illegible] [illegible] [illegible] [illegible] [illegible]
98   [illegible] [illegible] [illegible] [illegible] [illegible]
99   [illegible] [illegible] [illegible] [illegible] [illegible]
100  [illegible] [illegible] [illegible] [illegible] [illegible]
101  [illegible] [illegible] [illegible] [illegible] [illegible]
102  [illegible] [illegible] [illegible] [illegible] [illegible]
103  [illegible] [illegible] [illegible] [illegible] [illegible]
107  [illegible] [illegible] [illegible] [illegible] [illegible]
108  [illegible] [illegible] [illegible] [illegible] [illegible]
109  [illegible] [illegible] [illegible] [illegible] [illegible]
111  [illegible] [illegible] [illegible] [illegible] [illegible]
112  [illegible] [illegible] [illegible] [illegible] [illegible]
118  [illegible] [illegible] [illegible] [illegible] [illegible]
119  [illegible] [illegible] [illegible] [illegible] [illegible]
121  [illegible] [illegible] [illegible] [illegible] [illegible]
122  [illegible] [illegible] [illegible] [illegible] [illegible]

                 CONSUMER DATA (CONTINUED)
                 --------------------------

MEM   MAN EQUIP      CONS.FIXED
NUM   EQUIV..ZN-BL   FLOW RATE--F
----  ------------ - -------------
  4    [illegible]        24.6
  5    [illegible]        10.4
  6    [illegible]        24.6
  9    [illegible]        10.4
 17    [illegible]        13.4
 18    [illegible]        10.4
 19    [illegible]        16.4
 21    [illegible]         3.4
 22    [illegible]        13.5
 23    [illegible]        13.5
 25    [illegible]         3.4
 26    [illegible]        13.3
 28    [illegible]         3.4
 30    [illegible]        19.8
120    [illegible]         8.5
 33    [illegible]         8.5
 37    [illegible]         8.5
 38    [illegible]        17.8
 41    [illegible]         8.[illegible]
 42    [illegible]         8.5
 44    [illegible]        17.5
```

```
 47        [illegible]      5.5
 47        [illegible]      4.
 48        [illegible]      5.
 49        [illegible]      4.
 51        [illegible]      4.
 52        [illegible]      5.
 53        [illegible]      5.
 55        [illegible]      6.
 59        [illegible]      5.
 60        [illegible]      4.
 63        [illegible]      5
 67        [illegible]     10.8
 69        [illegible]      2.5
 70        [illegible]     10.8
 71        [illegible]      3.8
 74        [illegible]      5.8
 76        [illegible]      5.8
 [illegible] [illegible]    5.
 79        [illegible]     10.8
 82        [illegible]      5.8
 84        [illegible]     10.8
 85        [illegible]      5.8
 87        [illegible]      5.
 89        [illegible]     10.8
 90        [illegible]     28.
 91        [illegible]     10.
 92        [illegible]     18.4
 94        [illegible]     28.5
 95        [illegible]      7.
 97        [illegible]      4.5
 98        [illegible]     27.
 99        [illegible]      9.3
100        [illegible]      3.5
101        [illegible]     27.5
102        [illegible]     12.
103        [illegible]
105        [illegible]     27.
106        [illegible]     27.5
107        [illegible]     27.5
111        [illegible]     13.4
113        [illegible]     18.4
116        [illegible]     18.4
117        [illegible]     18.5
1[illegible] [illegible]   18.5
1[illegible] [illegible]   18.
***************************************************************

                        BOILER DATA
                        ------ ----

BOIL   LOCATED AT      UPSTREAM     DOWNSTREAM       PIPE        EQUIV LEN
NUM  MEMBER NUMBER     NODE#-UN      NODE#-UN   INSIDE DIA-IN   LENGTH-F
---- -------------  ------------  ------------  -------------  ----------
  1         1             1           1000            20            40

                  BOILER DATA (CONTINUED)
                  -----------------------

BOIL   ROUGHNESS     CONTROLLED      WATER HEAT
NUM    DEPTH-IN     TEMPERATURE-F    ADDITION
----  -----------   -------------   ----------
   1      .[illegible]       [illegible]        .[illegible]
```

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              CONSTANT PRESSURE NODES
              -------- -------- -----

NODE    CONSTANT
NUM     PRESSURE
----  ---- ----- --
  2        [illegible]

***************************************************

         NODE ELEVATION STATIC HEAD
         ---- --------- ------ ----

NODE    STATIC
NUM    PRESSURE
----  ----------
  2       2088
  3       2088
  4       2087
  5       2087
  6       [illegible]
  7       2087
  8       2087
  9       2087
 10       2089
 11       2089
 12       2089
 13       2089
 14       2089
 15       2089
 16       2088
 17       2086
 18       2086
 19       2086
 20       2084
 21       2082
 22       2080
 23       [illegible]
 24       2082
 25       2083
 26       2085
 27       2086
 28       2087
 29       2084
 30       2085
 31       2084
 32       2080
 33       2080
 34       2080
 35       2080
 36       2080
 37       2080
 38       2079
 39       2083
 40       2086
 41       2086
 42       2080
 43       2079
 44       2086
 45       2084
 46       2079
 47       2079
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48	2080
49	2082
50	2083
51	2083
52	2083
53	2084
54	2084
55	2084
56	2084
57	2084
58	2084
59	2080
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62	2079
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85	2077
86	2074
87	2076
88	2078
89	2080
90	2080
91	2076
92	2077
93	2079
94	[illegible]
95	2077
96	2076
97	2076
98	[illegible]
99	2076
100	2076
101	2087
102	2076
103	2084
104	2077
105	2072
106	2073
107	2075
108	2079
109	2079
110	[illegible]
111	2077
112	2075
113	2075

```
114          2070
115          2072
116          2076
117          2075
118          2073
119          2072
120          2077
121          2074
122          2074
124          2085
1000          2088
     [illegible]
     [illegible]
     [illegible]


          TASK REQUEST - ENTRY, 'R'=[illegible], 'P'=PRINTOUT, 'C'=CONTINUATION,
                          'EX'=EXTENSION, 'E'=EDIT, 'T'=TERMINATION,
                          'D'=INDEX DELETION.
```

APPENDIX 7

THE MODIFIED BERGGREN EQUATION

References:
1. Lotz, J. (1961)
2. Nixon, J.F. and McRoberts, E.C. (1973)
3. Phukan, A. and Andersland, O.B. (1978)
4. Smith, D.W. et.al., (1979)
5. Goodrich, L.E. and Gold, L.W. (1981)

Calculation of the depth of frost penetration is often based on the modified Berggren equation.

$$x = \lambda \left(\frac{7200\ k\ T_s\ t}{L} \right)^{\frac{1}{2}} \qquad (7.1)$$

where x = depth of frost penetration in m
k = thermal conductivity of the soil taken as the average for the frozen and unfrozen state in W/m °K
T_s = mean ground surface temperature during the freezing period in °C
t = length of freezing season in hours
L = latent heat of fusion of soil in J/m^3
λ = dimensional correctional coefficient usually determined from graphs of the thermal ratio α and the fusion parameter μ (Figure 7A)

$$\alpha = \frac{T_o}{T_s} \qquad (7.2)$$

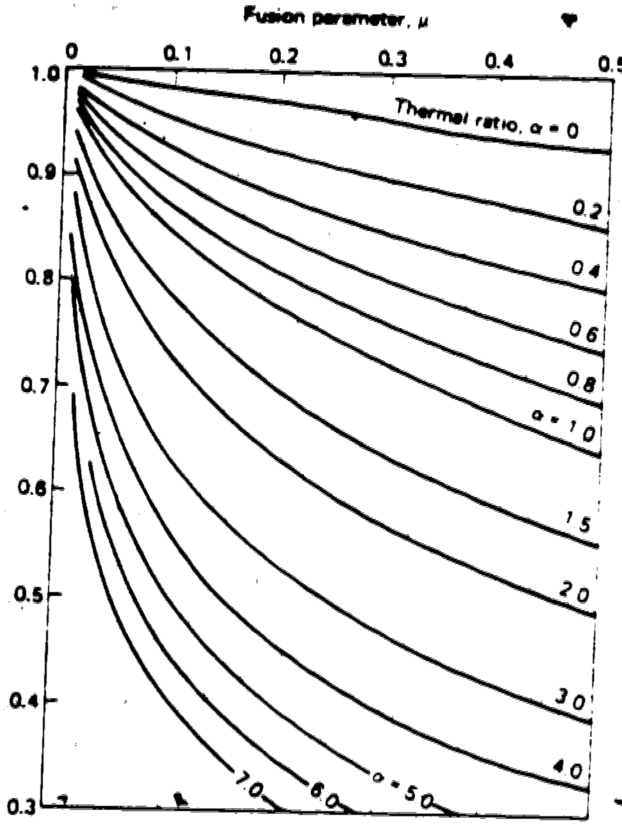
where T_o = mean annual air temperature in °C

$$\mu = \frac{c\ T_s}{L} \qquad (7.3)$$

= ratio of sensible heat to latent heat, the so-called Stephan number

where c = volumetric heat capacity of the soil in J/m^3·c

FIGURE 7A



THE CORRECTION COEFFICIENT IN THE MODIFIED BERGGREN EQUATION

SOURCE: PHUKAN, A. AND ANDERSLAND, O.B. [1978]

$$C_u = \gamma_d \left[C_{ms} + C_{mw} \left(\frac{w}{100} \right) \right] \quad (7.4)$$

$$C_f = \gamma_d \left[C_{ms} + C_{mi} \left(\frac{w}{100} \right) \right] \quad (7.5)$$

where C_u = volumetric heat capacity of the unfrozen soil in J/m^3 °C

C_f = volumetric heat capacity of the frozen soil in V/m^3 °C

γ_d = dry density of the soil in kg/m^3

C_{ms} = mass heat capacity of the dry soil matter (mineral content)
= 837 J/kg °C

C_{mw} = mass heat capacity of water
= 4184 J/kg °C

C_{mi} = mass heat capacity of ice
= 2092 J/kg °C

w = moisture content of the soil in % or decimal fraction

$$L = L_w \, w \, \gamma_d \quad (7.6)$$

where L_w = volumetric latent heat of water
= 334.72 kJ/kg

The modified Berggren equation is one of a number of Neumann or Stefan type solutions for determining a depth of thaw or freeze. The depth of freeze calculations assume a uniform homogenous soil originally isothermal at some temperature above freezing and suddenly subjected to a step decrease in surface temperature. All the latent heat is assumed lost at 0°C.

The modified Berggren equation is a simplification of the rigorous solution formulized by Neumann around 1860. The simplifying assumptions are that the thermal conductivities, thermal diffusivities, and volumetric heat capacities of frozen and unfrozen soil are all equal, i.e.,

$$k_u = k_f$$

$$K_u = K_f$$

$$c_u = c_f$$

Assume the following Whitehorse conditions:

1. $T_o = 35\ ^{o}F$
   $= 1.67\ ^{o}C$
2. FI = index of freezing
   $= 4000\ ^{o}F$ days
   $= 2222\ ^{o}C$ days
3. t = 287 days
   = 6888 hours
4. sand, saturated, 10% moisture content
   γ_d = dry density
   $= 2000\ kg/m^3$
   $K = \frac{1}{2}(K_u + K_f)$
   $= \frac{1}{2}(3.2 + 4.1)\ W/m\ ^{o}K$
   $= 3.65\ W/m\ ^{o}K$
5. no snow cover
   n = ratio of ground surface temperature to air temperature
   = 0.9

$$
\begin{aligned}
\therefore C_u &= 2000 \left[837 + 4184 \left(\frac{10}{100}\right)\right] \\
&= 2.51 \times 10^6 \ \mathrm{J/m^3 \cdot c} \\
C_f &= 2000 \left[837 + 2092 \left(\frac{10}{100}\right)\right] \\
&= 2.09 \times 10^6 \ \mathrm{J/m^3 \cdot c}
\end{aligned}
$$

since it is assumed $C_u = C_f$,

$$
\begin{aligned}
C &= \tfrac{1}{2} (C_u + C_f) \\
&= 2.31 \times 10^6 \ \mathrm{J/m^3 \cdot c}
\end{aligned}
$$

$$
\begin{aligned}
L &= 334.72 \ (0.10) \ (2000) \\
&= 66.94 \times 10^6 \ \mathrm{J/m^3}
\end{aligned}
$$

$$
\begin{aligned}
\alpha &= \frac{T_o}{T_s} \\
&= \frac{T_o}{n \ (FI/t)} \\
&= \frac{1.67 \ (287)}{0.9 \ (2222)} \\
&= 0.24
\end{aligned}
$$

$$
\begin{aligned}
\mu &= \frac{C \ T_s}{L} \\
&= \frac{C}{L} \left(\frac{FI}{t}\right) n \\
&= \frac{2.31 \times 10^6}{66.94 \times 10^6} \left(\frac{2222}{287}\right) 0.9 \\
&= 0.24
\end{aligned}
$$

from Figure 7A, $\gamma = 0.91$

$$
\begin{aligned}
\therefore x &= 0.92 \left[\frac{7200 \ (3.65) \left(\frac{2222}{284}\right) 0.9 \ (287 \times 24)}{66.94 \times 10^6}\right]^{\frac{1}{2}} \\
&= 4.0 \ \text{meters} \\
&= 13.1 \ \text{ft}
\end{aligned}
$$

APPENDIX 8

CITY OF WHITEHORSE
SOIL TEMPERATURE DATA

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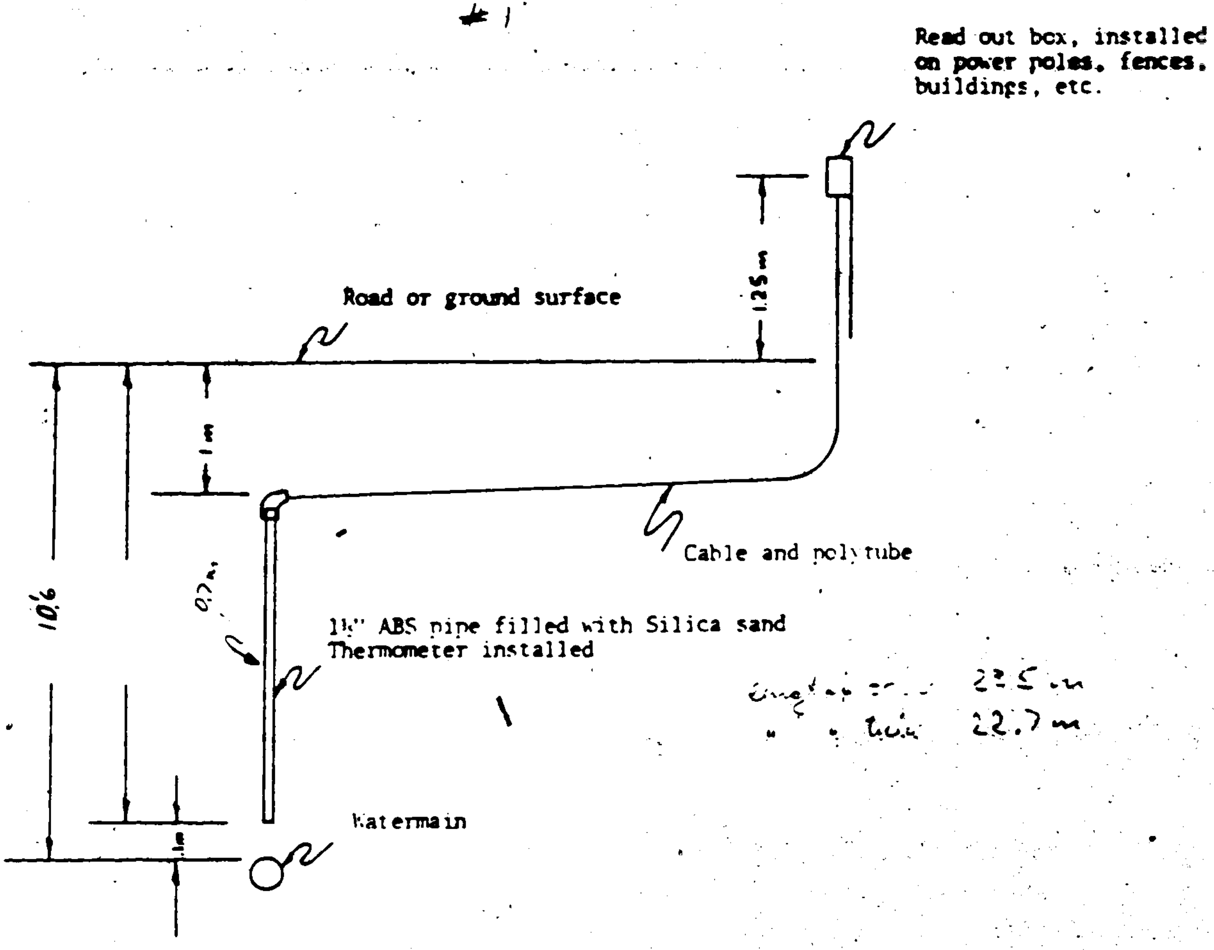
INSTALLATION OF RESISTANCE THERMOMETERS

1



Length of cable 22.5 m
" " tube 22.7 m

SENSOR # 1

Location OGILVIE

Address BAY STORE

Installation Date Oct. 1. 79

Installed By H. MULLER / R. DIMITROFF

Read and Approved By S. McGOWAN NOV. 28 79

Main Depth 3.2 m

Main Size 8" AC.

Sensor Depth Below Road Surface 3.0 m

Top of ABS Pipe Below Road Surface 2.3 m

Sensor Below ~~of of~~ Travelled Portion Travelled portion

Road Surface Material Asphalt

Backfill Material [illegible]

Length of 1¼" ABS Pipe 0.7 m

Length of Cable 23.5 m

Length of Polytubing 22.7 m

Readout Location MECHANICAL ROOM INSIDE BAY BLDG.

Height of Box from Ground Surface

SENSOR # 2

Location 2ND AVE. WORKS COMP. ENTRANCE

Address

Installation Date Oct. 19, 79

Installed By H. MUELLER

Read and Approved By J. McGuway Nov. 28. 79

Main Depth SENSOR 0.6 m NORTH OF SEWER SERVICE/BETWEEN MH° 227 & 228/1 m EAST OF WATERMAIN

Main Size 250 mm POLYWATER/

Sensor Depth Below Road Surface ELEV. 630.00 m / ROAD ELEV 632.2 m / DEPTH 2.2 m

Top of ABS Pipe Below Road Surface ELEV. 631.19 m / 1.1 m BELOW ROAD SURFACE

Sensor Below or of Travelled Portion

Road Surface Material ASPHALT

Backfill Material COMON

Length of 1¼" ABS Pipe 12 m

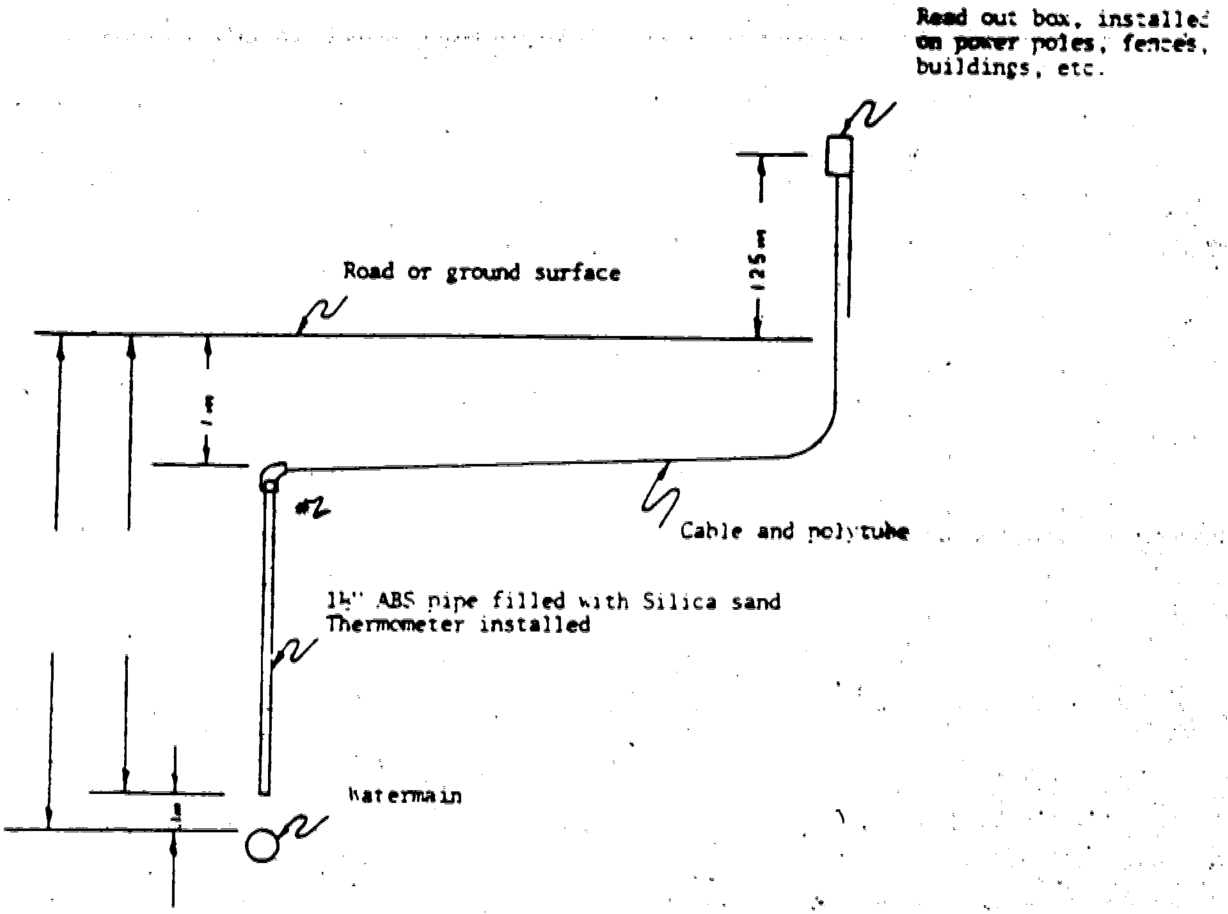
Length of Cable 22 m

Length of Polytubing 22 m

Readout Location COMPOUND FENCE

Height of Box from Ground Surface 1.5 m

INSTALLATION OF RESISTANCE THERMOMETERS



SELKIRK ANNEX

SENSOR # 3

Location LEWES + ALSEK

Address SELKIRK ANNEX

Installation Date OCT. 26.79

Installed By G.E. BONHAM

Read and Approved By J. McGOWAN Nov 28.79

Main Depth 2.6 m

Main Size 6" ⌀ AC

Sensor Depth Below Road Surface 2.5 m

Top of ABS Pipe Below Road Surface 1/m

Sensor [✓ Below] ~~out of~~ Travelled Portion

Road Surface Material 2" ASPHALT / IF RESTORED

Backfill Material SAND

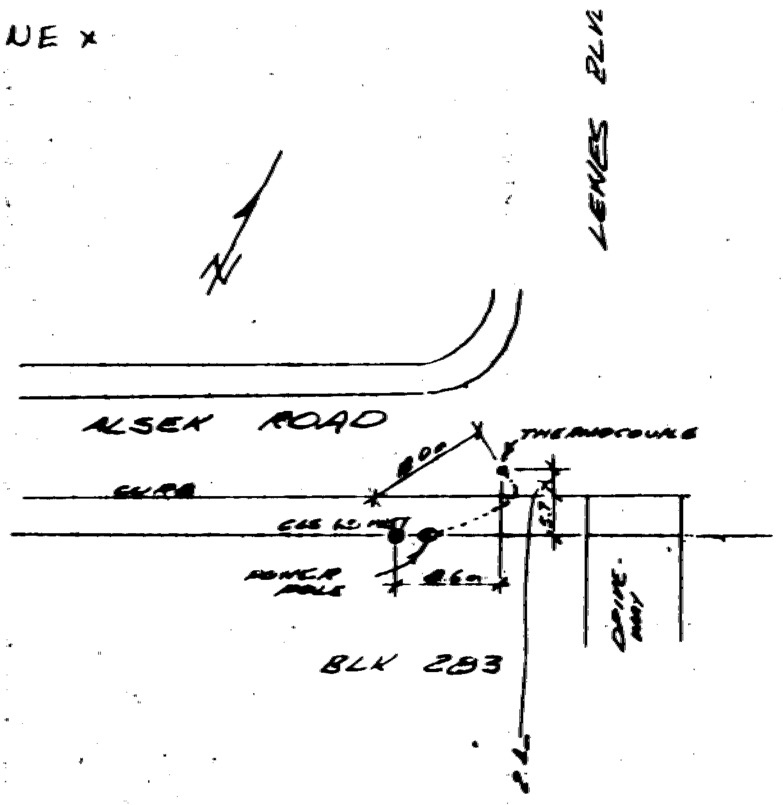
Length of 1¼" ABS Pipe 1.5 m

Length of Cable 23.5 m

Length of Polytubing 22 m

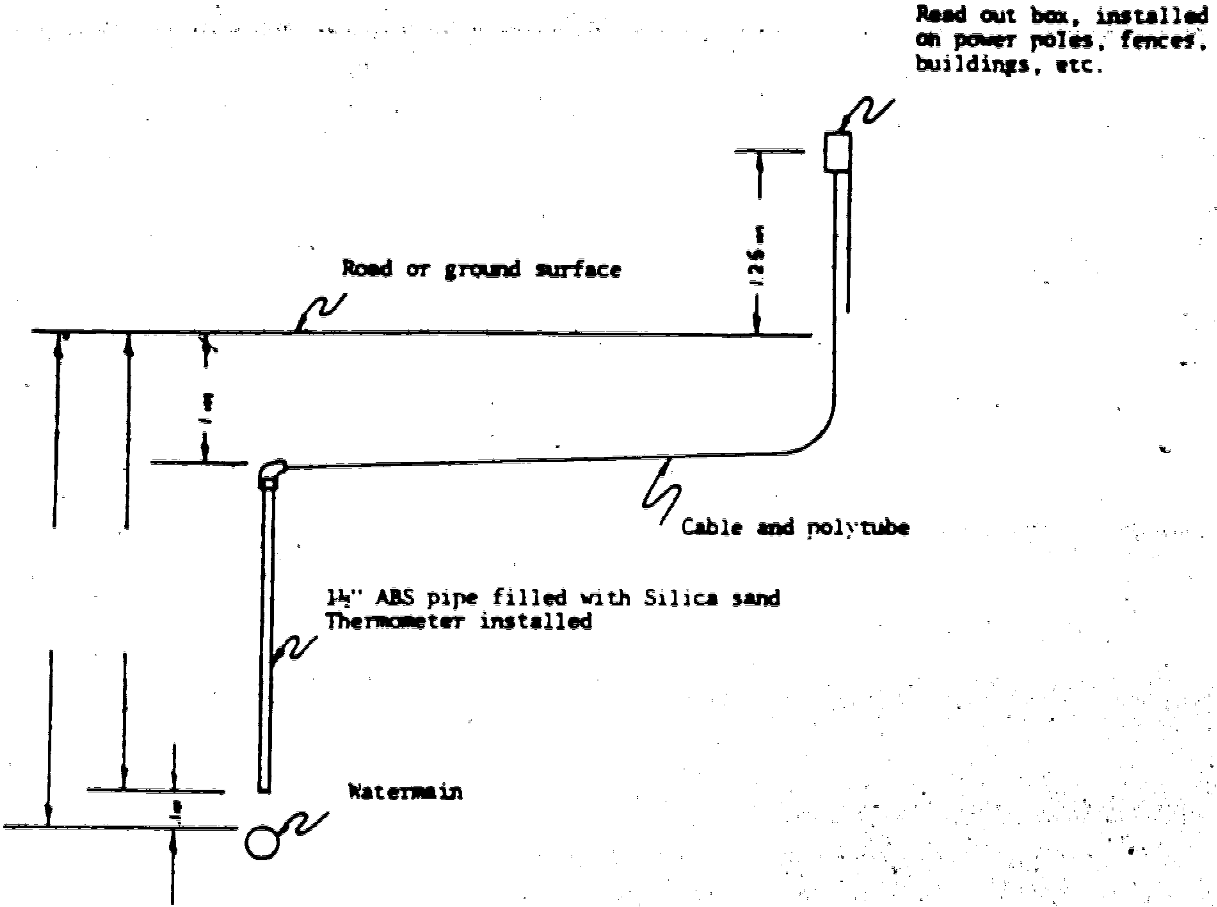
Readout Location POWER POLE NEAR CLS 60 NOT MARKED

Height of Box from Ground Surface 1.25 m



INSTALLATION OF RESISTANCE THERMOMETERS

#3



SENSOR # 4,5

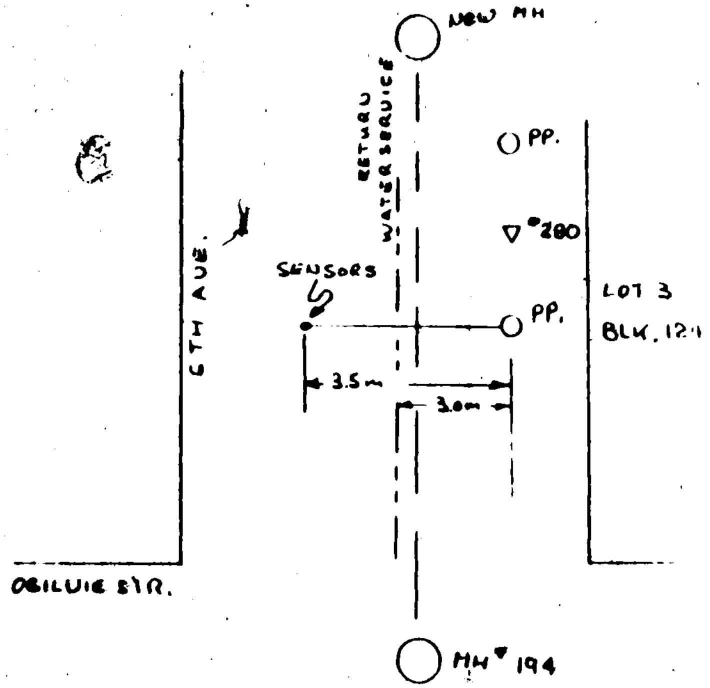
Location OGILVIE + 6TH. AVE.
Address 506 OGILVIE STR. LOT 3 BLK.124
Installation Date OCT.31.80
Installed By H. MUELLER
Read and Approved By

Main Depth NOT FOUND
Main Size
Road Surface Material UNPAVED
Backfill Material COMMON

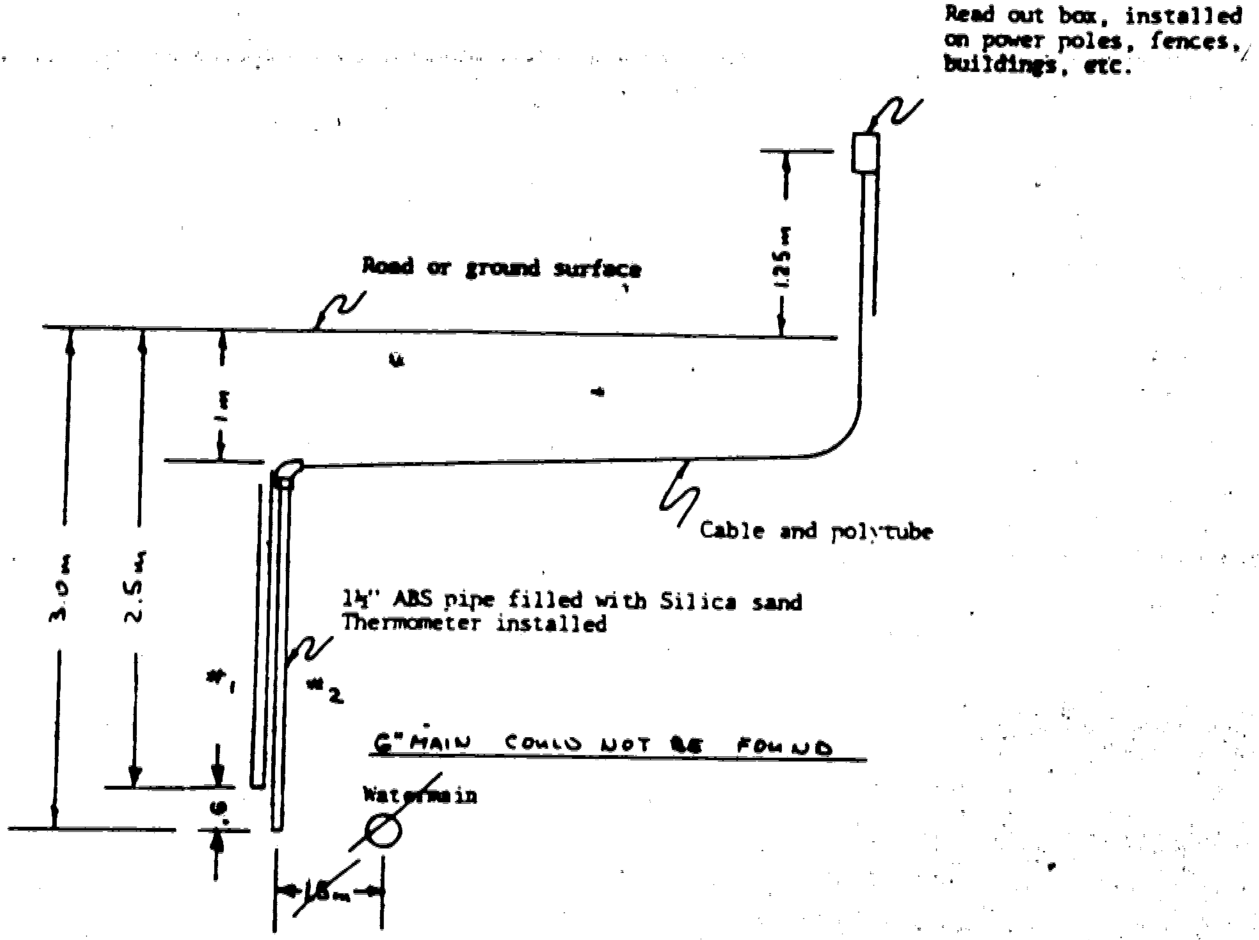
Sensor #1 SHORT FACING POLE RIGHT BOX
Sensor Depth Below Road Surface 2.6 m
Top of ABS Pipe Below Road Surface 1.0 m
Sensor Below / ~~of~~ Travelled Portion
Length of 1¼" ABS Pipe 1.5 m
Length of Cable 7.0 m
Length of Polytubing 6.5 m

Sensor #2 LONG FACING POLE LEFT BOX
Sensor Depth Below Road Surface 3.0 m
Top of ABS Pipe Below Road Surface 1.0 m
Sensor Below / ~~of~~ Travelled Portion
Length of 1¼" ABS Pipe 2.0 m
Length of Cable 7.0 m
Length of Polytubing 5.5 m

Readout Location POWER POLE
Height of Box from Ground Surface 1.6 m



INSTALLATION OF RESISTANCE THERMOMETERS



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OBSERVATION SHEET

SENSOR # 1 OGILVIE STR. BAY STORE

Sensor Depth below road surface 3.0 METER

Note: Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time 1979	Inspector's Name	Remarks
7.1		NOV. 8 - 11^{30}	H MÜLLER	BARE
6.0		NOV. 14, - 1^{30}	H MÜLLER	WET SNOW
5.9	4.1	NOV 21. - 11^{35}	H MÜLLER	WET SNOW
6.0	1.1	NOV. 26 - 11^{55}	H MUELLER	BARE
5.6	1.1	DEC. 5. 2^{00}	H MUELLER	LIGHT SNOW, SANDED
5.3	-24.2	DEC. 11 2^{00}	" "	" "
4.6	-1.0	DEC. 19 10:30	G. BONHAM	LIGHT SNOW, COMPACTED
U/A	+2.5	DEC 27 13:45	(BAY STORE LOCKED-UP)	
3.5	-21.6	JAN 2, 1980 11:15	"	FRESH SNOW COMPACTED
3.1	-21.1	JAN 10 10:15	"	COMPACTED SANDED
2.6	-5.7	JAN 16 15:30	"	GRADED TO PAVEMENT
2.0	-4.7	JAN 23 16:15	"	" " "
1.8	-14.9	JAN. 30 13:45	H. MUELLER	" " "
	+5.4	FEB 6 14:45	G. BONHAM	UNABLE TO RECORD, MECH ROOM LOCKED
1.8°	-13	FEB. 13 16^{00}	H. MUELLER	GRADED TO PAVEMENT
1.7°	-10.1	FEB. 20 16^{05}	H MUELLER	" " "
1.7°	+6.8	FEB. 27 14^{00}	H. MUELLER	" " "
1.9°	-3.3	MAR. 5 14^{30}	H. MUELLER	" " "
1.9°	-2.2	MAR. 12 14^{00}	H MUELLER	" " "
2.2°	-3.9	MAR. 26. 14^{55}	H. MUELLER	" " "

OBSERVATION SHEET

SENSOR # 1 OGILVIE STR. BAY STORE

Note: Sensor Depth below road surface 3.0 METER
Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time	Inspector's Name	Remarks
2.4°	+12.0	APR 2 80 14:00	H. MUELLER	BARE PAVEMENT
		APR 9 NO READING		STORE OPENING
3.1°	+7.0°	APR. 16. 80 19:55	H. MUELLER	BARE PAVEMENT
3.4°	+6.0°	APR. 23. 80 PM	H. MUELLER	" "
3.5°	+8.0	APR 30 80 PM	H MUELLER	" "
4.4°	-9.0	MAY 7 80 AM	H MUELLER	" "
5.9°	+11.0	MAY 14. 80 AM	H MUELLER	" "
7.2°	+12°	MAY 21 AM	H MUELLER	
8.0°	+18°	MAY 26 PM	H MUELLER	" "
9.4°	+20°	JUNE 5 AM	H MUELLER	" "
10.8°	-20°	" 11 PM	H MUELLER	" "
11.2°	+18°	JUNE 19 AM	H MULLER	" "
12.3°	+25	" 25 PM	H MUELLER	" "
14.3°	-21	JULY 2 PM	H MUELLER	" "
16.1°	-17	" 9 PM	H MUELLER	" "
16.6°	-17	" 17 AM	H MUELLER	" "
+17	+25	" 25 PM	H MUELLER	" "
16.7	19.0	" 30 PM	H MUELLER	" "
16.8	12.5	AUG. 19 PM	H MUELLER	
16.°	18.0	AUG 27 PM	H MUELLER	" "
15.2	11.7	SEPT. 3 PM	H MUELLER	" "

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OBSERVATION SHEET

SENSOR # 1 OGILUIE STR. BAY STORE

Note: Sensor Depth below road surface 3.0 METER
Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time 1980	Inspector's Name	Remarks
13.8°	7°	SEPT. 18 PM	H. MUELLER	BARE PAVEMENT
13.1°	4°	" 24 AM	H. MUELLER	" "
11.3°	7°	OCT. 2 PM	H. MUELLER	" "
11.0°	6°	" 8 AM	H. MUELLER	" "
10.1°	4°	" 16. PM	"	"
9.5°	1°	" 22. PM	"	"
8.8°	4°	" 29. PM	"	"
[illegible]2.	0°	NOV. 5 . AM	"	"
7.1	2°	NOV. 14 PM	"	" SLUSH ON EDGES
6.0	-5°	" 19 PM	"	"
5.1	0	" 26 PM	"	FRESH SNOW
3.6	-30	DEC. 9 AM	"	SNOW COMPACTED
3.6	-25	" 17 PM	"	" "

OBSERVATION SHEET

SENSOR # 2   2ND. AVE.   WORKSYARD ENTR.

Sensor Depth below road surface   2.2 METER

Note: Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time	Inspector's Name	Remarks
5.9		NOV.7 - 15^{00}	H Müller	BARE
5.6		NOV.8 - 11^{00}	H. Müller	BARE
5.0		NOV. 14 - 1^{15}	H MULLER	WET SNOW
4.3	4.1	NOV 21 11^{35}	H MULLER	WET SNOW
3.9	1.1	NOV.28 11^{00}	H MUELLER	BARE
3.6	1.1	DEC. 5 1^{45}	H MUELLER	LIGHT SNOW, SANDED
3.1	-24.2	DEC 11 2^{00}	H MULLER	" "
2.7	-1.0	DEC. 19 10:30	G BONHAM	LIGHT SNOW
2.5	-3.5	DEC 27 13:40	"	100mm SNOW
2.1	-21.6	JAN 2, 1980 11:00	"	125mm SNOW
2.0	-21.1	JAN 10, 10:10	"	LIGHT SNOW, SANDED
1.9	-15.7	JAN 16 15:30	"	" "
1.5	-4.7	JAN 23 16:30	"	BARE GRAVEL
1.2	-19.9	JAN.30 13:20	H.MUELLER	" "
0.9°	+5.4	FEB 6 14:20	G. BONHAM	5 mm SOFT SNOW
1.0°	-1.3	FEB.13 16^{00}	H MUELLER	SNOW - SANDED
0.8°	-10.1	FEB.20 16^{00}	H MUELLER	" "
0.7°	+6.8	FEB.27 14^{00}	H MUELLER	" "
0.9°	-3.3	MAR. 5 14^{15}	H MUELLER	BARE ASPHALT
1.0°	-2.2	MAR.12 14^{30}	H.MUELLER	" "
1.4°	+8.9	MAR.26 14^{30}	H MUELLER	" "

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OBSERVATION SHEET

SENSOR # 2   2ND. AVE. WORKSYARD ENTR.

Sensor Depth below road surface   2.2 METER
Note: Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time	Inspector's Name	Remarks
1.7°	+12.0	APR. 2. 80 14:45	H MUELLER	BARE PAVEMENT
1.4°	+6.0	APR. 9 13:40	H. MUELLER	" "
2.0°	+7.0	APR. 16. 14:45	H. MUELLER	" "
1.4°	+6.0	APR. 23 PM	H. MUELLER	" "
1.5°	+8.0	APR. 30. PM	H MUELLER	" "
1.5°	+9.0	MAY 9 AM	H MUELLER	" "
1.6°	+11.0	MAY 14 AM	H MUELLER	" "
1.7°	+12°	MAY 21. AM	H MUELLER	"
1.8°	+18°	MAY 28. PM	H MUELLER	" "
1.7°	+20°	JUNE 5. AM	H MUELLER	" "
2.1°	+20°	" 11. PM	H MUELLER	" "
2.4°	+18°	JUNE 19. AM	H MUELLER	" "
5.5°	+25°	" 25 PM	H MUELLER	" "
8.4°	+21°	JULY 2 PM	H MUELLER	" "
10.2°	+17°	" 9 PM	H MUELLER	" "
11.0°	+17°	" 17 AM	H MUELLER	" "
11.5°	+20	" 25 PM	H MUELLER	" "
11.5°	19.0	" 30 PM	H MUELLER	" "
11.8°	+12.5	AUG. 19 PM	H MUELLER	" "
11.8°	15.0	" 27 PM	H MUELLER	
11.2°	11.7	SEPT. 3 PM	H MUELLER	" "

OBSERVATION SHEET

SENSOR # 2 2ND. AVE. WORKSYARD ENTR.

Sensor Depth below road surface 2.2 meter

Note: Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

11.2

Sensor C°	Air C°	Date and Time 1980	Inspector's Name	Remarks
11.1°	7°	SEPT. 18. PM.	H. MUELLER	BARE PAVEMENT
10.4°	4°	" 24 AM	H. MUELLER	" "
9.5°	7°	OCT. 2. PM	H. MUELLER	" "
9.0°	6°	" . 8. AM	H. MUELLER	" "
8.8°	4°	" 16. PM	"	"
8.2°	1°	" 22. PM	"	"
7.2	4°	" 29. PM	"	"
6.7	0°	NOV. 5. AM	"	"
5.9	2°	NOV. 14 PM	"	"
5.5	-5°	" 19 PM	"	"
5.4	0	" 26 PM	"	FRESH SNOW
3.7	-30	DEC. 9 AM	"	SNOW COMPACTED
3.3	-25	" 17 PM	"	" "

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OBSERVATION SHEET

SENSOR # 3 SELKIRK ANNEX / LEWES - ALSEK

Note: Sensor Depth below road surface 2.5 METER
Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time	Inspector's Name	Remarks
4.8		NOV.7 - 15^{00}	H Müller	BARE
4.7		NOV.19. 1^{30}	H MÜLLER	WET SNOW
4.5	5.8	NOV.24. 2^{00}	H MÜLLER	WET SNOW
4.5	1.1	NOV. 28 11^{00}	H MUELLER	BARE
4.2	1.1	DEC. 5 2^{15}	H MUELLER	LIGHT SNOW, SANDED
3.9	-24.2	DEC 11 2^{00}	H MUELLER	" " "
3.6	-10	DEC 19 11 00	G BONHAM	LIGHT SNOW, SANDED
3.5	-3.5	DEC 27 12:00	"	" "
2.8	-21.6	JAN. 1, 1980 11:10	"	COMPACTED FROZEN SNOW, SANDED
2.8	-21.1	JAN 10 10:30	"	COMPACTED SNOW, SANDED
2.4		JAN 14 11:00	"	" "
2.4	-15.7	JAN 16 15:00	"	" "
1.7	-4.7	JAN 23 11:30	"	" "
1.1	-14.9	JAN 30 13:15	H. MUELLER	" "
1.2	+5.4	FEB 6 14:55	G BONHAM	SOFT SNOW SANDED
0.5°	-1.3	FEB.13 16^{00}	H. MUELLER	COMPACTED SNOW, SANDED
0.5°	-10.1	FEB.20 16^{00}	H. MUELLER	" " "
0.2°	+6.8	FEB.27 14^{00}	H. MUELLER	GRADED TO ROAD SURFACE
0.3°	-3.3	MAR. 5 14^{00}	H MUELLER	" " "
0.8°	-2.2	MAR.12 14^{00}	H MUELLER	" " "
0.8°	+8.9	MAR 26. 14^{00}	H MUELLER	" " "

OBSERVATION SHEET

SENSOR # 3 SELKIRK ANNEX / LEWES - ALSEK

Note: Sensor Depth below road surface 2.5 METER
Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time	Inspector's Name	Remarks
1.0°	+12.0	APR.2 86 19:30	H. MUELLER	BARE ROAD SURFACE
1.3°	-6.0	APR.9 14:30	H MUELLER	" "
1.5°	-7.0	APR.16 15:00	H MUELLER	" "
1.6°	+6.0	APR.23. PM	H. MUELLER	" "
1.6°	+5.0	APR 30 PM	H MUELLER	" "
2.1°	+9.0	MAY 7 AM	H MUELLER	" "
2.4°	-11.°	MAY 14 AM	H MUELLER	" "
2.9°	+12°	MAY 21 AM	H MUELLER	" "
9.2°	+18°	MAY 28 PM	H. MUELLER	" "
5.6°	+20	JUNE 5 AM	H. MUELLER	" "
7.1°	+20	" 11 PM	H. MUELLER	" "
8.0°	+18°	" 19 AM	H. MUELLER	" "
9.3°	+25	" 25 PM	H. MUELLER	" "
11.4°	+21	JULY 2 PM	H. MUELLER	" "
12.8°	+17°	" 9 PM	H. MUELLER	" "
13.5°	+17°	" 17 AM	H. MUELLER	" "
14.0°	+20	" 25 PM	H. MUELLER	" "
14.0	14.0	" 30 PM	H. MUELLER	" "
14.0	12.5	AUG. 19 PM	H MUELLER	" "
13.0	18.0	" 27 PM	H MUELLER	" "
13.0	11.7	SEPT. 3 PM	H. MUELLER	" " PAVEMENT RESTORED

OBSERVATION SHEET

SENSOR # 3 SELKIRK AVNUE / LEWES + ALSEK INTERSECTION

Sensor Depth below road surface 2.5 m

Note: Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

Sensor C°	Air C°	Date and Time 1980	Inspector's Name	Remarks
12.1°	7°	SEPT. 18. PM	H. MUELLER	BARE PAVEMENT
11.4°	4°	SEPT. 24 AM	H. MUELLER	" "
10.6°	7°	OCT. 2. PM	H. MUELLER	" "
9.3	6°	" 8. AM	H. MUELLER	" "
8.5°	4°	" 16 PM	"	"
8.5°	1°	" 22 PM	"	"
7.7°	4°	" 29 PM	"	"
7.1	0°	NOV. 5. AM	"	"
6.2	2°	NOV. 14 PM	"	"
5.4	-5°	" 19 PM	"	"
4.3	0	" 26 PM	"	FRESH SNOW
3.1	-30	DEC. 9 AM	"	SNOW COMPACTED
3.2	-25	" 17 PM	"	" "

OBSERVATION SHEET

SENSOR # 4 + 5 6TH. AVE. - OGILVIE STR.

Note: 1st Sensor Depth below road surface 2.5 m
2nd Sensor Depth below road surface 3.0 m
Temperature
Date and Time of Reading
Sensor Location, bare, snow covered, plowed
Name of Inspector

SOME FROZEN BACKFILL USED

Temperature			Date and Time	Inspector's Name	Remarks
RIGHT 1st Sensor	LEFT 2nd Sensor	Air			
1.0°	2.4°		OCT. 31. 80	H. MUELLER	INSTALLATION COMMON BACKFILL
2.3°	4.9°	-6°	NOV. 3. 80	"	BARE
3.2°	5.3°	0°.	NOV. 5 AM	"	BARE.
4.2°	5.5°	2°	NOV. 14 PM	"	SNOW, COMPACTED
4.2°	5.2°	-5°	NOV. 19 PM	"	" "
4.0°	5.2°	0	NOV. 26 PM	"	FRESH SNOW
3.3°	4.2°	-30°	DEC. 9 AM	"	SNOW COMPACTED
2.6°	4.1°	-25°	" 17 PM	"	" "