SOME EXPERIENCES WITH CONTROLLED DRAINAGE AND SUBSURFACE IRRIGATION

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by Robert S. Broughton, Ph.D., P.Eng.
Emeritus Professor, McGill University
15 Fairside Avenue, Toronto, ON M4C 3G8

I. INTRODUCTION

Controlled Drainage and Subsurface Irrigation (CDSI) are two soil and water management tools that some farmers can use to help reduce negative effects of uncertain rainfalls on crop production. CDSI can also conserve fertilizer nutrients and reduce downstream pollution.

This paper can be considered as a small supplement to the major presentations on CONSERVATION DRAINAGE, Controlled Drainage / Subirrigation CDSI, Background Report and Design Guide presented at the January 2008 meeting of LICO and DSAO by Gary Hunter and Associates. This paper provides observation information from farmers, contractors, students and colleagues with whom I have worked over 4 decades.

Firstly, experiences are presented from farms with **CDSI is controlled on the farm itself**. Controlled drainage is now being used to some extent on hundreds of farms in Ontario and Quebec. This paper gives details from 5 farms totaling about 4000 acres and a range of soils, summarized in table 2. Any errors in getting from the verbal interviews to the print are mine.

Secondly, some examples of control structures on Municipal Drains that affect crop water supply for several neighboring farms will be presented.

Thirdly, some summary guidelines from lessons learned will be presented.

II. EXPERIENCES and OBSERVATIONS from FIVE FARMS

The Charbonneau Family Farms have a current total crop area of approximately 1500 acres, (600 hectares), in **Richelieu County, Quebec**. Controls have been installed at the outlets, or along the collectors of most of the subsurface drainage systems, which means most of the crop area. Grain Corn, soybean and cereal grains are grown. In august 1977 Leandre Charbonneau introduced me and some others to the problem of EXCESSIVE SUBSURFACE DRAINAGE OF SOME SANDY SOILS. Leandre took us to fields where subsurface drains had been installed with laterals 100 ft (30m) apart. Subsurface drains were required because the flat sandy soil was underlain by clay at a depth of about 4 to 5 feet. The rain and snow melt water soaked into the permeable topsoil and the fields were saturated to the surface every April. The corn was healthy at mid-spacing between drain pipes, but wilted and sick within 10 ft (3m) either side of the drain line where the pipes were 3.5 to 4.5 feet deep. Surface gradients were less than 0.05%. Distances to outlets were approximately 1800 feet. Lateral drain pipes ranged from 2.5 feet deep at the upstream end to 4.5 feet near the outlet. The crop was relatively uniform where the drain pipes were 2.5 feet deep. We dug pits and found that the soil between 34 and 45 cm deep was approximately 3% silt and clay, 11% very fine sand, 73% fine sand, 10% medium sand and 3% coarse sand both at mid-spacing and near the drains. The soil was drier near the drains in the zone where the drain pipes were deeper than 3feet. The corn was suffering drought near the drains where the drains were deeper than 3 feet.

Leandre Charbonneau and I made our first attempts at "Conservation Drainage" in 1978 by placing home made controls at existing drain pipe outlets. Persons involved with designing and installing drainage systems in soils with a high sand content are invited to read the paper by Rashid-Noah et al (1987). Figures 1, 2 and 3 which were reproduced from that paper show soil particle size distributions and drainable porosities for 4 farms. Note in figure 1 the particle size distributions are not greatly different between the Charbonneau and the McRae soils. But figure 3 shows a dramatic difference in drainable porosities between those two soils. Figure 2 shows the significant additional volume of water that drains out of the Charbonneau soil as the water table drops from 60 to 120 cm (2 to 4 ft). **To prevent this excessive drainage, either the drain pipes should not be deeper than 2.5 feet, or water table controls are needed on the drainage systems.**

No more subsurface drainage systems were installed on the Charbonneau farms between 1977 and 1986. The Charbonneau Family and I started experiments with controlled drainage in 1979 and with **subsurface irrigation** on areas of a few acres from 1981 through 1987. We found considerable increase in yield of grain corn possible. In 1985 we drilled a well to be used for irrigation of additional fields. Unfortunately, the well water was too salty to be used. (Many wells in Richelieu County are salty. Potable water for domestic and animal needs is piped to farms from a municipal filtration plant that gets water from the Richelieu River.)

The water controls installed at the outlets of drainage systems on this farm before 1986 were home made. After 1986 Innotag Inc. Drainage Control System units have been used. See figure 4. These units have valves actuated by floats that rise and fall with water level in the soil. **The Charbonneau common management protocol** is to lower the level at which the float opens the valve, or to remove the valve completely, in September so that drainage is adequate for harvest conditions. The valves are closed and the float control levels are adjusted after planting in the spring.

Most of the land is currently cropped with grain corn, which is used to feed pigs. The pig manure is returned to the land as fertilizer. The Charbonneau Family is happy with crop yields improvements with controlled drainage. They are happy to be able to reduce the loss of nutrients though the drainage systems during summer rains. They would gladly use subirrigation on fields with coarser sandy subsoils if a suitable water source was available.

B. The Brouillard Family Farm, in Richelieu County, Quebec.

Controls have been installed on the outlets of subsurface drainage systems in about 200 acres (80 ha) on relatively level parts of the farm that have the deepest sandy soils. Controls have not been installed on drainage systems on the parts of the farm with higher clay content soils. Crops of soybean, maize and cereal grains are grown.

Subsurface irrigation is used on about 90 acres (36 ha). The irrigation water is obtained from the Yamaska River. In the small scale subsurface irrigation experiments in 1989 and 1990 a coil of drain pipe with sock filter was placed in the river on the pump intake pipe, and in-line drip irrigation filters were placed near the discharges of the irrigation pipes at the water level control chambers. The in-line filters had to be cleaned frequently. When the 1989 and 1990 irrigations showed yields of soybean 25 to 30 % higher than non-irrigated adjacent plots, plans were made to irrigate a larger area in future years. It was obvious that this would require a larger pump, new pipelines, modifications to some drainage systems and a better system to filter the river water.

Two grassed filter basin areas were designed in 1992. They were constructed in the spring of 1993 and put into service in June 1993. One grassed filter basin supplied water to sub-irrigate 30 acres and the other 60 acres. Water was pumped from the river into the filter basins. Filtered water gravitated into the control chambers of the existing subsurface drainage systems. A mixture of chewing fescue, tall fescue, tiller timothy, yellow blossom sweet clover, hybrid clover meadow foxtail and bent grass was planted in the basins in May 1993. **It was found that less than 0.2% of the area to be irrigated needs to be devoted to the grassed filter system.**

These filter and subirrigation systems have been used every year since 1993, except for 2008 which had plenty of rain. The grasses in the filter basins are cut two, or three times per year, and used for animal bedding, or composted, and spread on the cropland in subsequent years.

Controlled drainage has been used on another 100 acres (40 ha) with good yields and a reduction in fertilizer applications since 1993. **The general operating procedure** is to shut off the irrigation system, and open the drain outlets of both the irrigated and the controlled drainage systems in early September each year, to provide good drainage for the harvesting of corn and soybeans. The drainage controls are closed immediately after planting in the spring, to conserve moisture and nutrients.

In 1993 the Brouillard brothers invited me to investigate and help solve a problem of poor drain performance on a portion of a large field that had laterals at 40 spacings. With the help of the Contractor, Drainage Richelieu, who had installed the drains, we dug and found the situation shown in figure 5a. The lateral drains had been installed with a plow blade and boot sized for 4-inch pipe. In the problem area the pipes were 3.5 to 4 feet deep. Clay had closed over the pipe after installation and drainage was very slow from the upper layers. We arranged to use a plow with blade for 8-inch pipe and a boot for 6 or 4-inch pipe to install additional 3-inch diameter laterals through the area of poor drainage, see figure 6a. The new laterals were teed into existing laterals downstream of the wet area, then they were plowed into place at mid-spacing between existing laterals, at a depth of 3 to 2.5 feet. The drainage performance has been excellent ever since. For most soils it is beneficial to install all lateral drain pipes with plows with a blade that is also suitable for installing 6 or 8-inch pipes and a boot suitable for 6 or 4-inch pipes. The leading part of the blade should be flat, approximately 11 inches wide, or wider, and have a slope of about 23 degrees from the horizontal. The pipe guide box (boot) should have a steel plate, about 4-ft high, extending back on one side, that delays the heaved soil from falling back in from that side until after some soil from the other side has slid down the back of the pipe box onto the pipe, see Broughton et al (1991) and Broughton and Fouss (1999).

C. The Vincent Family Farm in Soulanges County, Quebec. The current total crop area is 280 acres. 100 acres are being subirrigated with water from a single well. 180 acres are managed with controlled drainage only. The crop rotation consists of 3 years of grain corn followed by one year with an early crop of peas for the cannery followed after harvest with a green manure/weed control crop of oats or barley.

Subirrigation began in 1993 on 50 acres (20 hectares) with a specially designed subsurface drainage system that was installed in 1992, see figures 7 and 8. This was the first subsurface drainage installation on this parcel of land. Subsurface drainage systems had previously been installed on adjacent parcels of land so the Vincents were able to compare crop results with, and without, controlled drainage and with, and without, subirrigation. The Vincents were very happy with the results of the subsurface irrigation in 1993, 1994 and 1995, so they retrofitted the old existing subsurface drainage system on the adjacent 50 acres and irrigated the whole100 acres with the 5 HP submersible pump in the well drilled in 1993. They have irrigated every year since 1993. In 2008 they pumped for only12 days, as there was sufficient rain for the rest of the summer.

The area being irrigated is very flat. There is a maximum of 6 inches (15 cm) difference in surface elevation in the land served by any one subsurface drainage outlet in the 100 acres. The common soil profile in this 100 acres is approximated in Table 1 below.

Table 1. Soil Particle Size Analyses, Vincent Subirrigation field, Soulanges, Co. Quebec

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture Description
0-25	10.17	33.67	56.17	Fine Sandy Loam
25-70	20.00	21.83	58.17	Sandy Loam
70-100	39.33	28.33	32.33	Sandy Clay
100-120	56.50	34.67	8.83	Clay Loam

The 180 acres with only controlled drainage is less level and less uniform in soil profile, and soil texture than the area being subirrigated. Much of the area with only controlled drainage has a higher silt and clay content with a good available water holding capacity. With controlled drainage most of this area can make use of most of the summer rain. The Vincents consider CDSI to be very beneficial. It has made it possible for them to get good crop yields every year with a significant reduction in purchased fertilizer. In recent years they have obtained overall farm average grain corn yields much above the regional average. In 2008 their farm average corn yield was 13 tonnes per hectare (205 bushels per acre).

D. The McRae Family, Bainsville, Glengarry County, Ontario, grows crops on approximately 450 acres. They converted from dairy farming to cash cropping in 1969. They installed subsurface drains gradually on most of their farm between 1960 and 1983. They have been active in the Eastern Ontario Soil and Crop Improvement Association. They participated in a LICO sponsored research project on CDSI from 1989 to 1994, in cooperation with Dr. Madramootoo of Macdonald Campus of McGill University. The experiments carried out in that interval showed yield increases and reduction in nitrogen leaching to drainage water. The individual lateral drain pipes used in that experiment emptied directly into a ditch that flowed to Lake St-Francis without pumping.

In another area the McRaes have achieved a small amount of controlled drainage and energy savings by changing the float levels at which the drainage pump switches for the 80 acres served by that pump. They tried **subirrigation** by siphoning river water back into the drainage pump chamber, but found that it was easy to get too much irrigation on the lowest land served by the drainage pump. They came to the conclusion that a major amount of retrofit plumbing would be required to convert their existing subsurface drainage systems to provide CDSI. The land slope had been well taken into account to provide good quality, cost effective drainage systems with long laterals. But if water control chambers were installed on the existing collectors, drainage from the upper end of the laterals would subirrigate the land near the lower end of the laterals, and some very complex fertilizer patterns would be required to try to get relatively uniform supply of nutrients to the crops. Also it was realized that the particular very fine sandy loam soil on much of their farm had about the best water holding capacity characteristics of any soil for crop production in Eastern Ontario, see figures 1 and 3. They decided to try to evolve a new cropping system that would reduce fertilizer requirements without requiring CDSI.

E. The Joyal Family, Richelieu County, Quebec, started installing Controlled Drainage in 1996. They now have 510 acres (205 hectares) of subsurface drains controlled by 12 Innotag Inc. Drainage Control System units placed near pipe outlets. They have no subsurface irrigation. The part of their farm with controlled drainage has a fine sandy loam top soil, and sandy loam subsoil underlain by clay at depths varying between 80 and 150cm (2.7 and 5 ft). They worked ahead gradually installing subsurface drainage systems and doing land leveling on about 50 ac (20ha) per year. The area planned for drainage in each year was planted to wheat in the spring. Then the drainage and land leveling work was done in August and September after harvesting the wheat.

Much of this land previously had surface drainage beds and no subsurface drains. Soybean, grain corn and wheat are grown in rotation. They feed pigs and spread the manure. The controlled drainage helps reduce loss of fertility from summer rains. The Joyal Family have observed 10 to 15% increase in yield of corn and soybean due to controlled drainage and land leveling. They normally open the drain control valves about 10 September to provide for good surface conditions for harvesting machines. The valves are left open until the day that a drainage zone is planted in the spring.

Table 2. Some information on 5 farms. Additional information in text.

Farm name, location	Ac Culti-vated	Ac Cont-rol Drai-nage	Ac Sub-irrig-gate	REMARKS and INFORMATION
Charbonneau Family, Quebec Richlieu Co.	1500	1500	Zero	Would subirrigate if water was available for area where sandy soil is deeper than 3 feet
Brouillard Family, Quebec Richelieu County	1000	100	90	Water from Yamaska River filtered in grass beds for irrigation since 1993 on part of farm with most sandy soil. Most of farm clay loam has no controls
Vincent Family, Quebec Soulanges Co.	280	180	100	5-HP pump from well providing subirrigation since 1993 on land with sandy loam 2 to 3 feet deep. Clay loam has Controlled Drainage only.
McRae Family Bainsville Glengarry Ontario	400	Zero	Zero	Experimented with subirrigation 1990-94 Deep very fine sandy loam soil has good water holding capacity and wicking from deeper soil; drainage systems not suited to retrofit; using new crop rotations
Joyal Family Richelieu QC	800	510	Zero	New subsurface drains and land leveling about 50 acres/year since 1996

Notes:

1. The areas being subirrigated on the Brouillard and Vincent farms have surface gradients less than 0.05%.
2. Most of the areas where controlled drainage has been retrofitted on existing subsurface drainage systems had surface gradients less than 0.07%.
3. See the text for details of soil profiles, particle sizes and moisture release (drainable porosity) curves.

III. WATER LEVEL CONTROL STRUCTURES ON WATER COURSES

Water level control structures have been built in water courses in flat land areas to conserve water for a variety of purposes including subsurface irrigation, reducing downstream pollution, reducing nutrient losses, reducing subsidence of organic soils, preservation of habitat for fish, water fowl and other biota. Usually these structures effect ground water levels for more than one property owner, so some community agreements are needed on operation, management, maintenance and financing.

Some examples of such water control structures in Quebec and North Carolina are shown in the photographs. Most of these examples are for control structures at the upstream end of culverts. This gives access to both sides of the watercourse. The culverts serve also as stilling basins for water flowing over the control weirs. The length of the culvert serves to increase the seepage path and decreases the hydraulic gradient to reduce seepage around the structure. Guidelines for the design of such structures were given by Broughton et al, 1990.

The South Nation Conservation Authority, in Eastern Ontario is Cooperating with Agriculture and Agri-Food Canada (AAFC) and Ducks Unlimited Canada in part of the National Project on Watershed Evaluation of Beneficial Management Practices (WEBs). This project is monitoring small watersheds in 7 provinces. According to the AAFC bulletin "Two micro-watersheds within the South Nation Watershed, each about 300-400 hectares, have been chosen to evaluate the effectiveness of two BMPs designed to alleviate pollutant loads on water courses. One of these watersheds – the Blanchard Municipal Drain – drains into the Little Castor River, and the other – the Bisaillon Municipal Drain – drains directly into the South Nation River. These two micro-watersheds feature agricultural-based activities typically found throughout [southern] Ontario." We can expect that a detailed report on the findings of this study to be presented at a future LICO – Drainage Superintendents meeting. For further interim information persons may contact Mark Sunohara at South Nation Conservation, phone (613) 715-5450, or email: sunoharam@agr.gc.ca

IV. SOME SUMMARY POINTS

1. By installing water level controls on subsurface drain collector pipes it has been possible to conserve water from summer rain falls and obtain increases in yields of corn and soybean from 10 to 30 % higher than fields without such controls on farms in Ontario and Quebec. The amount of increase varies from year to year depending on the rainfall distribution, the specific soils and the crop rotation and fertilizer management of individual farms.
2. Where the land has a surface slope less than 0.1% it is often possible to retrofit water level controls into existing drainage systems, but better performance of both Controlled Drainage and Subirrigation can usually be obtained if CDSI is planned at the time that the drainage system is being planned.

3. Many more farmers would be interested in subsurface irrigation if they had a suitable source of irrigation water nearby.
4. If you are thinking about drilling a well to get irrigation water, check information on nearby existing wells. Take a water sample from a nearby well and get it tested for sodium, calcium, magnesium, selenium, arsenic, chlorides, phosphates, and carbonates. Then get a soil chemist to check whether there are any dangers, or limitations to be considered about using well water in that region for subsurface irrigation.
5. It is recommended that the drainage plow that is used for installing 6 or 8-inch diameter pipe be used to install 3 or 4-inch diameter drain pipes. The plow blade used for installing 6 or 8-inch diameter pipes will create a wider opening that allows loose permeable upper subsoil to fall down over the pipe and provide better seepage conditions for both drainage and subirrigation, for details see Broughton et al (1991) and Broughton and Fouss (1999).
6. If you are thinking of pumping water from steams or rivers for subirrigation it is recommended that you consider constructing grassed filter basins in a location in the field from which the filtered water can gravitate into the subirrigation system. See the reference by Nsengiyumva et al, (1996).
7. To avoid excessive drainage of sandy soils, try to avoid placing drain pipes deeper than 3 feet (0.9m), or alternately, design the drainage systems with water control devices capable of keeping a static water table level between 50 and 70cm (20 to 28-inches) under much of the field. See reference Rashid-Noah et al 1987.
8. The simple sand, silt and clay designations that are used in the soil textural triangle to classify soils as "loamy sand", "sandy loam", etc., see figure 9a, are not sufficient to guide one as to whether there may be danger of excessive drainage from drain pipes deeper than 3 feet. The sand component can be better evaluated by wet sieving to obtain the percentages of very fine sand, fine sand, medium sand, etc. But it is best to also use undisturbed soil cores and the Haynes funnel to give moisture release and drainable porosity curves, as in figure 3, to supplement the particle size analyses, figure 1.

V. ACKNOWLEDGEMENTS

The author gratefully acknowledges the interest and collaboration of farmers, Leandre and Eric Charbonneau, Gaston and Daniel Brouillard, Ron and Shawn McRae, Guy and Daniel Vincent and Louis Frederic Joyal; contractors who helped with some of the irrigation and drainage construction work included Excavation Cap, cap de la Madeleine, QC, Drainage Richelieu, Drainage Division of Pavages Vaudreuil Inc. and Agrodrain Systems Inc., Osgoode ON. Thanks is expressed to Engineer Robert Beaulieu of the Minsitere de L'Agriculture et L' Alimentation du Quebec for information and photographs on control structures in Municipal water courses, and to Mark Sunohara for information on the Watershed Evaluation of Beneficial Management Practices that is underway. The following persons worked on some part of the field investigations, construction, laboratory work or computer analyses of the CDSI mentioned in this paper: Augustine Rashid-Noah, Jacques Gallichand, Robert Bonnell, Greg Bostock, Marc-Antoine Pelletier, Chandra Madramootoo, Nissar Memon, Bernhard von Hoyningan-Huene, France Papineau, Massoud Soultani, Stephen Broughton, Philippe Drouet, Etienne Perraton,

Yvonne Galganov, Vincent Lalonde, Natasha Huyberechts, Richard Tait, Pierre Bournival, Pierre Roy, Gilles Laverdure, Dominique Nsengiyumva, Catherine Senecal, Daniel Abraha, Benoit Lamarche and Sandra Ibarra.

VI. REFERENCES

Belcher, H.W. and F.M. D'Itri, editors of Subirrigation and Controlled Drainage, Proceedings of a conference at Michigan State University, 1991. Published as a book by Lewis Publishers, 1994. IBSN 1-56670-139-2

Broughton, R.S., F. Papineau, S.R. Broughton and R. Beaulieu, 1990. Some Guidelines for the Design of Water Control Structures on Drainage Water Courses, a paper presented to The Ontario Drainage Engineers Conference, University of Guelph, 19 October 1990.

Broughton, R.S., Y. Galganov, F. Papineau, and S. Ami, 1991. Special considerations for installing drain pipes and subsurface irrigation pipes in soils with layers of sand and layers of silt or clay, presented at the Ontario Farm Drainage Association Annual Meeting, Lamplighter Hotel, London, Ontario, 30 January 1991.

Broughton, R.S, F. Papineau and E. McKyes, 1991. Special considerations for installing drain pipes in soft, or sensitive, clay soils. Presented at the OFDA Annual Meeting, Lamplighter Hotel, London, Ontario, 30 January 1991.

Broughton, R.S. and J.L. Fouss, 1999. Subsurface Drainage Installation Machinery and Methods, Chapter 30 of Agricultural Drainage, American Society of Agronomy Monograph 38, ISBN: 0-89118-141-5.

Hunter and Associates, 2008. CONSERVATION DRAINAGE Controlled Drainage / Subirrigation (CDSI) Background Report and Design Guide, Presented at the Land Improvement Contractors of Ontario Annual Meeting, London, Ontario, January 2008.

Nsengiyumva, D, F. Papineau and R.S. Broughton, 1996, Use of grassed basins to filter river water for subsurface irrigation: system design, construction and performance. Can. Water Res. J. Vol. 21, No. 2, pp 109-120.

Rashid-Noah, A.B., R.S. Broughton and B. von Hoyningen-Huene, 1987. Droughtiness in sandy soils affected by depth of subsurface drains, pages D-43 to D-56 of the Proceedings of the Third International Workshop on Land Drainage, Ohio State University, Department of Agricultural Engineering, Columbus, Ohio, U.S.A., December 7-11, 1987.

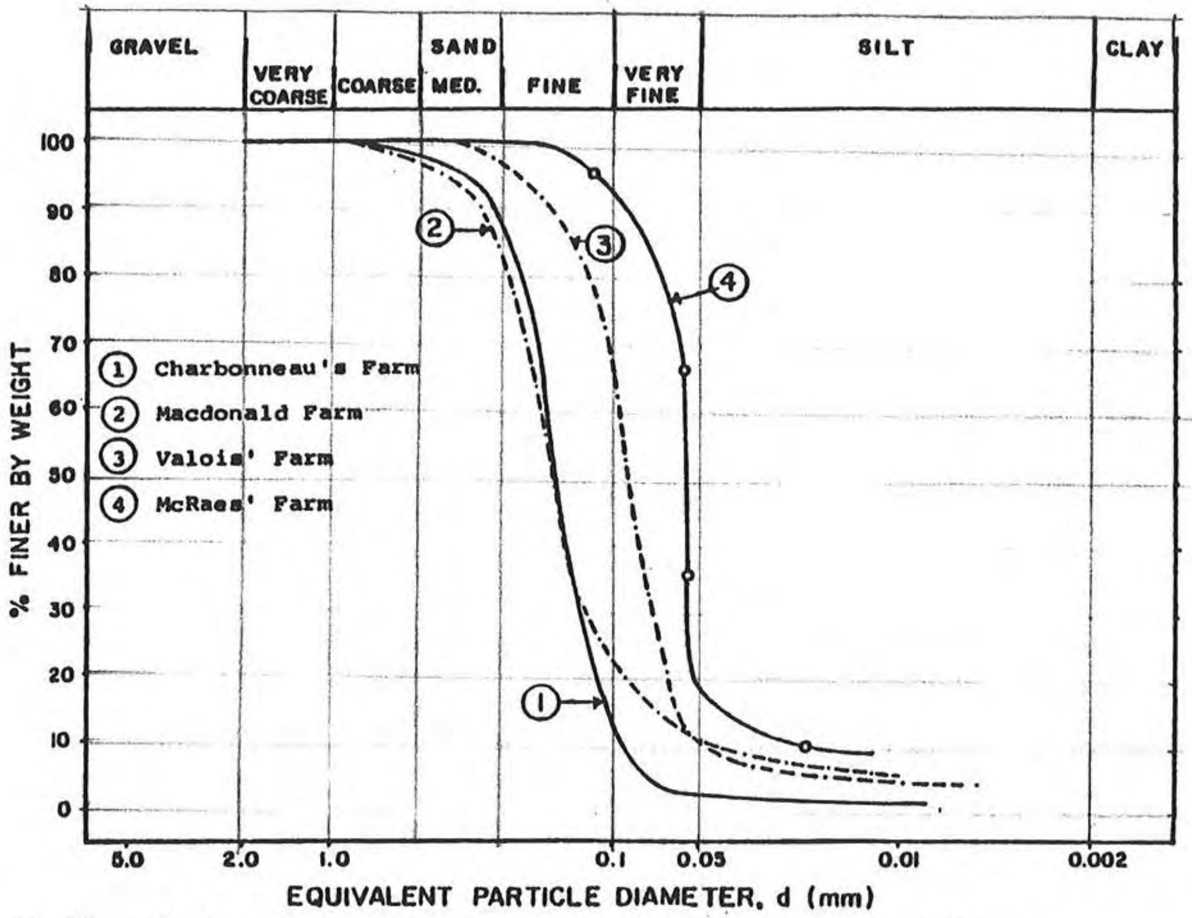


Figure 1. Particle size distributions of soils at 34 to 45 cm depth for 4 farms.

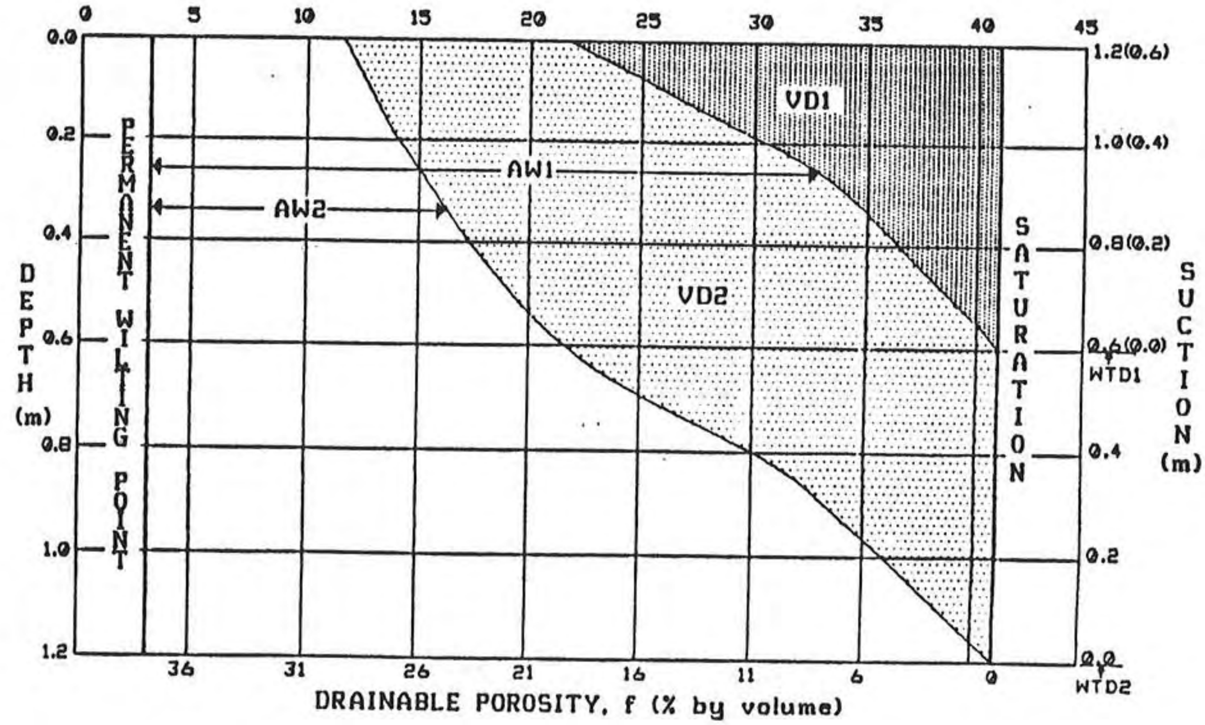


Figure 2: Soil moisture characteristics for a soil sample from Charbonneau's farm.

Refer to paper by Rashid-Noah et al (1987) for a full description of measurements relating to figures 1, 2 and 3.

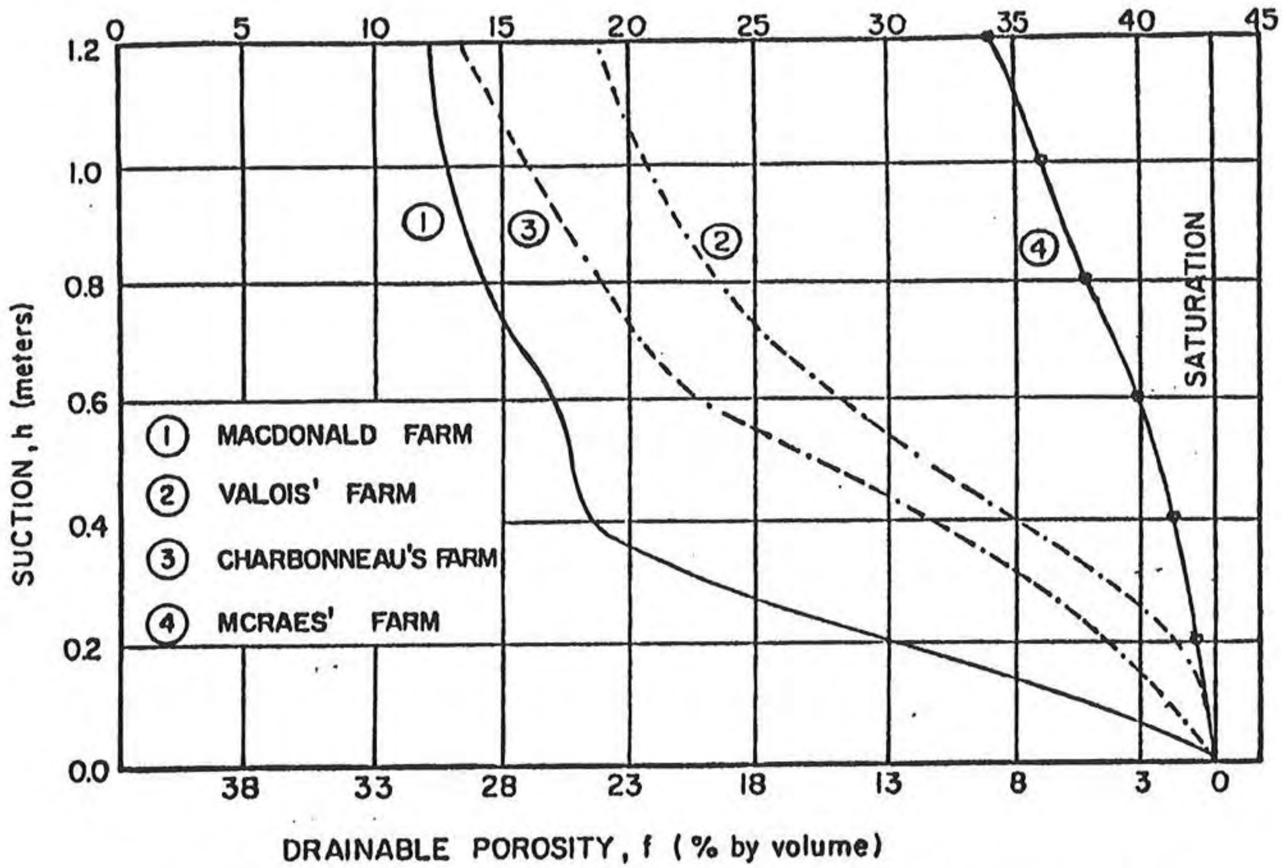
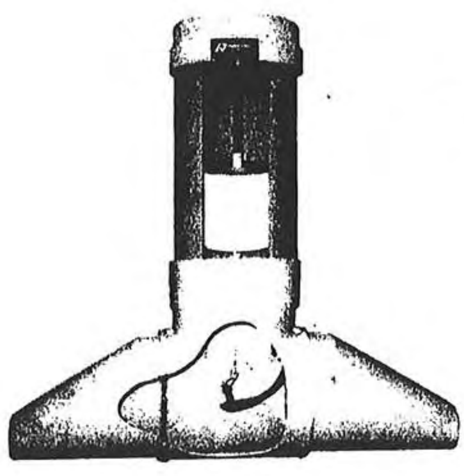


Figure 3: Mean values of drainable porosity vs. suction for all for all core samples obtained from each of the four farms.



Innotag Inc.

DCS Drainage Control System

The DCS is manufactured to be connected on 100 mm to 250 mm subsurface drainage collectors. The DCS improves your field management by:

- Increasing your yield at a minimal investment
- Reducing excessive drainage
- Reducing leaching of agro-chemicals from your soil
- Taking advantage of your soil's moisture holding capacity to maximize the storage of precipitation water

Don't drain your dollars down the ditch; take advantage of your soil's water holding capacity!

Figure 4: Cut-away view of a water level control system manufactured by Innotag Inc. of 1661 Boul. de L'Industrie, Beloil, QC J3G 4S5 Canada. Phone (450) 464-7427. More than five thousand of these units have been installed on farms in Quebec and Ontario since 1986. The height of the float and the riser pipe is adjustable. The tapered entrance and exit sections get cut by the installer to fit to the size of pipe being used. At least 20 feet of non-perforated pipe is used on the upstream side. The downstream side may be connected directly to an outlet pipe, or in-line on a drain collector. A special handle is provided to easily remove and reinstall the float and flap valve.

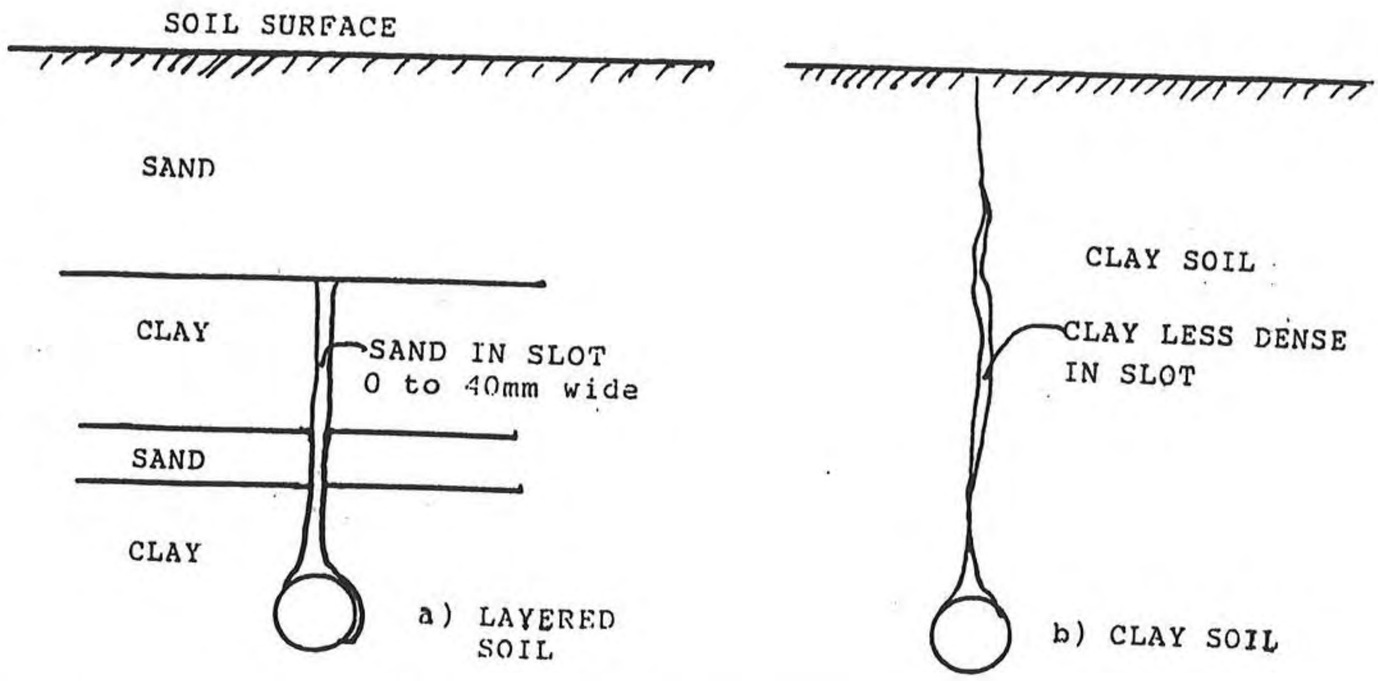


Figure 5. 100 mm (4-inch) nominal diameter drain pipes installed with a plow with normal blade and tubing box for 100 mm diameter pipes.

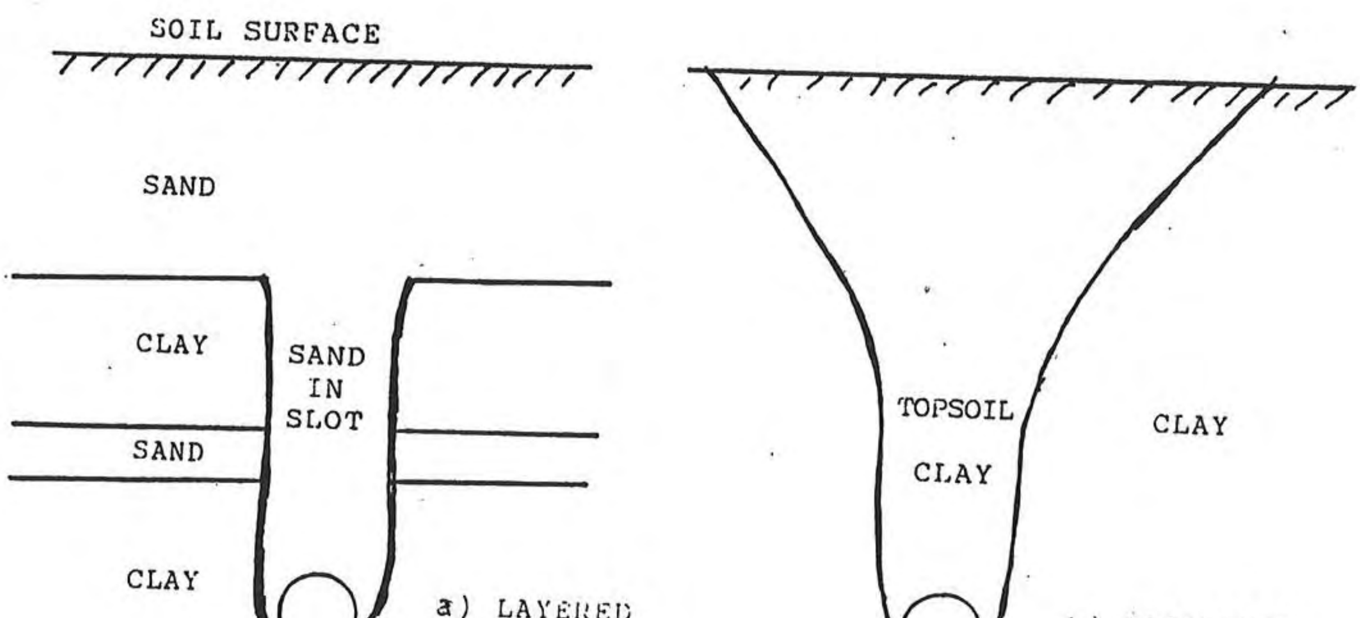


Figure 6. 100mm (4-inch) nominal diameter drain pipe installed with a plow with a 12-inch wide flat blade and a pipe box for 6, 4 and 3-inch pipe, plus a 4-ft high steel plate shield extending to the rear on one side of the pipe box.

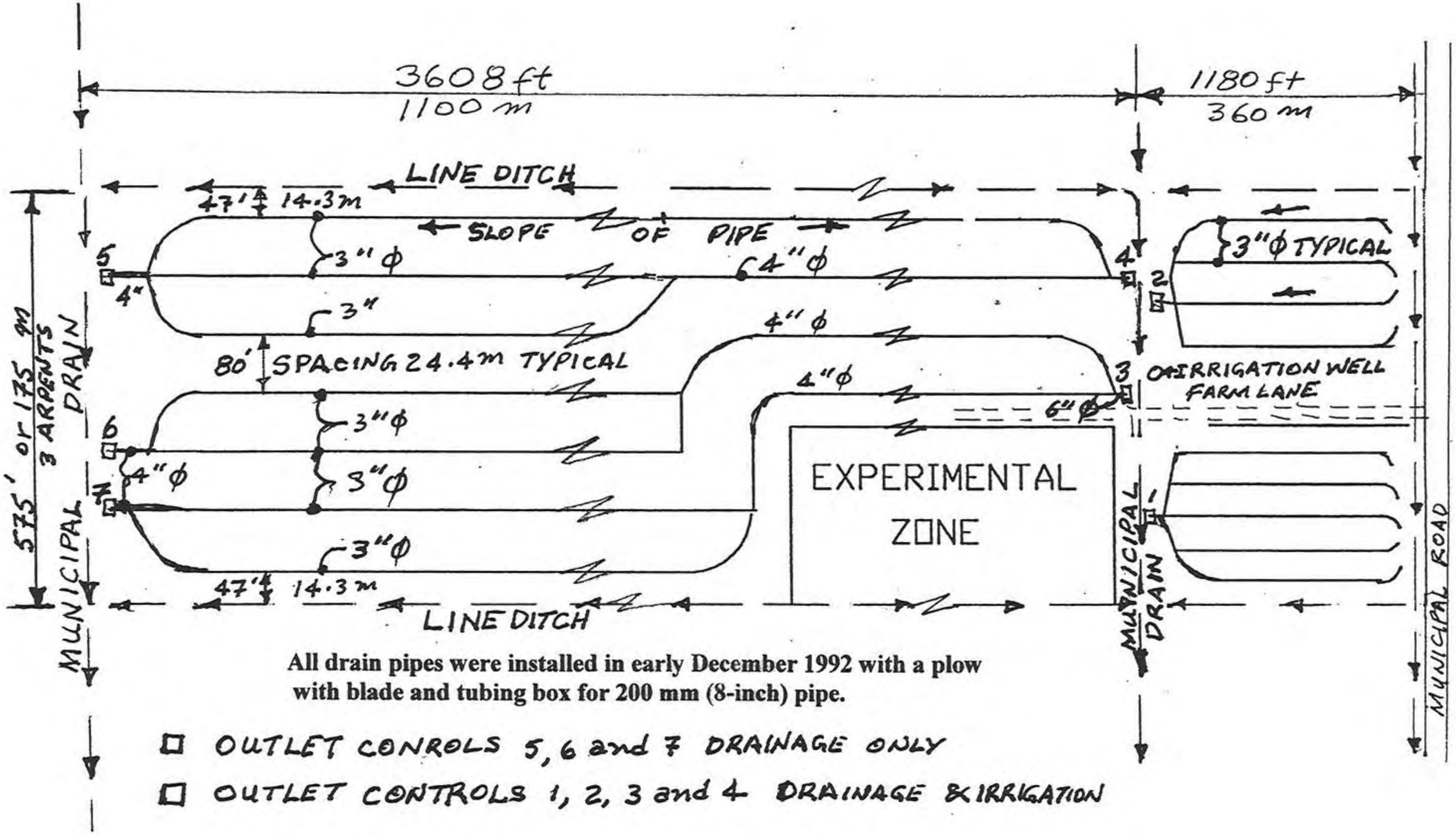
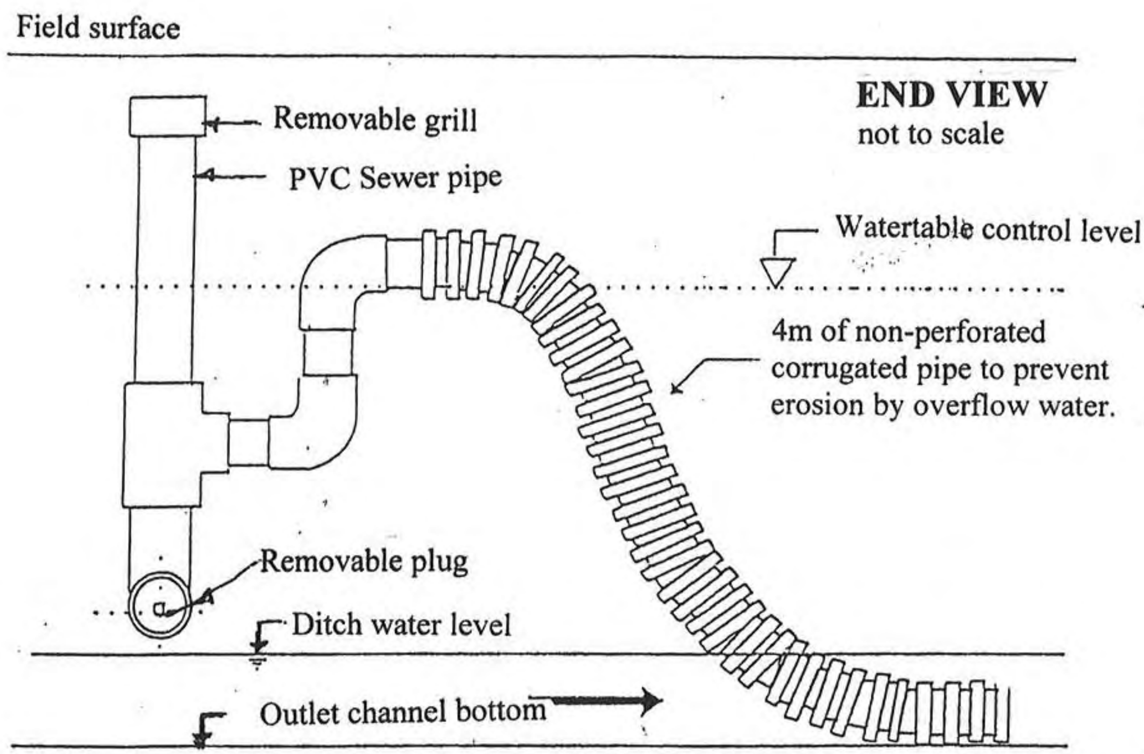
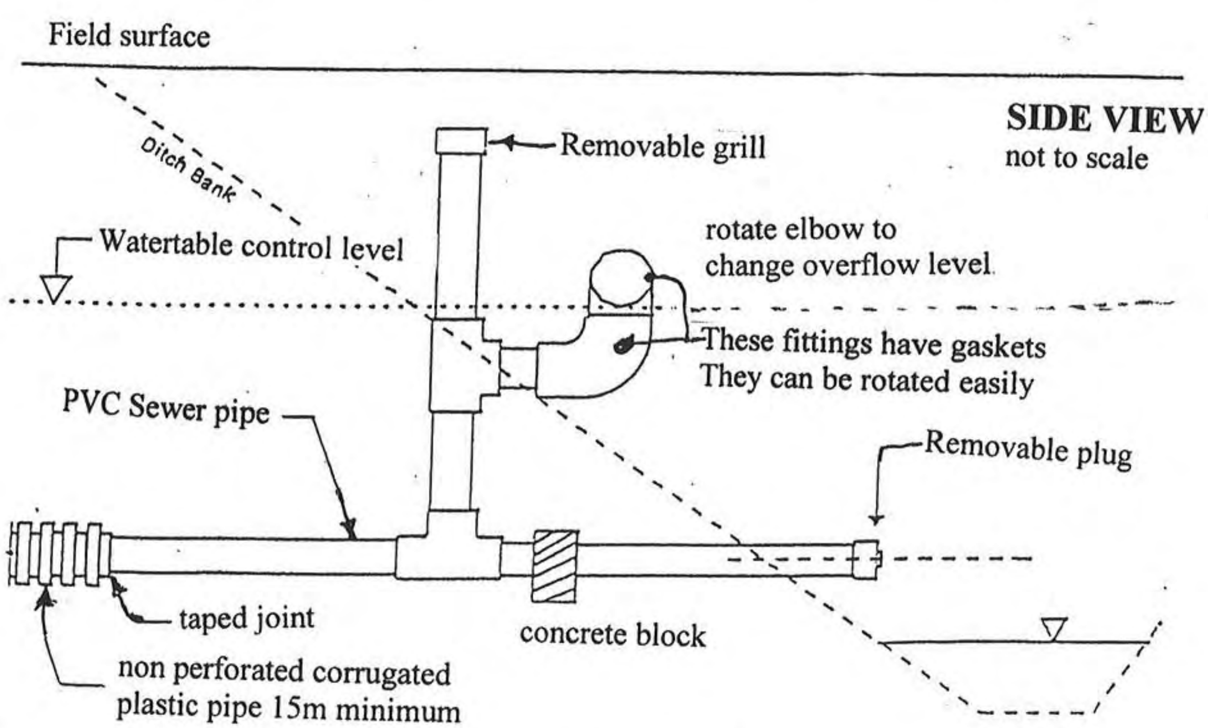


Figure 7. **SKETCH of COMBINATION SUBSURFACE DRAINAGE and IRRIGATION SYSTEM for 25 hectares of VINCENT FARM SOULANGES COUNTY, QUEBEC, CANADA.**

Figure 8. WATERTABLE CONTROL ADJUSTABLE OUTLET





TEXTURAL CLASSIFICATION

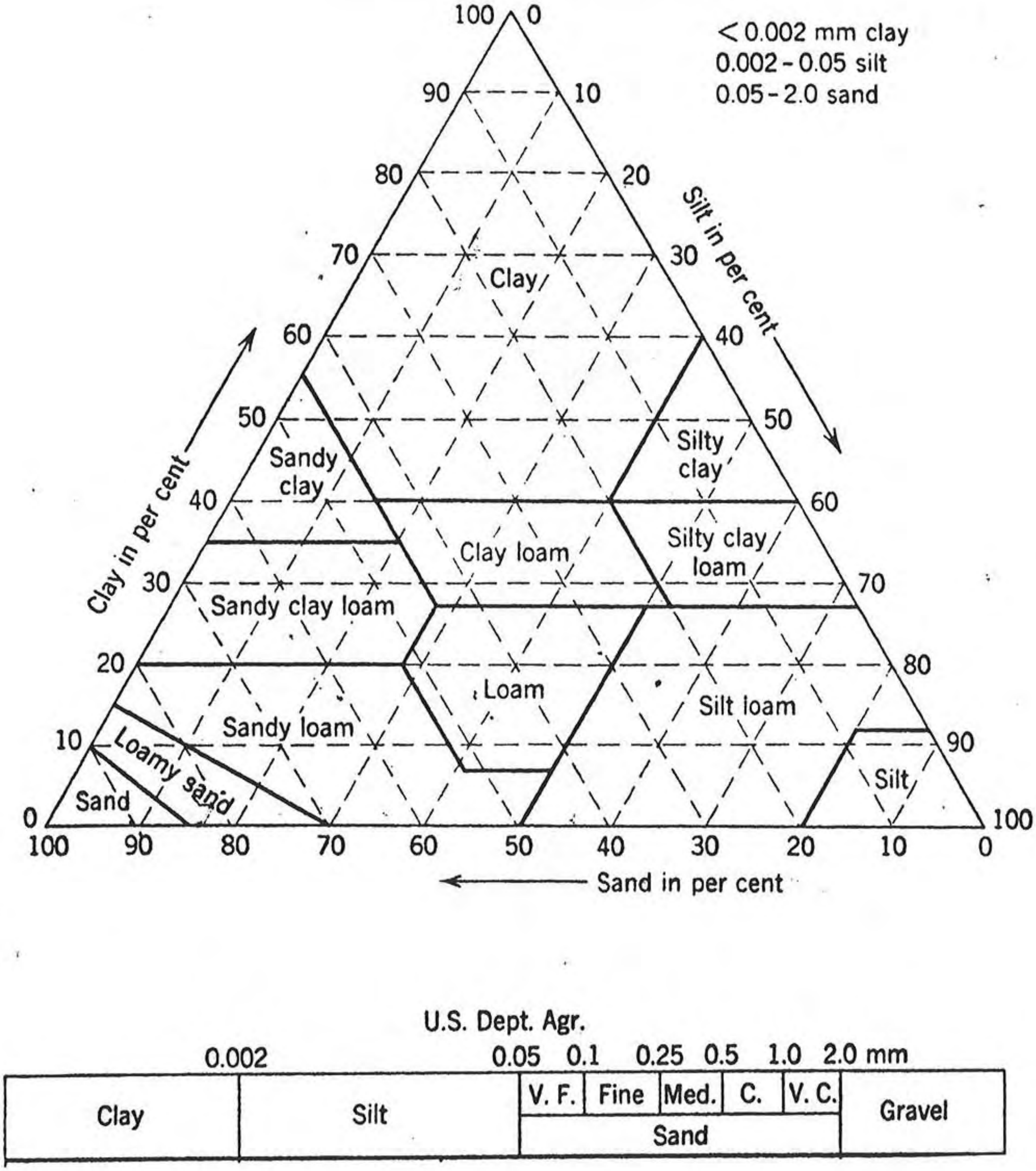
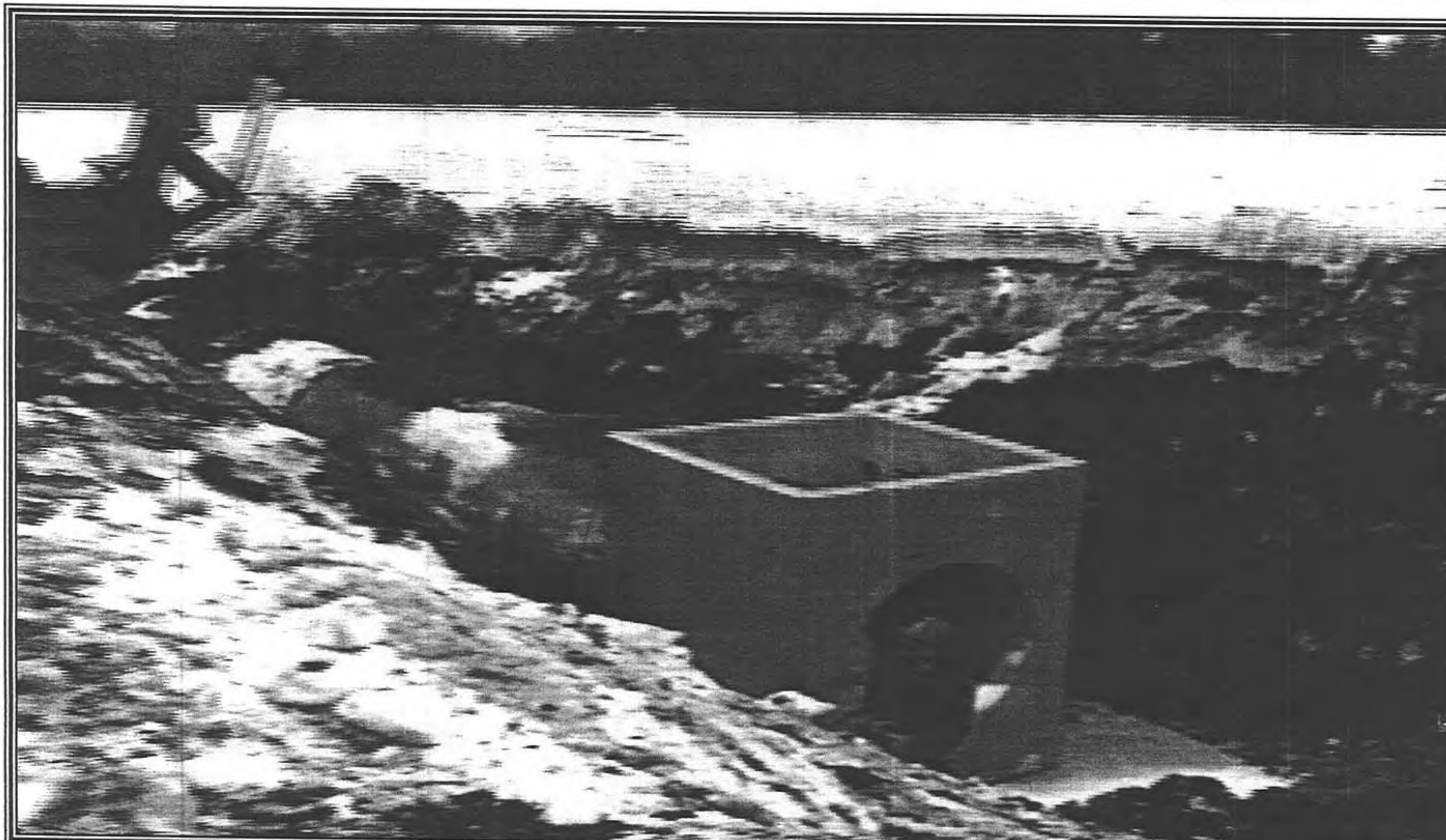


Figure 9. U.S.D.A. Soil particle size limits and textural classification chart.

Water Control Structure – Quebec – 1990's

J.F.-11/2003

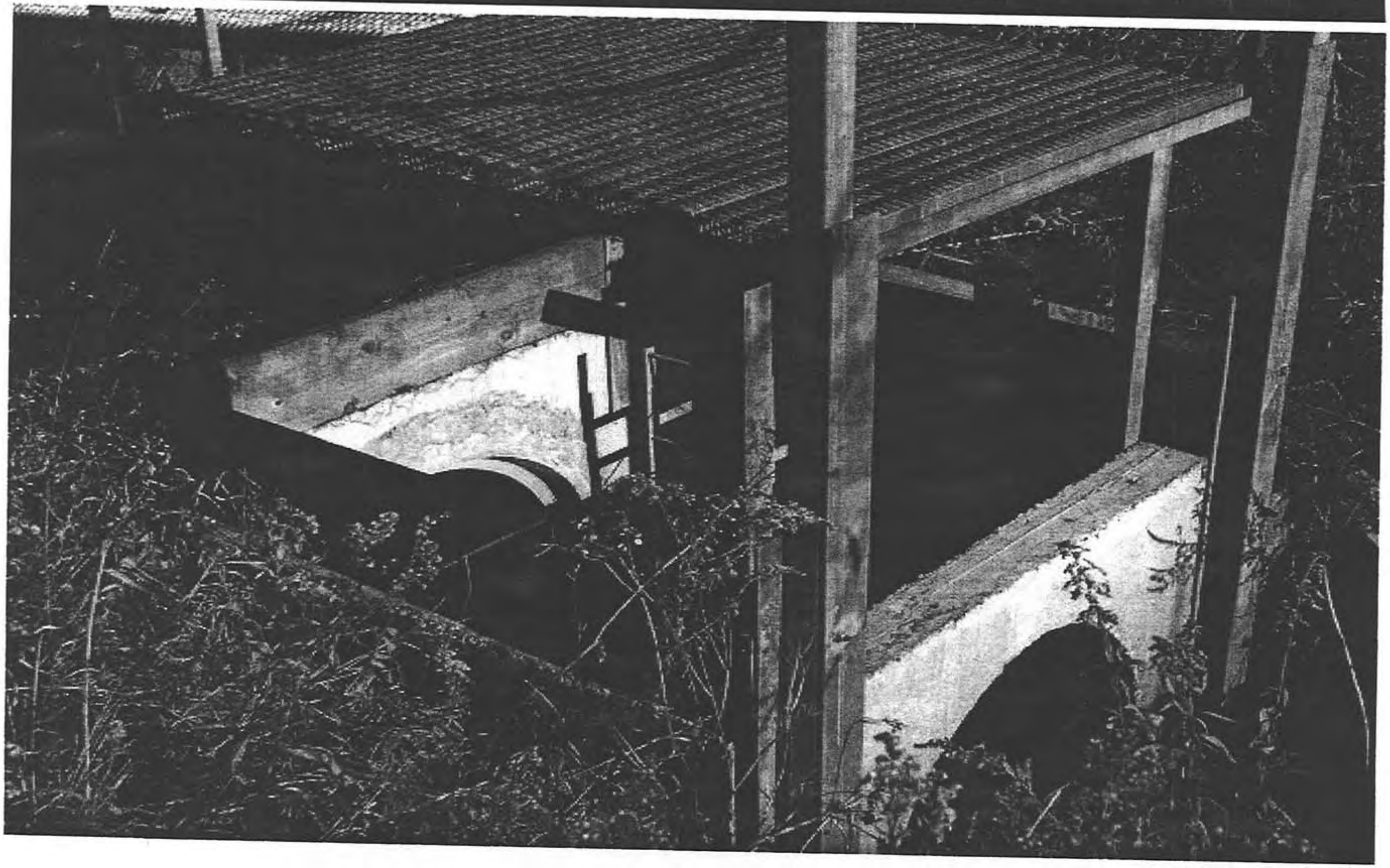
Small barrage under construction



J.F.-11/2003

Agriculture, Pêcheries et Alimentation Québec

Intake Open For Winter



Leandre Charbonneau and Bob Broughton in a field of subirrigated soybeans, 1989.

Greg Bostock and Drainage Richelieu trencher operator installing polyethylene pipe to retrofit a Charbonneau tile drainage system for Controlled Drainage and Subirrigation in 1982.

Dr. Dominique Nsengiyumva and Saif-Ur-Rehman in one of the vegetated basins used to filter water from the Yamaska River for subsurface irrigation on the Brouillard Family Farm, Massueville, Richelieu County, Quebec.

Natasha Huyberechts and Engineer France Papineau making measurements on a pipe laying plow with a 12-inch wide flat blade used for placing 4-inch drain pipes in soft clay soils. Note the steel plate added to one side of the pipe box to divide the heaved soil and allow pervious crumbly soil to fall over the pipe.

Leandre Charbonneau

lifting a flashboard

A water level control structure on a municipal watercourse near St-Robert, Richelieu County, Quebec. Flashboards are added and removed on front and sides to adjust the water level.