SOUTH SASKATCHEWAN RIVER BASIN

IRRIGATION
in the 21st Century

Volume 3:
Conveyance Water Management

SOUTH SASKATCHEWAN RIVER BASIN
IRRIGATION IN THE 21ST CENTURY

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South Saskatchewan River Basin Irrigation in the 21st Century

Volume 3:
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Volume 3 Conveyance Water Management

I. Seepage losses from irrigation canals in southern Alberta

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ABSTRACT

A study was conducted to estimate seepage losses from unlined irrigation canals in the 13 irrigation districts in southern Alberta. The ponding method for measuring the rate of seepage from canals was used to determine seepage losses at 29 sites in the irrigation districts. This method used poly-lined earth plugs at both ends of 150-m long straight canal segments. These reaches were filled with water to their operational depth, and the drop of water from full supply level to 80% of the design depth was recorded. Water levels were adjusted for rainfall and evaporation with nearby weather-station data and with pan evaporation data measured on-site. Seepage rates from each reach were grouped into one of three soil textural classes: coarse, medium, or fine. Attempts were made to get a broad range of soils; however, most soils were in the medium textural class, by far the dominant soil texture group in southern Alberta. Using the measured seepage rates, seepage curves based on canal capacity were developed to estimate the seepage rate per canal segment. Total seepage within each irrigation district was then determined using the seepage curves. The annual seepage within the irrigation districts in 1999 was about 89,800 dam^3 of water, or 2.5% of the proposed licence in the 1991 regulation. Annual seepage volumes in 1999 that included losses from headworks canals were estimated as 94,900 dam^3, or 2.6% of the proposed total licensed allocation. Canal rehabilitation has played a significant role in reducing seepage in conveyance works, making seepage losses a negligible factor in canal operations.

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INTRODUCTION

Background

The Government of Alberta established irrigation water allocations for the irrigation districts in 1991 through an Order-in-Council called the South Saskatchewan River Basin Water Allocation Regulation (Alberta Environment 1991). These water allocations were to be reviewed by Alberta Environment in 2000. One component in the 1991 regulation was canal losses (evaporation and seepage), which were estimated as 15 percent of the proposed total licensed allocation (Alberta Environment 1991). The irrigation industry, in partnership with the federal and provincial government, started a study in 1996 to obtain more accurate information on various components of water management in the irrigation districts within the South Saskatchewan River Basin of southern Alberta. Determination of seepage losses was one of the key components investigated.

Seepage in irrigated agriculture has been defined as the movement of water in or out of earthen irrigation canals through pores in the bed and bank material. There are many factors that affect seepage from canals (Worstell 1976): texture of the soil in the canal bed and banks; water temperature changes; siltation conditions; bank storage changes; soil chemicals; water velocity; microbiological activity; irrigation of adjacent fields; and water table fluctuations. Proper design and construction of conveyance systems are necessary to minimize seepage, due to the limited available water supply and ever increasing demand for water. Seepage is not only a waste of water, but may also lead to other problems, such as waterlogging and salinization of agricultural land.

Seepage measurements

Seepage from canals occurs due to a combined effect of gravitational force and water tension gradients (Hansen et al. 1980). When the water is first turned into a dry canal, the force of water tension is usually greater than that of gravity, but as the soil approaches saturation, these forces reverse in importance. This high initial loss rate soon decreases and is governed mainly by the percolation of water through the voids in the soil forming the canal bed and banks, and seepage rates eventually stabilize.

The key factor affecting seepage is the depth of water in the canal. If the groundwater level is above the design water surface of the canal, water will seep into the canal. On the other hand, if the groundwater level is below the water surface of the canal, water in the canal will continue to seep out of the canal until the groundwater level reaches equilibrium with the canal.

Methods for measuring the rate of seepage from canals include: two inflow-outflow methods (seasonal estimates based on diversion and delivery volumes for the district or actual measurements on specified reaches); the ponding method; and the seepage meter method (Worstell 1976). The ponding method is considered the most accurate (Brockway and Worstell 1968; Linsley and Franzini 1979; Hansen et al. 1980). This method involves construction of poly-lined earth plugs at both ends of the canal test reach. The reach is filled with water to its operational depth, and the drop in water level is recorded for several days. The seepage rate is adjusted for rainfall and evaporation. This method provides accurate, in-situ measurements of seepage in existing canals. The drawbacks to the method are many, as seepage determinations are measurement-based and do not attempt to analyze many of the factors mentioned earlier. The largest drawback seems to be that measurements reflect test reaches containing stagnant rather than flowing water (FAO 1977). Canals in coarse-textured soils have a tendency to have higher seepage rates than canals in fine-textured soils. If no water source is nearby to refill the canal, then the water level recording period is very short. Wind can adversely affect water elevation readings due to waves. Evaporation and rainfall data should also be measured so changes in water levels in the test reach can be corrected for these variables (Imperial Irrigation District 1992).

Objectives

The objectives of this seepage study were: (1) to determine unit seepage rates for fine-, medium-, and coarse-textured soils based on results from ponding tests on various sizes of unlined irrigation canals under a variety of soil conditions; (2) to determine the total length and size of canals in each of the three soil textural categories within each irrigation district; and (3) to estimate the total volume of seepage in the 13 irrigation districts.

MATERIALS AND METHODS

Site selection

Canal test reaches for measuring seepage losses were located in areas of different soil texture within 11 irrigation districts (Fig. 1). All canals selected were originally built in the 1950s. The capacity of these canals ranged from 0.42 to 8.49 $m^3 s^{-1}$. A total of 29 tests were conducted from 1996 to 1999.

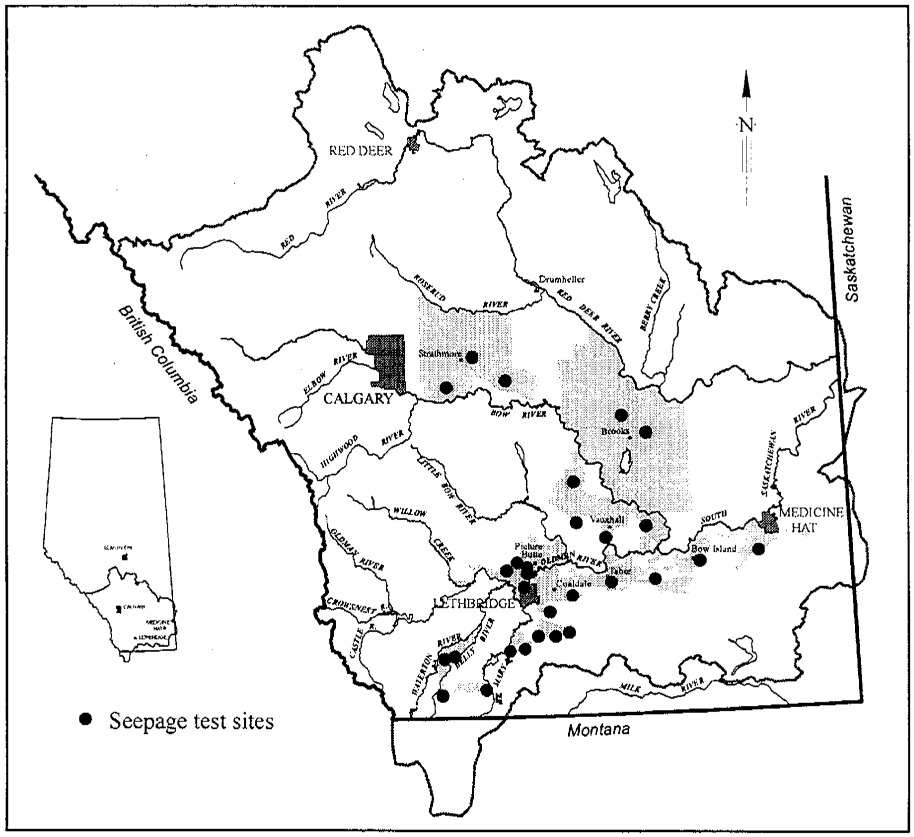


Fig. 1. Seepage test sites.

Ponding tests

Each 150-m long canal test section was constructed in an existing canal using poly-lined, water tight earth plugs at both ends of the test reach. Three to five canal cross-sections were surveyed with a hand level at a minimum of six points along the cross section, and an average cross section was determined. A datalogger, an air temperature probe, and a rain gauge were installed within a 0.45-m diam. polyvinyl chloride (PVC) stilling well in the middle of the test reach to record water levels, air temperature, and precipitation, respectively. Water levels were measured with a 5-volt potentiometer connected to a float, notched-pulley and beaded-cable system in the well. Voltages measured by the potentiometer were calibrated to detect 1 mm changes in water level. A Class A evaporation pan was also installed at each site. Evaporation data were adjusted using evaporation data from Agriculture and Agri-Food Canada.

The test reach was filled with water to the full supply level at the commencement of each test. Tests were conducted during the last two weeks of October after water in the conveyance system had been shut off, or during the first two weeks of May before water was released into the delivery system. Seepage rates from canals are normally measured with water levels held constant at their design depths. However, a constant water level was impossible to maintain for this study, because water was not available from the irrigation districts in the early spring or late fall. Water levels were measured every half hour under falling head conditions for 3 to 18 days, depending on the site. Because the depth of water in the canal is such an important factor, seepage rates for all test reaches were computed when the depth of water in the canal was dropping from full supply level to 80% of the design depth. Approximately 45% of the flow capacity occurs in the top 20% of canal depth in a trapezoidal canal under normal flow conditions (J. Ganesh, Irrigation Engineer, Irrigation Branch, Lethbridge, Alberta, pers. comm.). Most irrigation canals are maintained relatively full during the irrigation period. Mean daily seepage rates were then calculated for each reach based on the number of days of the test. The seepage rate from each test reach was calculated for each 24-h period using the following equation (Rasmussen and Lauritzen 1953) (Fig. 2):

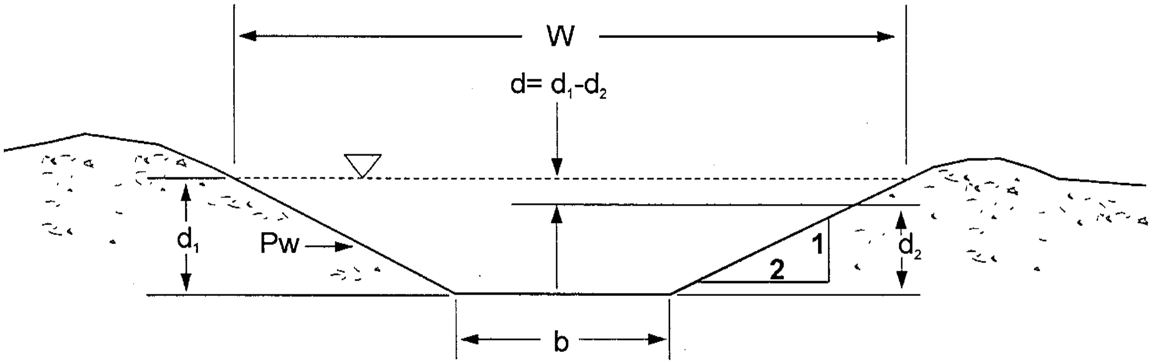


Fig. 2. Canal cross section showing seepage-related lengths.

$$S = \frac{W \times L\,(d_1 - d_2)}{P_w \times L} \qquad (1)$$

Where: S = seepage rate, $m^3\ m^{-2}\ day^{-1}$
W = $b + 2\,(z\,d_2)$ = water surface for depth d_2, m
b = bed width, m
z = side slope (vertical:horizontal), $m\ m^{-1}$

L = length of test reach, m
d_1 = initial water depth, m
d_2 = depth of water at end of 24 h, m
d = $d_1 - d_2$ = drop in water surface in 24 h, m
$P_w = b + 2\, d_2 \sqrt{1 + z^2}$ = wetted perimeter, m

The surface area of the test reach (W) was calculated daily using the average canal cross-section.

Soil characterization and grouping

Five to six holes, approximately 6-m deep, were bored with an auger using a mobile drill on top of the ditch bank adjacent to each canal test reach. The holes were bored about 30 m apart on one side of the test reach. Soil texture determined by hand texturing was categorized according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987). Each site was put into one of three soil textural categories - coarse, medium, or fine: coarse = sandy loam (SL), fine sandy loam (fSL), sand (S), and loamy sand (LS); medium = loam (L), silt loam (SiL), very fine sandy loam (vfSL), sandy clay loam (SCL), clay loam (CL), and silty clay loam (SiCL); and fine = clay (C), silty clay (SiC), sandy clay (SC), and heavy clay (HC). The Agricultural Region of Alberta Soil Inventory Database (AGRASID) (CAESA 1998), supplemented with unpublished data, was used to group the soil texture of the parent material (PM) for soils in each soil map unit within the irrigation districts of southern Alberta. Parent material texture, as defined by AGRASID, was grouped into one of the three textural categories - fine, medium, and coarse. Layered materials, where the textural change occurred between 0.3 m and 1.0 m, were placed into one of the three categories based on the texture of the underlying material. For example, gravel or gravelly coarse material over medium- or fine-textured till was placed into the medium-textured category. When bedrock was the underlying material, the texture of the upper material was used to place the PM into one of the three textural categories.

Each polygon or soil map unit is made up of one or more soil series. Each soil series occupies a percentage of the area within the polygon. Soils that were undifferentiated were assumed to be medium-textured, except those within polygons where fine- or coarse-textured soils were dominant. The undifferentiated soils within a dominantly fine-textured polygon were given a fine rating, and undifferentiated soils within dominantly coarse-textured polygons were given a coarse rating. A coarse, medium, or fine texture rating was assigned to each soil series. The total percentage of coarse-, medium-, and fine-textured soils in each AGRASID polygon was subsequently used to estimate the seepage rate for each length of unlined canal within each AGRASID polygon.

Irrigation district seepage estimates

Seepage rate as a function of canal capacity curves were generated from the seepage rates and from typical canal cross-section measurements (Table 1). Canals were grouped by canal capacity, standard bed width/depth of flow (b/d_2) ratios, side-slopes, and operating depths found in Alberta (Alberta Agriculture 1987). Canal capacities were arbitrarily selected to reflect canal systems in southern Alberta, wherein the majority of canal capacities are less than 14 $m^3\ s^{-1}$. The water contact area ($m^2\ km^{-1}$) was multiplied by the low, medium, and high seepage rates to develop three curves. The resulting curves produced seepage rates in $m^3\ s^{-1}\ km^{-1}$ of canal.

Table 1. Typical canal characteristics used for seepage calculations^z.

Canal characteristics						
(Q) Canal capacity (m^3 s^{-1})	(b) Bed width (m)	(d_2) Water depth (m)	(P_w) Wetted perimeter (m)	(z) Side slope (ratio)	Bed width/ depth (ratio)	Water contact area (m^2 km^{-1})
0.30	0.8	0.35	2.37	1:2	2.3	2,365
0.58	1.0	0.50	3.24	1:2	2.0	3,236
1.44	1.5	0.75	4.85	1:2	2.0	4,854
3.02	2.5	1.05	7.20	1:2	2.4	7,196
5.60	4.0	1.45	10.48	1:2	2.8	10,485
13.90	6.0	2.40	16.73	1:2	2.5	16,733
28.16	10.0	2.85	22.75	1:2	3.5	22,746
43.05	13.0	3.20	27.31	1:2	4.1	27,311
55.59	15.0	3.45	30.43	1:2	4.3	30,429

^{z}Where $P_w = b + 2\,d_2\sqrt{1+z^2}$

Spatial queries were performed using a Geographic Information System (GIS) by intersecting canal line work with soil texture polygons from AGRASID (Fig. 3). Canals in the database were segmented at any lateral turnout, as well as at stations where there was a change in flow, type of construction or rehabilitation. The spatial query then intersected these canal segments and the new length of each sub-segment was determined, keeping the capacity and construction information intact.

The seepage curves were then applied depending on the soil groupings encountered. The total seepage in m^3 s^{-1} was determined by multiplying the corresponding seepage rate (m^3 s^{-1} km^{-1}) by the length of segment. Seepage rates were weighted according to the percent of fine-, medium-, and coarse-textured soils in each polygon. The canal segments were then summarized to their original lengths, with seepage values being summed. The seepage volume for the 154-day irrigation season was subsequently calculated.

The Irrigation District Model (IDM) (Baker et al. 1999) was used to determine seepage along each canal segment and to estimate the total volume of seepage within each irrigation district. The model assumes that all canals, if in use, are “checked up,” meaning that the water is always near the full supply level as long as there is flow in the canal.

The seepage curves were applied to all unlined earthen canal reaches using the IDM. All rehabilitated canals with membrane liners, along with PVC or concrete pipelines, were assumed to have zero seepage rates. If the canal was rehabilitated using an earth liner, then the “low” seepage rate was applied, representing the fine-textured soils normally used in the construction.

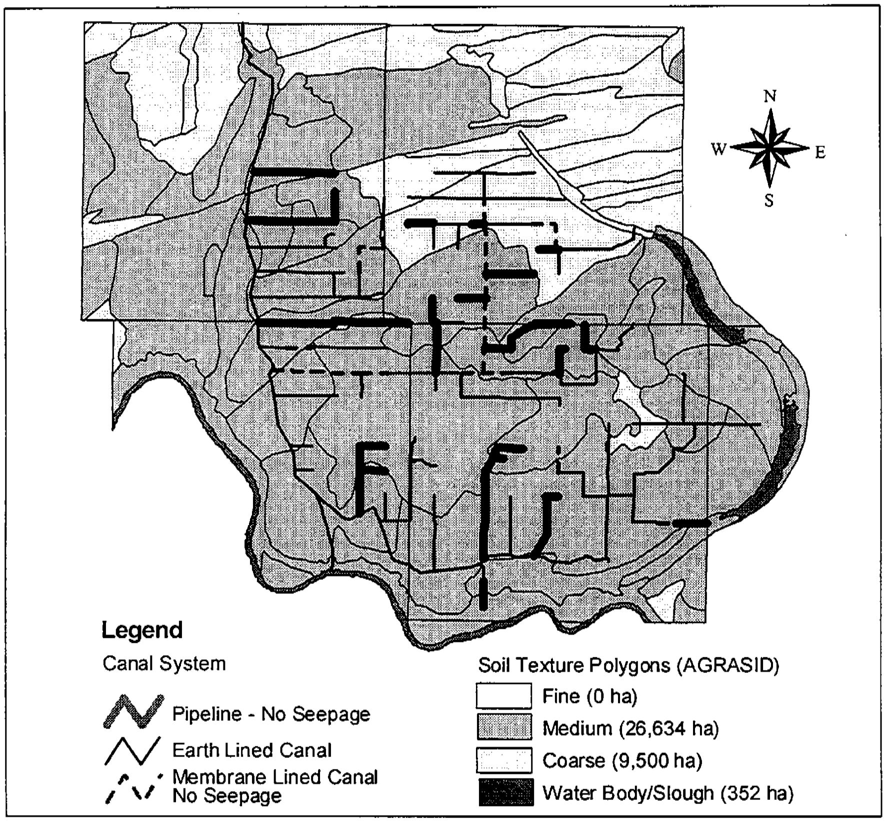


Fig. 3. **Soil texture polygons overlain on irrigation canals in the Rolling Hills block, Eastern Irrigation District.**

RESULTS AND DISCUSSION

Soil texture and seepage rates

According to AGRASID data, medium-textured soils are dominant in southern Alberta. About 78% of the soils in the southern portion of the province are medium-textured, 16% are coarse-textured, and 6% are fine-textured. Twenty-one of the 29 ponding tests were conducted in medium-textured soils, five were completed in fine-textured soils, and three were carried out in coarse-textured soils (Table 2).

Seepage test data from sites 14 and 25 were discarded due to significant site anomalies. Data from site 14 were discarded because a natural gas pipeline was present under the test reach that may have accounted for the high seepage rate in the fine-textured soils at this site. Site 25 data were not used because it was the only site lined with concrete, and the concrete was moderately cracked. Canals at all other test sites were unlined earth canals.

Table 2. Mean seepage rates and soil texture at each ponding test site.

Site No.	District [y]	Test date	Predominant soil texture	Number of Observations	Mean evaporation ($mm\ day^{-1}$)	Mean seepage rate x 10^{-3} [x] ($m^3\ m^{-2}\ day^{-1}$)	Seepage Rate [w] (%)
Fine							
14[z]	RID	Oct. '98	C-SiC	--	--	--	--
15	SMRID	May '98	SC	6	7.0 (0.1)	19.5 (2.0)	3.4
19	SMRID	Oct. '97	CL-SiCL	18	2.8 (0.2)	4.3 (0.5)	0.6
22	UID	May '99	C-SiC	13	5.0 (0.3)	3.5 (0.8)	0.6
27	EID	Oct. '99	CL-C	17	3.3 (0.9)	4.8 (0.5)	0.9
				Mean (n = 4)	4.5 (0.9)	8.0 (3.8)	1.4
Medium							
1	AID	Nov. '98	CL	11	2.8 (0.3)	9.1 (1.0)	1.8
2	BRID	May '99	SCL-CL	9	4.4 (0.6)	6.2 (1.4)	0.8
3	BRID	Oct. '97	CL-SCL	11	1.6 (0.1)	11.7 (0.8)	2.4
5[z]	EID	Oct. '97	CL-C/bdrk	--	--	--	--
6	LNID	May '97	SiCL	3	6.0 (0.1)	45.3 (6.4)	11.9
7	LNID	May '98	SCL	3	7.2 (0.3)	34.0 (1.8)	9.5
9	MID	Oct. '97	CL	5	5.0 (0.6)	19.0 (0.2)	3.9
10	MID	Oct. '98	SiCL-SiC	16	3.1 (0.3)	4.8 (0.3)	0.9
11	MVID	May '98	CL	10	5.4 (0.2)	7.3 (1.0)	1.5
12	RID	May '99	SiCL	7	4.2 (0.7)	17.1 (3.2)	2.8
13	RID	Oct. '97	CL-C	10	2.8 (0.4)	9.6 (0.6)	1.9
16	SMRID	May '99	CL-SCL/ bdrk	4	7.0 (0.0)	27.9 (2.3)	5.6
17	SMRID	Nov. '96	CL	10	4.1 (0.6)	5.4 (1.0)	1.4
18	SMRID	Nov. '96	CL-C	7	4.7 (0.2)	7.0 (0.7)	2.4
20	TID	May '97	CL	12	2.3 (0.6)	3.2 (0.5)	0.4
24	WID	Oct. '98	CL	11	1.9 (0.2)	15.2 (1.3)	2.5
25[z]	LNID	July '98	L-CL	--	--	--	--
26	WID	Oct. '99	CL-SCL	3	3.2 (0.0)	42.2 (0.9)	10.2
28	LNID	Oct. '99	CL-SiCL	4	5.4 (0.0)	21.3 (1.5)	5.9
29	BRID	Oct. '99	CL	6	2.2 (0.0)	21.4 (4.5)	4.5
					Mean (n = 18)	17.1 (2.9)	3.9
Coarse							
4	BRID	Oct. '98	SL-SCL	3	2.0 (0.0)	45.9 (3.1)	9.2
8	LNID	May '99	SCL-SL-S	5	4.4 (0.6)	131.2 (32.9)	18.7
21	UID	Apr. '98	SiCL-C/bdrk	3	5.8 (0.3)	45.5 (7.8)	9.2
23	WID	Oct. '97	SL-SCL	3	7.3 (0.0)	27.0 (3.5)	8.2
					Mean (n = 4)	62.4 (20.2)	11.3

[z] Sites 14 and 25 were not included due to significant site anomalies. Sites 5, 16 and 21 were not included due to shallow bedrock.

[y] Where AID=Aetna; BRID=Bow River; EID=Eastern; LNID=Lethbridge Northern; MID=Magrath; MVID=Mountain View; RID=Raymond; SMRID=St. Mary River; TID=Taber; UID=United; and WID=Western Irrigation Districts.

[x] Mean (standard error in parentheses).

[w] Average volume of water lost in a 24-h period over the total volume of water in the test section, as a percentage.

Data from site 5 were also discarded due to the shallow depth to bedrock. Drilling at site 5 found the bedrock to be mainly claystone, starting at about 2 m below the surface. Green and Copeland (1972) mapped the bedrock at site 5 as Oldman formation, consisting of sandstone, siltstone and mudstone. The depth of the canal at site 5 was about 2 m, putting the bottom of the canal at, or very near, the same depth as the bedrock.

The canal at site 16 was built in clay loam and sandy clay loam to sandy loam textured fill, fluvial-lacustrine, till, and bedrock material. Bedrock at site 16 was found as shallow as 0.5 m below the surface. Green and Copeland (1972) mapped site 16 as being of the Foremost formation, a nonmarine sandstone, siltstone, mudstone, and shale. Site 16 was put into the medium-textured group.

Bedrock at site 21 consisted of sandstone, claystone, and siltstone, as shallow as 1.5 m below the surface. Green and Copeland (1972) mapped the bedrock at site 21 as the St. Mary River formation, consisting of sandstone, siltstone, and mudstone. The depth of the canal at site 21 was approximately 1.5 m, putting the bottom of the canal at, or very near, the same depth as the bedrock. Site 21 was put in the coarse-textured group because of the high seepage rate. Bedrock was found at 3 m below the surface or deeper at the other 24 sites.

Seepage rates in the fine-textured soils varied from 3.5×10^{-3} to 19.5×10^{-3} m^3 m^{-2} day^{-1}, with a mean value of 8.0×10^{-3} m^3 m^{-2} day^{-1} (Table 2). The seepage rates for the medium-textured soils ranged from 3.2×10^{-3} to 45.3×10^{-3} m^3 m^{-2} day^{-1}, with a mean value of 17.1×10^{-3} m^3 m^{-2} day^{-1} (Table 2). The range in seepage rates for the medium-textured soils was not surprising due to: the broad range in soil texture for the medium-textured soils; the variable texture associated with lacustrine and fluvial deposits, wherein sand lenses may be present; and the dense nature and low permeability of medium-textured glacial till. Layers of sandy clay loam to sandy loam material may be the reason for the higher seepage rate at medium-textured site 6. The very fine sandy clay loam texture and layered nature of the lacustrine material at site 7 may partially explain the high seepage rate at the site.

Most of the soils in southern Alberta have developed in fine- to medium-textured glacial till that ranges in thickness from less than 1 m to more than 30 m (Pawluk and Bayrock 1969). Seepage rates in these fine- and medium-textured glacial till soils are about an order of magnitude lower than seepage rates determined elsewhere (Rasmussen and Lauritzen 1953; Worstell 1976; Linsley and Franzini 1979). Hendry (1982) reported that the bulk hydraulic conductivity of glacial till in southern Alberta ranges from about 0.43×10^{-3} to 17.3×10^{-3} m^3 m^{-2} day^{-1}. Trooien and Reichman (1990) observed similar mean hydraulic conductivity values of 2.13×10^{-3} to 15.4×10^{-3} m^3 m^{-2} day^{-1} in soil monoliths from North Dakota with slowly permeable glacial till below 1 m. Unit seepage rates for fine- and medium-textured soils examined in this study compare favorably to these hydraulic conductivity values.

The seepage rate for the coarse-textured sites ranged from 27.0×10^{-3} to 131.2×10^{-3} m^3 m^{-2} day^{-1}, with a mean value of 62.4×10^{-3} m^3 m^{-2} day^{-1} (Table 2). Soil texture ranged from sandy loam to sandy clay loam at sites 4 and 23, and from sandy clay loam to sand at site 8. Unit seepage rates for coarse-textured soils generally range from about 460×10^{-3} to 610×10^{-3} m^3 m^{-2} day^{-1} (Rasmussen and Lauritzen 1953; Worstell 1976; Linsley and Franzini 1979). Worstell (1976) indicated that mean unit seepage loss rates may be disproportionately high since seepage measurements are often made on canals where high loss rates are suspected. The unit seepage rates from ponding tests in southern Alberta may be disproportionately low since tests were conducted on canals recently scheduled for rehabilitation and the most leaky canals have already been rehabilitated.

Seepage in irrigation districts

Mean seepage rates for each soil textural grouping resulted in three distinct seepage curves for canals of different capacities (Fig. 4). The GIS analysis of canal characteristics in the irrigation districts indicated that approximately 5,000 km of canals have the potential to seep. Total annual seepage in 1999 was estimated as 89,800 dam^3 for all the districts combined, or 2.5% of the proposed total licensed allocation (Table 3). Inclusion of seepage values from headworks canals increased loss estimates to about 94,900 dam^3, or 2.6% of the proposed total licensed allocation.

Canal capacity ($m^3 s^{-1}$)	**Seepage rate (10^{-4} $m^3 s^{-1} km^{-1}$)**		
	Fine	**Medium**	**Coarse**
0.30	2.20	4.68	17.08
0.58	3.01	6.41	23.36
1.44	4.51	9.61	35.05
3.02	6.69	14.25	51.96
5.60	9.75	20.76	75.70
13.90	15.56	33.13	120.81
28.16	21.15	44.05	164.23
43.05	25.40	54.08	197.19
55.59	28.30	60.25	219.70

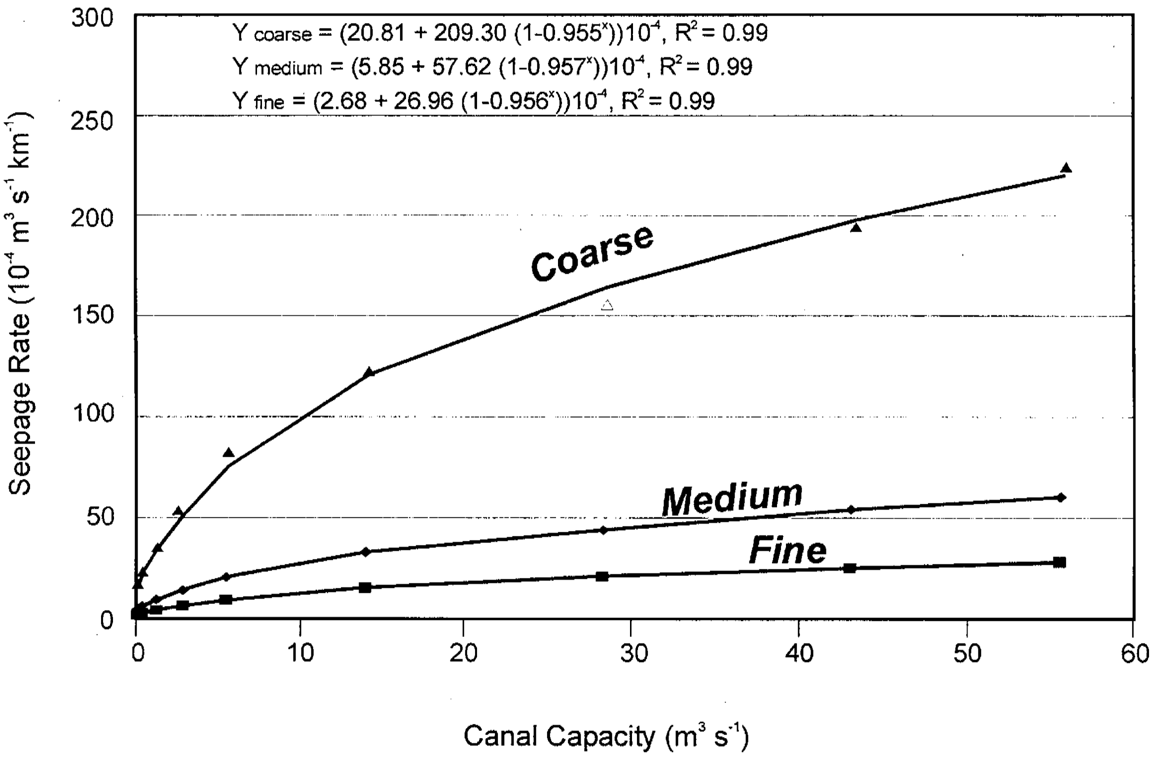


Fig. 4. Seepage curves for soil textural groups and various canal capacities.

Table 3. Estimated annual seepage volume associated with the irrigation districts in 1999.

Irrigation District[z]	Volume lost due to seepage[y] (dam^3)		Estimated length of canals that seep (km)		Proposed license in 1991 regulation (dam^3)	Seepage loss[x] (%)	
	District	Total[w]	District	Total[w]		District	Total[w]
AID	170	194	17	22	11,102	1.5	1.7
BRID	13,799	16,989	641	709	619,217	2.2	2.7
EID	23,672	23,672	1,242	1,242	918,958	2.6	2.6
LID	238	364	39	62	14,802	1.6	2.5
LNID	5,346	7,105	422	491	391,020	1.4	1.8
MID	491	521	62	95	41,939	1.2	1.2
MVID	224	228	26	27	9,868	2.3	2.3
RCID	116	120	18	18	3,701	3.1	3.2
RID	1,971	1,971	181	181	99,914	2.0	2.0
SMRID	18,084	18,084	1,003	1,003	890,587	2.0	2.0
TID	1,289	1,289	94	94	194,893	0.7	0.7
UID	1,111	1,111	173	173	83,878	1.3	1.3
WID	23,242	23,242	1,101	1,101	342,913	6.8	6.8
TOTAL	89,753	94,890	5,019	5,218	3,622,792	2.5	2.6

[z] Where AID=Aetna; BRID=Bow River; EID=Eastern; LID=Leavitt; LNID=Lethbridge Northern; MID=Magrath; MVID=Mountain View; RID=Raymond; RCID=Ross Creek; SMRID=St. Mary River; TID=Taber; UID=United; and WID=Western Irrigation Districts.

[Y] Total seepage volume within each district calculated using the AGRASID soil database and the attributes of canals. Seepage loss is based on 154 days of canal operation.

[X] Seepage loss, % = Volume of water lost due to seepage, dam^3 / District license proposed in the 1991 regulation, dam^3.

[W] Total = Seepage losses from irrigation district and headworks canals.

The Eastern Irrigation District, the second largest irrigation district in southern Alberta, has the highest district seepage at 23,672 dam^3; however, this represents only 2.6% of their proposed licensed allocation. The highest percent seepage to total licensed allocation was found in the Western Irrigation District (WID) at 6.8%. There are about 1,100 km of canal in the WID that seep in a variety of coarse- and medium-textured soils. Many of these canals have not been rehabilitated. Lower than expected values were observed in the Magrath Irrigation District and the three mountain districts (Aetna, Leavitt, and Mountain View), where canals were constructed on the contour in primarily medium-textured soils, some of which are overlying fractured bedrock. Further analysis with AGRASID is required to evaluate these soil conditions.

In 1991, the canal losses (seepage and evaporation) component of the South Saskatchewan allocation regulation was estimated as 15% of the proposed total licensed allocation (Alberta Environment 1991). This value was estimated based on soil information, canal seepage equations, and other water balance data available at the time. Unknown, however, was the rate at which many of the soils seeped in southern

Alberta. Net evaporation losses from irrigation district canals in 1999 have been estimated as 0.5% of the total licensed allocation (C. Vos, Irrigation Engineer, Irrigation Branch, Lethbridge, Alberta, pers. comm.).

Medium-textured soils comprise a large portion of the soils within the irrigation districts. These ponding tests have shown that canals in the fine- and medium-textured soils do not seep as much as originally thought. Canal rehabilitation has often targeted areas of high seepage within the irrigation districts. Canals constructed in coarse-textured soils, or in high seepage areas, have already been rehabilitated using a variety of modern materials, i.e., pipelines, earth liners, membrane liners, and other materials, making seepage a negligible factor. Nearly all small laterals (< 1.5 $m^3 s^{-1}$) rehabilitated in the last 15 years have been replaced with buried PVC pipe, eliminating the canals and any seepage.

SUMMARY AND CONCLUSIONS

Ponding tests were performed in 11 irrigation districts in southern Alberta to determine seepage rates in soils of different texture. Seepage rates were determined for three soil textural groups: fine-, medium-, and coarse-textured soils. These seepage rates were used to calculate the seepage rate per segment of canal for use in the Irrigation District Model. The AGRASID database, the primary source of soils information, was used in conjunction with a GIS and the Irrigation District Model to estimate the total volume of seepage within the irrigation districts. Results indicated that seepage volumes were significantly less than estimated earlier. Estimates made in 1991 indicated that about 15% of the proposed total licensed allocation was lost from irrigation district canals (seepage and evaporation), whereas the volume of water lost to seepage within the irrigation districts in 1999 was about 89,800 dam^3, or 2.5% of the total licensed allocation proposed in the 1991 regulation. Total seepage volumes in 1999 that included losses from headworks canals were estimated as 94,900 dam^3, or 2.6% of the proposed total licensed allocation. Canal rehabilitation has played a significant role in reducing seepage in conveyance works, making seepage losses a negligible factor in canal operations. Seepage losses will likely be reduced even further in the future as irrigation districts continue to modernize their conveyance systems.

REFERENCES

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. 2nd ed. Agriculture Canada Publication 1646. 164 pp.

Alberta Agriculture. 1987. Channel systems design for southern Alberta. Irrigation Branch, Lethbridge, Alberta.

Alberta Environment. 1991. South Saskatchewan basin water allocation regulation. Order in Council pursuant to Section 12 of the Province of Alberta Water Resources Act. Queen's Printer, Edmonton, Alberta, Canada.

Baker, D.R., Ryan, L.M. and Hill, D.F. 1999. The Irrigation District Model: A real-time approach to operations of irrigation districts. Proceedings of a Water Management Conference: Benchmarking Irrigation System Performance Using Water Measurement and Water Balances. U.S. Committee on Irrigation and Drainage, California Polytechnic State University and the Bureau of Reclamation. San Luis Obispo, California. March 10-13.

Brockway, C.E. and Worstell, R.V. 1968. Field evaluation of seepage measurement methods. Phoenix, Arizona. ARS 41-147, pp. 121-127. Proceedings of the Second Seepage Symposium.

CAESA - Soil Inventory Project Working Group. 1998. AGRASID: Agricultural region of Alberta soil inventory database (Ver. 1.0). Edited by J.A. Brierley, B.D. Walker, P.E. Smith, and W.L. Nikiforuk. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta. CD-ROM.

Green, R. and Copeland, F.L. 1972. Geological map of Alberta. Scale: 1:1,267,000. Research Council of Alberta, Edmonton, Alberta.

Food and Agricultural Organization of the United Nations (FAO). 1977. Irrigation canal lining Irrigation and Drainage Paper No. 2. Rome, Italy.

Hansen, V.E., Israelsen, O.W. and Stringham, G.E. 1980. Irrigation principles and practices. 4th ed. John Wiley and Sons. Toronto, Ontario.

Hendry, M.J. 1982. Hydraulic conductivity of a glacial till in Alberta. Groundwater 20(2):162-169.

Imperial Irrigation District. 1992. Ponding test procedures manual. Imperial Irrigation District Water Resources Unit, California, October 1992.

Linsley, R.K. and Franzini, J.B. 1979. Water resources engineering. 3rd ed. McGraw Hill, New York, NY. pp. 268-270.

Pawluk, S. and Bayrock, L.A.. 1969. Some characteristics and physical properties of Alberta tills. Bulletin 26. Research Council of Alberta. Edmonton, Alberta.

Rasmussen, W.W. and Lauritzen, C.W. 1953. Measuring seepage from irrigation canals. Agricultural Engineering 34:326-329, 331.

Trooien, T.P. and Reichman, G.A. 1990. Hydraulic conductivity of till subsoil in North Dakota. Transactions of the American Society of Agricultural Engineers 33:1492-1496.

Worstell, R.V. 1976. Estimating seepage losses from canal systems. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers 102 (IR1):137-147.

APPENDIX A

AGRASID Parent-Material Codes and Descriptions

Table A-1. Coarse-texture parent material.

Classification	AGRASID parent-material code and description	
CO - Coarse	C0 -	Coarse textured (S, LS, SL) material (undifferentiated)
	C1 -	Gravels or gravely (cobbly/stony) coarse textured material
	C2 -	Very coarse (S, LS) sediments deposited by wind or water
	C3 -	Moderately coarse (SL, FSL) sediments deposited by wind or water
	C4 -	Very coarse textured till (Till name
	C5 -	Moderately coarse textured tills (Till name)
	C6 -	Coarse textured (S, LS, SL) softrock
	C7 -	Coarse grained bedrock
	L4 -	Coarse textured over gravel or gravelly coarse (includes cobbly and stony variations)
	L5 -	Medium textured over gravel or gravelly coarse (includes cobbly and stony variations)
	L7 -	Coarse (not till) over softrock
	L11 -	Peat (any) over coarse textured
	L18 -	Medium textured material over coarse textured material

Table A-2. Medium-textured parent material.

Classification	AGRASID parent material code and description	
ME - Medium	M0 -	Medium textured (VFSL, L, SiL, SiCL, CL, SCL) materials (undifferentiated)
	M1 -	Gravelly medium textured sediments deposited by water (includes cobbly and stony variations
	M2 -	Medium textured (L, VFSL) sediments deposited by wind and water
	M3 -	Moderately fine textured (CL, SCL, SiCL) sediments deposited by water
	M4 -	Medium textured (L to CL) till (Till name)
	M5 -	Medium textured (L to CL) softrock
	M6 -	Gravelly and stony medium textured till
	L1 -	Gravel or gravelly coarse over medium or fine textured till (includes cobbly and stony variations)
	L2 -	Coarse textured (S, LS, SL) over medium or fine textured till
	L3 -	Medium textured (VFSL, L, SiCL, CL) over medium or fine textured till
	L6 -	Till (Till name) over softrock
	L8 -	Medium (not till) over softrock
	L12 -	Peat (any) over medium textured
	L14 -	Fine textured (not till) over medium to moderately fine textured till
	L15 -	Very fine textured (not till) over medium to moderately fine textured till
	L17 -	Gravelly (includes stony variations) medium textured material over medium or fine textured till
	L19 -	Gravelly medium textured material over softrock
	L20 -	Coarse textured over medium or moderately fine (not till)
	L21 -	Gravelly coarse textured over medium or moderately fine (not till
	L22 -	Fine (not till) over medium (not till)

Table A-3. Fine-textured parent material.

Classification	AGRASID parent-material code and description	
FI - Fine	F0 -	Fine textured (C, SiC, HC) materials (undifferentiated)
	F1 -	Fine textured (C, SiC) water-laid sediments
	F2 -	Very fine textured (HC) water-laid sediments
	F3 -	Fine textured (C) water-laid sediments with till-like features
	F4 -	Fine textured (C) till (Till name)
	F5 -	Fine textured (C, SiC) softrock
	L9 -	Coarse (not till) textured over fine or very fine (not till)
	L10 -	Medium (not till) textured over fine or very fine (not till)
	L13 -	Peat (any) over fine texture
	L16 -	Fine to very fine textured (not till) over softrock

APPENDIX B

Soil Descriptions by Site

Soil Descriptions – Murray Peters and Frank Hecker

Site No. **Soil Description**

1. SW 27-02-25-W4 (AID, Lateral A1): The test section of this lateral was built in clay loam textured lacustrine underlain by clay loam to clay textured till (Figure B-1). Test hole #1 had bedrock within about 4.5 m of the surface. The soil was dry to 0.9 m and slightly moist to 6 m.

2. NE 12-13-14-W4 (BRID, Main Canal): This test section of the BRID Main Canal was built in clay loam and sandy clay loam textured fluvial material underlain by clay loam and sandy clay loam textured till (Figure B-2). Very moist to saturated layers were present between 1.2 and 2.5 m below the surface and deeper.

3. SE 19-12-16-W4 (BRID, Lateral H): This section of Lateral H had clay loam to sandy clay loam textured till to 6 m (Figure B-3). Saturated sandy loam to fine sandy loam layers were found in the till in test hole #2 and 5. Agriculture and Agri-Food Canada (1996) described the parent material and texture of the soils covering this location as discontinuous, moderately fine-to medium-textured fluvial or glaciolacustrine veneer underlain by moderately fine-textured till on undulating topography.

4. NW 20-13-16-W4 (BRID, Lateral A1): This section of Lateral A1 had clay loam to sandy clay loam textured till to 6 m (Figure B-4). Saturated sandy clay loam layers were found in the till in test hole #1. Test hole #5 had a layer of claystone bedrock in the till between 4.8 and 5.7 m.

5. NW 08-19-13-W4 (EID, Lateral G): The test section of this lateral was built in clay loam to silty clay loam textured lacustrine underlain by clay loam to clay textured till (Figure B-5). Bedrock was found in all test holes starting as shallow as 2.4 m in test hole #3 and 4. A very moist layer of sandy loam textured material and a saturated layer of clay loam to clay was found in test hole # 1, between 2.4 and 3.4 m. Agriculture Canada (1983) described the parent material and texture of the soils covering this location as fine loamy, moderately calcareous, weakly saline fluvial-lacustrine material on undulating to level topography.

6. SE 27-10-23-W4 (LNID, Lateral B11): The test section of this lateral was built in silty clay loam, sandy clay loam, and silty clay textured fluvial or lacustrine material (Figure B-6). The silty clay loam textured fluvial or lacustrine was very moist to saturated within 2 m of the surface. Very moist to saturated sandy clay loam to sandy loam textured layers were also present at depths greater than 1.5 m. The fluvial or lacustrine material was underlain by clay loam to sandy clay loam textured till. Bedrock was encountered at about 4 m below the surface or deeper.

7. NW 10-10-22-W4 (LNID, Lateral D1A): The test section of this lateral was built in clay loam to very fine sandy clay loam textured lacustrine material underlain by clay textured till (Figure B-7). The lacustrine material was very moist to saturated underlain by moist till deposits. Agriculture Canada (1980) described the parent material and texture of the soils covering this location as fine loamy to fine silty lacustrine material greater than 1 m and less than 1 m underlain by fine loamy till developed on level to very gently sloping topography.

8. SE 17-10-23-W4 (LNID, Lateral B9B): The test section of this lateral was built with clay loam to sandy clay loam and clay to silty clay textured material about 1.2 m deep, underlain by fine sand, loamy sand, sandy loam, and sandy clay loam textured material (Figure B-8).

9. NE 09-05-22-W4 (MID, Lateral B1D): The test section of this lateral was built in up to 2.0 m of silty clay loam textured lacustrine material underlain by clay loam textured till material (Figure B-9). Bedrock was found within 3.1 m of the surface in test holes #3, 5, and 6. Saturated sandy loam layers were found within the till in test hole #2. Agriculture Canada (1991) described the parent material and texture of the soils covering this location as fine-textured lacustro-till and fine-textured lacustrine on level to undulating topography.

10. NW 03-05-23-W4 (MID, Highline Main Canal.): The test section of the Highline Main Canal was built in silty clay loam textured lacustrine material underlain by clay loam textured till (Figure B-10). A layer of ice rafted bedrock was found between 1.8 and 2.1 m in test hole #5. All test holes were slightly moist.

11. NE 14-02-28-W4 (MVID, Lateral A2): This section of Lateral A2 had clay loam to very fine sandy clay loam textured till to 6 m (Figure B-11). Agriculture Canada (1991) described the parent material and texture of the soils for this location as medium-textured till developed on undulating to hummocky topography.

12. SW 07-06-20-W4 (RID, Old Raymond Main Canal): The test section of the Old Raymond Main Canal was built in clay loam and silty clay to silty clay loam textured lacustrine and till material (Figure B-12).

13. SE 23-06-19-W4 (RID, Craddock-Stirling Main Canal): The test section of the Craddock-Stirling Main Canal was built in clay loam to silty clay loam textured lacustrine material underlain by clay loam to clay textured till (Figure B-13). Bedrock was found as shallow as about 4.8 m below the surface. Moist to saturated layers were found within the till. Agriculture Canada (1984) described the parent material and texture of the soils for this location as medium to moderately fine-textured lacust rine developed on gently to undulating topography.

14. SE 18-06-21-W4 (RID, Lateral 7): The test section of Lateral 7 was built in silty clay loam, silty clay, and clay textured lacustrine material underlain by clay loam and very fine sandy clay loam textured till (Figure B-14). The high rate of seepage at this site in relation to the fine-textured soils may be due to a pipeline going under the test section.

15. NW 25-07-21-W4 (LNID, Lateral A4): The test section of this lateral was built in clay loam to very fine sandy clay loam textured till with sandy clay loam to sandy loam textured layers (Figure B-15). All layers were very moist to saturated. Agriculture Canada (1980) described the parent material and texture of the soils as fine loamy to fine silty lacustrine material, greater than 1 m and less than 1 m, underlain by fine morainal material on very gentle to gentle sloping topography.

16. NW 34-09-14-W4 (SMRID, South Grassy Main): The canal at this test location was built in mainly clay loam and sandy clay loam to sandy loam textured material (Figure B-16). Sandstone bedrock was found as shallow as 0.5 m below the surface. Very moist to saturated layers were present at about 1 m or deeper.

17. NE 05-11-10-W4 (SMRID, Lateral 20C): The test section of this lateral was built in less than 1 m of sandy loam textured material underlain by clay loam to clay textured till (Figure B-17). The level II land classification for irrigation, dated February 4, 1987, described the soil texture as less than 1 m to greater than 1 m of sandy loam to loam textured fluvial material underlain by clay loam to clay textured till.

18. NE 26-08-19-W4 (SMRID, Lateral B3): The test section of Lateral B3 was built in mainly clay loam to clay textured till (Figure B-18). The level II land classification for irrigation dated August 9, 1991, described the soil texture as less than 1 m to greater than 1 m of clay loam and silty clay loam to clay and silty clay loam lacustrine material underlain by clay loam to clay textured till.

19. NW 09-11-06-W4 (SMRID, Main Canal): The test section of the Main Canal was built in clay loam, silty clay loam, and sandy clay loam textured lacustrine material underlain by clay loam and sandy clay loam textured till (Figure B-19). The layer of lacustrine material immediately above the till in test hole #2 was very moist to saturated. Canada Department of Agriculture (1963) described the parent material and texture of the soils covering this location as moderately fine-textured lacustrine material underlain by moderately fine-textured water-sorted glacial till.

20. NW 28-09-16-W4 (TID, Lateral 15): The test section of this lateral was built in clay loam and clay loam to sandy clay loam textured till (Figure B-20).

21. NW 04-05-27-W4 (UID, Lateral B2): This section of Lateral B2 was built in clay loam and very fine sandy clay loam textured lacustrine material underlain by silty clay to clay textured till in test holes #1, 2, and 3, and silty clay loam to sandy clay loam to clay loam and silty clay textured till in test holes #4, 5, and 6 (Figure B-21). All test holes had bedrock within 3 m of the surface. The lacustrine material was moist to very moist, while the till was moist. Agriculture Canada (1991) described the parent material and texture of the soils covering this location as medium-textured till and fine-textured lacustro-till developed on undulating topography. The shallow bedrock is likely the reason for the relatively high seepage rate at this site despite the medium to fine soil textures.

22. NE 01-05-27-W4 (UID, Lateral F): The test section of this lateral was built in clay and silty clay textured lacustrine material underlain by clay loam to clay till (Figure B-22).

23. NW 09-22-26-W4 (WID, Lateral 81C1): The test section of this lateral was built in clay loam to sandy clay loam textured till to 6 m below the surface (Figure B-23). Very moist to saturated layers were embedded in the till deposits in test holes #2, 3, 4, 5, and 6. Bedrock was found at about 4.5 m in test hole #3 and 4. Harron (1983) described the parent material and texture of the soil map unit covering this location as clay loam to silty clay loam textured till developed on gently undulating topography.

24. NE 31-22-22-W4 (WID, Lateral 81J): The test section of this lateral was built in clay loam and silty clay loam textured lacustrine material underlain by clay loam and sandy clay loam textured till (Figure B-24). Weathered sandstone bedrock underlain by claystone bedrock was found at about 4.8 m in test hole # 5. The soils in every hole were either very moist or saturated, except test hole # 2. Test hole # 3 had a water table at 4.5 m.

25. SE 15-10-22-W4 (LNID, cracked concrete canal): The test section of this lateral was built in fine sandy clay and sandy clay loam and clay loam textured lacustrine material underlain by clay to clay loam textured till or lacustrine (Figure B-25). CAESA (1998) described the soils in this quarter as having developed in less than 1 m or greater than 1 m of medium-textured loam, silt loam, or very fine sandy loam lacustrine material underlain by clay loam, sandy clay loam or silty clay loam textured till. The level II land classification completed for the SE 15, dated May 21, 1986, described the soil texture as ranging from loam to clay loam. Soil texture of the subsoil was described as clay loam and sandy clay loam lacustrine material in the SW 15-10-22-W4 by drill logs for a level II land classification completed November 23, 1995.

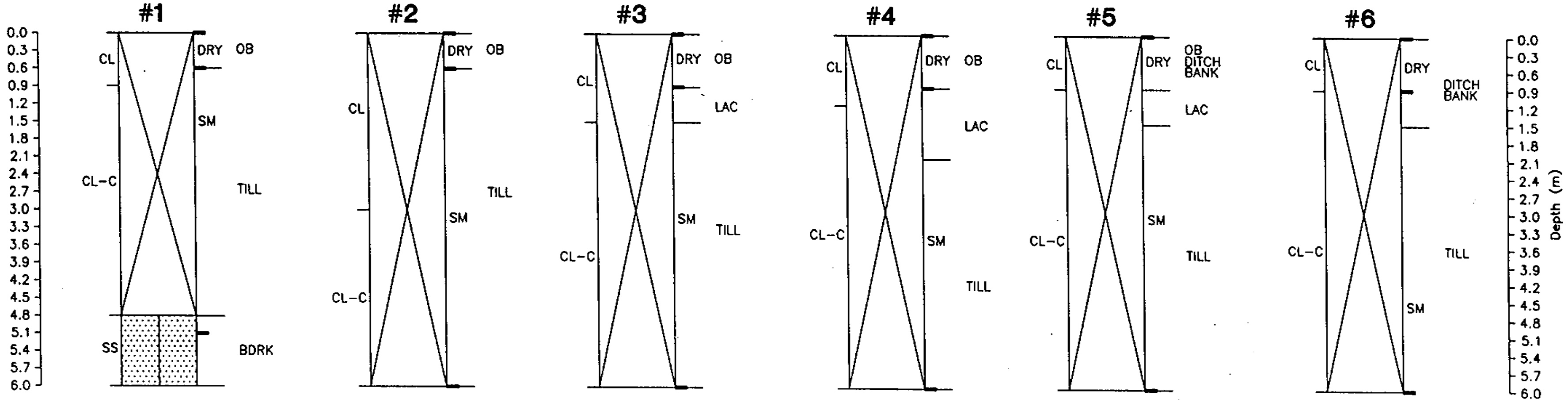
26. NE 34-24-24-W4 (WID, Lateral 85): The test section of this lateral was constructed in silty clay loam textured lacustrine material about 1.5 m deep, underlain by clay loam to sandy clay loam textured till (Figure B-26). Sandstone bedrock was found at 3 m and deeper.

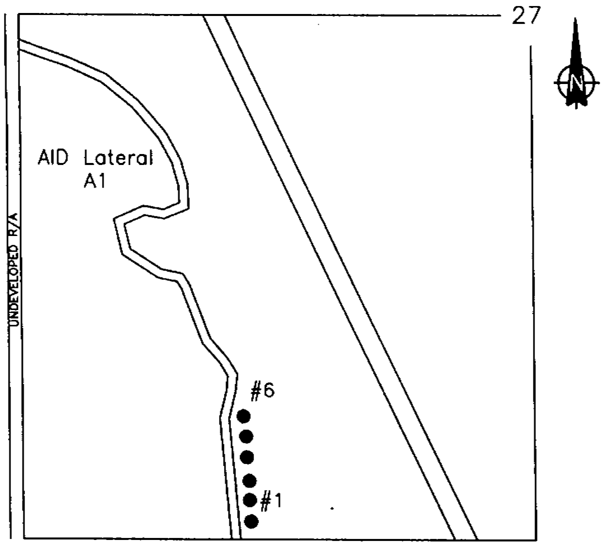
27. SE 11-20-15-W4 (EID, C Springhill Canal): Three drill holes along the test section of this canal found clay loam to clay textured till to a depth of 6 m (Figure B-27).

28. NW 21-9-22-W4 (LNID, South Park Lake Canal): The test section of this canal was constructed in clay loam to clay textured fill material, ranging from 0.6 to 1.6 m deep, underlain by silty clay loam to silty clay textured lacustrine material to about 6 m (Figure B-28).

29. SE 33-15-18-W4 (BRID, lateral H5-2): The test section of this canal was built in clay loam textured till (Figure B-29). Soil texture at one test hole consisted of 1.2 m of clay loam textured lacustrine material, underlain by very moist to saturated coarse sand to coarse sandy clay loam textured fluvial material, which was underlain by clay loam to clay textured till.

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C - Clay
C-SiC - Clay to Silty Clay
SiC - Silty Clay
C-SC - Clay to Sandy Clay
SC - Sandy Clay
SiC-VFSC - Silty Clay to Very Fine Sandy Clay
SiC-SiCL - Silty Clay to Silty Clay Loam
C-CL - Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL - Clay Loam
CL-SCL - Clay Loam to Sandy Clay Loam
SCL-CL - Sandy Clay Loam to Clay Loam
SCL-SC - Sandy Clay Loam to Sandy Clay
SCL - Sandy Clay Loam
FSCL - Fine Sandy Clay Loam
VFSCL - Very Fine Sandy Clay Loam
SiCL-SiC - Silty Clay Loam to Silty Clay
SiCL - Silty Clay Loam
CL-C - Clay Loam to Clay
FSCL-CL - Silty Clay Loam
VFSCL-SiCL - Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL - Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL - Loam to Clay Loam
SiL - Silty Loam
SiL-SiCL - Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL - Sandy Loam
SL-SCL - Sandy Loam to Sandy Clay Loam
SCL-SL - Sandy Clay Loam to Sandy Loam
LS - Loamy Sand
S - Sand

▩ SiS - Siltstone
MDS - Mudstone

▤ CS - Claystone

▨ SS - Sandstone

SOIL MOISTURE

D - Dry
M - Moist
SM - Slightly Moist
VM - Very Moist
SAT - Saturated

GEOLOGIC UNIT

FILL
TILL
OB - OVERBURDEN
LAC - LACUSTRINE
FLUV - FLUVIAL
BDRK - BEDROCK

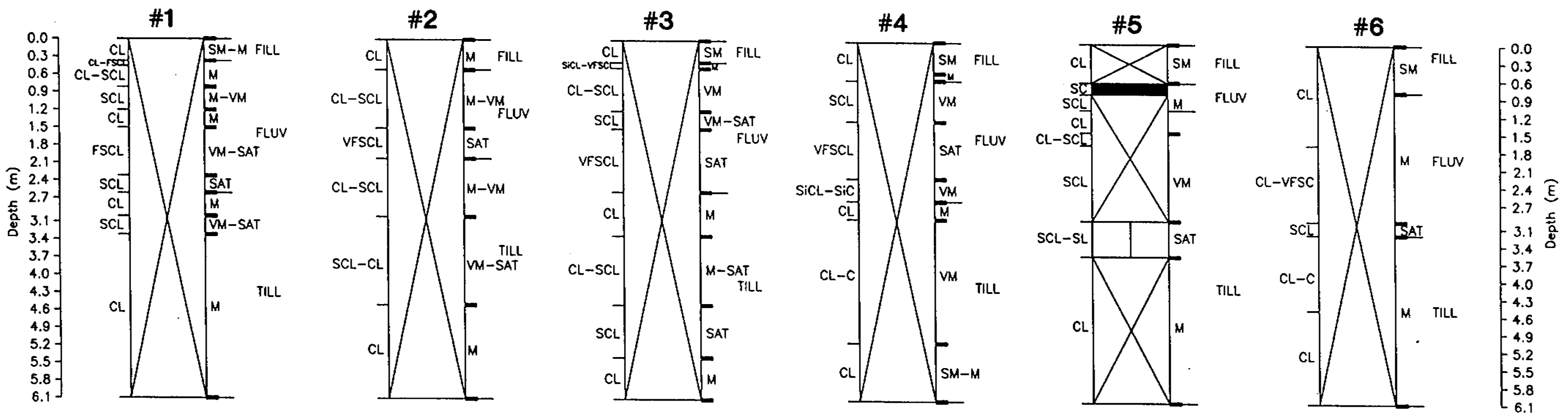
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

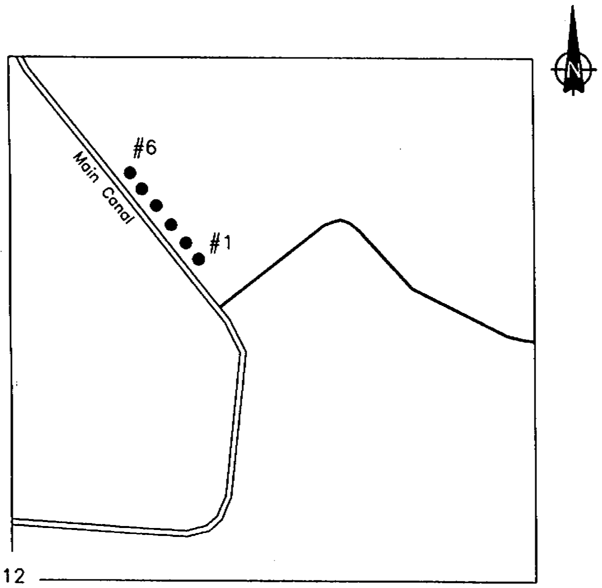
DRAWN B.F.C.
DATE Feb. 19,1999

SCALE N.T.S.
REV DATE

A.I.D.
SW 27-002-25-W4
Figure B-1
Seepage Study, Site 1
FILE NAME M9900103
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

◫ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

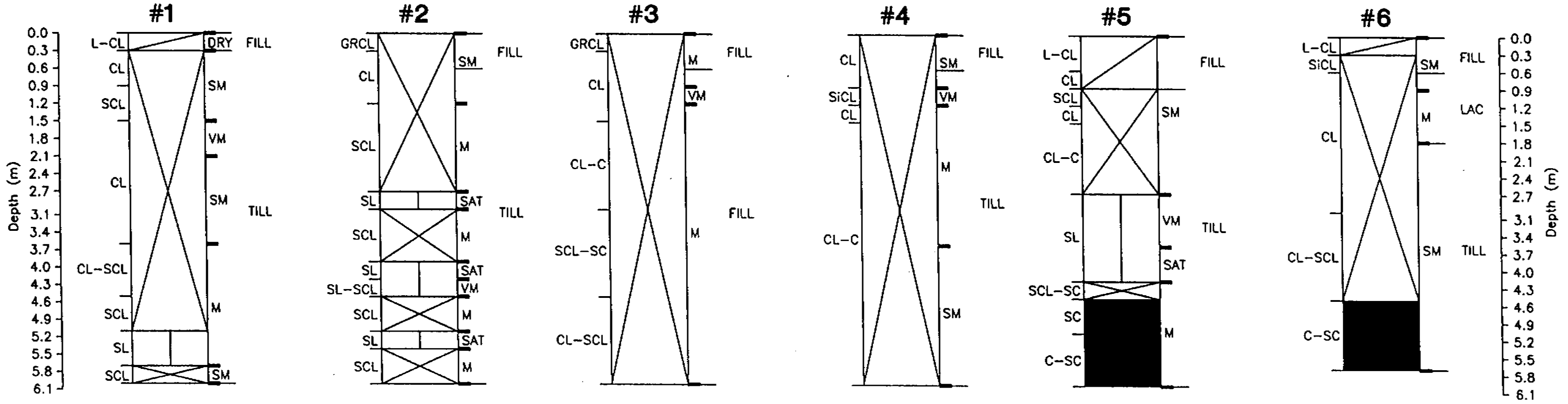
B.R.I.D.
NE 12-13-14-W4

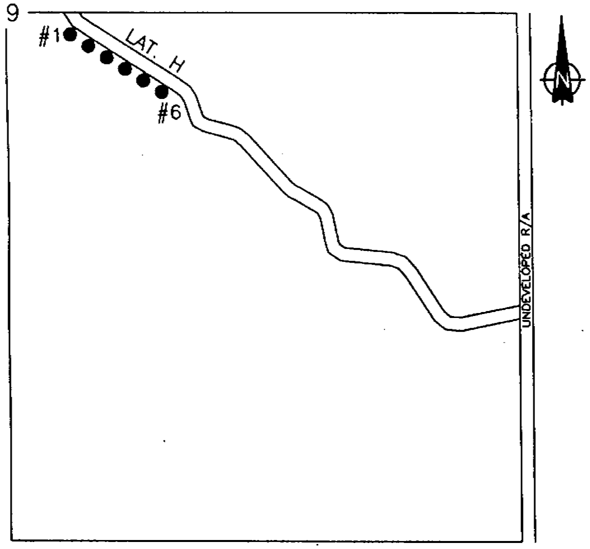
DRAWN BFC
DATE June 1999
SCALE N.T.S.
REV DATE

Figure B-2
Seepage Study, Site 2

FILE NAME L9900101
SHEET OF

TEST HOLES





SOIL TEXTURE

▇ FINE TEXTURED:

C	Clay
C-SiC	Clay to Silty Clay
SiC	Silty Clay
C-SC	Clay to Sandy Clay
SC	Sandy Clay
SiC-VFSC	Silty Clay to Very Fine Sandy Clay
SiC-SiCL	Silty Clay to Silty Clay Loam
C-CL	Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	Clay Loam
CL-SCL	Clay Loam to Sandy Clay Loam
SCL-CL	Sandy Clay Loam to Clay Loam
SCL-SC	Sandy Clay Loam to Sandy Clay
SCL	Sandy Clay Loam
FSCL	Fine Sandy Clay Loam
VFSCL	Very Fine Sandy Clay Loam
SiCL-SiC	Silty Clay Loam to Silty Clay
SiCL	Silty Clay Loam
CL-C	Clay Loam to Clay
FSCL-CL	Silty Clay Loam
VFSCL-SiCL	Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL	Loam to Clay Loam
SiL	Silty Loam
SiL-SiCL	Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL	Sandy Loam
SL-SCL	Sandy Loam to Sandy Clay Loam
SCL-SL	Sandy Clay Loam to Sandy Loam
LS	Loamy Sand
S	Sand

▩	SiS MDS	Siltstone Mudstone
▤	CS	Claystone
▒	SS	Sandstone

SOIL MOISTURE

D	Dry
M	Moist
SM	Slightly Moist
VM	Very Moist
SAT	Saturated

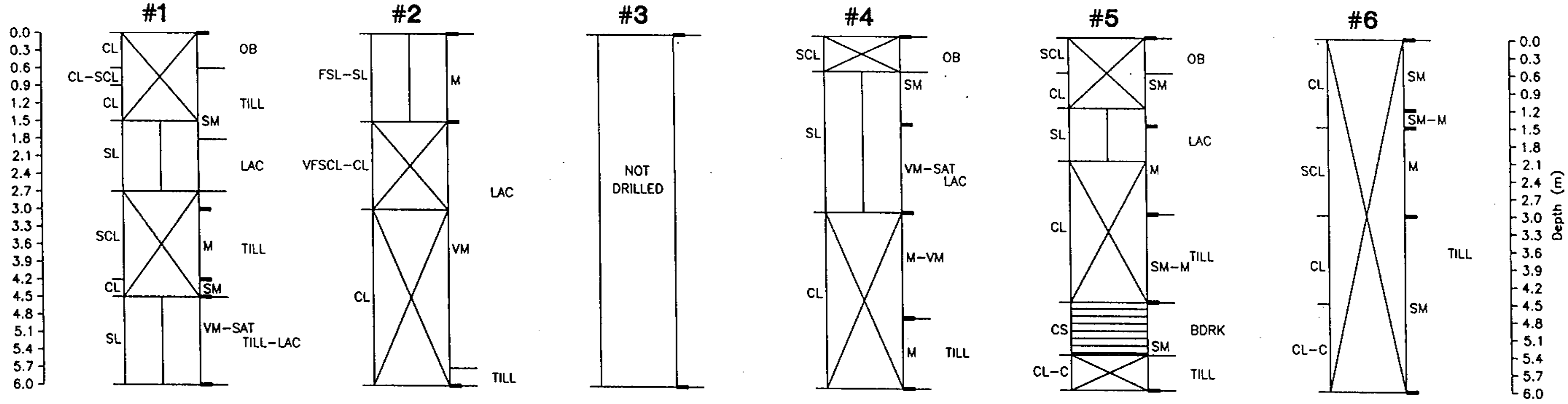
GEOLOGIC UNIT

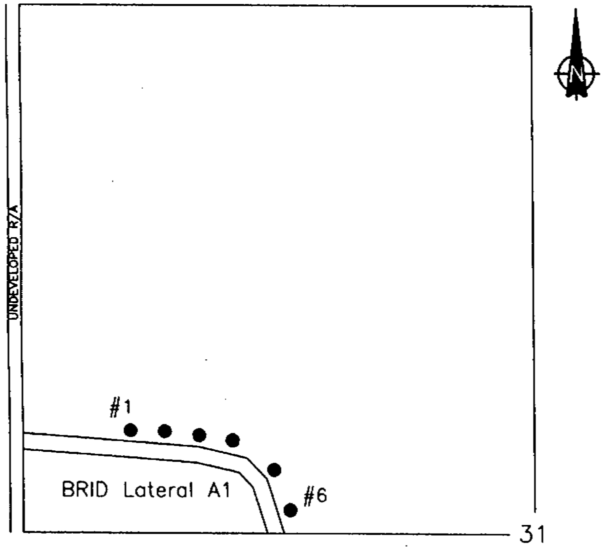
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.	SCALE N.T.S.	B.R.I.D.
DATE Mar. 9, 1998	REV DATE	SE 19-12-16-4
		Figure B-3 Seepage Study, Site 3
		FILE NAME U9800101 SHEET OF

TEST HOLES





SOIL TEXTURE

■ **FINE TEXTURED:**
- C – Clay
- C-SiC – Clay to Silty Clay
- SiC – Silty Clay
- C-SC – Clay to Sandy Clay
- SC – Sandy Clay
- SiC-VFSC – Silty Clay to Very Fine Sandy Clay
- SiC-SiCL – Silty Clay to Silty Clay Loam
- C-CL – Clay to Clay Loam

☒ **MODERATELY FINE TEXTURED:**
- CL – Clay Loam
- CL-SCL – Clay Loam to Sandy Clay Loam
- SCL-CL – Sandy Clay Loam to Clay Loam
- SCL-SC – Sandy Clay Loam to Sandy Clay
- SCL – Sandy Clay Loam
- FSCL – Fine Sandy Clay Loam
- VFSCL – Very Fine Sandy Clay Loam
- SiCL-SiC – Silty Clay Loam to Silty Clay
- SiCL – Silty Clay Loam
- CL-C – Clay Loam to Clay
- FSCL-CL – Silty Clay Loam
- VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
- GRCL – Gravelly Clay Loam

▨ **MEDIUM TEXTURED:**
- L-CL – Loam to Clay Loam
- SiL – Silty Loam
- SiL-SiCL – Silty Loam to Silty Clay Loam

◫ **COARSE TEXTURED:**
- SL – Sandy Loam
- SL-SCL – Sandy Loam to Sandy Clay Loam
- SCL-SL – Sandy Clay Loam to Sandy Loam
- LS – Loamy Sand
- S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▦ SS – Sandstone

SOIL MOISTURE

- D – Dry
- M – Moist
- SM – Slightly Moist
- VM – Very Moist
- SAT – Saturated

GEOLOGIC UNIT

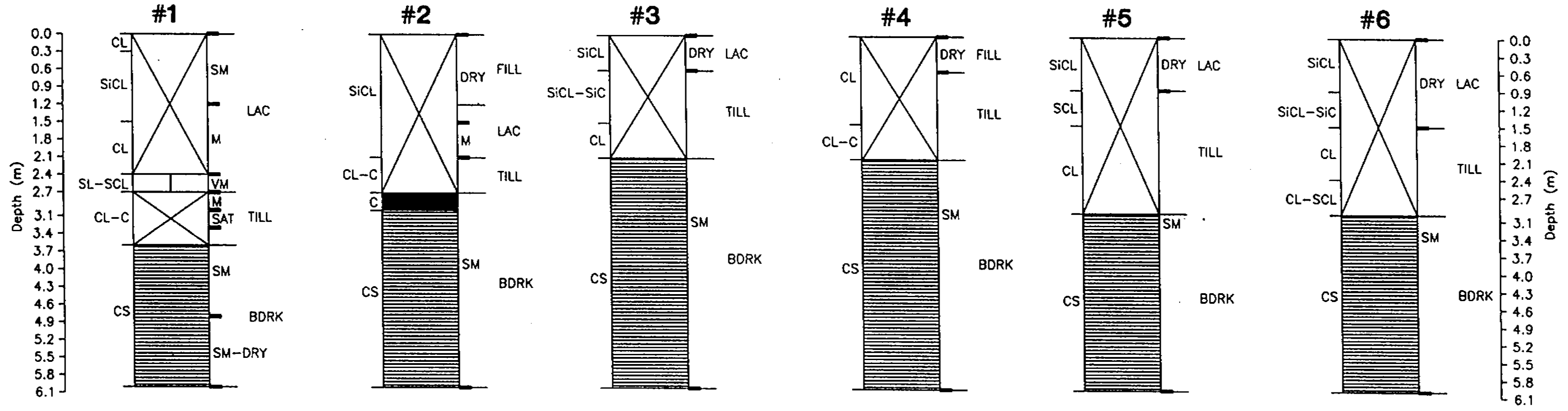
- FILL
- TILL
- OB – OVERBURDEN
- LAC – LACUSTRINE
- FLUV – FLUVIAL
- BDRK – BEDROCK

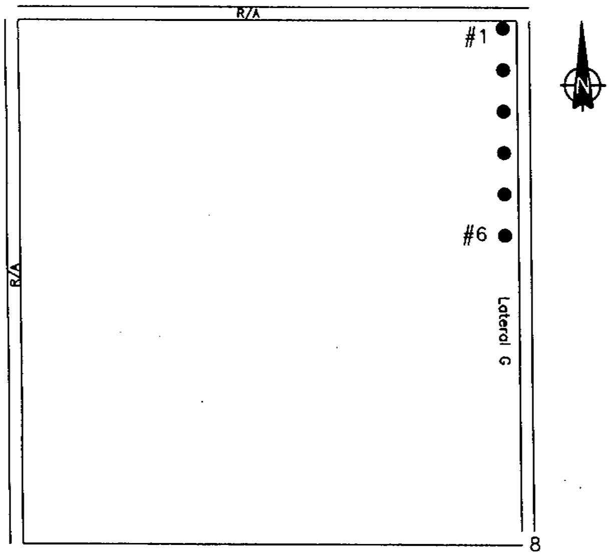
Alberta
Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.
DATE Feb. 19,1999
SCALE N.T.S.
REV DATE

B.R.I.D.
NW 20-013-16-W4
Figure B-4
Seepage Study, Site 4
FILE NAME M9900102
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C	– Clay
C-SiC	– Clay to Silty Clay
SiC	– Silty Clay
C-SC	– Clay to Sandy Clay
SC	– Sandy Clay
SiC-VFSC	– Silty Clay to Very Fine Sandy Clay
SiC-SiCL	– Silty Clay to Silty Clay Loam
C-CL	– Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	– Clay Loam
CL-SCL	– Clay Loam to Sandy Clay Loam
SCL-CL	– Sandy Clay Loam to Clay Loam
SCL-SC	– Sandy Clay Loam to Sandy Clay
SCL	– Sandy Clay Loam
FSCL	– Fine Sandy Clay Loam
VFSCL	– Very Fine Sandy Clay Loam
SiCL-SiC	– Silty Clay Loam to Silty Clay
SiCL	– Silty Clay Loam
CL-C	– Clay Loam to Clay
FSCL-CL	– Silty Clay Loam
VFSCL-SiCL	– Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	– Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL	– Loam to Clay Loam
SiL	– Silty Loam
SiL-SiCL	– Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL	– Sandy Loam
SL-SCL	– Sandy Loam to Sandy Clay Loam
SCL-SL	– Sandy Clay Loam to Sandy Loam
LS	– Loamy Sand
S	– Sand

▩	SiS MDS	– Siltstone – Mudstone
▤	CS	– Claystone
⁙	SS	– Sandstone

SOIL MOISTURE

D	– Dry
M	– Moist
SM	– Slightly Moist
VM	– Very Moist
SAT	– Saturated

GEOLOGIC UNIT

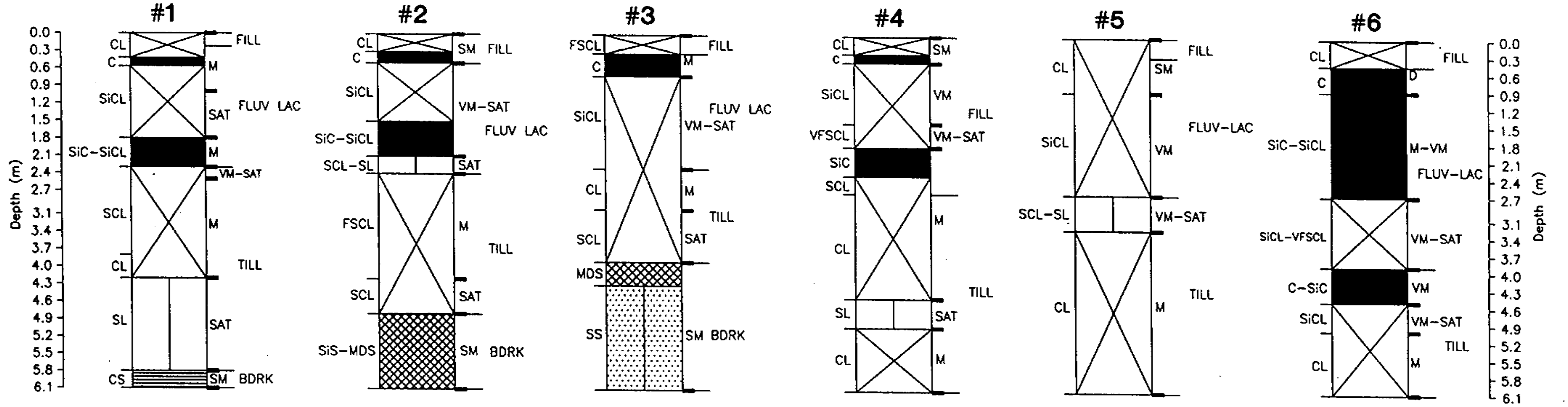
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

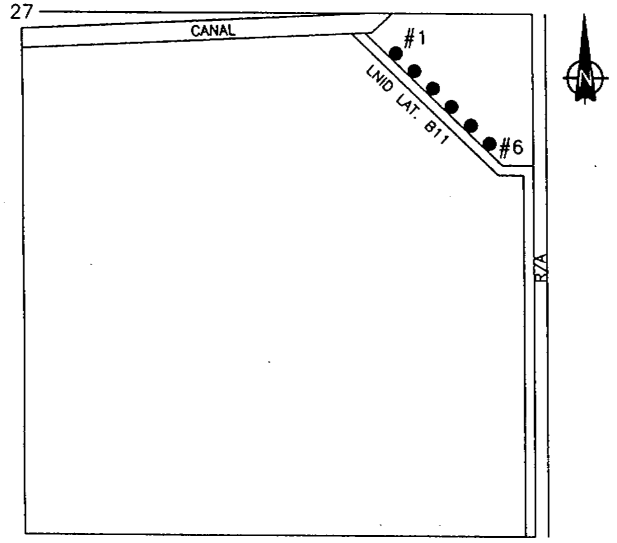
Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch

DRAWN L.B.K.
DATE Mar. 9, 1998
SCALE N.T.S.
REV DATE

E.I.D.
NW 8-19-13-4
Figure B-5
Seepage Study, Site 5
FILE NAME N9800101 SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C	– Clay
C-SiC	– Clay to Silty Clay
SiC	– Silty Clay
C-SC	– Clay to Sandy Clay
SC	– Sandy Clay
SiC-VFSC	– Silty Clay to Very Fine Sandy Clay
SiC-SiCL	– Silty Clay to Silty Clay Loam
C-CL	– Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	– Clay Loam
CL-SCL	– Clay Loam to Sandy Clay Loam
SCL-CL	– Sandy Clay Loam to Clay Loam
SCL-SC	– Sandy Clay Loam to Sandy Clay
SCL	– Sandy Clay Loam
FSCL	– Fine Sandy Clay Loam
VFSCL	– Very Fine Sandy Clay Loam
SiCL-SiC	– Silty Clay Loam to Silty Clay
SiCL	– Silty Clay Loam
CL-C	– Clay Loam to Clay
FSCL-CL	– Silty Clay Loam
VFSCL-SiCL	– Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	– Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL	– Loam to Clay Loam
SiL	– Silty Loam
SiL-SiCL	– Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL	– Sandy Loam
SL-SCL	– Sandy Loam to Sandy Clay Loam
SCL-SL	– Sandy Clay Loam to Sandy Loam
LS	– Loamy Sand
S	– Sand

▦	SiS MDS	– Siltstone – Mudstone
▤	CS	– Claystone
▒	SS	– Sandstone

SOIL MOISTURE

D	– Dry
M	– Moist
SM	– Slightly Moist
VM	– Very Moist
SAT	– Saturated

GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

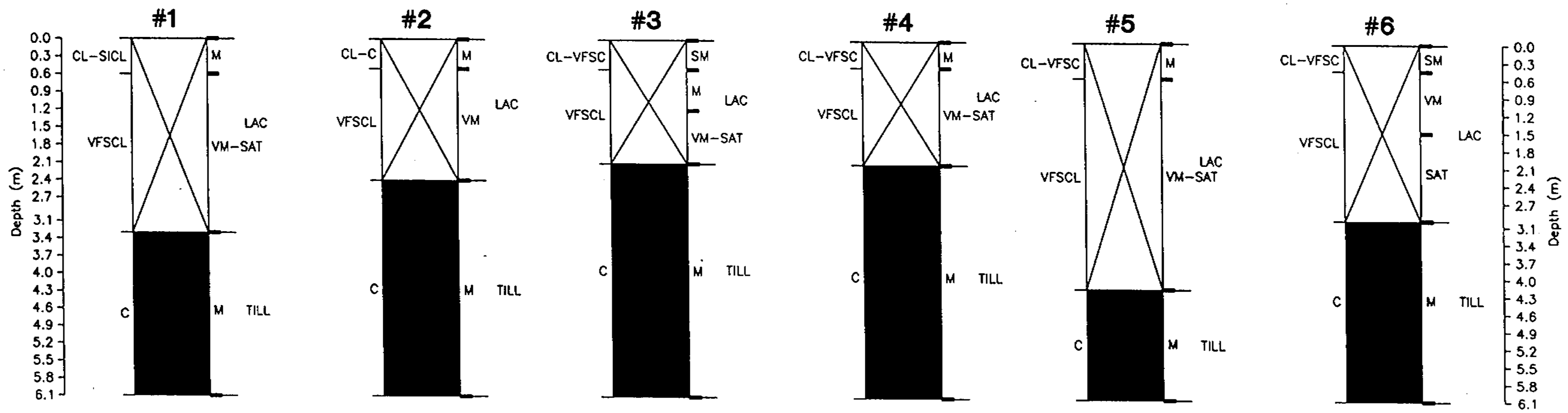
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

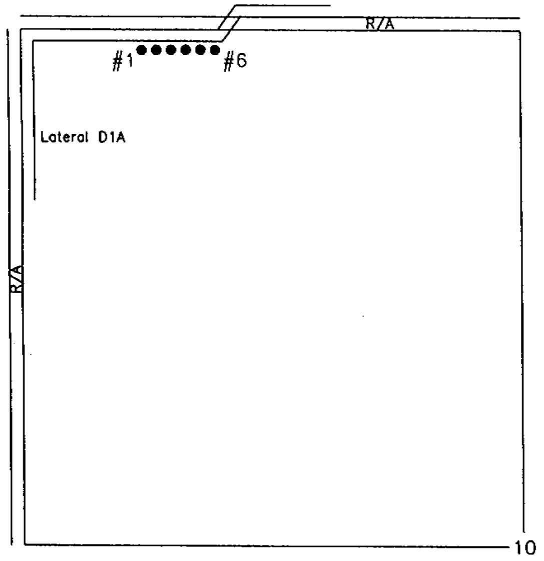
DRAWN L.B.K.	SCALE N.T.S.
DATE July 23, 1997	REV DATE

L.N.I.D.
SE 27-10-23-4
Figure B-6
Seepage Study, Site 6

FILE NAME G9700201 SHEET OF

TEST HOLES





SOIL TEXTURE

▇ FINE TEXTURED:

C	Clay
C–SiC	Clay to Silty Clay
SiC	Silty Clay
C–SC	Clay to Sandy Clay
SC	Sandy Clay
SiC–VFSC	Silty Clay to Very Fine Sandy Clay
SiC–SiCL	Silty Clay to Silty Clay Loam
C–CL	Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	Clay Loam
CL–SCL	Clay Loam to Sandy Clay Loam
SCL–CL	Sandy Clay Loam to Clay Loam
SCL–SC	Sandy Clay Loam to Sandy Clay
SCL	Sandy Clay Loam
FSCL	Fine Sandy Clay Loam
VFSCL	Very Fine Sandy Clay Loam
SiCL–SiC	Silty Clay Loam to Silty Clay
SiCL	Silty Clay Loam
CL–C	Clay Loam to Clay
FSCL–CL	Silty Clay Loam
VFSCL–SiCL	Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L–CL	Loam to Clay Loam
SiL	Silty Loam
SiL–SiCL	Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:

SL	Sandy Loam
SL–SCL	Sandy Loam to Sandy Clay Loam
SCL–SL	Sandy Clay Loam to Sandy Loam
LS	Loamy Sand
S	Sand

▩	SiS MDS	Siltstone Mudstone
▤	CS	Claystone
▦	SS	Sandstone

SOIL MOISTURE

D	Dry
M	Moist
SM	Slightly Moist
VM	Very Moist
SAT	Saturated

GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

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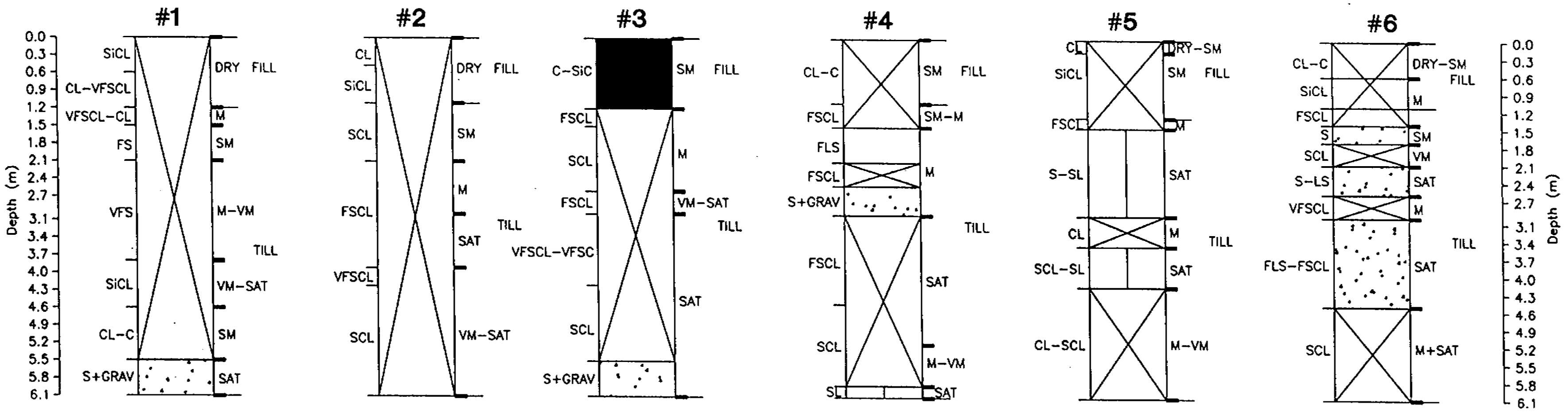
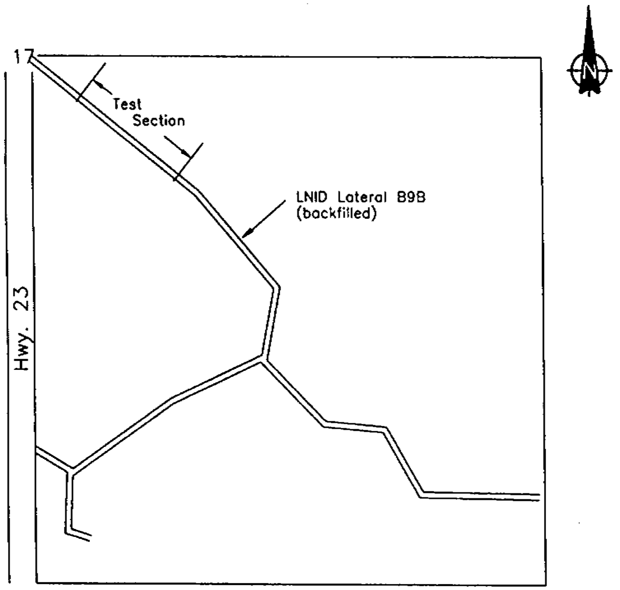
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.	SCALE N.T.S.	L.N.I.D. NW 10–10–22–4
DATE Oct. 6/98	REV DATE	Figure B–7 Seepage Study, Site 7
		FILE NAME G9800301 | SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C	– Clay
C-SiC	– Clay to Silty Clay
SiC	– Silty Clay
C-SC	– Clay to Sandy Clay
SC	– Sandy Clay
SiC-VFSC	– Silty Clay to Very Fine Sandy Clay
SiC-SiCL	– Silty Clay to Silty Clay Loam
C-CL	– Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	– Clay Loam
CL-SCL	– Clay Loam to Sandy Clay Loam
SCL-CL	– Sandy Clay Loam to Clay Loam
SCL-SC	– Sandy Clay Loam to Sandy Clay
SCL	– Sandy Clay Loam
FSCL	– Fine Sandy Clay Loam
VFSCL	– Very Fine Sandy Clay Loam
SiCL-SiC	– Silty Clay Loam to Silty Clay
SiCL	– Silty Clay Loam
CL-C	– Clay Loam to Clay
FSCL-CL	– Silty Clay Loam
VFSCL-SiCL	– Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	– Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL	– Loam to Clay Loam
SiL	– Silty Loam
SiL-SiCL	– Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL	– Sandy Loam
SL-SCL	– Sandy Loam to Sandy Clay Loam
SCL-SL	– Sandy Clay Loam to Sandy Loam
LS	– Loamy Sand
S	– Sand

▩	SiS MDS	– Siltstone – Mudstone
▤	CS	– Claystone
⁘	SS	– Sandstone

SOIL MOISTURE

D	– Dry
M	– Moist
SM	– Slightly Moist
VM	– Very Moist
SAT	– Saturated

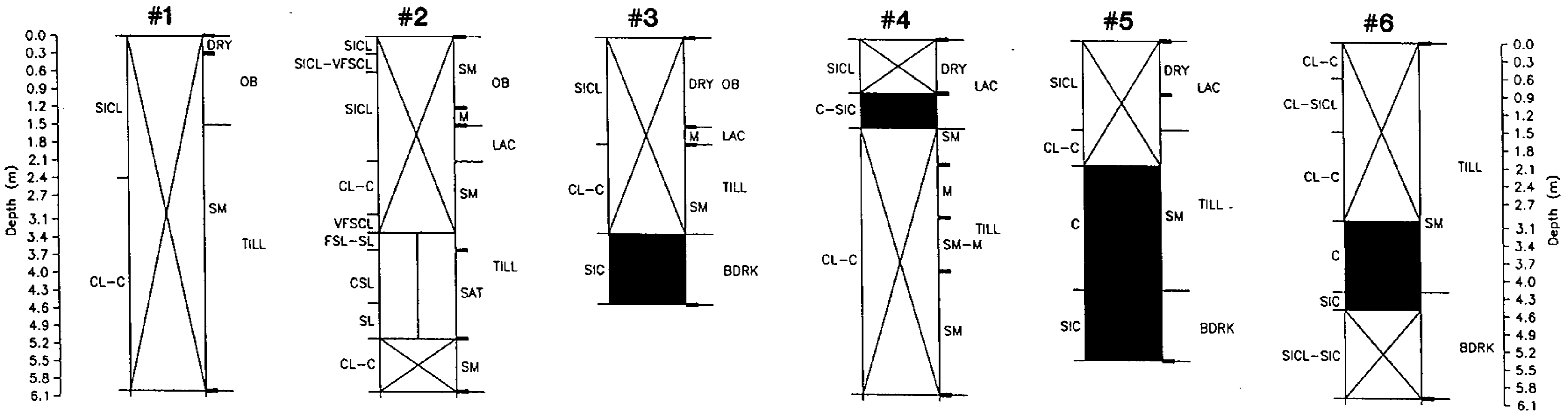
GEOLOGIC UNIT

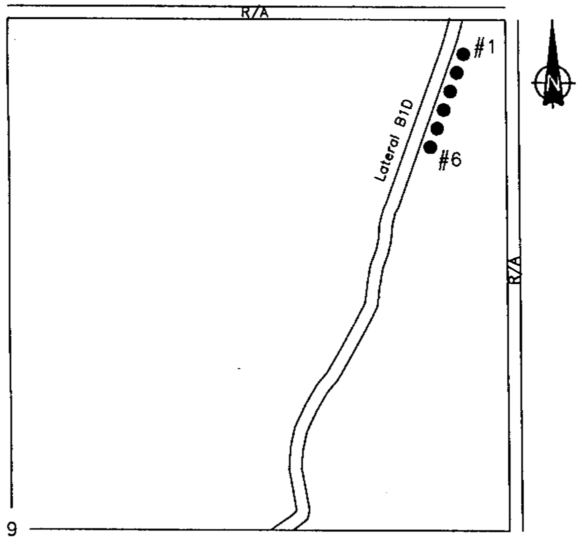
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN BFC	SCALE N.T.S.	L.N.I.D.
DATE Oct 1999	REV DATE	SE 17-010-23-W4
		Figure B-8 Seepage Study, Site 8
		FILE NAME G9900101 | SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

░ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

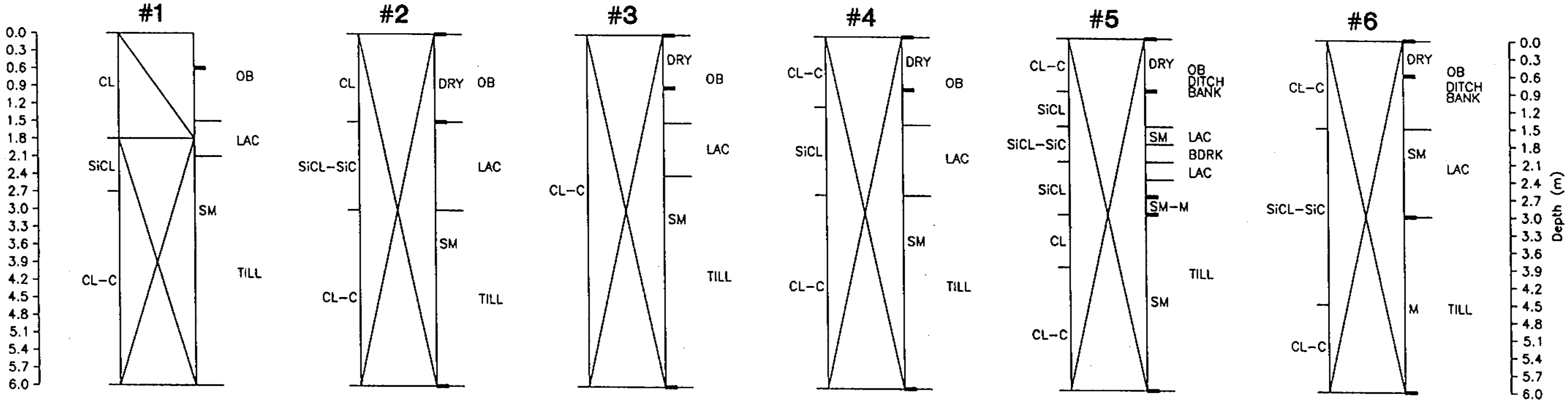
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

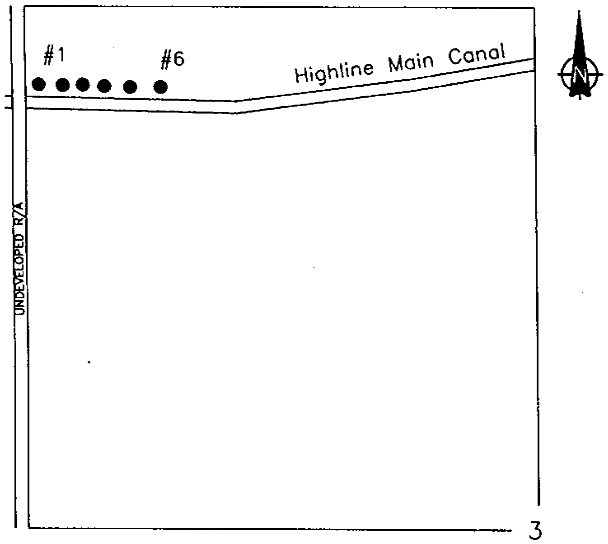
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.	SCALE N.T.S.
DATE Jan. 15, 1998	REV DATE

M.I.D.
NE 9-005-22-4
Figure B-9
Seepage Study, Site 9
FILE NAME E9800101 | SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

⁙ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

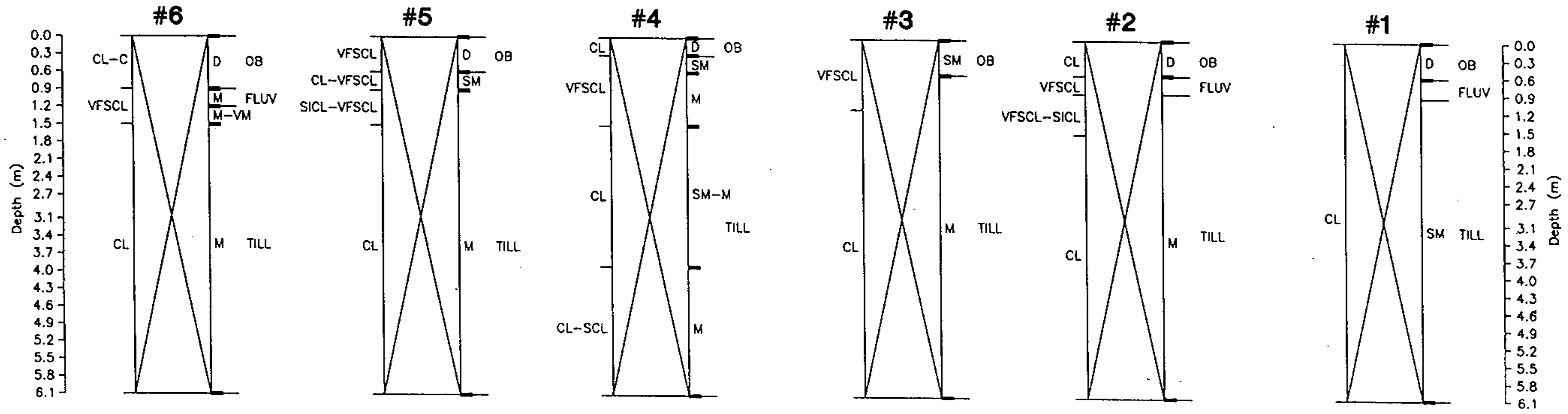
GEOLOGIC UNIT

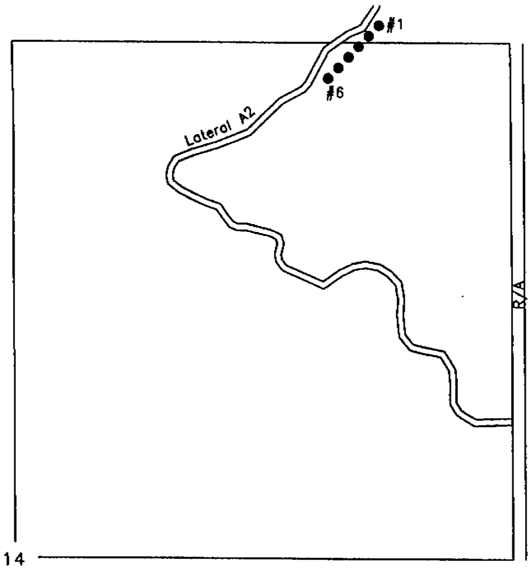
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.	SCALE N.T.S.	M.I.D.
		NW 3-005-23-W4
DATE Feb. 19,1999	REV DATE	Figure B-10 Seepage Study, Site 10
		FILE NAME M9900104 | SHEET . OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

- C – Clay
- C–SiC – Clay to Silty Clay
- SiC – Silty Clay
- C–SC – Clay to Sandy Clay
- SC – Sandy Clay
- SiC–VFSC – Silty Clay to Very Fine Sandy Clay
- SiC–SiCL – Silty Clay to Silty Clay Loam
- C–CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

- CL – Clay Loam
- CL–SCL – Clay Loam to Sandy Clay Loam
- SCL–CL – Sandy Clay Loam to Clay Loam
- SCL–SC – Sandy Clay Loam to Sandy Clay
- SCL – Sandy Clay Loam
- FSCL – Fine Sandy Clay Loam
- VFSCL – Very Fine Sandy Clay Loam
- SiCL–SiC – Silty Clay Loam to Silty Clay
- SiCL – Silty Clay Loam
- CL–C – Clay Loam to Clay
- FSCL–CL – Silty Clay Loam
- VFSCL–SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
- GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:

- L–CL – Loam to Clay Loam
- SiL – Silty Loam
- SiL–SiCL – Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:

- SL – Sandy Loam
- SL–SCL – Sandy Loam to Sandy Clay Loam
- SCL–SL – Sandy Clay Loam to Sandy Loam
- LS – Loamy Sand
- S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

- D – Dry
- M – Moist
- SM – Slightly Moist
- VM – Very Moist
- SAT – Saturated

GEOLOGIC UNIT

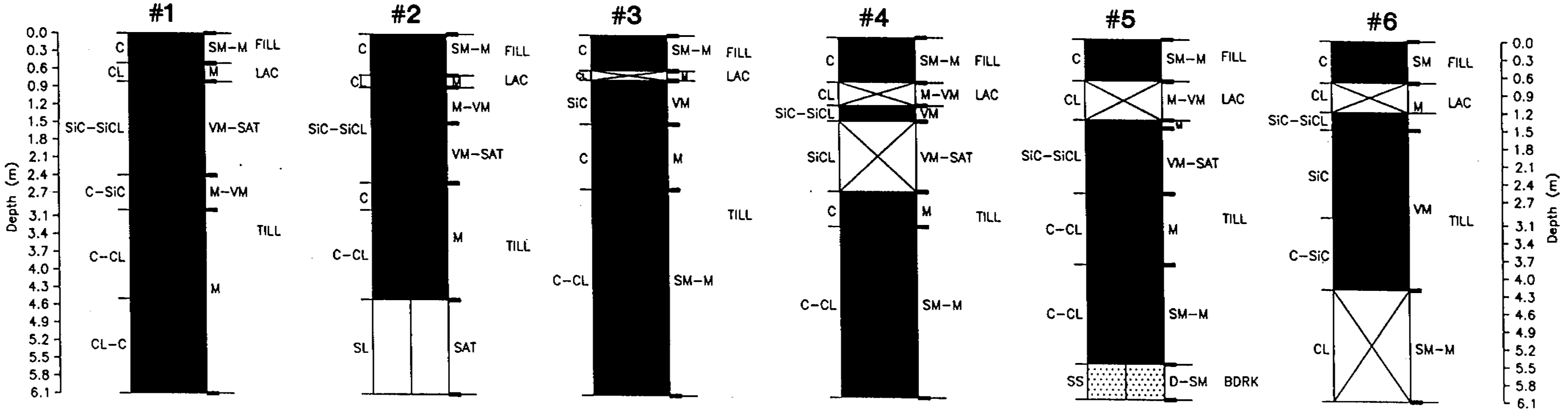
- FILL
- TILL
- OB – OVERBURDEN
- LAC – LACUSTRINE
- FLUV – FLUVIAL
- BDRK – BEDROCK

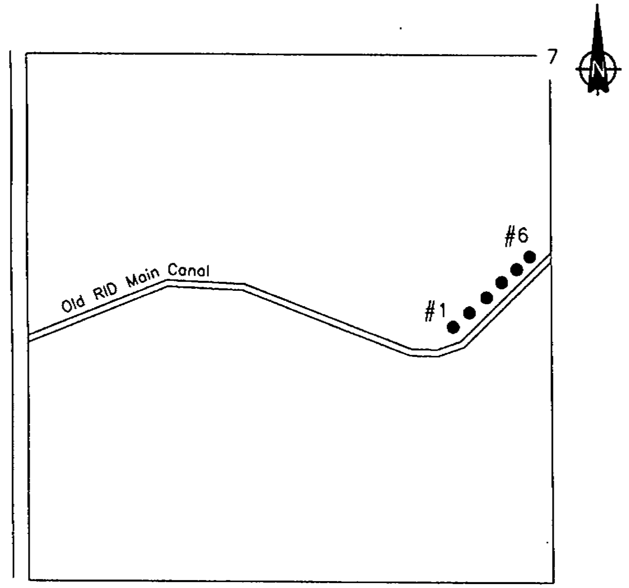
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.
DATE Oct. 5/98
SCALE N.T.S.
REV DATE

M.V.I.D.
NE 14-002-28-4
Figure B-11
Seepage Study, Site 11
FILE NAME A9800101
SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

░ SS – Sandstone

SOIL MOISTURE

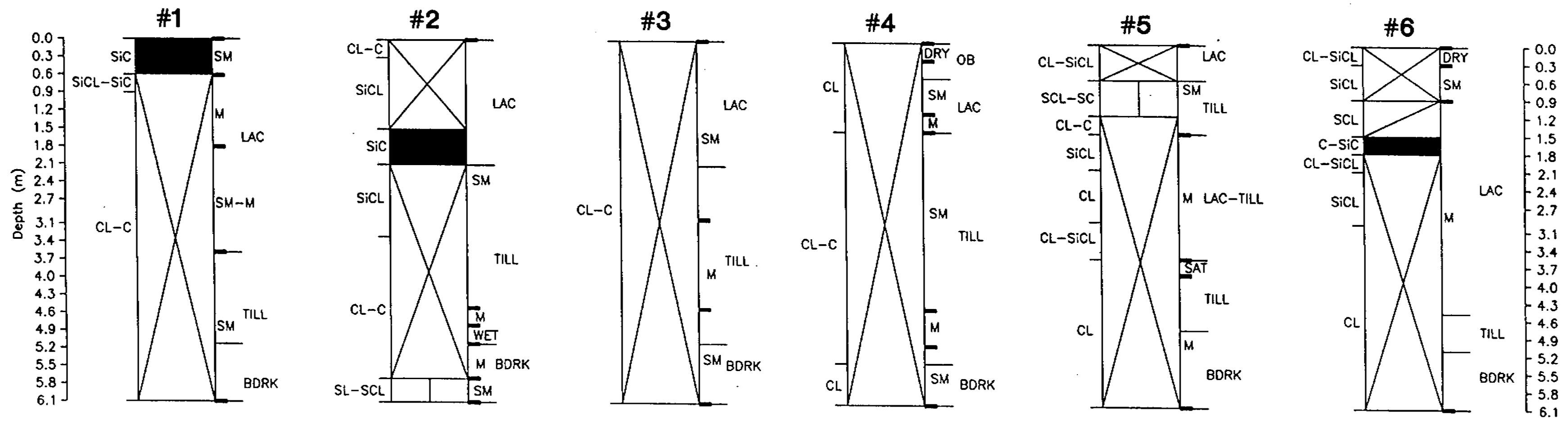
D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

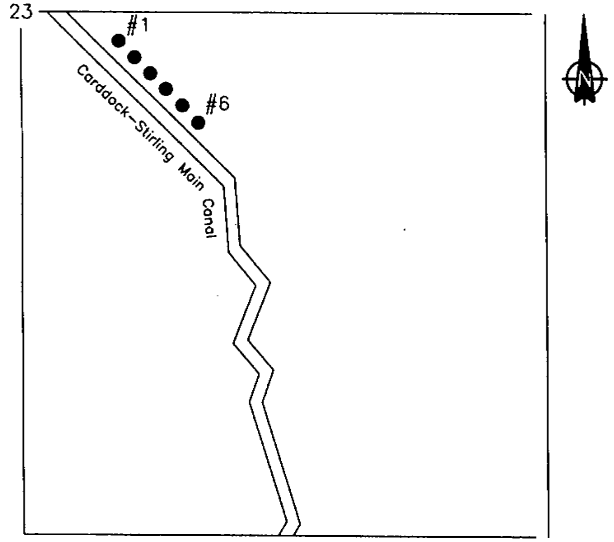
GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch		R.I.D. SW 7-006-20-W4
DRAWN BFC DATE June 1999	SCALE N.T.S. REV DATE	Figure B-12 Seepage Study, Site 12
		FILE NAME D9900201 | SHEET OF

TEST HOLES





SOIL TEXTURE

■ **FINE TEXTURED:**

- C – Clay
- C-SiC – Clay to Silty Clay
- SiC – Silty Clay
- C-SC – Clay to Sandy Clay
- SC – Sandy Clay
- SiC-VFSC – Silty Clay to Very Fine Sandy Clay
- SiC-SiCL – Silty Clay to Silty Clay Loam
- C-CL – Clay to Clay Loam

☒ **MODERATELY FINE TEXTURED:**

- CL – Clay Loam
- CL-SCL – Clay Loam to Sandy Clay Loam
- SCL-CL – Sandy Clay Loam to Clay Loam
- SCL-SC – Sandy Clay Loam to Sandy Clay
- SCL – Sandy Clay Loam
- FSCL – Fine Sandy Clay Loam
- VFSCL – Very Fine Sandy Clay Loam
- SiCL-SiC – Silty Clay Loam to Silty Clay
- SiCL – Silty Clay Loam
- CL-C – Clay Loam to Clay
- FSCL-CL – Silty Clay Loam
- VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
- GRCL – Gravelly Clay Loam

◿ **MEDIUM TEXTURED:**

- L-CL – Loam to Clay Loam
- SiL – Silty Loam
- SiL-SiCL – Silty Loam to Silty Clay Loam

▯ **COARSE TEXTURED:**

- SL – Sandy Loam
- SL-SCL – Sandy Loam to Sandy Clay Loam
- SCL-SL – Sandy Člay Loam to Sandy Loam
- LS – Loamy Sand
- S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

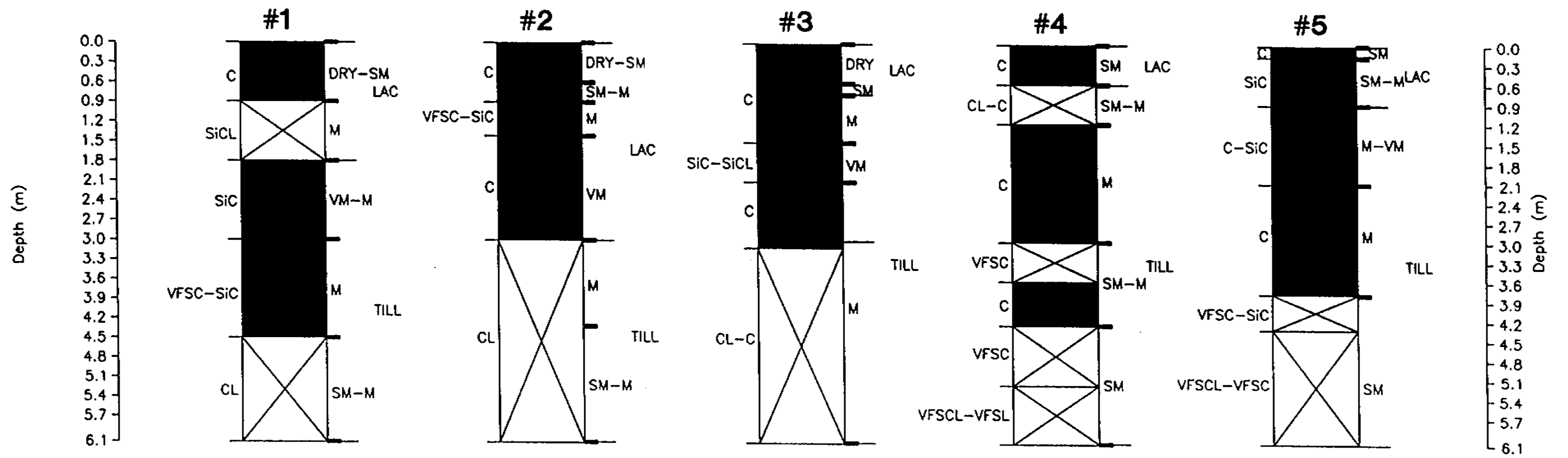
- D – Dry
- M – Moist
- SM – Slightly Moist
- VM – Very Moist
- SAT – Saturated

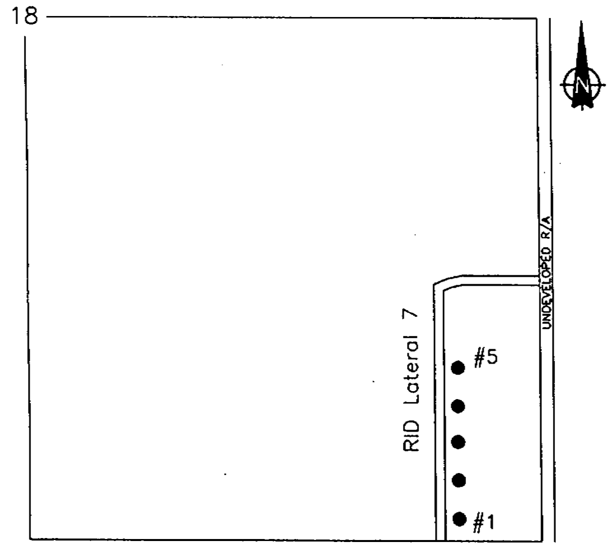
GEOLOGIC UNIT

- FILL
- TILL
- OB – OVERBURDEN
- LAC – LACUSTRINE
- FLUV – FLUVIAL
- BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch		R.I.D.
		SE 23-006-19-4
DRAWN BFC	SCALE N.T.S.	Figure B-13
DATE June 1999	REV DATE	Seepage Study, Site 13
		FILE NAME J9900101 SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

⧄ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

◫ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▦ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

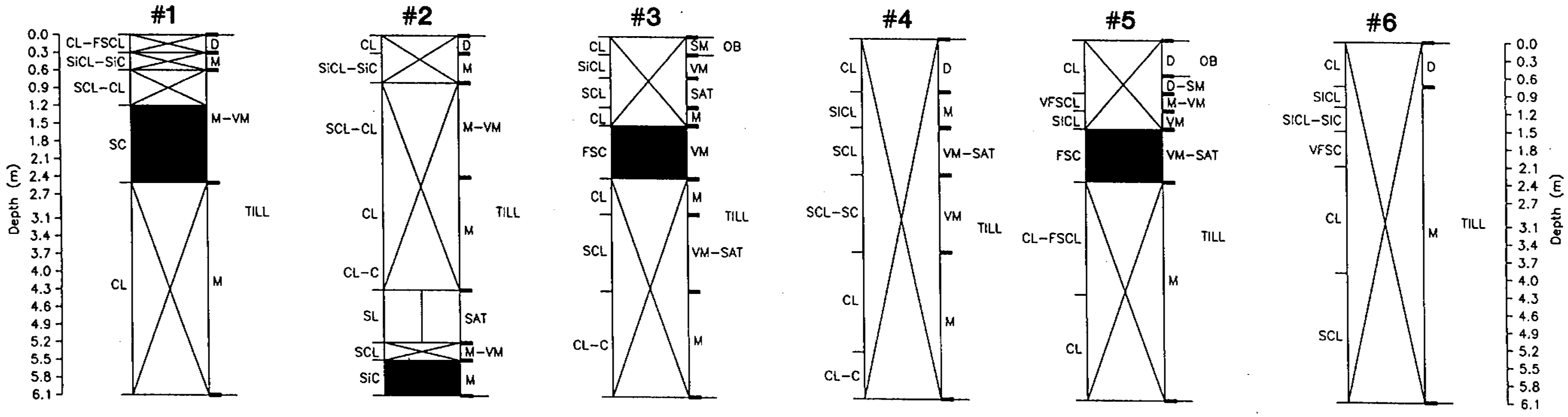
GEOLOGIC UNIT

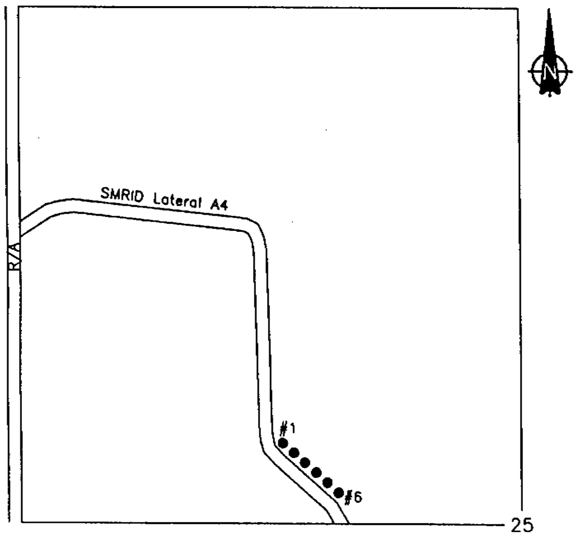
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.	SCALE N.T.S.	R.I.D.
DATE Feb. 19,1999	REV DATE	SE 18-006-21-W4
		Figure B-14 Seepage Study, Site 14
		FILE NAME M9900105 SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C–SiC – Clay to Silty Clay
SiC – Silty Clay
C–SC – Clay to Sandy Clay
SC – Sandy Clay
SiC–VFSC – Silty Clay to Very Fine Sandy Clay
SiC–SiCL – Silty Clay to Silty Clay Loam
C–CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL–SCL – Clay Loam to Sandy Clay Loam
SCL–CL – Sandy Clay Loam to Clay Loam
SCL–SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL–SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL–C – Clay Loam to Clay
FSCL–CL – Silty Clay Loam
VFSCL–SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L–CL – Loam to Clay Loam
SiL – Silty Loam
SiL–SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL–SCL – Sandy Loam to Sandy Clay Loam
SCL–SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

⬚ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

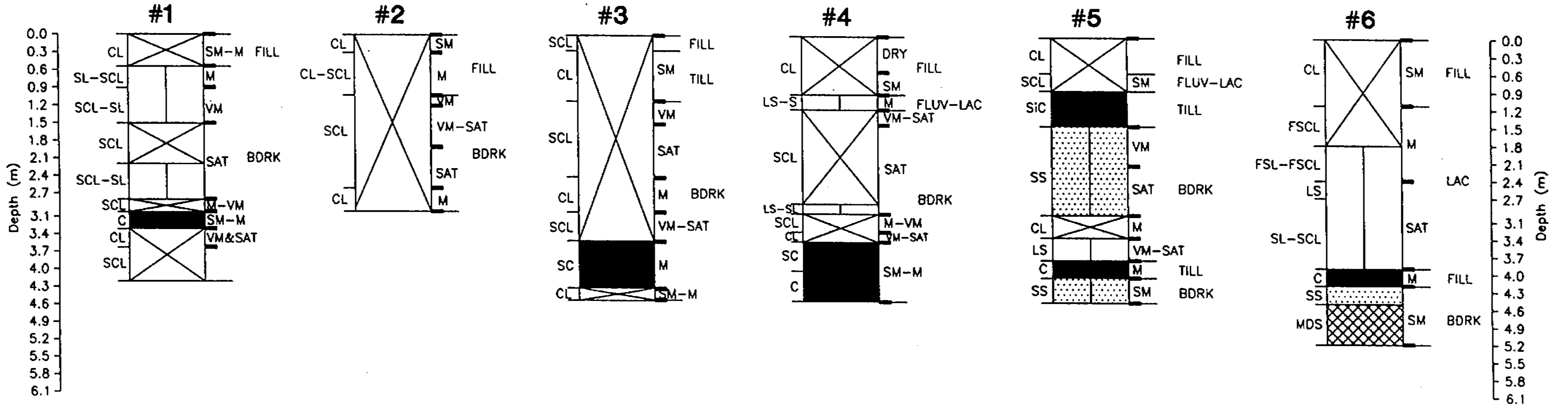
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

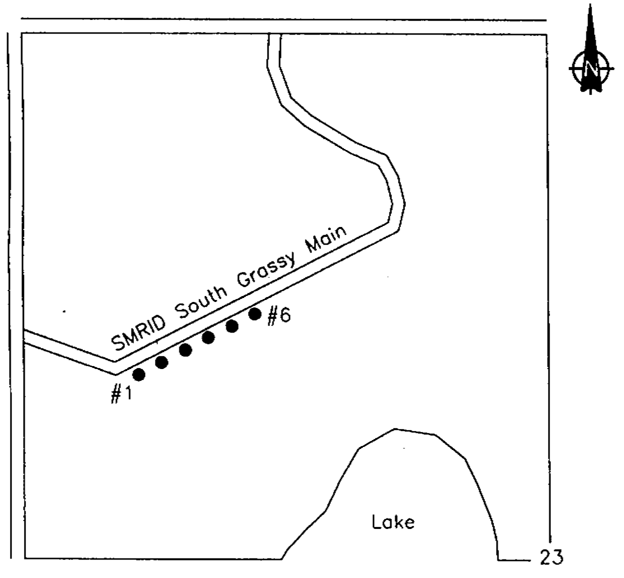
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.
DATE Oct. 5/98
SCALE N.T.S.
REV DATE

S.M.R.I.D.
NW 25-007-21-4
Figure B-15
Seepage Study, Site 15
FILE NAME J9800102
SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C	– Clay
C-SiC	– Clay to Silty Clay
SiC	– Silty Clay
C-SC	– Clay to Sandy Clay
SC	– Sandy Clay
SiC-VFSC	– Silty Clay to Very Fine Sandy Clay
SiC-SiCL	– Silty Clay to Silty Clay Loam
C-CL	– Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL	– Clay Loam
CL-SCL	– Clay Loam to Sandy Clay Loam
SCL-CL	– Sandy Clay Loam to Clay Loam
SCL-SC	– Sandy Clay Loam to Sandy Clay
SCL	– Sandy Clay Loam
FSCL	– Fine Sandy Clay Loam
VFSCL	– Very Fine Sandy Clay Loam
SiCL-SiC	– Silty Clay Loam to Silty Clay
SiCL	– Silty Clay Loam
CL-C	– Clay Loam to Clay
FSCL-CL	– Silty Clay Loam
VFSCL-SiCL	– Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL	– Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL	– Loam to Clay Loam
SiL	– Silty Loam
SiL-SiCL	– Silty Loam to Silty Clay Loam

◫ COARSE TEXTURED:

SL	– Sandy Loam
SL-SCL	– Sandy Loam to Sandy Clay Loam
SCL-SL	– Sandy Clay Loam to Sandy Loam
LS	– Loamy Sand
S	– Sand

▦	SiS	– Siltstone
	MDS	– Mudstone
▤	CS	– Claystone
⁙	SS	– Sandstone

SOIL MOISTURE

D	– Dry
M	– Moist
SM	– Slightly Moist
VM	– Very Moist
SAT	– Saturated

GEOLOGIC UNIT

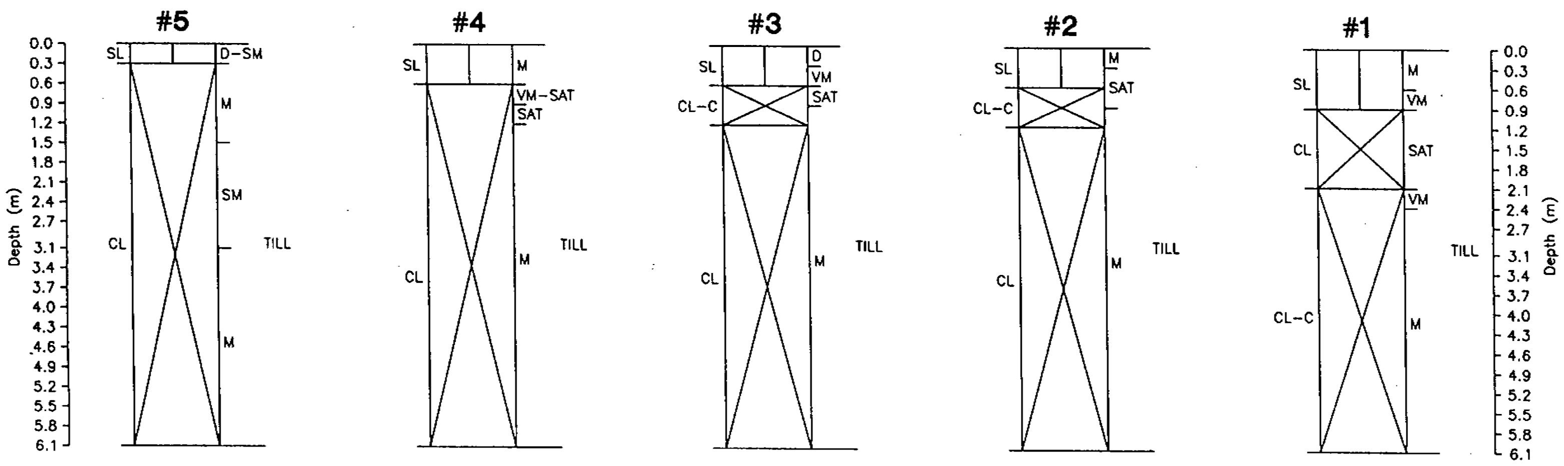
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

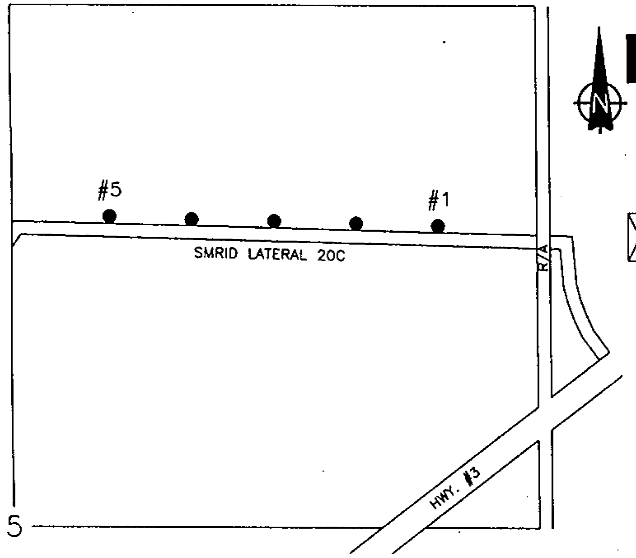
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN BFC
DATE June 1999
SCALE N.T.S.
REV DATE

S.M.R.I.D.
NW 34-009-14-W4
Figure B-16
Seepage Study, Site 16
FILE NAME J9900201
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

░ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

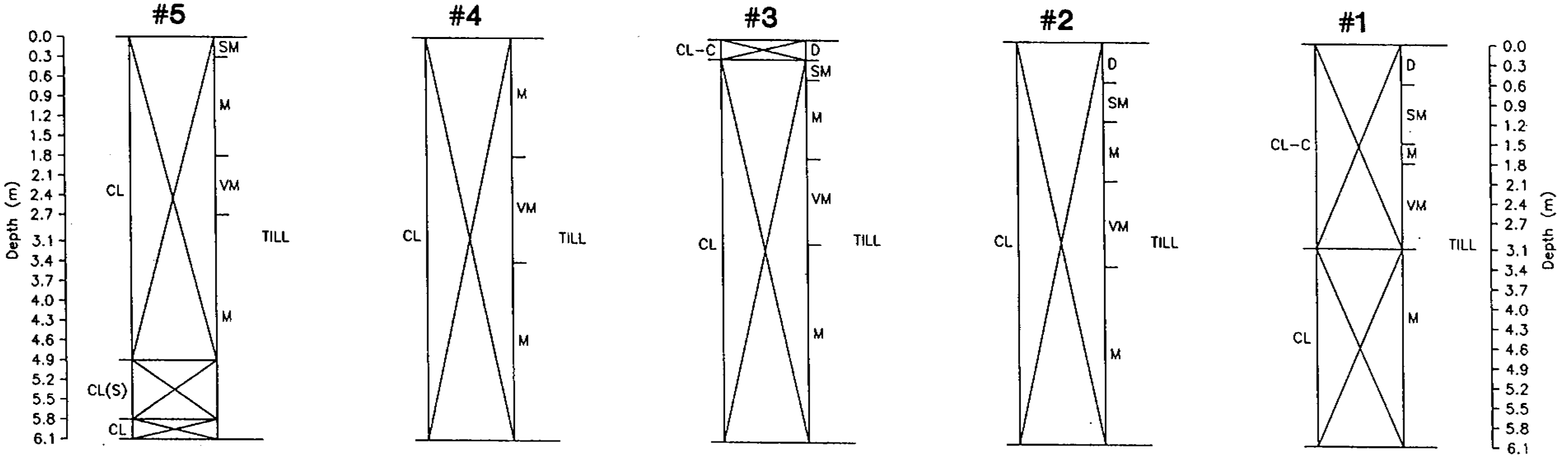
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

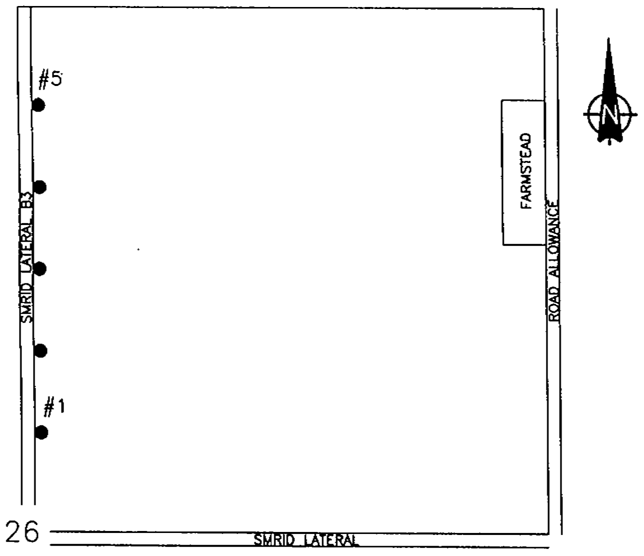
Alberta Agriculture, food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

S.M.R.I.D.
NE 5-011-10-W4
Figure B-17
Seepage Study, Site 17

DRAWN L.B.K.
DATE Feb. 25, 1997
SCALE N.T.S.
REV DATE
FILE NAME J9700102
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C - Clay
C-SiC - Clay to Silty Clay
SiC - Silty Clay
C-SC - Clay to Sandy Clay
SC - Sandy Clay
SiC-VFSC - Silty Clay to Very Fine Sandy Clay
SiC-SiCL - Silty Clay to Silty Clay Loam
C-CL - Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL - Clay Loam
CL-SCL - Clay Loam to Sandy Clay Loam
SCL-CL - Sandy Clay Loam to Clay Loam
SCL-SC - Sandy Clay Loam to Sandy Clay
SCL - Sandy Clay Loam
FSCL - Fine Sandy Clay Loam
VFSCL - Very Fine Sandy Clay Loam
SiCL-SiC - Silty Clay Loam to Silty Clay
SiCL - Silty Clay Loam
CL-C - Clay Loam to Clay
FSCL-CL - Silty Clay Loam
VFSCL-SiCL - Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL - Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL - Loam to Clay Loam
SiL - Silty Loam
SiL-SiCL - Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL - Sandy Loam
SL-SCL - Sandy Loam to Sandy Clay Loam
SCL-SL - Sandy Clay Loam to Sandy Loam
LS - Loamy Sand
S - Sand

▩ SiS - Siltstone
MDS - Mudstone

▤ CS - Claystone

▒ SS - Sandstone

SOIL MOISTURE

D - Dry
M - Moist
SM - Slightly Moist
VM - Very Moist
SAT - Saturated

GEOLOGIC UNIT

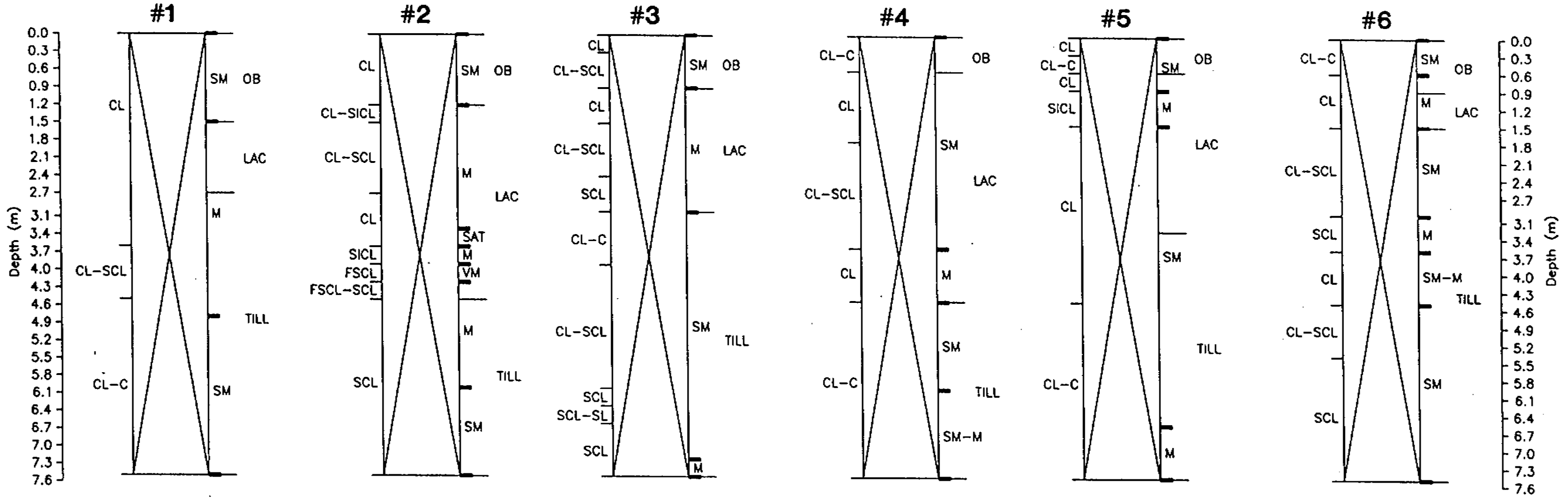
FILL
TILL
OB - OVERBURDEN
LAC - LACUSTRINE
FLUV - FLUVIAL
BDRK - BEDROCK

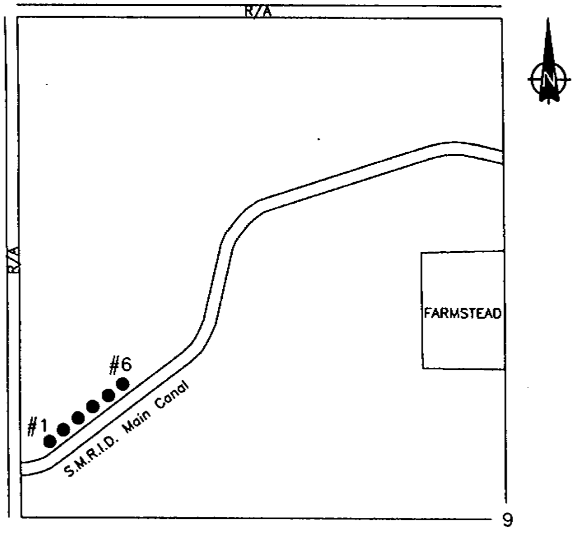
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.
DATE Feb. 25, 1997
SCALE N.T.S.
REV DATE

S.M.R.I.D.
NE 26-008-19-W4
Figure B-18
Seepage Study, Site 18
FILE NAME J9700101
SHEET OF

TEST HOLES





SOIL TEXTURE

■ **FINE TEXTURED:**

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ **MODERATELY FINE TEXTURED:**

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ **MEDIUM TEXTURED:**

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▥ **COARSE TEXTURED:**

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

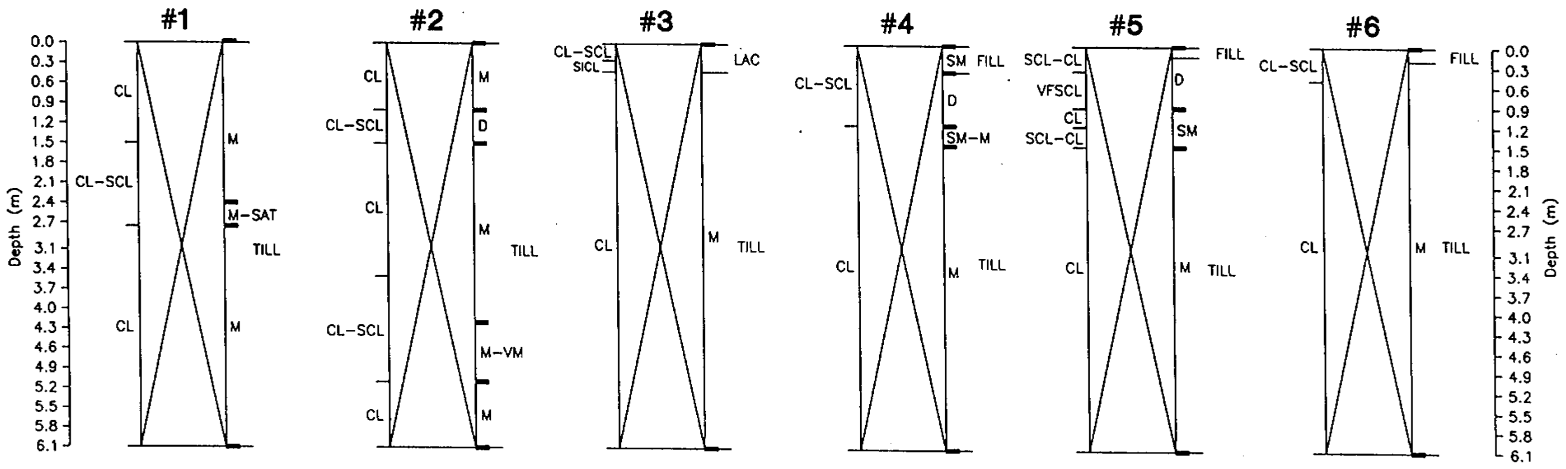
D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

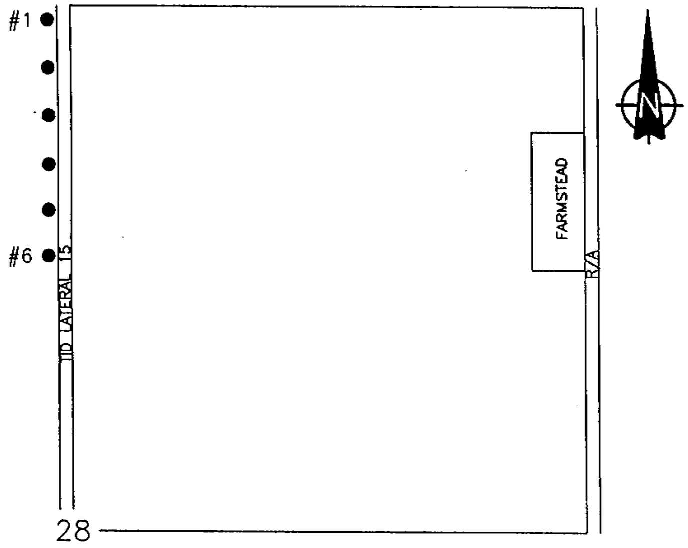
GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch		S.M.R.I.D.
		NW 9-011-06-4
DRAWN L.B.K.	SCALE N.T.S.	Figure B-19 Seepage Study, Site 19
DATE Feb. 9, 1998	REV DATE	FILE NAME J9800101 SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C - Clay
C-SiC - Clay to Silty Clay
SiC - Silty Clay
C-SC - Clay to Sandy Clay
SC - Sandy Clay
SiC-VFSC - Silty Clay to Very Fine Sandy Clay
SiC-SiCL - Silty Clay to Silty Clay Loam
C-CL - Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL - Clay Loam
CL-SCL - Clay Loam to Sandy Clay Loam
SCL-CL - Sandy Clay Loam to Clay Loam
SCL-SC - Sandy Clay Loam to Sandy Clay
SCL - Sandy Clay Loam
FSCL - Fine Sandy Clay Loam
VFSCL - Very Fine Sandy Clay Loam
SiCL-SiC - Silty Clay Loam to Silty Clay
SiCL - Silty Clay Loam
CL-C - Clay Loam to Clay
FSCL-CL - Silty Clay Loam
VFSCL-SiCL - Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL - Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL - Loam to Clay Loam
SiL - Silty Loam
SiL-SiCL - Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL - Sandy Loam
SL-SCL - Sandy Loam to Sandy Clay Loam
SCL-SL - Sandy Clay Loam to Sandy Loam
LS - Loamy Sand
S - Sand

▩ SiS - Siltstone
MDS - Mudstone

▤ CS - Claystone

⬚ SS - Sandstone

SOIL MOISTURE

D - Dry
M - Moist
SM - Slightly Moist
VM - Very Moist
SAT - Saturated

GEOLOGIC UNIT

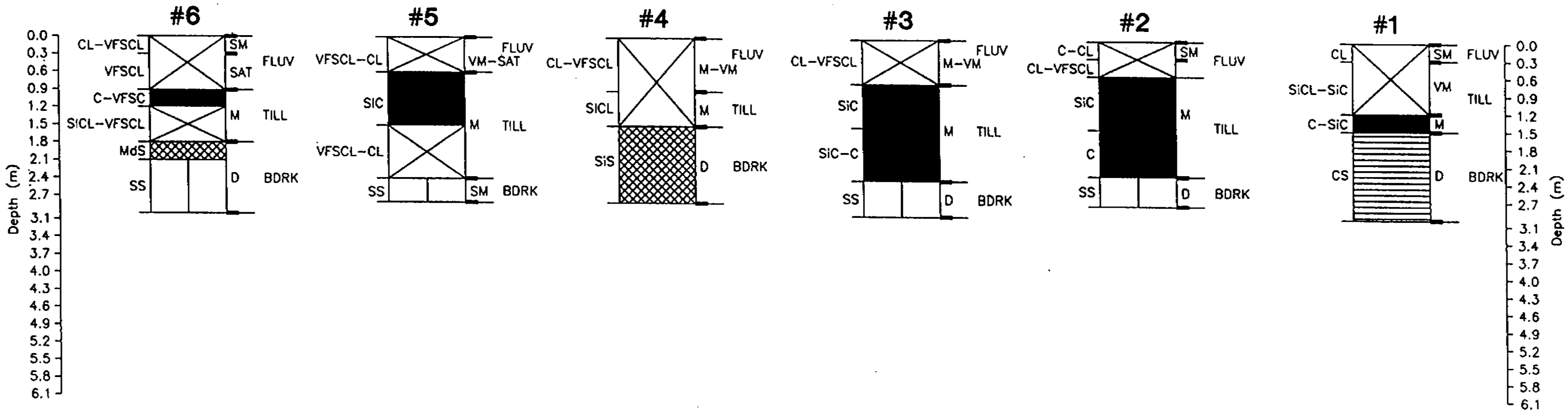
FILL
TILL
OB - OVERBURDEN
LAC - LACUSTRINE
FLUV - FLUVIAL
BDRK - BEDROCK

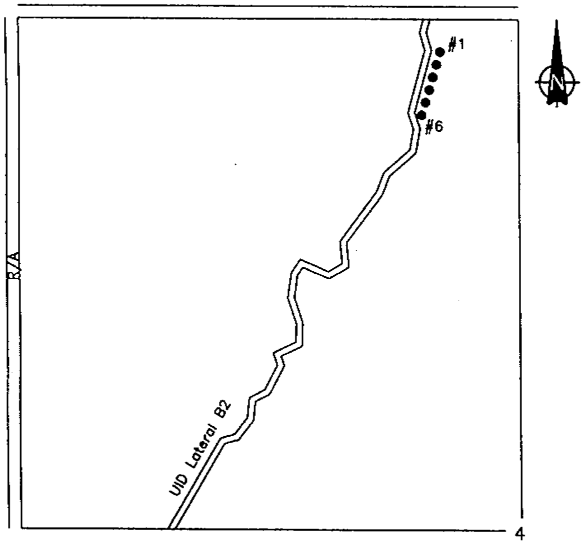
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.
DATE July 22, 1997
SCALE N.T.S.
REV DATE

T.I.D.
NE 28-009-16-4
Figure B-20
Seepage Study, Site 20
FILE NAME H9700101
SHEET OF

TEST HOLES





SOIL TEXTURE

■ **FINE TEXTURED:**

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ **MODERATELY FINE TEXTURED:**

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ **MEDIUM TEXTURED:**

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▯ **COARSE TEXTURED:**

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▦ SiS – Siltstone
MDS – Mudstone

☰ CS – Claystone

⁙ SS – Sandstone

SOIL MOISTURE

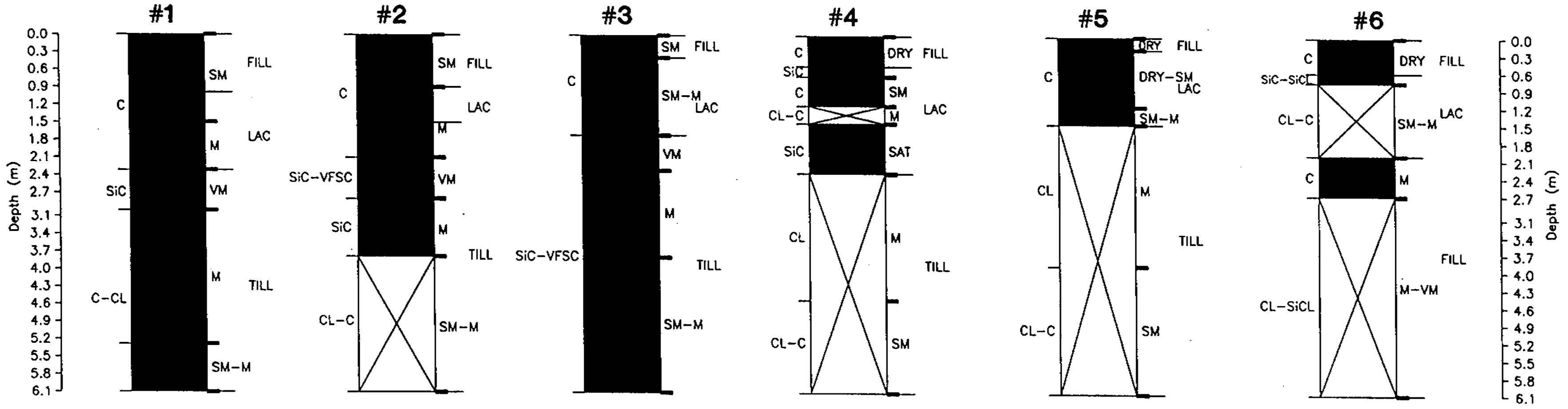
D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

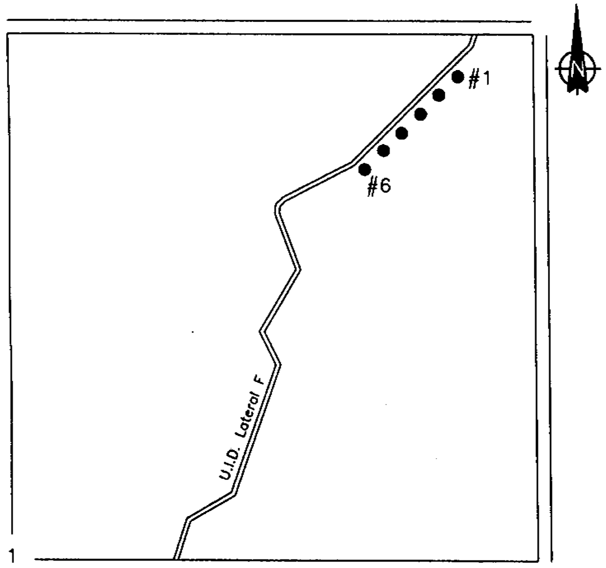
GEOLOGIC UNIT

FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch	U.I.D.
	NW 4-005-27-4
DRAWN L.B.K. SCALE N.T.S.	Figure B-21 Seepage Study, Site 21
DATE Oct. 5/98 REV DATE	FILE NAME D9800101 SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

░ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

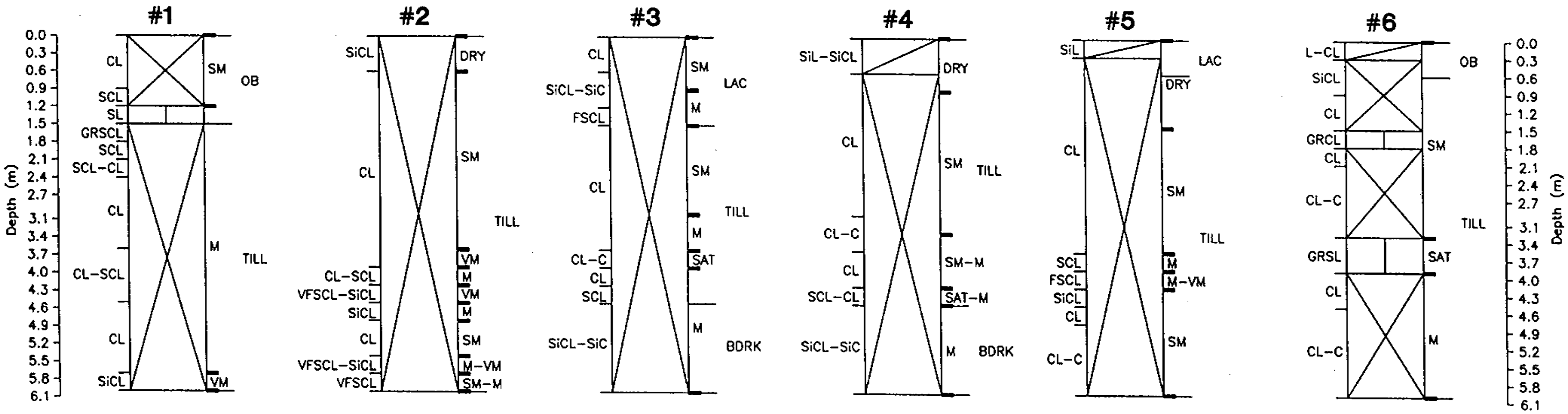
FILL
TILL
OB – OVERBURDEN
LAC – LACUSTRINE
FLUV – FLUVIAL
BDRK – BEDROCK

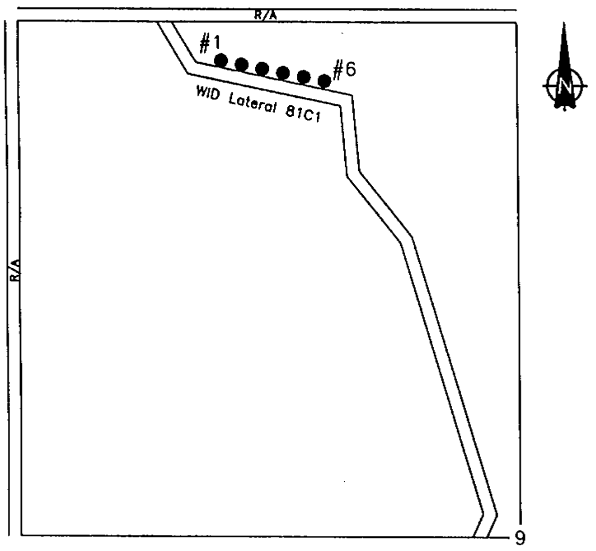
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN BFC
DATE June 1999
SCALE N.T.S.
REV DATE

U.I.D.
NE 1-005-27-W4
Figure B-22
Seepage Study, Site 22
FILE NAME D9900101
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:
C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:
CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:
L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:
SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

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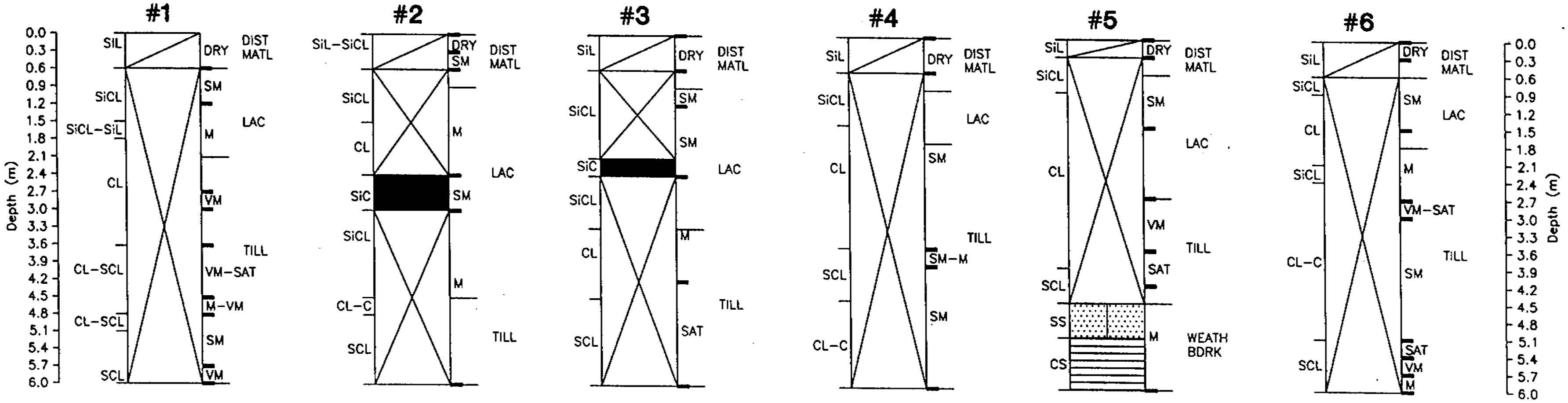
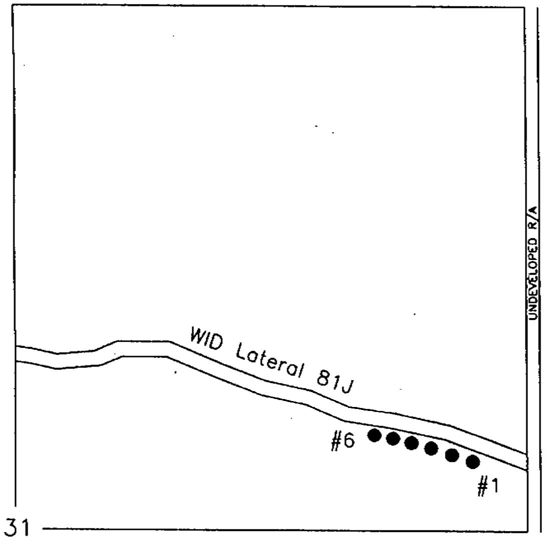
BDRK – BEDROCK

Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN L.B.K.	SCALE N.T.S.	W.I.D.
DATE Mar. 9, 1998	REV DATE	NW 9-022-26-4
		Figure B-23 Seepage Study, Site 23
		FILE NAME M9800101 | SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C–SiC – Clay to Silty Clay
SiC – Silty Clay
C–SC – Clay to Sandy Clay
SC – Sandy Clay
SiC–VFSC – Silty Clay to Very Fine Sandy Clay
SiC–SiCL – Silty Clay to Silty Clay Loam
C–CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL–SCL – Clay Loam to Sandy Clay Loam
SCL–CL – Sandy Clay Loam to Clay Loam
SCL–SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL–SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL–C – Clay Loam to Clay
FSCL–CL – Silty Clay Loam
VFSCL–SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

◺ MEDIUM TEXTURED:

L–CL – Loam to Clay Loam
SiL – Silty Loam
SiL–SiCL – Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL – Sandy Loam
SL–SCL – Sandy Loam to Sandy Clay Loam
SCL–SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
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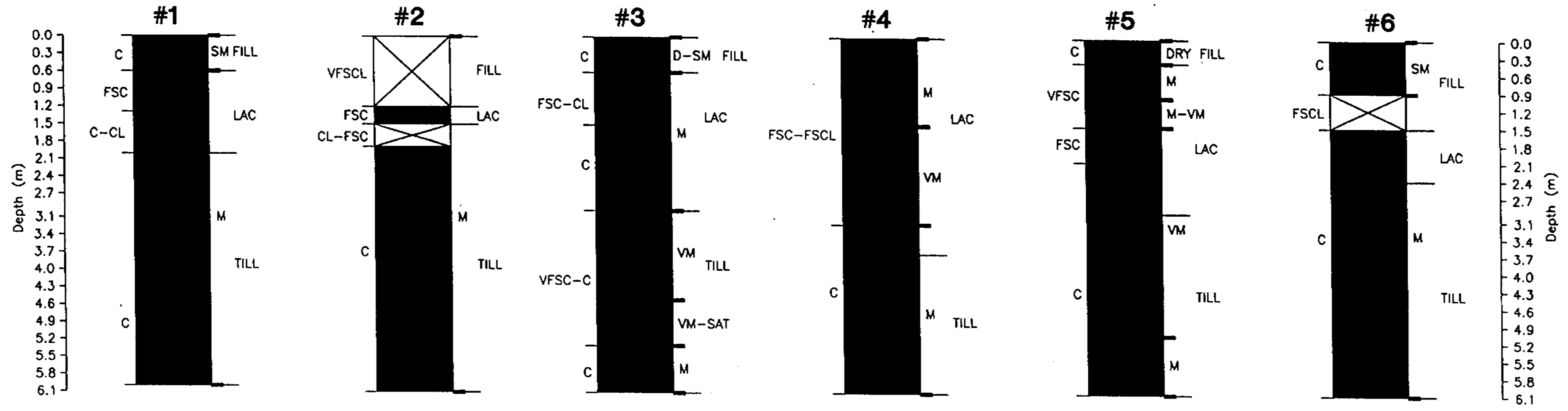
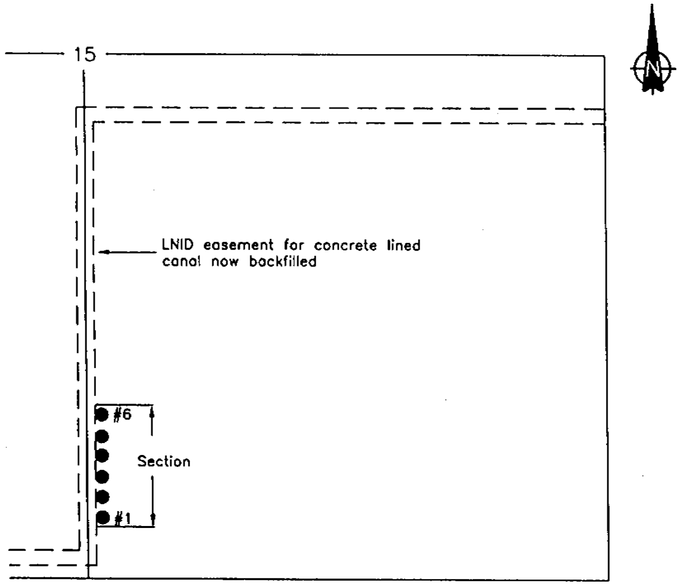
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.
DATE Feb. 19,1999
SCALE N.T.S.
REV DATE

W.I.D.
NE 31–022–22–W4
Figure B–24
Seepage Study, Site 24
FILE NAME M9900101
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C - Clay
C-SiC - Clay to Silty Clay
SiC - Silty Clay
C-SC - Clay to Sandy Clay
SC - Sandy Clay
SiC-VFSC - Silty Clay to Very Fine Sandy Clay
SiC-SiCL - Silty Clay to Silty Clay Loam
C-CL - Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL - Clay Loam
CL-SCL - Clay Loam to Sandy Clay Loam
SCL-CL - Sandy Clay Loam to Clay Loam
SCL-SC - Sandy Clay Loam to Sandy Clay
SCL - Sandy Clay Loam
FSCL - Fine Sandy Clay Loam
VFSCL - Very Fine Sandy Clay Loam
SiCL-SiC - Silty Clay Loam to Silty Clay
SiCL - Silty Clay Loam
CL-C - Clay Loam to Clay
FSCL-CL - Silty Clay Loam
VFSCL-SiCL - Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL - Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL - Loam to Clay Loam
SiL - Silty Loam
SiL-SiCL - Silty Loam to Silty Clay Loam

▯ COARSE TEXTURED:

SL - Sandy Loam
SL-SCL - Sandy Loam to Sandy Clay Loam
SCL-SL - Sandy Clay Loam to Sandy Loam
LS - Loamy Sand
S - Sand

▩ SiS - Siltstone
MDS - Mudstone

▤ CS - Claystone

░ SS - Sandstone

SOIL MOISTURE

D - Dry
M - Moist
SM - Slightly Moist
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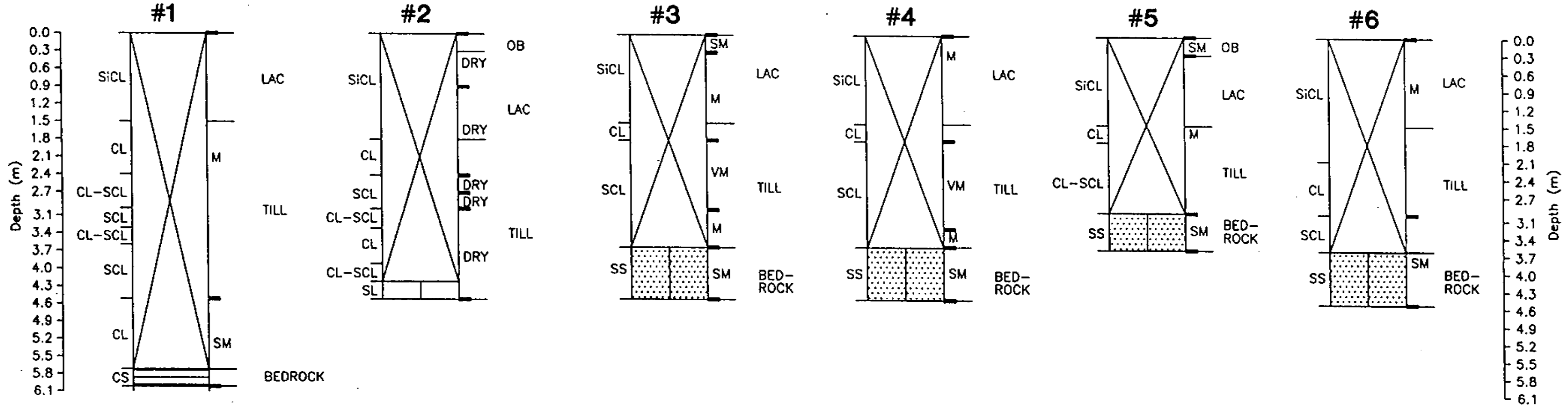
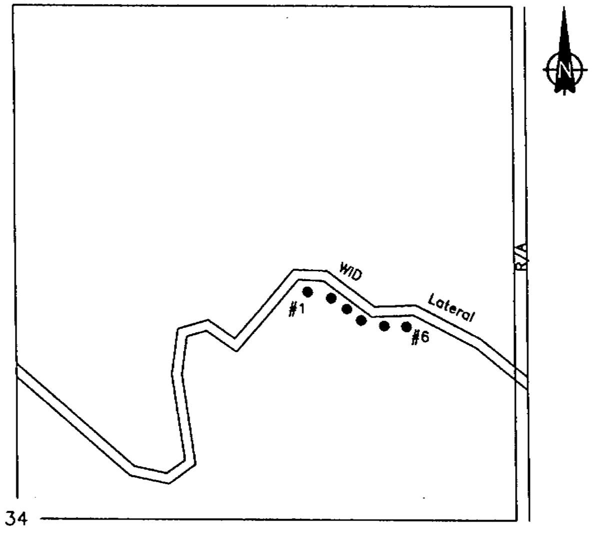
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN BFC	SCALE N.T.S.	L.N.I.D.
DATE Oct 1999	REV DATE	SE 15-010-22-W4
		Figure B-25 Seepage Study, Site 25
		FILE NAME G9900201 · SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

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CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to

GRCL – Gravelly Clay Loam

◪ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

◫ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▨ SS – Sandstone

SOIL MOISTURE

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M – Moist
SM – Slightly Moist
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GEOLOGIC UNIT

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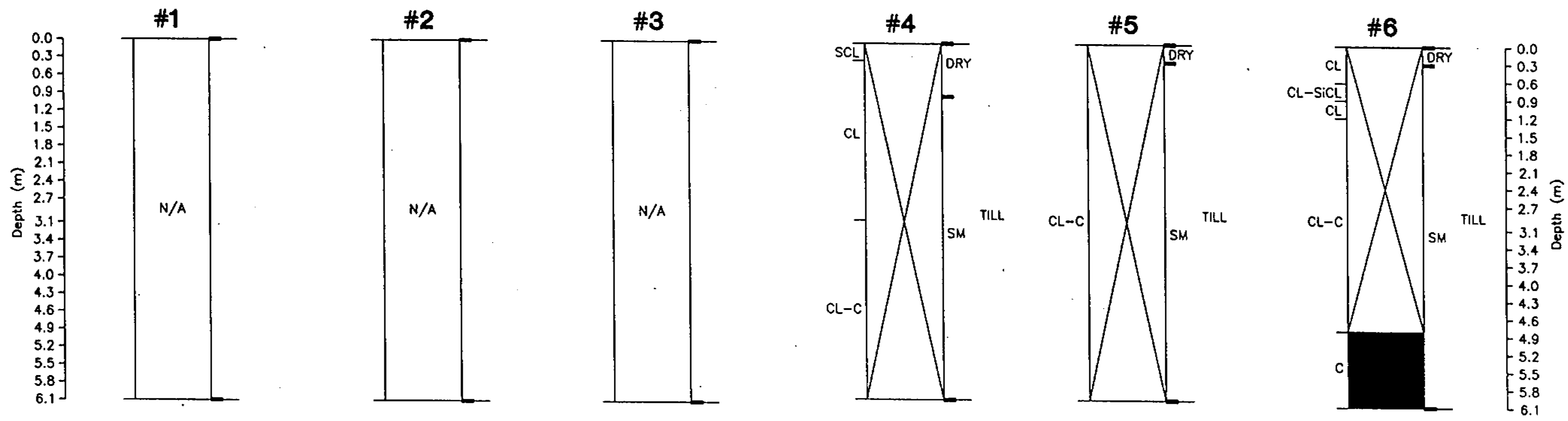
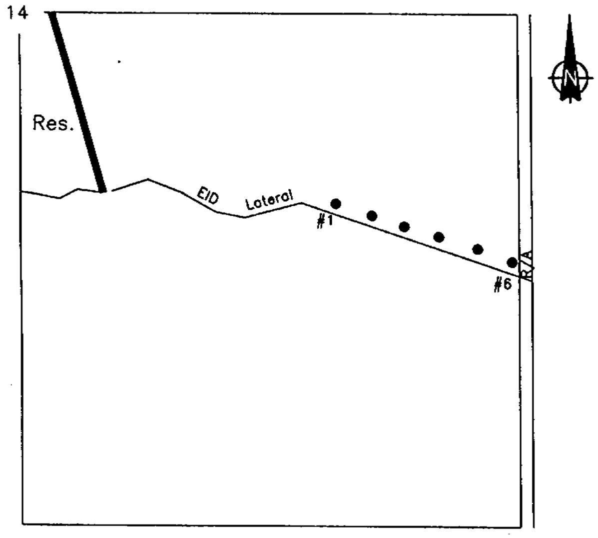
Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch

DRAWN B.F.C.
DATE Sept. 12/00
SCALE N.T.S.
REV DATE

W.I.D.
NE 34-024-24-W4
Figure B-26
Seepage Study, Site 26
FILE NAME M0000101
SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C - Clay
C-SiC - Clay to Silty Clay
SiC - Silty Clay
C-SC - Clay to Sandy Clay
SC - Sandy Clay
SiC-VFSC - Silty Clay to Very Fine Sandy Clay
SiC-SiCL - Silty Clay to Silty Clay Loam
C-CL - Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL - Clay Loam
CL-SCL - Clay Loam to Sandy Clay Loam
SCL-CL - Sandy Clay Loam to Clay Loam
SCL-SC - Sandy Clay Loam to Sandy Clay
SCL - Sandy Clay Loam
FSCL - Fine Sandy Clay Loam
VFSCL - Very Fine Sandy Clay Loam
SiCL-SiC - Silty Clay Loam to Silty Clay
SiCL - Silty Clay Loam
CL-C - Clay Loam to Clay
FSCL-CL - Silty Clay Loam
VFSCL-SiCL - Very Fine Sandy Clay Loam to

GRCL - Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL - Loam to Clay Loam
SiL - Silty Loam
SiL-SiCL - Silty Loam to Silty Clay Loam

◫ COARSE TEXTURED:

SL - Sandy Loam
SL-SCL - Sandy Loam to Sandy Clay Loam
SCL-SL - Sandy Clay Loam to Sandy Loam
LS - Loamy Sand
S - Sand

▩ SiS - Siltstone
MDS - Mudstone

▤ CS - Claystone

⬚ SS - Sandstone

SOIL MOISTURE

D - Dry
M - Moist
SM - Slightly Moist
VM - Very Moist
SAT - Saturated

GEOLOGIC UNIT

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OB - OVERBURDEN
LAC - LACUSTRINE
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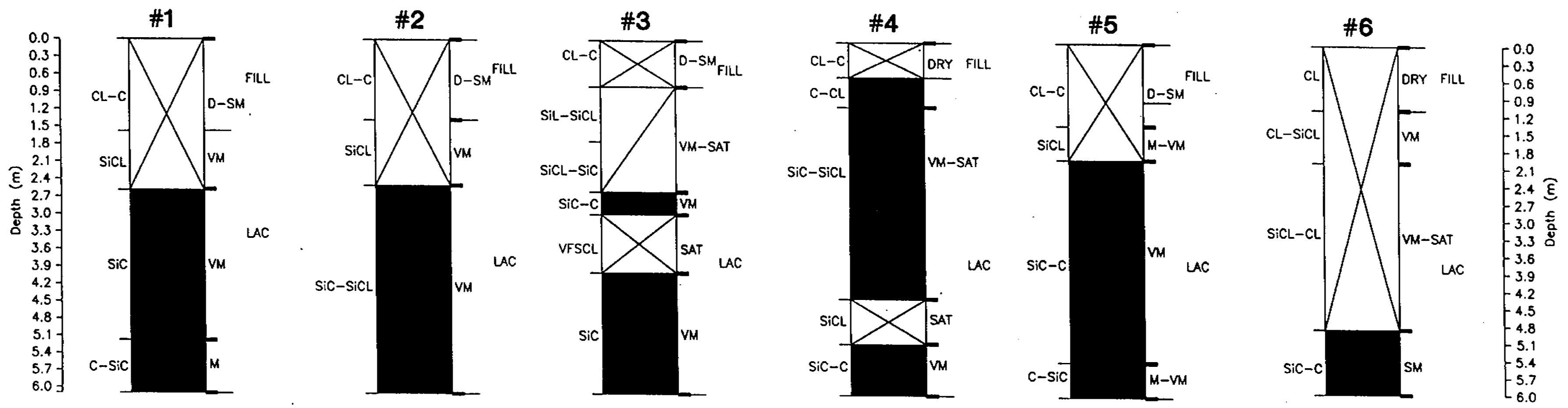
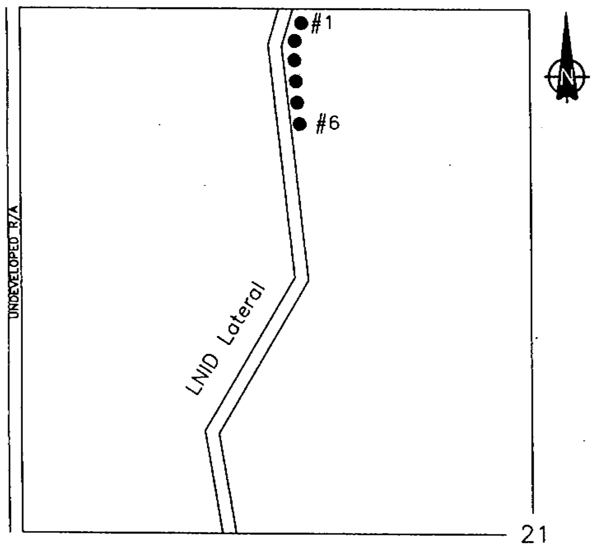
Alberta Agriculture, Food and Rural Development Resource Management and Irrigation Division Irrigation Branch	E.I.D.
	SE 11-020-15-W4
DRAWN B.F.C. SCALE N.T.S.	Figure B-27 Seepage Study, Site 27
DATE Sept. 12/00 REV DATE	FILE NAME N0000101 SHEET 1 OF 1

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:

C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:

CL – Clay Loam
CL-SCL – Clay Loam to Sandy Clay Loam
SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▨ MEDIUM TEXTURED:

L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:

SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
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▦ SiS – Siltstone
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SOIL MOISTURE

D – Dry
M – Moist
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GEOLOGIC UNIT

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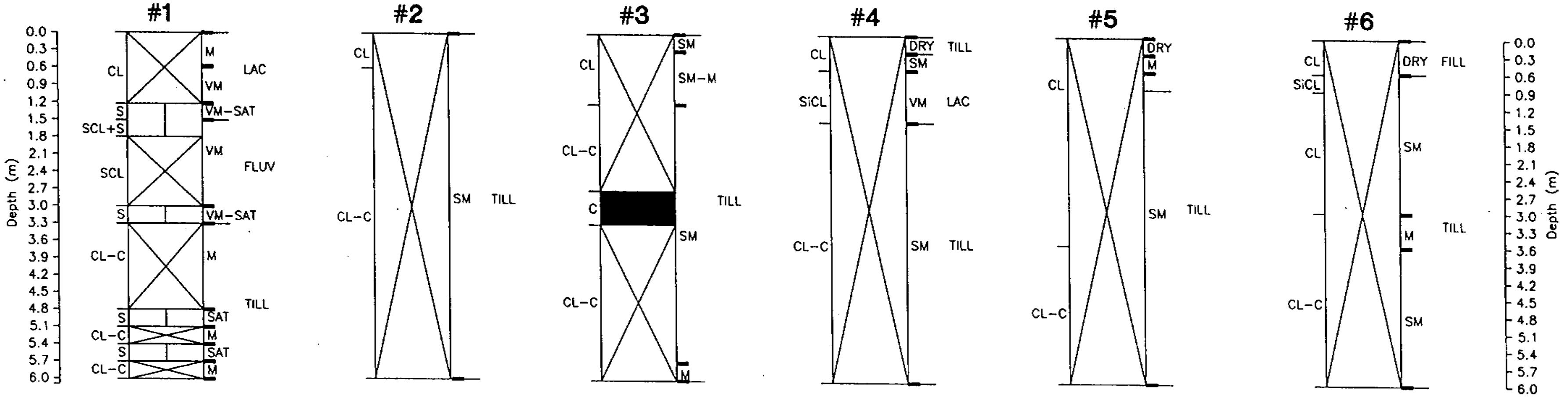
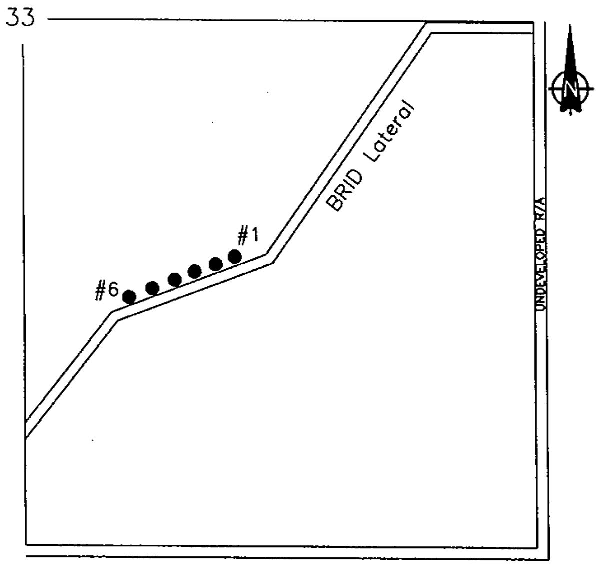
Alberta Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.
DATE Sept. 8,2000
SCALE N.T.S.
REV DATE

L.N.I.D.
NW 21-009-22-W4
Figure B-28
Seepage Study, Site 28
FILE NAME G0000101
SHEET OF

TEST HOLES





SOIL TEXTURE

■ FINE TEXTURED:
C – Clay
C-SiC – Clay to Silty Clay
SiC – Silty Clay
C-SC – Clay to Sandy Clay
SC – Sandy Clay
SiC-VFSC – Silty Clay to Very Fine Sandy Clay
SiC-SiCL – Silty Clay to Silty Clay Loam
C-CL – Clay to Clay Loam

☒ MODERATELY FINE TEXTURED:
CL – Clay Loam
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SCL-CL – Sandy Clay Loam to Clay Loam
SCL-SC – Sandy Clay Loam to Sandy Clay
SCL – Sandy Clay Loam
FSCL – Fine Sandy Clay Loam
VFSCL – Very Fine Sandy Clay Loam
SiCL-SiC – Silty Clay Loam to Silty Clay
SiCL – Silty Clay Loam
CL-C – Clay Loam to Clay
FSCL-CL – Silty Clay Loam
VFSCL-SiCL – Very Fine Sandy Clay Loam to Silty Clay Loam
GRCL – Gravelly Clay Loam

▧ MEDIUM TEXTURED:
L-CL – Loam to Clay Loam
SiL – Silty Loam
SiL-SiCL – Silty Loam to Silty Clay Loam

▥ COARSE TEXTURED:
SL – Sandy Loam
SL-SCL – Sandy Loam to Sandy Clay Loam
SCL-SL – Sandy Clay Loam to Sandy Loam
LS – Loamy Sand
S – Sand

▩ SiS – Siltstone
MDS – Mudstone

▤ CS – Claystone

▒ SS – Sandstone

SOIL MOISTURE

D – Dry
M – Moist
SM – Slightly Moist
VM – Very Moist
SAT – Saturated

GEOLOGIC UNIT

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Alberta
Agriculture, Food and Rural Development
Resource Management and Irrigation Division
Irrigation Branch

DRAWN B.F.C.
DATE Sept. 8,2000
SCALE N.T.S.
REV DATE

B.R.I.D.
SE 33-015-18-W4
Figure B-29
Seepage Study, Site 29
FILE NAME L0000101
SHEET OF

APPENDIX C

Ponding Test Results by Site

SEEPAGE STUDY
Site No. 1
AID - Lateral A1 - Data and Results

(SW 27-2-25-4)

Initial Water Depth (d1) = 0.6561 m

Bottom Width (b) = 3.0480 m

Width of Water Surface (w1) = 4.2673 m

Side Slope (z) = 0.9292

Length (L) = 152 m

MONTH/DAY 1998	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/17	0.6561	0.0000	0.6561	0.6344	0.0020	0.0197	0.6561	4.2673	4.8392	0.0174
10/18	0.6344	0.0000	0.6344	0.6181	0.0020	0.0143	0.6364	4.2307	4.7855	0.0126
10/19	0.6181	0.0000	0.6181	0.6056	0.0020	0.0105	0.6221	4.2041	4.7464	0.0093
10/20	0.6056	0.0000	0.6056	0.5930	0.0010	0.0116	0.6116	4.1846	4.7178	0.0103
10/21	0.5930	0.0000	0.5930	0.5811	0.0040	0.0079	0.6000	4.1630	4.6861	0.0070
10/22	0.5811	0.0000	0.5811	0.5678	0.0032	0.0101	0.5921	4.1484	4.6645	0.0090
10/23	0.5678	0.0000	0.5678	0.5562	0.0032	0.0084	0.5820	4.1296	4.6369	0.0075
10/24	0.5562	0.0000	0.5562	0.5454	0.0032	0.0076	0.5736	4.1140	4.6140	0.0068
10/25	0.5454	0.0000	0.5454	0.5335	0.0032	0.0087	0.5660	4.0999	4.5933	0.0078
10/26	0.5335	0.0000	0.5335	0.5233	0.0032	0.0070	0.5573	4.0837	4.5695	0.0063
10/27	0.5233	0.0002	0.5235	0.5135	0.0032	0.0068	0.5503	4.0707	4.5504	0.0061

Total Rainfall = 0.0002 Total Evaporation = 0.0302

Means = 0.0102 4.1542 4.6731 **0.0091**

Stanard Error = **0.0010**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **1.77%**

SEEPAGE STUDY

Site No. 2

BRID - Main Canal - Data and Results

(NE 12-13-14-4)

Initial Water Depth (d1) = 0.9649 m

Bottom Width (b) = 9.1441 m

Width of Water Surface (w 1) = 12.1921 m

Side Slope (z) = 1.5794

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
04/15	0.9649	0.0000	0.9649	0.9442	0.0047	0.0160	0.9649	12.1921	12.7517	0.0153
04/16	0.9442	0.0000	0.9442	0.9305	0.0047	0.0090	0.9489	12.1416	12.6918	0.0086
04/17	0.9305	0.0000	0.9305	0.9186	0.0047	0.0072	0.9399	12.1131	12.6582	0.0069
04/18	0.9186	0.0000	0.9186	0.9064	0.0047	0.0075	0.9327	12.0904	12.6313	0.0072
04/19	0.9064	0.0000	0.9064	0.8974	0.0047	0.0043	0.9252	12.0667	12.6032	0.0041
04/20	0.8974	0.0020	0.8994	0.8924	0.0046	0.0024	0.9209	12.0531	12.5871	0.0023
04/21	0.8924	0.0029	0.8953	0.887	0.0082	0.0001	0.9185	12.0455	12.5782	0.0001
04/22	0.887	0.0012	0.8882	0.8812	0.0012	0.0058	0.9184	12.0452	12.5778	0.0056
04/23	0.8812	0.0000	0.8812	0.8725	0.0025	0.0062	0.9126	12.0269	12.5561	0.0059

Total Rainfall = 0.0061 Total Evaporation = 0.0400

Means = 0.0065 12.0861 12.6262 **0.0062**

Stanard Error = **0.0014**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **0.76%**

SEEPAGE STUDY
Site No. 3
BRID - Lateral H - Data and Results

(SE 19-12-16-4)

Initial Water Depth (d1) = 0.6843 m

Bottom Width (b) = 2.4384 m

Width of Water Surface (w 1) = 6.3063 m

Side Slope (z) = 2.8262

Length (L) = 152 m

MONTH/DAY 1997	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2/ day)
10/17	0.6843	0.0000	0.6843	0.6648	0.0013	0.0182	0.6843	6.3063	6.5413	0.0175
10/18	0.6648	0.0020	0.6668	0.6509	0.0013	0.0146	0.6661	6.2035	6.4322	0.0141
10/19	0.6509	0.0000	0.6509	0.6357	0.0013	0.0139	0.6515	6.1209	6.3447	0.0134
10/20	0.6357	0.0000	0.6357	0.6209	0.0013	0.0135	0.6376	6.0424	6.2613	0.0130
10/21	0.6209	0.0000	0.6209	0.6086	0.0013	0.0110	0.6241	5.9661	6.1804	0.0106
10/22	0.6086	0.0002	0.6088	0.5956	0.0012	0.0120	0.6131	5.9039	6.1144	0.0116
10/23	0.5956	0.0000	0.5956	0.5832	0.0019	0.0105	0.6011	5.8361	6.0425	0.0101
10/24	0.5832	0.0002	0.5835	0.5714	0.0019	0.0102	0.5906	5.7767	5.9795	0.0099
10/25	0.5714	0.0002	0.5717	0.5604	0.0019	0.0094	0.5804	5.7191	5.9184	0.0091
10/26	0.5604	0.0000	0.5604	0.5468	0.0019	0.0117	0.5710	5.6659	5.8620	0.0113
10/27	0.5468	0.0000	0.5468	0.5361	0.0019	0.0088	0.5593	5.5998	5.7919	0.0085

Total Rainfall = 0.0026 Total Evaporation = 0.0172

Means = 0.0122 5.9219 6.1335 **0.0117**

Stanard Error = **0.0008**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **2.40%**

SEEPAGE STUDY
Site No 4
BRID - Lateral A1 - Data and Results

(NW 20-13-16-4)

Initial Water Depth (d1) = 0.6656 m

Bottom Width (b) = 2.7432 m

Width of Water Surface (w 1) = 4.9531 m

Side Slope (z) = 1.6601

Length (L) = 152 m

MONTH/DAY 1998	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**y** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
10/16	0.6656	0.0000	0.6656	0.6080	0.0020	0.0556	0.6656	4.9531	5.3231	0.0517
10/17	0.6080	0.0002	0.6082	0.5587	0.0020	0.0475	0.6100	4.7685	5.1076	0.0443
10/18	0.5587	0.0000	0.5587	0.5124	0.0020	0.0443	0.5625	4.6108	4.9235	0.0415

Total Rainfall = 0.0002 Total Evaporation = 0.0060

Means = 0.0491 4.7775 5.1180 **0.0459**

Stanard Error = **0.0031**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **9.17%**

SEEPAGE STUDY
Site No. 5
EID - Lateral G - North Bantry - Field Data and Results
(NW 8-19-13-4)

Initial Water Depth (d1) = 1.0092 m

Bottom Width (b) = 4.27 m

Width of Water Surface (w 1) = 8.579 m

Side Slope (z) = 2.1362

Length (L) = 315 m

MONTH/DAY (1997)	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
08/28	1.0092	0.0000	1.0092	0.9975	0.0088	0.0029	1.0092	8.5790	9.0280	0.0028
08/29	0.9975	0.0000	0.9975	0.9895	0.0078	0.0002	1.0063	8.5666	9.0144	0.0002
08/30	0.9895	0.0000	0.9895	0.9798	0.0088	0.0009	1.0061	8.5658	9.0134	0.0009
08/31	0.9798	0.0000	0.9798	0.9706	0.0091	0.0001	1.0052	8.5619	9.0092	0.0001
09/01	0.9706	0.0000	0.9706	0.9606	0.0091	0.0009	1.0051	8.5615	9.0087	0.0009
09/02	0.9606	0.0000	0.9606	0.9445	0.0091	0.0070	1.0042	8.5576	9.0045	0.0067
09/03	0.9445	0.0061	0.9506	0.9505	0.0001	-0.0000	0.9972	8.5277	8.9714	-0.0000
09/04	0.9505	0.0000	0.9505	0.9427	0.0043	0.0035	0.9972	8.5277	8.9714	0.0033
09/05	0.9427	0.0000	0.9427	0.9318	0.0044	0.0065	0.9937	8.5128	8.9549	0.0062
09/06	0.9318	0.0000	0.9318	0.9143	0.0067	0.0108	0.9872	8.4850	8.9243	0.0103
09/07	0.9143	0.0000	0.9143	0.8954	0.0073	0.0116	0.9764	8.4389	8.8733	0.0110
09/08	0.8954	0.0000	0.8954	0.8835	0.0076	0.0043	0.9648	8.3893	8.8186	0.0041

Total Rainfall = 0.0061 Total Evaporation = 0.0831

Means = 0.0041 8.5228 8.9660 **0.0038**

Stanard Error = **0.0011**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **0.53%**

SEEPAGE STUDY
Site No. 6
LNID - Lateral B11 - Field Data and Results
(SE 27-10-23-4)

Initial Water Depth (d1) = 0.5778 m

Bottom Width (b) = 1.2954 m

Width of Water Surface (w 1) = 3.9963 m

Side Slope (z) = 2.337

Length (L) = 152 m

MONTH/DAY (1997)	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**y** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
05/14	0.5778	0.0000	0.5778	0.5365	0.0048	0.0365	0.5778	3.9963	4.2331	0.0345
05/15	0.5365	0.0000	0.5365	0.4714	0.0052	0.0599	0.5413	3.8257	4.0476	0.0566
05/16	0.4714	0.0000	0.4714	0.4159	0.0081	0.0474	0.4814	3.5457	3.7430	0.0449

Total Rainfall = 0.0000 Total Evaporation = 0.0181

Means = 0.0479 3.7892 4.0079 **0.0453**

Stanard Error = **0.0064**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **11.88%**

SEEPAGE STUDY
Site No. 7
LNID - Lateral DIA - Field Data and Results
(NW 10-10-22-4)

Initial Water Depth (d1) = 0.5789 m

Bottom Width (b) = 0.9144 m

Width of Water Surface (w 1) = 3.81 m

Side Slope (z) = 2.50

Length (L) = 152 m

MONTH/DAY 1998	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
05/10	0.5789	0.0005	0.5794	0.5321	0.0075	0.0398	0.5789	3.8100	4.0329	0.0376
05/11	0.5321	0.0000	0.5321	0.4904	0.0075	0.0342	0.5391	3.6109	3.8185	0.0323
05/12	0.4904	0.0000	0.4904	0.4500	0.0065	0.0339	0.5049	3.4399	3.6343	0.0321

Total Rainfall = 0.0005 Total Evaporation = 0.0215

Meams = 0.0360 3.6203 3.8285 **0.0340**

Stanard Error = **0.0018**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **9.52%**

SEEPAGE STUDY
Site No. 8
LNID - Lateral B9B - Data and Results
(SE 17-10-23-4)

Initial Water Depth (d1) = 0.7932 m

Bottom Width (b) = 1.6764 m

Width of Water Surface (w1) = 3.9624 m

Side Slope (z) = 1.4410

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
05/08	0.7932	0.0000	0.7932	0.5924	0.0051	0.1957	0.7932	3.9624	4.4589	0.1739
05/09	0.5924	0.0022	0.5946	0.4109	0.0051	0.1786	0.5975	3.3984	3.7724	0.1609
05/10	0.4109	0.0022	0.4131	0.2354	0.0051	0.1726	0.4189	2.8837	3.1459	0.1582
05/11	0.2354	0.0000	0.2354	0.0569	0.0048	0.1737	0.2463	2.3862	2.5404	0.1632
05/12	0.0569	0.0000	0.0569	0.0549	0.0018	0.0002	0.0726	1.8856	1.9311	0.0002

Total Rainfall = 0.0044 Total Evaporation = 0.0219

Means = 0.1442 2.9033 3.1697 **0.1312**

Stanard Error = **0.0329**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **18.71%**

SEEPAGE STUDY
Site No. 9
MID - Lateral B1D - Field Data and Results
(NE 9-5-22-4)

Initial Water Depth (d1) = 0.6109 m

Bottom Width (b) = 3.3528 m

Width of Water Surface (w1) = 4.57 m

Side Slope (z) = 1.00

Length (L) = 152 m

MONTH/DAY 1997	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/12	0.6109	0.0000	0.6109	0.5844	0.0057	0.0208	0.6109	4.5721	5.0789	0.0187
10/13	0.5844	0.0000	0.5844	0.5579	0.0058	0.0207	0.5901	4.5306	5.0201	0.0187
10/14	0.5579	0.0000	0.5579	0.5309	0.0060	0.0210	0.5694	4.4893	4.9617	0.0190
10/15	0.5309	0.0000	0.5309	0.5059	0.0046	0.0204	0.5484	4.4474	4.9023	0.0185
10/16	0.5059	0.0000	0.5059	0.4810	0.0030	0.0219	0.5280	4.4066	4.8447	0.0199

Total Rainfall = 0.0000 Total Evaporation = 0.0251

Means = 0.0210 4.4892 4.9615 **0.0190**

Stanard Error = **0.0002**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **3.89%**

SEEPAGE STUDY
Site No. 10
MID - Main Canal - Data and Results
(NW 3-5-23-4)

Initial Water Depth (d1) = 0.6933 m

Bottom Width (b) = 5.4865 m

Width of Water Surface (w 1) = 5.4865 m

Side Slope (z) = 0.0000

Length (L) = 152 m

MONTH/DAY 1998	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / mt2 / day)
10/16	0.6933	0.0005	0.6938	0.6856	0.0025	0.0057	0.6933	5.4865	6.8731	0.0046
10/17	0.6856	0.0000	0.6856	0.6727	0.0055	0.0074	0.6876	5.4865	6.8617	0.0059
10/18	0.6727	0.0000	0.6727	0.6627	0.0055	0.0045	0.6802	5.4865	6.8469	0.0036
10/19	0.6627	0.0000	0.6627	0.6533	0.0030	0.0064	0.6757	5.4865	6.8379	0.0051
10/20	0.6533	0.0000	0.6533	0.6424	0.0010	0.0099	0.6693	5.4865	6.8251	0.0080
10/21	0.6424	0.0000	0.6424	0.6329	0.0029	0.0066	0.6594	5.4865	6.8053	0.0053
10/22	0.6329	0.0000	0.6329	0.6247	0.0029	0.0053	0.6528	5.4865	6.7921	0.0043
10/23	0.6247	0.0000	0.6247	0.6178	0.0029	0.0040	0.6475	5.4865	6.7815	0.0032
10/24	0.6178	0.0000	0.6178	0.6097	0.0029	0.0052	0.6435	5.4865	6.7735	0.0042
10/25	0.6097	0.0000	0.6097	0.6001	0.0029	0.0067	0.6383	5.4865	6.7631	0.0054
10/26	0.6001	0.0000	0.6001	0.5922	0.0029	0.0050	0.6316	5.4865	6.7497	0.0041
10/27	0.5922	0.0002	0.5924	0.5830	0.0040	0.0054	0.6266	5.4865	6.7397	0.0044
10/28	0.583	0.0000	0.5830	0.5747	0.0040	0.0043	0.6212	5.4865	6.7289	0.0035
10/29	0.5747	0.0000	0.5747	0.5651	0.0040	0.0056	0.6169	5.4865	6.7203	0.0046
10/30	0.5651	0.0000	0.5651	0.5566	0.0016	0.0069	0.6113	5.4865	6.7091	0.0056
10/31	0.5566	0.0000	0.5566	0.5497	0.0016	0.0053	0.6044	5.4865	6.6953	0.0043

Total Rainfall = 0.0007 Total Evaporation = 0.0501

Means = 0.0059 5.4865 6.7812 **0.0048**

Stanard Error = **0.0003**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **0.85%**

SEEPAGE STUDY

Site No. 11

MVID - Lateral A2 - Field Data and Results

(NE 14-2-28-4)

Initial Water Depth (d1) = 0.6936 m

Bottom Width (b) = 2.44 m

Width of Water Surface (w1) = 5.00 m

Side Slope (z) = 1.85

Length (L) = 145 m

MONTH/DAY 1998	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
05/03	0.6936	0.0000	0.6936	0.6728	0.0053	0.0155	0.6936	4.9988	5.3504	0.0145
05/04	0.6728	0.0000	0.6728	0.6600	0.0053	0.0075	0.6781	4.9416	5.2854	0.0070
05/05	0.66	0.0000	0.6600	0.6456	0.0053	0.0091	0.6706	4.9139	5.2539	0.0085
05/06	0.6456	0.0000	0.6456	0.6335	0.0053	0.0068	0.6615	4.8803	5.2157	0.0064
05/07	0.6335	0.0000	0.6335	0.6206	0.0053	0.0076	0.6547	4.8552	5.1871	0.0071
05/08	0.6206	0.0000	0.6206	0.6058	0.0053	0.0095	0.6471	4.8271	5.1552	0.0089
05/09	0.6058	0.0002	0.606	0.5921	0.0050	0.0089	0.6376	4.7921	5.1153	0.0083
05/10	0.5921	0.0034	0.5955	0.5892	0.0050	0.0013	0.6287	4.7592	5.0780	0.0012
05/11	0.5892	0.0002	0.5894	0.5779	0.0050	0.0065	0.6274	4.7544	5.0725	0.0061
05/12	0.5779	0.0000	0.5779	0.5654	0.0070	0.0055	0.6209	4.7304	5.0452	0.0052

Total Rainfall = 0.0038 Total Evaporation = 0.0538

Means = 0.0078 4.8453 5.1759 **0.0073**

Stanard Error = **0.0010**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **1.47%**

SEEPAGE STUDY
Site No. 12
RID - Old Raymond Main - Data and Results
(SW 7-6-20-4)

Initial Water Depth (d1) = 0.7162 m

Bottom Width (b) = 5.7913 m

Width of Water Surface (w 1) = 7.3153 m

Side Slope (z) = 1.0639

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
04/20	0.7162	0.0000	0.7162	0.6704	0.0071	0.0387	0.7162	7.3153	7.8828	0.0359
04/21	0.6704	0.0002	0.6706	0.6512	0.0071	0.0123	0.6775	7.2330	7.7698	0.0115
04/22	0.6512	0.0000	0.6512	0.6327	0.0030	0.0155	0.6652	7.2068	7.7339	0.0144
04/23	0.6327	0.0000	0.6327	0.6128	0.0030	0.0169	0.6497	7.1738	7.6886	0.0158
04/24	0.6128	0.0000	0.6128	0.5950	0.0030	0.0148	0.6328	7.1378	7.6392	0.0138
04/25	0.5950	0.0000	0.5950	0.5766	0.0030	0.0154	0.6180	7.1063	7.5960	0.0144
04/26	0.5766	0.0000	0.5766	0.5588	0.0030	0.0148	0.6026	7.0736	7.5511	0.0139

Total Rainfall = 0.0002 Total Evaporation = 0.0292

Means = 0.0183 7.1780 7.6944 **0.0171**

Stanard Error = **0.0032**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **2.81%**

SEEPAGE STUDY
Site No. 13
RID - Craddock Stirling Main - Field Data and Results
(SE 23-6-19-4)

Initial Water Depth (d1) = 0.6356 m

Bottom Width (b) = 3.81 m

Width of Water Surface (w1) = 5.0813 m

Side Slope (z) = 1.00

Length (L) = 152 m

MONTH/DAY 1997	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	y (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/11	0.6356	0.0000	0.6356	0.6173	0.0030	0.0153	0.6356	5.0813	5.6078	0.0139
10/12	0.6173	0.0000	0.6173	0.6025	0.0033	0.0115	0.6203	5.0507	5.5645	0.0104
10/13	0.6025	0.0000	0.6025	0.5875	0.0040	0.0110	0.6088	5.0277	5.5320	0.0100
10/14	0.5875	0.0000	0.5875	0.5732	0.0036	0.0107	0.5978	5.0057	5.5009	0.0097
10/15	0.5732	0.0000	0.5732	0.5590	0.0037	0.0105	0.5871	4.9843	5.4706	0.0096
10/16	0.5590	0.0000	0.5590	0.5461	0.0037	0.0092	0.5766	4.9633	5.4409	0.0084
10/17	0.5461	0.0002	0.5463	0.5345	0.0038	0.0080	0.5674	4.9449	5.4149	0.0073
10/18	0.5345	0.0000	0.5345	0.5244	0.0009	0.0092	0.5594	4.9289	5.3923	0.0084
10/19	0.5244	0.0000	0.5244	0.5137	0.0008	0.0099	0.5502	4.9105	5.3663	0.0091
10/20	0.5137	0.0000	0.5137	0.5033	0.0009	0.0095	0.5403	4.8907	5.3383	0.0087

Total Rainfall = 0.0002 Total Evaporation = 0.0277

Means = 0.0105 4.9788 5.4629 **0.0096**

Stanard Error = **0.0006**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **1.85%**

SEEPAGE STUDY
Site No. 14
RID - Lateral 7 - Data and Results

(SE 18-6-21-4)

Initial Water Depth (d1) = 0.5518 m

Bottom Width (b) = 2.1336 m

Width of Water Surface (w1) = 6.0961 m

Side Slope (z) = 3.5905

Length (L) = 152 m

MONTH/DAY 1998	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**y** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
10/16	0.5518	0.0002	0.5520	0.519	0.0018	0.0312	0.5518	6.0961	6.2469	0.0304
10/17	0.5190	0.0000	0.5190	0.4888	0.0020	0.0282	0.5206	5.8721	6.0143	0.0275
10/18	0.4888	0.0000	0.4888	0.4583	0.0020	0.0285	0.4924	5.6695	5.8041	0.0278
10/19	0.4583	0.0000	0.4583	0.4282	0.0020	0.0281	0.4639	5.4649	5.5917	0.0275

Total Rainfall = 0.0002 Total Evaporation = 0.0078

Means = 0.0290 5.7756 5.9143 **0.0283**

Stanard Error = **0.0007**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **7.38%**

SEEPAGE STUDY
Site No. 15
SMRID - Lateral A4 - Field Data and Results
(NW 25-7-21-4)

Initial Water Depth (d1) = 0.7540 m

Bottom Width (b) = 3.6576 m

Width of Water Surface (w1) = 6.0961 m

Side Slope (z) = 1.62

Length (L) = 152 m

MONTH/DAY 1998	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**y** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
05/06	0.7540	0.0000	0.7540	0.7291	0.0065	0.0184	0.7540	6.0961	6.5247	0.0172
05/07	0.7291	0.0000	0.7291	0.6924	0.0071	0.0296	0.7356	6.0366	6.4547	0.0277
05/08	0.6924	0.0002	0.6926	0.6612	0.0074	0.0240	0.7060	5.9409	6.3422	0.0225
05/09	0.6612	0.0000	0.6612	0.6336	0.0072	0.0204	0.6820	5.8632	6.2509	0.0191
05/10	0.6336	0.0007	0.6343	0.6091	0.0071	0.0181	0.6616	5.7973	6.1734	0.0170
05/11	0.6091	0.0000	0.6091	0.5878	0.0070	0.0143	0.6435	5.7387	6.1045	0.0134

Total Rainfall = 0.0009 Total Evaporation = 0.0423

Means = 0.0208 5.9119 6.3082 **0.0195**

Stanard Error = **0.002**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **3.35%**

SEEPAGE STUDY
Site No. 16
SMRID - South Grassy Main - Data and Results

(NW 34-9-14-4)

Initial Water Depth (d1) = 0.6466 m

Bottom Width (b) = 3.6576 m

Width of Water Surface (w1) = 6.7057 m

Side Slope (z) = 2.3570

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
04/16	0.6466	0.0002	0.6468	0.6061	0.0069	0.0338	0.6466	6.7057	6.9687	0.0325
04/17	0.6061	0.0000	0.6061	0.5691	0.0069	0.0301	0.6128	6.5463	6.7956	0.0290
04/18	0.5691	0.0000	0.5691	0.5325	0.0069	0.0297	0.5827	6.4044	6.6414	0.0286
04/19	0.5325	0.0005	0.5330	0.5038	0.0069	0.0223	0.5530	6.2644	6.4894	0.0215

Total Rainfall = 0.0007 Total Evaporation = 0.0276

Means = 0.0290 6.4802 6.7238 **0.0279**

Standard Error = **0.0023**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period = **5.59%**

SEEPAGE STUDY
Site No. 17
SMRID - Lateral 20c - Field Data and Results

(NE 5-11-10-4)

Initial Water Depth (d1) = 0.4583 m

Bottom Width (b) = 3.0333 m

Width of Water Surface (w1) = 3.9667 m

Side Slope (z) = 1.0183

Length (L) = 152 m

MONTH/DAY (1996)	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/18	0.4583	0.0000	0.4583	0.4412	0.0042	0.0129	0.4583	3.9667	4.3415	0.0118
10/19	0.4412	0.0000	0.4412	0.4286	0.0055	0.0071	0.4454	3.9404	4.3047	0.0065
10/20	0.4286	0.0000	0.4286	0.4162	0.0016	0.0108	0.4383	3.9259	4.2844	0.0099
10/21	0.4162	0.0000	0.4162	0.4050	0.0075	0.0037	0.4275	3.9039	4.2536	0.0034
10/22	0.4050	0.0000	0.4050	0.3969	0.0057	0.0024	0.4238	3.8964	4.2430	0.0022
10/23	0.3969	0.0000	0.3969	0.3891	0.0039	0.0039	0.4214	3.8915	4.2362	0.0036
10/24	0.3891	0.0000	0.3891	0.3835	0.0031	0.0025	0.4175	3.8836	4.2250	0.0023
10/25	0.3835	0.0000	0.3835	0.3750	0.0043	0.0042	0.4150	3.8785	4.2179	0.0039
10/26	0.3750	0.0000	0.3750	0.3678	0.0031	0.0041	0.4108	3.8699	4.2059	0.0038
10/27	0.3678	0.0000	0.3678	0.3585	0.0023	0.0070	0.4067	3.8616	4.1942	0.0064

Total Rainfall = 0.0000 Total Evaporation = 0.0412

Means = 0.0059 3.9019 4.2506 **0.0054**

Standard Error = **0.0010**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period = **1.43%**

SEEPAGE STUDY
Site No. 18
SMRID - Lateral B-3 - Field Data and Results
(NE 26-8-19-4)

Initial Water Depth (d1) = 0.3900 m

Bottom Width (b) = 1.5333 m

Width of Water Surface (w1) = 2.1867 m

Side Slope (z) = 0.8377

Length (L) = 152 m

MONTH/DAY (1996)	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/19	0.3900	0.0000	0.3900	0.3734	0.0050	0.0116	0.3900	2.1867	2.5508	0.0099
10/20	0.3734	0.0000	0.3734	0.3589	0.0049	0.0096	0.3784	2.1673	2.5205	0.0083
10/21	0.3589	0.0000	0.3589	0.3459	0.0044	0.0086	0.3688	2.1512	2.4955	0.0074
10/22	0.3459	0.0000	0.3459	0.3340	0.0043	0.0076	0.3602	2.1368	2.4731	0.0066
10/23	0.3340	0.0000	0.3340	0.3236	0.0042	0.0062	0.3526	2.1240	2.4532	0.0054
10/24	0.3236	0.0000	0.3236	0.3121	0.0059	0.0056	0.3464	2.1137	2.4371	0.0049
10/25	0.3121	0.0000	0.3121	0.3005	0.0042	0.0074	0.3408	2.1043	2.4224	0.0064

Total Rainfall = 0.0000 Total Evaporation = 0.0329

Means = 0.0081 2.1406 2.4789 **0.0070**

Standard Error = **0.0007**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period = **2.39%**

SEEPAGE STUDY
Site No. 19
SMRID - Main Canal - Field Data and Results
(NW 9-11-6-4)

Initial Water Depth (d1) = 0.9865 m

Bottom Width (b) = 6.0961 m

Width of Water Surface (w1) = 9.5418 m

Side Slope (z) = 1.7464

Length (L) = 152 m

MONTH/DAY 1997	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/17	0.9865	0.0000	0.9865	0.9771	0.0024	0.0070	0.9865	9.5418	10.0667	0.0066
10/18	0.9771	0.0002	0.9773	0.9677	0.0024	0.0072	0.9795	9.5174	10.0385	0.0068
10/19	0.9677	0.0000	0.9677	0.9588	0.0024	0.0065	0.9723	9.4922	10.0095	0.0062
10/20	0.9588	0.0000	0.9588	0.9473	0.0042	0.0073	0.9658	9.4695	9.9834	0.0069
10/21	0.9473	0.0000	0.9473	0.9439	0.0024	0.0010	0.9585	9.4440	9.9540	0.0009
10/22	0.9439	0.0005	0.9444	0.9366	0.0043	0.0035	0.9575	9.4405	9.9500	0.0033
10/23	0.9366	0.0000	0.9366	0.9306	0.0023	0.0037	0.9540	9.4283	9.9359	0.0035
10/24	0.9306	0.0012	0.9318	0.9239	0.0023	0.0056	0.9503	9.4154	9.9210	0.0053
10/25	0.9239	0.0000	0.9239	0.9165	0.0023	0.0051	0.9447	9.3958	9.8984	0.0048
10/26	0.9165	0.0000	0.9165	0.9120	0.0023	0.0022	0.9396	9.3780	9.8779	0.0021
10/27	0.9120	0.0000	0.9120	0.9062	0.0023	0.0035	0.9374	9.3703	9.8691	0.0033
10/28	0.9062	0.0000	0.9062	0.8969	0.0023	0.0070	0.9339	9.3581	9.8550	0.0066
10/29	0.8969	0.0002	0.8971	0.8916	0.0023	0.0032	0.9269	9.3336	9.8268	0.0030
10/30	0.8916	0.0000	0.8916	0.8850	0.0045	0.0021	0.9237	9.3224	9.8139	0.0020
10/31	0.8850	0.0000	0.8850	0.8780	0.0045	0.0025	0.9216	9.3151	9.8055	0.0024
11/01	0.8780	0.0000	0.8780	0.8686	0.0023	0.0071	0.9191	9.3064	9.7954	0.0067
11/02	0.8686	0.0000	0.8686	0.8628	0.0023	0.0035	0.9120	9.2816	9.7668	0.0033
11/03	0.8628	0.0000	0.8628	0.8569	0.0023	0.0036	0.9085	9.2694	9.7527	0.0034

Total Rainfall = 0.0021 Total Evaporation = 0.0501

Averages = 0.0045 9.3933 9.8956 **0.0043**

Standard Error = **0.0005**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period = **0.55%**

SEEPAGE STUDY
Site No. 20
TID - Lateral 15 - Field Data and Results
(NW 28-9-16-4)

Initial Water Depth (d1) = 1.1543 m

Bottom Width (b) = 4.8769 m

Width of Water Surface (w1) = 9.8756 m

Side Slope (z) = 2.1653

Length (L) = 152 m

MONTH/DAY (1997)	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
04/25	1.1543	0.0000	1.1543	1.1473	0.0005	0.0065	1.1543	9.8756	10.3830	0.0062
04/26	1.1473	0.0000	1.1473	1.1421	0.0007	0.0045	1.1478	9.8475	10.3519	0.0043
04/27	1.1421	0.0000	1.1421	1.1370	0.0007	0.0044	1.1433	9.8280	10.3305	0.0042
04/28	1.1370	0.0017	1.1387	1.1332	0.0005	0.0050	1.1389	9.8089	10.3095	0.0048
04/29	1.1332	0.0000	1.1332	1.1284	0.0024	0.0024	1.1339	9.7873	10.2856	0.0023
04/30	1.1284	0.0005	1.1289	1.1272	0.0005	0.0012	1.1315	9.7769	10.2742	0.0011
05/01	1.1272	0.0023	1.1295	1.1235	0.0016	0.0044	1.1303	9.7717	10.2685	0.0042
05/02	1.1235	0.0010	1.1245	1.1199	0.0020	0.0026	1.1259	9.7526	10.2475	0.0025
05/03	1.1199	0.0000	1.1199	1.1128	0.0031	0.0040	1.1233	9.7414	10.2351	0.0038
05/04	1.1128	0.0000	1.1128	1.1049	0.0035	0.0044	1.1193	9.7240	10.2160	0.0042
05/05	1.1049	0.0000	1.1049	1.0989	0.0058	0.0002	1.1149	9.7050	10.1950	0.0002
05/06	1.0989	0.0000	1.0989	1.0919	0.0067	0.0003	1.1147	9.7041	10.1941	0.0003

Total Rainfall = 0.0056 Total Evaporation = 0.0280

Means = 0.0033 9.7770 10.2744 **0.0032**

Standard Error = **0.0005**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **0.38%**

SEEPAGE STUDY
Site No. 21
UID - Lateral B2 - Field Data and Results
(NW 4-5-27-4)

Initial Water Depth (d1) = 0.7537 m

Bottom Width (b) = 1.5240 m

Width of Water Surface (w1) = 3.3528 m

Side Slope (z) = 1.2132

Length (L) = 152 m

MONTH/DAY 1998	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**d2** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
04/24	0.7537	0.0005	0.7542	0.6787	0.0051	0.0703	0.7537	3.3528	3.8940	0.0605
04/25	0.6787	0.0002	0.6790	0.6248	0.0062	0.0479	0.6834	3.1822	3.6729	0.0415
04/26	0.6248	0.0002	0.6251	0.5796	0.0062	0.0394	0.6354	3.0658	3.5221	0.0343

Total Rainfall = 0.0009 Total Evaporation = 0.0175

Means = 0.0525 3.2003 3.6963 **0.0455**

Standard Error = **0.0078**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **9.15%**

SEEPAGE STUDY
Site No. 22
UID - Lateral F - Data and Results
(NE 1-5-27-4)

Initial Water Depth (d1) = 0.7265 m

Bottom Width (b) = 3.0480 m

Width of Water Surface (w1) = 4.8769 m

Side Slope (z) = 1.2587

Length (L) = 152 m

MONTH/DAY 1999	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**d2** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
04/14	0.7265	0.0000	0.7265	0.7101	0.0046	0.0118	0.7265	4.8769	5.3838	0.0107
04/15	0.7101	0.0005	0.7106	0.6991	0.0046	0.0069	0.7147	4.8472	5.3459	0.0063
04/16	0.6991	0.0000	0.6991	0.6885	0.0046	0.0060	0.7078	4.8298	5.3237	0.0054
04/17	0.6885	0.0000	0.6885	0.6788	0.0046	0.0051	0.7018	4.8147	5.3044	0.0046
04/18	0.6788	0.0000	0.6788	0.6692	0.0046	0.0050	0.6967	4.8019	5.2880	0.0045
04/19	0.6692	0.0000	0.6692	0.6621	0.0046	0.0025	0.6917	4.7893	5.2719	0.0023
04/20	0.6621	0.0000	0.6621	0.6529	0.0065	0.0027	0.6892	4.7830	5.2639	0.0025
04/21	0.6529	0.0078	0.6607	0.6543	0.0064	0.0000	0.6865	4.7762	5.2552	0.0000
04/22	0.6543	0.0049	0.6592	0.6565	0.0026	0.0001	0.6865	4.7762	5.2552	0.0001
04/23	0.6565	0.0002	0.6567	0.6488	0.0064	0.0015	0.6864	4.7760	5.2549	0.0014
04/24	0.6488	0.0000	0.6488	0.6410	0.0053	0.0025	0.6849	4.7722	5.2501	0.0023
04/25	0.6410	0.0000	0.6410	0.6327	0.0053	0.0030	0.6824	4.7659	5.2420	0.0027
04/26	0.6327	0.0000	0.6327	0.6242	0.0053	0.0032	0.6794	4.7583	5.2324	0.0029

Total Rainfall = 0.0134 Total Evaporation = 0.0654

Means = 0.0039 4.7975 5.2824 **0.0035**

Standard Error = **0.0008**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period **0.64%**

SEEPAGE STUDY
Site No. 23
WID - Lateral 81C1 - Data and Results

(NW 9-22-26-4)

Initial Water Depth (d1) = 0.4466 m

Bottom Width (b) = 1.9982 m

Width of Water Surface (w1) = 3.5967 m

Side Slope (z) = 1.8906

Length (L) = 152 m

MONTH/DAY 1997	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
09/26	0.4466	0.0000	0.4466	0.4028	0.0073	0.0365	0.4466	3.5967	3.9086	0.0336
09/27	0.4028	0.0000	0.4028	0.3686	0.0073	0.0269	0.4101	3.5489	3.7524	0.0254
09/28	0.3686	0.0000	0.3686	0.3384	0.0073	0.0229	0.3832	3.4472	3.6374	0.0217

Total Rainfall = 0.0000 Total Evaporation = 0.0219

Means = 0.0288 3.5309 3.7661 **0.0270**

Standard Error = **0.0035**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **8.15%**

SEEPAGE STUDY
Site No. 24
WID - Lateral 81J - Data and Results
(NE 31-22-22-4)

Initial Water Depth (d1) = 0.8924 m

Bottom Width (b) = 2.4384 m

Width of Water Surface (w1) = 6.2485 m

Side Slope (z) = 2.1347

Length (L) = 152 m

MONTH/DAY 1998	**d1** (m)	**RAINFALL** (m)	**Adjusted d1** (m)	**d2** (m)	**EVAPOR** (m)	**d** (m)	**d2** (m)	**W** (m)	**Pw** (m)	**SEEPAGE RATE** (m3 / m2 / day)
10/07	0.8924	0.0002	0.8926	0.8709	0.0032	0.0185	0.8924	6.2485	6.6458	0.0174
10/08	0.8709	0.0000	0.8709	0.8505	0.0032	0.0172	0.8739	6.1695	6.5586	0.0162
10/09	0.8505	0.0000	0.8505	0.8292	0.0015	0.0198	0.8567	6.0961	6.4775	0.0186
10/10	0.8292	0.0000	0.8292	0.8084	0.0015	0.0193	0.8369	6.0115	6.3842	0.0182
10/11	0.8084	0.0002	0.8086	0.7874	0.0015	0.0197	0.8176	5.9291	6.2932	0.0186
10/12	0.7874	0.0000	0.7874	0.7687	0.0016	0.0171	0.7979	5.8450	6.2003	0.0161
10/13	0.7687	0.0000	0.7687	0.7636	0.0016	0.0035	0.7808	5.7720	6.1197	0.0033
10/14	0.7636	0.0000	0.7636	0.7460	0.0016	0.0160	0.7773	5.7571	6.1032	0.0151
10/15	0.7460	0.0000	0.7460	0.7300	0.0016	0.0144	0.7613	5.6888	6.0277	0.0136
10/16	0.7300	0.0000	0.7300	0.7141	0.0016	0.0143	0.7469	5.6273	5.9598	0.0135
10/17	0.7141	0.0005	0.7146	0.6952	0.0016	0.0178	0.7326	5.5662	5.8924	0.0168

Total Rainfall = 0.0009 Total Evaporation = 0.0205

Means = 0.0161 5.8828 6.2420 **0.0152**

Standard Error = **0.0013**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **2.45%**

SEEPAGE STUDY
Site No. 25
LNID (concrete canal) - Field Data and Results
(SE 15-10-22-4)

Initial Water Depth (d1) = 0.5134 m

Bottom Width (b) = 0.6096 m

Width of Water Surface (w1) = 2.1763 m

Side Slope (z) = 1.5258

Length (L) = 152 m

MONTH/DAY 1998	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
07/05	0.5134	0.0000	0.5134	0.4961	0.0045	0.0128	0.5134	2.1763	2.4828	0.0112
07/06	0.4961	0.0000	0.4961	0.4808	0.0045	0.0108	0.5006	2.1372	2.4361	0.0095
07/07	0.4808	0.0020	0.4828	0.4631	0.0045	0.0152	0.4898	2.1043	2.3967	0.0133
07/08	0.4631	0.0005	0.4636	0.4458	0.0046	0.0132	0.4746	2.0579	2.3412	0.0116
07/09	0.4458	0.0000	0.4458	0.4296	0.0046	0.0116	0.4614	2.0176	2.2931	0.0102
07/10	0.4296	0.0000	0.4296	0.4110	0.0046	0.0140	0.4498	1.9822	2.2507	0.0123
07/11	0.4110	0.0000	0.4110	0.3897	0.0063	0.0150	0.4358	1.9395	2.1997	0.0132

Total Rainfall = 0.0025 Total Evaporation = 0.0336

Means = 0.0132 2.0593 2.3429 **0.0116**

Standard Error = **0.0005**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **3.80%**

SEEPAGE STUDY
Site No. 26
WID - Lateral 85 - Data and Results

(NE 34-24-24-4)

Initial Water Depth (d1) = 0.5210 m

Bottom Width (b) = 4.8769 m

Width of Water Surface (w1) = 8.8393 m

Side Slope (z) = 3.8027

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/19	0.5210	0.0000	0.5210	0.4735	0.0032	0.0443	0.5210	8.8393	8.9740	0.0436
10/20	0.4735	0.0000	0.4735	0.4272	0.0032	0.0431	0.4767	8.5024	8.6256	0.0425
10/21	0.4272	0.0000	0.4272	0.3830	0.0032	0.0410	0.4336	8.1746	8.2867	0.0404

Total Rainfall = 0.0000 Total Evaporation = 0.0096

Means = 0.0428 8.5054 8.6288 **0.0422**

Standard Error = **0.0009**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **10.18%**

SEEPAGE STUDY
Site No. 27
EID - C Springhill Canal - Field Data and Results
(SE 11-20-15-4)

Initial Water Depth (d1) = 0.7456 m

Bottom Width (b) = 4.2673 m

Width of Water Surface (w1) = 8.598 m

Side Slope (z) = 2.9041

Length (L) = 130 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/23	0.7456	0.0000	0.7456	0.7322	0.0040	0.0094	0.7456	8.5979	8.8474	0.0091
10/24	0.7322	0.0000	0.7322	0.7211	0.0040	0.0071	0.7362	8.5433	8.7897	0.0069
10/25	0.7211	0.0000	0.7211	0.7111	0.0040	0.0060	0.7291	8.5021	8.7461	0.0058
10/26	0.7111	0.0000	0.7111	0.7011	0.0020	0.0080	0.7231	8.4672	8.7092	0.0078
10/27	0.7011	0.0000	0.7011	0.6914	0.0020	0.0077	0.7151	8.4207	8.6601	0.0075
10/28	0.6914	0.0000	0.6914	0.6839	0.0020	0.0055	0.7074	8.3760	8.6128	0.0053
10/29	0.6839	0.0002	0.6841	0.6743	0.0047	0.0051	0.7019	8.3441	8.5790	0.0050
10/30	0.6743	0.0000	0.6743	0.6658	0.0047	0.0038	0.6968	8.3145	8.5477	0.0037
10/31	0.6658	0.0012	0.6670	0.6602	0.0047	0.0021	0.6930	8.2924	8.5243	0.0020
11/01	0.6602	0.0010	0.6612	0.6518	0.0048	0.0046	0.6909	8.2802	8.5114	0.0045
11/02	0.6518	0.0002	0.6520	0.6462	0.0048	0.0010	0.6863	8.2535	8.4832	0.0010
11/03	0.6462	0.0000	0.6462	0.6400	0.0023	0.0039	0.6853	8.2477	8.4770	0.0038
11/04	0.6400	0.0000	0.6400	0.6355	0.0023	0.0022	0.6814	8.2250	8.4531	0.0021
11/05	0.6355	0.0000	0.6355	0.6288	0.0023	0.0044	0.6792	8.2122	8.4396	0.0043
11/06	0.6288	0.0000	0.6288	0.6213	0.0023	0.0052	0.6748	8.1867	8.4125	0.0051
11/07	0.6213	0.0000	0.6213	0.6160	0.0023	0.0030	0.6696	8.1565	8.3806	0.0029
11/08	0.6160	0.0000	0.6160	0.6091	0.0023	0.0046	0.6666	8.1391	8.3622	0.0045

Total Rainfall = 0.0027 Total Evaporation = 0.0554

Means = 0.0049 8.3266 8.5605 **0.0048**

Standard Error = **0.0005**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **0.86%**

SEEPAGE STUDY
Site No. 28
LNID - South Park Lake Canal - Data and Results
(NW 21-09-22-4)

Initial Water Depth (d1) = 0.4242 m

Bottom Width (b) = 4.5721 m

Width of Water Surface (w1) = 6.5533 m

Side Slope (z) = 2.3352

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/19	0.4242	0.0000	0.4242	0.3973	0.0055	0.0214	0.4242	6.5533	6.7273	0.0208
10/20	0.3973	0.0002	0.3975	0.3735	0.0055	0.0185	0.4028	6.4534	6.6186	0.0180
10/21	0.3735	0.0002	0.3737	0.3468	0.0055	0.0214	0.3843	6.3669	6.5246	0.0209
10/22	0.3468	0.0000	0.3468	0.3157	0.0051	0.0260	0.3629	6.2670	6.4159	0.0254

Total Rainfall = 0.0004 Total Evaporation = 0.0216

Averages = 0.0218 6.4102 6.5716 **0.0213**

Standard Error = **0.0015**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24-hr. period = **5.93%**

SEEPAGE STUDY
Site No. 29
BRID - Lat. H5-2 - Data and Results

(SE 33-15-18-4)

Initial Water Depth (d1) = 0.7196 m

Bottom Width (b) = 1.3716 m

Width of Water Surface (w1) = 3.2004 m

Side Slope (z) = 1.2707

Length (L) = 152 m

MONTH/DAY 1999	d1 (m)	RAINFALL (m)	Adjusted d1 (m)	d2 (m)	EVAPOR (m)	d (m)	d2 (m)	W (m)	Pw (m)	SEEPAGE RATE (m3 / m2 / day)
10/15	0.7196	0.0002	0.7198	0.6700	0.0021	0.0477	0.7196	3.2004	3.6988	0.0413
10/16	0.6700	0.0000	0.6700	0.6384	0.0021	0.0295	0.6719	3.0792	3.5445	0.0256
10/17	0.6384	0.0002	0.6386	0.6134	0.0021	0.0231	0.6424	3.0042	3.4491	0.0201
10/18	0.6134	0.0000	0.6134	0.5920	0.0021	0.0193	0.6193	2.9455	3.3744	0.0168
10/19	0.5920	0.0000	0.5920	0.5766	0.0025	0.0129	0.6000	2.8964	3.3120	0.0113
10/20	0.5766	0.0000	0.5766	0.5592	0.0025	0.0149	0.5871	2.8637	3.2703	0.0130

Total Rainfall = 0.0005 Total Evaporation = 0.0134

Means = 0.0246 2.9980 3.4412 **0.0214**

Standard Error = **0.0045**

Average Seepage Rate % = Using w - volume of water lost due to seepage in a 24 hr. period = **4.48%**

Volume 3 Conveyance Water Management

II. Evaporation losses from irrigation canals and reservoirs in southern Alberta

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ABSTRACT

A study was conducted, as part of the South Saskatchewan River Basin (SSRB) Irrigation Water Management Study, to determine evaporation losses from open water surfaces for use in modeling conveyance system losses within the irrigation districts of southern Alberta. The modified Priestley-Taylor method for estimation of potential evapotranspiration was examined to determine its applicability in determining lake evaporation using a grid climate data set for southern Alberta. Alberta Agriculture, Food and Rural Development uses a modified Priestley-Taylor method to estimate potential evapotranspiration in the Irrigation District Model (IDM). The Morton method for determination of lake evaporation is currently used by Alberta Environment for modeling water management in the SSRB. The Meyer method has been utilized by the Prairie Farm Rehabilitation Administration (PFRA), Agriculture and Agri-Food Canada, for estimating evaporation from shallow water bodies on the prairies. Lake evaporation has also been estimated from measurements using a Class A evaporation pan. The concordance correlation coefficient index was used to compare potential evaporation estimates from the modified Priestley-Taylor, Meyer lake evaporation and lake evaporation from Class A pan methods to the Morton method. None of the three methods compared favourably to the Morton method. A regression equation was developed to adjust the modified Priestley-Taylor potential evapotranspiration estimates to Morton lake evaporation equivalent values. Climate data from 1920 to 1995 from the grid locations in southern Alberta, and the surface area of reservoirs and open canals in 1999, were subsequently used with the equation to estimate the volume of mean net evaporation losses from irrigation district reservoirs and canals. Mean net evaporation from district reservoirs during the irrigation season was estimated as 122,771 dam^3, or about 3.4% of the proposed total licensed allocation for the irrigation districts. Mean net evaporation from open canal surfaces during the irrigation season was estimated as 19,245 dam^3, or 0.5 % of the proposed total licensed allocation.

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INTRODUCTION

The Government of Alberta established irrigation water allocations for the irrigation districts in 1991 through an Order-in-Council called the South Saskatchewan River Basin Water Allocation Regulation (Alberta Environment 1991). Water allocations were to be reviewed by Alberta Environment in the Year 2000. In 1996, a process was initiated by the irrigation industry, in partnership with federal and provincial governments, to review and update information available on different components of water management in the irrigation districts in southern Alberta.

Conveyance losses affect the overall efficiency of an irrigation district water delivery system, i.e. the percent of water diverted at the source that is actually delivered to the farm and used for production of agricultural crops. Evaporation from open water surfaces is one component in conveyance losses associated with the operation of an irrigation distribution system. In the 1991 regulation, reservoir evaporation losses were estimated as 3.6 percent of the proposed total licensed allocation (Alberta Environment 1991). Canal losses due to evaporation were not considered separately in the 1991 regulation, although total canal conveyance losses (evaporation and seepage) were estimated as 15 percent of the proposed total allocation.

Evaporation losses in an irrigation distribution system occur from open water surfaces along canals and from storage reservoirs. Districts vary significantly in the layout of the distribution system, length and design capacity of canals, and the capacity and characteristics of reservoirs. Some districts have few reservoirs and deliver irrigation water primarily through direct diversion from a river. Other districts utilize reservoirs for a significant amount of the water supply. Evaporation losses from storage reservoirs that occur throughout the year, and canal losses that occur throughout the irrigation season, are dependant on meteorological factors and can vary significantly.

On-farm evaporative losses are not attributed to distribution system conveyance losses. On-farm losses include evaporation that occurs in sprinkler application of water, evaporation from open water typical of surface irrigation methods, and evaporation from soil surfaces. Evaporation losses from surface irrigation return flow that enters open channels is also accounted for on-farm.

Several methods have been developed to estimate evaporation and evapotranspiration. The Morton method for determination of lake evaporation (Bothe and Abraham 1987, 1993) is currently used by Alberta Environment for modeling water management in the South Saskatchewan River Basin. Tabulated monthly evaporation data are available for the Morton method for Brooks, Calgary, Lethbridge, Medicine Hat and Vauxhall. Alberta Agriculture, Food and Rural Development uses a modified Priestley-Taylor method (Jensen et al. 1990; Riewe et al. 2000) to estimate potential evapotranspiration in the Irrigation District Model (IDM) (Baker et al. 1999). The meteorological factors required for calculation of potential evapotranspiration by the modified Priestley-Taylor method in the irrigation districts are available in a 50 km x 50 km grid data set for southern Alberta (McGinn et al. 1994). The Meyer method (Woodvine 1994) has been utilized by PFRA, Agriculture and Agri-Food Canada, for estimating evaporation from shallow water bodies on the prairies. Monthly net evaporation data by the Meyer method have been compiled for Calgary, Lethbridge and Medicine Hat. Lake evaporation has also been estimated from measurements using a Class A evaporation pan (Environment Canada 1982). Pan evaporation data have been collected at Calgary, Lethbridge and Vauxhall and are available through the Atmospheric Environment Service (AES), Environment Canada.

The South Saskatchewan River Basin Irrigation Water Management Study required that calculations be made of conveyance losses, including evaporation, seepage and return flow. This study was conducted to examine use of the modified Priestley-Taylor method and the grid climate data set for southern Alberta to estimate mean net evaporation losses during the irrigation season from storage reservoirs and canals in each of the 13 irrigation districts.

METHODS

Evaluation of Evaporation Estimation Methods

There are several meteorological factors that determine the rate of evaporation from an open water surface. They include temperature, relative humidity, solar radiation and wind velocity. Four methods were evaluated for use in estimating evaporation from an open water surface - lake evaporation calculated from Class A pan evaporation measurements, the Morton method used by Alberta Environment, the Meyer method employed by PFRA, and the modified Priestley-Taylor method of estimating potential evapotranspiration used by Irrigation Branch.

Historical pan evaporation data have been collected in Canada since 1956 (Environment Canada 1982). Observations were made during the frost-free period. The process required daily observation to add or subtract water. Historical pan evaporation data for southern Alberta have been determined at Lethbridge, Vauxhall and Calgary (Fig. 1) and are available through the Atmospheric Environmental Service (AES). Evaporation data from the Lethbridge site have been collected since 1969 using a Class A evaporation pan. Data available from previous years were collected using a sunken pan evaporimeter. Calculation of lake evaporation from pan data was based on work by Kohler et al. (1955).

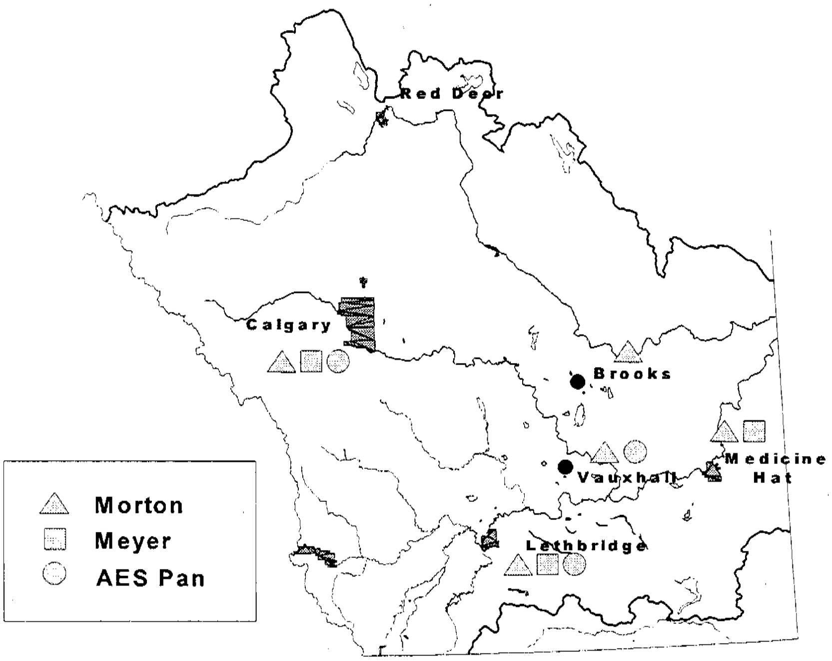

Fig. 1. Data sites for evaporation in southern Alberta.

Class A pan evaporation data at Lethbridge were adjusted to provide an estimate of lake evaporation:

$$\text{Lake evaporation} = \text{Class A pan evaporation} \times 0.7 \qquad (1)$$

For shallow lake evaporation estimates, it was assumed the water bodies had negligible heat storage and the mean air and pan water temperatures were equal (Kohler et al. 1967).

In the operation of the Water Resources Management Model (WRMM), Alberta Environment uses estimates of evaporation computed using the complementary relationship lake evaporation model developed by F.I. Morton at the National Hydrology Research Institute, Environment Canada (Bothe and Abraham 1987, 1993). The Morton method uses an energy balance approach. Evaporation is a function of available energy and water. Monthly lake evaporation values have been tabulated for Lethbridge, Calgary, Brooks, Medicine Hat and Vauxhall (Fig. 1).

The Meyer method has been used by PFRA for estimating gross evaporation from small to moderate-sized water bodies on the prairies (Martin 1988). The water bodies described would typically be less than 10 metres in depth and less than a few kilometers wide. Monthly gross evaporation data (Woodvine 1994) have been developed for Lethbridge, Medicine Hat and Calgary (Fig. 1).

The Irrigation Requirements Module (IRM) of the IDM uses a modified Priestley-Taylor equation to determine potential evapotranspiration (Jensen et al., 1990):

$$\lambda E_p = \alpha*(\Delta/(\Delta + \gamma))*(Rn - G) \qquad (2)$$

Where:
γ - psychrometric constant
$\gamma = (c_p*P)/(0.622*\lambda)$, kPa /°C
Δ - slope of the saturation vapour pressure-temperature curve
$\Delta = (0.200*(((0.00738*T) + 0.8072)^7)) - 0.000116$, kPa/°C
λ - latent heat of vaporization
$\lambda = 2.501 - (0.002361*T)$, MJ/kg
α - regional calibration constant
c_p - specific heat at a constant pressure = 0.001013, MJ/kg/°C
P - atmospheric pressure
$P = 101.3*((((T + 273.16) - (0.0065*H))/(T + 273.16))^{5.256})$, kPa
Rn - net radiation
$Rn_{(W/m^2)} = (0.63*Rs*(1000*1000)/43200) - 40$
$Rn_{(MJ/m^2)} = Rn_{(W/m^2)}*43200/(1000*1000)$, MJ/m^2
R_s - total incoming solar radiation, MJ/m^2
G - soil heat flux = 0, MJ/m^2 day
T - mean daily air temperature
$T = (Tmax + Tmin)/2$, °C
H = elevation, m
T_{max} = mean maximum daily air temperature, °C
T_{min} = mean minimum daily air temperature, °C

An α value of 1.66 has been calibrated for southern Alberta conditions (Riewe et al. 2000). A grid climate data set has been developed for use in the IDM that contains variables required for estimating lake evaporation (McGinn et al. 1994). Data were compiled on a 50 km x 50 km grid of southern Alberta (Fig. 2). Reservoirs and canal systems extend over large geographic areas. An advantage to using the modified Priestley-Taylor method is that weather data are available at numerous locations within the irrigation districts of southern Alberta.

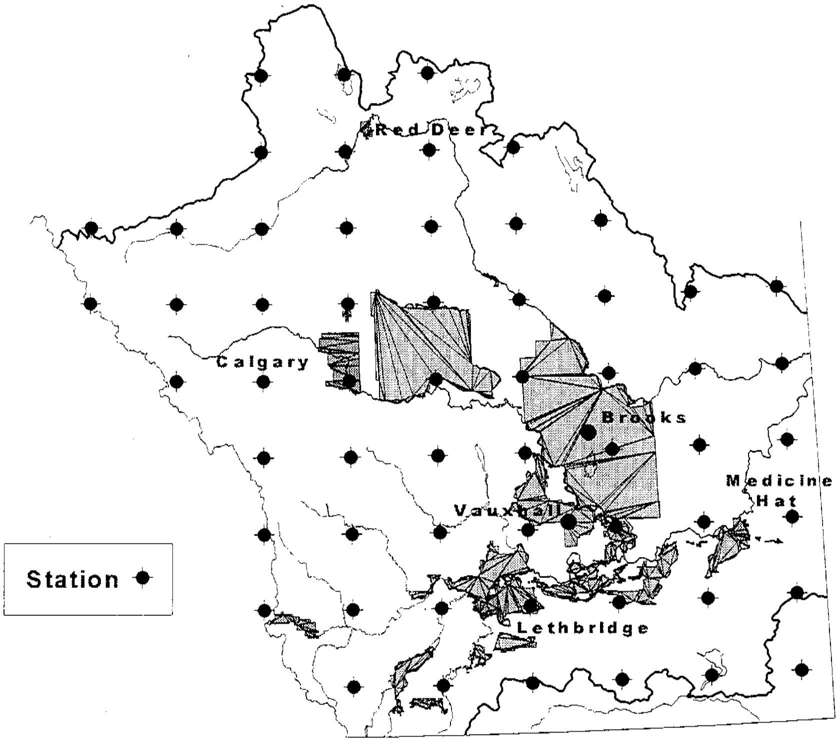

Fig. 2. Climate database stations in southern Alberta (50 km x 50 km grid).

A uniform data set of the monthly lake evaporation adjusted from Class A pan data, lake evaporation calculated using the Morton method, gross evaporation from the Meyer formula and the modified Priestley-Taylor potential evapotranspiration results was compiled for use in evaluating the four evaporation methods. Monthly data from April to October for 1969 to 1992 were used (Appendix A).

The concordance correlation coefficient index (Lin 1989) was used to compare potential evaporation estimates from the modified Priestley-Taylor, Meyer and lake evaporation methods to the Morton method. A concordance correlation coefficient contains measurements of precision and accuracy. The index evaluates the degree to which data pairs fall on a 45 degree (1:1) line through the origin. A concordance correlation coefficient of 1 indicates the data pair lie on the line. Any departure from this line produces a concordance correlation coefficient less than 1, even though the Pearson correlation coefficient may be equal to one (Lin 1989).

The difference between gross evaporation amounts and precipitation is referred to as net evaporation. Data were selected from the 50 km x 50 km grid climate data set for April to October in 1920 to 1995 to develop a historical data set of net evaporation. An annual gross evaporation amount for each irrigation season was calculated using the modified Priestley-Taylor method adjusted to Morton equivalent lake evaporation. Precipitation values for the same period were subtracted from the gross values for that year to obtain net evaporation values. A mean value of net evaporation from 1920 to 1995 was calculated at all points of the 50 km x 50 km grid data set in southern Alberta. Data from a grid point representative of each reservoir were used in the calculation of mean net reservoir evaporation (Appendix B). A grid point representative of each irrigation district was selected to estimate net evaporation losses from canals (Appendix B).

Reservoir Evaporation Determinations

There are 49 reservoirs used to supply water to the 13 irrigation districts in southern Alberta, with capacities ranging from 125 dam^3 to 490,180 dam^3 of live storage (Table 1). Reservoirs used to supply the irrigation districts as part of the headworks system are owned and operated by Alberta Environment. Evaporation losses from headworks reservoirs are not part of conveyance losses attributed to irrigation districts.

Evaporation from open water surfaces is calculated as a function of surface area. The surface area varies as the water level in a reservoir is raised and lowered throughout the season. In a modeling exercise, the reservoir water level and corresponding surface area can be estimated for a given time period. The surface area for the reservoirs supplying the irrigation districts was obtained from several sources. Surface areas for the headworks reservoirs were taken from Alberta Environment reports. Information on the surface area at full supply level (FSL) of the reservoirs within the districts was taken from data compiled by Irrigation Branch or was estimated using irrigation district infrastructure data (Table 1). Reservoirs have control structures to regulate water level.

Reservoir evaporation was determined by multiplying the surface area at FSL by the mean net evaporation from the Morton equivalent lake evaporation grid climate data for 1920 to 1995.

Headworks Reservoirs. Approximately 60% of the live storage available as a water supply to irrigation districts is part of the Alberta Environment headworks system. The 11 headworks reservoirs are owned and operated by Alberta Environment. Major storage sites include the Oldman River Reservoir, Waterton Reservoir, St. Mary Reservoir, Travers Reservoir and Lake McGregor. The major reservoirs are used to support water management in the basin and can be the water supply for more than one irrigation district.

Losses due to evaporation from headworks reservoirs are not treated as losses attributed to individual districts but are considered in overall basin water management. Alberta Environment estimates evaporation from headworks reservoirs in the Water Resources Management Model (WRMM). In the 1991 regulations (Alberta Environment 1991), evaporation demands for the irrigation district reservoirs were input to the WRMM as a fixed demand on the system. For comparison purposes, the mean net evaporation for headworks reservoirs was calculated based on reservoir surface area at FSL and mean net evaporation from the grid point closest to the location of the reservoir.

Table 1. Reservoirs associated with irrigation districts in Alberta.

Location	Reservoir Name	Live Storage (dam^3)	Surface Area at FSL (ha)
Alberta Environment Headworks Reservoirs			
Carseland-Bow River (BRID)	Little Bow	21,078	530
	McGregor Lake	351,059	5,100
	Travers	104,638	2,265
Cavan Lake (RCID)	Cavan Lake	4,625	135
Lethbridge Northern (LNID)	Keho	95,635	2,350
	Oldman River	490,180	2,425
Mountain View, Leavitt, Aetna (MVID, LID, AID)	Payne Lake	8,690	240
Waterton-St. Mary (SMRID, MID, RID, TID)	Jensen	19,000	200
	Milk River Ridge	127,297	1,415
	St. Mary	369,310	3,765
	Waterton	111,196	1,095
Headworks Reservoirs Total		1,702,708	19,520
Irrigation District Reservoirs			
Bow River Irrigation District	Badger	53,650	890
	H Reservoir	2,220	130
	Lost Lake	5,050	485
	Scope	19,740	575
Eastern Irrigation District	Cowoki	19,735	730
	Crawling Valley	130,500	2,515
	J Reservoir	615	115
	Kitsim	26,520	690
	Lake Newell	320,215	6,495
	One Tree	2,345	90
	Rock Lake	9,250	225
	Rolling Hills	17,515	585
	Snake Lake	18,230	105
	Tilley "A"	33,300	620
	Tilley "B"	38,235	1,410
Lethbridge Northern Irrigation District	Park Lake	740	85
	Picture Butte	1,600	100
Raymond Irrigation District	Corner Lake	495	15
	Craddock	615	13
	Factory Lake	370	29
St. Mary River Irrigation District	Bullshead	125	13
	Chin	190,330	1,590
	Cross Coulee	2,590	85
	Forty Mile	86,345	745
	Murray	30,590	1,665
	North East	2,095	210
	Raymond	1,600	60
	Sauder	37,745	1,245
	Seven Persons	1,355	60
	Sherburne (Grassy Lake)	10,625	410
	Stafford	23,315	490
	Yellow	n/a	1,105
Taber Irrigation District	Fincastle	3,085	185
	Horsefly	9,250	565
	Taber	6,415	405
United Irrigation District	Cochrane Lake	3,100	90
Western Irrigation District	Chestermere :Lake	5,180	260
	Langdon	7,895	245
District Reservoirs Total		**1,122,580**	**25,330**
Totals		**2,825,288**	**44,850**

Irrigation District Reservoirs. The irrigation districts own and operate 38 major water storage reservoirs and are responsible for supplying water to several smaller water management and wildlife habitat projects. Reservoirs are used in district operations for water supply storage, as well as to balance flows and recapture return flows. Natural flows from rainfall events in the surrounding area may also be captured in the reservoir system. Irrigation district reservoirs are operated using reservoir rule curves based on expected demand and operational requirements. These reservoirs are located within the distribution system and supply water to one or more of the distribution blocks in the irrigation districts. Mean net evaporation was calculated based on reservoir surface area at FSL and the mean net evaporation from the grid point selected for the location of the reservoir.

Canal Evaporation Determinations

There are approximately 5900 km of open canals in the 13 irrigation districts as calculated using 1999 data. These canals vary in capacity from 0.01 $m^3 s^{-1}$ to 95 $m^3 s^{-1}$. The overall surface area is equivalent to 4100 hectares.

There are fundamental differences in measuring evaporation from standing surface water and flowing water. There has been little research on evaporation from flowing water. Methods commonly used to physically measure evaporation are difficult to apply to flowing water since the volumes are small compared to flow volumes and fall within the margin of error in measuring flows.

Mean net evaporation from canals was estimated for each district based upon an inventory of canal sizes and lengths, and upon mean net evaporation estimates for the general location of the districts. Surface areas were estimated from typical canal geometry, assuming the canals were running full or checked to their full capacity during the irrigation season. Surface area was estimated by multiplying top width by length of canal. Top width of a canal will vary depending on the capacity and the operation of any structures within a reach of canal. For purposes of this study, top width was estimated using a formula based on maximum design capacity at FSL for each canal segment. Lengths of canal within each district were calculated from Irrigation Branch data and included earth canals as well as membrane and concrete lined canals. Open and closed pipelines, as well as constructed and natural drains, were not included. Main canals considered part of the Alberta Environment headworks system were not included.

RESULTS AND DISCUSSION

Method Comparison

Comparison of mean monthly evaporation at Lethbridge by various methods using from 1969 to 1992 indicated that the Meyer method gave the highest estimates of evaporation and the Morton method provided the lowest values (Fig. 3). The modified Priestley-Taylor and lake evaporation estimates for Lethbridge were comparable during the spring and summer months, and generally were less than estimates by the Meyer method and greater than those by the Morton method (Fig. 3).

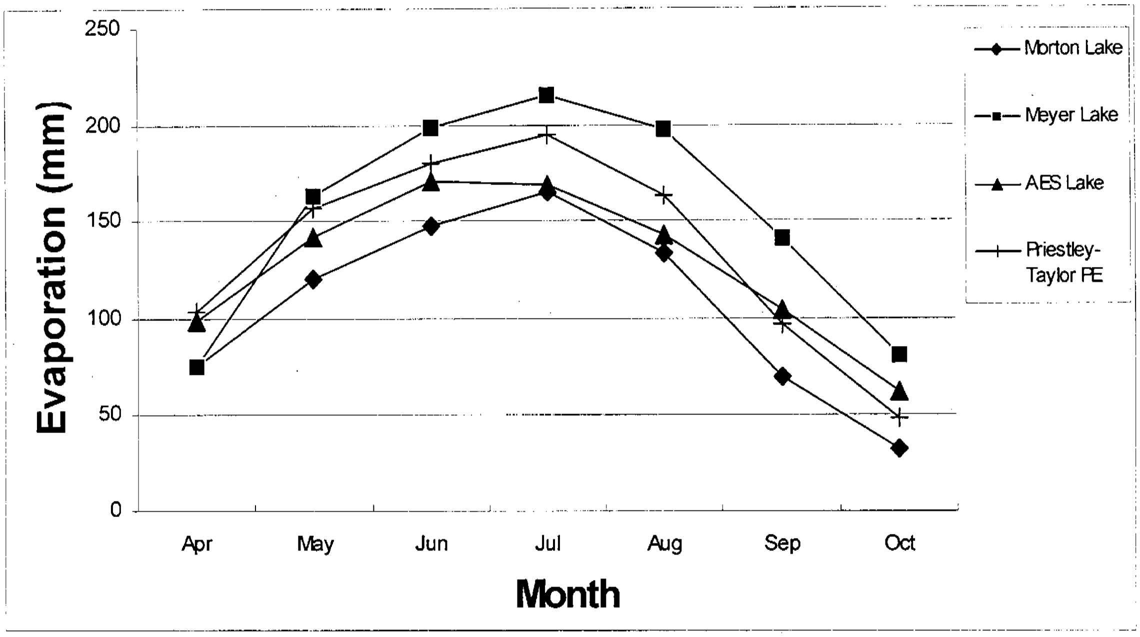

Fig. 3. Mean monthly evaporation estimates for Lethbridge from 1969 to 1992.

None of the three alternative evaporation methods compared favourably to the Morton lake evaporation method (Fig. 4; Table 2). The modified Priestley-Taylor method had the highest Pearson and concordance correlation coefficients, however, a substantial location shift was observed (Fig. 4). The lake evaporation method had a smaller location shift than the comparison with the modified Priestley-Taylor method, but a greater amount of data scatter was reflected in the lower Pearson and concordance correlation coefficients for the lake evaporation method.

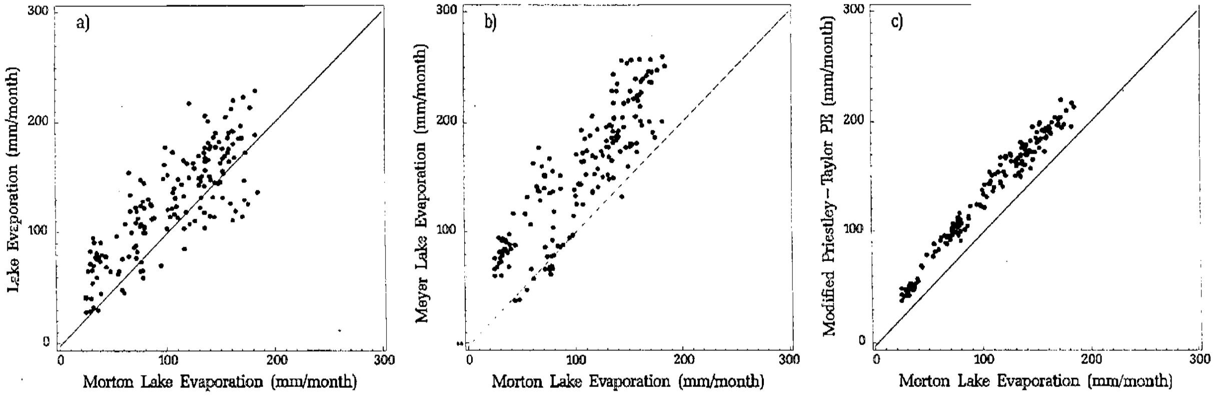

Fig. 4. Comparison of mean monthly evaporation estimates by the (a) lake evaporation, (b) Meyer, and (c) modified Priestley-Taylor methods to Morton lake evaporation.

Table 2. Comparison of different evaporation methods to Morton lake evaporation (1969-1992).

Evaporation Method	Pearson Correlation Coefficient (r)	Concordance Correlation Coefficient (cc)	Location Shift (1:1 line has 0)	Scale Shift (1:1 line has 1)
Meyers Lake Evaporation	0.87	0.61	0.90	0.79
Lake Evaporation	0.82	0.74	0.45	0.99
Modified Priestley-Taylor	0.99	0.84	0.58	0.91

The relationship between the modified Priestley-Taylor potential evapotranspiration and Morton lake evaporation methods was used to develop a regression equation to adjust modified Priestley-Taylor daily potential evapotranspiration estimates to Morton daily lake evaporation equivalent values (Fig. 5):

$$\text{Morton equivalent} = (0.90 \times \text{modified Priestley-Taylor}) - 0.48 \qquad (3)$$

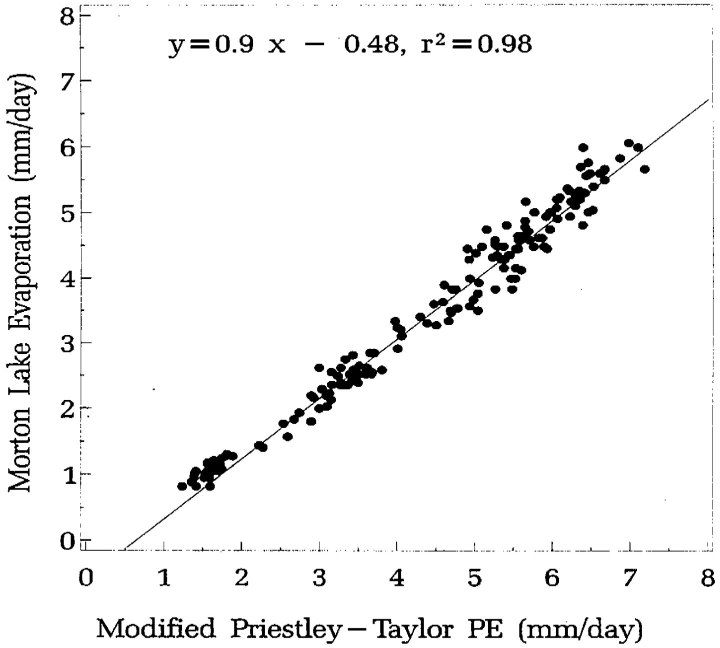

Fig. 5. Relationship between modified Priestley-Taylor daily evaporation estimates and Morton daily lake evaporation equivalent values.

A grid climate data set was developed using the Morton lake evaporation equivalent calculation and data from the 50 km x 50 km grid. A map with isopleths of the net lake evaporation from April to October for southern Alberta was created (Fig. 6). Monthly results at Lethbridge were calculated from 1920 to 1995 (Appendix C).

The equations were developed using historic climate grid data and have not been validated for use on real time data.

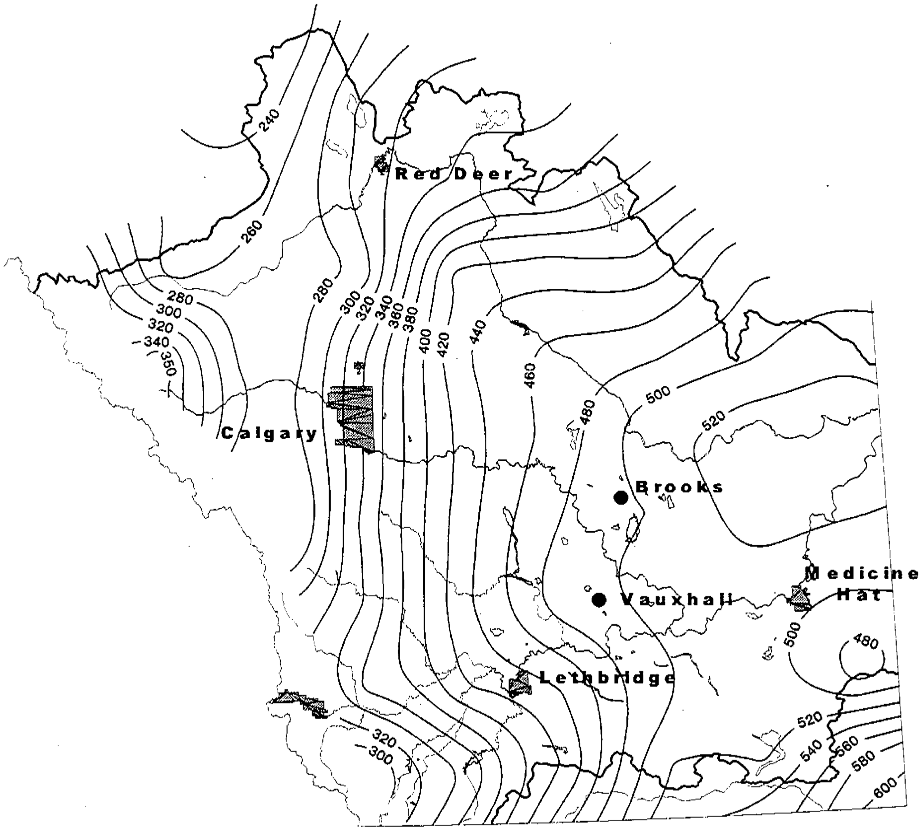

Fig. 6. Mean net evaporation isopleths for southern Alberta.

Reservoir Evaporation Losses

Net evaporation losses from individual reservoirs in the irrigation districts and the headworks system ranged from 55 to 32,540 dam^3 (Table 3). Total net evaporation losses from district reservoirs were about 122,771 dam^3 (Table 3). This represents only 3.4 percent of the proposed total licensed allocation in the 1991 regulation. This volume compares favourably to the 1991 estimate of 132,000 dam^3. These estimates are likely higher than those that would be computed in a modeling exercise since they are based on surface area at FSL.

Evaporation from open water surfaces of canals and reservoirs owned by the irrigation districts is an additional demand on the districts' water allocations. Losses from headworks canals and reservoirs is accounted for in the headworks licenses issued to Alberta Environment. Evaporation from most reservoirs within the irrigation districts is a component in the WRMM modeling conducted by Alberta Environment. Computations were based upon simulated weekly reservoir levels and surface areas. These surface areas could be considerably less than the areas at full supply levels, particularly in years of low runoff and high irrigation demand when the reservoirs would be drawn down. The reservoir evaporation demand is variable from year to year. Each scenario considered in the modeling process would have specific water demands and operational characteristics that would include a reservoir evaporation component.

Table 3. Mean net evaporation from reservoirs associated with irrigation districts in Alberta.

Location	Reservoir Name	Live Storage (dam^3)	Surface Area at FSL (ha)	Net Evaporation (dam^3)	Net Evaporation by District (dam^3)
Alberta Environment Headworks Reservoirs					
Carseland-Bow River (BRID)	Little Bow	21,078	530	2,602	
	McGregor Lake	351,059	5,100	24,429	
	Travers	104,638	2,265	10,849	37,881
Cavan Lake (RCID)	Cavan Lake	4,625	135	678	658
Lethbridge Northern (LNID)	Keho	95,635	2,350	9,870	
	Oldman River	490,180	2,425	6,645	16,515
Mountain View, Leavitt, Aetna	Payne Lake	8,690	240	658	658
Waterton-St. Mary (SMRID,	Jensen	19,000	200)	688	
	Milk River Ridge	127,297	1,415	6,014	
	St. Mary	369,310	3,765	12,952	
	Waterton	111,196	1,095	3,000	22,654
Headworks Reservoirs Total		**1,702,708**	**19,520**	**78,384**	
Irrigation District Reservoirs					
Bow River Irrigation District	Badger	53,650	890	4,263	
	H Reservoir	2,220	130	660	
	Lost Lake	5,050	485	2,381	
	Scope	19,740	575	2,921	10,226
Eastern Irrigation District	Cowoki	19,735	730	3,657	
	Crawling Valley	130,500	2,515	11,720	
	J Reservoir	615	115	576	
	Kitsim	26,520	690	3,457	
	Lake Newell	320,215	6,495	32,540	
	One Tree	2,345	90	451	
	Rock Lake	9,250	225	1,127	
	Rolling Hills	17,515	585	2,931	
	Snake Lake	18,230	105	503	
	Tilley "A"	33,300	620	3,106	
	Tilley "B"	38,235	1,410	7,064	67,132
Lethbridge Northern Irrigation	Park Lake	740	85	357	
	Picture Butte	1,600	100	420	777
Raymond Irrigation District	Corner Lake	495	15	64	
	Craddock	615	13	55	
	Factory Lake	370	29	123	242
St. Mary River Irrigation	Bullshead	125	13	65	
	Chin	190,330	1,590	7,060	
	Cross Coulee	2,590	85	361	
	Forty Mile	86,345	745	3,703	
	Murray	30,590	1,665	8,442	
	North East	2,095	210	932	
	Raymond	1,600	60	255	
	Sauder	37,745	1,245	6,412	
	Seven Persons	1,355	60	304	
	Sherburne (Grassy Lake)	10,625	410	2,038	
	Stafford	23,315	490	2,176	
	Yellow	n/a	1,105	5,492	37,239
Taber Irrigation District	Fincastle	3,085	185	821	
	Horsefly	9,250	565	2,509	
	Taber	6,415	405	1,798	5,128
United Irrigation District	Cochrane Lake	3,100	90	310	310
Western Irrigation District	Chestermere Lake	5,180	260	884	
	Langdon	7,895	245	833	1,717
District Reservoirs Total		**1,122,580**	**25,330**	**122,771**	
Totals		**2,825,288**	**44,850**	**201,155**	

Canal Evaporation Losses

Mean annual canal evaporation estimates were calculated for the 13 irrigation districts (Table 4). Losses from canals ranged from 18 to 5554 dam^3 per district (Table 4). The total annual net evaporation from canal surfaces for all the districts was estimated to be about 19,245 dam^3, or 0.5% of the proposed total licensed allocation in the 1991 regulation. This is a small component of the total water demand within the districts.

Table 4. Mean net evaporation from irrigation district canals in southern Alberta.

District	Exposed Canal Length (km)	Total Water Surface Area (ha)	Proposed License in 1991 Regulation (dam^3)	Annual Net Canal Evaporation Loss [z] (dam^3)	%
Aetna Irrigation District	17	5	11,102	18	0.2
Bow River Irrigation District	857	648	619,217	3,181	0.5
Eastern Irrigation District	1,451	987	918,958	4,945	0.5
Leavitt Irrigation District	43	11	14,802	39	0.2
Lethbridge Northern Irrigation District	529	280	391,020	1,242	0.3
Magrath Irrigation District	64	28	41,939	121	0.3
Mountain View Irrigation District	27	9	9,868	30	0.3
Ross Creek Irrigation District	19	6	3,701	31	0.8
Raymond Irrigation District	182	161	99,914	684	0.7
St. Mary River Irrigation District	1,192	1,178	890,587	5,554	0.6
Taber Irrigation District	181	109	194,893	485	0.3
United Irrigation District	187	75	83,878	257	0.3
Western Irrigation District	1,153	627	342,913	2,658	0.8
Total	**5,902**	**4,124**	**3,622,792**	**19,245**	**0.5**

[z] Evaporation loss, % = Volume of water lost due to evaporation, dam^3/District license proposed in the 1991 regulation, dam^3.

CONCLUSIONS

A satisfactory relationship was developed to convert modified Priestley-Taylor daily evaporation estimates to Morton daily lake evaporation equivalent values. This relationship was applied to a grid climate data set for southern Alberta using a geographic information system to determine evaporation losses from irrigation reservoirs and canals. Total evaporation losses from irrigation district reservoirs were about 122,771 dam^3, or 3.4% of the total licensed allocation proposed in the 1991 regulation. Evaporation losses from canals in all the districts were about 19,245 dam^3, or 0.5% of the proposed total district licensed allocation.

The volume of evaporation in the irrigation districts was directly related to existing infrastructure characteristics. Canal evaporation losses may decrease slightly as new pipelines replace some canals. Evaporation losses may increase with the construction of new reservoirs. This additional water use should be a consideration in decisions related to development of new storage reservoirs.

REFERENCES

Alberta Environment. 1991. South Saskatchewan Basin Water Allocation Regulation: Order in Council pursuant to Section 12 of the Province of Alberta Water Resources Act. Queen's Printer. Edmonton, Alberta.

Environment Canada. 1982. Canadian climate normals 1951-1980. Volume 9 Soil Temperature, Lake Evaporation Days With Blowing Snow, Hail, Fog, Smoke/Haze, Frost. Atmospheric Environment Service. Ottawa, Ontario.

Baker, D. R., Ryan, L.M. and Hill, D.F. 1999. The Irrigation District Model: A real-time approach to operations of irrigation districts. In Proceedings of A Water Management Conference: Benchmarking Irrigation system Performance Using Water Measurement and Water Balances. U.S. Committee on Irrigation and Drainage, California Polytechnic State University and the Bureau of Reclamation. San Luis Obispo, California. March 10-13.

Bothe, R.A. and Abraham, C. 1987. Evaporation and evapotranspiration in Alberta 1912 to 1985. Hydrology Branch, Technical Services Division, Water Resources Management Services, Alberta Environment. Edmonton, Alberta.

Bothe, R.A. and Abraham, C. 1993. Evaporation and evapotranspiration in Alberta 1986 to 1992, Addendum. Surface Water Assessment Branch, Technical Services & Monitoring Division, Water Resources Services, Alberta Environmental Protection. Edmonton, Alberta.

Jensen, M.E., Burman, R.D. and Allen, R.G. 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering practice No. 70. American Society of Civil Engineers. New York.

Kohler, M.A., Nordenson, T.J. and. Fox, W.E. 1955. Evaporation from ponds and lakes. U.S. Weather Bureau, Research Paper No. 38.

Kohler, M.A. and Parmele, L.H. 1967. Generalized estimates of free-water evaporation. Water Resources Research, 3(4):997-1005

Lin, L. I-Kuei. 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics 45:255-268.

McGinn, S.M., Akinremi, O.O. and Barr, A.G. 1994. Description of the Gridded Prairie Climate Database (GRIPCD) for years 1960 - 1989. Manual. Agriculture and Agri-Food Canada. Lethbridge, Alberta.

Martin, F.R.J. 1988. Determination of gross evaporation for small to moderate-sized water bodies in the Canadian Prairies using the Meyer formula. Hydrology Report #113. Agriculture Canada. Prairie Farm Rehabilitation Administration, Engineering Service. Regina, Saskatchewan.

Riewe, R.V., Mikalson, D.E., Bennett, D.R., Entz, T. and Harms, T.E. 2002. Potential evapotranspiration in southern Alberta from historical weather data. In Irrigation Water Management Study Committee. South Saskatchewan River Basin: Irrigation in the 21st Century. Volume 2 (I): On-Farm Irrigation Water Demand. Alberta Irrigation Projects Association. Lethbridge, Alberta.

Woodvine, R.J. 1994. Gross evaporation for the 30-year period 1961- 1990 in the Canadian Prairies. Hydrology Report #133. Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration, Engineering and Sustainability Service. Regina, Saskatchewan.

APPENDIX A

Evaporation data from various methods - 1969 to 1992

Table A1. Lake evaporation (mm) based on class A pan evaporation at Lethbridge from 1969 to 1992 [z].

Year	April	May	June	July	August	September	October
1969	66	111	218	125	111	83	28
1970	48	108	191	129	132	87	33
1971	65	122	145	147	154	78	54
1972	59	104	126	132	104	65	42
1973	46	115	151	137	118	100	29
1974	148	104	114	119	136	77	45
1975	79	178	177	172	85	100	41
1976	74	179	147	163	151	124	40
1977	70	148	192	186	113	76	30
1978	65	114	168	156	143	155	59
1979	63	121	176	186	150	124	70
1980	113	147	145	197	123	108	78
1981	145	120	178	168	146	122	71
1982	104	132	157	192	165	109	76
1983	88	159	166	183	187	134	91
1984	113	173	173	214	207	97	65
1985	123	163	205	229	150	79	83
1986	130	144	191	181	176	69	74
1987	149	182	213	170	118	112	91
1988	162	202	220	223	167	119	80
1989	100	163	176	186	140	105	78
1990	106	117	173	165	166	153	95
1991	126	133	168	189	148	108	81
1992	128	170	132	114	142	119	66

[z] Pan evaporation was taken from Environment Canada data. Data adjusted to estimate lake evaporation using the relationship: Lake evaporation = 0.7 x pan evaporation.

Table A2. Morton lake evaporation (mm) at Lethbridge from 1969 to 1992 ^{z}.

Year	April	May	June	July	August	September	October
1969	78	127	122	176	162	73	25
1970	59	122	147	173	153	70	32
1971	76	132	146	173	154	65	31
1972	78	117	160	144	136	56	25
1973	61	141	141	185	136	68	29
1974	77	101	171	165	107	72	39
1975	44	100	137	174	117	81	25
1976	77	142	133	151	134	87	30
1977	95	112	162	158	111	59	36
1978	48	104	164	153	131	66	35
1979	55	106	159	168	131	77	32
1980	89	133	149	170	110	62	34
1981	80	102	147	153	151	80	29
1982	80	109	137	163	137	72	35
1983	72	127	117	150	145	67	33
1984	74	107	136	178	137	54	27
1985	72	126	156	183	122	43	29
1986	84	115	159	163	141	44	38
1987	98	140	161	155	119	87	39
1988	99	140	163	172	138	73	40
1989	79	120	153	171	108	80	37
1990	76	108	158	159	140	102	32
1991	86	117	137	183	142	77	35
1992	79	131	133	145	136	67	31

^{z}Taken from Bothe and Abraham (1993).

Table A3. Meyer lake evaporation (mm) at Lethbridge from 1969 to 1992 [z].

Year	April	May	June	July	August	September	October
1969	69	150	141	186	257	151	61
1970	67	158	217	246	228	160	79
1971	69	152	205	236	256	142	73
1972	79	137	220	174	186	133	77
1973	59	190	235	251	229	129	82
1974	62	133	236	240	164	140	98
1975	39	139	182	191	170	119	67
1976	68	187	178	220	198	152	77
1977	95	174	215	239	153	107	91
1978	40	144	197	181	196	138	93
1979	49	144	224	242	183	167	82
1980	88	169	177	246	185	163	84
1981	104	125	196	178	160	156	72
1982	79	165	149	227	218	152	84
1983	67	170	206	254	256	177	94
1984	78	193	197	247	244	117	69
1985	87	174	221	259	194	117	95
1986	88	188	181	201	186	88	69
1987	97	184	225	180	153	140	89
1988	115	229	237	257	204	152	85
1989	67	168	178	201	172	137	82
1990	66	125	205	173	187	171	93
1991	87	136	192	201	192	136	85
1992	93	178	148	132	165	137	61

[z] Taken from Woodvine (1994).

Table A4. Adjusted Priestley-Taylor potential evapotranspiration (mm) at Lethbridge from 1969 to 1992.

Year	April	May	June	July	August	September	October
1969	113	169	169	198	196	107	38
1970	84	167	195	220	198	93	48
1971	106	160	173	204	199	96	47
1972	97	161	186	174	169	82	49
1973	92	171	179	214	170	96	48
1974	107	134	198	200	143	100	58
1975	68	138	164	195	145	107	43
1976	112	172	162	190	153	112	48
1977	124	152	195	191	140	84	48
1978	79	131	189	176	151	89	53
1979	88	144	194	204	165	110	52
1980	123	166	173	197	137	95	50
1981	110	143	165	183	181	111	46
1982	92	151	180	190	162	97	50
1983	103	164	168	185	183	95	53
1984	104	154	181	210	176	78	42
1985	102	171	192	217	151	70	42
1986	102	154	185	190	178	68	53
1987	124	170	192	185	141	113	55
1988	122	174	194	203	161	100	55
1989	105	154	182	202	146	100	50
1990	99	146	173	186	161	122	43
1991	105	144	156	196	170	104	48
1992	116	163	167	158	150	89	43

APPENDIX B

Climate database stations (50 km x 50 km grid)

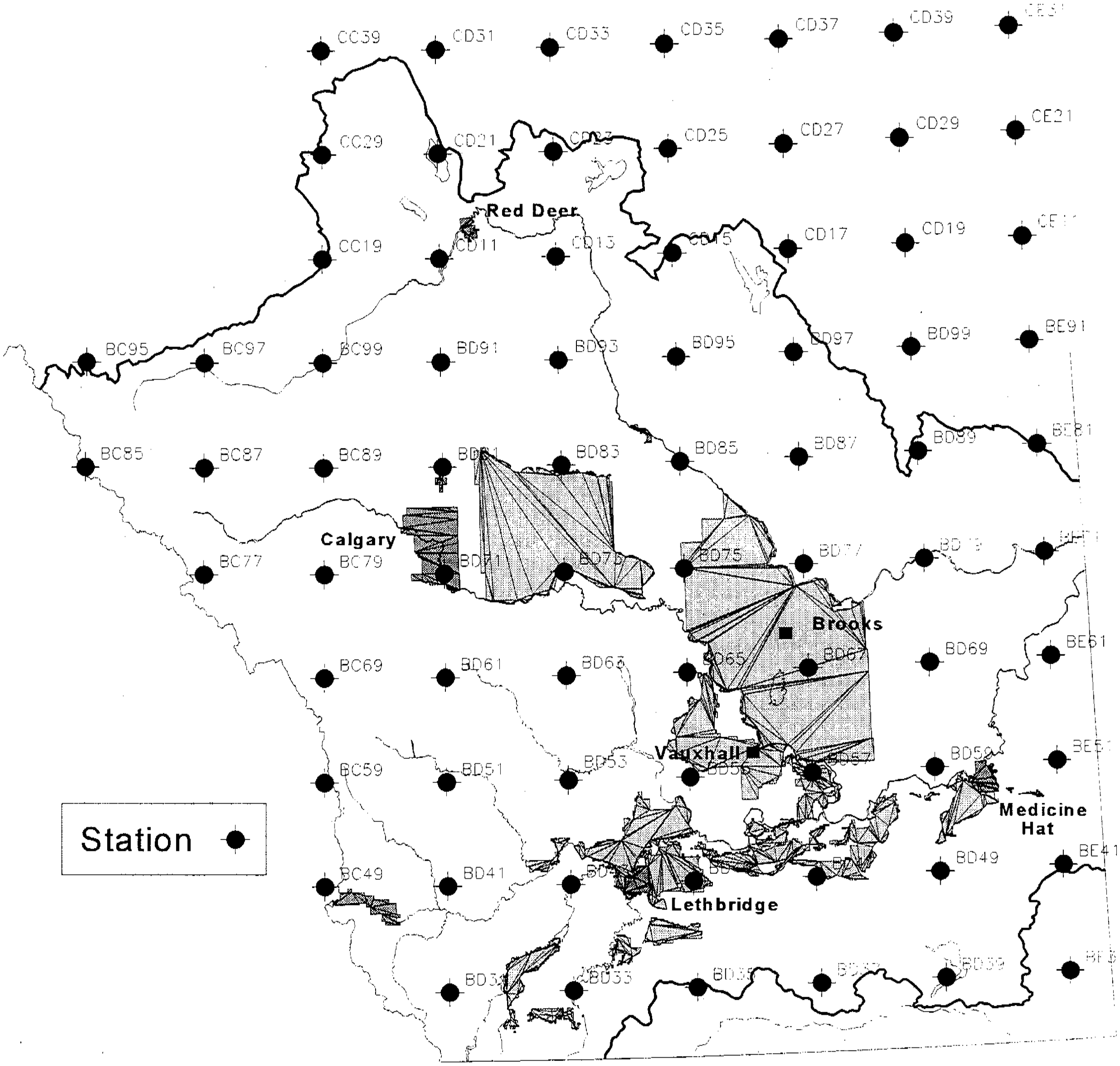

Fig. B1. Climate database stations (50 km x 50 km grid).

Table B1. Reservoir grid climate stations and mean net evaporation (mm).

Alberta Environment Headworks Reservoirs		Grid Station	Mean Net Evaporation
Carseland-Bow River (BRID)	McGregor	BD65	479
	Travers	BD65	479
	Little Bow	BD55	491
Lethbridge Northern (LNID)	Oldman River	BD31	274
	Keho	BD43	420
Mountain View, Leavitt, Aetna (MVID, LID, AID)	Payne Lake	BD31	274
Ross Creek (RCID)	Cavan Lake	BE51	502
Waterton-St. Mary (SMRID, MID, RID, TID)	St. Mary	BD33	344
	Milk River Ridge	BD35	425
	Waterton	BD31	274
	Jensen	BD33	344
Irrigation District Reservoirs			
Bow River Irrigation District	Badger	BD65	479
	Scope	BD57	508
	Lost Lake	BD55	491
	H Reservoir	BD57	508
Eastern Irrigation District	Newell	BD67	501
	Crawling Valley	BD75	466
	Tilley "B"	BD67	501
	Tilley "A"	BD67	501
	Kitsim	BD67	501
	Cowoki	BD67	501
	Rolling Hills	BD67	501
	Snake Lake	BD65	479
	Rock Lake	BD67	501
	One Tree Reservoir	BD67	501
	J Reservoir	BD67	501
Lethbridge Northern Irrigation District	Picture Butte Reservoir	BD43	420
	Park Lake	BD43	420
Raymond Irrigation District	Craddock	BD35	425
	Corner	BD35	425
	Factory	BD35	425
St. Mary River Irrigation District	Chin Reservoir	BD45	444
	Forty Mile Reservoir	BD47	497
	Sauder Reservoir	BD59	515
	Murray Lake	BD49	507
	Stafford Reservoir	BD45	444
	Sherburne (Grassy	BD47	497
	Cross Coulee	BD35	425
	North East	BD45	444
	Raymond	BD35	425
	Seven Persons	BD49	507
	Yellow Lake	BD47	497
Taber Irrigation District	Horsefly Lake	BD45	444
	Taber Reservoir	BD45	444
	Fincastle Reservoir	BD45	444
United Irrigation District	Cochrane Lake	BD33	344
Western Irrigation District	Langdon Reservoir	BD71	340
	Chestermere	BD71	340

Table B2. Irrigation district grid climate stations and mean net evaporation.

District	Grid Station	Mean Net Evaporation (mm)
Aetna Irrigation District	BD33	344
Bow River Irrigation District	BD55	491
Eastern Irrigation District	BD67	501
Leavitt Irrigation District	BD33	344
Lethbridge Northern Irrigation District	BD45	444
Magrath Irrigation District	BD35	425
Mountain View Irrigation District	BD33	344
Ross Creek Irrigation District	BE51	502
Raymond Irrigation District	BD35	425
St. Mary River Irrigation District - Central	BD47	497
St. Mary River Irrigation District - East	BD49	507
St. Mary River Irrigation District - West	BD45	444
Taber Irrigation District	BD45	444
United Irrigation District	BD33	344
Western Irrigation District	BD73	424

APPENDIX C

Morton equivalent evaporation from modified Priestley-Taylor evapotranspiration at Lethbridge from 1920 to 1995

Table C1. Morton equivalent evaporation (mm) from modified Priestley-Taylor for Lethbridge from 1920 to 1995.

Year	April	May	June	July	August	September	October
1920	47	114	148	163	140	80	27
1921	75	123	165	168	142	64	37
1922	60	124	159	155	141	77	34
1923	80	127	132	152	129	88	33
1924	75	139	135	171	122	74	27
1925	79	140	146	165	130	56	15
1926	91	129	149	178	119	48	31
1927	76	85	137	145	120	62	30
1928	68	151	122	132	117	81	22
1929	65	113	136	175	151	67	34
1930	87	111	145	173	151	67	22
1931	85	131	155	164	142	69	35
1932	75	123	142	171	128	78	23
1933	65	118	163	177	129	65	26
1934	98	143	130	168	140	58	27
1935	59	119	142	166	130	79	30
1936	75	153	153	198	139	68	31
1937	79	124	143	163	121	75	26
1938	72	108	145	169	134	95	31
1939	86	129	117	174	143	71	23
1940	60	141	157	157	147	75	24
1941	92	121	137	167	118	55	29
1942	80	114	116	158	124	67	31
1943	86	115	132	172	136	78	32
1944	94	136	131	162	123	73	40
1945	57	111	121	167	143	63	34
1946	86	122	135	175	134	65	19
1947	78	124	127	184	121	61	26
1948	63	119	132	156	135	80	38
1949	97	133	142	160	148	78	21
1950	68	121	142	151	126	78	20
1951	74	117	116	154	106	57	18
1952	94	124	135	142	118	75	34
1953	48	116	123	167	139	79	39
1954	52	119	124	171	113	62	29
1955	66	100	151	142	146	69	29
1956	72	127	145	151	121	70	24
1957	75	131	137	174	119	76	16

Table C1. Morton equivalent evaporation (mm) from modified Priestley-Taylor for Lethbridge from 1920 to 1995 - continued.

Year	April	May	June	July	August	September	October
1958	68	149	132	148	137	71	36
1959	74	112	144	168	120	63	22
1960	73	114	151	185	121	80	29
1961	70	121	177	160	144	61	26
1962	92	120	150	158	126	77	32
1963	80	128	138	162	132	82	36
1964	74	114	144	171	124	56	35
1965	76	116	131	159	130	48	37
1966	68	134	131	160	126	87	24
1967	48	104	137	176	153	93	31
1968	71	122	137	164	120	69	25
1969	86	135	135	160	159	81	19
1970	60	133	158	179	160	68	28
1971	80	127	138	166	162	71	27
1972	71	128	151	139	135	58	29
1973	67	137	144	174	136	71	29
1974	81	104	161	162	112	74	37
1975	47	107	131	157	114	81	24
1976	85	137	129	154	121	85	29
1977	96	120	158	154	110	60	28
1978	56	102	153	141	119	65	32
1979	64	112	157	166	131	84	31
1980	94	132	138	159	106	70	31
1981	83	112	132	147	145	84	27
1982	67	119	145	153	129	72	30
1983	77	131	134	149	147	70	33
1984	78	122	146	171	141	55	23
1985	76	137	156	177	119	48	23
1986	76	122	150	153	143	46	33
1987	95	136	156	149	110	86	34
1988	94	140	157	165	128	75	35
1989	79	122	147	164	115	75	30
1990	74	114	139	149	128	94	24
1991	79	113	123	158	136	78	28
1992	89	130	133	125	118	64	24
1993	77	130	127	115	109	67	29
1994	82	124	144	165	132	91	20
1995	69	116	138	144	128	75	23

Volume 3 Conveyance Water Management

III. Return Flow from Alberta's Irrigation Districts

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This study was a joint effort of Jack Ganesh, Rod MacLean, Lawrence Schinkel and Dick Hart. Lawrence Schinkel gathered data from the irrigation districts and assisted in its analysis. Jack Ganesh conducted most of the analysis related to the block studies. Data analysis was carried out and an early draft of the report was prepared by Rod MacLean and Jack Ganesh. The final report was written by Dick Hart. Editorial assistance provided by Rod Bennett, Wally Chinn and other staff members of AAFRD is also very much appreciated.

EXECUTIVE SUMMARY

During the past decade, the irrigation districts and Alberta Agriculture, Food and Rural Development (AAFRD) have made a concerted effort to better quantify return flow, to understand the factors affecting it, and to identify ways to minimize it. This effort has involved intensive monitoring and study of small irrigation blocks within the Bow River Irrigation District (BRID) and the Lethbridge Northern Irrigation District (LNID), extensive monitoring of district return flows, and computer simulation modeling. Return flows were a significant factor in determining the proposed licence volume (PLV) for the 1991 irrigation expansion guidelines.

Intensive monitoring in irrigation blocks K5 in the BRID and J12 in the LNID indicated that return flows could be broken down into three primary components: base flow, operational spills, and on-farm drainage. Base flow and operational spills averaged about 0.07 cubic metres per second per lateral. On-farm drainage of surplus applications was usually small for sprinkler systems, but was significant for some gravity surface systems. In Block K5, gravity surface irrigators returned about 40% of their total application to drains.

Six of the 13 districts conducted sufficient monitoring to permit reasonably accurate return flow estimates for 1997 to 2000. Being the largest districts, these six districts contain more than 90% of the total irrigated area within all districts. Return flows expressed as a percentage of gross diversion vary substantially from district to district. They were the highest in the Western Irrigation District (WID), averaging 65%, and the lowest in the St. Mary River Irrigation District (SMRID), averaging 7.9%. Variations are a function of a combination of several factors, including the size of the district, irrigation area density and the extent of infrastructure rehabilitation. In five of the six districts, average unit return flows were substantially higher than those assumed in establishing the PLV in the 1991 irrigation expansion guidelines. The exception is the SMRID, which returns less than what was assumed in computing the PLV.

To administer the inter-provincial apportionment agreement, the Prairie Provinces Water Board estimates return flows for the irrigation districts based on recorded flows at about 20 hydrometric stations. For the four years that PPWB estimates could be compared with recorded data, the PPWB estimates were inaccurate for some districts, but the estimates of total return flow for all districts were remarkably consistent with recorded data.

With the data base and analytical tools that are now available, most of the larger irrigation districts are well-positioned to identify physical and operational factors that have the greatest effect on return flows, and to define and prioritize measures to reduce return flows and thereby increase irrigation efficiencies.

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INTRODUCTION

Rapid expansion of irrigation and growing interest in environmental issues during the 1970s led to concerns about the limits of the water supply in the South Saskatchewan River Basin (SSRB). Irrigation water supply shortages became noticeably more frequent, particularly on uncontrolled streams. At the same time, a number of environmental issues were raised related to water quality, fisheries and impacts of structural water management measures.

In the early 1980s, Alberta Environment (AENV) initiated a process to address water management policy issues in the SSRB. The process led to the development of the SSRB Water Management Policy. The policy was announced on May 28, 1990 (AENV 1990). It provided guidelines related to:

- Multi-purpose use of water.
- Priority of uses, and minimum and preferred in-stream flows.
- Irrigation expansion.
- Administration of the Prairie Provinces Water Board (PPWB) Agreement.
- Water conservation.
- Public consultation.

With respect to irrigation expansion, the policy calls for establishing the maximum amounts of water that can be allocated for irrigation, with due consideration for the needs of all other users, including in-stream users and inter-provincial apportionment. Alberta Environment worked with other government agencies to establish the guidelines.

The guidelines were approved by Order-in-Council on September 20, 1991. They are defined in and are being implemented through the South Saskatchewan Basin Water Allocation Regulation (AENV 1991) pursuant to Section 173 of the *Water Act.* The Regulation states that the amount of water allocated to each of the four sub-basins (Red Deer, Bow, Oldman and South Saskatchewan) and to various expansion areas within each sub-basin, including the 13 irrigation districts, must not exceed the amount sufficient for the irrigation of a specific maximum area. The maximum area for each of the irrigation districts is shown in Column (7) of Table 1. Recognizing the limitations of the databases and the 1990 estimates of current and future water uses, the government committed to reviewing and refining the irrigation expansion guidelines in the year 2000.

Subsequent to establishing the expansion areas, the volume of water that would be required for licensing the maximum irrigation areas within each of the irrigation districts were determined by AENV and Alberta Agriculture, Food and Rural Development (AAFRD). The ninetieth percentile irrigation demand was selected for computing the proposed licence volumes. (The ninetieth percentile demand is a demand that would be expected to occur under high temperature and low precipitation conditions, during the course of a long period of time, and would be exceeded in only 10% of the years.) A full description of the assumptions and criteria that were used to determine the licence volumes (Table 1) is provided in the report on the irrigation water management study (Irrigation Water Management Study Committee 2002). In this report, the return flow component of the determination is of primary interest.

Table 1. 1991 irrigation expansion guidelines and proposed licence volumes.

Irrigation District	(1) Optimum Farm Irrigation Demand (mm)	(2) Projected Canal Losses (mm)	(3) Reservoir Evap. Losses (mm)	Return Flow (mm)		(6) Total Projected Diversion Req't (mm)	(7) Irrigation Area Limit (hectares)	(8) Proposed Licence Volumes (dam^3)	(9) Projected Return Flow (dam^3)	(10) Return Flow Proportion of Licence Volumes
				(4) Circa 1990	(5) Projected					
Aetna	457	219	9	503	91	776	1,429	11,102	1,306	11.8%
Bow River	555	82	9	186	82	728	84,984	619,217	69,941	11.3%
Eastern	576	98	67	189	85	826	111,289	918,958	94,982	10.3%
Leavitt	457	207	6	503	91	761	1,930	14,802	1,764	11.9%
Lethbridge Northern	442	70	15	52	52	579	67,583	391,020	35,020	9.0%
Magrath	442	73	0	61	52	567	7,406	41,939	3,836	9.1%
Mountain View	457	88	9	503	91	645	1,497	9,868	1,369	13.9%
Raymond	436	43	0	61	52	531	18,818	99,914	9,745	9.8%
Ross Creek	686	76	0			762	486	3,701	0	
St. Mary River	463	55	21	61	52	591	150,543	890,587	78,008	8.8%
Taber	479	43	12	61	52	586	33,265	194,893	17,232	8.8%
United	457	70	3	347	79	609	13,759	83,878	10,904	13.0%
Western	485	305	6	399	98	894	38,445	342,913	37,499	10.9%
Totals							531,434	3,622,792	361,606	
Weighted Means	500	88	24		67	683				10.0%

Column (4) of Table 1 lists the ninetieth percentile return flows for the districts as determined from Water Survey of Canada estimates from 1979 to 1989. Ninetieth percentile return flows are values that would not be expected to be exceeded in more than 10% of the years. These return flows were assumed to be indicative of 1990 management practices and infrastructure. Unit return flows (millimetres) were computed based upon actual irrigated areas. It was assumed that the volume of return flow would increase as the irrigated area increases.

Projected return flows listed in Column (5) were estimated assuming that district management and infrastructure improvements would reduce return flows by varying amounts within each district.

AENV has used the irrigation expansion guidelines to guide the processing of irrigation water right applications and the issuing of irrigation licences in the (SSRB). The licences fix the amount of water that each district is entitled to divert (subject to priorities, terms and conditions).

Return flow from an irrigation project is the quantity of water diverted from a source that exceeds the consumptive requirements of the irrigation project, and losses. This surplus water flows to the river system – not necessarily the source stream – through drainage channels.

Return flows are an inevitable consequence of operating an irrigation system. They occur in large part because variable supplies and demands cannot be perfectly matched in a canal distribution system. The irrigation districts are concerned about return flows for several reasons. Uncontrolled spills and sudden changes in canal water levels can damage the canals and increase maintenance costs. They are concerned about public perceptions of wasteful management practices and impacts on the source streams. They are also concerned that inefficient operations could jeopardize further expansion of irrigation. The irrigation districts have worked closely with government to develop the principle that, with improvements in efficiencies and/or reduced return flows, the districts could expand beyond their area limits provided that such expansion can be served within their respective licensed volumes. During the past decade, the districts and AAFRD have made a concerted effort to better quantify return flow, to understand the factors affecting it, and to identify ways to minimize it. This effort has involved intensive monitoring and study of small irrigation blocks within the BRID and LNID, extensive monitoring of district return flows, and computer simulation modeling.

This report summarizes the findings of the Block Studies as they relate to return flows, and the results of return flow monitoring conducted by the irrigation districts and AAFRD from 1997 to 2000. Monitored return flows were compared with return flows assumed in determining the proposed licence volumes for irrigation expansion (Col. 9, Table 1). They were also compared with return flow estimates prepared by the PPWB for use in administering the inter-provincial apportionment agreement.

IRRIGATION BLOCK STUDIES

Objectives

The objectives of the Block Studies were to monitor the inflows to, outflows from, and the movement of water within the blocks for different infrastructure characteristics, irrigation methods, crop types and management techniques (MacLean et al. 1999). The results were used to assist in calibrating the Irrigation District Model (IDM) (Irrigation Water Management Study Committee 2002)

Methods

Two irrigation blocks were established and fitted with a variety of monitoring equipment to record flows and meteorological information. Block K5 was established within the BRID in 1994 (Fig. 1). It has an area of 1,467 hectares, about half of which is irrigated by gravity surface methods and half by sprinklers. Block J12, with an area of 1,435 hectares, was established within the LNID in 1995 (Fig. 2). It is irrigated entirely by sprinkler systems.

Data collected included crop type, on-farm irrigation system, field area, weather, canal capacities and farm management characteristics. Flow data were collected at 20-minute intervals at turnouts, drains and spill channels.

Inflows and outflows were also monitored on two larger blocks, Block B in the BRID and Block K in the LNID, to further assist in calibrating the Irrigation District Model. Block B contains the more intensively monitored Block K5; Block K is adjacent to Block J12. Information from all blocks was used to relate area irrigated, on-farm water management, and irrigation methods and systems, to flows within the distribution systems and return flows.

A summary of the of block sizes, inflows and return flows from each of the four blocks is given in Table 2.

Results and Discussion

Components of Return Flow. Intensive monitoring of irrigation block K5 in the BRID and J12 in the LNID has helped to track and quantify the water balance within the blocks, and to understand factors affecting return flows. For discussion purposes, return flows can be broken down into three primary components.

- Operational spills.
- Base flow.
- On-farm drainage.

Operational spills usually occur as a result of flushing the distribution system or sudden reductions in demand. The need to flush canals and some reservoirs at start-up results in high

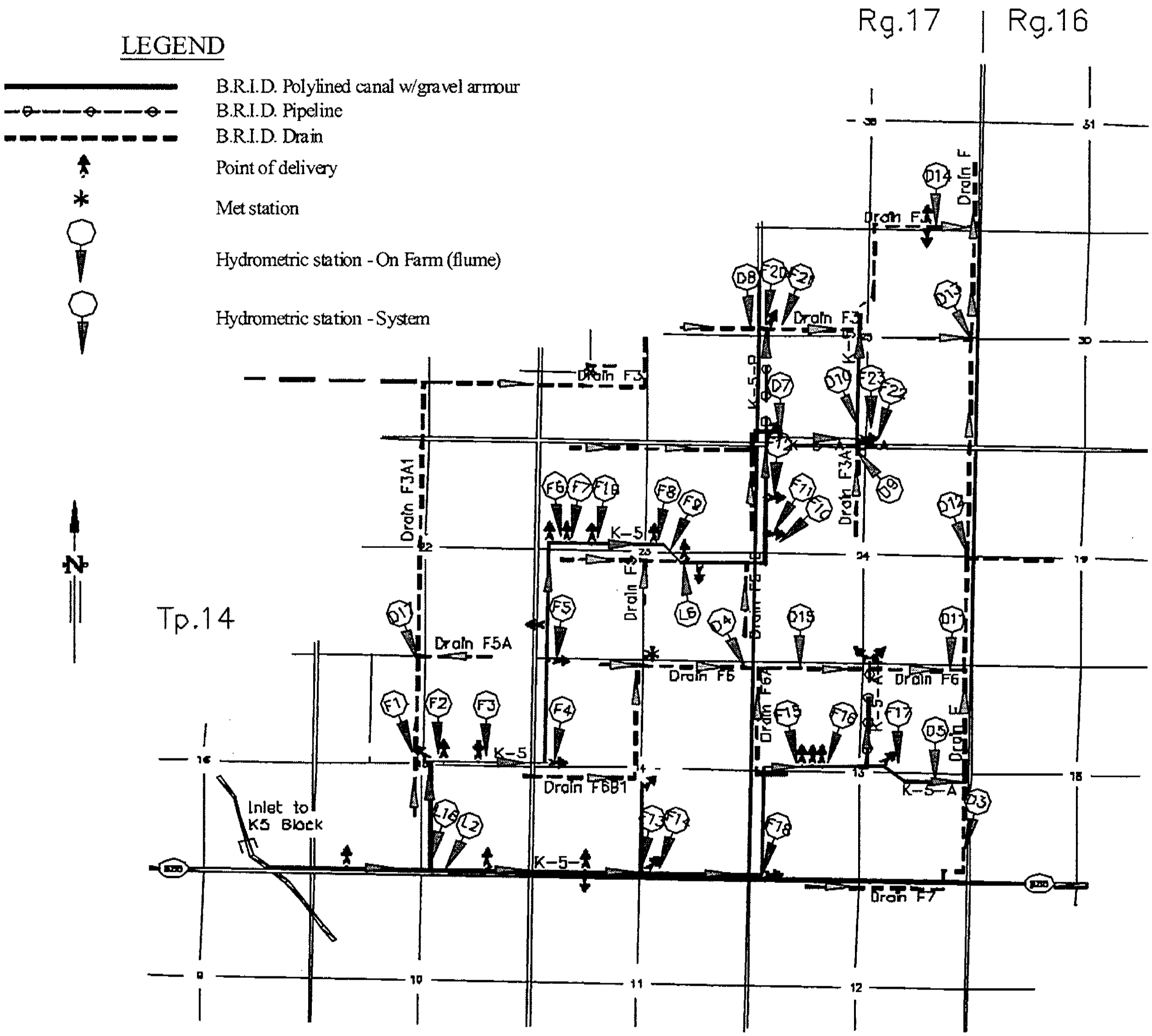

Figure 1. Block K5 in the Bow River Irrigation District.

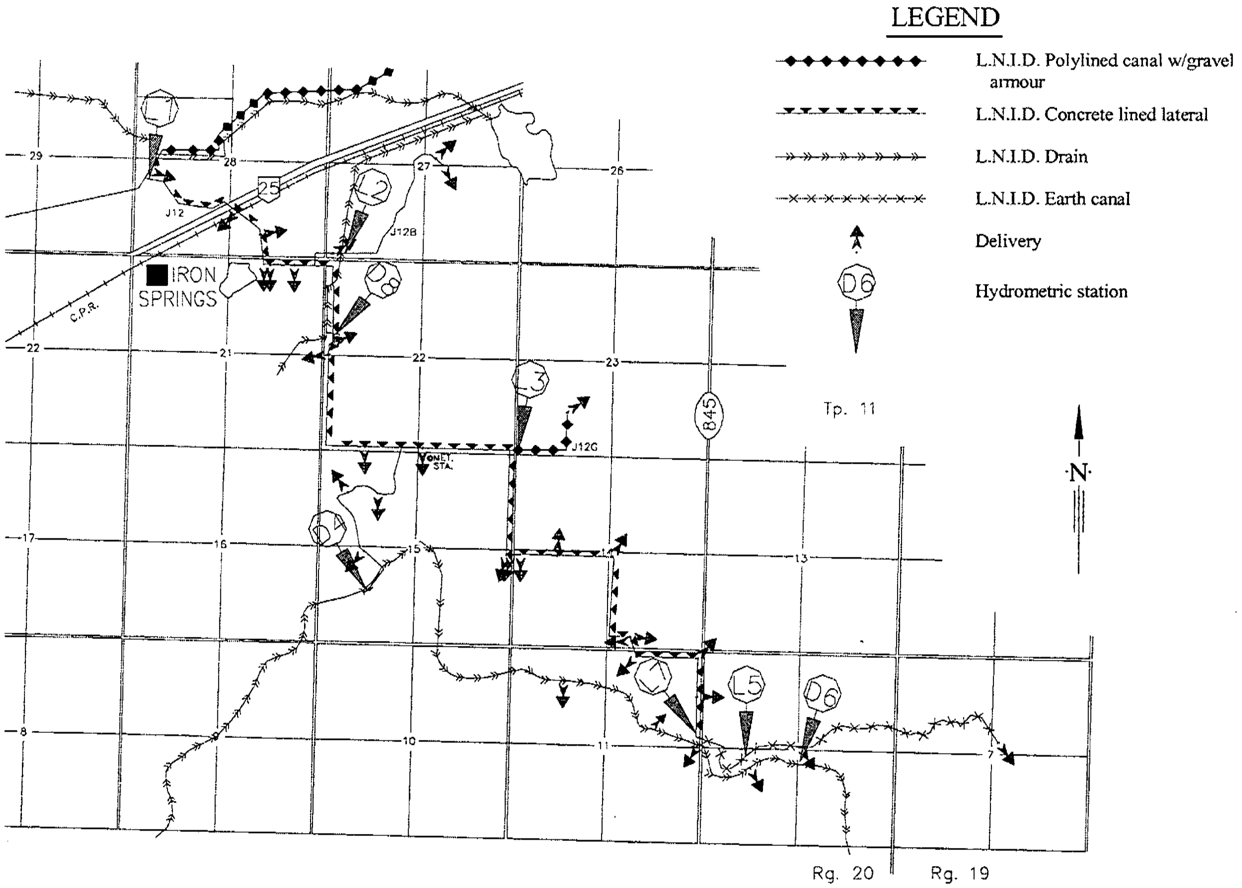

Figure 2. Block J12 in the Lethbridge Northern Irrigation District.

Table 2. Summary of irrigation block size, inflows and return flows.

Irrigation District Block	Year				Average	Depth (mm)	Standard Deviation (SD)	SD%
	1994	1995	1996	1997				
K5 Block								
Irrigated Area (ha)	1,173	1,142	1,262	1,262	1,210		62	5%
Inflow (dam^3)	7,203	5,020	7,573	7,430	6,807	549	1,040	15%
Return Flow * (dam^3)	3,533	2,717	3,657	3,628	3,384	274	387	11%
Portion Returned	49%	54%	48%	49%	50%			
B Block								
Irrigated Area (ha)	7,040	7,031	7,204	7,157	7,108		86	1%
Inflow (dam^3)	40,729	28,208	38,697	45,744	38,344	549	7,378	19%
Return Flow (dam^3)	21,354	16,720	21,436	19,596	19,777	274	2,207	11%
Portion Returned	52%	59%	55%	43%	50%			
J12 Block								
Irrigated Area (ha)		1,250	1,322	1,267	1,280		37	3%
Inflow (dam^3)		3,680	6,099	5,319	5,033	396	1,235	25%
Return Flow (dam^3)		1,124	1,391	1,530	1,348	91	206	15%
Portion Returned		31%	23%	29%	27%			
K Block								
Irrigated Area (ha)		5,894	6,687	6,626	6,402		442	7%
Inflow (dam^3)		15,452	27,646	27,674	23,591	366	7,048	30%
Return Flow (dam^3)		7,275	8,268	8,456	7,999	122	634	8%
Portion Returned		47%	30%	31%	34%			

* Return Flow in all four blocks includes all returns including field run-off.

Note: 1) The return flow as a depth per unit of irrigated area for Block B is 150 mm more than K Block because of surface irrigation in B.

2) The return flow as a depth per unit of irrigated area for Block K5 is 180 mm more than J12 Block because of surface irrigation in K5.

return flows early in the irrigation season. Irrigation demands can change very suddenly for numerous reasons, such as shut-downs due to heavy rains, freezing temperatures, power failures, or equipment breakdowns; end gun or corner arm shut-offs on pivot systems; and set changes on side-roll systems. Shut-downs will result in increased return flows and will continue until adjustments can be made to the system to restore the supply-demand balance.

During normal operations, a base flow is required along canals to meet seepage and evaporation losses, to ensure that the last users in the system have sufficient water to operate their pumps or turnouts, and to provide a margin of safety to accommodate sudden increases in demand. The lower end of a canal, downstream of all uses supplied by the canal, is commonly referred to as a tailout. The number of tailouts in a distribution system has a major effect on return flows. A branched system with numerous laterals and sub-laterals canals will have higher return flows than a linear system with fewer laterals. The number of tailouts can be reduced by replacing laterals with closed pipelines.

On-farm drainage of surplus applications is usually small for sprinkler systems, but can make a significant contribution to return flows in areas where gravity surface irrigation systems are common. In Block K5, gravity surface irrigators returned about 40% of their total application to drains. The return flows from the irrigation block with a high percentage of gravity surface irrigation were typically 75 to 100% higher than that of the block with only sprinkler systems, mainly because of on-farm drainage.

Base Flow and Operational Spills. Base flows and operational spills are flows that are not diverted at the farm turnouts. They remain in the laterals through to the tailouts. From the block studies, the average return flow at the tailout of every lateral was 0.07 cubic metres per second (Figure 3). The base flow component is believed to be substantially higher than the operational spills, perhaps at about 0.057 cubic metres per second. The tailout flows did not vary significantly with changing inflows or with the size of the irrigation area supplied from the lateral.

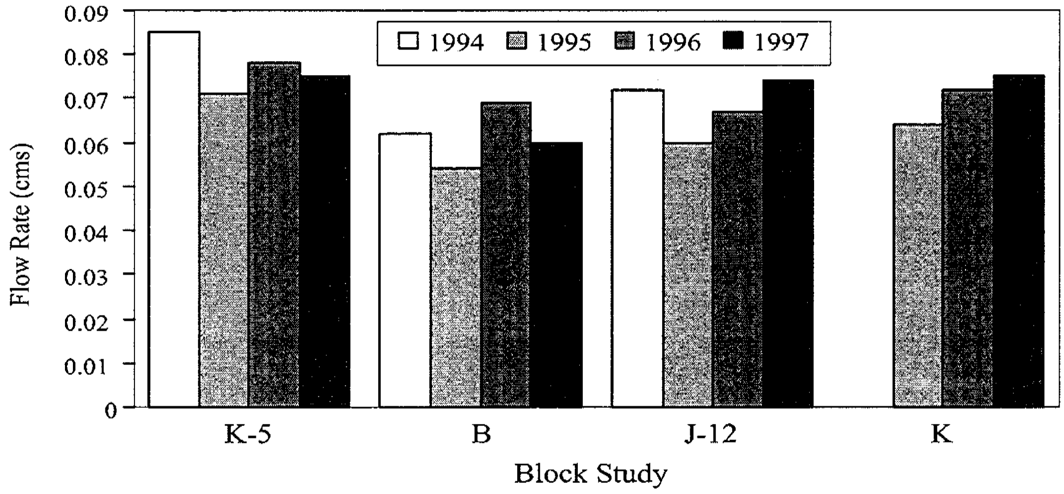

Figure 3. **Average base flow and operational spill per tailout.**

Tailout flows are not necessarily lost to the irrigation system as return flows. Some districts have strategically placed reservoirs that capture the surplus flows for downstream use. Replacing laterals with closed pipelines eliminates tailout flows. Automated diversion and check structures along canals can significantly reduce tailout flows.

On-farm Field Runoff. When water is applied to irrigation fields at rates that exceed soil infiltration rates, surface runoff often results. Continued irrigation applications at times when the soil is at field capacity will result in surface runoff and/or percolation beyond the root zone. Water that has percolated beyond the root zone could enter a groundwater system that discharges to return flow channels or directly to river systems. The magnitude of field runoff varies markedly between sprinkler and gravity irrigation projects.

A well designed and managed sprinkler system should not have a significant field runoff component. Most irrigators in Alberta tend to under-irrigate for a variety of reasons, one of which is energy costs related to operating irrigation pumps. Under-irrigation would tend to minimize surface runoff from irrigated fields.

Field runoff from gravity irrigation projects in Block K5 and Block B were on average about 40% of the diversions to the fields (Fig. 4). The unit return flow (millimetres per unit area irrigated) in Blocks K5 and B were substantially higher than those of Blocks J12 and K, primarily due to the gravity surface irrigation in Blocks K5 and B (Table 2). About half of the irrigation in Blocks K5 and B occurs within gravity surface irrigation projects.

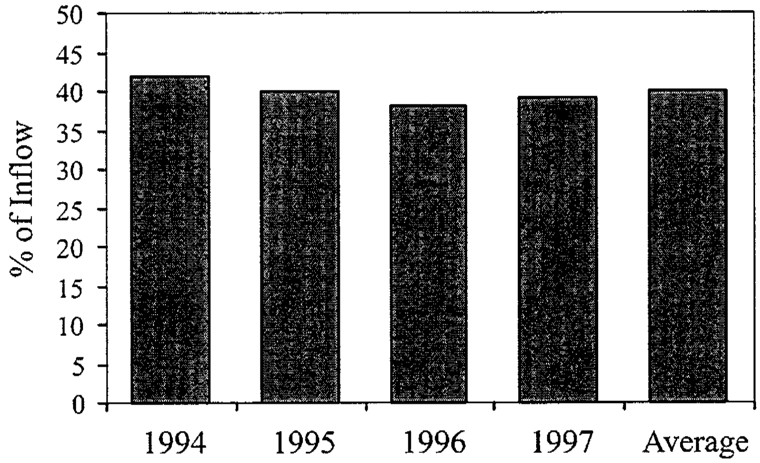

Figure 4. **Gravity irrigation field runoff as a proportion of field inflow in Block K5.**

PRAIRIE PROVINCES WATER BOARD
RETURN FLOW ESTIMATES

Objectives

In order to assist in validating return flow volumes and to be able to extrapolate those return flows to inflows and return flows to an earlier historical period of time, a correlation between historical Prairie Provinces Water Board (PPWB) documented return flows and irrigation district recorded return flows needed to be carried out.

Methodology

Estimates of return flow from the irrigation districts have been made by the Water Survey of Canada (WSC) or the PPWB for the purpose of administering the inter-provincial apportionment agreement (Komax International Ltd. 1993; PPWB 1995). Return flow estimates are required for computing natural flows in the SSRB. While procedures for estimating return flows have changed during the years, typically they involve the following:

1. For the larger districts (BRID; Eastern – EID; LNID; Western –WID; the St. Mary's Project (SMP), which includes Magrath - MID, Raymond - RID, St. Mary River – SMRID, and Taber - TID) the procedures involve the use of monthly regression equations (April to October) to relate return flows recorded at about 20 hydrometric stations operated by WSC to total return flows. Data for the regression analysis were determined from synoptic surveys conducted in several years to estimate total return flows from the districts. For some districts, the same equation is used for two or more months.

2. For the smaller, most-westerly districts (Aetna – AID; Leavitt – LID; Mountain View – MVID; and United - UID), there are no WSC hydrometric stations on return flow channels. Return flow is estimated as a percentage of the monthly inflow to the districts, as follows:

	May	June	July	August	Sept.	October
AID, LID, MVID	100%	100%	40%	35%	20%	35%
UID	100%	100%	35%	30%	25%	20%

   For these smaller districts, it is felt that the above procedure is sufficiently accurate for apportionment purposes considering the small contribution that the return flows make to the total natural flow of the SSRB system. These districts also occasionally receive significant natural flows from rainfall events which would present problems in attempts to gauge return flows. Return flows for AID, LID and MVID can be, for the most part, captured in St. Mary Reservoir, available for re-use elsewhere in the basin.

3. Return flows for the Ross Creek Irrigation District (RCID) are believed to be insignificant for apportionment purposes and are not estimated.

PPWB Estimated Return Flows

PPWB estimates of return flows from 1985 to 2000 are given in Table 3. Note that some of the estimates are based upon WSC provisional hydrometric data. For the ID, April data are excluded from Table 3. Diversions to the WID do not begin until the last few days in April or in early May. Including April data in the return flow estimates results in unrealistically high return flows in years of high snow melt runoff, such as 1997.

Comparisons between PPWB estimates and recorded return flows are addressed in the following report section IV.

Table 3. Summary of PPWB return flow estimates - 1985 to 2000 (dam^3).

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Mean
BRID	84,284	82,440	84,284	103,111	101,550	101,692	105,100	114,167	101,125	99,395	69,880	80,138	77,322	76,451	72,439	77,423	89,425
EID	251,709	263,619	211,448	202,382	227,387	246,869	269,340	284,610	202,002	239,913	270,647	243,952	271,340	250,195	199,406	210,648	240,341
LNID	13,867	21,983	26,530	27,234	25,081	31,642	37,734	38,051	28,669	38,580	32,273	38,502	35,600	39,905	41,428	35,500	32,036
MVLA[2]	16,196	9,602	12,899	17,891	7,999	6,184	7,587	15,755	2,822	7,506	3,641	7,181	7,141	9,297	10,644	22,516	10,303
SMP, MID[3]	98,864	151,146	116,932	101,597	89,901	93,789	127,623	121,968	162,054	117,397	116,708	142,889	103,488	139,616	95,593	67,215	115,424
UID	14,806	11,409	14,574	19,175	11,290	7,337	9,000	13,166	4,021	8,448	3,276	9,694	9,002	5,482	13,419	26,678	11,300
WID[4]	68,284	92,459	66,447	77,296	62,643	73,545	70,910	87,916	72,881	62,350	67,262	73,026	90,322	93,647	81,885	77,319	76,137
Totals	548,010	632,658	533,114	548,686	525,851	561,058	627,294	675,633	573,574	573,589	563,687	595,382	594,215	614,593	514,814	517,299	574,966

[1] All 1985 to 1992 data, except highlighted data, taken from PPWB report (PPWB 1995).
Highlighted data computations based on PPWB equations and methodology.
All 1993 to 2000 data obtained directly from Jim Chen, P.Eng., PPWB.
Some return flow estimates may be based on Water Survey of Canada provisional data.

[2] MVLA includes MVID, LID and AID.

[3] SMP includes SMRID, RID and TID. The PPWB estimates the total return flow from SMP and MID together.

[4] For the WID, April data are excluded from the estimates.

RECORDED RETURN FLOWS

Objectives of the District Monitoring Initiative

Return flows occur through numerous drainage channels, many of these being naturally occurring drainage courses. Return flows are often low and intermittent, and are sometimes combined with natural flows. Monitoring all return flows would be expensive and a technical challenge. Historically, a relatively small number of return flow channels have been monitored by WSC for the purposes of estimating total annual natural flow of the South Saskatchewan River, downstream of its confluence with the Red Deer River, for inter-provincial apportionment purposes. The accuracy of these return flow estimates is considered to be sufficient for PPWB apportionment purposes.

Additional data were required by the districts to gain a better understanding of the amount of return flow from the districts, and its variability, components, and cause and effect relationships. Knowing these characteristics, it may be possible to identify measures to reduce return flows. Return flows from irrigation districts are a major consideration in the quest to make additional water available for expanding the irrigated area within districts. Irrigation district water use efficiency, E_d, is generally considered to be the ratio between the amount of irrigation water applied and retained within the active root zone, and the total amount of water delivered to the district:

$$\text{District Efficiency, } E_d\ (\%) = \frac{\begin{array}{c}\text{Irrigation water stored}\\ \text{in active root zone}\end{array}}{\text{Gross Diversion}} \text{ X } 100\% \qquad (1)$$

Return flow is a significant component of the gross diversion. Reductions in the return flow volume will increase the district efficiency. In many districts, it is a focus area for efficiency improvements.

Return flow monitoring was also required to calibrate the Irrigation District Model to enable realistic simulations of a range of water supply and demand conditions within the districts.

The Return Flow Monitoring Network

In 1994, the EID began a major initiative to monitor flows returning to the Red Deer and Bow Rivers. Since then, seven other districts have begun monitoring. In 1999, there were more than 80 return flow sites being monitored, primarily by the districts themselves, but supplemented by AAFRD and WSC stations (Fig. 5). Additional information was collected in the Irrigation Block monitoring programs. In 1996, MPE Engineering Ltd. was retained to review the irrigation district monitoring programs and to develop standards for data collection, storage and handling, to maintain quality control, and to ensure the data were in a form that could be readily used in modelling (MPE Engineering Ltd. 1997).

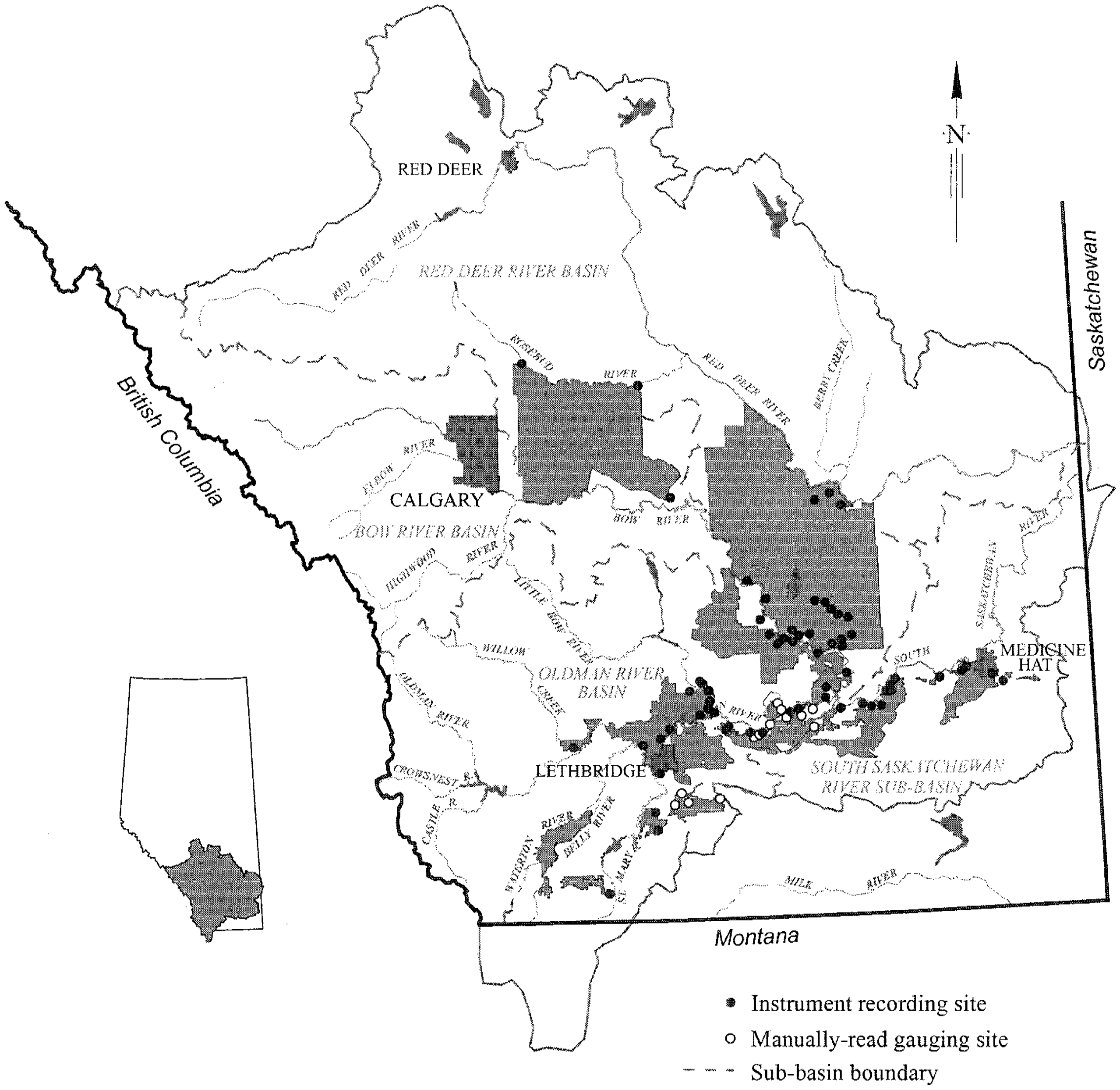

Figure 5. The locations of return flow monitoring stations.

Almost all the district stations are located at drop or check structures, or are at weirs or flumes constructed specifically for monitoring purposes. As such, the stations have stable stage-discharge relationships, unaffected by erosion, siltation or weed growth. Most stations have a stilling well and monitor water levels using either a float mechanism or an ultrasonic sensor. Water levels are recorded hourly, or more frequently, on electronic data-loggers. There are also a number of manually-read staff gauges in the network. Staff gauges are usually read once a day. Stations are metered periodically to verify the discharges computed from weir or flume formulae.

Stage data are converted to flow records by the districts in a consistent format. All data are forwarded to AAFRD for inclusion in their Data Warehouse.

Monitoring Results

Daily data for all stations were assembled and reviewed. Apparent anomalies in the data were identified and discussed with district staff. Adjustments made to the daily records included the following:

1. On some channels more than one hydrometric station was in operation at the same time. Monitoring was carried out by different agencies for different purposes. The records that were considered to be most accurate were selected for the return flow computations. Stations with data-loggers were favoured over stations with manually-read staff gauges. Stations with stable controls or measurement weirs were favoured over those that are subject to shifting control due to erosion, sedimentation or weed growth.

2. Stations that started late or ended early were extended to cover a reasonable expectation of the return flow season. Extensions were based on the patterns established in years of full-period monitoring relative to turn-on/shut-off dates for delivery canals.

3. Long data gaps were filled by correlations with nearby return flow stations with similar characteristics. Short data gaps were filled by interpolation between flows at both ends of the gap.

4. In all cases except one, it was assumed that natural rain-induced runoff in the return flow channels would not be significant. The exception is Six Mile Coulee in SMRID where a portion of the watershed is in an urban area with impervious roof-tops and streets. SMRID staff used precipitation records to identify and remove the obvious rainfall-induced runoff from the hydrometric record. The TID felt that natural runoff could be significant in some years at some of their stations. It is recognized that other districts, particularly the more westerly districts such as the WID, could experience a significant amount of natural runoff in their return flow channels in some years. No attempt was made to remove natural runoff from these records.

5. There are a few stations in the network that have significant flow well past the canal shutdown dates. These include the BRID's Expanse Coulee and Drain K, and the EID's Matzhiwin Creek and One-Tree Creek. Some of these continue to flow throughout the winter. These return flow channels are probably fed by groundwater discharges during late fall and winter months. It is not known the extent to which the groundwater discharges are irrigation-induced. The late fall and winter flows were not included in the return flow records.

6. Two return flow stations are located upstream of a small amount of irrigation development – Site 3 in the MID, and AID Spill in the AID. The flow records for these two stations were adjusted based on an approximate application volume for the area of irrigation located downstream of the hydrometric station.

7. Each district was requested to estimate the percentage of total return flow that was not monitored, based upon experience, observations and judgment. The percentage was used to estimate the volume of un-gauged return flow for each district.

A summary of total annual recorded and estimated return flow for all stations monitored is given in Appendix A.

The irrigated area, gross diversion and return flow for each district where and when monitoring was carried out is summarized in Table 4.

Observations from Table 4 include:

1. Six of the 13 districts conducted sufficient monitoring to permit reasonably accurate return flow estimates for all four years. Being the largest districts, these six districts contain more than 90% of the total irrigated area within all districts. Conclusions drawn from the results of monitoring in the six districts may be considered representative of all district irrigation. The WID did not conduct return flow monitoring during the 1977 to 2000 period. However, WSC stations on the Rosebud River and Crowfoot Creek record in the order of 80% of the WID return flow. The WID is, therefore, included as one of the six districts with reasonably accurate return flow estimates.

2. The EID had the highest volume of return flow, averaging 174,015 dam^3 for the four years (Table 4(e)). This amounts to about 35% of the total return flow for the six districts. The EID is the second largest district in terms of irrigated area, having the longest length of conveyance works and by far the greatest area of gravity surface irrigation, all of which contribute to high return flows.

3. The EID showed a pronounced decrease in return flows during the four-year period. This could be attributed to an improved awareness of return flows and a concerted effort by district managers and operations staff to improve management of the infrastructure and to increase irrigation efficiency. The EID began monitoring return flows in 1994, three years before other districts began monitoring.

Table 4. Irrigation district irrigated area (ha), gross diversion (dam^3) and return flow.

District	1997				
	Irrigated Area	Gross Diversion	Return Flow		
			dam^3	mm	Area
AID					
BRID	80,092	423,613	126,134	158	29.8%
EID	111,244	705,748	215,495	195	30.5%
LNID	58,706	238,774	40,651	70	17.0%
MID					
RID					
SMRID	138,502	574,811	42,551	30	7.4%
TID	30,791	142,570	29,007	94	20.3%
WID	25,273	143,999	87,491	347	60.8%

Table 4(a)

1998				
Irrigated Area	Gross Diversion	Return Flow		
		dam^3	mm	% of GD
80,210	374,447	127,844	158	34.1%
111,269	787,590	186,862	168	23.7%
49,527	198,347	37,524	76	18.9%
138,709	523,867	44,478	34	8.5%
31,108	143,456	33,993	110	23.7%
27,374	175,610	100,321	366	57.1%

Table 4(b)

District	1999				
	Irrigated Area	Gross Diversion	Return Flow		
			dam^3	mm	% of GD
AID	757	4,229	3,387	448	78.8%
BRID	80,155	368,229	109,064	137	29.6%
EID	112,394	526,443	149,873	134	28.5%
LNID	58,998	222,014	46,220	79	20.8%
MID	5,958	25,657	14,571	244	56.8%
RID	15,770	52,991	6,953	43	13.1%
SMRID	144,068	507,614	39,006	27	7.7%
TID	32,038	129,774	40,958	128	31.6%
WID	20,653	109,054	84,883	411	77.8%

Table 4(c)

2000				
Irrigated Area	Gross Diversion	Return Flow		
		dam^3	mm	% of GD
80,889	515,476	118,057	146	22.9%
112,893	832,613	143,815	128	17.3%
61,514	303,189	49,320	79	16.3%
6,243	37,202	13,138	210	35.3%
142,605	666,337	38,539	27	5.8%
32,055	172,747	28,673	88	16.6%
26,,067	192,919	78,462	302	40.7%

Table 4(d)

District	Four-year Means				
	Irrigated Area	Gross Diversion	Return Flow		
			dam^3	mm	% of GD
AID					
BRID	80,337	420,443	119,298	148	28.4%
EID	111,950	713,099	174,011	155	24.4%
LID					
LNID	57,187	24,0581	43,429	76	18.1%
MID					
MVID					
RCID					
RID					
SMRID	140,972	568,158	41,143	30	7.2%
TID	31,499	147,137	33,158	107	22.5%
UID					
WID	24,842	155,395	87,789	354	56.5%
Totals	446,787	2,244,813	498,828		
Weighted Mean				112	22.2%

Table 4(e)

1991 Guidelines				
Irrigation Area Limit	PLV*	Return Flow		
		dam^3	mm	% of GD
1,429	11,102	1,306	91	11.8%
84,984	619,217	69,939	82	11.3%
111,289	918,958	94,980	85	10.3%
1,930	14,802	1,764	91	11.9%
67,583	391,020	35,019	52	9.0%
7,406	41,939	3,836	52	9.1%
1,497	9,868	1,369	91	13.9%
486	3,701			
18,818	99,914	9,745	52	9.8%
150,543	890,587	78,007	52	8.8%
33,265	194,893	17,232	52	8.8%
13,759	83,878	10,904	79	13.0%
38,445	342,913	37,498	98	10.9%
531,434	3,622,792	361,599		
			67	10.0%

Table 4(f)

* PLV = Proposed Licence Volume

4. Return flows expressed as a percentage of gross diversion vary substantially from district to district. They are the highest in the WID, averaging 56.5%, and lowest in the SMRID, averaging 7.2% (Table 4(e)).

   Variations are a function of a combination of several factors, including the size of the district, water user density and the extent of infrastructure rehabilitation. Return flows expressed as a percent of gross diversions tend to be higher in smaller districts with low densities of irrigation users (hectares irrigated per km of canal). Canals with a high density of users have more predictable average demand conditions. As some users are ceasing operations, others are starting up. As rehabilitation progresses within the districts, lateral canals are replaced with pipelines and structures are automated, which increases response times to changes in demand and helps to reduce return flows. The number and location of storage reservoirs in the district can also be effective in reducing return flows. Storage reservoirs reduce canal travel times, making possible more effective matching of supply and demand. Strategically located reservoirs also enable surplus canal flows to be stored for subsequent use downstream. Timely and accurate communication between water users and district operators are also important aspects of water management and minimizing return flows within irrigation districts.

   The WID has little internal storage, long canals with low irrigation densities in some areas, a relatively low level of rehabilitation of their conveyance system and a high traditional dependence on the district works for domestic and municipal water supplies, all of which tend to increase return flows. Rainfall runoff can also affect estimates of return flows for individual districts, particularly in high precipitation years and in districts, such as the WID, that normally have high amounts of natural precipitation.

   At the other end of the spectrum, the SMRID is the largest district and has a relatively high irrigation area density, a high percentage of pipe laterals and a low percentage of gravity surface irrigation. These characteristics tend to reduce return flows expressed as a percentage of the gross diversion. The SMRID is also unique in its ability to recapture much of its unused irrigation deliveries in reservoirs and subsequently release it for downstream use.

5. Unit return flows, expressed as millimeters per unit area irrigated (or just mm), vary markedly from district to district in a ranking pattern similar to return flow expressed as a percent of gross diversions.

6. In five of the six districts, average unit return flows are substantially higher than those assumed in establishing the proposed licence volumes (PLV) for the 1991 irrigation expansion guidelines (Table 4(f)). The exception is the SMRID, which returns less than what was assumed in computing the PLV.

Analysis of Significant Variables

Return flows and nine district characteristics were used in a regression analysis to identify the most significant district characteristics that affect return flows. Year 1999 was used because it has the most complete record of recorded return flows and is the most recent year for which district characteristics have been tabulated. The district characteristics and the stepwise regression analysis are shown in Appendix B.

The procedure involved the following steps:

1. Computing a correlation matrix to determine which of the nine characteristics accounts for most of the variance in return flows (highest r^2).
2. Developing a simple regression equation using that characteristic, and determining the residuals.
3. Computing a correlation matrix to determine which of the remaining eight characteristics account for most of the variance in the residuals.
4. Add that variable to the regression analysis.
5. Continue to add variables until the increase in R^2 for the multi-variable regression equation becomes insignificant.

The analysis indicated that the characteristics that correlated best with return flow or the residuals were, in order, the area of gravity surface irrigation ($r = 0.85$), the proportion of the conveyance system in pipelines ($r = -0.71$), and the district irrigation density ($r = 0.55$). The first two correlations were significant at $P < 0.05$. The latter correlation was not significant, and in fact indicates a positive relationship when one would expect a negative one. Using the first two variables, the equation for return flow was determined to be:

Return flow (dam^3) = 79,726 + 2.5378 x (surface irrigation area (ha)) – 1,645 x (% pipelines).

The equation has a coefficient of determination (R^2) of 0.87, indicating that it explains 87 percent of the variance of return flows in 1999.

Comparisons Between Recorded and PPWB Return Flows

Table 5 compares return flows recorded by the districts and those estimated by the PPWB for 1997 to 2000. Note that the estimates prepared by the PPWB include the combined return flow from the three foothills districts (MVID, LID and AID) and from the three districts in the St. Mary project (RID, SMRID and TID), together with the MID. Observations from Table 5 are as follows:

1. The PPWB estimates of return flow for the BRID were consistently low, averaging 63.3% of recorded values for the four years. PPWB estimates for the EID were consistently high, averaging 135% of recorded values.

2. The EID began recording return flows in 1994. The relationship between PPWB estimates and recorded values for 1994 to 2000 is shown in Figure 6. The trend line, equation and coefficient of determination ($r^2 = 0.94$) show that the correlation is consistent and strong (significant at $P < 0.01$). PPWB data (Table 3) and the equation could be used to estimate return flow comparable to recorded data for years prior to 1994.

Table 5. Comparisons between recorded return flow and PPWB estimates.

District	1997			1998		
	Recorded Return Flow (dam^3)	PPWB Return Flow		Recorded Return Flow (dam^3)	PPWB Return Flow	
		(dam^3)	% of Recorded		(dam^3)	% of Recorded
BRID	126,134	77,322	61.3%	127,884	76,451	59.8%
EID	215,495	271,340	125.9%	186,862	250,195	133.9%
LNID	40,651	35,600	87.6%	37,524	39,905	106.3%
MVID		MVLA[2] 7,141			MVLA[2] 9,297	
LID						
AID						
MID		SMP, MID[3] 103,488			SMP, MID[3] 139,616	
RID						
SMRID	42,551			44,478		
TID	29,007			33,993		
UID		9,002			5,482	
WID[4]	87,491	90,322	103.2%	100,321	93,647	93.3%
Sum[5]	469,771	474,584	101.0%	452,551	460,198	101.7%

District	1999			2000		
	Recorded Return Flow (dam^3)	PPWB Return Flow		Recorded Return Flow (dam^3)	PPWB Return Flow	
		(dam^3)	% of Recorded		(dam^3)	% of Recorded
BRID	109,064	72,439	66.4%	118,057	77,423	65.6%
EID	149,873	199,406	133.1%	143,815	210,648	146.5%
LNID	46,220	41,428	89.6%	49,320	35,500	72.0%
MVID		MVLA[2] 10,644			MVLA[2] 22,516	
LID						
AID	3,387					
MID	14,571	SMP, MID[3] 95,593		13,138	SMP, MID[3] 67,215	
RID	6,953					
SMRID	39,006		94.2%	38,539		
TID	40,958			28,673		
UID		13,419			26,678	
WID[4]	84,883	81,885	96.5%	78,462	77,319	98.5%
Sum[5]	491,528	490,751	99.8%	389,654	400,890	102.9%

[1] Data obtained directly from Jim Chen, P.Eng., PPWB. Some return flow estimates may be based on Water Survey of Canada provisional data.

[2] PPWB estimate labeled MVLA is total return flow for MVID, LID and AID.

[3] PPWB estimate labeled SMP, MID is total return flow for SMRID, RID, TID and MID.

[4] For the WID, April data are excluded from the estimates.

[5] Sums for 1997, 1998 and 2000 include the BRID, EID, LNID and WID only. Sums for 1999 include the BRID, EID, LNID, MID, RID, SMRID, TID, and WID only.

3. Where comparisons can be made for districts other than the BRID and EID, the PPWB estimates are generally within 10% of recorded values.

4. PPWB estimates of total return flow for all districts for which comparisons can be made are remarkably consistent with recorded data (within 2%). The best year for comparison is 1999, when eight districts, representing about 98% of the total irrigated area, can be compared. PPWB estimates of the total return flow for the eight districts is 99.2% of the recorded return flow. In 1997, 1998 and 2000, only four districts representing 58% of the irrigated area can be compared. For these districts, the PPWB estimates of total return flow average 101% of the recorded values.

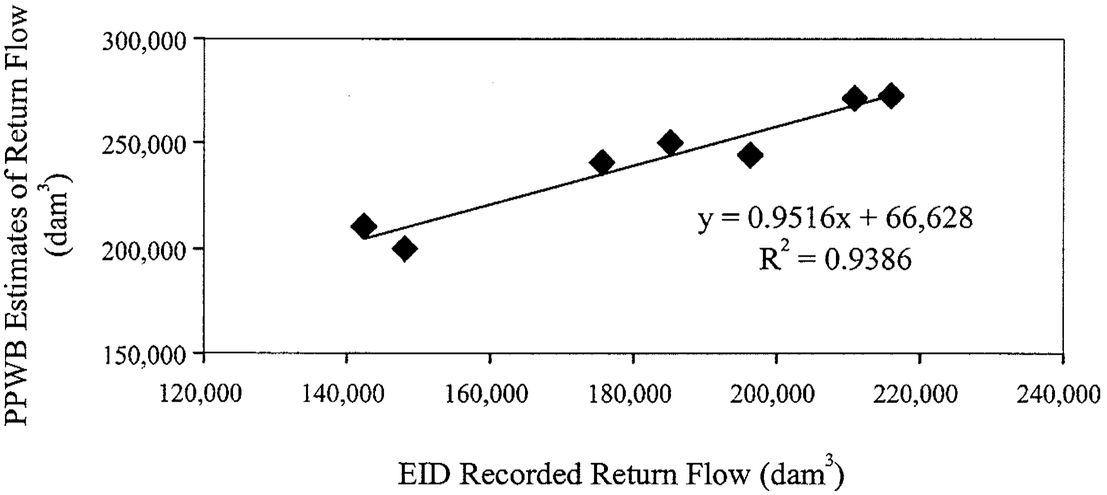

Figure 6. Relationship between EID recorded return flow and PPWB estimates.

From the comparison of recorded return flow and PPWB estimates, it would appear that the PPWB estimates are a good representation of total return flow from all districts. Figure 7 shows the total return flow from all districts from 1985 to 2000, based on PPWB estimates. Also shown on Figure 7 are the irrigated areas and the gross diversions as reported annually (AAFRD. 2000). Observations from Figure 7 are as follows:

1. There has been a significant variation in year-to-year gross diversion, with major reductions in wet years and increases in dry years. A trend line shows a significant reduction in gross diversion during the 10-year period, in spite of an increase in the irrigated area.

2. The irrigated area has steadily increased since 1985. In high precipitation years (1993 and 1995), the irrigation area drops significantly.

3. Return flow has been consistently around 600,000 dam^3 per year during the 16-year period.

4. Return flow appears to be independent of irrigated area and gross diversion. Return flows are less variable and do not appear to follow the wet year/dry year variations that affect gross diversions and irrigated area.

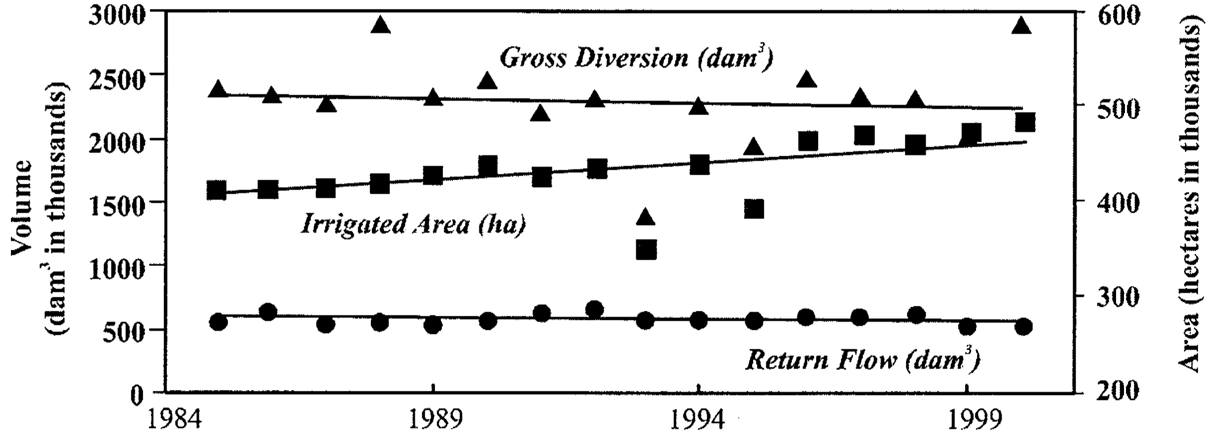

Figure 7. **Return flow, gross diversion and irrigated area for Alberta's irrigation districts.**

CONCLUSIONS

1. Return flows are unavoidable in a canal irrigation system – they cannot be completely eliminated. The irrigation districts are concerned about the magnitude of return flows for several reasons, including canal damage and increased maintenance costs, public perceptions of wasteful management practices and impacts on the source streams. They are also concerned that inefficient operations could jeopardize further expansion of irrigation. During the past decade, the districts and AAFRD have made a concerted effort to better quantify return flow, to understand the factors affecting it, and to identify ways to minimize it. This effort has involved intensive monitoring and study of small irrigation blocks within the BRID and LNID, extensive monitoring of district return flows, and computer simulation modeling.

2. Intensive monitoring in irrigation blocks K5 in the BRID and J12 in the LNID has helped to understand factors affecting return flows. Return flows can be broken down into three primary components: base flow, operational spills, and on-farm drainage.

   A base flow in canals is required to meet seepage and evaporation losses, to ensure that the last users in the system have sufficient water to operate their pumps or turnouts, and to provide a margin of safety to accommodate sudden increases in demand. Operational spills usually occur as a result of sudden reductions in demand that may result from shut-downs due to heavy rains, freezing temperatures, power failures, or equipment breakdowns; end-gun or corner arm shut-offs on pivot systems; and set changes on side-roll systems. Monitoring within the two blocks has indicated that base flow and operational spills average about 0.07 cubic metres per second per lateral.

   On-farm drainage of surplus applications is usually small for sprinkler systems, but can be significant for gravity surface systems. In Block K5, gravity surface irrigators returned about 40% of their total application to drains. The return flows from the irrigation block with a high percentage of gravity surface irrigation were typically 75 to 100% higher than that of the block with only sprinkler systems, mainly because of on-farm drainage.

3. The EID began a major initiative to monitor return flows in 1994. Since then, seven other districts have begun monitoring. In 1999, there were more than 80 return flow sites being monitored. Six of the 13 districts conducted sufficient monitoring to permit reasonable accurate return flow estimates for the four-year period 1997 to 2000. Being the largest districts, these six districts contain more than 90% of the total irrigated area within all districts. Conclusions drawn from the monitoring were:

   a) The four-year average return flow from all six districts was about 502,662 dam^3.

   b) The EID had the highest volume of return flow, averaging 174,051 dam^3 for the four years, about 35% of the total return flow for the six districts. The EID is the second largest district in terms of irrigated area, having the longest length of conveyance works, and by far the largest area of gravity surface irrigation, all of which contribute to high return flows. The EID showed a significant decrease in return flows during the four-year period.

c) Return flows expressed as a percentage of gross diversion vary substantially from district to district. They were the highest in the WID, averaging 56.5%, and the lowest in the SMRID, averaging 7.2%. Variations are a function of several factors, including the size of the district, water user density and the extent of infrastructure rehabilitation.

d) In five of the six districts, average unit return flows are substantially higher than those assumed in establishing the proposed licence volumes (PLV) for the 1991 irrigation expansion guidelines. The exception is the SMRID which returns less than what was assumed in computing the PLV.

e) A step-wise regression analysis of 1999 return flows and nine district characteristics was conducted to determine the characteristics that had the greatest effect on return flows. Results indicated that the area of gravity surface irrigation and the proportion of the distribution system in pipelines had significant correlation coefficients at $P < 0.05$. Those two variables used in a regression equation explained 87 percent of the variation in return flow.

4. To administer the inter-provincial apportionment agreement, the PPWB estimates return flows for the irrigation districts based on recorded flows at about 20 hydrometric stations. For the four years that PPWB estimates could be compared with recorded data, PPWB estimates for the BRID were consistently low and for the EID were consistently high. For all other districts that could be compared, the PPWB estimates were generally within 10% of recorded data.

   PPWB estimates of total return flow for all districts for which comparisons can be made are remarkably consistent with recorded data (within 2%), indicating that the PPWB estimates for a longer historical period are probably a good indication of total return flow from all districts.

5. A plot of 1985 to 2000 gross diversions to all irrigation districts, total irrigated areas and the total return flow from all districts based on PPWB estimates shows that:

a) There has been a significant variation in year-to-year gross diversion, with major reductions in wet years and increases in dry years.

b) The irrigated area has steadily increased since 1985.

c) The return flow has been consistently around 600,000 dam^3 per year during the 16-year period.

    d) Return flow appears to be independent of irrigated area and gross diversion. It is less variable and does not appear to follow the wet year/dry year variations that affect gross diversions and irrigated area.

6. With the Irrigation District Model that is now available and with the four-year return flow data base that most of the larger irrigation districts now have, the districts are well-positioned for analysis of return flow cause and effect relationships. This information could be used to identify physical and operational factors that have the greatest effect on return flows and to define and prioritize measures to reduce return flows and increase irrigation efficiencies.

REFERENCES

Alberta Agriculture, Food and Rural Development (AAFRD). 2000. Alberta Irrigation Districts Crop and Water Information. Irrigation Branch. Lethbridge, Alberta.

Alberta Environment (AENV). 1990. South Saskatchewan River Basin Water Management Policy. Planning Division, Alberta Environment. Edmonton, Alberta.

Alberta Environment (AENV). 1991. South Saskatchewan Basin Water Allocation Regulation. Alberta Environment. Edmonton, Alberta.

Komex International Ltd. 1993. Final Report on Irrigation Hydrometric Study. Alberta Agriculture, Food and Rural Development, Irrigation Branch. Lethbridge, Alberta.

Irrigation Water Management Study Committee. 2002. South Saskatchewan River Basin: Irrigation in the 21st Century. Volume 1: Summary Report. Alberta Irrigation Projects Association. Lethbridge, Alberta.

MacLean, R.T., J. Ganesh, D.R. Roth. 1999. Intensive Flow Measurement of an Irrigated Block to Benchmark Irrigation District Operations. Presented at a conference at San Luis Obispo, CA. March 10 - 13, 1999. Alberta Agriculture, Food and Rural Development, Irrigation Branch. Lethbridge, Alberta.

MPE Engineering Ltd. 1997. Year 2000 Data Analysis Standards for Return Flow Collection. Alberta Agriculture, Food and Rural Development, Irrigation Branch. Lethbridge, Alberta.

Prairie Provinces Water Board. 1995. Assessment of Natural Flow Computation Procedures and Monitoring Network for Administering Apportionment of the South Saskatchewan River Basin at the Alberta-Saskatchewan Boundary. PPWB Report No. 133. PPWB. Regina, Saskatchewan.

APPENDIX A

Return Flow Summaries

Appendix A -- Return Flow Summaries

Aetna Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
AID Spill			3,387		Adjusted for downstream use on 60 hectares.
Estimated ungauged			1,122		Based on 2 channels -- 0.425 cms/channel.
AID Total			4,510		

Bow River Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
Drain A	11,380	10,501	7,543	10,227	
Drain C	4,088	3,572	2,220	3,799	
Drain D	5,064	6,740	6,075	4,927	
Drain E	3,762	2,524	2,445	385	
New West	28,619				
Drain G	6,032				
Drain F		37,934	31,288	33,940	Drain F equivalent to New West plus Drain G.
Drain K	5,556	6,911	8,569	8,257	
Drain TA	12,253	10,520	7,195	8,902	
Expanse	21,127	20,075	17,819	18,491	
Ronalane	10,259	9,219	11,445	10,474	
Drain 31	***2,159***	2,584	1,638	2,668	1997 estimated from ratio Drain 31/Drain 35.
Drain 35	4,371	5,642	3,092	5,256	
Other			***9,734***		Estimated for individual drains by BRID.
Estimated ungauged (9%)	***11,467***	***11,622***		***10,733***	Based on 1999 estimate of Other RF.
BRID Total	126,134	127,844	109,064	118,058	

Note:
Estimated values shown in ***bold italics***.

Eastern Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
Site 15-Coal Creek	2,782	3,945	2,251	5,168	
Site 14-Minipoka Drain	7,047	4,670	4,499	2,164	
Site 13-Sauki Spill	8,394	6,652	7,045	2,041	
Site 12-Bow Slope Spill	4,154	5,693	5,950	2,556	
Site 1- Rolling Hills Spill	6,636	6,798	7,127	3,349	
WSC -12 Mile Coulee	60,113	59,333	44,533	50,612	
Bow R. Ungauged	***5,802***	***5,665***	***5,484***	***3,270***	Estimated by EID based on flow in gauged stations.
Site 17-Matziwin Coulee	76,066	66,351	45,643	40,122	
Site 18-One Tree	29,349	15,974	17,194	22,572	
Site 19-Sandhill Creek	7,814	7,787	5,848	6,319	
Red Deer R. Ungauged	***7,337***	***3,994***	***4,299***	***5,643***	Estimated by EID based on flow in gauged stations.
EID Total	215,495	186,862	149,873	143,815	

Lethbridge Northern Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
A1 Spill	***775***	423	865	1,534	1997 estimated from Monarch Drain.
Monarch Drain	2,885	2,529	3,340	4,038	
C12 Outflow (Szteina Drain)	***1,933***	2,214	1,897	1,832	1997 estimated by mean ratio of 5 sites to total.
Piyami Coulee	11,937	9,985	12,007	10,923	
Battersea Drain	8,248	10,574	7,116	11,872	
K8 Spill LB6-12			211		Little Bow tributary drains -- 6 stations.
Arrowsmith Coulee			4,795	4,066	
K2E Spill LB6-5			183		
K1 Spill LB5-1			1,718		
Sorgaard Drain			2,846	1,764	
Albion Ridge			6,621	6,515	
Ungauged L. Bow trib drains				***1,844***	Estimated from 1999 data.
Little Bow	10,808	8,047			Calculated as L. Bow near Mouth minus D/S Travers.
Estimated ungauged (10%)	***4,066***	***3,752***	***4,622***	***4,932***	Ungauged amount estimated by LNID.
LNID Total	40,651	37,524	46,220	49,320	

Note:
Estimated values shown in ***bold italics***.

Magrath Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
Site 1			9,346	9,650	
Site 3			4,496	2,831	Year 2000 recorded and estimated.
Estimated ungauged (10%)			***729***	***657***	
MID Total			14,571	13,138	

Raymond Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
Site 1 -- Welling Lateral 7			254		
Site 2 -- Laycock Weir			1,120		
Site 4 -- Sterling Drain			4,882		
Estimated ungauged (10%)			***696***		
RID Total			6,953		

St. Mary River Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
Site 3	3,571	371	3,602	***2,600***	2000 estimated by ratio Site 3/Sites (4-21 inc).
Site 4	4,849	2,945	2,657	2,919	
Site 5	4,714	6,250	5,710	5,970	
Six Mile	***2,564***	2,448	1,771	4,241	1997 estimated by ratio Six Mile/Sites (3-21inc).
Site 10	364	669	595	647	
Site 11	321	116	168	172	
Site 21	947	737	893	530	
Site 31			1,124	2,104	
Site 32			145	450	
Site 33			1,843	1,588	
Site 34			3,367	2,509	
Site 35			1,990	1,693	
Site 36			709	859	
Site 37	***13,004***	***18,173***	12,481	10,330	1997 and 1998 estimated from WSC station.
Estimated Sites 31 to 36	***10,088***	***10,544***			1997 and 1998 estimated by ratio to total.
Estimated ungauged (5%)	***1725***	***1803***	***1581***	***1562***	
SMRID Total	42,148	44,057	38,637	38,175	

Note:

Estimated values shown in ***bold italics***.

Taber Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
TD 2 & 3 Bountiful Coulee	7,696	6,999	6,551	3,533	
TD4* Lat. 1 Barnwell	1,505	1,633	1,597	1,129	
TD5* Lat. 6 Barnwell	2,822	3,781			T2 Drain equivalent to TD5 plus TD6.
TD6* Lat. 9 Taber	1,119	1,378			
TD7* SW Big Bend Drain	1,890	1,119	1,481	826	
TD8* Lat. E Big Bend	1,810	2,039	2,431	1,115	
TD9* Lat G7 Big Bend	1,250	1,922	2,557	1,060	
TD10* Lat. G Big Bend	654	669	894	591	
TD11 Lat. K Big Bend	817				T11 Drain same as TD11.
TD 13 N. Fincastle W. Canal	4,141	4,563	6,679	7,781	
TD15* N. Fincastle E. Canal	3,143	3,614	3,090	1,567	
TD16* Lat. 10A E. Horsefly	2,162	2,170	2,611	2,082	
T2 Drain (AAFRD)			9,218	5,401	Equivalent to TD5 plus TD6.
T11 Drain (AAFRD)		3330	3,847	3,588	Same as TD11.
TID Total	29,007	33,215	40,958	28,673	TID is considered to be 100% gauged.

Western Irrigation District

Monitoring Station	Return Flow -- dam3				Comments
	1997	1998	1999	2000	
WSC Crowfoot Creek nr. Cluny	21,986	28,892	25,393	26,176	May to Oct
WSC Rosebud R. near Redland	57,744	53,292	45,447	36,764	May to Oct
WSC Rosebud R. D/S Carstairs	9,737	1,928	2,934	171	May to Oct
Estimated ungauged (20%)	***17,498***	***20,064***	***16,977***	***15,692***	
WID Total	87,491	100,321	84,883	78,461	Cluny + Redland - Carstairs + ungauged.

Note:

Estimated values shown in ***bold italics***.

APPENDIX B

Analysis of 1999 Return Flow and District Characteristics

Appendix B -- Analysis of 1999 Return Flows and District Characteristics

Nine districts -- Stepwise regression analysis

District Characteristics

Irrigation District	Total Works (km)	Density (ha/km)	Proportion of Pipelines (%)	Length of Pipeline (km)	Length of Canals (km)	Actual Area (ha)	Proportion Grav. (%)	Gravity Area (ha)	Actual Area vs. Assessed (%)	1999 return Flow		
										dam3	mm	% of GD
AID	27.0	28.0	37.0	10.0	17.0	757	22.0	166.5	54.80	3,387	448	78.8%
BRID	1,082.1	74.1	17.5	189.3	892.8	80,155	17.0	13,626.3	94.07	109,064	137	29.6%
EID	1,921.4	58.2	22.3	427.7	1,493.7	111,762	40.0	44,704.8	97.99	149,873	134	28.5%
LNID	713.7	82.7	23.8	169.7	544.0	58,998	2.1	1,238.9	79.80	46,220	79	20.8%
MID	102.0	58.4	37.8	38.6	63.4	5,958	10.6	631.6	61.14	14,571	244	56.8%
RID	266.7	59.1	31.4	83.7	183.0	15,770	8.3	1,308.9	70.85	6,953	43	13.1%
SMRID	1,780.9	80.9	33.1	590.0	1,190.9	144,068	5.1	7,347.5	95.01	39,006	27	7.7%
TID	356.6	89.8	44.6	159.2	197.4	32,038	4.8	1,537.9	95.55	40,958	128	31.6%
WID	1,194.1	25.1	4.1	49.1	1,145.0	29,987	16.0	4,797.9	77.96	84,883	283	77.8%

Round 1: Correlation matrix

Characteristic	Total Works (km)	Density (ha/km)	Proportion of Pipelines (%)	Length of Pipeline (km)	Length of Canals (km)	Actual Area (ha)	Proportion Grav. (%)	Gravity Area (ha)	Actual Area vs. Assessed (%)	1999 return Flow		
										dam3	mm	% of GD
Works km	1											
hectares/km	0.1476484	1										
% Pipes	-0.5193343	0.3930248	1									
km Pipes	0.8315649	0.4869397	0.0081426	1								
km Canals	0.9809327	0.0174111	-0.6633918	0.7077631	1							
Irrig. Area	0.9054619	0.4642740	-0.2112724	0.9609306	0.8154235	1						
% Flood	0.3964781	-0.4850872	-0.3076293	0.1387740	0.4557236	0.1772397	1					
Flood Area	0.7270043	0.0097526	-0.3118349	0.5593312	0.7289650	0.6011102	0.8272403	1				
Actual/Ass'd	0.7524892	0.6211601	-0.1949165	0.7362168	0.6994860	0.7929493	0.0972180	0.5620116	1			
RF by dam3	0.7712162	0.0377993	-0.6334763	0.4239196	0.8325797	0.5797085	0.6530642	0.8531889	0.6943035	1		
RF by mm	-0.4176451	-0.7889125	-0.0278466	-0.6027907	-0.3202836	-0.5916059	0.3668020	-0.1798788	-0.6597506	-0.1764936	1	
RF by % of GD	-0.3599436	-0.8209378	-0.2007918	-0.6513811	-0.2298907	-0.6169183	0.2988693	-0.2102448	-0.6095904	-0.1046655	0.9526004	1

Best correlation with RF (by volume) is area of gravity surface irrigation.

Simple regression -- RF (by volume) vs area of gravity surface irrigation -- SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.85318905
R Square	0.727931555
Adjusted R Squa	0.689064634
Standard Error	22576.7736
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	1	9546279965	9546279965	18.7288198	0.003447617
Residual	7	3567974943	509710706.1		
Total	8	13114254908			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	24355.65824	8858.666145	2.749359535	0.028530315	3408.256418	45303.06005	3408.256418	45303.06005
X Variable 1	0.977528244	0.225878091	4.327680649	0.003447617	0.443411814	1.511644674	0.443411814	1.511644674

Equation: RF (dam3) = 30,043 +2.4155 x (Gravity hectares) R squared = 0.73

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals
1	24757.81335	-22011.81335
2	57269.22972	31148.77028
3	132337.3382	-10835.33818
4	27348.2632	10122.7368
5	25881.18881	-14068.18881
6	27517.18008	-21880.18008
7	42103.07452	-10481.07452
8	28070.26556	5134.734438
9	35944.64658	32870.35342

Round 2: Correlation matrix -- Characteristics vs residuals

Irrigation District	Total Works (km)	Density (ha/km)	Proportion of Pipelines (%)	Length of Pipeline (km)	Length of Canals (km)	Actual Area (ha)	Proportion Grav. (%)	Actual Area vs. Assessed (%)	Residuals
AID	27.0	28.0	37.0	10.0	17.0	757	22.0	54.80	-22011.81335
BRID	1,082.1	74.1	17.5	189.3	892.8	80,155	17.0	94.07	31148.77028
EID	1,921.4	58.2	22.3	427.7	1,493.7	111,762	40.0	97.99	-10835.33818
LNID	713.7	82.7	23.8	169.7	544.0	58,998	2.1	79.80	10122.7368
MID	102.0	58.4	37.8	38.6	63.4	5,958	10.6	61.14	-14068.18881
RID	266.7	59.1	31.4	83.7	183.0	15,770	8.3	70.85	-21880.18008
SMRID	1,780.9	80.9	33.1	590.0	1,190.9	144,068	5.1	95.01	-10481.07452
TID	356.6	89.8	44.6	159.2	197.4	32,038	4.8	95.55	5134.734438
WID	1,194.1	25.1	4.1	49.1	1,145.0	29,987	16.0	77.96	32870.35342

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Column 1	1								
Column 2	0.1476308	1							
Column 3	-0.5188675	0.3936799	1						
Column 4	0.8315649	0.4869223	0.0087714	1					
Column 5	0.9809327	0.0173948	-0.6630181	0.7077631	1				
Column 6	0.9054619	0.4642640	-0.2106370	0.9609306	0.8154235	1			
Column 7	0.3964781	-0.4853379	-0.3070273	0.1387740	0.4557236	0.1772397	1		
Column 8	0.7524869	0.6211412	-0.1943183	0.7362176	0.6994828	0.7929469	0.0972102	1	
Column 9	0.2893856	0.0566280	-0.7050300	-0.1021770	0.4038226	0.1281587	-0.1010890	0.4118052	1

Highest correlation with residuals is Proportion of Pipelines (%).

Multiple regression -- RF (by volume) vs. area of gravity surface irrigation and proportion of pipelines-- SUMMARY OUTPUT

Irrigation District	Proportion of Pipelines (%)	Gravity Area (ha)	RF (dam3)
AID	37.0	166.5	3,387
BRID	17.5	13,626.3	109,064
EID	22.3	44,704.8	149,873
LNID	23.8	1,238.9	46,220
MID	37.8	631.6	14,571
RID	31.4	1,308.9	6,953
SMRID	33.1	7,347.5	39,006
TID	44.6	1,537.9	40,958
WID	4.1	4,797.9	84,883

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.936812089
R Square	0.877616891
Adjusted R Squa	0.836822521
Standard Error	16355.2402
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	2	11509291617	5754645808	21.51318665	0.001833008
Residual	6	1604963291	267493881.9		
Total	8	13114254908			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	64634.10888	16194.35805	3.9911498	0.007191151	25007.91327	104260.3045	25007.91327	104260.3045
X Variable 1	-1333.56618	492.2775854	-2.708971974	0.035154077	-2538.126921	-129.0054436	-2538.126921	-129.0054436
X Variable 2	0.83263577	0.172152005	4.836631277	0.002890678	0.411394682	1.253876858	0.411394682	1.253876858

RESIDUAL OUTPUT

Observation	Residuals
1	-12888.706
2	19086.2864
3	-5369.8607
4	2026.73512
5	-3711.7186
6	-19816.041
7	-3987.9037
8	24883.9269
9	-222.71764

Equation: RF (dam3) = 79,726 + 2.5378 x (Gravity hectares) - 1,645 x (% Pipelines) R squared = 0.87

Round 3: Correlation matrix -- Characteristics vs residuals

Irrigation District	Total Works (km)	Density (ha/km)	Length of Pipeline (km)	Length of Canals (km)	Actual Area (ha)	Proportion Grav. (%)	Actual Area vs. Assessed (%)	Residuals
AID	27	28.0	10.0	17.0	757	22.0	54.80	-12888.70649
BRID	1082.1	74.1	189.3	892.8	80,155	17.0	94.07	19086.28641
EID	1921.4	58.2	427.7	1,493.7	111,762	40.0	97.99	-5369.860711
LNID	713.7	82.7	169.7	544.0	58,998	2.1	79.80	2026.735117
MID	102	58.4	38.6	63.4	5,958	10.6	61.14	-3711.718566
RID	266.7	59.1	83.7	183.0	15,770	8.3	70.85	-19816.04136
SMRID	1780.9	80.9	590.0	1,190.9	144,068	5.1	95.01	-3987.9037
TID	356.6	89.8	159.2	197.4	32,038	4.8	95.55	24883.92693
WID	1194.1	25.1	49.1	1,145.0	29,987	16.0	77.96	-222.7176366

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Column 1	1							
Column 2	0.147630835	1						
Column 3	0.831564886	0.48692229	1					
Column 4	0.980932707	0.017394808	0.70776312	1				
Column 5	0.905461859	0.464264011	0.960930606	0.815423504	1			
Column 6	0.396478057	-0.485337851	0.13877401	0.455723554	0.177239701	1		
Column 7	0.752486891	0.621141154	0.736217618	0.699482761	0.792946859	0.097210224	1	
Column 8	0.090572335	0.54592158	0.060054346	0.094185787	0.163303467	-0.208912194	0.591072062	1

Highest correlations with residuals are actual/assessed and density. Neither are significant at P < 0.05.
A negative "r" would be expected for both characteristics.

Multiple regression -- RF (ac ft) vs acres of flood irrigation, % pipelines and density -- SUMMARY OUTPUT

Irrigation District	density acres/km	Proportion of Pipelines (%)	Gravity Area (ha)	RF (dam3)
AID	28.0	37.0	166.5	3,387
BRID	74.1	17.5	13,626.3	109,064
EID	58.2	22.3	44,704.8	149,873
LNID	82.7	23.8	1,238.9	46,220
MID	58.4	37.8	631.6	14,571
RID	59.1	31.4	1,308.9	6,953
SMRID	80.9	33.1	7,347.5	39,006
TID	89.8	44.6	1,537.9	40,958
WID	25.1	4.1	4,797.9	84,883

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.960096733
R Square	0.921785736
Adjusted R Squa	0.874857178
Standard Error	14322.86138
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	3	12088533118	4029511039	19.64231957	0.00338645
Residual	5	1025721790	205144358.1		
Total	8	13114254908			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	49630.29241	16758.72712	2.961459547	0.031465794	6550.68329	92709.90152	6550.68329	92709.90152
X Variable 1	164.3466528	97.80494583	1.680351146	0.153721835	-87.06855356	415.7618592	-87.06855356	415.7618592
X Variable 2	-1666.21235	474.3843114	-3.512368162	0.017057473	-2885.654053	-446.7706507	-2885.654053	-446.7706507
X Variable 3	0.793974481	0.152505133	5.206214807	0.003449165	0.401948197	1.186000765	0.401948197	1.186000765

RESIDUAL OUTPUT

Observation	Residuals
1	3049.70048
2	11137.7067
3	-2293.9681
4	-8510.1331
5	211.235927
6	-18253.143
7	-10124.484
8	18385.7185
9	6397.36603

Equation: RF (dam3) = 61,219 + 2.4201(gravity hectares) - 2,055.3(% pipelines) + 500.95(ha/km Density) R squared = 0.92

Round 4: Correlation matrix -- Characteristics vs residuals

Irrigation District	Total Works (km)	Length of Pipeline (km)	Length of Canals (km)	Actual Area (ha)	Proportion Grav. (%)	Actual Area vs. Assessed (%)	Residuals
AID	27.0	10.0	17.0	757	22.0	54.80	3049.700479
BRID	1,082.1	189.3	892.8	80,155	17.0	94.07	11137.70671
EID	1,921.4	427.7	1,493.7	111,762	40.0	97.99	-2293.968077
LNID	713.7	169.7	544.0	58,998	2.1	79.80	-8510.133072
MID	102.0	38.6	63.4	5,958	10.6	61.14	211.2359269
RID	266.7	83.7	183.0	15,770	8.3	70.85	-18253.14279
SMRID	1,780.9	590.0	1,190.9	144,068	5.1	95.01	-10124.48375
TID	356.6	159.2	197.4	32,038	4.8	95.55	18385.71854
WID	1,194.1	49.1	1,145.0	29,987	16.0	77.96	6397.366031

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Column 1	1						
Column 2	0.831564886	1					
Column 3	0.980932707	0.70776312	1				
Column 4	0.905461859	0.960930606	0.815423504	1			
Column 5	0.396478057	0.13877401	0.455723554	0.177239701	1		
Column 6	0.752486891	0.736217618	0.699482761	0.792946859	0.097210224	1	
Column 7	-0.10944191	-0.256870726	-0.049318734	-0.183594145	0.128375013	0.222971443	1

No other significant correlation.

Equation: **RF (dam3) = 61,219 + 500.95(ha/km Density) - 2,055.27(% Pipelines) + 2.4201(Gravity hectares)**

Unit Conversion Factors

	SI Units		Imperial Units
Area:	1.0 hectare (ha)	=	2.471 acres
Length:	1.0 millimetre (mm)	=	0.0394 inches
	1.0 metre (m)	=	3.281 feet
	1.0 kilometre (km)	=	0.621 miles
Volume:	1.0 cubic metre (m^3)	=	35.315 cubic feet
	1.0 cubic decametre (dam^3)	=	0.811 acre feet
Rate of Flow:			
	1.0 cubic metre per second (m^3/s)	=	35.315 cubic feet per second
Yield:			
	1.0 kilogram per hectare (kg/ha)	=	0.893 pounds per acre
	1.0 tonne per hectare (t/ha)	=	0.446 tons per acre