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IRRIGATION WATER MANAGEMENT ASSESSMENT IN LATERAL CANALS OF SOUTHERN ALBERTA

BY

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ABSTRACT

There has been little research on assessing the performance of irrigation delivery systems in meeting crop-water demands in an adequate, timely and equitable manner. Presented is a technique/strategy used to quantitatively assess and compare overall performance of lateral canals in southern Alberta. Performance assessment is based on the hypothetical demands in an adequate and timely manner and in achieving water conservation. This performance study considered the important role of rainfall in irrigation water management. Included are quantitative measures of irrigation delivery system performance to compare existing performance levels in different lateral systems, and suggestions to help managers adjust lateral canals for improved performance.

The study considered two management objectives: water control and resource conservation. Various performance and water balance parameters; inflow, spill, supply, hypothetical demand, evapotranspiration, abundance and rainfall were considered as the key performance indicators. Data and information sources included monitored data sets, direct observations through field visits, ditch rider waterbooks, farmer interviews and simulations of hypothetical crop-water needs. Performance was assessment using a seasonal water balance and graphical and statistical analyses for four irrigation laterals in two irrigation districts of southern Alberta.

Water applied by farmers in all study laterals and years were less than hypothetically required for maximum yields, i.e. crops were under-irrigated. Analyses indicated that spill characteristics of all laterals were different, yet their net water use (abundance) characteristics were similar. Supplies and inflows were best correlated to demands during the weeks receiving rainfall between 1 and 10 mm. Overall supplies and inflows were best related to demands in Lateral B followed by those in Lateral A, D and C. However, Lateral A conserved water the best, followed closely by Lateral B. Laterals C and D performed poorly. Regression analyses confirmed that ditch riders are not effectively conserving water, especially after rainfall. However, on-farm management decisions of irrigators were based on crop water demands and accounted for rain.

Personal interviews with farmers provided an insight into farmer irrgation scheduling decision-making. Historical experience of farmers was the key in making most of their management decisions. Interviews also helped identify reasons for underirrigation as observed in the seasonal water balance and graphical and statistical analyses. Farmer concerns of the high cost of irrigation, their lack of knowlege about irrigation scheduling, and maintainence of their on-farm irrigation systems resulted in underirrigation. Factors causing high spills included large inflows, switching off irrigation pumps while changing irrigation sets (in case of side rolls), the draining of pipelines at the start of the season, power failures and the tardiness of some farmers in informing ditch riders about irrigation pumps being switched off. Improving the overall water use within existing lateral canals would require improvements in farm water management, delivery control, and canal system management.

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1.1 Status of Irrigation Delivery Systems

Adequate, timely and equitable water delivery at the lateral outlets is necessary to maximize crop production and fully utilize investments below the outlet. Bottrall (1981) stated that if water deliveries to the water users are not adequate and timely then investments made below the outlet will produce disappointing results. Replacing existing conveyance systems with new ones would be extremely expensive, hence emphasis world-wide is to improve the performance of existing conveyance systems. In order to improve the performance of a system, its present performance level must be known.

Low performance may be attributed to the following reasons:

- inflexible design of delivery systems and the assumption that on-farm irrigation systems will not change in the future;
- inadequate knowledge of canal operation by the ditch rider;
- water users may not be fully aware of their crop water demands and critical growth stages;
- poor communication and/or relations between the water user and the operating personnel, resulting in delays in providing irrigation water to users and in large spills;
- unexpected rains may delay other farm operations affecting timely irrigation;
- inaccurate weather forecasts and farmer interpretation may delay start of an irrigation event, and
- high cost of operating electric/gas pumps, labour and maintenance (to avoid system failure).

1.2 Background

Most of the irrigated land in Southern Alberta is organized into thirteen irrigation districts totalling approximately 500,000 ha, and varying in size from 800 to 120,000 ha. The districts are quasi-municipal water users associations which control the system downstream of the main diversion structures. The districts normally operate on an arranged demand schedule (Clemens, 1984) where the water user telephones either the ditch rider responsible for the canal or the district office, which in turn informs the ditch rider, when water is required and when it is to be shut off. There are few flow monitoring devices at farm turnouts.

1.3 Objective

This study was undertaken to examine water use characteristics within lateral canals, especially in response to precipitation timing and amount, in southern Alberta with particular emphasis on level of service to the farmers and on water conservation within the canal. The key physical points of interest were the canal inlet and outlets, and the turnouts from the canal to the individual farms. For such a study to be realistic, it must be holistic in nature, financially feasible and directed towards incorporation into the management structure.

Particular attention was paid to utilizing existing data, practicality and cost of data collection, completeness of description, importance of the information to management of the system, and identification of key variables. Various performance and water balance parameters; inflow, spill, supply, hypothetical demand, evapotranspiration and rainfall have been considered as the key performance indicators. Performance assessment has been achieved using seasonal water balance and graphical and statistical analyses for four irrigation laterals in two irrigation districts of southern Alberta.

From the initial analysis there was considerable variation in basic seasonal indicators used to describe lateral canal water management. With this in mind, the objectives of this research were:

- to examine the water use characteristics within lateral canals in terms of key indicators and with particular emphasis on whether hypothetical crop demands are being met with the available inflows and supplies;

- to assess the performance of lateral canals based on spill and spill ratios and to identify possible reasons for differences in spill characteristics;

- to identify reasons attributing to temporal abundance (supplies exceeding the hypothetical demands);

- to assess the role of rainfall in irrigation water management (i.e. if various rainfall events were considered by irrigators while implementing water management decisions and whether the system conserved water for its utilization in the later part of the season), and

- to determine whether waterbook records are reliable enough to be used in performance assessment at the farm level.

1.4 Scope and Limitation of the study

The management study mainly considered two critical objectives, namely water control and resource conservation in the management of laterals that feed farm turnout gates of southern Alberta. However, the on-farm irrigation systems were not completely overlooked. Besides utilizing existing data sets, data were collected through direct observations during field visits, ditch rider water-books, and simulations of hypothetical crop-water needs. A questionnaire was also prepared and farmers at selected farm outlets were interviewed. The interviews were designed to gain an understanding of the operation of on-farm irrigation systems and their management and to provide insight into the performance of delivery systems serving individual farm turnouts.

Due to financial constraints, absense of measuring devices, inaccurate waterbook records and unavailability of farm pumping capacities, performance of the lateral canals could not be assessed using volumetric ratios as suggested for southern Alberta by McCornick (1991).

This study is aimed at providing tools to irrigation district managers for monitoring a conveyance system and making necessary adjustments to attain better performance. The methodology developed can be used to compare existing performance levels in different lateral systems on a weekly basis using common variables. However, the target values will vary among different systems and are to be evaluated by considering major project characteristics.

2. LITERATURE REVIEW

This chapter presents a critical review of the literature on performance parameters in irrigation water management under different case studies. The aspects covered are status of irrigation in southern Alberta, parameters and variables considered as positive indicators of performance, and terminology of parameters selected in the present study.

2.1 Irrigation in Southern Alberta

Irrigated agriculture has contributed substantially to the southern Alberta economy for nearly a century. Irrigation has encouraged agricultural diversification, as evidenced by the concentration of several speciality crops. The irrigated cash crops include soft wheat, alfalfa, barley, sugar beets, dry beans, peas and potatoes. Soft wheat is primarily exported to foreign markets. The continued significance and viability of irrigation depends on a number of factors including economic, cultural and environmental and the availability of adequate water at reasonable cost.

2.1.1 Physical Environment

Southern Alberta (south of Calgary) is a dry region of Canada. The climate is semi-arid with considerable temporal and spacial variation in precipitation. Average precipitation varies from 355 to 510 mm from southeast to southwest. Precipitation averages 270.9 mm for rain and 134.4 mm for snow, with a 140-day crop growing season (Hobbs, 1977 pp. 1 and 4). The frost-free period ranges from 110 to 140 days in the southeast to 90 to 110 days in the southwest and the average high temperatures for July and January are 25.9 and -3.0 °C respectively, with lows of 10.2 and -15.2 °C.

Almost all the irrigated land in southern Alberta lies in the drainage basin of the South Saskatchewan River. Tributary rivers of the south Saskatchewan (Bow, Oldman, Saint Mary, Belly and Waterton) supply the water used by the major irrigation districts. More than 90% of the water carried by these rivers comes from dependable tributaries in the mountains and the foothills. Available water supplies are not normally a constraint, but in the event of a discrepancy between supply and demand, especially in a drought year, the districts change delivery schedules to rotation at the lateral level, as described by Ross (1990).

2.1.2 Irrigation Districts

Most of the irrigation districts in southern Alberta were organized between 1919 and 1936 after the province enacted the Irrigation Districts Act in 1915. This act enabled the farmers to organize themselves into districts and thus raise capital to finance construction works for irrigation. In 1968, another major irrigation act was introduced. Based on this, the province now shares 86 percent of all the irrigation rehabilitation cost and the district contributes 14 percent of the costs (Smith, 1978 pp. 11-15).

The six largest irrigation districts account for 406,274 ha or nearly 94 percent of the total irrigated area. A majority of the farms are large, or over a section in areal extent (at least 260 ha), with the mean being 472 ha. However, the mean irrigated land on these farms is only 38.7 percent of total irrigable area. The difference between the total and irrigated hectares is the highest where the farms are the largest. The largest farms are those that are privately irrigated and their average size is approx. 1200 ha, of which less than one-fifth is being irrigated. The average farm size in the Lethbridge Northern and Taber irrigation districts is under 304 ha, but at least 60 percent of the land is irrigated (Kromm, 1991).

The districts are quasi-municipal water users associations which control the system downstream of the main diversion structures. That is, the conveyance and delivery systems that serve each district are owned, managed and operated by the farmers' organization in that district.

These district are responsible for supplying water to farmers in the quantities and times requested. When farmers want to begin an irrigation, they contact the ditch rider responsible for water deliveries to the farm. The ditch rider is, under normal conditions, obligated to deliver water within 48 hours of the order being placed. Although the water users are theoretically restricted to 0.46 m (1.5 feet) of water per year, there are few devices for measuring flows at the farm turnouts. Service should be provided to all farmers fairly (equitable) and with an acceptable level of efficiency (water conservation).

Recently the irrigation districts in southern Alberta have been required to improve their water conservation, while maintaining or improving the level of service to the farmers.

2.1.3 Canal Delivery System

The majority of the delivery systems are open canals with some having been replaced by pipelines. Turnouts generally comprise a circular section sliding gate connected to a corrugated culvert discharging through the canal bank. This is a relatively simple device, but possible hydraulic conditions are numerous, depending on upstream and downstream conditions. The three common turnout conditions found in southern Alberta (McCornick, 1991) are:

- a farm sump directly beside the canal from which the water is pumped into the on-farm system,
- a farm ditch which conveys water to a sump, and
- a farm ditch for gravity application systems.

As the physical systems are rehabilitated and canals placed near or below field level, turnouts terminating in a farm sump adjacent to the canal are usually installed (Manz, 1990). This provides a flexible on-farm system, but if the farm pump fails or is switched off to move sets, excess water remains in the canal causing fluctuations downstream and potential spill, especially if more than one pump is involved. Further discussion of this general situation can be found in Manz (1990).

As canals are rehabilitated, even replaced with pipelines, the irrigation districts are gradually capping the flow rates per quarter section (farm turnout) at approximately 0.075 cumecs (1200 gpm). Theoretically the lack of measurement structures at farm turnouts does not present a great problem as most irrigators use sprinkler systems, therefore, peak rate is limited by the system capacity.

2.1.4 On-Farm Irrigation Systems

According to an irrigation survey in Alberta (Sterling and Schissel, 1988), the on-farm systems in prevalence today are side roll wheel moves, centre pivots and gravity/flood. Sprinkler irrigation has gained preference over the other methods of irrigation in recent times. An average system age (years in service) for gravity/flood is 21.2 years, compared to 10.3 years for side rolls and only 7.2 years for centre pivots. Although system age is lowest for centre pivots, these are being used on many new irrigated fields and on those where old systems are being replaced. The main reason for its adoption over other systems is that its labour requirement is low.

Irrigators perceive that economic problems are more serious than water availability. Pumping costs are often mentioned as their concern in applying more water. Some farmers likely apply too little rather than too much water to produce crops efficiently. Kromm et al. (1991) indicated that in the recent times one-fifth of the farmers in the Taber and St. Mary irrigation districts raised fewer moisture intensive crops than a few years ago, indicating that irrigated farming may have become less profitable in recent times. The same study indicated that the emphasis is somehow shifting from production maximization to profit maximization.

2.2 Irrigation Water Management

Irrigation is an artificial application of water so that crops can utilize it for maximizing production. Based on this, the function of management is to supply the right quantity of water at the right times and places, with the objectives of water control and resource conservation. With these objectives, deliveries made from a tertiary conveyance system are expected to be made in an adequate, equitable and reliable manner such that losses at the end of lateral outlet are minimized.

2.3 Performance Parameters in Various Studies

Performance, which is basically the effectiveness with which management achieves the set objectives, has been evaluated by different research groups using different management objectives and parameters, and is the difference between the set goal and the measured value. The variables used to define performance parameters are believed to be important in the systems delivery schedule. Unfortunately, the performance studies by various groups have used a wide variety of variables, making comparisons among various projects difficult or nearly impossible.

Whether the objectives of service to the farmers and water conservation are being achieved or not can be determined by comparing the differences between the actual and intended or desired performance, described by certain indicators. If performance is found to be low, contributing factors can be identified and improved strategies formulated. If remedial measures do not achieve the intended performance, then perhaps the target values are beyond the scope of the physical and organizational environment (Oad et al., 1989 and Wolters et al., 1989). Therefore, appropriate indicators must be identified and their target values established.

The need for performance standards has been emphasized by Wolters et al. (1989) and others for ease in comparisons of different irrigation projects. The actual or measured value of a variable must be compared with the target value and not 100%. The target value of a variable representing the indicator must take project characteristics into consideration including climate, physical characteristics, crops, on-farm system, uniformity of supply and application, and management levels.

2.3.1 Summary of Terminology in Performance Assessment

The following includes the summary of commonly used performance and water balance parameters which are used to describe performance of irrigation delivery systems. Various research groups have used these parameters as discussed in the following section. Some of these parameters have also been used in the present study to assess performance of lateral canals in southern Alberta.

- **Adequacy** - water delivered to a particular point in the system over a selected period of time divided by the water demand over the same period. Basically, this term specifies the system's ability to deliver water to meet the farm requirements. This term is identical to relative water supply (RWS) used by some research groups, which is expressed as a ratio of water supply to the water demand and these two terms are analogous to the efficiency term.

- **Equity** - a system's capability to uniformly deliver water in an adequate manner over the system. More precisely it is a measure of spatial variation of adequacy within an irrigation delivery system.

- **Reliability** - describes a system's ability to make intended deliveries of water with respect to timing and amount. It is also expressed as the percentage of time a given performance ratio is maintained within an acceptable level, or expressed as the temporal variation of adequacy.

- **Spill ratio (SR)** - the ratio of average spill for a given week to the average inflow for the same week (McCornick, 1993).

- **Normalized Spill Ratio (NSR)** - the ratio of average spill for a given week to the average weekly inflow for the whole season (McCornick, 1993).

- **Supply** - weekly supply is defined as the weekly inflow minus the weekly spill from the lateral.

- **Hypothetical Demand** - the weekly evapotranspiration minus the weekly precipitation.

- **Abundance** - supply minus the hypothetical demand, which is the net water balance without consideration of losses. This term has been introduced in this study.

2.3.2 Crop Yield Parameter

The most commonly used parameter of irrigation system performance would appear to be crop yield e.g. Lenton (1982) and Malhotra et al. (1982). The problem of using crop yield is that it is influenced by factors other than water supply and can not be used in the management plan requiring timely feedback.

2.3.3 Efficiency Parameter

Project efficiency or overall efficiency, a product of conveyance, distribution and application efficiency, was used as an indicator of performance by Wolters et al. (1989). It was chosen as an indicator of performance because of the following advantages associated with raising efficiency:

- a larger area could be brought under irrigation with the same volume of water;
- a water shortage could be made less severe;
- the investment cost for drainage would be reduced;
- competition with other water users would be reduced, and
- energy would be saved.

The efficiency term was expressed in volume terms by a relation between required (VR), intended (VI) and actual (VA) volume, and is given as follows:

$$\frac{VA}{VR}=\frac{VA}{VI}\cdot\frac{VI}{VR} \tag{1}$$

Where,
VI/VR gives the performance of the physical system and theoretically should be less than 1, where the intention of the management is to provide a protective layer of water to as large area as possible, as in case of the Warabandi system of irrigation management, which is discussed later. However, in delivery systems where supplies are adequate to meet the system demand, the value of this ratio could be set greater than or equal to 1. The ratio VA/ VI evaluates the performance of the delivery system and the management.

The results indicated that efficiency could be used as a performance assessment parameter provided the measured efficiency value is compared with the target value. The target values may not be 100 percent because of differences in climatological, technical and socio-economical conditions.

The efficiency approach helps in identifying areas of low performance and comparisons can be made in different reaches served by a canal. However, the following drawbacks are associated with the efficiency approach:

- does not provide information about the performance of the managing staff;

- gives no information as to whether the crop water requirements are met in terms of quantity, timing and places, and

- does not consider social, economic and political constraints within which a system must function.

McCornick (1991) observed that parameters such as conveyance efficiency and on-farm application efficiency, after Bos and Nugteren (1978), were important concerns in irrigation water management, and that considerable work has been done on quantification in southern Alberta towards identifying the effectiveness of the rehabilitation program (Thompson and Jonas, 1988). However, such studies are data intensive and are not conveniently interpreted for adjustments to the day-to-day management of an irrigation system.

2.3.4 Wetted Area Parameter

Malhotra et al. (1984) considered wetted area as a performance assessment parameter for the Warabandi management system, which serves approx. 35 million acres in India and Pakistan. The Warabandi management system is of imposed water scarcity (large area is irrigated with limited supplies during the year) over a large area and over a long period of time. The study considered two management objectives:

- allocative effectiveness (AE), and

- productive effectiveness (PE).

The criteria considered for measuring allocative effectiveness was total wetted area (TWA), which is the sum of all areas wetted by each irrigation. The coefficient of variation (CV = standard deviation/ mean) of TWA indicated AE. Malhotra et al. (1984) also used regression analysis to evaluate AE as, theoretically, TWA should have a linear relationship with cultivable command area (gross area that can be brought under irrigation, CCA). Therefore, R^2 of the following equation can be used as an index of AE:

$$TWA = f\,(CCA,..) \tag{2}$$

If the variation in TWA is perfectly correlated to the variation in CCA, then $R^2 = 1$ and AE would be perfect, i.e. 100% equity. The advantages associated with this parameter are that only moderately trained people are required to measure or estimate TWA and this parameter can ideally be monitored aerially or through a satellite. However, the drawbacks are:

- measures performance at the field rather than at the farmer's inlet, thus taking into account variability due to soil type, topography, cropping pattern and management practices;

- farmers are free to irrigate areas adequately or not, and the staff responsible for measuring TWA are not reliable due to personal gains involved in submitting incorrect data. By submitting incorrect TWA data the Staff gains illegal money from the farmers on the upstream end.

Malhotra et al. (1984) related productive effectiveness (PE) to adequacy and reliability of water supplies and evaluated PE by determining the crop water requirements and by evaluating the soil moisture balance during the critical growth stages. The effect of low soil moisture values at critical growth stage would indicate crops were stressed and yields would be reduced drastically.

A more recent study by Seckler et al. (1988) also considered actual TWA as an indicator of performance with the following objective function:

$$TWA^{*} = \frac{1}{3} \times CCA \times no.\ of\ irrigations \qquad (3)$$

where,

TWA^{*} is the objective function of Warabandi system with respect to TWA

The ratio TWA/CCA described adequacy in supply and the coefficient of variation (CV) of this ratio as equity. The following two types of errors were identified with these estimates of adequacy and equity:

- mean error, and

- uniformity error

Since, neither of the above two management errors conveyed how well or how poorly the system was operating, a performance index, or Theil's index, was defined to combine both types of errors in the total error (TE):

$$TE = \sqrt{\frac{\sum (TWA^{*} - TWA)^2}{\sum TWA^{*2}}} \tag{4}$$

If TE = 0%, performance is perfect in terms of adequacy and equity, and
If TE = 20%, the system is 80% effective.

2.3.5 Water Delivery Performance Parameter

Lenton, 1983 considered the following four measures of performance:

- actual area irrigated;
- water delivery;
- crop yield from irrigated land, and
- variation in the above (equity).

He suggested that water delivery performance (WDP), which accounts for quantity and timing of water to the farm, was the most complete indicator of performance of an irrigation system and defined this indicator at the farm turnout, the lateral canal outlet and the lateral. Water delivery performance for the lateral turnout and lateral were given by the following relationships:

Water delivery performance at the turnout, j:

$$WDP_j = \frac{1}{N} \sum_{i=1}^{N} \sum_{t=1}^{n} \frac{K(t) \times Vi(t)}{Vi^{*}(t)} \quad where,\ Vi(t) \le Vi^{*}(t), \sum_{t=1}^{n} K(t) = 1 \tag{5}$$

Water delivery performance for the lateral, k:

$$WDP_k = \frac{1}{N_k} \sum_{j=1}^{N} WDP_j \qquad (6)$$

Where,

WDP_j is the water delivery performance at the jth turnout;

WDP_k is the water delivery performance of the kth lateral;

Vi(t) is the volume of water delivered to farm i, during week, t of the cropping season;

$Vi^*(t)$ is target or hypothetical volume of water to be delivered to farm, i, during week,t;

K(t) is the weighting factor indicating relative importance of water at different stages of crop growth or a yield reduction function;

n is the no. of weeks in a cropping season;

N is total number of farms served by the outlet, and

N_k is the total number of outlets along the lateral

Equity in water delivery (EWD) was defined as follows:

$$EWD = 1 - \frac{s}{WDP} = 1 - CV \qquad (7)$$

Where,

s is the sample standard deviation;

WDP is the mean water delivery performance of all the outlets, and

CV is the coefficient of variation (s/WDP).

Water delivery performance is theoretically an accurate parameter in assessing the performance at lateral and farmer outlet levels, and will allow timely feedback with intensive data collection at various turnout gates. However cost, time and labour will be a limiting factor. Also, although this study defined adequacy and equity quantitatively, there was no mention of reliability with which the system was meeting water users requirements under different irrigation events.

2.3.6 Adequacy, Equity, Reliability and Management Delivery Ratio Parameters

Holistic, interdisciplinary team approaches, as described by Oad and McCornick (1989), utilize a broader base of parameters. However, evaluation of these parameters can be expensive. Many of the concepts described by Oad and McCornick (1989) and Mohammed (1987) have been applied in Alberta by McCornick (1991), but limited to irrigation water management at the lateral canal and farm levels.

In proposing a methodology for assessing irrigation water management, Mohammed (1987) considered four variables (volume, rate, duration and frequency) from which he developed three key indicators:

- **Adequacy** - water delivered to a particular point in the system over a selected period of time divided by the water demand over the same period,
- **Equity** - a system's ability to uniformly deliver water in an adequate manner, or a measure of spatial variation in adequacy,
- **Reliability/Dependability** - a system's ability to make intended deliveries of water with respect to timing and amount. It is also expressed as the percentage of time a given performance ratio, such as adequacy, is maintained within an acceptable level, or expressed as the temporal variation of adequacy.

These indicators are supply/demand ratios expressed over time and space. Francis (1990) built on this concept using "management delivery ratios" as performance assessment indicators in Sudan's Gaziera irrigation project. Performance was assessed using the following ratios:

$$\textit{Mangement Delivery Ratio (MDR)} = R_1 . R_2 . R_3 \tag{8}$$

$$\textit{where} \quad R_1 = \frac{Q_r}{Q_R}, \; R_2 = \frac{Q_i}{Q_r}, \; R_2 = \frac{Q_a}{Q_i} \tag{9}$$

Q_r = *requested rate by water-user,*
Q_R = *required (hypothetical) rate,*
Q_i = *intended rate by management,*
Q_a = *actual rate.*

MDR is analogous to adequacy (Mohammed, 1987) and relative water supply (RWS), as defined by Oad and Podmore (1989). All of these methodologies involve the application of supply/demand ratios spatially and temporally within the system. However, direct measurement of the necessary data required to assess these indicators would be prohibitively expensive.

For Alberta conditions the irrigation water demand at the farm turnout has been defined in three forms (McCornick, 1991):

- Water-user demand. The timing (T_r), rate (Q_r) and duration (D_r) of water requested by the water-user.
- Water-book demand. The water-book is the record kept by the ditch rider of the timing, rate and duration of water ordered by the water-users (T_{wb}, Q_{wb} and D_{wb}, respectively).
- Hypothetical crop-water use. The water a well watered crop uses during a particular period can be determined from the theoretical crop-water needs (T_h, Q_h and D_h, respectively). The expected water losses should also be included in this term.

The actual supply at each turnout was described in terms of the timing, rate and duration (T_a, Q_a and D_a). However, for short time periods the hypothetical rate of crop-water use is of little practical significance relative to the actual supply. Realistically the hypothetical crop-water use needs to be described in terms of volume ($V_h(t)$) over time step t of at least a week. At the canal level, the demand and supply variables (T_c, Q_c, D_c and $V_c(t)$) are the cumulative values of the turnout variables plus the losses in the system.

For each turnout, the performance was described in terms of the adequacy (Mohammed, 1987) of delivery rates, as described in Equation 10. Without turnout measurement devices the rate supplied can be determined from farm pumping capacity or by installation of a temporary measuring device, where practical. Over longer time periods, when the use of the hypothetical crop water use becomes practical, the adequacy can be described as shown in Equation 11.

$$ADEQUACY = \frac{Q_s}{Q_r} = \frac{Q_s}{Q_{wb}} \cdot \frac{Q_{wb}}{Q_r} \tag{10}$$

where

Q_s = *rate supplied*
Q_r = *rate requested by water-user*
Q_{wb} = *water-book record*

$$ADEQUACY = \frac{V_s(t)}{V_h(t)} = \frac{V_s(t)}{V_{wb}(t)} \cdot \frac{V_{wb}(t)}{V_r(t)} \cdot \frac{V_r(t)}{V_h(t)} \tag{11}$$

where, for time t:

$V_s(t)$ = *volume supplied*
$V_h(t)$ = *hypothetical crop-water use*
$V_{wb}(t)$ = *water-book recorded volume*
$V_r(t)$ = *volume requested by water user*

Equity was quantified in terms of the standard deviation of the ratios between the turnouts in the system, and reliability was expressed as the temporal variation of the various ratios at a given turnout.

With few or no measurement structures at the farm turnouts, district management rely on the lack of complaints from farmers as a key indicator of correct canal operation. Such a management technique is referred to by Mohammed (1987) as the "happy water users" approach, which he points out is very difficult to quantify for systematic management of the system. Seasonal performance is also considered to be high if lateral supplies match the average crop water demand. With the concern for improved water use within the districts, canal spill is now being introduced as a key indicator and may be in conflict with the "happy farmer" concept. The amount of spill through a lateral would normally depend on the type of on-farm irrigation system, effectiveness of communication between the water user and the ditch rider, number of water users, and the area to be irrigated by the lateral.

3. METHODOLOGY

Performance was assessed using seasonal water balance, graphical and statistical analysis along with an understanding of farmer decision-making (obtained by conducting farmer interviews). Management objectives and parameters, and irrigation management practices within various lateral canals with particular emphasis on performance assessment have been included in this chapter.

3.1 Relevant Management Objectives and Parameters

The various objectives of management considered by numerous researchers are water control, agricultural productivity, resource conservation and returns on investment. The present study considers the objectives of water control and resource conservation rather than considering the objectives of agricultural productivity and return on investment. Though the objectives of agricultural productivity and return on investment can be directly measured and can also be compared with set standards, these are influenced by a wide range of factors such as financial arrangements, prices, markets, government policies, climatological variations and so forth. Thus they are not solely the reflections of irrigation water supplies. Also, parameters to assess the achievement of these objectives are difficult to incorporate in the management plan requiring timely feedback for operating the system.

Various performance and water balance parameters; inflow, spill, supply, hypothetical demand, evapotranspiration, abundance (supply minus demand or net water balance) and rainfall have been considered as the key performance indicators, as a broad framework. Particular attention is paid to practicality and cost of data collection, importance of the information to the system management and identification of the key variables. The parameter ABUNDANCE has been introduced in this study to represent weeks where supplies on-farm exceeded the demands and to identify the reasons for temporal variation of such an event. The weeks where the supplies on-farm exceeded the demands have been referred to as WEEKS OF ABUNDANCE. This was considered important because the preliminary analysis indicated that farmers in general underirrigate.

Data and information sources included existing data sets, direct observations through field visits, ditch rider water-books, farmer interviews and simulations of hypothetical crop-water needs.

3.2 Existing Monitoring

The Irrigation Branch of Alberta Agriculture in Lethbridge has been collecting inflow and spill data from selected lateral canals in the region since 1988. The hydraulic stations consist of a stilling well, an intake pipe and an electronic datalogger, and are calibrated by developing rating curves for the measurement structures. Depth of discharge readings are taken at 20-min intervals. The Irrigation Branch also collects other data pertinent to the water demand and supply within each of the canals (Irrigation Branch, 1990a, 1990b and 1991). Monitored data have been obtained for two sets of laterals for two years and 22 weeks of growing season each. The two sets have been termed as Set X (consisting of Laterals A and B, 1989-1990) and Set Y (consisting of Laterals C and D, 1990-1991). The initial intention was to use data from Set X for three years (1989-1991), but Alberta Agriculture ceased monitoring laterals included in this Set.

3.3 Description of laterals

All laterals studied were recently rehabilitated and schematics of their layouts are included in Appendix A. To avoid direct comparison of individual laterals or irrigation districts, the four laterals described in the analysis will be referred to as A, B, C and D. It would not be difficult for a reader to locate these particular laterals, but this study is not intended to judge one better than the other, but rather include the potential performance variability.

3.3.1 Set X (Laterals A and B)

These two canals are in irrigation districts approximately 60 km apart. The canals were monitored during 1989 and 1990. Lateral A is an open channel canal whereas Lateral B includes sections of pipeline, concrete and earth canal. Lateral B is unusual in that it has a high percentage of closed pipeline serving 28 turnouts to domestic parcels. The large number of turnouts makes it difficult to operate this canal.

3.3.2 Set Y (Laterals C and D)

The two lateral canals lie in the same irrigation district. These canals were monitored during 1990 and 1991. Lateral C consists of two laterals which run adjacent to each other and spill into the same reservoir. It has sections that are polythene-lined with rock armour, pipelines, and open earth canal serving 1670 assessed hectares of irrigated land. There are three hydrometric stations; two to measure inflow and one to measure the combined spill into the Fincastle Reservoir. Lateral D has sections of concrete, polylining, pipelines and open earth canals. There are five flow monitoring stations. One is used to measure the inflow and four stations measure outflows or spills.

3.4 Analysis

Crop evapotranspiration is a combined process of evaporation from the ground surface and transpiration from plants. It is defined as the product of potential evaporation and a crop water use coefficient:

$$ETc,t = Kc,t \; (ETp,t) \qquad (12)$$

where,

$ET_{c,t}$ is crop evapotranspiration on day t

$ET_{p,t}$ is potential evapotranspiration on day t, and

$K_{c,t}$ is the crop coefficient on day t.

The term potential evapotranspiration was proposed by Thornthite (1948) and is defined as the rate of evaporation from a continuously moist area with a lush crop covering the ground. Potential evapotranspiration is also termed as reference evapotranspiration if crop evapotranspiration is estimated with respect to a reference crop. Potential or reference evapotranspiration was computed using the modified Jensen-Haise equation, developed for the southern Alberta chinook region (Foroud et al. 1989). The daily values for various crops grown in the region are estimated from the crop water use function calibrated to the region. The daily crop evapotranspiration was generated from a spreadsheet (CROPCALC), developed by Alberta Agriculture.

In this study the preliminary analysis on the performance of the irrigation lateral canals was based on seasonal water balance. The four key parameters examined were inflow, spill, supply and hypothetical demand. The necessary data for the volumetric ratios expressed in Equation 11 could not be collected due to financial constraints, complete lack of measuring devices, inaccurate waterbook records and unavailability of farm pumping capacities.

3.4.1 Statistical Analyses

The monitored data were analyzed for both the Sets, Set X (Laterals A and B for the years 1989-90) and Set Y (Laterals C and D for the years 1990-91). Graphical and statistical techniques were used to investigate the various performance and water balance parameters such as inflow, spill, supply, rainfall, spill ratios (SR and NSR), evapotranspiration and abundance. The interdependence and interaction of these parameters were considered. Simple and multiple regression analyses were carried out to compare inflow and supply relations with respect to hypothetical demands and to investigate whether the unpredictable factor, rainfall, plays a role in the irrigation water management in southern Alberta. These analyses assessed and compared the performance in all laterals and years of study. In both the graphical and statistical analysis, data sets were analyzed using weekly time-steps unless otherwise stated.

In the analyses of variance within Sets the identified sources of variation in these experiments were laterals ($l = 2$), years ($y = 2$) and weeks ($w = 22$). This analysis was used to identify significant differences and interactions in the weekly values of abundance, spill ratios and spills, in laterals of Sets X and Y. The two years were considered to be replicates (block) in the experiment. It is recognized that a replicated experiment needs to be completed to validate the results of the pseudoreplicated experiment and therefore may be considered as psuedo replicates (Hulbert, 1984). The GLM and REG procedures in SAS (SAS Institute Inc., 1985) were used to perform all statistical analyses. A probability level of 0.05 was considered significant for testing the data of both Set X and Set Y.

3.5 Farmer, Waterbook and On-Off Records

Field visits were made for a period of about a week, starting July 31 to August 7, 1991. Two lateral canals, C and D, within Set Y were considered in this study. Each was managed by a different ditch rider. Field visits were made twice a day to both laterals to determine which farm pumps were on and which were off.

During the earlier part of the 1991 crop season, farmers from the same laterals were asked to maintain records of their first two or three irrigations. The details in these records included date and time irrigation pumps were started, number of sets per day (in the case of side rolls), the date and time that irrigations were completed, along with information on total shut down time due to power failure, draining and moving lines (changing sets), and system failure. Twelve farmers from about 30, responded to this request, six each from Laterals C and D.

The farmer and ditch rider records of water use were compared with each other, and with information gathered during two weeks of field visits. Data for comparison of these records from Lateral C and D are presented in Appendix C. The on-off observations are also presented in this appendix for irrigation dates (July 31- August 7 for Lateral C and August 2-7, 1991 for Lateral D) to verify the farmer record. Various land locations are represented only by turnout gate numbers to avoid identification of individual farmers on these laterals.

Farmer records were obtained for eight and nineteen turnout gates in Laterals C and D, respectively. A total of 15 and 41 records of irrigation dates (days when water was applied to fields) were provided by the farmers of Lateral C and D, respectively, for direct comparison against the waterbook and on-off observations. On average, two irrigation records were provided by the farmers from Lateral C and three from Lateral D. Waterbook records not available for the turnouts are indicated as missing. Also, periods where waterbook records do not match irrigation dates reported by the farmers over a period of two weeks time were considered as a no record. The on-off observations have been presented only for turnouts, where pumps were running during the period of observation. Comparing the dates when pumps were running (ON) with irrigation records from the waterbooks was considered more realistic than comparing off dates. Thus, comparison of only ON records were considered as a valid indication of ditch rider's performance in maintaining records.

3.6 Questionnaire

Active participation by farmers is required to assess and improve the performance of an irrigation system (Lowdermilk, 1986). A questionnaire was developed to help understand farmer's management decisions related to the operation of on-farm irrigation systems (Appendix B). The questions were structured to provide an insight into farmer criteria for deciding when and how much to irrigate. Also, the questionnaire considered the farmer's awareness of pump capacities and the effect of his operation on canal flow fluctuations.

Personal interviews were preferred and implemented over other survey methods such as mailed, mass, and self-administered questionnaires. Although this method is more expensive and slow, it has numerous advantages (Kidder, 1981), including:

- improved response as most respondents lack the patience and motivation to fill up the questionnaires as fully as they might speak;
- corrects the misunderstanding of respondents;
- enables more in-depth coverage of the subject matter;
- more appropriate in revealing complex information; and
- likelihood of establishing rapport with respondents.

4. ANALYSIS AND DISCUSSION

The following section presents the initial analysis of both Sets X and Y, consisting of four laterals, as seasonal water balance.

4.1 Seasonal Water Balance

Summaries of the data collected for Set X (Laterals A and B for years 1989 and 1990) and for Set Y (Laterals C and D for years 1990 and 1991) and their service areas are given in Tables 1 and 2.

Water consumed within all laterals over observed seasons was less than or equal to hypothetically required for maximum crop yields i.e. shortfall (Table 1). These estimations were without the inclusion of missing data, ranging from 2-8 weeks and without the consideration of conveyance and application losses in the system.

In Set X for both years and for both laterals, the cumulative inflow was less than the evapotranspirational demands (Table 1). This suggests that farmers are either not fully aware of their crop water demands, or they were anticipating more rainfall, an unpredictable factor involving a high degree of risk. The justification of such a risk by the farmers might be the potential of a rainstorm over-watering their crops which might affect crop yields.

Inflows into laterals of Set Y (Laterals C and D) were sufficiently large to meet the demands, resulting in large spills in both laterals and years. Thus, crops were underirrigated even when inflows provided in laterals were sufficiently large to meet the hypothetical demands. Substantial spills (over 40 % in the case of laterals with Set Y), suggested a great potential for water conservation, although charging of reservoirs to feed other laterals contributed to their high spill values. This indicates that spill as an indicator of performance should be used with caution. This would also indicate farmer's dependence on rainfall to meet the crop water demands. As expected, there was less seasonal shortfall in the year of very high rainfall (1991). Spills from Lateral C goes into a reservoir, which feeds other lateral canals, thus, high spills are not of much concern to the district.

Table 1 Summary of water-use data in monitored laterals of Sets X (A & B) and Y (C & D), 1989-1991.

LATERALS - YEAR	A - 1989	A - 1990	B - 1989	B - 1990	C - 1990	C - 1991	D - 1990	D - 1991
PARAMETERS								
Inflow, ha-m	602.6	675.6	468.0	646.5	955.6	655.3	1556.5	1531.1
Spill, ha-m	101.2	88.1	181.6	191.1	608.8	423.0	651.7	874.4
Inflow-Spill, ha-m	501.5	587.5	286.5	455.4	346.8	232.3	904.8	658.7
Spill (%)	16.8	13.0	39.0	29.6	63.7	64.6	41.9	57.0
Assessed area, ha	1897.2	1928.0	1304.3	1304.3	1671.8		3535.6	
Irrigated area, ha	1822.7	1759.0	1225.4	1254.6	1575.5	1726.0	3475.6	3470.7
(1)Irrigation depth, (including losses)~ ,m	0.28	0.34	0.24	0.25**	0.22	0.13	0.26	0.19
(2) Precipitation, m	0.20	0.19	0.23	0.13	0.13	0.23	0.13	0.29
(3) Evapotranspiration (ET), m~	0.55	0.56	0.53	0.53	0.47	0.45	0.54	0.48
(4) Hypothetical demand (3) - (2), m	0.35	0.37	0.30	0.40	0.34	0.22	0.41	0.19
Shortfall, m (4)-(1)~	0.07	0.03	0.06	0.15**	0.12*	0.09****	0.15	0.00***

~ Different from original reference (Irrigation Branch, 1990a,b & 1991) because of missing data and analysis at weekly time-step.
* Two weeks of missing supply data.
** Three weeks of missing supply data.
*** Four weeks of missing supply data.
**** Eight weeks of missing supply data.

Table 2 Cropping Pattern and Application Systems for Sets X (A & B) and Y (C & D).

LATERAL-YEAR	A-1989	A-1990	B-1989	B-1990	C-1990	C-1991	D-1990	D-1991
APPLICATION								
Centre pivots (%)	0.0	0.0	10	10	0.0	21.2	33.8	33.8
Side-roll (%)	99.0	98.0	86.0	86.0	98.2	77.2	66.2	66.2
Border (%)	1.0	2.0	4.0	4.0	1.8	2.0	0.0	0.0
CROP PATTERN (percent area)								
Barley	45.8	43.7	11.8	8.4	22.7	15.4	17.4	21.1
Oats	4.6	0.7	0.2	0.0	0.5	0.0	0.6	5.5
Wheat	9.2	11.8	36.7	35.6	43.0	42.5	18.6	22.8
Sweet Corn	0.3	0.4	5.2	5.4	1.3	1.5	16.2	12.8
Alfalfa	31.3	30.8	12.3	12.1	14.8	20.4	17.7	12.8
Pasture	3.0	3.0	4.3	3.4	2.1	4.9	0.0	0.0
Potatoes	2.5	3.2	6.8	5.6	2.6	1.6	12.8	8.0
Beans	0.0	0.0	4.3	2.4	0.8	2.4	7.1	6.8
Sugar Beets	0.0	0.0	18.4	22.6	10.2	9.8	9.3	10.0
Sunflower	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0
Canola	1.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0
Flax	2.3	0.9	0.0	0.0	1.4	0.0	0.0	0.0

The parameters shown in Table 1 partly describe the irrigation canal management in terms of the discrepancies between seasonal supply and demand at canal level, the spill ratio, and, if a lack of complaints from farmers is assumed, a reasonable level of service.

The performance of a particular lateral depends on the type of on-farm irrigation system, effectiveness of communication between the water user and the ditch rider, number of water users and the area to be irrigated by the lateral. The variation in the basic performance indicators among the laterals and from season to season suggested that further monitoring will be required to establish any relationships and potential target values for performance.

4.2 Graphical Analysis

The data were further analyzed using the same data sets, but with weekly-time steps. The hypothetical demand diverged from the supply around late July for all four situations (Figures 1 and 2), although there were three weeks of missing supply data from Lateral B (1990). As the supply curves do not include the conveyance, distribution and application losses, the discrepancies between actual crop-water use and hypothetical demand would be even greater.

Hypothetical demands declined relatively rapidly and were at zero for extended periods when the supply was not (Figures 3 and 4), which would suggest potential water savings. These periods coincided with major rainfall events earlier in the seasons. Apart from these discrepancies, the weekly supplies and hypothetical demands show some agreement.

There is not much yearly variation in spill ratio (SR) in Laterals A and B of Set X. The average spill in Lateral B was considerably higher at approximately 35%, than from Lateral A 15% (Figure 5). The spill from Lateral A in the early part of the 1990 season was lower than the previous year, 1989, when there was a high rainfall period and low supplies. There is some potential for water conservation although the impact of such measures on the quality of delivery to farm turnouts is unknown, particularly considering most farmers on these canals use pumps.

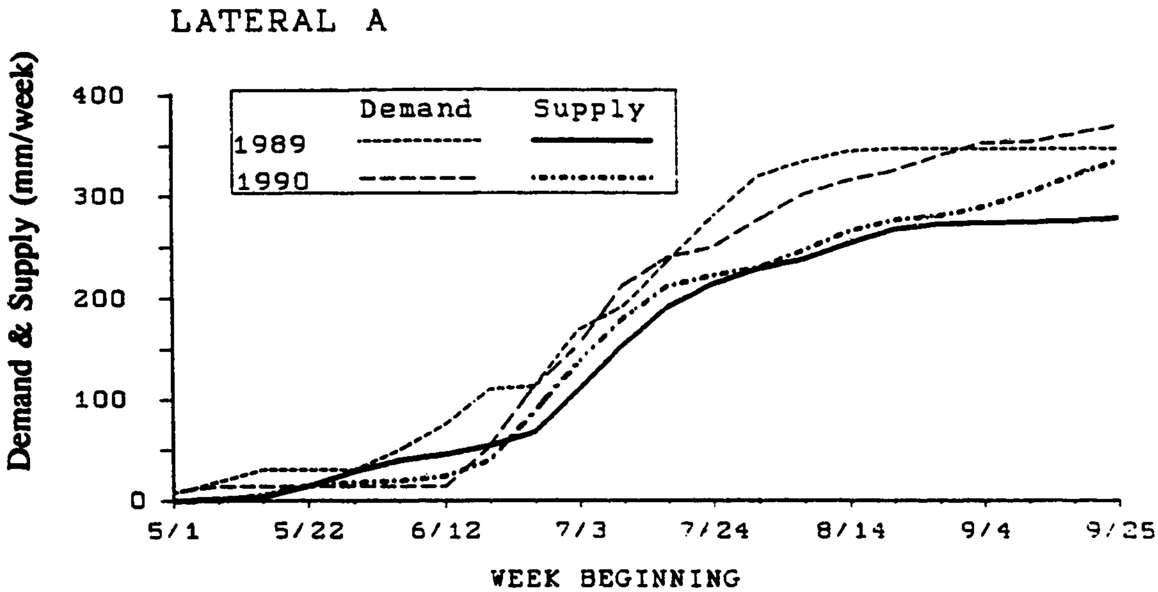

Figure 1 Cumulative supply and hypothetical demand for Lateral A (Set A) (mm/week)

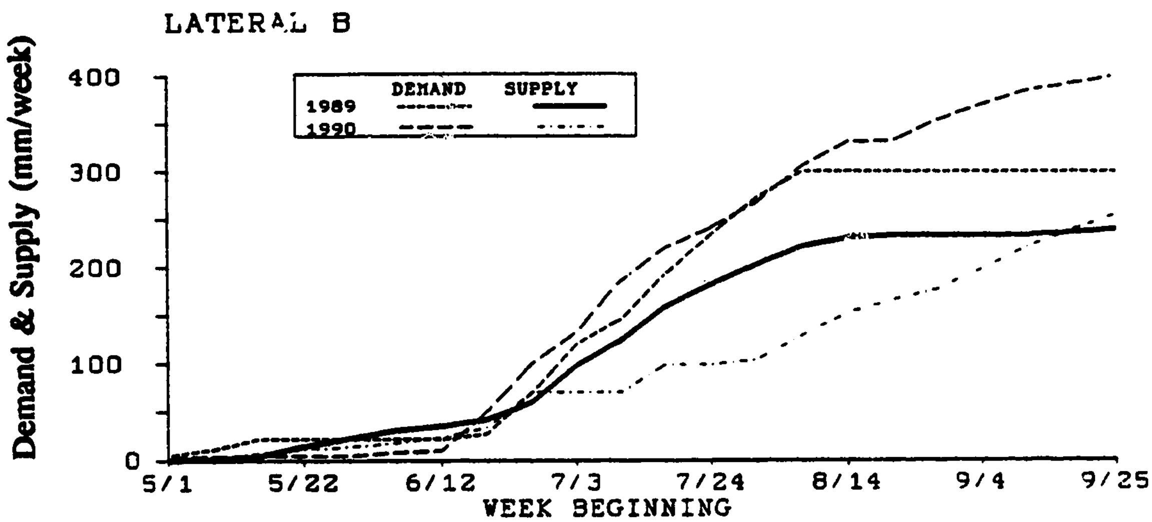

Figure 2 Cumulative supply and hypothetical demand for Lateral B (Set A) (mm/week)

It was observed from the graphical analysis that in both Sets X and Y, the cumulative inflow was much greater than the hypothetical demands. However, supplies were lower than the hypothetical demands, except for the weeks where rainfall exceeded 20 mm per week.

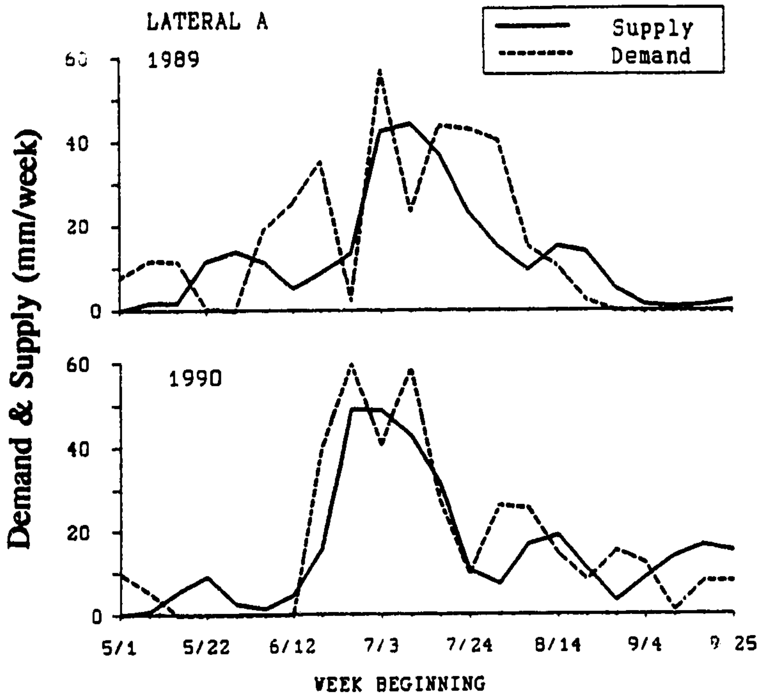

Figure 3 Supply and hypothetical demand for Lateral A (Set X) (mm/week)

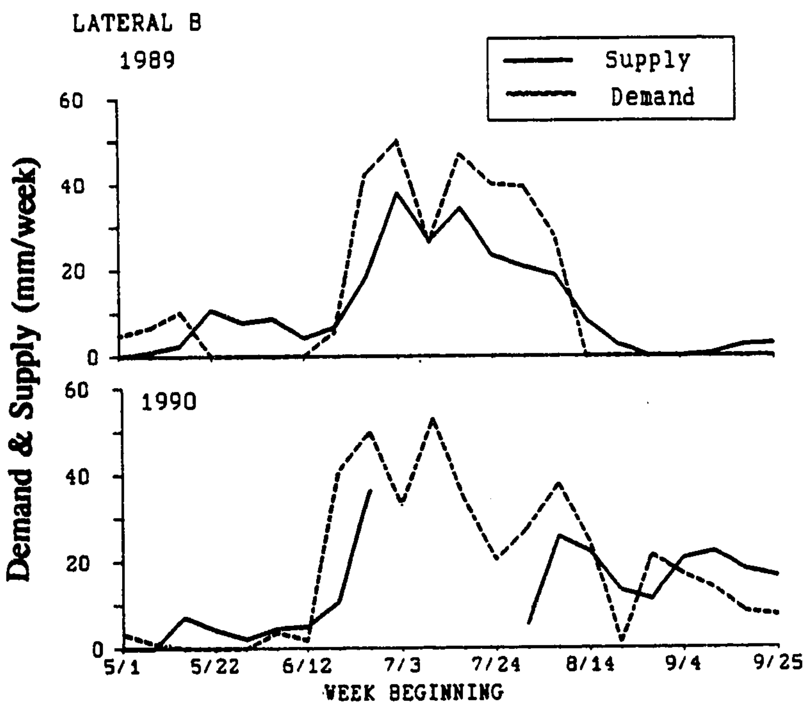

Figure 4 Supply and hypothetical demand for Lateral B (Set X) (mm/week)

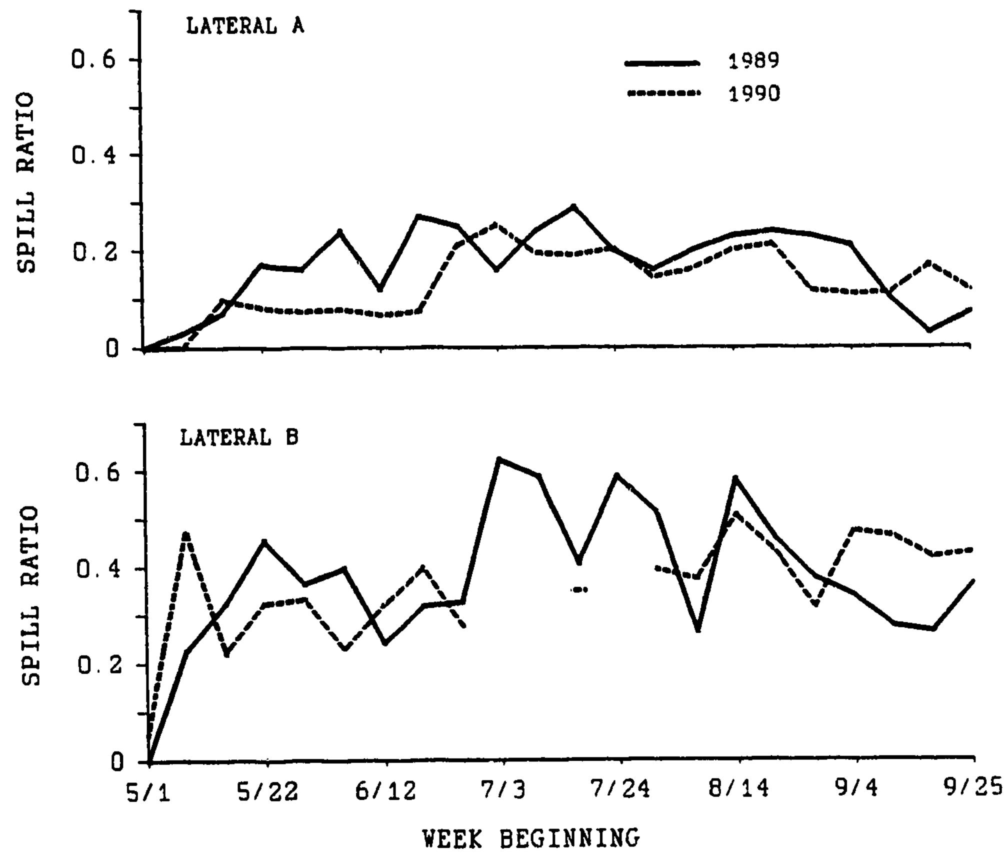

Figure 5 Spill ratios for Laterals A and B of Set X.

Inflow appears to correspond to crop demand on a day-to-day basis (Figure 6), despite the dynamic nature of crop-water demand and unpredictable nature of rainfall. The exception to this trend was for rainfall periods lasting 7-10 days and for rainfall amounts ranging from 5-30 mm/day. At these times, the inflow decreased sharply, suggesting that the canal management was responding to the hypothetical demand. The temporal variation of inflow during and in various seasons was thus caused by the variation in the hypothetical demands, which are influenced by both the crop growth stage and the variations in the precipitation amount during the season.

The analysis of abundance and rainfall (Figure 7) suggested that abundance occurred only in weeks where weekly rainfall exceeded 15 mm and during the last 2-3 weeks of the season where the hypothetical demands were very low. In 1991, when total rainfall during the growing season was twice of that in 1990, there were more weeks of

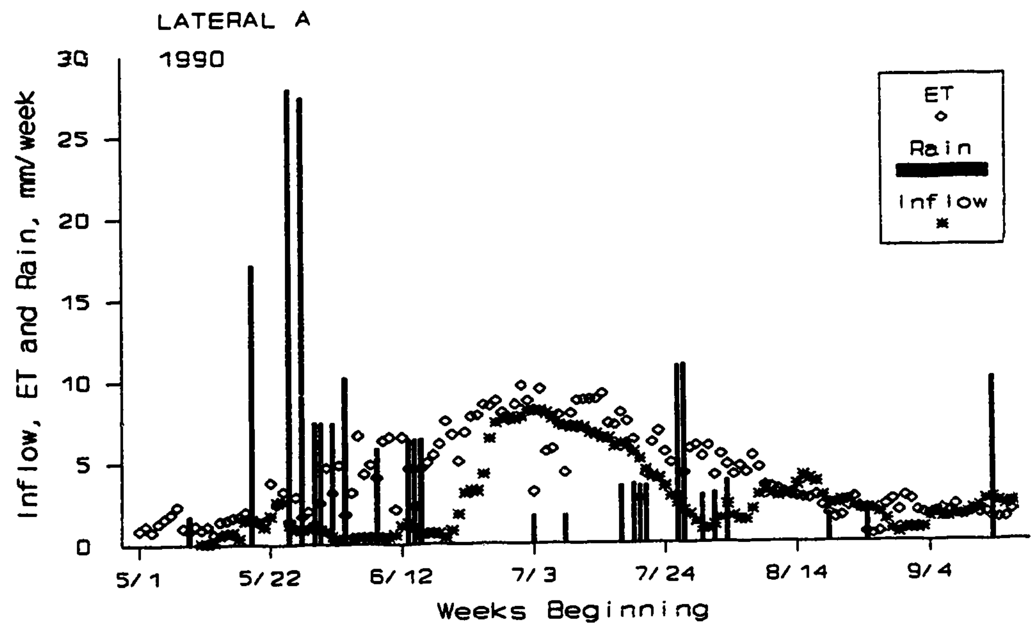

Figure 6 Daily Evapotranspiration (ET), Inflow and Rainfall for Lateral A, 1990

abundance, and a better correlation with rainfall.

The characteristics of spill from these laterals were examined using two parameters, spill ratio (SR) and normalized spill ratio (NSR) as defined earlier. Interestingly, in Set Y, both the laterals behaved differently when average spill ratios (SR and NSR) for two years for these laterals were considered (Figure 8). Different spill characteristics in study laterals and a little yearly variation in SR and NSR in these laterals would suggest similar spill characteristics and probably similar management decision over the period of study within individual laterals. The differences in spill characteristics expressed by spill and spill ratios (SR and NSR) may be due to reasons such as differences in irrigated areas served (thus different inflows), temporal and spatial variability in precipitation, training and expertise of the ditch riders and their communication with farmers, types of on-farm irrigation systems and crop diversification. However, further work with more years of monitoring will be required to determine on the suitability of spill ratios in the assessment of performance.

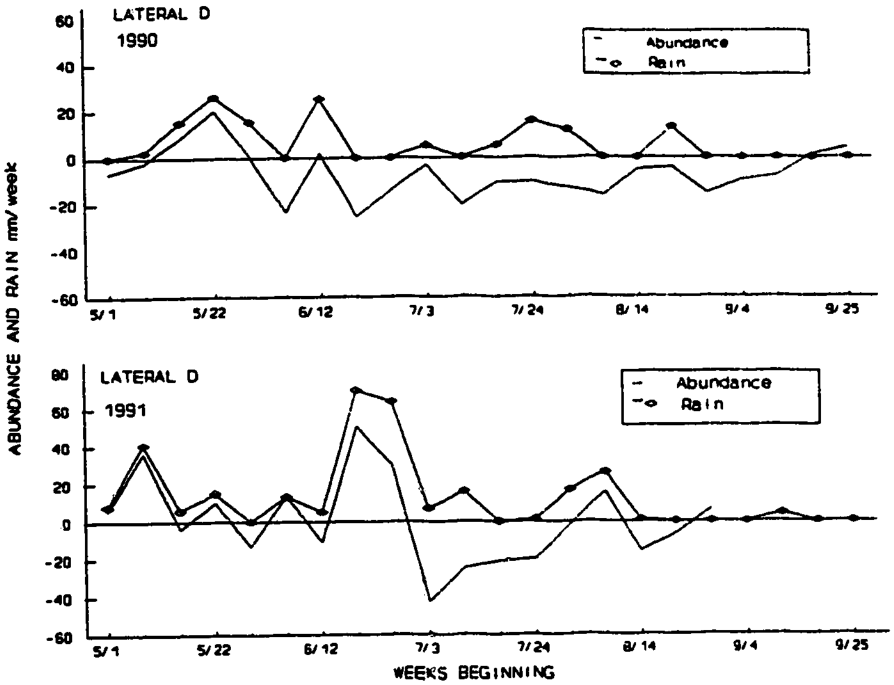

Figure 7 Abundance as related to Rainfall during the two irrigation seasons for Lateral D of Set Y.

4.3 Statistical Analysis

Analyses of variance for Set X and Set Y are presented in Table 3 and 4 respectively. Preliminary analysis of Set X, the parameters, abundance, spill ratio, and spill for both the laterals indicated no significant difference for the year by lateral interaction, and, therefore, the year by lateral interaction was pooled with the error term. The sources of variation in the final analysis of variance (ANOVA) were Year, Lateral, Weeks, Weeks*Lateral and Error.

In the preliminary analysis of the data from laterals of Set Y, the observed significance levels of year by lateral for abundance, spill ratios (SR, NSR) and spill were 0.264, 0.752, 0.387 and 0.040 respectively. Therefore, for each parameter the year by lateral interaction were pooled with the error. For spill ratios and spills, the non-significant weeks by year interaction were pooled into the error, but for abundance, the significant week by year interaction was not pooled. The sources of variation in the final

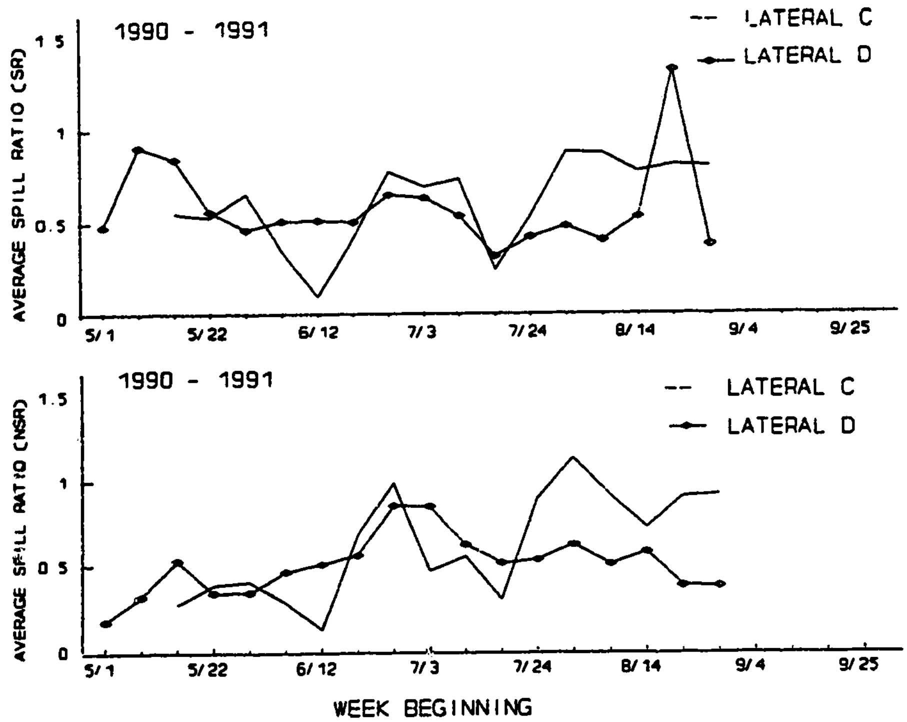

Figure 8 Average spill ratios (SR and NSR) in Lateral C and D (Set Y) within the same irrigation district

analysis of variance (ANOVA) are shown in Table 4.

Spills and spill ratios were highly different for all Laterals (Tables 3 and 4). However, variation in the net water use (abundance) was low, indicating that the spill characteristics of these canals were different, yet the net water use characteristics remain similar, supporting the graphical analysis. This would indicate similar irrigation management practices by the farmers, independent of the spill characteristics from these laterals. In laterals of Set X, normalized spill ratio (NSR) was different in both laterals and years, but not significantly. The week-to-week variation in spill ratio was not significant, indicating that variation in outflows on a weekly basis was nullified while ignoring weekly inflow variations in this ratio. However, in laterals of Set Y, NSR was significantly different in both laterals, i.e., the proportion of weekly outflows to average weekly inflow for the season for these laterals was quite different.

Table 3 Analysis of Variance (ANOVA) of Abundance, Spill Ratio, and Spill from laterals of Set X.

a) **ABUNDANCE**

SOURCE	DF	MEAN SQUARE	F VALUE	Pr>F
YEAR	1	157.55		
LATERAL	1	414.94	0.02	0.8809
WEEKS	21	63537.03	3.48	0.0003
WEEKS*LATERAL	21	7650.72	0.42	0.9820
ERROR	40	18239.10		

b) **SPILL RATIO** (SR)

SOURCE	DF	MEAN SQUARE	F VALUE	Pr>F
YEAR	1	0.11		
LATERAL	1	1.34	25.4	0.0001
WEEKS	21	0.07	1.27	0.2509
WEEKS*LATERAL	21	0.04	0.84	0.6637
ERROR	40	0.05		

c) **SPILL**

SOURCE	DF	MEAN SQUARE	F VALUE	Pr>F
YEAR	1	0.71		
LATERAL	1	37099.0	304.8	0.0001
WEEKS	21	857.80	7.05	0.0001
WEEKS*LATERAL	21	248.43	2.04	0.0257
ERROR	40	121.68		

The spill ratio (SR) for the two laterals on Set X in observed years was significantly different due to temporal variability of inflows. However, there was little variation in spill ratio between the two laterals observed in Set Y. Weekly variation in normalized spill ratio (NSR) in laterals of Set Y resulted from temporal variation in spills. The volume of spill was a large proportion (about 50%) of the average inflow and varied significantly over the season in both laterals.

The temporal variation in spills resulted from the variation in inflow under the influence of changing crop water needs and rainfall, changing on-farm demands, and runoff resulting from rainstorms.

Table 4 Analysis of Variance (ANOVA) Of abundance, spill ratios (SR and NSR) and Spill from laterals of System Y.

a) ABUNDANCE

SOURCE	DF	MEAN SQUARE	F VALUE	Pr >F
YEAR	1	62932.1		
LATERAL	1	2623.8	2.50	0.1382
WEEK	21	41654.4	0.66	0.8176
WEEK*LATERAL	20	4551.8	2.04	0.0948
WEEK*YEAR	17	63051.8	14.92	0.0001
ERROR	13	4226.9		

b) SPILL RATIO (SR)

SOURCE	DF	MEAN SQUARE	F VALUE	Pr >F
YEAR	1	0.11		
LATERAL	1	0.48	3.45	0.0731
WEEK	21	0.13	0.97	0.5169
WEEK*LATERAL	20	0.12	0.88	0.6141
ERROR	30	0.14		

c) NORMALIZED SPILL RATIO (NSR)

SOURCE	DF	MEAN SQUARE	F VALUE	Pr >F
YEAR	1	0.08		
LATERAL	1	0.76	14.65	0.0006
WEEK	21	0.13	2.54	0.0097
WEEK*LATERAL	20	0.10	1.98	0.0436
ERROR	30	0.05		

d) SPILL

SOURCE	DF	MEAN SQUARE	F VALUE	Pr >F
YEAR	1	4561.3		
LATERAL	1	125111.3	32.48	0.0001
WEEK	21	8815.6	2.29	0.0187
WEEK*LATERAL	20	7411.7	1.19	0.0510
ERROR	30	3852.3		

In laterals of Set X, the temporal variation in abundance was significant and was mainly caused by the temporal variation in rainfall events. In the analysis of variance

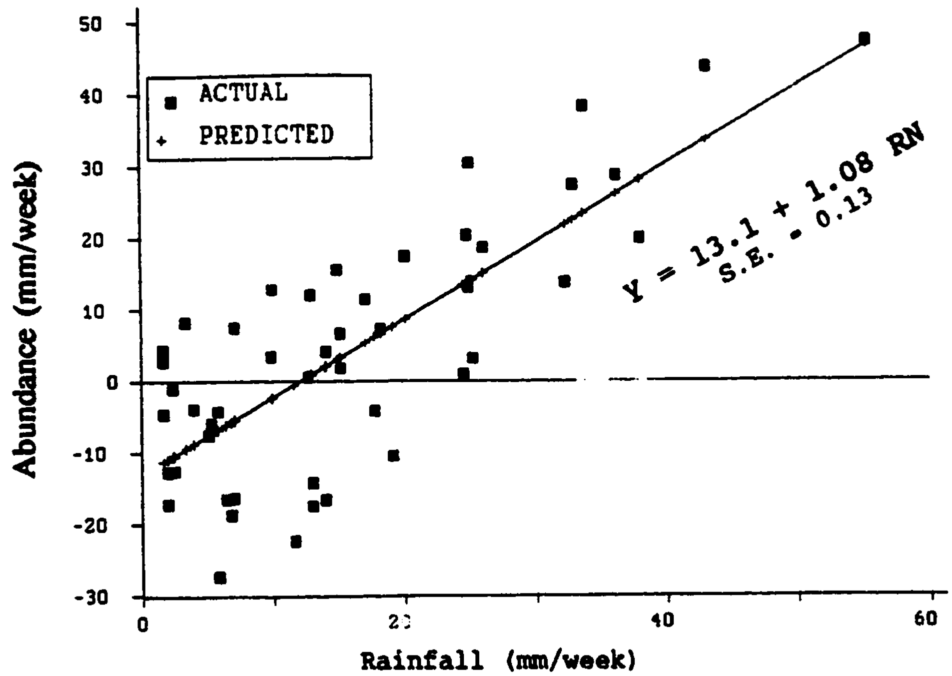

Figure 9 Regression of Abundance on Rainfall in the study Laterals for Set X.

(ANOVA) of Set Y, week-by-year interaction in abundance was significant. This was due to large temporal differences in precipitation amounts during the years 1990 and 1991.

Abundance was regressed against rainfall for Sets X and Y. The regression of abundance on rainfall computed for weekly rainfall greater than zero produced an R^2 =0.60 and 0.55, and standard errors of 0.13 and 0.12 for laterals of Sets X and Y respectively. Regression of abundance on rainfall for laterals of Set Y, on a yearly basis (not shown), indicated that abundance and rainfall were better related in 1991 (R^2 = 0.60, standard error = 0.151) than in 1990 (R^2 = 0.32, standard error = 0.294) due to the higher seasonal rainfall. Regression of abundance on rainfall for Set X laterals (Figure 9) shows that abundance increased 1.08 times with increase in rainfall.

Relationships of inflow and supply with respect to hypothetical demands were also established using regression analysis. The regression of inflow and supply on hypothetical demand was made considering all weeks (0-75 mm), weeks of no rainfall (0 mm), weeks of rainfall (1-75 mm) and for various rainfall ranges from one to seventy five mm per week in both Sets.

Table 5 R^2 values of Supply/Demand and Inflow/Demand relationships to rainfall in laterals of Set X 1989-1990.

Set X 1990-91	All Weeks	No Rain week	Weeks of Rain	1-10 mm/wk	10-20 mm/wk	20-30 mm/wk	30-75 mm/wk
Sup*Dem (All)	0.59	0.69	0.53	0.71	0.44	0.67	0.0
Lateral A	0.54	0.74	0.44	0.64	0.44	0.61	0.0
Lateral B	0.68	0.64	0.72	0.94	0.35	0.10	0.0
Year 1	0.56	0.79	0.49	0.85	0.64	0.98	0.0
Year 2	0.62	0.62	0.60	0.67	0.33	1.00	0.0
Inf*Dem (All)	0.59	0.62	0.54	0.74	0.44	0.61	0.0
Lateral A	0.52	0.73	0.45	0.63	0.43	0.63	0.0
Lateral B	0.64	0.60	0.71	0.98	0.40	0.18	0.0
Year 1	0.53	0.72	0.48	0.85	0.51	0.95	0.0
Year 2	0.60	0.54	0.62	0.69	0.39	1.00	0.0

NOTE: Sup, Dem and Inf refers to supply, hypothetical demand and inflow.

For various rainfall conditions showed that supply and inflow were correlated more closely to demand for the "no rainfall" weeks than the weeks receiving rainfall (Tables 5 and 6). Overall, Set X performed better than Set Y as the inflows and supplies were better correlated to the hypothetical demands.

Inflow and supply were better related to hypothetical demands during weeks receiving rainfall in the range of 1-10 mm/week than during the weeks of no rainfall. In fact this range of rainfall gave the best correlation of inflow and supply with hypothetical demands. As discussed earlier, this supports the contention that farmers in general under-irrigate. Thus, during the weeks of low rainfall ranging from 1-10 mm/week, supplies matched the reduced hypothetical demands more closely.

Table 6 Rainfall response to Supply/Demand and Inflow/Demand relationships in Set Y

Set Y 1990-91	All weeks	Weeks of No Rain	Weeks of Rain	1-10 mm/wk	10-20 mm/wk	20-30 mm/wk	30-75 mm/wk
Sup*Dem (All)	0.57	0.68	0.54	0.76	0.03	0.35	0.00
Lateral C	0.52	0.79	0.51	0.65	0.00	1.00	0.00
Lateral D	0.63	0.63	0.59	0.86	0.14	0.27	0.00
Year 3	0.67	0.79	0.68	0.90	0.34	0.73	0.00
Year 4	0.43	0.31	0.43	0.71	0.08	1.00	0.00
Inf*Dem	0.44	0.45	0.49	0.89	0.28	0.67	0.00
Lateral C	0.47	0.42	0.55	0.92	0.39	0.12	0.00
Lateral D	0.46	0.62	0.43	0.67	0.20	0.03	0.00
Year 3	0.57	0.55	0.69	0.93	0.37	0.24	0.0
Year 4	0.30	0.08	0.36	0.76	0.20	1.00	0.00

In the rainfall range of 10-20 mm/week, inflow and supply were poorly related to hypothetical demands. This was probably due to farmers continuing to irrigate after a precipitation event, thus being over-supplied, while those irrigators who planned to irrigate during those weeks postponed their irrigation dates, even if they had placed an order for water. Inflow and supply again were closely related with the demands during the weeks receiving rainfall in the range of 20-30 mm/week. Rainfall in this range was probably sufficient for farmers to shut down their irrigation pumps and inform the ditch rider about their decision to discontinue irrigating. In this rainfall range, water continued to flow into the laterals, but at a much reduced rate. This flow in the laterals was mainly to meet future demands with minimum delay.

As expected, there was no water demand during the weeks of very high rainfall (30-75 mm/week). In this rainfall range, inflows and supplies were not related to the zero hypothetical demands. Inflows during such weeks were much larger than the minimum flows. These weeks of higher than required inflows occurred more frequently in Set Y than X. It is the management policy in both Sets that a minimum flow be maintained in the lateral canals throughout the season as it takes two to three days to recharge them, depending upon their length and area serviced. Keeping the laterals charged meets farmer demand which may arise within a relatively short period of time, especially when a rainstorm is followed by high hypothetical demands.

In general, farmers of Set X, met the hypothetical demands better than the farmers of Set Y, especially during the weeks receiving rainfall in the range of 10 to 30 mm. Inflow management was also better in Set X than Set Y and more so during this rainfall range. Thus overall irrigation water management in meeting the hypothetical demands and in conserving water was better in Set X than in Set Y.

Regression analyses were also conducted to determine how inflows and supplies were related to the demands in individual laterals and years and for all conditions of rainfall described in the previous analysis (Tables 5 and 6 and Figures 10 and 11). Lateral B had the highest R^2 values for supply versus demands and inflow versus demands followed by Laterals A, D and C respectively. In general, supplies were better related to the demand during periods of no rainfall than during rainfall periods. The exception to this was Lateral B.

In both Sets, inflow was related better to the demands in laterals generating lower spills (Laterals A and D) than in laterals of higher spills (Laterals B and C). This was particularly true in the weeks of no rainfall, indicating that Laterals B and C spill considerable water in the weeks of no rain. The greater spills might have been in anticipation of large demands from farmers, and water managers may have attempted to conserve water during the weeks of rainfall by reducing inflows into the laterals.

Inflow and supplies in all these laterals are fairly strongly correlated with the demands during weeks receiving rainfall up to 10 mm, but these laterals behave quite differently in the weeks of high rainfall (10-30 mm). In this rainfall range, both inflow

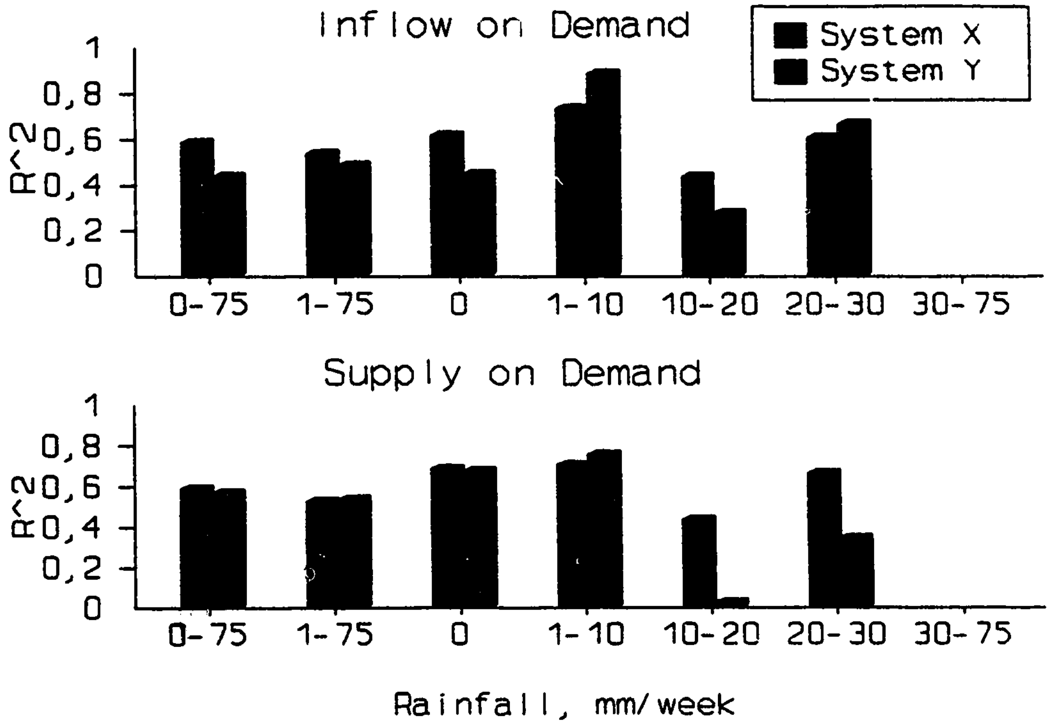

Figure 10 Regression of Inflow and Supply on Demand for laterals of System X and Y

and supply were best correlated to demands in the case of Lateral A followed closely by Lateral B. The correlation of these variables in Laterals C and D was poor.

In the yearly analysis of inflow, supply relationship with the hypothetical demands, 1990 has been referred to as year 2 in Set X and 3 in Set Y, to differentiate the two Sets. Inflow and supply were better related to the demands in 1990, next best in 1989, and the worst year was 1991 in achieving the above relationship (Tables 5 and 6). In 1989 and 1990 (years 1,2 and 3), supplies during the weeks of no rainfall met the demands better than in 1991 (year 4). In all the years, inflow and supply were best correlated during the weeks receiving rainfall in the range of 1-10 mm/week.

Inflow and supply met the demands better in 1989 and 1990 than in 1991 in the rainfall range of 10-20 mm/week. All these years behaved the same during very high rainfall events (> 30 mm/week), where there was no relationship of inflows and supplies with the hypothetical demands.

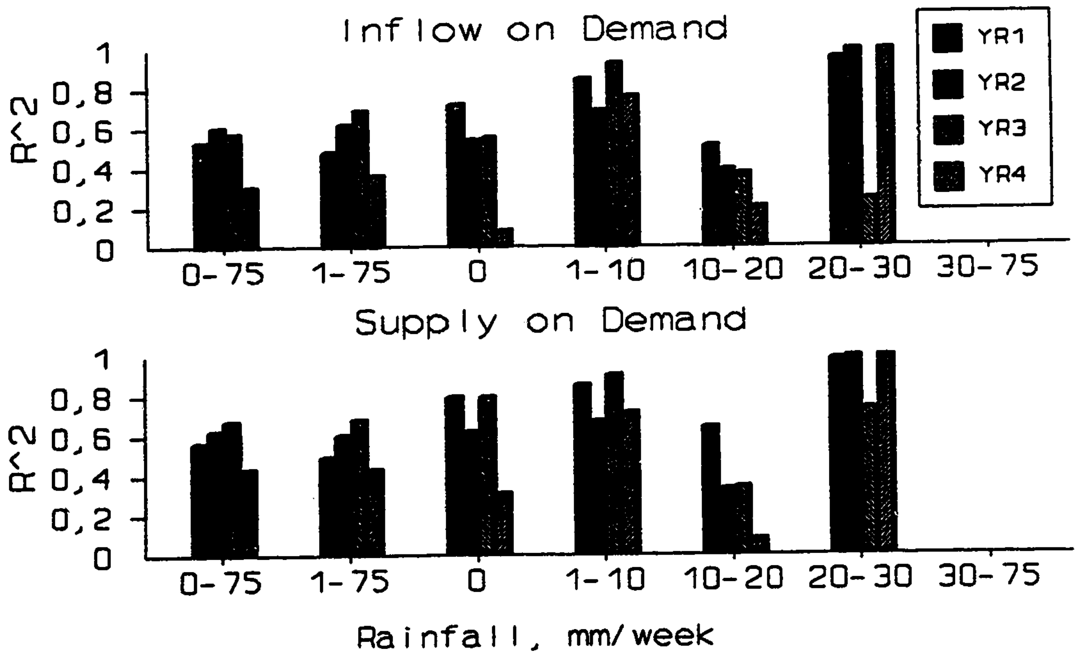

Figure 11 Regression of Inflow and Supply on Demand Versus Rainfall for laterals of Systems X and Y (Yearly Basis)

Inflow and supply were not correlated with demands in the very large weekly rainfall range (30-75 mm). This indicates that most of the water released into the laterals was spilled because the demands were theoretically zero at those times. Generally during such weeks, a minimum inflow has to be maintained so that whenever a farmer's need for water arises, it could be met adequately and reliably. However, inflows observed during such weeks were larger than minimum (see Table 7). The deviation of inflows from supplies was larger in Laterals C and D of Set Y than in the Laterals A and B of Set X during the weeks of very large rainfall events (>30 mm). This may then indicate that a large quantity of water was spilled from laterals of Set Y and the system management during such weeks was extremely poor in conserving water when demands were practically zero.

Further analysis was used to investigate whether supplies were better correlated to hypothetical demands (using simple regression) or if they were better related to its components, evapotranspirational requirements of the crop mix (ET) and rainfall (RN)

Table 7 Inflow, supply, and hypothetical demands in all laterals for all years of the study during high rainfall weeks (>30 mm/week) for Sets X and Y.

Lateral	Year	Week	Rain mm/week	Inflow mm/week	Supply mm/week	Demand mm/week
A	1989	5	33.0	16.4	13.9	0.0
A	1989	17	33.8	17.6	13.9	0.0
A	1990	5	32.4	4.1	2.8	0.0
A	1990	4	55.3	10.8	9.4	0.0
B	1989	4	43.2	18.8	10.9	0.0
B	1989	6	38.1	15.6	8.7	0.0
B	1989	17	36.3	10.7	2.7	0.0
C	1991	8	70.1	40.7	6.5	0.0
C	1991	9	64.0	26.7	0.0	0.0
D	1991	2	41.0	10.1	.28	0.0
D	1991	8	70.1	24.9	8.3	0.0
D	1991	9	64	28.5	0.0	0.0

Note: Week 1 refers to May 1-8

(using multiple regression). The three conditions considered were; all weeks (0-75 mm/week), weeks of rainfall (1-75 mm/week), and the weeks of no rainfall (0 mm/week). The R^2 values obtained under these conditions are tabulated in Table 8. Supplies were better related to the demands than to ET and RN. An exception to this was year 1 (1989), where supplies were better related to ET and RN than to demands. It is also observed that like simple regression of supply on demand, supplies were better related to ET and RN during the weeks of no rainfall than during the weeks of rainfall. A similar comparison of inflow with demand and its components ET and rain (RN), indicated that inflows were related better to the demands than to ET and rain (RN) combined, excepting year 1 and Lateral D. The R^2 values obtained under the same set of conditions are presented in Table 9.

Table 8 Comparison of Supply on Demand versus Supply on ET and Rain using R^2

SUPPLY ON DEMAND				SUPPLY ON ET AND RAIN		
	ALL WEEKS	WEEKS OF RAIN	NO RAIN WEEKS	ALL WEEKS	WEEKS OF RAIN	NO RAIN WEEKS
All data	0.58	0.53	0.67	0.44	0.30	0.63
Lateral A	0.54	0.44	0.74	0.51	0.33	0.70
Lateral B	0.68	0.72	0.64	0.56	0.55	0.56
Lateral C	0.52	0.51	0.79	0.33	0.21	0.75
Lateral D	0.63	0.59	0.63	0.45	0.34	0.60
Year1 (1989)	0.57	0.49	0.79	0.69	0.55	0.84
Year2 (1990)	0.62	0.60	0.62	0.45	0.31	0.51
Year3 (1990)	0.66	0.68	0.79	0.65	0.63	0.72
Year4 (1991)	0.43	0.43	0.32	0.17	0.13	0.32

For each rainfall condition, the nine R^2 values of supply on demand were compared with the nine R^2 values of supply on ET and rain (RN) as given in Table 8. Similarly, for the same rainfall conditions, the nine R^2 values of inflow on demand were compared with the nine R^2 values of inflow on ET and rain (RN), as given in Table 9. These comparisons were computed using ANOVA to determine whether the R^2 values obtained in simple and multiple regression were significantly different. The results of the comparison of R^2 values in the relationship of supplies and inflow with demand and its components ET and RN as obtained from the 't'-test are tabulated in Tables 10, for all the three conditions of the experiment. A probability level of 0.05 was considered significant for this test. Results clearly indicate that R^2 values obtained from the regression of supplies on demands were significantly different from the regression of supplies on ET and Rainfall for all the three conditions. This would indicate that the irrigator's management decision benefits from the rainfall in estimating the net water

Table 9. Comparison of Inflow on Demand versus Inflow on ET and Rain using R^2

	INFLOW ON DEMAND			INFLOW ON ET AND RAIN		
	ALL WEEKS	WEEKS OF RAIN	NO RAIN WEEKS	ALL WEEKS	WEEKS OF RAIN	NO RAIN WEEKS
All data	0.47	0.47	0.52	0.42	0.36	0.49
Lateral A	0.52	0.45	0.73	0.51	0.33	0.69
Lateral B	0.64	0.71	0.60	0.53	0.53	0.53
Lateral C	0.47	0.55	0.42	0.19	0.11	0.39
Lateral D	0.46	0.43	0.62	0.63	0.61	0.66
Year 1	0.53	0.48	0.72	0.69	0.59	0.79
Year 2	0.60	0.62	0.54	0.42	0.31	0.44
Year 3	0.57	0.69	0.55	0.55	0.61	0.53
Year 4	0.30	0.36	0.08	0.11	0.16	0.00

Table 10 Comparison of R^2 values under Simple and Multiple Regression using Paired Comparison 'T'- Test.

	Supply and Demand Versus Supply on ET and Rain			Inflow and Demand Versus Inflow on ET and Rain		
	S.E.	T	Pr>|T|	S.E.	T	Pr>|T|
All Weeks	0.039	2.82	0.023	0.051	1.11	0.299
Weeks of Rain	0.042	4.33	0.003	0.064	2.00	0.080
No Rain Weeks	0.016	2.59	0.032	0.018	1.58	0.153

requirement (Demand), while irrigating their crops.

On the contrary, R^2 values obtained from the regression of inflow on demand were not significantly different from the R^2 values obtained from the regression of inflow on ET and rain. A non-significant difference in the R^2 values would indicate that the ditch riders are not fully conserving water in the event of rainfall, i.e, the inflows are not reduced in proportion to the demands, which are largely affected by rains.

4.4 Secondary Data

4.4.1 Farmer, Waterbook and On-Off observations

This section presents the results of the analysis of farmer, ditch rider, and on-off records to check the accuracy of the ditch rider's record on water deliveries to individual farmers; and confirm the results of farmer interviews. An understanding of the actual operation of on-farm irrigation systems and their management will provide an insight on the performance of delivery systems serving individual farm turnouts.

4.4.1.1 Comparison of waterbook records, farmer's record and observations

A comparison of farmer, ditch rider and on-off records is presented in Appendix B. The on-off observations recorded are presented in these tables for irrigation dates (July 31 - August 7 for Lateral C and August 2 - 7, 1991 for Lateral D) to verify the farmer and waterbook records.

The observed on-off records matched the farmer's records, indicating that farmer records were fairly accurate and reliable. A comparison of farmer records with waterbook records indicated that only five irrigation dates mentioned in the waterbook matched out of the 18 dates reported by the farmers of Lateral C within plus or minus 4 days of accuracy. It may be noted that not even one irrigation period from farmer records matched exactly with the ditch riders' record. On the contrary, 22 irrigation dates from waterbook records matched the 33 irrigation dates reported by the farmers served by Lateral D. The waterbook record was not available for four turnout gates (9 irrigation dates). The above comparisons would indicate that farmers on Laterals C and D accurately recorded the irrigation dates and that the ditch rider on Lateral D maintained a much better record of water deliveries in waterbook than the ditch rider managing Lateral C.

The waterbook record was also compared against the on-off observations for the entire length of these laterals. The period of comparison was July 31 - August 7, 1991 for Lateral C and August 2 - 7, 1991 for Lateral D. The on-off record was obtained for 29 turnout gates from Lateral C and 52 turnout gates from Lateral D. The on-off record indicated that 23 turnouts operated out of 29, ranging from 1 to 8 days for Lateral C during the period of observation. However, the ditch rider record reported only 3 turnout gates operating during the same period for Lateral D. Lateral D, the waterbook record reported 16 turnout gates operating out of 24 observed during field visits.

The on-record comparisons thus clearly indicated that the waterbook was well maintained by the ditch rider of Lateral D, but that Waterbook records of Lateral C were very unreliable. Thus, it may be concluded that waterbook records may not be a reliable source of information with which to assess performance.

4.4.2 Farmer Interviews

The farmer is key to understanding management performance (Dedrick et al., 1991). All 18 farmers interviewed (8 on Lateral C and 10 on Lateral D) managed the on-farm irrigation systems themselves. One farmer had rented out some land and two of the farmers have been renting land for the past several years. The results of farmer interviews are summarized with the questionnaire in Appendix B.

Farmers decide independently when a crop needs to be irrigated. The irrigation management decision is based on certain criteria. Theoretically such a decision is based on the estimation of soil moisture depletion by the growing crop, but this information is rarely gathered by farmers as seen in recent related studies (Dedrick et al., 1991 and McCornick, 1991). Within this study area, the actual decision to irrigate is based on soil moisture estimation by hand feel, looking at soil cracks, crop colour, and, above all the farmer's own past experience. All eighteen farmers interviewed reported that soil moisture content is estimated either by looking at soil cracks, or by digging the soil with a shovel up to a depth of 150 to 250 mm. Two farmers reported using an auger, relating soil moisture to crop water requirements according to crop growth stage. Only one farmer used the services of the local irrigation specialist from Alberta Agriculture to schedule irrigations for his potato crop.

Since haying operations are critical, most farmers schedule their irrigations based on cutting or bailing dates for this crop. Only one farmer reported using measured soil water depletion to schedule the next irrigation. It may be concluded that the methods/criterion used to schedule irrigation are inadequate to achieve maximum yields. Six farmers said that they use fall irrigation as a water management practice, while seven mentioned that they fall irrigated depending on the quantity of rain that year. Only five farmers expressed an unwillingness to fall irrigate.

Determining the depth of water to be applied per irrigation event is another important aspect in irrigation management. Almost all irrigators were not sure of how much water they were applying within plus or minus half an inch (12.5 mm), but had an approximate idea. The majority of irrigators estimated the depth to be about 75 mm (3 inches), four were applying between 25 - 50 mm (1 - 2 inches), one applying heavy irrigations of about 150 mm (6 inches) and three irrigators responded that they irrigate until they are convinced the soil moisture level is adequate. Farmers expressed an understanding about variable crop water requirements during the season and requirement variations from one crop to another.

Theoretically, irrigators need to evaluate the success of their irrigation by determining if the applied depth meets their set target depth. Only two out of eighteen farmers monitor the amount of water applied. Other farmers estimate the depth by the set time (time required to apply a set, in the case of side rolls), hours/circle (time required to complete a circle, in the case of centre pivots). Those two farmers, both on Lateral D, use a rain gauge placed above the crop canopy. This was not done on a regular basis, but was used occasionally. Thus, information about performance of each unit during an irrigation event could not be established.

Most of the on-farm irrigation systems on the observed laterals are either pivots, with or without a corner system, and side rolls except for a parcel of 28 ha under gravity irrigation. A dugout pond to buffer inflows has been constructed by all farmers. The dugouts vary in size, but sit beside the lateral and are connected through a pipe culvert, making the installation of a measuring device at the inlet end of the turnout impossible. To assess the performance of selected irrigation units, it was important to establish an average flow capacity of the pumps so that spatial and temporal variability among different units can be established.

Farmers were asked about their pump capacities, number of sets per day, set time in case of side rolls and hours/circle in case of pivots. Five of the irrigators had no idea about their pump capacity, while the other thirteen quoted standard figures based on length of wheel line, number of nozzles and nozzle sizes. In case of pivots, flow capacities varied with the type of systems, i.e., the presence or absence of the corner system. Flow rate figures thus obtained, varied from as low as 0.044 cumecs (700 gpm) to a maximum of 0.114 cumecs (1800 gpm) in case of side rolls. This flow rate depended on whether one or two pumps were running, length of wheel line and number of nozzles/line. In the case of pivots, the discharge quoted ranged from 0.07 - 0.095 cumecs (1100 - 1500 gpm), depending on whether the system had a corner unit.

In general, irrigators were aware that nozzles wear out with time and standard discharge values could vary as a result. Farmers reported that they replace old nozzles from time to time upon seeing indication of deterioration.

The normal set time by farmers is 7 - 7.5 hours. This they commonly term as an 8-hour set, making 3 sets/day the norm for side rolls. Irrigators on an average take approx. 0.5 - 1 hour to move their lines to the next setting. Thus, a pump remains off for approx. 1.5 - 3.0 hours a day, provided there are no failures due to power fluctuations and other break-downs. Farmers also spend approx. 12 - 24 hours draining and fixing their pipes before the start of their first irrigation. In the case of pivots, one circle is completed in 1 - 3 days. The time varies depending on the depth of water to apply to meet perceived crop demands.

Although the turnout gates remain open and the water level of dugout ponds is the same as that of the lateral, farmers are supposed to request water from the ditch rider. The official policy is that farmers make this request two days in advance and provide at least a day's notice before turning off their pumps. Most of the farmers reported that they make such a request a day or two in advance and have no problems in receiving water. Occasional request made with less than 24 hours notice are usually accepted. All but three farmers reported that they inform the ditch rider 24 hours in advance before switching off their pumps. Two irrigators informed him between 12 - 24 hours and one irrigator does not inform him as it does not cause any spill on his farm. At a personal level 3 - 4 farmers stated that sometimes they inform the ditch rider after completing their irrigation.

Farmers expressed that they were quite content with the deliveries made at their turnouts and thus with the management of the irrigation system. However, six out of eighteen irrigators stated fluctuating flow rates affected their water applications once or twice during the crop season. Two of these were at the tail end of the laterals. One tail end farmer stated that his problem was too much water on occasion. This occurred mainly when a large number of farmers stopped irrigating on the same day due to completion of their irrigation or because a large rainfall event (exceeding 50 mm) occurred. Others having problems with canal fluctuations included farmers whose pumps run on water supplies fed by a farm channel, two farmers on a pipeline section, and one on an earth section of lateral.

Farmer interviews helped identify reasons for underirrigation as observed in seasonal, graphical and statistical analysis. Results of farmer interview clearly demonstrated that farmer management-decisions for irrigation scheduling are entirely based on their farming experience. Thus, the timing and quantity of applied of water applied was not decided using theoretical principles. Farmers are not aware of their pump capacities and their decision to change the nozzles is based on observation. Farmers also believe that the operating cost in irrigation is quite high and they prefer taking some risks by depending on expected rainfall.

Interviews also provided information relating to the high spills in laterals of Set Y. The occasional requests made by the farmers to irrigate with less than 24 hours notice and accepted by the ditch riders would suggest that the open system carried more inflow than was requested by the irrigators. The reasons for temporal fluctuation in spill were that not all farmers report the completion of irrigation one day in advance and farmers with side rolls spend 1.5 - 3.0 h in changing sets, during which water flowing in the canals is not utilized. Another reason for high spills and temporal variation is large number of farmers switching off irrigation pumps on the same day on completion of their irrigation or in an event of a large rainfall (> 50 mm).

5. SUMMARY AND CONCLUSIONS

Water applied by farmers in all laterals and years was less than or equal to that hypothetically required for maximum yields, especially as application and conveyance losses were not considered. Thus crops were under-irrigated, even when inflow provided in the laterals was sufficiently large to meet hypothetical demands, suggesting need for improved water control in all laterals.

Substantial spills (over 40 % in the case of laterals with Set Y), suggested a great potential for water conservation, although charging of reservoirs to feed other laterals contributed to their spill values. This indicates that spill as an indicator of performance should be used with caution. Spills and spill ratios from these laterals were significantly different in the observed years, implying that the proportion of weekly spills to weekly inflow and to average weekly inflow for the season was different in all laterals. Average spill ratios (SR and NSR) from Laterals C and D were different. Different spill ratios (SR and NSR) in all laterals are expected because of differences in irrigated areas served, temporal and spatial variability in precipitation, training and expertise of ditch riders, types of on-farm irrigation systems, crop diversification etc. Analysis of variance suggested that spill characteristics of these laterals are different, yet their net water use characteristics remain similar. Further work with more years of data is required to establish performance standards.

Rainfall played an important role in the irrigation water management in all the four lateral canals considered in the study. Supplies exceeded demands only in weeks where rainfall exceeded approx. 15 mm or during the last 2-3 weeks of the season. Temporal variation in abundance (supply minus hypothetical demand) was attributed largely to the variation in rainfall amount and time. There was a fairly strong relationship between abundance and rainfall, which were better related in 1991 than in 1990 due to higher seasonal rainfall in 1991.

Although inflow diverted into laterals was less in the weeks of rainfall, irrigation water deliveries met the demands better during no-rainfall weeks than during weeks of high rainfall. Supply and inflow were better related to hypothetical demands during the weeks with no rainfall rather than during the weeks with rainfall. The best relation of supply and inflow on demand was observed during the weeks receiving rainfall in the range of 1-10 mm. During the weeks of very high rainfall (30-75 mm), the hypothetical demands were theoretically zero and were not correlated to inflow and supply in all laterals. Inflows during such weeks were larger than the minimum operational flows, resulting in large spills relating to poor water conservation. Set Y had very large inflows during rainy weeks, particularly in the year of very high rainfall, 1991. Overall, the irrigation water management was better in Set X than in Set Y, in respect to supply meeting hypothetical demands and in achieving water conservation. Poor irrigation water management in laterals of Set Y was caused by large spills from Lateral C into a reservoir, which feeds other laterals; the size of Lateral D is twice the size of other study laterals and in the year of very high rainfall, 1991, a lot of water was spilled to keep the reservoir levels from getting too high.

Lateral-wise regression analysis, an indicator of relative performance in various laterals, indicated that inflows and supplies were best related to the hypothetical demands in Lateral B, followed by Laterals A, D and C in decending order. In both Sets, inflows were better related to demands in laterals generating lower spills (Laterals A and D) than in laterals of higher spills (Laterals B and C) particularly in the weeks of no rainfall. This implies that Laterals B and C are charged with an excess amount of water during the weeks of no rainfall, perhaps in anticipation of higher demands from farmers. The relationship of inflow and supply to the hypothetical demands was fairly strong during the weeks receiving rainfall up to 10 mm in all these laterals, but all laterals performed differently during the weeks of high rainfall (10-30 mm). In this higher rainfall range, Lateral A performed the best in conserving water followed closely by Lateral B, whereas Lateral C and D performed poorly. During the weeks of very high rainfall (30-75 mm), crop demands on the irrigation system were theoretically zero, and inflow and supply had no relationship with demand. Inflows during such weeks were much larger in the laterals of Set Y than in the laterals of Set X, resulting in extremely high spills and thus, poor water conservation in laterals of Set Y.

Both supplies and inflows were better related to hypothetical demands than to evapotranspirational demands (ET) and rainfall (RN). R^2 values obtained from the regression of supply on demand were significantly different from those obtained by regressing supply on ET and RN, indicating that management decisions by irrigators were based on demands and not ET and RN separately.

R^2 values obtained from the regression of inflow on demand were higher than those obtained from the multiple regressions on ET and RN in most laterals and years, but were not significant at 0.05 level of significance. This indicates that ditch riders are not effectively conserving water in the event of rainfall, i.e., inflows were not reduced in proportion to weekly demands as affected by rainfall.

The on-record comparisons clearly indicated that the waterbook was well maintained by the ditch rider of Lateral D, but that waterbook records of Lateral C were unreliable. Thus waterbook records may not be reliable sources for actual irrigation dates and, therefore, would be misleading if used to assess irrigation performance at the farm level.

Personal interviews with farmers helped identify reasons for underirrigation and variations in spills in these laterals as observed through the seasonal, graphical and statistical analyses. Interviews provided an insight into farmer decision-making especially related to the timing and quantity of irrigation water applied. Farmers did not use a quantitative approach to decision-making. Farmer historical experience was the key criterion in making most of these decisions. Though official policies have been formulated regarding the start and stopping of deliveries at these turnouts, some level of flexibility exists between the farmers and the ditch riders. lateral rehabilitation has largely mitigated the effects of canal fluctuations on water applications on-farm. Farmer concerns of the high cost of irrigation, their lack of knowlege about irrigation scheduling, and maintainence of their on-farm irrigation systems resulted in underirrigation. Factors causing high spills included large inflows, switching off irrigation pumps while changing irrigation sets (in case of side rolls), the draining of pipelines at the start of the season, power failures and tardiness of some farmers in informing ditch riders about irrigation pumps being switched off.

6. RECOMMENDATIONS FOR FUTURE WORK

Based on this study, there are several recommendations for further research and extension:

- Agencies like Alberta Agriculture should monitor the same laterals for more years and must analyse the data in order to, among other things, further document the role of rainfall on irrigation water management. Targets or standards with expected variation must be established so that the operating staff could aim to achieve them. Continued monitoring will be needed to determine whether target values are being met.
- Performance of other lateral canals in various irrigation districts having a variety of technical and climatological conditions should be studied using similar statistical analyses to assess and compare the existing performance levels.
- To evaluate the spatial and temporal variability of irrigation deliveries at the farm level, ditch riders must keep an accurate record of irrigation deliveries (days with time of start and stop of deliveries), type of on-farm irrigation systems (to estimate time lost in changing irrigation sets) and time information related to system failure. A technique similar to the one used in this study to assess the water-book records could be effectively used by management on an on-going basis.
- Through improved extension services, farmers must be made aware of quantitative water management concepts and procedures. Farmers increased understanding of quantitative water management concepts would help them to select moisture stress levels for different crops at different crop growth stages and thus save operating costs in irrigation, without sacrificing the crop productivity.
- Upgrade the skills of ditch riders for improved water control and water conservation. Ditch riders must divert inflows in laterals according to the farmers demand.

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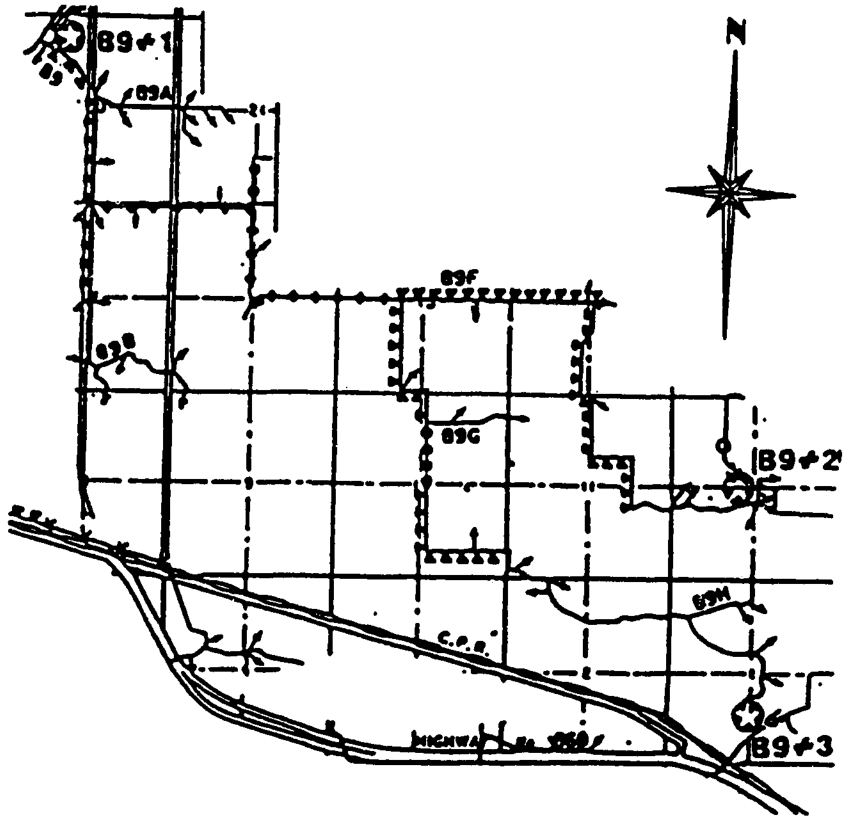
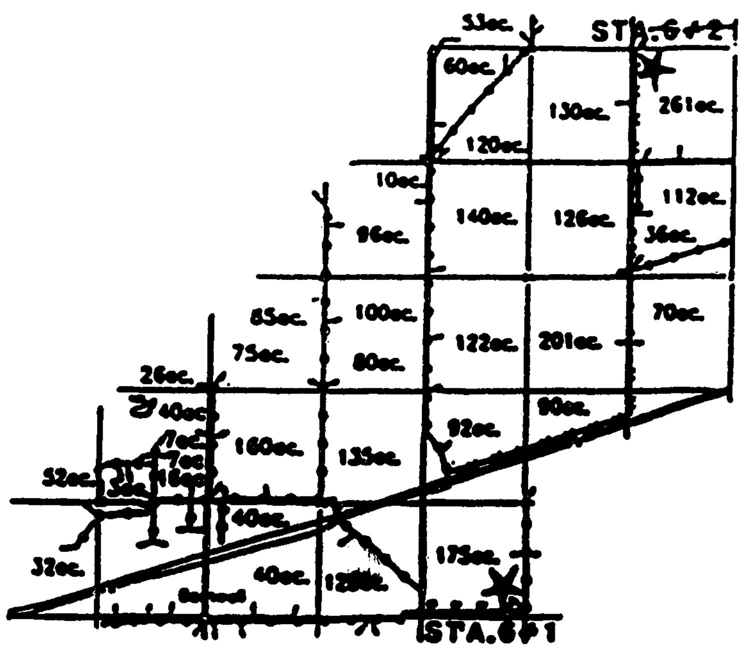
8. APPENDICES

APPENDIX - A : Schematics of Laterals A, B, C and D

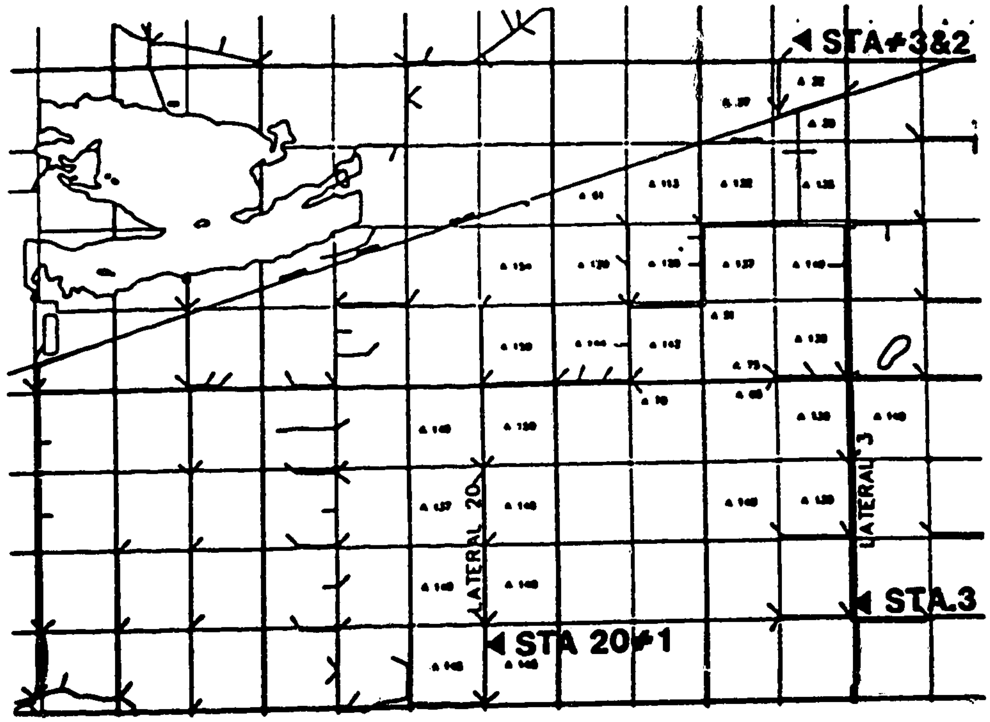
Lateral A



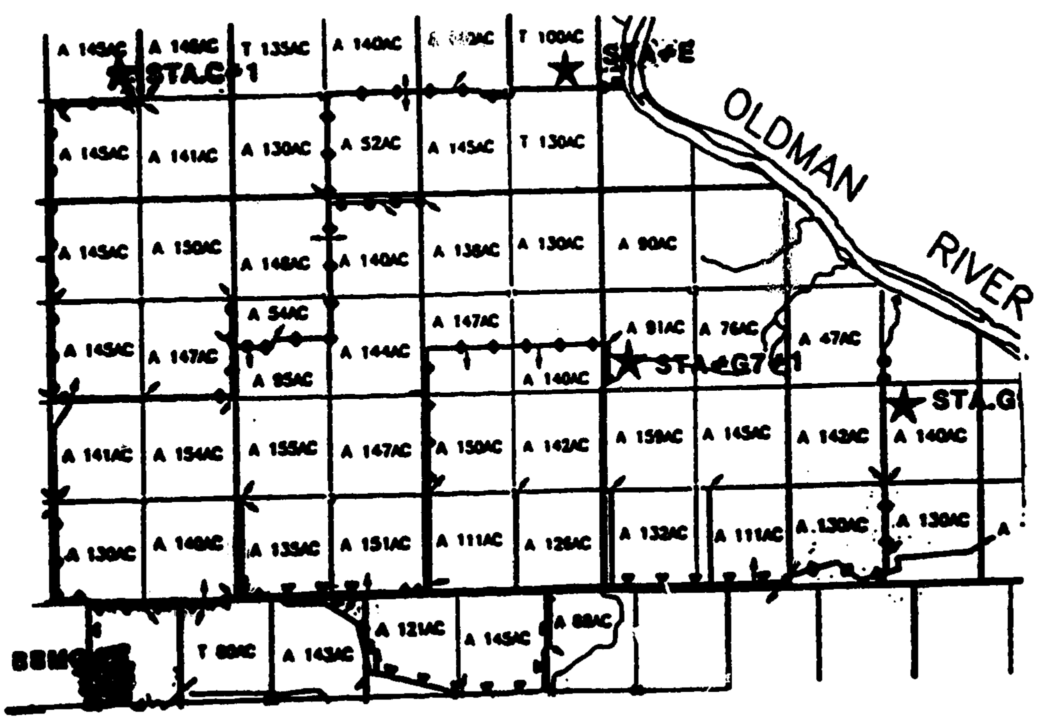
Lateral B



Schematics of Lateral A and B



LATERAL C



LATERAL D

APPENDIX - B: Questionnaire

Results of Irrigation Water Management Questionnaire in Southern Alberta

1. How do you decide when a crop needs to be irrigated?

   Soil 16 Crop 9 Experience 7 Time of Season 8

   ET curve 1

2. How much water do you put on per irrigation set?

   1.0 - 2.0" 4 2.0 - 3.5" 10 > 3.5" 1 Until convinced 3

3. How do you determine this?

   Rain gauge 2 No idea 16

4. Is your set - time or time/circle fixed or does it vary?

   Side rolls: Fixed 10 Vary 5 Pivots: Fixed 4 Vary 2

5. How many sets do you make per day in case of side rolls?

   2 Sets 2 3 Sets 8 Varies (Between 2, 3 and 4) 5

6. Do you know approximately your pump capacity?

   Yes 13 No 5

7. Do you normally fall irrigate?

   Yes 6 No 5 Sometimes 7

8. How long do you normally wait for water after ordering?

   1 - 2 days 18 > 2 days Nil

9. How much in advance do you inform about your decision to turn off your pump?

   24 hrs. 15 12 - 24 hrs. 2 Never 1

10. Do canal flow fluctuations cause you problems?

    Sometimes 6 Never 12

11. Do you stop irrigating if it rains suddenly?

    Yes 15 (If rain > 2.0") No 3

APPENDIX - C: Farmer, Ditch rider and On-Off Record for Laterals C and D

Comparison of irrigation dates recorded in farmer, ditch rider and ON records in Lateral C

Gate #'s	Farmer's record	Total Time (h)	Pump ON Time (h)	Down Time (h)	Waterbook Record	ON Observations
1	May 22-27	129.0	93.5	35.5	May 21-27	
1	July 23-28	135.5	124.5	11.0	July 8-18	
2	June 13-24	93.5	80.5	13.0	June 9-18	
2	July 23-Aug. 5	368.0	327.0	41.0	Aug. 5-10	July 31-Aug. 6
3	June 4-12	208.0	182.0	26.0	May 28-June 11	
3	July 24-27	82.0	56.0	26.0	July 10-15	
4	June 17-21	114.5	100.0	14.5	No Record	
5	May 21-June 2	287.0	257.5	29.5	No Record	
5	July 22-Aug. 2	275.0	252.0	23.0	June 4-10	July 31-Aug. 2
6	June 1-10	216.0	189.0	27.0	July 8-14	
6	June 16-21	120.0	105.0	15.0	No Record	
7	May 28-June 1	89.0	89.0	0.0	May 22-26	
7	July 19-21	46.0	46.0	0.0	July 15-19	
7	July 23-25	39.0	39.0	0.0	July 20-25	
8	July 26-Aug. 7	237.0	207.5	29.5	July 23-Aug.2	July 31-Aug. 6

Comparison of Water book records with ON-OFF observations in Lateral C

Gate #'s	ON RECORD	OFF RECORD	WATER BOOK ON RECORD
1	July 31-Aug. 6	Aug. 7	Aug. 5-10
2	July 31-Aug. 6	Aug. 7	July 23-Aug. 2
3	Aug. 6	July 31-Aug. 5 and 7	No Record
4	Aug. 6-7	July 31-Aug. 5	No Record
5	July 31-Aug. 1 and 3	Aug. 2 and 4-7	No Record
6	July 31-Aug. 1	Aug. 2-7	No Record
7	Aug. 6-7	July 31-4	Aug. 5-7
8	July 31-Aug. 3	Aug. 4-7	July 29-Aug. 2 and 5-9
9	July 31-Aug. 3	Aug. 4-7	No Record
10	Aug. 2-3	July 31-Aug. 1 and 4-7	No Record
11	July 31-Aug. 3	Aug. 4-7	No Record
12		July 31-Aug. 7	No Record
13		July 31-Aug. 7	No Record
14	July 31-Aug. 31		No Record
15	July 31-Aug. 2 and 4-6	Aug. 3 and 6-7	No Record
16	July 31-Aug. 7		Missing
17	July 31-Aug. 2	Aug. 3-7	No Record
18	Aug. 2	July 31-Aug. 1 and 3-7	No Record
19	Aug. 1	July 31 and Aug. 2-7	Missing
20		July 31-Aug. 7	No Record
21		July 31-Aug. 7	Aug.3-4
22	Aug. 2 and 5	July 31-Aug. 1,3,4,6 and 7	No Record
23	July 31 and Aug. 1	Aug. 2-7	No Record
24		July 31-Aug. 7	No Record
25	July 31-Aug. 2	Aug. 3-7	No Record
26	July 31-Aug. 3 and 7	Aug. 4-6	No Record
27	Aug. 5	July 31-Aug. 4 and 6-7	No Record
28	July 31-Aug. 1 and 3-7	Aug. 2	No Record
29	July 31-Aug. 3	Aug. 4-7	No Record

Comparison of irrigation dates recorded in farmer, ditch rider and ON records in Lateral D

Gate #'s	Farmer's Record	Total Time (h)	Pump ON Time (h)	Down Time (h)	Waterbook Record	ON Record
1	June 5-7	49.0	49.0	0.0	June 5-7	
1	June 9-14	137.0	71.0	66.0	June 10-17	
1	July 16-18	43.0	43.0	0.0	July 16-18	
2	June 5-9	120.0	112.0	8.0	June 5-10	
2	July 16-18	48.0	48.0	0.0	July 16-18	
3	June 5-14	224.0	224.0	0.0	June 5-14	
3	July 16-18	50.0	50.0	0.0	July 16-18	
4	July 18-21	130.0	130.0	0.0	July 18-24	
5	July 18-22	98.0	98.0	0.0	July 18-23	
6	July 18-22	98.0	98.0	0.0	July 18-23	
7	July 18-23	119.0	119.0	0.0	July 18-23	
8	June 6-10	108.0	98.0	10.0	No Record	
8	June 13	24.0	13.0	11.0	June 10-17	
8	July 23-27	100.0	96.0	4.0	July 24-27	
9	June 10-17	167.0	95.0	72.0	June 13-23	
9	July 10-11	23.0	23.0	0.0	No Record	
9	July 14-15	11.0	11.0	0.0	No Record	
9	July 17-19	72.0	55.5	16.5	No Record	
9	July 24-26	50.0	50.0	0.0	July 23-27	
9	July 30-Aug. 2	47.0	46.0	1.0	No Record	Aug. 2
10	July 16-20	80.0	71.0	9.0	July 16-20	
11	May 23-24	27.5	25.5	2.0	May 23-25	
11	July 19-Aug. 3	364.0	363.0	1.0	July 20-Aug. 3	Aug. 2-3
12	June 10-17	184.0	161.0	23.0	No Record	
13	May 31-June2	72.0	54.0	18.0	No Record	
13	July 18-Aug. 3	408.0	390.0	18.0	July 17-Aug. 3	Aug. 2-3
14	June 10-16	168.0	154.0	14.0	Missing	
14	July 7-13	168.0	150.0	18.0	Missing	
14	July 24-25	48.0	26.0	22.0	Missing	

15	June 10-16	168.0	156.0	12.0	June 14-21	
15	July 7-13	168.0	151.0	17.0	No Record	
15	July 24-26	72.0	47.0	25.0	No Record	
16	June 10-14	120.0	101.0	19.0	June 10-12	
16	July 7-13	168.0	147.0	21.0	No Record	
16	July 17-24	192.0	179.0	13.0	June 17-24	
16	July 29-Aug. 2	120.0	104.0	16.0	July 24-28	Aug. 2
17	June 10-15	120.0	120.0	0.0	Missing	
17	July 19-21	72.0	49.5	22.5	Missing	
17	July 27-Aug. 2	168.0	138.0	30.0	Missing	
18	July 25-Aug. 6	292.0	273.5	18.5	Missing	
19	July 25-Aug. 3	184.0	166.5	17.5	Missing	

Comparison of Water book records with ON-OFF observations in Lateral D

TURNOUT GATE #	ON RECORD	OFF RECORD	WATER BOOK ON RECORD
1	Aug. 2-3 and 5-6	Aug. 4 and 7	No Record
2	Aug. 2-7		No Record
3	Aug. 2	Aug. 3-7	No Record
4	Aug. 2	Aug. 3-7	July 31-Aug. 3
5	Aug. 2-3	Aug. 4-6	July 20-Aug. 3
6		Aug. 2-7	Aug. 7-11
7	Aug. 3	Aug. 2 and 4-7	July 31-Aug. 3
8	Aug. 2-3	Aug. 4-7	July 31-Aug. 3
9	Aug. 2-3	Aug. 4-7	July 28-Aug. 3
10		Aug. 2-7	No Record
11	Aug. 2	Aug. 3-7	July 29-Aug. 3
12		Aug. 2-7	July 25-Aug. 1
13	Aug. 2-7		July 30-Aug. 8
14		Aug. 2-7	July 22-Aug. 2
15	Aug. 6-7	Aug. 2-5	July 30-Aug. 2 and 6-10
16		Aug. 2-7	No Record
17		Aug. 2-7	July 30-Aug. 2
18	Aug. 2 and 7	Aug. 3-6	Aug. 7-10
19	Aug. 2	Aug. 3-7	July 28-Aug. 2
20		Aug. 2-7	No Record
21		Aug. 2-7	No Record
22	Aug. 2 and 4-5	Aug. 3 and 6-7	No Record
23		Aug. 2-7	No Record
24		Aug. 2-7	No Record
25		Aug. 2-7	No Record
26	Aug. 6-7	Aug. 2-5	Aug. 6-10
27		Aug. 2-7	No Record
28		Aug. 2-7	No Record

29	Aug. 2	Aug. 3-7	July 28-Aug. 7
30		Aug. 2-7	No Record
31		Aug. 2-7	No Record
32	Aug. 2-7		July 29-Aug. 10
33		Aug. 2-7	No Record
34	Aug. 6	Aug. 2-5 and 7	July 25-Aug. 2
35		Aug. 2-7	July 25-Aug. 2
36		Aug. 2-7	No Record
37	Aug. 2-4	Aug. 5-7	July 31-Aug. 4
38	Aug. 2 and 6	Aug. 3-5 and 7	July 25-Aug. 2 and 6-13
39	Aug. 2	Aug. 3-7	July 30-Aug. 2
40		Aug. 2-7	Missing
41	Aug. 2 and 5-7	Aug. 3-4	July 17-Aug.3 and 7-9
42	Aug. 2-6	Aug. 7	July 26-Aug. 3
43	Aug. 2 and 7	Aug. 3-6	No Record
44		Aug. 2-7	No Record
45		Aug. 2-7	No Record
46		Aug. 2-7	No Record
47		Aug. 2-7	No Record
48		Aug. 2-7	No Record
49		Aug. 2-7	Missing
50		Aug. 2-7	No Record
51		Aug. 2-7	Missing
52		Aug. 2-7	No Record
53		Aug. 2-7	No Record

APPENDIX D: Original Data for Laterals A,B,C AND D Used in Analyses

Lateral A : 1989 - 1990

	Lateral A - 1989				Lateral A - 1990			
Julian Day	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day
121	1.17	0.00	M*	M	0.89	0.00	M	M
122	1.38	0.00	M	M	1.15	0.00	M	M
123	0.69	0.00	M	M	0.79	0.00	M	M
124	1.21	0.00	M	M	1.31	0.00	M	M
125	1.20	0.00	M	M	1.59	0.00	M	M
126	1.58	0.00	M	M	1.88	0.00	M	M
127	1.86	0.00	M	M	2.34	0.00	M	M
128	1.29	0.00	M	M	1.02	0.00	M	M
129	0.24	0.00	M	M	0.85	1.71	M	M
130	2.27	0.00	0.30	0.00	1.14	0.00	M	M
131	2.19	0.00	0.27	0.13	0.92	0.00	0.07	0.00
132	2.52	0.00	0.35	0.09	1.11	0.00	0.08	0.00
133	1.46	0.00	0.35	0.17	0.63	0.00	0.10	0.00
134	1.50	0.00	0.35	0.02	1.42	0.00	0.54	0.00
135	1.24	0.00	0.34	0.03	1.47	0.00	0.67	0.04
136	0.28	0.00	0.36	0.15	1.64	0.00	0.72	0.27
137	2.27	0.00	0.41	0.23	1.69	0.00	0.34	0.22
138	2.72	0.00	0.47	0.25	1.96	0.00	1.44	0.23
139	1.88	5.10	0.52	0.27	1.49	17.10	1.52	0.30
140	2.50	0.00	0.43	0.14	1.39	0.00	1.40	0.29
141	3.51	0.00	0.39	0.06	1.45	0.00	1.08	0.33
142	2.50	0.00	0.39	0.21	3.77	0.00	1.77	0.27
143	2.56	0.00	1.78	0.27	2.45	0.00	2.58	0.32
144	1.40	0.00	2.58	0.82	3.21	0.00	2.60	0.06
145	1.70	9.90	2.26	0.70	1.40	27.90	1.18	0.12
146	2.26	0.00	2.51	0.20	2.89	0.00	0.89	0.28

Note: M* denotes missing data

147	3.36	0.00	2.47	0.10	1.68	27.40	0.89	0.21
148	2.30	15.00	2.19	0.23	2.01	0.00	0.90	0.16
149	0.86	0.00	1.63	0.04	1.23	7.40	1.05	0.09
150	0.30	9.00	1.63	0.04	2.51	7.40	0.86	0.07
151	3.49	0.00	2.07	0.14	4.66	0.00	0.80	0.22
152	3.83	0.00	3.08	0.42	3.15	7.40	0.45	0.27
153	3.67	0.00	2.76	0.34	4.84	0.00	0.31	0.22
154	3.41	14.00	2.72	0.72	1.82	10.20	0.30	0.21
155	3.94	10.00	2.47	0.78	3.14	0.00	0.33	0.22
156	4.81	0.00	2.37	0.62	6.61	0.00	0.38	0.28
157	6.05	0.00	2.58	0.41	4.25	0.00	0.38	0.28
158	6.08	0.00	2.40	0.66	4.84	0.00	0.38	0.29
159	4.59	0.00	2.13	0.48	4.04	5.80	0.41	0.27
160	6.27	0.00	2.08	0.51	6.27	0.00	0.40	0.14
161	5.09	0.00	2.07	0.52	6.53	0.00	0.40	0.03
162	1.80	7.00	1.39	0.51	2.14	0.00	0.54	0.09
163	3.81	0.00	0.86	0.26	6.54	0.00	1.12	0.23
164	3.53	0.00	0.88	0.22	4.61	6.40	1.30	0.37
165	7.02	0.00	1.08	0.23	2.32	6.40	1.02	0.19
166	4.99	0.00	1.07	0.27	4.59	6.40	0.61	0.03
167	6.74	0.00	1.29	0.31	4.93	0.00	0.62	0.07
168	6.17	0.00	1.03	0.26	5.41	0.00	0.62	0.13
169	6.80	0.00	0.83	0.30	6.10	0.00	0.61	0.14
170	7.14	0.00	1.05	0.34	7.48	0.00	0.34	0.13
171	3.88	0.00	0.95	0.36	6.67	0.00	0.79	0.12
172	[illegible]	0.00	1.66	0.33	5.04	0.00	1.80	0.12
173	[illegible]	0.00	2.62	0.69	6.82	0.00	3.09	0.25
174	[illegible]	0.00	2.56	0.85	7.79	0.00	3.27	0.27
175	[illegible]	0.00	2.31	0.79	7.85	0.00	3.20	0.20
176	[illegible]	13.00	1.83	0.71	8.49	0.00	4.23	0.23
177	5.03	0.00	1.08	0.48	8.43	0.00	6.40	0.63
178	5.55	0.00	1.71	0.42	8.74	0.00	7.37	0.76
179	3.41	0.00	2.27	0.91	8.01	0.00	7.61	0.57
180	6.86	13.00	2.53	0.57	7.54	0.00	7.73	0.54
181	7.77	0.00	3.19	0.58	8.52	0.00	7.62	0.50
182	8.01	0.00	3.25	0.47	9.66	0.00	7.78	0.35
183	7.38	0.00	3.23	0.35	8.75	0.00	8.17	0.36
184	10.13	0.00	3.48	0.39	3.16	1.70	8.10	0.54
185	8.13	0.00	5.41	0.49	9.45	0.00	8.14	0.61
186	7.97	0.00	6.54	0.44	5.60	0.00	7.96	0.74
187	7.48	0.00	7.01	0.17	5.75	0.00	7.63	0.86
188	8.65	0.00	7.55	0.44	7.86	0.00	7.26	0.56
189	9.38	0.00	7.51	0.24	4.29	1.70	7.17	0.49
190	9.83	0.00	7.28	0.26	7.95	0.00	7.07	0.66

191	4.95	0.00	8.01	0.62	8.74	0.00	7.15	0.55
192	2.41	6.10	8.35	0.70	8.78	0.00	7.05	0.58
193	8.36	0.00	7.99	0.49	8.81	0.00	6.73	0.38
194	7.47	2.00	7.31	0.60	8.82	0.00	6.63	0.57
195	2.52	17.00	5.12	0.40	9.16	0.00	6.40	0.64
196	5.42	0.00	5.38	0.27	7.32	0.00	6.38	0.40
197	7.71	0.00	5.59	0.58	7.22	0.00	5.88	0.29
198	7.83	0.00	5.62	0.29	7.98	3.50	6.07	0.37
199	2.98	2.00	5.87	0.34	7.46	0.00	5.90	0.62
200	8.37	0.00	6.18	0.64	6.31	3.60	5.53	0.62
201	7.78	0.00	6.36	0.57	2.72	3.50	5.11	0.35
202	7.42	0.00	6.06	0.74	4.20	3.50	4.42	0.41
203	9.36	0.00	5.83	0.66	6.11	0.00	4.04	0.39
204	7.73	0.00	5.27	1.22	6.79	0.00	3.91	0.59
205	6.67	0.00	4.39	0.95	5.52	0.00	3.43	0.65
206	4.71	0.00	3.43	0.20	4.86	0.00	2.80	0.72
207	6.37	0.00	3.95	0.50	2.87	10.80	2.38	0.63
208	6.57	0.00	3.61	0.40	4.23	10.90	1.91	0.61
209	7.27	0.00	3.63	0.18	5.73	0.00	1.66	0.40
210	6.84	0.00	3.62	0.41	5.92	0.00	1.28	0.36
211	6.35	0.00	3.50	0.35	5.25	2.90	0.85	0.21
212	5.22	0.00	3.21	0.56	5.87	0.00	0.79	0.08
213	4.40	0.00	2.81	0.06	4.05	3.00	1.05	0.31
214	7.55	0.00	2.75	0.17	5.35	0.00	1.47	0.48
215	7.82	0.00	2.27	0.30	4.73	3.80	2.28	0.29
216	4.45	0.00	2.20	0.22	4.10	0.00	1.60	0.57
217	1.88	2.00	2.27	0.66	4.62	0.00	1.35	0.43
218	2.90	0.00	1.86	0.41	4.24	0.00	1.37	0.38
219	3.34	0.00	1.68	0.38	5.26	0.00	2.00	0.37
220	3.61	0.00	1.89	0.42	4.54	0.00	2.89	0.31
221	2.39	0.00	1.91	0.42	3.44	0.00	3.28	0.51
222	1.12	2.80	1.95	0.36	3.31	0.00	2.93	0.72
223	3.10	0.00	1.93	0.48	3.19	0.00	2.78	0.36
224	2.93	1.00	1.62	0.51	2.96	0.00	2.92	0.30
225	3.08	0.00	1.56	0.49	2.83	0.00	2.96	0.27
226	2.20	2.00	2.23	0.52	2.75	0.00	3.48	0.40
227	2.55	0.00	2.65	0.56	2.70	0.00	4.04	0.58
228	2.58	2.00	2.90	0.48	2.65	0.00	3.84	0.58
229	2.41	0.00	2.69	0.62	2.84	0.00	3.65	0.55
230	1.67	0.00	2.67	0.37	2.21	0.00	2.81	0.54
231	1.36	0.00	2.69	0.36	1.71	1.70	2.34	0.38
232	1.95	0.00	2.70	0.54	1.46	0.00	2.32	0.51
233	1.85	5.10	2.70	0.64	1.57	0.00	2.50	0.55
234	2.10	0.00	2.48	0.49	2.15	0.00	2.49	0.53

235	1.45	0.00	2.40	0.30	2.67	0.00	2.11	0.47
236	0.72	0.00	2.42	0.46	2.05	0.00	1.95	0.43
237	0.79	0.00	2.58	0.60	0.56	1.70	1.99	0.57
238	1.36	0.00	2.50	0.53	0.44	0.00	2.01	0.60
239	1.09	0.00	2.49	0.69	0.55	0.00	1.75	0.59
240	0.63	17.80	2.28	0.64	2.20	0.00	1.31	0.59
241	0.87	16.00	2.01	0.52	2.52	0.00	0.70	0.34
242	1.18	0.00	1.23	0.54	1.86	0.00	0.48	0.08
243	0.58	3.10	0.78	0.27	2.71	0.00	0.77	0.08
244	1.37	0.00	0.80	0.26	2.51	0.00	0.76	0.27
245	1.57	0.00	0.79	0.57	1.85	0.00	0.77	0.32
246	1.73	0.00	0.79	0.62	1.73	0.00	0.82	0.37
247	1.51	17.10	0.80	0.57	1.58	0.00	1.47	0.38
248	1.69	0.00	0.79	0.52	1.81	0.00	1.72	0.38
249	0.92	7.90	0.82	0.59	1.94	0.00	1.46	0.26
250	1.01	0.00	0.63	0.55	1.75	0.00	1.44	0.29
251	0.83	0.00	0.49	0.32	2.17	0.00	1.57	0.17
252	1.06	0.00	0.49	0.33	1.51	0.00	1.56	0.23
253	0.78	0.00	0.49	0.29	1.65	0.00	1.67	0.22
254	0.79	2.00	0.47	0.32	1.86	0.00	1.90	0.20
255	0.83	0.00	0.49	0.31	1.63	0.00	2.09	0.14
256	1.23	0.00	0.42	0.30	1.73	0.00	2.53	0.43
257	1.23	0.00	0.26	0.20	1.42	10.00	2.60	0.34
258	1.73	0.00	0.26	0.10	1.37	0.00	2.36	0.30
259	1.34	0.00	0.24	0.12	1.36	0.00	2.18	0.28
260	1.63	0.00	0.24	0.12	1.80	0.00	2.34	0.26
261	0.32	2.00	0.24	0.14	1.12	0.00	2.51	0.24
262	0.79	2.00	0.23	0.10	1.13	0.00	2.73	0.36
263	1.11	0.00	0.23	0.00	1.14	0.00	3.14	0.43
264	1.05	0.00	0.23	0.00	1.02	0.00	3.06	0.55
265	1.01	0.00	0.22	0.02	1.07	0.00	2.82	0.49
266	1.12	0.00	0.22	0.07	1.06	0.00	2.74	0.45
267	1.36	0.00	0.22	0.06	1.61	0.00	2.54	0.43
268	1.03	0.00	0.22	0.05	1.45	0.00	2.63	0.53
269	0.98	0.00	0.36	0.04	1.38	0.00	2.81	0.45
270	1.10	0.00	0.49	0.05	0.93	0.00	2.60	0.24
271	1.33	0.00	0.60	0.20	0.93	0.00	2.49	0.21
272	0.96	0.00	0.60	0.26	0.87	0.00	2.24	0.23
273	1.16	0.00	0.57	0.27	1.30	0.00	2.11	0.12

Note: M* denotes missing value.

Lateral B: 1989 - 1990

	Lateral B - 1989				Lateral B - 1990			
Julian Day	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day
121	0.57	0.00	M*	M	0.22	0.00	M	M
122	0.69	0.00	M	M	0.31	0.00	M	M
123	0.35	0.00	M	M	0.23	0.00	M	M
124	0.62	0.00	M	M	0.41	0.00	M	M
125	0.63	0.00	M	M	0.54	0.00	M	M
126	0.84	0.00	M	M	0.69	0.00	M	M
127	1.01	0.00	M	M	0.91	0.00	0.95	0.96
128	0.71	0.00	M	M	0.42	0.00	0.91	1.92
129	0.14	0.00	M	M	0.37	0.00	0.90	1.83
130	1.30	0.00	0.54	0.27	0.52	0.00	0.88	1.62
131	1.27	0.00	0.86	0.78	0.44	0.00	0.88	1.67
132	1.49	0.00	0.92	0.74	0.55	0.00	0.80	0.53
133	0.87	0.00	1.28	0.97	0.32	2.40	0.71	0.34
134	0.91	0.00	1.35	1.18	0.76	0.00	0.66	0.51
135	0.76	0.00	1.30	1.06	0.81	0.00	0.57	0.34
136	0.18	0.00	1.30	0.82	0.93	0.00	1.15	0.54
137	1.42	0.00	1.20	0.90	0.99	0.00	1.61	0.47
138	1.74	0.00	1.17	0.79	1.17	0.00	1.87	0.54
139	1.23	0.00	1.08	0.93	0.91	2.11	2.05	0.48
140	1.66	0.00	0.95	0.57	0.86	0.00	2.02	0.67
141	2.38	0.00	1.11	0.57	0.92	12.90	1.89	0.86
142	1.72	0.00	1.11	0.43	2.43	0.00	1.76	0.61
143	1.78	0.00	3.09	1.45	1.60	0.00	1.58	0.76
144	0.99	0.00	3.59	1.62	2.13	0.00	1.43	0.98
145	1.21	12.70	3.06	1.40	0.94	25.30	1.37	1.02
146	1.63	0.00	2.71	1.02	1.97	0.00	1.31	0.83
147	2.45	0.00	2.56	0.72	1.16	0.00	1.29	0.78
148	1.69	0.00	2.65	1.28	1.40	0.85	1.25	0.78
149	0.64	30.50	2.45	1.10	0.87	0.00	1.23	0.99
150	0.23	0.00	2.15	0.97	1.79	5.30	1.21	0.91

Note: M* denotes missing data

151	2.64	0.00	2.03	0.78	3.34	0.00	1.19	0.79
152	2.92	0.00	1.99	0.87	2.28	3.60	1.16	0.85
153	2.81	0.00	1.93	1.10	3.53	6.30	1.11	0.87
154	2.63	0.00	1.86	0.78	1.34	0.00	1.10	0.80
155	3.06	0.00	1.86	0.77	2.32	0.00	0.96	0.69
156	3.76	0.00	2.15	0.75	4.93	0.00	0.94	0.60
157	4.75	0.00	2.39	0.89	3.18	0.00	0.88	0.51
158	4.80	0.00	2.34	1.06	3.65	0.00	0.82	0.37
159	3.64	7.60	2.20	0.85	3.06	0.00	0.78	0.31
160	5.00	0.00	2.20	0.69	4.78	0.00	1.52	0.48
161	4.08	0.00	2.18	1.15	5.00	0.00	1.81	0.90
162	1.45	30.50	2.18	1.53	1.65	0.00	1.84	0.89
163	3.07	0.00	1.61	1.11	5.07	0.00	1.76	0.94
164	2.86	0.00	1.21	0.61	3.59	0.00	1.60	1.07
165	5.72	0.00	1.20	0.57	1.81	25.30	1.46	0.25
166	4.08	0.00	1.16	0.64	3.61	0.00	1.51	0.52
167	5.54	0.00	1.08	0.56	3.89	0.00	1.49	0.84
168	5.09	14.00	1.03	0.55	4.29	0.00	1.47	1.02
169	5.63	0.00	1.14	0.17	4.86	0.00	1.46	1.07
170	5.93	0.00	1.32	0.36	5.98	0.00	1.45	1.02
171	3.23	0.00	1.08	0.39	5.35	0.00	1.58	0.82
172	4.94	0.00	1.69	0.55	4.06	0.00	2.11	1.01
173	3.59	0.00	2.03	0.98	5.53	0.00	2.35	0.33
174	4.13	5.10	2.05	1.17	6.34	0.00	2.97	1.84
175	4.50	0.00	2.03	1.48	6.41	0.00	3.18	0.73
176	3.99	0.00	2.02	0.63	6.97	0.00	4.21	1.31
177	4.29	12.70	1.91	0.57	6.95	0.00	5.21	0.79
178	4.61	0.00	2.05	0.59	7.23	0.00	5.58	0.44
179	2.93	0.00	2.41	0.68	6.66	0.00	5.86	1.15
180	5.92	0.00	2.48	0.51	6.29	0.00	5.90	0.69
181	6.73	0.00	4.22	0.66	7.14	0.00	6.11	0.27
182	6.96	0.00	5.38	1.24	8.14	0.00	6.33	0.40
183	6.44	0.00	5.40	1.43	7.41	0.00	6.44	1.18
184	8.88	0.00	6.09	1.42	2.69	0.00	6.43	1.15
185	7.16	0.00	6.79	1.45	8.08	0.00	6.58	0.69
186	7.05	0.00	7.18	1.78	4.81	5.10	M*	0.49
187	6.65	0.00	7.27	1.59	4.97	0.00	M	0.95
188	7.72	0.00	7.14	1.20	6.83	0.00	M	1.15
189	8.42	0.00	7.22	1.53	3.74	0.00	M	1.67
190	8.86	0.00	7.10	1.86	6.99	0.00	M	1.72
191	4.49	0.00	6.59	1.86	7.72	0.00	M	1.13

Note: M* denotes missing data

192	2.20	0.00	6.26	1.57	7.80	0.00	M*	0.98
193	7.67	0.00	5.87	1.54	7.89	0.00	M	0.77
194	6.89	0.00	5.50	1.51	7.95	0.00	M	1.14
195	2.34	12.70	4.68	1.35	8.31	0.00	M	1.42
196	5.07	0.00	4.07	1.29	6.69	0.00	M	2.01
197	7.25	0.00	3.92	1.09	6.65	0.00	6.81	1.37
198	7.42	0.00	4.82	1.31	7.41	0.00	6.97	1.08
199	2.85	0.00	5.29	1.21	6.98	0.00	7.07	0.28
200	8.06	0.00	6.04	0.98	5.96	0.00	7.10	1.46
201	7.56	0.00	6.35	1.08	2.60	5.30	7.10	0.91
202	7.27	0.00	6.34	1.05	4.04	0.00	6.32	0.81
203	9.27	0.00	6.34	0.71	5.94	0.00	M	0.51
204	7.72	0.00	6.30	0.72	6.69	0.00	M	1.15
205	6.75	2.50	6.35	1.63	5.50	0.00	M	1.51
206	4.81	6.40	5.86	2.16	4.90	0.00	M	2.28
207	6.60	0.00	4.87	1.67	2.93	15.40	M	2.85
208	6.89	0.00	4.39	1.13	4.39	0.00	M	2.77
209	7.75	0.00	4.13	1.32	6.04	0.00	M	2.59
210	7.40	0.00	3.97	1.11	6.35	0.00	M	2.44
211	6.99	0.00	3.99	1.19	5.73	0.00	M	1.91
212	5.86	0.00	4.72	1.16	6.53	0.00	M	1.40
213	5.04	0.00	4.95	1.22	4.60	5.10	M	1.21
214	8.84	0.00	4.68	1.44	6.22	0.00	M	1.22
215	9.39	0.00	4.15	0.99	5.65	6.50	3.04	1.04
216	5.49	0.00	3.94	1.31	5.04	0.00	3.09	0.40
217	2.39	0.00	3.66	1.22	5.86	0.00	3.07	0.62
218	3.83	0.00	3.47	1.57	5.57	0.00	3.23	1.10
219	4.59	0.00	3.47	1.43	7.18	0.00	3.51	0.54
220	5.19	0.00	3.28	0.77	6.48	0.00	4.36	0.74
221	3.62	0.00	3.21	0.81	5.18	0.00	4.72	0.90
222	1.75	0.00	3.34	0.59	5.12	0.00	4.81	1.02
223	4.78	0.00	3.24	0.49	4.92	0.00	5.12	0.86
224	4.48	0.00	3.36	0.16	4.56	0.00	4.90	1.31
225	4.65	0.00	3.44	0.35	4.35	0.00	4.91	1.28
226	3.28	0.00	3.52	0.75	4.20	0.00	4.95	1.27
227	3.74	0.00	3.65	1.23	4.11	0.00	5.03	1.78
228	3.73	12.50	3.26	1.86	4.00	0.00	4.88	1.49
229	3.41	0.00	2.58	1.81	4.27	0.00	4.46	1.50
230	2.31	0.00	1.94	1.52	3.30	0.00	4.26	1.09
231	1.84	0.00	1.73	1.58	2.52	0.00	[illegible]	1.10
232	2.59	12.50	1.69	1.36	2.12	0.00	3.57	0.75

Note: M* denotes missing data

233	2.44	0.00	1.68	1.09	2.26	0.00	3.13	0.62
234	2.69	0.00	1.62	0.91	3.03	0.00	3.11	0.68
235	1.83	0.00	1.58	0.83	3.74	0.00	3.07	0.83
236	0.92	0.00	1.66	1.12	2.88	0.00	3.00	1.23
237	1.01	0.00	1.51	1.49	0.79	12.90	2.88	1.34
238	1.72	21.60	1.32	1.18	0.62	0.00	2.88	1.43
239	1.39	0.00	1.29	1.35	0.77	0.00	2.84	1.50
240	0.79	14.70	1.21	1.35	3.09	0.00	2.55	1.30
241	1.10	13.20	1.12	1.23	3.54	0.00	2.38	1.05
242	1.50	0.00	1.02	1.17	2.60	0.00	2.41	0.90
243	0.73	0.00	0.96	1.09	3.79	0.00	2.39	0.87
244	1.73	0.00	0.80	1.05	3.51	0.00	2.32	0.49
245	1.96	0.00	0.73	0.98	2.59	0.00	2.31	0.33
246	2.17	0.00	0.80	1.11	2.41	0.00	2.55	0.66
247	1.89	5.10	0.86	1.18	2.20	0.00	3.36	1.12
248	2.10	0.00	0.88	1.14	2.50	0.00	3.48	0.90
249	1.13	0.00	0.81	1.11	2.67	0.00	4.04	1.23
250	1.24	0.00	0.81	1.09	2.40	0.00	4.61	1.37
251	1.02	0.00	0.83	1.09	2.96	0.00	4.67	1.45
252	1.29	0.00	0.88	1.08	2.04	0.00	4.60	1.31
253	0.94	0.00	0.83	1.08	2.22	0.00	4.48	1.03
254	0.95	0.00	0.75	1.07	2.48	0.00	4.97	0.82
255	0.99	0.00	0.33	1.06	2.15	0.00	5.35	1.21
256	1.45	0.00	0.72	1.06	2.27	0.00	5.08	1.34
257	1.44	0.00	0.72	0.88	1.85	0.00	4.44	1.48
258	1.99	0.00	0.85	0.72	1.76	0.00	3.73	1.08
259	1.32	0.00	0.80	0.72	1.45	0.00	3.57	1.20
260	1.59	7.60	0.70	0.70	1.91	0.00	3.35	1.05
261	0.31	7.60	0.71	0.64	1.18	0.00	3.39	1.02
262	0.75	0.00	0.83	0.54	1.18	0.00	3.58	0.78
263	1.05	0.00	0.80	0.54	1.18	0.00	3.61	0.73
264	0.99	0.00	1.02	0.61	1.04	0.00	4.01	1.31
265	0.94	0.00	1.30	0.61	1.09	0.00	3.74	1.10
266	1.03	0.00	1.30	0.70	1.06	0.00	3.57	1.16
267	1.23	0.00	1.29	0.98	1.60	0.00	3.69	1.34
268	0.92	0.00	1.30	1.01	1.42	0.00	3.90	1.02
269	0.87	0.00	1.29	1.06	1.33	0.00	3.92	1.14
270	0.96	0.00	1.29	1.05	0.89	0.00	3.61	1.23
271	1.13	0.00	1.30	1.00	0.87	0.00	3.28	1.18
272	0.81	0.00	1.34	0.75	0.80	0.00	3.11	0.97
273	0.96	0.00	1.38	0.54	1.17	0.00	2.95	0.97

LATERAL C - 1990 - 1991

	Lateral C - 1990				Lateral C - 1991			
Julian Days	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day	ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day
121	0.36	0.00	M*	M	0.25	0.00	0.29	M
122	0.48	0.00	M	M	0.13	1.00	0.69	M
123	0.34	0.00	M	M	0.15	7.00	1.03	M
124	0.60	0.00	M	M	0.35	0.00	0.98	M
125	0.75	0.00	M	M	0.56	0.00	0.94	M
126	0.92	0.00	M	M	0.52	0.00	1.54	M
127	1.19	0.00	M	M	0.87	0.00	2.08	M
128	0.54	0.00	M	M	0.46	1.00	2.38	M
129	0.46	0.00	M	M	1.05	0.00	2.31	M
130	0.64	0.00	0.90	M	0.96	0.00	2.25	M
131	0.54	0.00	1.99	M	0.49	4.00	2.22	M
132	0.66	0.00	2.44	M	0.42	22.00	2.02	M
133	0.39	2.40	2.44	M	1.24	14.00	1.51	M
134	0.90	0.00	2.34	M	1.16	0.00	1.39	M
135	0.95	0.00	2.37	0.05	1.63	0.00	1.34	M
136	1.09	0.00	0.70	0.05	1.26	0.00	1.30	M
137	1.15	0.00	2.79	0.36	1.41	0.00	1.87	1.99
138	1.36	0.00	2.79	1.74	0.87	1.00	1.46	3.83
139	1.05	2.11	2.73	2.27	2.51	4.00	1.43	M
140	1.00	0.00	2.76	2.36	2.84	0.00	1.34	M
141	1.06	12.90	2.78	2.39	1.99	1.00	1.73	M
142	2.79	0.00	2.96	2.58	1.73	0.00	2.79	M
143	1.84	0.00	3.24	3.24	1.58	0.00	3.11	M
144	2.44	0.00	3.27	3.00	1.33	8.00	2.86	M
145	1.07	25.30	2.92	2.98	2.64	0.00	2.81	M
146	2.25	0.00	3.23	3.18	2.37	0.00	2.87	M
147	1.32	0.00	2.92	3.12	2.62	0.00	3.01	M
148	1.59	0.85	2.75	3.37	1.48	7.00	3.64	1.18
149	0.99	0.00	2.70	3.54	3.82	0.00	3.92	M
150	2.03	5.30	2.62	3.65	3.56	0.00	4.04	M

Note: M* denotes missing data

151	3.80	0.00	2.61	3.27	3.66	0.00	3.68	M
152	2.59	3.60	2.56	3.90	4.89	0.00	2.40	M
153	4.01	6.30	2.58	3.00	4.33	0.00	2.42	M
154	1.52	0.00	2.61	3.49	5.28	0.00	3.71	M*
155	2.64	0.00	2.64	3.17	4.31	0.00	4.24	M
156	5.59	0.00	2.73	2.65	1.23	1.00	4.73	M
157	3.61	0.00	3.27	2.70	2.53	2.00	4.73	M
158	4.14	0.00	3.49	2.20	4.23	6.00	3.17	M
159	3.47	0.00	3.48	2.34	4.68	0.00	4.36	M
160	5.42	0.00	3.45	2.22	5.43	0.00	4.19	M
161	5.67	0.00	3.54	2.17	3.16	0.00	4.17	M
162	1.87	0.00	3.71	2.28	3.10	4.00	4.71	M
163	5.74	0.00	3.51	2.51	7.23	0.00	5.09	M
164	4.06	0.00	3.24	M	7.03	0.00	4.94	M
165	2.05	25.30	3.20	M	5.77	0.00	5.63	M
166	4.08	0.00	3.04	M	6.60	0.00	6.83	M
167	4.40	0.00	2.96	M	5.14	0.00	6.50	M
168	4.84	0.00	2.90	M	3.36	4.00	6.66	M
169	5.48	0.00	3.06	M	5.89	1.00	6.59	4.30
170	6.75	0.00	3.65	M	3.98	0.00	6.30	4.34
171	6.03	0.00	3.88	M	1.23	19.00	6.36	4.84
172	4.58	0.00	4.49	M	7.08	21.00	6.49	5.73
173	6.22	0.00	5.84	M	4.07	0.00	6.22	5.59
174	7.12	0.00	6.07	M	5.74	6.00	5.69	5.16
175	7.20	0.00	6.15	M	5.16	0.00	5.16	4.91
176	7.81	0.00	6.22	M	3.37	24.00	4.47	3.61
177	7.78	0.00	6.61	3.27	3.90	2.00	4.39	3.40
178	8.08	0.00	6.98	3.54	5.59	7.00	4.39	3.77
179	7.43	0.00	6.95	3.21	1.56	14.00	4.30	3.98
180	7.01	0.00	6.94	4.42	5.95	23.00	4.35	4.13
181	7.95	0.00	7.23	4.31	3.81	18.00	4.94	6.36
182	9.04	0.00	7.70	4.31	7.72	0.00	3.08	4.18
183	8.21	0.00	7.59	3.21	8.07	0.00	1.21	1.53
184	2.97	0.00	7.99	2.13	7.89	0.00	0.79	0.98
185	8.92	0.00	8.16	2.33	7.47	5.00	0.73	0.80
186	5.30	5.10	7.92	3.20	8.43	1.00	0.58	0.54
187	5.46	0.00	7.62	2.56	7.01	0.00	0.48	0.42
188	7.49	0.00	7.01	4.19	7.61	0.00	0.41	0.33
189	4.09	0.00	7.34	4.70	7.01	0.00	0.38	0.26
190	7.62	0.00	7.15	4.42	7.72	1.00	0.37	0.23

Note: M" denotes missing data

191	8.39	0.00	6.94	4.19	2.18	16.00	0.79	0.38
192	8.46	0.00	7.03	4.78	7.77	0.00	1.69	1.52
193	8.52	0.00	7.39	4.80	7.69	0.00	2.18	1.83
194	8.56	0.00	7.59	0.00	6.49	0.00	1.29	1.69
195	8.91	0.00	7.78	3.54	6.56	0.00	1.23	1.64
196	7.14	0.00	7.65	0.00	9.34	0.00	1.19	1.62
197	7.08	0.00	7.26	3.26	7.86	0.00	1.24	1.70
198	7.85	0.00	6.80	M	7.51	0.00	1.50	2.06
199	7.36	0.00	6.47	2.59	7.89	0.00	2.53	3.30
200	6.25	0.00	6.01	M	6.51	0.00	3.10	M
201	2.71	5.30	6.13	M	7.53	0.00	4.06	M
202	4.19	0.00	6.08	M	6.12	0.00	3.89	M
203	6.13	0.00	6.41	4.92	6.35	0.00	4.19	M
204	6.85	0.00	7.08	M	6.54	0.00	6.61	3.40
205	5.60	0.00	7.33	M	7.47	0.00	6.62	3.58
206	4.95	0.00	6.44	M	6.79	0.00	6.82	3.73
207	2.94	15.40	6.05	4.39	8.08	0.00	7.08	3.89
208	4.37	0.00	5.56	3.83	6.37	0.00	7.00	3.51
209	5.95	0.00	5.15	4.25	6.29	0.00	7.23	4.10
210	6.19	0.00	5.26	4.86	7.42	0.00	7.16	4.27
211	5.53	0.00	5.28	4.75	6.04	1.00	7.11	3.20
212	6.23	0.00	5.23	4.61	6.22	0.00	7.87	4.35
213	4.34	5.10	5.21	4.35	1.47	16.00	8.09	4.87
214	5.79	0.00	4.95	4.08	5.24	1.00	5.46	6.23
215	5.18	6.50	4.78	3.93	6.58	0.00	4.58	3.78
216	4.55	0.00	4.19	4.80	5.87	0.00	4.09	3.98
217	5.20	0.00	[illegible]	4.59	5.07	0.00	3.87	4.00
218	4.84	0.00	4.27	4.41	4.54	0.00	3.89	3.76
219	6.12	0.00	3.99	3.06	5.09	0.00	3.60	3.91
220	5.39	0.00	3.77	2.64	4.92	0.00	3.47	3.20
221	4.19	0.00	3.62	2.78	4.31	0.00	4.10	4.03
222	4.06	0.00	4.28	3.38	3.48	1.00	4.00	4.22
223	3.87	0.00	4.87	2.87	3.03	3.00	3.91	4.16
224	3.55	0.00	4.62	3.09	2.86	9.00	3.89	4.42
225	3.34	0.00	4.42	3.32	2.85	13.20	4.05	4.05
226	3.19	0.00	4.64	3.29	3.12	1.00	3.50	3.29
227	3.07	0.00	4.24	2.56	2.45	0.00	3.23	3.06
228	2.94	0.00	4.05	2.47	3.42	0.00	2.81	2.83
229	3.08	0.00	4.31	2.41	3.29	0.00	2.59	2.48
230	2.33	0.00	4.22	2.90	3.28	0.00	3.12	2.67
231	1.74	0.00	4.11	3.24	3.45	0.00	3.55	2.91
232	1.41	0.00	4.19	3.04	2.86	0.00	3.28	2.31
233	1.44	0.00	4.24	2.70	2.66	0.00	3.75	2.26
234	1.86	0.00	4.21	3.23	2.56	0.00	4.73	3.00

235	2.26	0.00	4.25	3.35	1.97	0.00	4.89	3.43
236	1.74	0.00	4.22	3.45	2.19	0.00	4.52	3.35
237	0.48	12.90	3.97	4.36	1.81	0.00	4.51	3.45
238	0.38	0.00	4.10	4.36	2.70	0.00	4.89	4.22
239	0.46	0.00	4.17	4.11	2.23	0.00	4.65	4.21
240	1.87	0.00	4.13	4.17	2.24	0.00	4.34	3.70
241	2.14	0.00	3.90	3.77	1.96	0.00	4.32	3.39
242	1.58	0.00	3.65	3.32	2.04	0.00	4.54	3.76
243	2.30	0.00	3.76	3.29	1.96	0.00	4.73	3.85
244	2.13	0.00	6.18	3.77	1.97	0.00	4.41	3.12
245	1.57	0.00	5.93	3.88	1.86	0.00	4.57	3.01
246	1.47	0.00	3.38	3.77	1.87	0.00	M*	M
247	1.34	0.00	4.16	3.60	1.96	0.00	M	M
248	1.53	0.00	4.98	3.43	2.01	0.00	M	M
249	1.64	0.00	5.12	3.46	1.89	0.00	M	M
250	1.47	0.00	5.23	3.21	1.40	0.00	M	M
251	1.82	0.00	5.70	3.34	0.75	0.00	M	M
252	1.26	0.00	5.63	2.87	1.57	0.00	M	M
253	1.37	0.00	5.60	3.43	0.84	0.00	M	M
254	1.54	0.00	6.01	2.86	1.57	0.00	M	M
255	1.35	0.00	5.73	2.51	1.66	0.00	M	M
256	1.43	0.00	5.37	3.97	1.08	0.00	M	M
257	1.17	0.00	5.09	4.31	0.96	2.00	M	M
258	1.12	0.00	5.17	3.71	1.22	0.00	M	M
259	1.05	0.00	4.95	4.33	0.89	2.00	M	M
260	1.38	0.00	4.75	4.21	0.91	0.00	M	M
261	0.86	0.00	4.61	3.00	1.11	0.00	M	M
262	0.86	0.00	2.51	3.37	1.47	0.00	M	M
263	0.87	0.00	2.59	4.53	1.35	0.00	M	M
264	0.77	0.00	2.47	4.05	0.64	0.00	M	M
265	0.81	0.00	2.44	3.85	1.03	0.00	M	M
266	0.79	0.00	2.55	3.99	1.17	0.00	M	M
267	1.19	0.00	2.51	3.68	1.41	0.00	M	M
268	1.07	0.00	2.72	4.00	1.11	0.00	M	M
269	1.01	0.00	2.87	3.60	1.06	0.00	M	M
270	0.67	0.00	2.65	3.09	1.14	0.00	M	M
271	0.67	0.00	2.53	2.90	1.01	0.00	M	M
272	0.62	0.00	2.36	M	0.50	0.00	M	M
273	3.42	0.88	4.26	M	0.64	0.00	M	M

Note: M* denotes missing value

LATERAL D: 1990 - 1991

Julian Day	Lateral D - 1990 ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day	Lateral D - 1991 ET mm/day	Rain mm/day	Inflow mm/day	Spill mm/day
121	0.73	0.00	M*	M	0.27	0.00	1.92	1.99
122	0.51	0.00	M	M	0.13	1.00	1.38	1.19
123	0.86	0.00	M	M	0.15	7.00	1.05	0.77
124	1.06	0.00	M	M	0.34	0.00	1.11	1.00
125	1.26	0.00	M	M	0.53	0.00	1.11	1.12
126	1.59	0.00	M	M	0.48	0.00	1.11	1.16
127	0.70	0.00	M	M	0.78	0.00	1.06	1.14
128	0.59	0.00	M	M	0.40	1.00	0.95	1.04
129	0.80	0.00	M	M	0.91	0.00	0.88	1.01
130	0.65	0.00	1.25	0.73	0.82	0.00	1.36	1.13
131	0.79	0.00	1.55	1.26	0.42	4.00	1.59	1.41
132	0.45	2.40	1.22	1.19	0.35	22.00	1.62	1.56
133	1.03	0.00	0.75	0.81	1.03	14.00	1.81	1.78
134	1.07	0.00	0.82	0.75	0.96	0.00	1.86	1.87
135	1.21	0.00	0.90	0.83	1.35	0.00	1.91	1.97
136	1.25	0.00	1.25	0.96	1.04	0.00	2.05	1.96
137	1.46	0.00	1.77	1.07	1.16	0.00	2.37	2.38
138	1.11	2.11	2.19	1.52	0.71	1.00	2.47	2.45
139	1.04	0.00	1.83	1.02	2.06	4.00	2.58	2.55
140	1.09	12.90	1.66	1.23	2.34	0.00	2.57	2.52
141	2.85	0.00	1.60	1.31	1.64	1.00	2.49	2.32
142	1.86	0.00	1.74	1.20	1.43	0.00	1.97	1.25
143	2.44	0.00	1.63	0.96	1.31	0.00	1.84	1.03
144	1.07	25.30	1.82	0.99	1.10	8.00	1.97	0.84
145	2.21	0.00	2.02	1.37	2.20	0.00	1.98	0.93
146	1.29	0.00	1.86	1.02	1.97	0.00	1.73	0.95
147	1.55	0.85	1.70	0.87	2.19	0.00	2.03	1.01
148	0.95	0.00	1.79	0.93	1.24	7.00	2.54	1.57
149	1.95	5.30	1.70	0.68	3.22	0.00	2.22	1.09
150	3.62	0.00	1.67	0.92	3.01	0.00	2.61	1.21
151	2.46	3.60	1.60	1.00	3.10	0.00	2.88	1.58

Note: M* denotes missing data

152	3.78	6.30	1.68	0.62	4.16	0.00	3.00	1.65
153	1.43	0.00	1.71	0.51	3.70	0.00	3.22	1.31
154	2.46	0.00	1.73	0.83	4.52	0.00	3.71	1.35
155	5.20	0.00	1.44	0.82	3.70	0.00	4.37	1.93
156	3.35	0.00	1.55	1.07	1.06	1.00	4.83	1.61
157	3.82	0.00	1.84	1.27	2.19	2.00	4.64	1.40
158	3.20	0.00	1.67	1.42	3.67	6.00	4.36	1.23
159	4.97	0.00	1.80	1.31	4.08	0.00	4.11	1.30
160	5.19	0.00	2.32	1.73	4.74	0.00	3.83	1.22
161	1.71	0.00	2.89	2.10	2.76	0.00	4.54	1.03
162	5.23	0.00	2.89	1.87	2.72	4.00	5.00	1.64
163	3.69	0.00	2.84	1.48	6.37	0.00	4.72	1.34
164	1.86	25.30	2.65	1.46	6.21	0.00	4.62	2.01
165	3.69	0.00	2.41	1.77	5.11	0.00	4.17	1.14
166	3.97	0.00	2.48	2.26	5.87	0.00	4.10	1.26
167	4.37	0.00	2.45	2.19	4.58	0.00	4.05	1.43
168	4.94	0.00	2.50	1.96	3.01	4.00	3.99	1.18
169	6.07	0.00	2.27	1.51	5.28	1.00	4.26	0.99
170	5.43	0.00	2.29	1.21	3.57	0.00	4.07	1.39
171	4.11	0.00	2.88	1.18	1.11	19.00	4.09	1.85
172	5.58	0.00	3.29	0.96	6.39	21.00	3.74	2.19
173	6.39	0.00	3.95	1.36	3.68	0.00	3.37	2.31
174	6.46	0.00	4.28	1.36	5.20	6.00	2.92	2.57
175	7.01	0.00	4.34	1.38	4.69	0.00	2.98	2.83
176	6.98	0.00	4.42	1.41	3.07	24.00	3.72	3.42
177	7.26	0.00	4.62	0.91	3.56	2.00	3.75	4.29
178	6.67	0.00	5.09	1.09	5.11	7.00	3.74	4.42
179	6.30	0.00	5.10	1.14	1.43	14.00	3.79	4.45
180	7.15	0.00	5.50	0.90	5.47	23.00	3.88	4.56
181	8.13	0.00	6.28	1.39	3.51	18.00	4.18	3.45
182	7.39	0.00	6.49	1.46	7.12	0.00	4.42	5.01
183	2.68	0.00	7.01	1.53	7.45	0.00	4.69	5.01
184	8.05	0.00	6.69	1.40	7.30	0.00	4.49	4.71
185	4.79	5.10	6.70	1.43	6.92	5.00	4.49	4.71
186	4.94	0.00	6.63	1.38	7.83	1.00	4.45	4.67
187	6.79	0.00	6.46	1.03	6.52	0.00	3.98	4.13
188	3.72	0.00	6.00	1.13	7.08	0.00	3.88	4.00
189	6.93	0.00	5.58	1.56	6.54	0.00	3.70	3.96
190	7.65	0.00	5.63	1.22	7.21	1.00	3.50	4.05
191	7.73	0.00	5.98	1.41	2.04	16.00	3.32	3.94
192	7.81	0.00	5.98	1.55	7.28	0.00	3.02	3.32
193	7.87	0.00	6.33	1.79	7.21	0.00	2.87	3.23
194	8.21	0.00	6.37	1.72	6.10	0.00	2.44	2.06
195	6.61	0.00	6.20	1.72	6.17	0.00	2.22	1.44

196	6.57	0.00	6.19	1.83	8.79	0.00	2.57	0.85
197	7.31	0.00	6.09	1.69	7.40	0.00	3.42	1.12
198	6.89	0.00	6.18	1.74	7.08	0.00	4.30	1.07
199	5.88	0.00	6.04	1.68	7.44	0.00	4.61	1.17
200	2.56	5.30	5.59	2.00	6.14	0.00	4.66	1.23
201	3.98	0.00	4.97	1.82	7.11	0.00	4.67	1.42
202	5.85	0.00	4.59	2.11	5.79	0.00	4.79	1.70
203	6.57	0.00	3.79	2.22	6.01	0.00	5.27	1.41
204	5.40	0.00	3.31	1.61	6.19	0.00	5.32	0.87
205	4.81	0.00	3.45	1.29	7.07	0.00	5.79	1.83
206	2.88	15.40	3.83	1.65	6.43	0.00	5.57	1.66
207	4.31	0.00	3.80	2.01	7.65	0.00	5.36	1.92
208	5.92	0.00	3.74	2.68	6.03	0.00	4.92	1.94
209	6.21	0.00	2.57	2.10	5.96	0.00	4.57	1.07
210	5.61	0.00	2.41	1.45	7.03	0.00	4.58	1.17
211	6.38	0.00	2.55	1.07	5.72	1.00	4.97	1.37
212	4.49	5.10	3.67	1.45	5.88	0.00	5.21	1.41
213	6.07	0.00	3.90	1.46	1.39	16.00	5.22	2.43
214	5.50	6.50	3.73	1.03	4.95	1.00	4.91	3.14
215	4.91	0.00	3.60	1.63	6.21	0.00	4.43	2.78
216	5.71	0.00	3.43	1.31	5.53	0.00	3.96	2.46
217	5.41	0.00	3.43	1.89	4.77	0.00	4.06	2.65
218	6.97	0.00	3.68	2.16	4.26	0.00	3.75	2.05
219	6.29	0.00	3.44	1.43	4.77	0.00	3.62	1.97
220	5.01	0.00	4.00	1.08	4.60	0.00	3.61	1.49
221	4.97	0.00	4.02	1.32	4.02	0.00	4.18	1.30
222	4.83	0.00	4.31	1.45	3.25	1.00	4.04	1.77
223	4.52	0.00	4.52	1.60	2.87	3.00	3.84	1.90
224	4.35	0.00	3.90	1.82	2.74	9.00	3.82	1.85
225	4.26	0.00	4.00	1.57	2.77	13.20	3.65	1.87
226	4.22	0.00	4.55	1.70	3.08	1.00	3.00	2.11
227	4.17	0.00	4.66	1.67	2.45	0.00	3.17	2.00
228	4.52	0.00	4.27	1.27	3.49	0.00	3.18	2.59
229	3.56	0.00	3.92	1.92	3.42	0.00	3.25	2.77
230	2.76	0.00	3.67	0.94	3.49	0.00	3.40	3.09
231	2.36	0.00	3.49	0.77	3.75	0.00	3.64	2.87
232	2.56	0.00	3.26	0.77	3.20	0.00	3.60	1.75
233	3.51	0.00	0.00	0.73	3.07	0.00	3.06	1.26
234	4.36	0.00	0.00	0.91	3.06	0.00	3.16	1.67
235	3.35	0.00	0.00	0.79	2.38	0.00	3.33	1.84
236	0.92	12.90	0.00	0.90	2.64	0.00	3.36	2.01
237	0.72	0.00	0.00	0.89	2.18	0.00	3.39	1.67
238	0.89	0.00	0.00	0.73	3.25	0.00	3.50	1.27
239	3.57	0.00	2.62	0.71	2.68	0.00	4.45	1.91

240	4.07	0.00	2.20	1.34	2.69	0.00	4.73	1.69
241	2.99	0.00	2.57	1.25	2.35	0.00	4.79	1.63
242	4.35	0.00	2.38	1.27	2.45	0.00	4.91	1.30
243	4.01	0.00	2.00	1.16	2.35	0.00	4.58	1.39
244	2.95	0.00	2.09	0.65	2.35	0.00	4.22	1.20
245	2.74	0.00	2.28	1.04	2.21	0.00	4.25	0.43
246	2.49	0.00	2.38	1.12	2.21	0.00	M*	M
247	2.82	0.00	2.70	1.03	2.31	0.00	M	M
248	3.01	0.00	2.69	0.74	2.36	0.00	M	M
249	2.69	0.00	2.69	1.23	2.21	0.00	M	M
250	3.31	0.00	2.38	1.01	1.63	0.00	M	M
251	2.27	0.00	2.37	1.19	0.87	0.00	M	M
252	2.45	0.00	2.56	1.55	1.81	0.00	M	M
253	2.73	0.00	2.28	1.54	0.96	0.00	M	M
254	2.36	0.00	2.05	1.69	1.77	0.00	M	M
255	2.47	0.00	1.82	1.46	1.87	0.00	M	M
256	2.00	0.00	1.91	1.31	1.20	0.00	M	M
257	1.90	0.00	1.64	1.17	1.06	2.00	M	M
258	1.10	0.00	2.06	1.10	1.33	0.00	M	M
259	1.46	0.00	2.10	1.31	0.63	2.00	M	M
260	0.90	0.00	1.58	1.09	0.65	0.00	M	M
261	0.91	0.00	1.47	0.85	0.79	0.00	M	M
262	0.92	0.00	1.38	0.56	1.06	0.00	M	M
263	0.82	0.00	1.79	0.90	0.97	0.00	M	M
264	0.86	0.00	1.70	0.51	0.46	0.00	M	M
265	0.84	0.00	1.78	0.45	0.74	0.00	M	M
266	1.28	0.00	1.82	0.38	0.85	0.00	M	M
267	1.15	0.00	1.84	0.38	1.03	0.00	M	M
268	1.09	0.00	2.19	0.60	0.81	0.00	M	M
269	0.73	0.00	2.37	0.78	0.77	0.00	M	M
270	0.73	0.00	2.27	0.61	0.83	0.00	M	M
271	0.68	0.00	2.29	0.87	0.75	0.00	M	M
272	1.01	0.00	1.98	0.68	0.37	0.00	M	M

Note: M* denotes missing data.