IRRIGATION CONVEYANCE LOSS

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Eastern Snake Plain Aquifer Model Enhancement Project Scenario
Document DDW-020 Final As-built

DESIGN DOCUMENT OVERVIEW

Design documents are a series of technical papers addressing specific design topics on the Eastern Snake Plain Aquifer Model Enhancement Project. Each design document will contain the following information: topic of the design document, how that topic fits into the whole project, which design alternatives were considered and which design alternative is proposed. In draft form, design documents are used to present proposed designs to reviewers. Reviewers are encouraged to submit suggested alternatives and comments to the design document. Reviewers include all members of the Eastern Snake Hydrologic Modeling (ESHM) Committee as well as selected experts outside of the committee. The design document author will consider all suggestions from reviewers, update the draft design document, and submit the design document to the Eastern Snake Plain Model Enhancement Project Model Upgrade Program Manager. The Program Manager will make a final decision regarding the technical design of the described component. The author will modify the design document and publish the document in its final form in .pdf format on the ESPAM web site.

The goal of a draft design document is to allow all of the technical groups which are interested in the design of the ESPAM Enhancement to voice opinions on the upgrade design. The final design document serves the purpose of documenting the final design decision. Once the final design document has been published for a specific topic, that topic will no longer be open for reviewer comment. Many of the topics addressed in design documents are subjective in nature. It is acknowledged that some design decisions will be controversial. The goal of the Program Manager and the modeling team is to deliver a well-documented, defensible model which is as technically representative of the physical system as possible, given the practical constraints of time, funding and manpower. Through the mechanism of design documents, complicated design decisions will be finalized and documented. Final model documentation will include all of the design documents, edited to ensure that the “as-built” condition is appropriately represented. This is the final as-built document for conveyance loss in irrigation canals.

INTRODUCTION

Some of the water lost from irrigation is seepage from canals and ditches. This water is not available for irrigation and therefore neither available for crop evapotranspiration (ET) nor for recharge associated with irrigated agricultural fields. However, the leakage is still a component of recharge associated with irrigation activity. Seepage from canals can be an important source of aquifer recharge. Long canals in porous soils can loose 40% or more of the water diverted from the source (Chavez-Morales 1985). In Idaho’s climate, virtually all of this loss is associated with leakage to the aquifer (Dreher and Tuthill 1999).[1] This Design Document explores options for treating canal leakage in the water budget.

SPATIAL DISTRIBUTION OF LOSSES

One possible approach is to identify the locations and volumes of all canal leakage, and apply the volumes as aquifer recharge at those locations (Booker et al 1990). To keep the water budget in balance, all water applied as leakage must be subtracted from irrigation supply, before calculating recharge from irrigation:

$$\text{Field Delivery} = \text{Diversions} - \text{Canal Leakage} - \text{Return Flows} \qquad \text{(eq. 1)}$$

$$\text{Net Recharge (surface water source)} = (\text{Field Delivery} + \text{Precipitation}) - (\text{ET} \times \text{Adjustment Factor}) \qquad \text{(eq. 2)}$$

Another option is to ignore canal loss entirely, and assume that all diverted water is applied to the place of use. The “leakage” term in the field delivery calculation becomes zero. If the other terms are correct, this option gives the correct total volume of recharge, even if canal leakage actually does occur. If the leaky canals are contiguous with the irrigated place of use, and if the spacing between channels is small relative to model cell size, the spatial distribution of recharge will be approximately correct, as well.

Most canal systems have a large main canal or canals, supplying secondary laterals. These in turn supply individual farm ditches. Because size, construction, and maintenance of laterals and farm ditches is highly variable, estimating leakage on these secondary conveyances is difficult. Alternate wetting and drying can damage the “skin of sediment and biological slime” that helps seal canals. Smaller channels have more frequent drying cycles, and have more wetted perimeter relative to total flow capacity, so losses in these ditches are often higher than in main canals (Hubble 1991). These laterals and farm ditches are widely distributed across irrigated areas. For these reasons, the simplified approach often closely reflects reality. Figure 1 shows the spatial distribution of canals in relationship to irrigated lands and model cells in one part of the study area.

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[1] Dreher and Tuthill point out that transpiration from plants in or near the channel can also be a significant loss. However, canal maintenance programs virtually eliminate this loss on the large canals of interest within the study area.

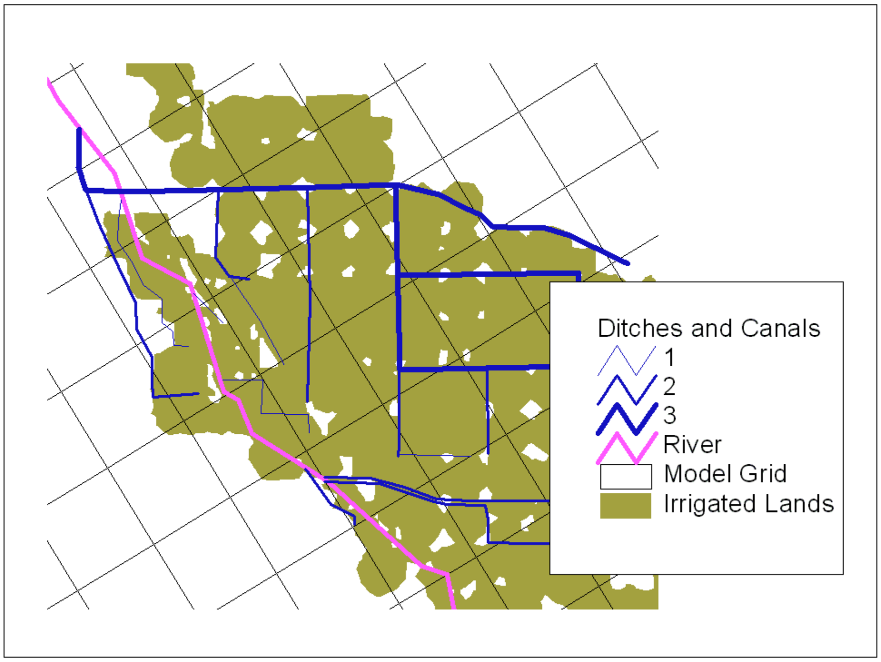

Figure 1. Spatial Distribution of Canals and Irrigated Lands,
Little Lost River

In prior Eastern Snake Plain models, a mixed approach has been taken. Garabedian (1992) treated three canals - Aberdeen-Springfield (95,000 acre feet/year), Milner-Gooding (97,000 acre feet/year), and Reservation (11,000 acre feet/year) - as leaky. IDWR (1997) treated only the Milner-Gooding Canal as leaky and attributed 146,000 acre feet of annual leakage to that canal. In both models, all other canal leakage was assumed to have similar spatial distribution as the irrigated lands.

In the Eastern Snake Plain Model Enhancement project, Northside, Milner-Gooding and Aberdeen-Springfield canals are represented as leaky. These are high-volume canals with significant leakage along reaches that do not correspond with the irrigated places of use.

Calculation and Expression of Losses

Seepage is a function of the infiltration rate of the bed material, the wetted perimeter, and the head (depth of water) in the canal. Because wetted perimeter and head can vary with flow, there is conceptual justification for using a percentage of flow to describe leakage. This is sometimes done in irrigation system assessment (Hubble 1991) and has been used in aquifer modeling (Booker et al 1990).

If the canal is significantly wider than it is deep, a small change in depth produces a large change in cross-sectional area with little change in wetted perimeter. Flow can increase substantially with only a small change in the component of leakage associated with wetted perimeter. The Manning's Equation (US Bureau of Reclamation 1984) shows that even with narrower channels, depth has a compound effect on flow rate (as a positive component of area and as a positive component of hydraulic radius).

$$Q = (\text{Area})(1.486/n)(\text{Hydraulic Radius})^{2/3}(\text{Slope})^{1/2} \qquad \text{(eq. 3)}$$

Where: Factor "n" is a roughness factor, and hydraulic radius is area divided by wetted perimeter.

For a given channel, depth and therefore changes in head-related leakage will increase more slowly than flow rate. Furthermore, sometimes stage is controlled by diversion works or check structures rather than flow. In this case, wetted perimeter and head are virtually independent of flow. These factors justify conceptual treatment of leakage as a volume per time per length of canal, or as a depth per time applied to average wetted area (Hubble 1991). This is the approach chosen by IDWR for water-right recommendations in the Snake River Basin Adjudication (Dreher and Tuthill 1999), and this approach has been used in aquifer modeling (Garabedian 1992, IDWR 1997).

Figure 2 shows average actual losses expressed as volumes and as percentages, from inflow-outflow measurements over a 14-year period on a large canal in Mexico. The canal bottom was composed of approximately two feet of clay-based materials over a sandy soil. The irrigation season starts in October, with largest diversion volumes occurring in the winter months. October is month one on the horizontal axis. The variation in the loss volume line illustrates the potential inaccuracy of treating leakage as a fixed rate per time, while the variation in the percentage line illustrates the potential inaccuracy of treating leakage as a percentage of diversion volume.

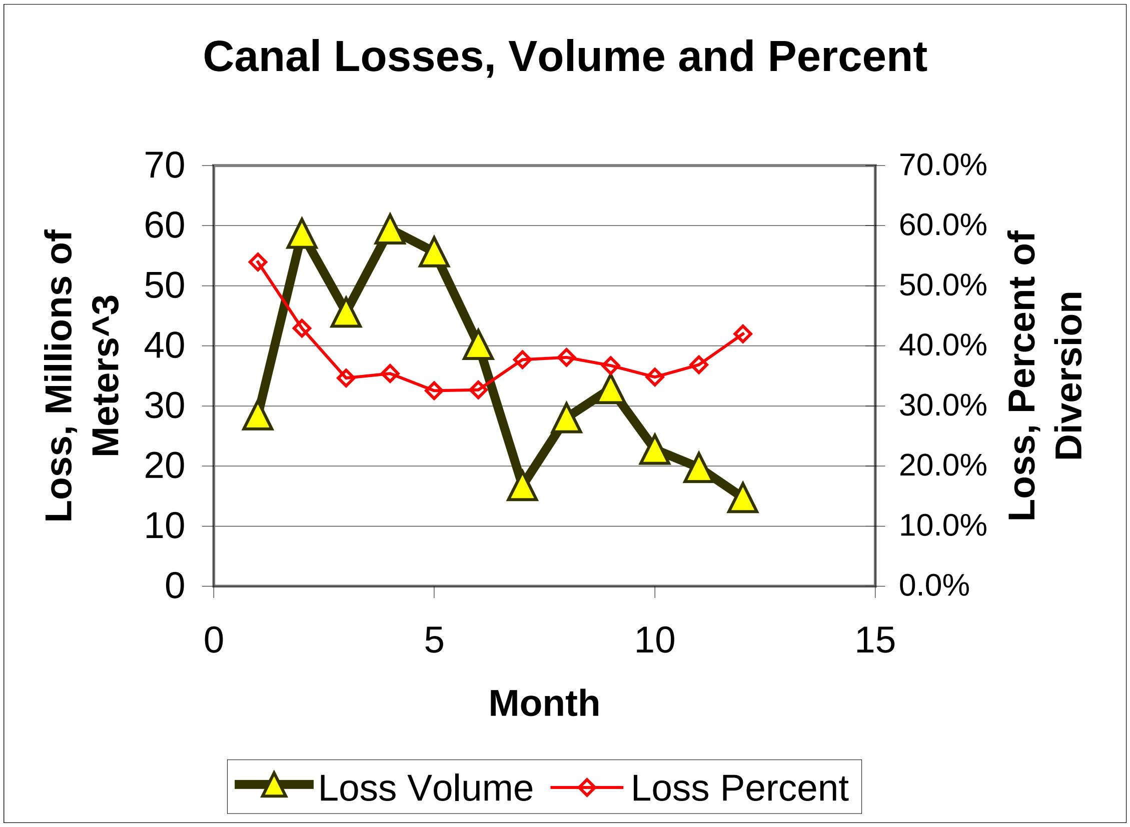

Figure 2. Canal Losses, Volume and Percent. (Calculated from data in Chavez-Morales 1985 and Excebio-Garcia et al circa 1985.)

Because both fixed-rate and percentage-based leakage rates are supported in the literature and can be justified conceptually, either is a candidate for use in the Eastern Snake Plain Aquifer Model Enhancement. Since a percentage-based calculation showed less month-to-month variability in the Mexico data, and since a percentage calculation guarantees that there will never be leakage calculated in a period without diversions, a percentage-based method was selected for the Eastern Snake Plain Aquifer Model Enhancement effort. Canal leakage was applied to linear GIS features representing leaky sections of canal. The recharge tools accommodate multiple leaky canal sections, each with a unique leakage rate, per irrigation entity. Locations and leakage rates were assigned based on interviews with canal company personnel and results of previous studies. Some laterals of the Northside Canal were added in response to comparisons between model-predicted hydrographs and observed hydrographs at some wells, during early stages of calibration. For the Northside and Milner-Gooding canals, a constant leakage rate was used throughout the study period. For the Aberdeen-Springfield canal, unique values were assigned to each stress period based on canal-company data (Howser 2002).

There is indication that parts of the Aberdeen-Springfield Canal are interconnected with the aquifer, so that leakage rates may be controlled in part by aquifer water levels (Warner 2002). Because aquifer-level depressions caused by well pumping may induce increased leakage from the canal, increased canal leakage may partly offset impacts that well pumping might otherwise have had upon the river and spring flows. If this actually occurs, it would be desirable that the model be able to represent it. Initial calibration efforts tested the possibility of treating the Aberdeen-Springfield Canal as an interconnected river reach, with the leakage calculated from the canal company data as a calibration target. Final calibration relied on the fall-back position of representing leakage from the Aberdeen-Springfield Canal as a percentage of diversions.

TEMPORAL DISTRIBUTION OF LEAKAGE

Actual temporal distribution of leakage is non-uniform, as illustrated in Figure 2. Losses can change year-to-year due to siltation (Dreher and Tuthill 1999) or mechanical disturbance (Excebio-Garcia et al circa 1985). However, leakage rates should stabilize as a system matures and a regular maintenance schedule is adopted. The Mexico data show stable year-to-year leakage patterns, and all the systems within the study area have been in place for decades.

Leakage can also vary within a season. Generally losses are highest in the early part of the season, then tend to decrease and stabilize unless something causes a change. A freezing or drying cycle, changes in the water table,[2] damage to the bed, or increased wetted perimeter due to plant growth slowing flows can cause a mid-season increase in leakage rate (Dreher and Tuthill 1999). Figure 2 illustrates that after higher startup losses, percentage losses in the Mexico system stayed within a narrow range throughout the irrigation season. The early high leakage percentage appears to be a double effect of higher initial infiltration rates and higher wetted-perimeter-to-flow ratio due to lower flows. A numerical infiltration model calibrated to the data indicated that infiltration rate (volume per area per time per unit head) stabilized after only a few days (Excebio-Garcia et al circa 1985).

In previous Eastern Snake Plain studies, seepage rate (as a volume per time per length) has been held constant over a season (Garabedian 1992, IDWR 1997), though the capability of varying seepage within a season has been explored (Johnson and Brockway 1983). In another United States study, canal seepage was treated as a constant percentage of diversions in a model with two-week stress periods (Booker et al 1990).

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[2] From examination of depth-to-water maps it appears that only the Aberdeen-Springfield Canal is potentially connected with the aquifer, of the canals selected for leaky-canal representation.

It has been suggested that varying canal seepage within a season may allow a better fit to measured heads in wells. While it is acknowledged that intra-season variation in canal leakage may occur, and that these differences may propagate into aquifer heads, adequate data were not available to adequately represent these conditions for the calibration period. Leakage rates were based on interviews with canal personnel, checked against Garabedian's (1992) and IDWR's (1997) work. Two cycles of interviews indicated that leakage has been relatively constant during the calibration period. Because imprecision in calculating canal leakage affects only the spatial distribution and not the total amount of recharge, and because of the danger of introducing even more error by synthesizing data, canal leakage for the model calibration period was estimated as a constant percentage of diversion volume. To allow for future testing of various scenarios, the GIS and FORTRAN recharge tools will allow unique canal leakage percentages to be applied to each stress period. The data available from the Aberdeen-Springfield Canal Company are annual volume totals and so the fractions calculated were based upon annual volumes.

The calibrated model can be used to investigate the effect of different canal-leakage assumptions. In addition to the adjusting the leakage percentages automatically applied to diversion volumes, specific leakage volumes associated with individual locations or time periods may be directly applied to the model using the GIS tool's scenario-point capacity.[3]

DESIGN DECISION

Canal leakage was calculated as a percentage of diversion volume for portions of the Aberdeen-Springfield, Northside and Milner-Gooding canals. Leaky canal reaches were represented by GIS line shapes illustrated in Figure 3. The data table in Appendix A lists leakage rates assigned as a fraction of diversions, for each stress period. Three leaky sections - Northside Main, Wilson Lake, and Northside Laterals - were assigned to entity IESW032. Locations and leakage rates were based on interviews with canal company personnel and previous work (Garabedian 1992, IDWR 1997). Uncertainties in leakage data do not affect the water budget balance, but only the spatial distribution of recharge.

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[3] Users will need to take care to subtract from diversions any volumes assigned to scenario points, prior to calculating recharge from irrigation.

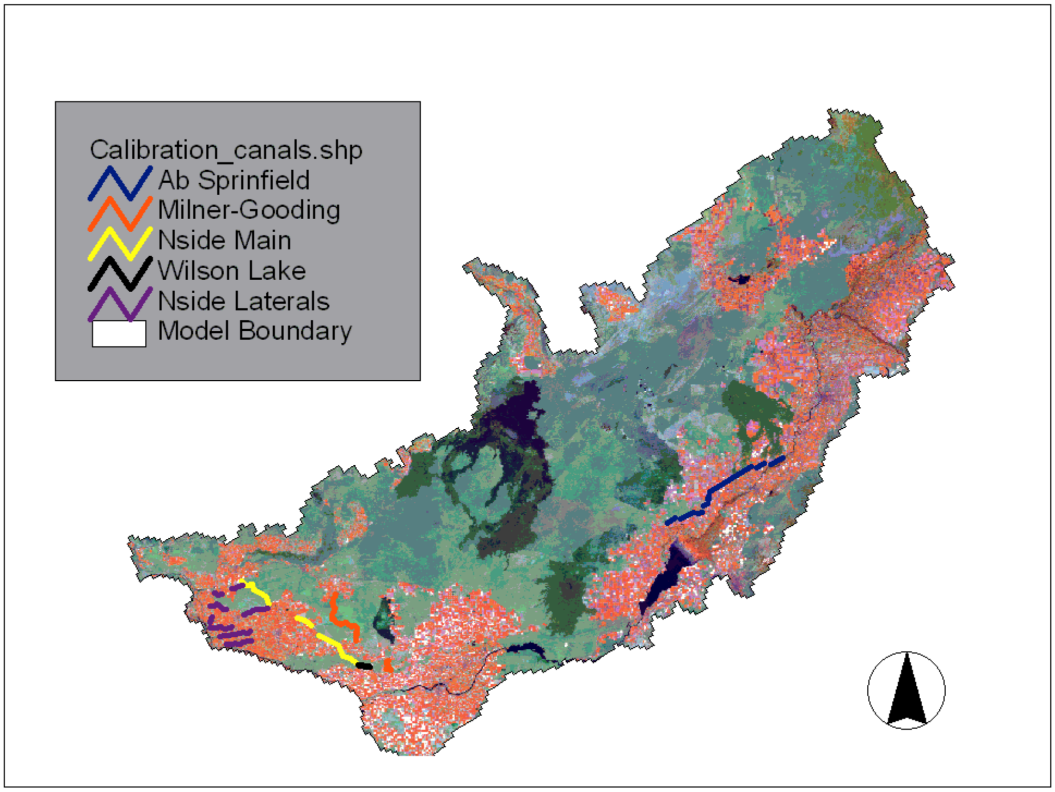

Figure 3. Map of leaky canals used in model calibration.

The GIS tool identifies the model cells to which recharge is applied, and hands cell ID, entity ID, number of leaky cells per canal reach and leakage rate to the FORTRAN-language recharge program. The FORTRAN program calculates the volume of recharge per model cell using actual entity diversion volumes. It also calculates the total leakage for each irrigation entity and subtracts it from diversion volume, prior to calculation of surface-water irrigation recharge. For other irrigation entities the “canal leakage” term in the calculations

Field Delivery = Diversions - Canal Leakage - Return Flows (eq. 1)

Net Recharge (surface water source) = (eq. 2)
(Field Delivery + Precipitation) - (ET x Adjustment Factor)

was zero. This effectively applied all leakage from canals, laterals, and farm ditches for those entities uniformly over the irrigated area served by the irrigation entity. The scenario-generation capabilities of the GIS recharge tool allow users to apply different assumptions during use of the calibrated model.

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Appendix A. Leakage Fraction Applied to Diversion Volume, By Stress Period

CANAL_ID	Name	SP001	SP002	SP003	SP004	SP005	SP006	SP007	SP008	SP009	SP010
	Start Month	May-80	Oct-80	May-81	Oct-81	May-82	Oct-82	May-83	Oct-83	May-84	Oct-84
007-Canal	Milner-Gooding	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
032-Canal	Northside Main	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
032-Lake	Wilson Lake	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
002-Canal	Aberdeen-Springfield	0.26	0.40	0.42	0.37	0.39	0.31	0.33	0.33	0.30	0.30
032-Rim	Northside Laterals	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

CANAL_ID	Name	SP011	SP012	SP013	SP014	SP015	SP016	SP017	SP018	SP019	SP020
	Start Month	May-85	Oct-85	May-86	Oct-86	May-87	Oct-87	May-88	Oct-88	May-89	Oct-89
007-Canal	Milner-Gooding	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
032-Canal	Northside Main	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
032-Lake	Wilson Lake	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
002-Canal	Aberdeen-Springfield	0.36	0.36	0.26	0.26	0.40	0.40	0.42	0.42	0.37	0.37
032-Rim	Northside Laterals	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

CANAL_ID	Name	SP021	SP022	SP023	SP024	SP025	SP026	SP027	SP028	SP029	SP030
	Start Month	May-90	Oct-90	May-91	Oct-91	May-92	Oct-92	May-93	Oct-93	May-94	Oct-94
007-Canal	Milner-Gooding	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
032-Canal	Northside Main	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
032-Lake	Wilson Lake	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
002-Canal	Aberdeen-Springfield	0.39	0.39	0.31	0.31	0.51	0.51	0.43	0.43	0.47	0.47
032-Rim	Northside Laterals	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

CANAL_ID	Name	SP031	SP032	SP033	SP034	SP035	SP036	SP037	SP038	SP039	SP040
	Start Month	May-95	Oct-95	May-96	Oct-96	May-97	Oct-97	May-98	Oct-98	May-99	Oct-99
007-Canal	Milner-Gooding	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
032-Canal	Northside Main	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
032-Lake	Wilson Lake	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
002-Canal	Aberdeen-Springfield	0.43	0.43	0.41	0.41	0.38	0.38	0.39	0.39	0.39	0.39
032-Rim	Northside Laterals	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

CANAL_ID	Name	SP041	SP042	SP043	SP044						
	Start Month	May-00	Oct-00	May-01	Oct-01						
007-Canal	Milner-Gooding	0.15	0.15	0.15	0.15						
032-Canal	Northside Main	0.05	0.05	0.05	0.05						
032-Lake	Wilson Lake	0.05	0.05	0.05	0.05						
002-Canal	Aberdeen-Springfield	0.42	0.42	0.49	0.49						
032-Rim	Northside Laterals	0.10	0.10	0.10	0.10						