MEMORANDUM

To: ESHMC
Fr: Bryce Contor
Date: 6 February 2008

Re: Recharge from canal seepage for ESPAM 2

At the ESHMC meeting, discussion of recharge from canal seepage included the following important points:

1. The full ESHMC generally agreed we should expand the representation of leaky canals to include most major canals, but not laterals or field ditches.
2. IWRRI agreed to revisit the Mexico data that were considered in deciding the ESPAM1.1 representation, as well as to look at data from the Republican River Basin in Nebraska provided by Dr. Schreuder.
3. Geology of the Republican Basin and the Mexico canals will be different from geology of the Eastern Snake Plain.
4. We are not interested in canal leakage per se, but only in the recharge that results from canal leakage. Early-season high leakage rates may indicate charging of bank storage and the wetted bulb below the canal, rather than an actual higher aquifer recharge rate.

This memo reports on the results of reviewing the Mexico data, as well as data provide by Dr. Schreuder and data provided by Aberdeen-Springfield Canal Company. It also considers possible application of the findings to ESPAM 2 calibration and discusses implementation with the Recharge Tool.

Data

The Mexico data represent a 14-year average of monthly seepage volume and seepage fraction, as shown in Figure 2 of Design Document DDW-020 from ESPAM1.1 (http://www.if.uidaho.edu/%7ejohnson/DDW020_Leak_Asbuilt%20_9_2_04.pdf). For this investigation, diversion volumes were back calculated from seepage volumes and fractions.

The Nebraska (Republican River) data represent 30 to 40 years of monthly diversion and loss volumes on US Bureau of Reclamation canals. Dr. Schreuder reported that US Bureau of Reclamation has defined a fixed-percentage partition of losses to evaporation and seepage. This was not applied in the assessment, since the purpose of this investigation was to understand processes and relationships rather than to establish exact seepage fractions.

The Aberdeen-Springfield Canal data include daily diversions and losses for 2002 through 2006, provided by the canal company. These were summed into monthly values for this evaluation. ESPAM1.1 data include diversion and loss fractions for earlier years also, but these were not examined here.

Methods

The first effort applied was to graph cross plots of annual diversions versus losses for the Republican data, by decade. This was done in order to determine if relationships have changed over time. The Mexico data were an average of a relatively short time period and there were only five years of Aberdeen-Springfield data considered, so this activity was not applied to those data.

The second effort was to plot diversion and loss relationships by month, considering "prior months of diversion," or months since wetting. This was done to test for both diversion/seepage and time/seepage relationships.

The third effort was to consider various prediction equations to represent what the data appeared to show.

Results

Visual inspection of the cross plots suggested no long-term changes in seepage relationships in the Nebraska canals, as shown in Figures 1 through 4. This has no particular meaning for the Snake Plain but it suggested that it would be valid to consider all the Nebraska data in further analysis.

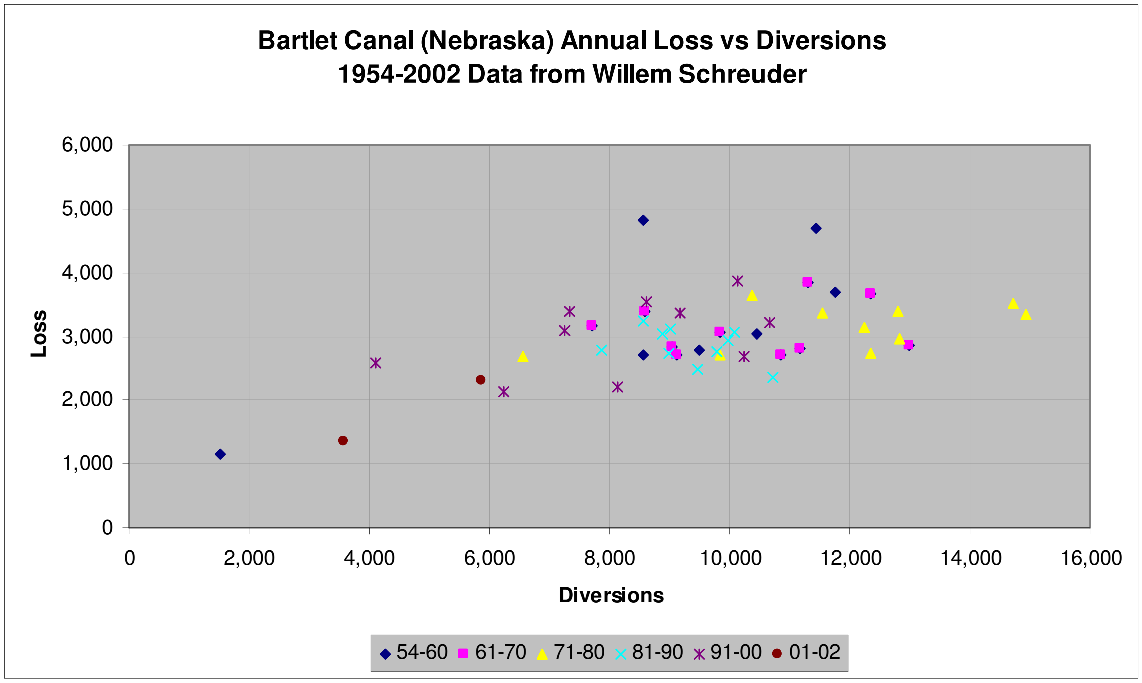

Figure 1. Bartlet Canal loss vs. Diversion. Acre feet.

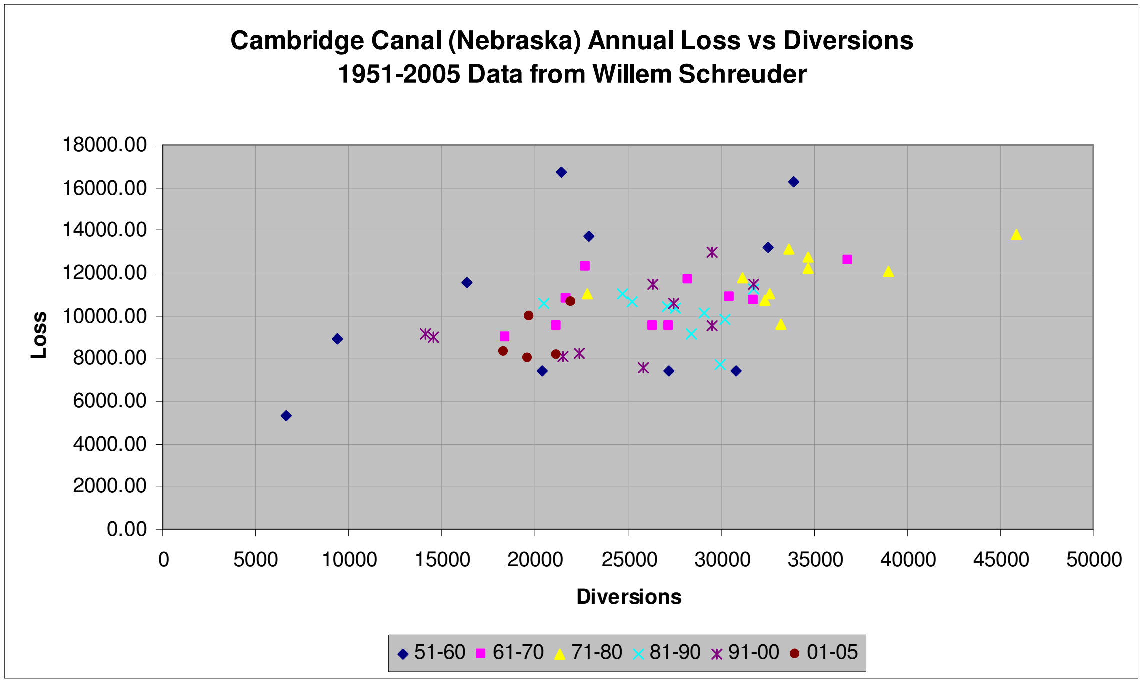

Figure 2. Cambridge Canal loss vs. Diversion. Acre feet.

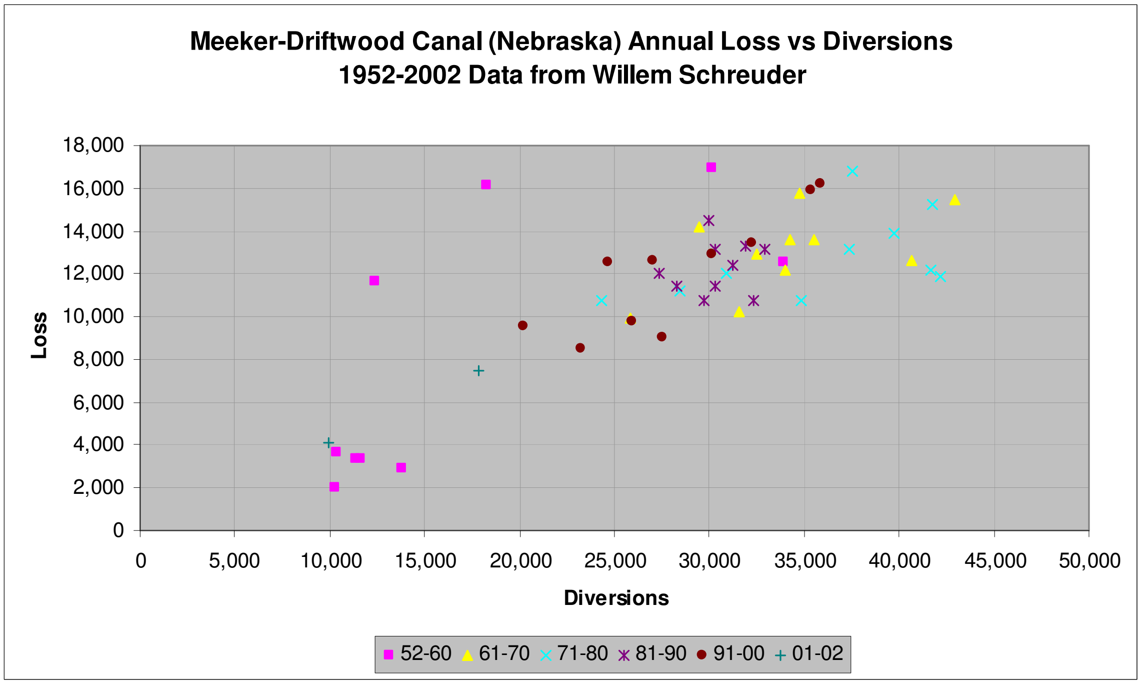

Figure 3. Meeker Driftwood Canal loss vs diversions, acre feet.

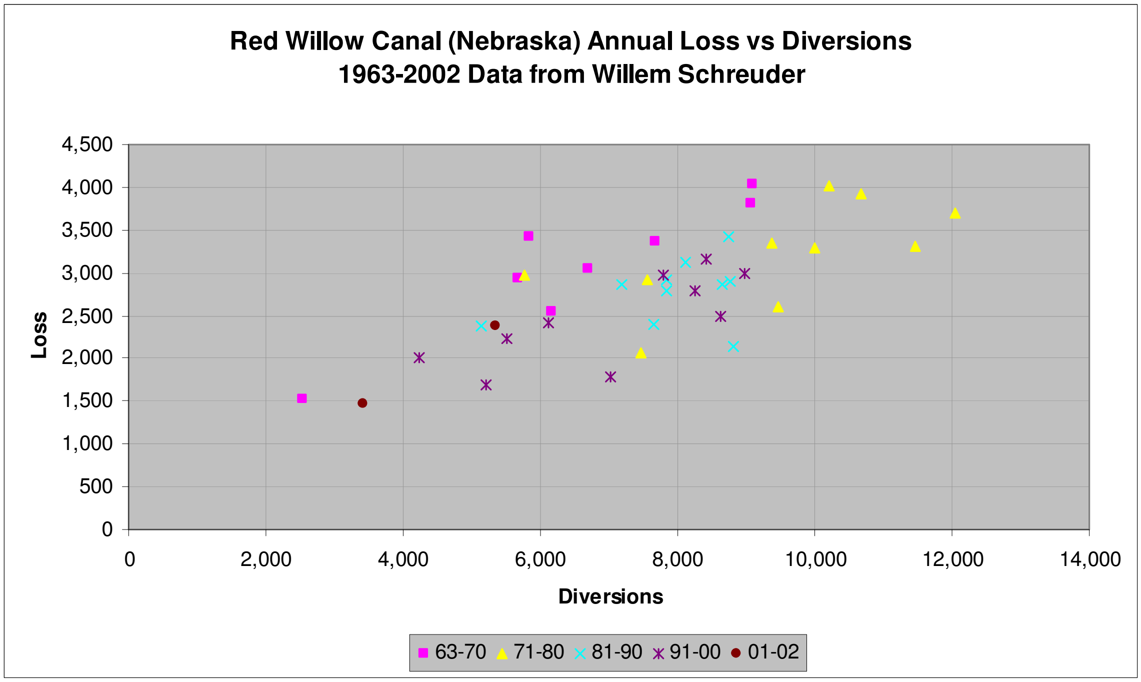

Figure 4. Red Willow Canal loss vs. diversions, acre feet.

The next effort was to consider loss relationships by the number of months since the canal was wetted. Figures 5 through 10 show loss fraction (losses/diversions) plotted against diversions. In the figures, the "P" values indicate the number of months of "Prior Wetting" before the month for which the loss/diversion relationship is illustrated. Red colors indicate fewer months of prior wetting, with blue colors indicating more months of prior wetting. All the canals exhibited higher seepage fractions with lower diversion volumes, and all showed tendency for greater seepage in the first months after wetting.

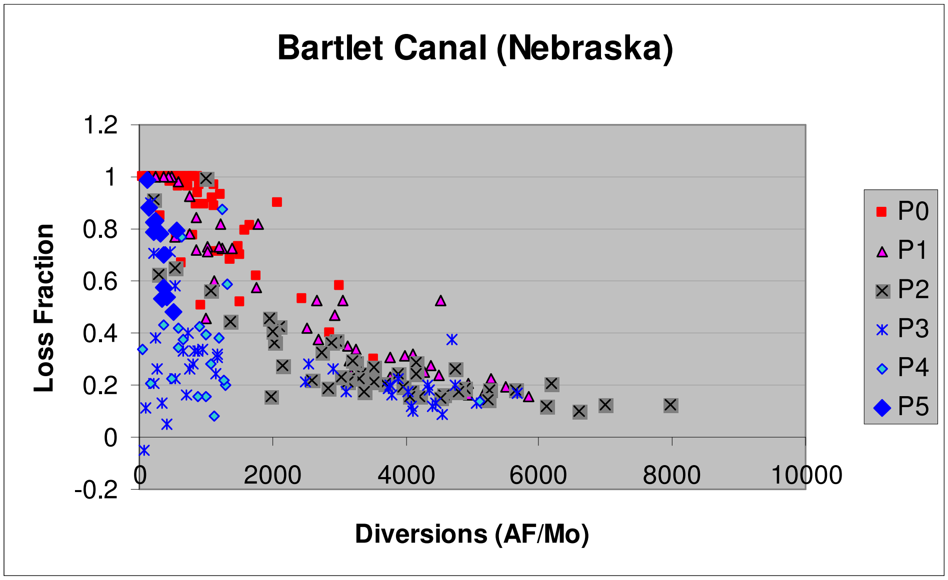

Figure 5. Bartlet Canal loss fractions by months of prior wetting.

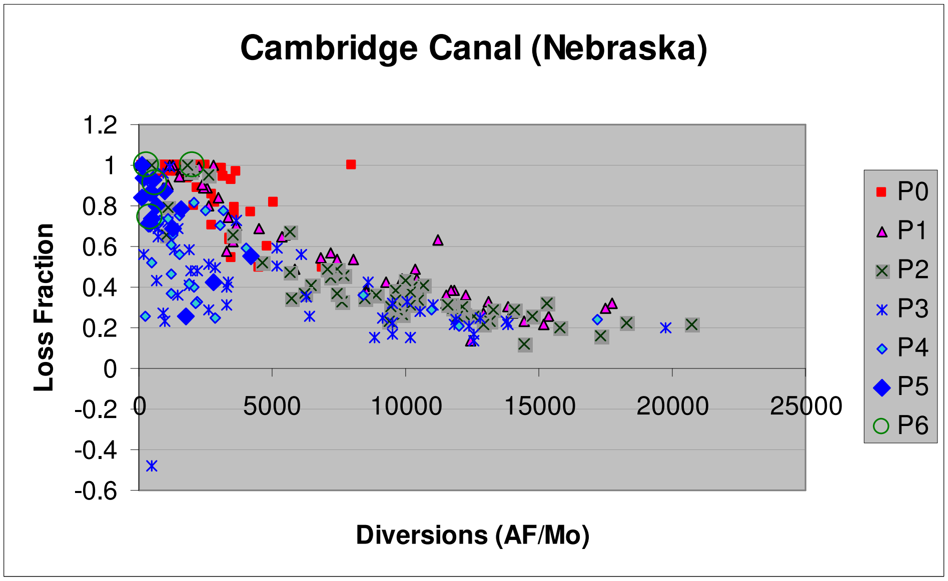

Figure 6. Cambridge Canal loss fractions by months of prior wetting.

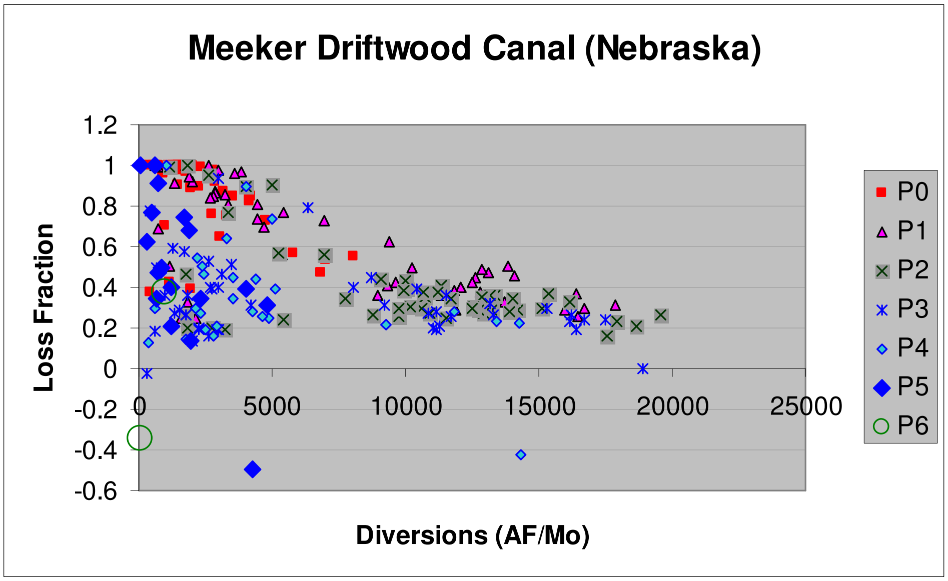

Figure 7. Meeker Driftwood Canal loss fractions by months of prior wetting.[1]

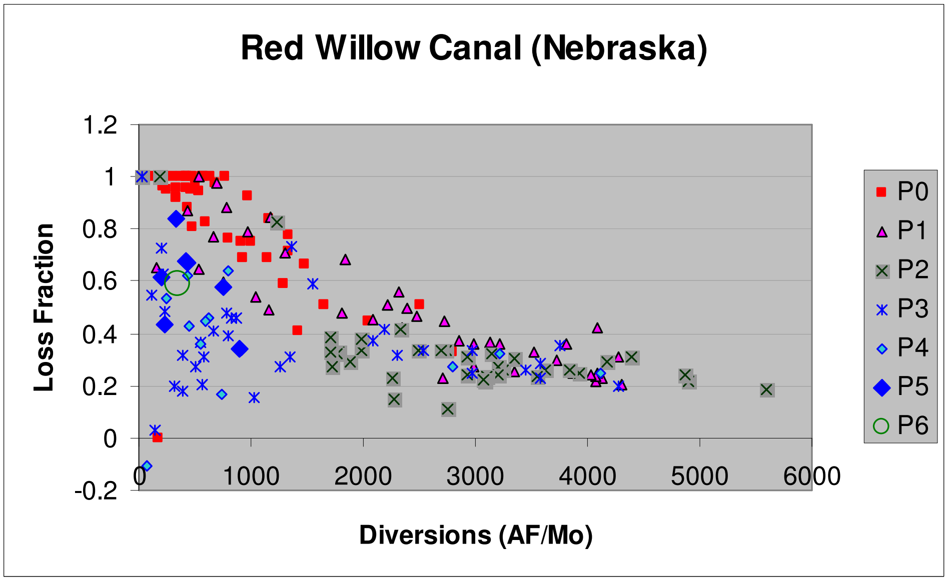

Figure 8. Red Willow Canal loss fractions by months of prior wetting.

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[1] One data point (suggesting 700% losses) was removed.

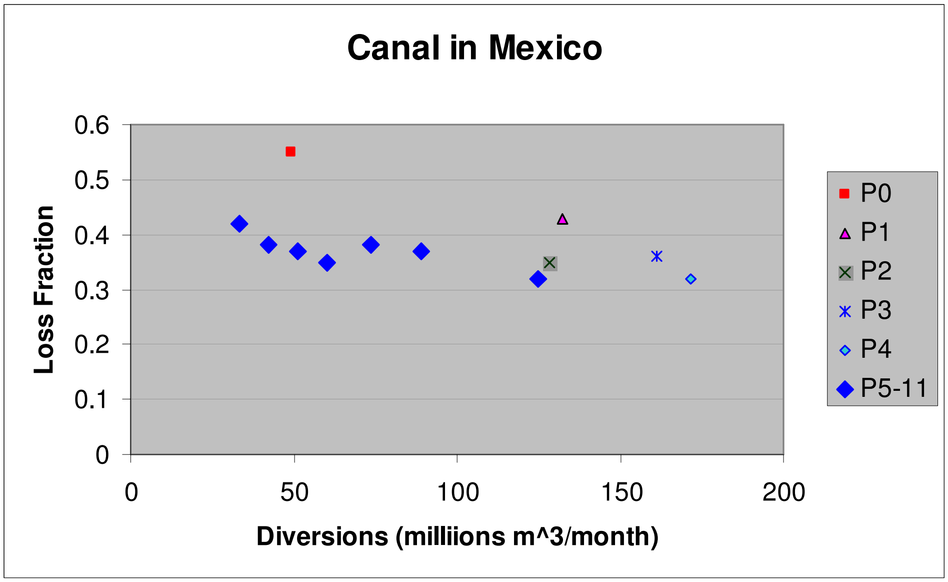

Figure 10. Mexican canal loss fractions by months of prior wetting. These are average values from 14 years of data.

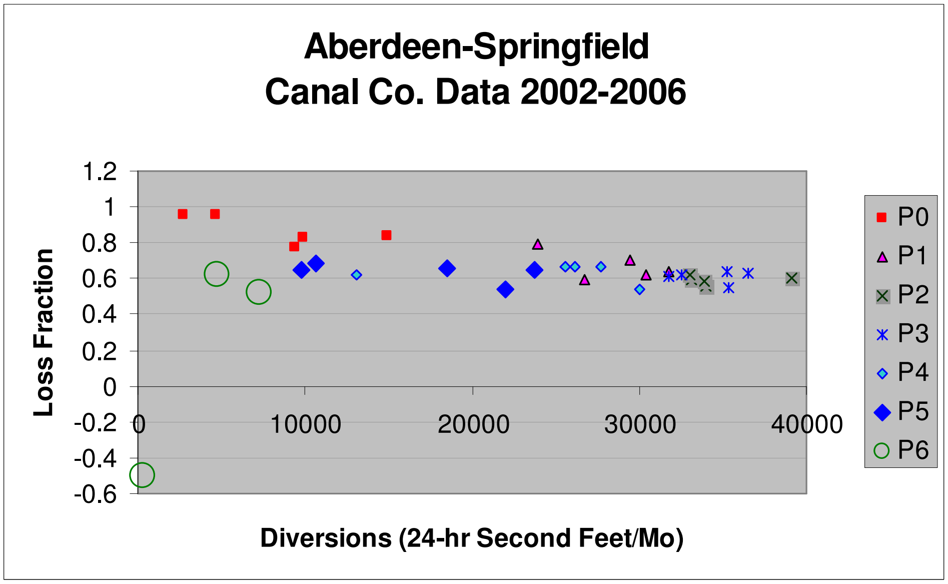

Figure 11. Aberdeen-Springfield Canal loss fractions by months of prior wetting.

The data in Figures 5 through 11 suggested a possible logarithmic relationship. Figure 12 shows a regression for the Bartlet Canal which represents canal losses as a linear function of the natural logarithm of diversions. The regression is statistically significant (P-value less than 0.001) and the r^2 (indicating predictive power) is 0.48.

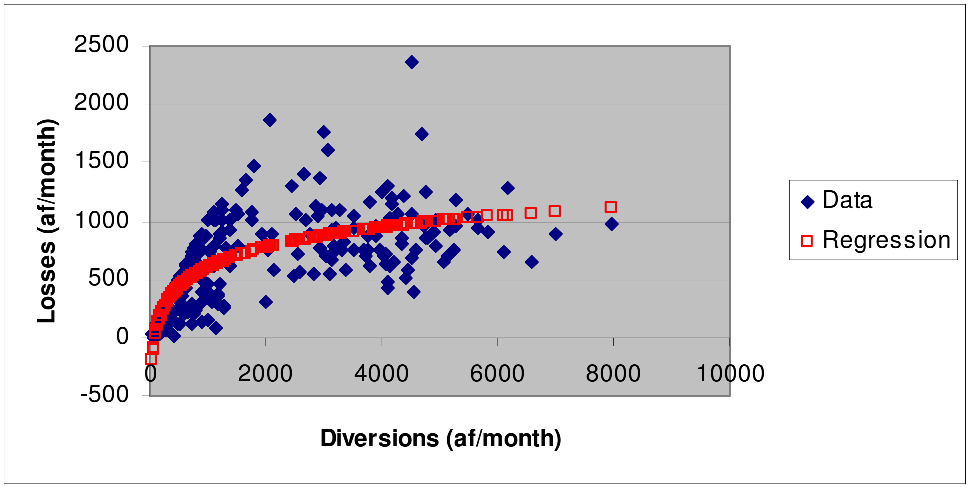

Figure 12. Single-variable regression of Bartlet Canal seepage data.

If the primary purpose were to predict canal seepage (rather than aquifer recharge from seepage), the data suggest that adding the number of months of prior wetting might improve predictive ability. Figure 13 shows a regression of the Bartlet Canal data with the natural logarithm of diversions and the number of months of prior wetting as predictors. This regression is statistically significant and its r^2 value is 0.63, which is higher than the r^2 for the diversions-only regression.

While the predictive power for *seepage* is improved by this modification, it is important to remember that early-season seepage may contribute to bank storage and storage in the vadose zone rather than directly to aquifer recharge. Therefore, an appropriate equation for representing *recharge* from seepage might purposely under-estimate seepage in early months.

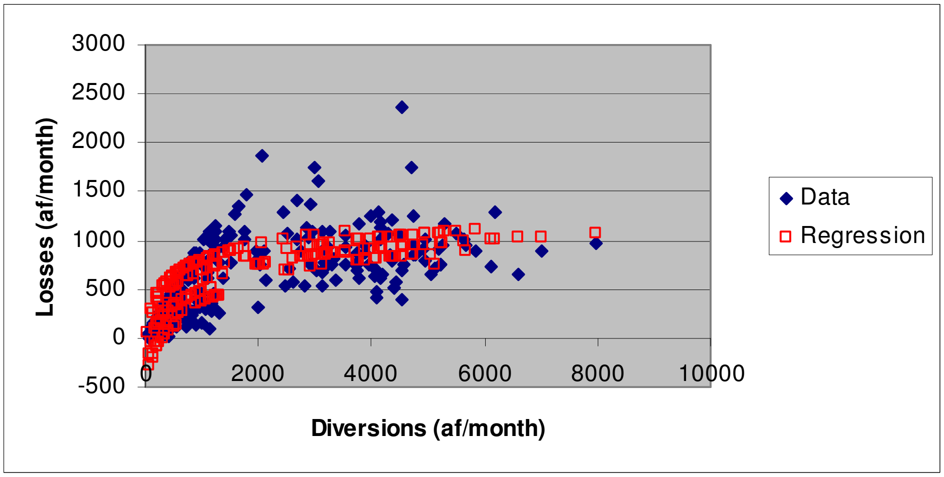

Figure 13. Two-variable regression of Bartlet Canal seepage data.

The regressions shown above predict volumes (acre feet) of seepage losses, from which recharge volumes could be estimated. However, the existing Recharge Tool is designed to accept time series of *fractions of diversions* so that recharge volume is calculated from diversion data. One of the reasons for this was to guarantee that recharge from canal seepage would never be represented during a period when there were no diversions. Figure 14 shows sample regressions to predict the seepage fraction of the Cambridge Canal. Regression 1 was developed from early-season data, and it does better represent the earlier-period seepage (red and pink symbols). Regression 2 (which was derived from later-period data, blue-colored symbols) may better represent the actual recharge that occurs from canal seepage, since higher early-season seepage may be charging bank storage rather than recharging the aquifer. At higher monthly volumes typical of mid-season months, the equations give similar estimates.

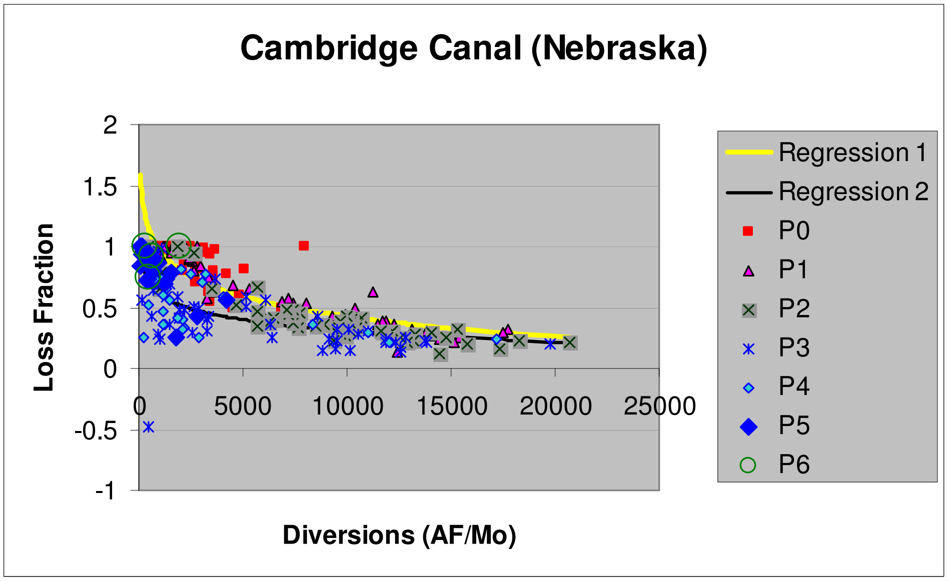

Figure 14. Two different regressions for representing seepage fraction from the Cambridge Canal.

<u>Application to ESPAM2</u>

The development of regressions from data is interesting, but cannot be applied in the ESPAM effort. We only have data for one canal (the Aberdeen-Springfield Canal), and these show significantly higher seepage rates than are generally believed to apply to other canals. An equation developed from the Aberdeen data would not be needed for that canal (since we have data) and would not be applicable to other canals. However, the regressions explored (including regressions on the Mexico and Aberdeen-Springfield data) suggest a general form of equation that could be used. Figures 15, 16 and 17 show the application a "generic equation" (equation (1) below) to normalized data from all the canals considered.

$$\text{Monthly Seepage Fraction} = 0.30 - 0.10 * \ln(\text{Diversion Index}) \qquad (1)$$

where:

$$\text{Diversion Index} = (\text{Monthly Diversion})/(\text{Maximum Diversion})$$

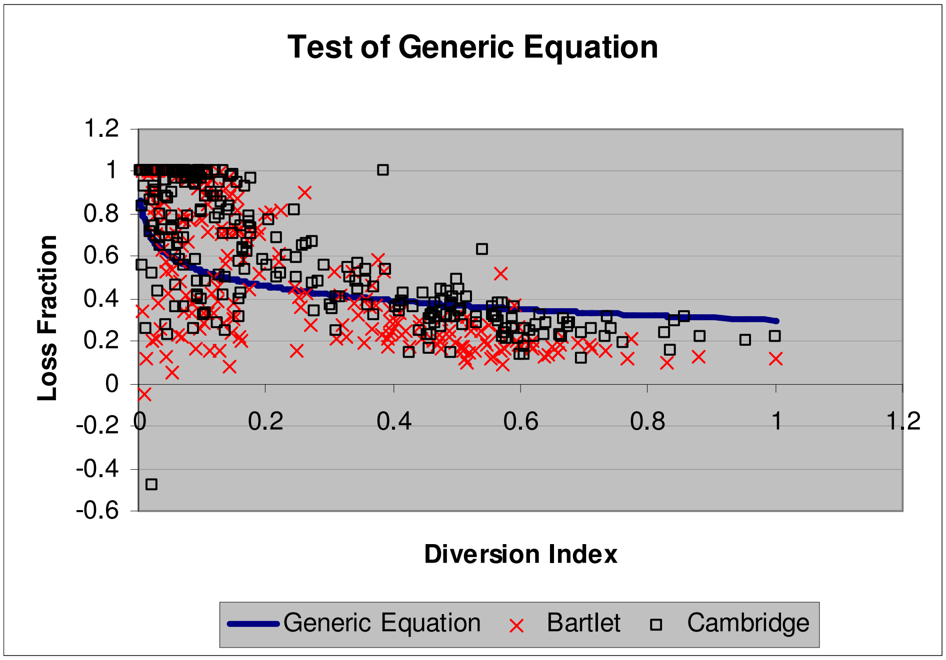

Figure 15. Generic equation and data from Bartlet and Cambridge canals.

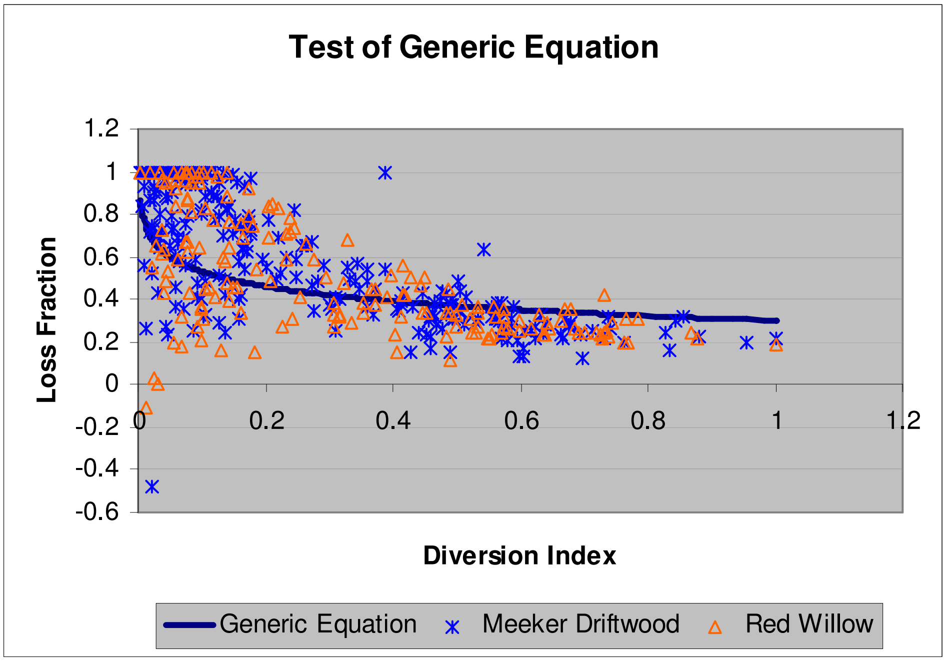

Figure 16. Generic equation and data from Meeker Driftwood and Red Willow canals.

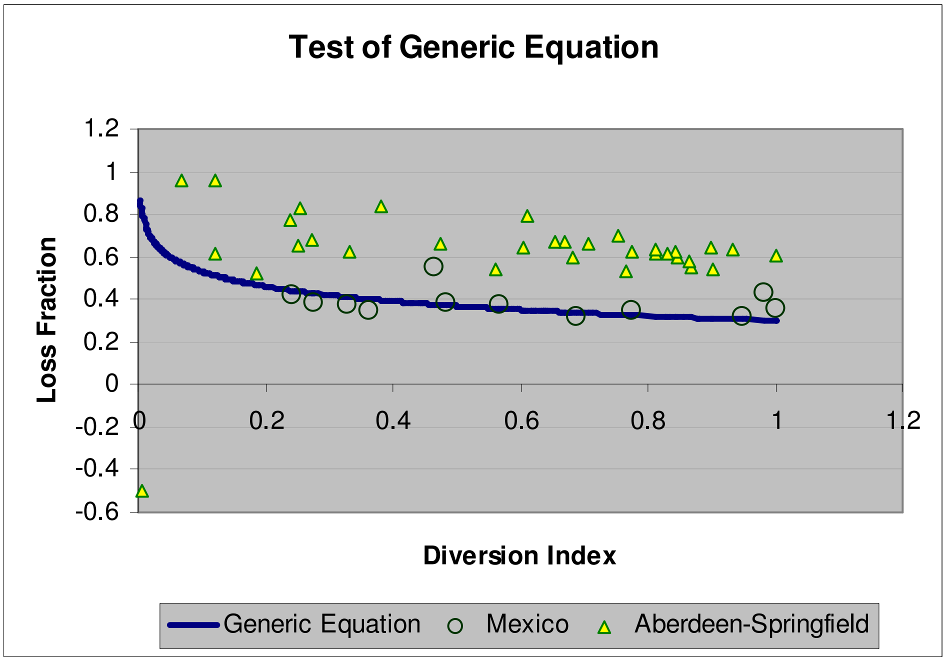

Figure 17. Generic equation and data from Aberdeen-Springfield and Mexico canals.

Important points about these figures are:

1. Careful comparison of Figures 5 through 11 with Figures 15 through 17 shows that the generic relationship tends to match the mid-season and late-season data, and under-represent the early-season data. This is exactly the outcome desired.

2. Since the data do suggest an increase in leakage percentage as diversion volumes decline in late season, the non-linear relationship is conceptually superior to a constant seepage representation.

3. Our knowledge of actual seepage rates is very poor. In most cases, we have only general guidelines, obtained from managers in two rounds of interviews during ESPAM1.1. Therefore, potential advantages of the more-complex approach of equation (1) may be completely overshadowed by our lack of knowledge and data.

4. Because representing canal seepage at best only redistributes the spatial locations of recharge, attempts to adjust seepage in model calibration may only provide opportunity for non-unique solutions without actually improving the validity of the model.

5. It is interesting that this generic relationship did a reasonable job of representing most of the canals, though the Mexico and Nebraska data came from different areas.

6. The Aberdeen-Springfield canal seepage, which is believed to be higher than the general seepage rates in the ESPA, plots above the results of the generic equation.

To adjust canal seepage in parameter estimation, the current Recharge Tool allows the supplied leakage fractions to be scaled. Figure 17 shows that the generic equation, scaled in this fashion, reasonably matches Aberdeen-Springfield data. In calibration, of course, Aberdeen-Springfield would be represented by the actual data and not a calculated seepage; the figure is shown simply to demonstrate the scalability of the generic equation.

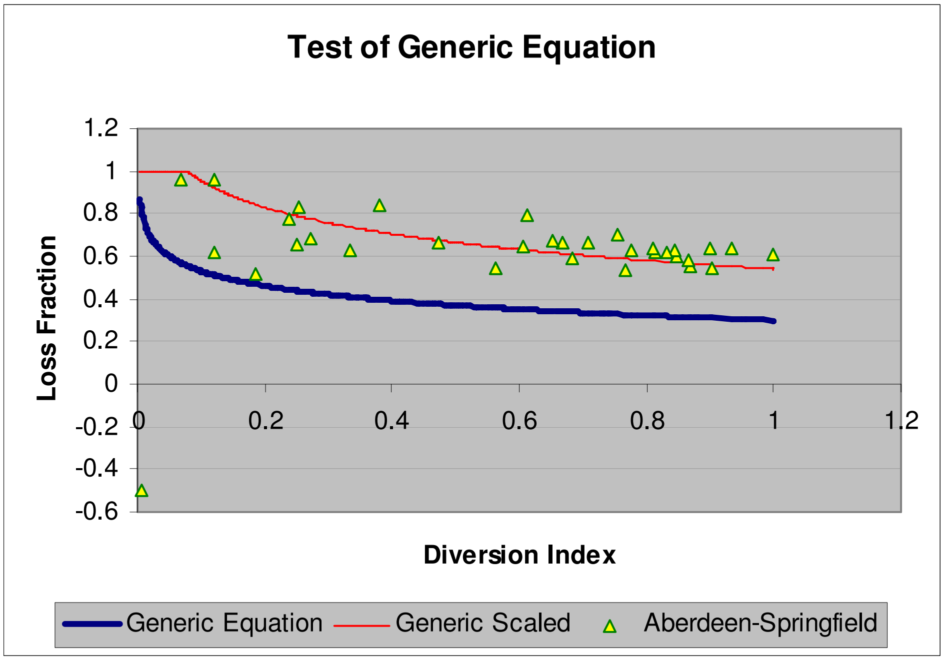

Figure 17. Demonstration of scaling of generic equation.

<u>Discussion</u>

The simplest representation of the leakage rate would be to use a fixed seepage fraction for all stress periods. If a variable fraction is deemed important, canal leakage for ESPAM 2 could be represented as follows:

1. The existing recharge-tool representation could be retained. This representation is as follows:
    a) A table of leakage fractions, by canal and stress period, is supplied by the user to the GIS part of the recharge tool. This table associates canals with individual irrigation entities. A GIS map of canal locations is also supplied.
    b) The GIS part of the recharge tool identifies the model cells associated with individual canals and passes this information to the FORTRAN part of the tool, along with the leakage table as well as diversion, return, and offsite-pumping data for each irrigation entity.
    c) The FORTRAN program calculates the total leakage volume to be applied to each leaky canal reach and apportions that volume to the cells that the reach intersects.

2. The leakage fractions for the Aberdeen-Springfield canal could be calculated from data provided by the company, as was done in ESPAM1.1. These data are already in hand.

3. The leakage fraction for the Wilson Lake reach of the Northside Canal could be held at the ESPAM1.1 level.

4. The leakage fraction for other canals could be calculated using equation (1). This would be done off line, prior to operating the recharge tool.

5. The recharge tools allow scaling of leakage fractions during parameter estimation, if desired.

This plan would offer the opportunity to reflect the reality of higher seepage percentages during periods of lower flows, without over-estimating recharge from early-season seepage. Retaining a percentage calculation guarantees that no recharge will ever be imputed from an empty canal. Developing the table of percentages with off-line calculations minimizes run times in the recharge tool and the degree of modification needed to the tool, and retains the flexibility to use other methods of determining leakage fraction. The limited test shown here suggests that scaling the generic equation (equation (1)) can provide adequate ability to match different leakage conditions, if adjustment in calibration is decided upon.

It is acknowledged that the advantages of this plan over a simple fixed seepage fraction are advantages of perception more than of substance. Additionally, there is danger that by adopting a more complex calculation we will over-represent our understanding of recharge from canal seepage.

Recommendation

As discussed in the January ESHMC meeting, it is recommended that additional canals be added from the "hyd2mil" data set and aerial imagery, so that all major main canals are represented as leaky in the ESPAM 2 calibration. IWRRI is already proceding with this work.

It is proposed that following discussion with the ESHMC in the March meeting, IWRRI prepare a recommendation for determination of canal seepage, in the form of a Design Document which will be presented to IDWR and the ESHMC for review.