# SEEPAGE EVALUATIONS IN CACHE VALLEY IRRIGATION CANALS

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## ABSTRACT

The Logan and the Blacksmith Fork irrigation systems in the Cache Valley, Utah, convey water distribution through earthen canals. Previous researchers and local water masters reported the existence of seepage problems in these canals, but there is very little knowledge of the amount of seepage, and of the spatial locations and temporal variation of these losses. The present study provides a better understanding of the seepage behavior within and between these canals throughout the irrigation area, as these canals pass through a varying landscape, including agricultural fields, steep slopes, marshes, and residential areas.

Measurements of the canal seepage were performed from June to October, 2008. The inflow-outflow method was used to measure steady-state seepage loss rates in selected canal reaches, using an acoustic flow meter. As a result, seepage gaining streams, losing streams, and gaining-losing streams were identified. Spatial and temporal variation of the seepage was observed. In this regard, spatial variation was observed along the canals whereby a descending trend of the mean seepage loss was found in the downstream direction. Spatial variation was also found between canals because the reaches on canals located in the eastern part of Logan City presented higher seepage losses than those of the canal reaches in the western part of the city. Moreover, temporal variations were identified in that a monthly comparison of seepage losses within reaches indicated higher seepage losses in late July and August. Additionally, comments about the performance of the acoustic flow meter are presented in this paper.

## INTRODUCTION

Effective management of water in an irrigation system requires knowledge of the quantity of water flowing in the canal in order to send the right quantity of water to every user at the right time, avoid unnecessary losses, and avoid physical and environmental damages. Seepage outflows affect the operation and maintenance of the canals in the sense that part of the water diverted for the users is lost from the conveyance system, and at the same time this water might produce piping, canal bank erosion (whether the canal is lined or not), produce excessive saturation, uplift pressure, which might produce failures of the canal and other structures (Rushton and Redshaw 1979). At the same time, canal seepage

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potentially constitutes a usable water resource even after it leaves the canals since it recharges the aquifers, though it requires energy to re-acquire this water.

In the Cache Valley, the Nibley Blacksmith Fork canal conveys water from the Blacksmith Fork River, and the Logan River irrigation system conveys water from the Logan River through ten open channels. The conveyance system operates only during the irrigation season (April-October) to distribute water to the users. Recently, efforts have been made to improve water management in many of the canals, including the installation of a data acquisition and telemetry system and data loggers on flumes. Nevertheless, there are very few measurements to quantify the amount of seepage affecting these canals, seepage that the managers must deal with in order to provide the right amount of water to the users. In fact, Tammali (2005) and local water masters indicated that these irrigation water delivery systems have seepage problems, but there is very little knowledge of the amount and, in some cases, of the spatial locations and temporal variation of the losses. Moreover the Cache Valley Regional Council (through the "Vision to 2020" commission), considered that the effective management of water resources in the Cache Valley will only be done through knowledge of the quantity and quality of this resource, and deemed it necessary to evaluate canal seepage (Cache Chamber of Commerce 2006).

Therefore, the aim of the present applied research project was to quantify and better understand canal seepage in the Logan and Fork Blacksmith River irrigation systems during most of the 2008 irrigation season. The acquired information is expected to contribute to improve water management in the Cache Valley, Utah, and to help determining the most important canal reaches in terms of canal lining requirements.

## LITERATURE REVIEW

Seepage from an irrigation canal refers to the water that percolates into the soil strata through the wetted perimeter of a canal (Rushton and Redshaw 1979). Once the surface water from the canals seeps through the wetted perimeter, it enters into the groundwater reservoir. This flow through porous media is governed by Darcy's law expressed by Eq. 1 (Rushton and Redshaw 1979), and the amount of seepage through an area A is expressed by Eq. 2 (Cedergren 1988).

$$v = ki \tag{1}$$

$$Q = kiAt \tag{2}$$

where, v = seepage velocity; $k$ = hydraulic conductivity, or permeability; $i$ = hydraulic gradient; Q = volume of seepage; $A$ = area of contact between water and soil; and, $t$ = time. Additionally, according to Winter et al. (2002) surface and groundwater interactions occur in three different ways: gaining stream (groundwater enters through the streambed), losing stream (surface water enters to groundwater reservoir through the streambed), and gaining-losing stream (gaining and losing streams are present in different reaches of the stream).

According to the Unites States Geological Survey (1977), seepage from an irrigation canal is usually measured by inflow-outflow studies, ponding tests, or seepage-meter studies. Seepage-meters are rarely used because they can give variable, and sometimes inconsistent, values (USGS 1977). According to different authors (Alam and Butha 2004; Blackwell 1951; United States Geological Survey 1977) the ponding method is the most accurate method to measure canal seepage, but does not reflect the usual operating conditions of the irrigation system, also it has the disadvantage that the canal cannot be in operation while the test is performed (the test can take several days), and the construction of the dikes might be expensive and could damage the canal (United States Geological Survey 1977). In this regard, Alam and Butha (2004) concluded that the selection of the best method for a particular project depends on different factors such as the nature of the project, the time availability, the magnitude of the seepage loss, the availability of equipment, and others. For the execution of the present project the inflow-outflow method was used. This method is a water balance approach that consists in the direct measurement of the flow rate entering and exiting a reach of canal. Thus, from Eq. 3 it is possible to estimate the seepage losses (S). Figure 1 shows the scheme of this method.

$$S = Q_i + R - Q_o - D + I - E \qquad (3)$$

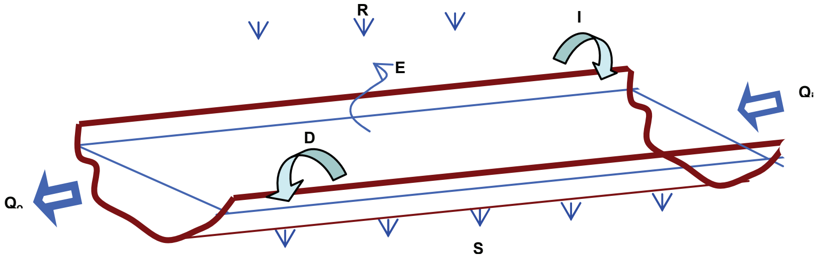


Figure 1. Mass balance for the inflow-outflow method

where $S$ is the seepage rate; $Qi$ is the upstream inflow; $R$ is rainfall; $Q_o$ is the downstream outflow; $D$ is the flow diverted along the reach; $I$ is the inflow along the reach; and, $E$ is evaporation. To use this method it is necessary to have steady flow conditions (whereby the change in reach storage is zero), and sufficiently long canal reaches to obtain a measurable loss (Blackwell 1951).

Flow rate in a cross section, perpendicular to the main flow direction, is estimated by Eq. 4:

$$Q = V * A \qquad (4)$$

where Q is the discharge (in volume per unit time); V is the mean velocity of the flow; and, A is the area of the cross section. For measuring flow in open channels the cross section is usually divided in sub-sections. The area is obtained by direct measurement of the sub-section width and water depth at the edges of every sub-section. The estimation of the mean velocity in a sub-section was done in this study using the Reduced Point Method. This method consists in measuring the velocity at fixed water depths (0.2, 0.6, 0.8 of the water depth in the cross section) and usually is done using current meters.

Some of the most common arithmetic methods to calculate the total discharge in a channel cross section are the mean-section and the mid-section methods. These methods differ in the location of the station in which the velocity measurement is done. According to Young (1950), quoted by Rantz (1982), the midsection-method is slightly more accurate than the mean-section method. Therefore, the mid-section method was used in the present project. For applying the mid-section method**,** the channel cross section is divided in subsections and the center of the subsection constitutes the station in which velocity measurements are done. Then, the total discharge is obtained by the sum of the discharge in each subsection into which the channel cross section was divided (Eq. 5).

$$Q = \Sigma V_i * d_i * (b_{i+1} - b_{i-1})/2 \qquad (5)$$

where Q = flow rate; b = position of the station along the tag line; d = water depth in the station; $_i$ = position number; and, V = mean velocity in the station.

Finally, according to Skogerboe and Merkley (1996) one of the three common ways to express the seepage rate is in lps/100 m (Eq. 6):

$$Q_l = 10^5 * (Q_u - Q_d)/L \qquad (6)$$

where $Q_l$ = seepage loss; $Q_u$ = inflow rate ($m^3/s$); $Q_d$ = outflow rate ($m^3/s$); and, L = reach length (m).

The measurement of mean velocity at a fixed point in a stream cross section is commonly done using current meters. In the present research, the FlowTracker® ADV® manufactured by SonTek/YSI, Inc., was used to measure flow velocity at points in the canal cross section. It uses acoustic signals to determine the velocity of remote particles into the water, then it is assumed that the velocity of the particles represents the velocity of the water. In this device a beam transmits an acoustic signal with a known frequency, then this signal hits moving particles (small sediments or bubbles suspended in the water) in a remote sampling volume, and immediately the signal is rebound with a different frequency. Finally, the rebound signal is picked up by two receivers localized upstream and downstream to the position of the beam. The determination of the velocity of the particles is made using the Doppler acoustic law which states that the frequency of the sound is shifted when the source of sound is moving relative to the receiver (SonTek 2007).

## METHODOLOGY AND SELECTED REACHES

### Canal reach selection

Preliminary reach selection was done using a GIS map developed by Tammali (2005). Definitive selection was done during field inspection during the spring of 2008. For the present project some preferred characteristics were defined in order to select the most adequate reaches and cross sections to make the measurements.

Preferred Characteristic for a Canal Reach Selection:

*Accessibility and safety*: The safety and accessibility by car or walking through an access road was critical since it facilitates the inspection of inflows and outflows present along the reach, reduce the time to commute between upstream and downstream cross sections, and reduce the chance of having un-steady flow between cross sections. For this reason, locations covered with vegetation or surrounded by fences were avoided when possible; otherwise the inspection was done by walking inside the canal.

*Few inflows and outflows*: Less number of outflows means less time used to finish the measurements in one reach and less potential measurement error. For this reason, the reaches were first selected based on the number of existent inflows and outflows reported by Tammali (2005), and the definitive reaches were selected at the moment of field inspection, considering the number of inflow and outflow (gates, pipes, and pumps) locations with flowing water.

*Measurable inflows and outflows*: For more accurate seepage estimation the inflows and outflows had to be measurable, for this reason submerged pipes, pumps, gates diverting direct into houses and gates diverting into buried pipes were avoided.

*Long reaches*: When using the inflow-outflow method, sufficiently long reaches are required to have a measurable loss (Blackwell 1951), as stated above. In this study the longest possible reaches were selected in each case.

*Spatially distributed reaches*: The reaches were located as equally distributed as possible, given several practical considerations, along each channel.

*Type of lining*: The measurements were taken in reaches with the same type of lining. The types of linings found in the canals included plastic, concrete, and unlined earthen material (the most common, by far).

Preferred Characteristics of a Channel Cross Section: Safety and recommendations of the International Standard Organization (2007) ISO 748:2007(E) and the Unites States Geological Survey (2007) were evaluated to select proper cross sections:

- Restrict measurements to steady flow conditions
- Use a straight section of channel
- Avoid vortices, reverse flow or dead water
- There should not be any obstructions in the cross section
- Look for locations where the main flow is orthogonal to the cross section
- Regular distribution of the velocity

Finally, the reaches selected for the present study are shown in Fig. 2 where every reach was named SX, where X is a consecutive number that represents the position of the reach in the canal (from upstream to downstream starting with 1). The reaches were selected based on the criteria previously stated, and selection of representative reaches based on other canal characteristics (such us type of soil, soil hydraulic conductivity, slope, canal lining, groundwater table depth, geological faults, slope, and other factors affecting seepage) was not affordable under the used methodology.

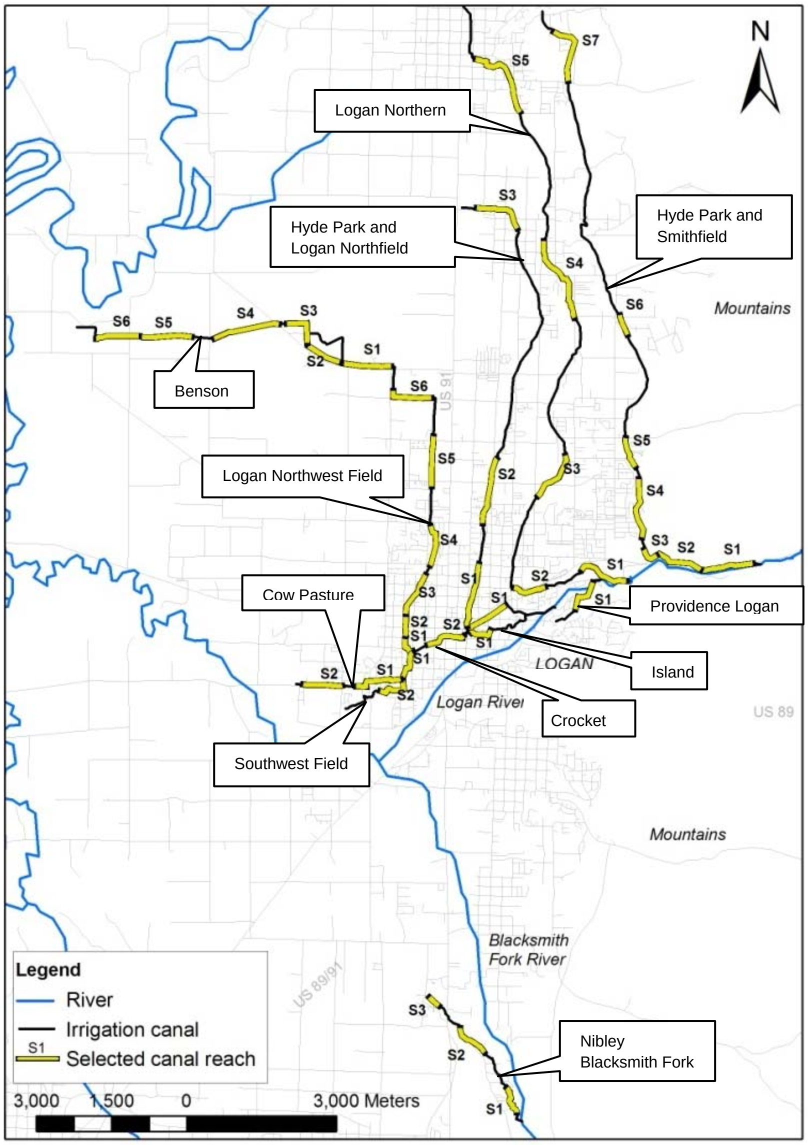


Figure 2. Selected reaches

## Seepage Estimation

The seepage measurements were done using the inflow-outflow method in the selected canal reaches, and evaporation was assumed to be negligible. Discharge measurements were estimated using an acoustic current meter, and the measurement of velocities was done using the wading method. The estimation of the mean velocity in each station and in the cross section was obtained using the reduced-point method. The area was obtained from the measurement of water depth at every station along the cross section; for a more accurate estimation of the area at the edges, the velocities at the edges of the canal were measure in order to determine the boundary between the flowing water and dead water, vortices, and other factors. The computation of the discharge was done using the mid-section method, and the measurement of low-flow pipe discharges (lateral inflow and outflow) was done using the volumetric method.

## FIELD WORK AND EQUIPMENT PERFORMANCE

### Field Work

The field work was done from June to October 2008. Activities performed in the field were:

- Monitoring of water levels: water level marks were located in preliminary upstream and downstream cross sections and inflows and outflows along the reach, in order to observe if the water depth varies. Measurements were done while the water depth remained constant; otherwise the field work at the canal was stopped (because unsteady flow conditions were detected).

- Reach and cross section selection: Based on preliminary selection, the inflow and outflows (gates, pipes, pumps, etc) were located and evaluated to determine if measurement with the available equipments were possible, otherwise the reach length was reduced or abandoned. Nevertheless, repeated visits were done in reaches that presented high number of open outlets and inlets at the moment of the survey, until few operating inlets and outlets were found.

- Measurement of velocities: Upstream inflow, downstream outflow, flow diverted and inflows were measured. The number of verticals per section was determined in the field, taking into account the canal width, the uniformity of the canal bottom, eddies, the available time to develop the measurement, and the ISO 748.2007 (E) and United States Geological Survey recommendations. Also, some parameters were monitored during the velocity measurement, in order to observe if debris, eddies, lack of perpendicularity, or lack of particles in the water affected the velocity measurements. Those parameters are the standard error of velocity, flow angle, the Signal-to-Noise ratio (SNR) value (measure of the strength of the reflected acoustic signal), and spikes in velocity (velocities that exceed Eq. 7 or are lower than Eq. 8).

$$Q_3 + 2*IQR = UL \tag{7}$$

$$Q_1 + 2*IQR = LL \tag{8}$$

where $Q_3$ = Lower quartile of the velocity samples, $Q_1$ = Upper quartile of the velocity samples, $IQR = Q_3 – Q_1$, UL is the Upper limit and LL is the Lower limit.

### Equipment Performance

The FlowTracker® ADV® was used in widely varying conditions, and its performance for the present project is briefly explained in this section.

Measurement in Low Water Depth with Low Velocities: The flow meter was useful to determine velocities at water depths as low as 8 cm and low velocity flows (such as 0.05 m/s).

Measure Under Low SNR: SNR stands for Signal-to-Noise Ratio and is expressed in logarithmic units (dB). It is a quality control parameter given by the FlowTracker. It indicates the strength of the acoustic signal reflected by particles in the water with respect to the ambient noise level. Thus, the more abundant the particles reflecting the sound are, the greater the SNR is. The recommendable SNR is 10dB; however, it can work accurately from 4 dB and higher (SonTek 2007).

During the velocity measurement in the S6 reach of the Benson canal a low SNR was detected. At the moment of the measurement the water had visible suspended particles. However, SNR values such as 10.6 dB and 0 dB were found at the beginning and at the end of this section, respectively. The SNR increased once a person walked upstream into the canal; also, there were no hydraulic jumps for at least 2.5 km in the upstream direction, and the mean velocity at the furthest downstream cross section was around 0.09 m/s. Therefore, this low SNR might be due to the lack of mixing, and low flow velocities, which contribute to the reduction of air bubbles and to the settlement of suspended solids that reflect the sound transmitted by the acoustic flow meter.

Measurement in Vegetated Canals or with Presence of Debris: Heavy bottom vegetation in channels disturbs the flow and produces spikes in velocity measurement, inappropriate velocity profiles, negative velocities behind the aquatic plants, etc. Also, aquatic plants and debris blocked the probe and fouled the equipment operation.

Flow Direction: The angle of the flow given by the flow meter was useful to determine if the tag line needed adjustments to be perpendicular to the flow, or otherwise if the cross section was not adequate.

Measurement in Irregular Cross Sections: In sections with irregular bed channel additional depth measurements were done using the “None” feature in the FlowTracker in order to obtain a better estimation of the cross-sectional area.

Inspection of Submerged Gates and Pipes: During the inspection of lateral inflows and outflows along a selected reach, it was difficult to determine if submerged pipes and gates were working. In order to figure out if laterals were diverting or picking water up from the canal, the FlowTracker® ADV® was used to estimate the velocity and direction of the water entering or exiting the lateral. For this purpose the flow meter was used in the “General” mode and the probe was located as close as possible to the pipe or gate entrance avoiding producing quality control boundary warnings. Then, the velocities in the X axis (Vx) and Y axis (Vy) corresponding to the probe coordinate system (X and Y axes are as shown in Fig. 3) were observed in order to determine the resultant direction of the flow at the entrance of the laterals. Figure 3 shows some of the velocity directions obtained during measurements. In cases 1 and 2 it was assumed the outflow laterals were not diverting water, and in case 3 it was assumed that water was entering the lateral.

## RESULTS

The resultant average seepage in each reach is shown in Table 1, where positive values mean net seepage losses from the reach, and negative values mean a net seepage gain of water into the reach. Also, comparison of the canals in a particular period is desired to show the spatial seepage behavior in the irrigation system area. Due to time limitations and other factors, measurements could not be done in a single month for all of the eleven canals under evaluation, but most of the reaches were measured in August. Thus, 28 reaches corresponding to five canals had measurements taken in August, four reaches corresponding to three canals had measurements taken towards the end of July and beginning of August, and measurements could not be taken in three of the canals in August. Hence, the end of July and August was selected as the period for comparing the eight canals. This is done to illustrate the variation of the seepage over time during a particular period. Figure 4 shows the Logan irrigation canals, the measured sections and the estimated mean seepage (represented by bars) for the period of comparison.

As observed in Figure 4, the seepage manifests spatial variation along all the canals. Seepage losses in the east part of the city are higher than seepage on the west side, were losing and gaining streams exist. Also, reaches close to the Logan River presented higher seepage losses than reaches located further downstream in the canal.

Table 1. Estimated Average Seepage

| **Canal** | **Reach** | **Estimated Seepage (lps/100 m)** | | | | |
|---|---|---|---|---|---|---|
| | | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** |
| ***Black Smith Fork River*** | | | | | | |
| Nibley-Blacksmith Fork Canal | S1 | | 7.03 | | | |
| | S2 | | 8.65 | | | |
| | S3 | | -5.02 | | | |
| ***Logan River*** | | | | | | |
| Hyde Park and Smithfield Irrigation Canal | S1 | 8.99 | 12.4 | 11.3 | | 11.5 |
| | S2 | | 10.1 | 16.5 | | |
| | S3 | | 6.14 | 11.8 | | |
| | S4 | 5.95 | | 3.53 | | 2.10 |
| | S5 | | | 9.04 | | |
| | S6 | | | 10.0 | | |
| | S7 | | | 6.84 | | |
| Logan Northern Irrigation Canal | S1 | 2.52 | 9.37 | 12.7 | | 3.55 |
| | S2 | | | 11.29 | | |
| | S3 | | | 2.88 | | |
| | S4 | | | 2.64 | | |
| | S5 | | | 1.09 | | |
| Hyde Park and Logan Northfield | S1 | | 2.44 | 7.10 | | 0.86 |
| | S2 | | | 5.96 | | |
| | S3 | | | -0.01 | | |
| Logan Northwest Field canal | S1 | 21.6 | 20.2 | 16.5 | | 3.63 |
| | S2 | 1.51 | 1.79 | 1.94 | | 5.97 |
| | S3 | | 2.50 | 5.46 | | |
| | S4 | | 0.76 | -2.65 | | |
| | S5 | | -3.51 | 1.20 | | |
| | S6 | | -1.30 | 3.23 | | |
| Benson Irrigation canal | S1 | -2.30 | | 5.01* | | 3.88 |
| | S2 | | | | | -2.13 |
| | S3 | | | 0.01 | | -4.63 |
| | S4 | 1.36 | | 1.77* | 0.87 | |
| | S5 | | | 2.75 | | |
| | S6 | | | 0.41 | | |
| Crocket Canal | S1 | 7.53 | -13.2 | -3.79 | | -1.72 |
| | S2 | | 6.02 | 16.7 | | 0.19 |
| Cow Pasture Canal | S1 | 1.72 | | 3.21 | | |
| | S2 | | | 0.49* | | |
| Southwest Field Canal | S1 | 1.63 | | 1.95 | | |
| | S2 | | | 1.66* | | |
| Providence Logan | S1 | 1.76 | | | | |
| Logan Island Canal | S1 | | | | 4.90 | |

**Measurements in these reaches were made at the end of July*

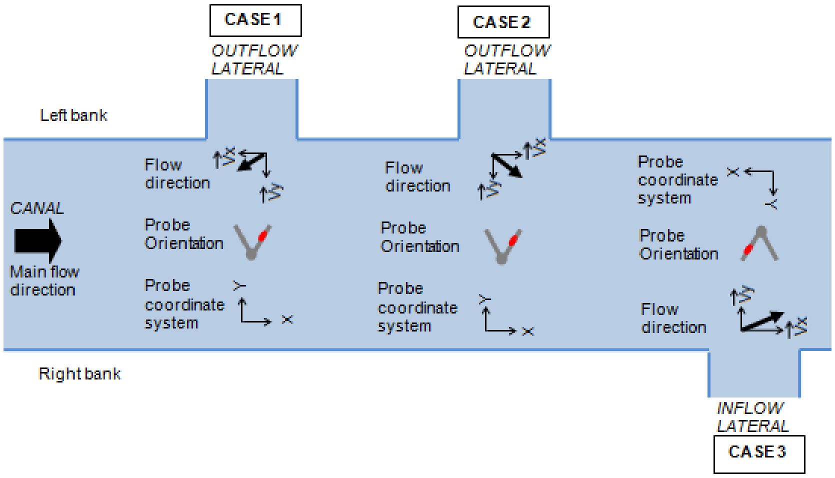


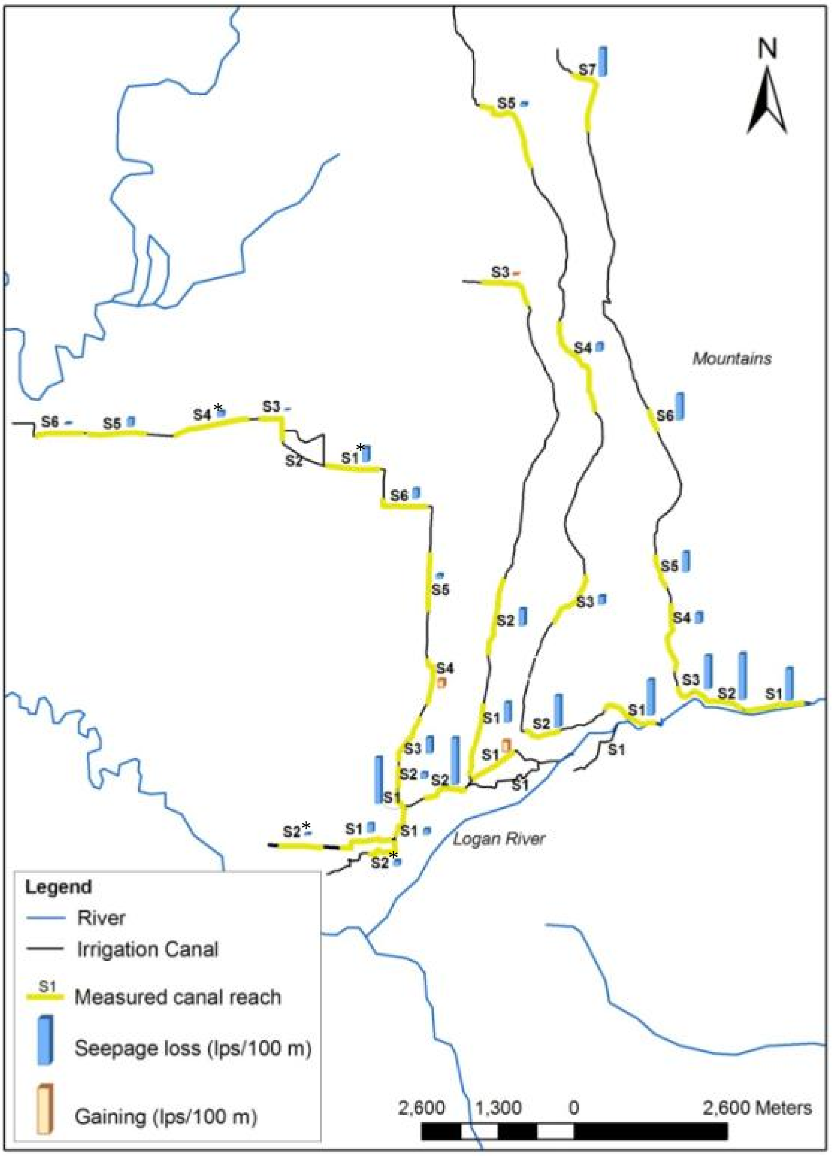
Figure 3. Flow directions at canal inflow/outflow locations

## DISCUSSION

From the analysis of the results, it can be stated that in the evaluated reaches the seepage presented spatial and temporal variation. With respect to the temporal variation, 12 out of the 17 reaches show the highest seepage in late July and August. Also, six reaches (S1 in the Crocket canal; S4, S5, S6 in the Logan Northwest canal; and, S1and S3 in the Benson canal) switched from seepage gain to seepage looses and vice-versa. With respect to spatial variation, Fig. 4 compiles the seepage for the comparison month, and shows the spatial variation along every canal. It is observed in Fig. 4 that most of the canals showed a descending trend in the mean seepage losses in the downstream direction. Thus, the upstream reaches presented higher seepage losses than the downstream reaches. Also, losing-gaining streams can be observed.

Additionally, from Fig. 4, the reaches exhibited spatial seepage rate variations as canals move from the east to the west part of the city. In this sense the sections in the Hyde Park and Smithfield canal shows higher seepage losses than sections in the Logan Northern canal, and in turn the Logan Northern canal shows higher seepage rates than the Hyde Park and Logan Northfield canals. The Logan Northfield canal had slightly higher seepage losses than the Logan Northwest Field canal, which presented both losing and gaining streams. Highest seepage gains were measured in reach S1 of the Crocket canal.

The highest seepage losses were found in the Hyde Park and Smithfield canals in reaches S1, S2, and S3 (along Canyon Road), in the Logan Northern canal in reaches S1 and S2 (along Canyon Road), in the Crocket canal in reach S2, and in the Logan Northwest Field Canal in reach S1. It is important to mention that flowing water beside the canal was observed in the first six reaches mentioned above. Likewise, infiltration of water in basements close to the seventh mentioned reach was reported. Further studies are required to know if this water come as part of the seepage losses in these reaches and to know the precise location of the leakage if any.



**Measurements in these reaches were made towards the end of July.*

Figure 4. Estimated mean seepage in August 2008 for the Logan irrigation canals

Also, losses were expected in the Crocket canal because Tammali (2005) reported that this canal had seepage losses affecting Canyon Road; however, net seepage gains were observed in the present study. From careful inspection it was concluded that there were no pipes or springs along this reach, therefore the gain might come through the streambed. The possible reason for this conflicting observation could be the recent repair work performed after Tammali's study was undertaken. This implies that there were seepage gains at the time of the previous study, but were negligible in comparison to the seepage losses prior to the repair work, hence net seepage was accounted as seepage loss and not as a gain. Additionally, in order to confirm the calculated seepage value, repeated measurements were done on July 14 and 27 using different cross sections for reach S1, and in both measurements net seepage gains were again obtained.

Using GIS soil coverages from the Natural Resources Conservation Service (source SSURGO http://soils.usda.gov/ 2008), and the maps provided in the State of Utah - GIS division webpage (source http://gis.utah.gov/ 2008), some maps (such as contour level, geologic faults, shallow groundwater, wetlands, type of soil, and saturated hydraulic conductivity maps) were overlayed with the canals in order to contrast and observe patterns in the seepage behavior. . From the superposition it was observed that the Logan and Blacksmith Fork irrigation systems are surrounded by agricultural areas (recharge for the aquifer). The higher topographic level is located in the east part toward the mountains and the lower topographic level is located in the west part of the Logan and Nibley canals, in which shallow groundwater area is observed (this shallow groundwater zone might be variable due to recharges coming from spring runoff and irrigation water). High permeability soils are located close to the mountains and around the Logan and Blacksmith Fork rivers. Geological faults are observed crossing reach S3 at the Hyde Park and Smithfield canal; however, no extraordinary seepage was found in this reach. As a result of the superposition the following was observed:

- Two reaches (S1, S2 at Hyde Park and Smithfield canal) with the highest seepage losses located in the hillside of the mountains over natural rock. Most likely seepage is driven by the permeability of interstices (cracks and joints) in the rock. A seepage face was also observed in the hillside and this probably comes from the canal.

- Four reaches with the highest seepage (S3 at Hyde Park and Smithfield canal, S1 and S2 at Hyde Park and Logan Northern, S1 at Crocket canal) are located in gravelly loam soils, which also correspond to areas with the highest saturated hydraulic conductivity, steep slopes, far away from the shallow ground water and consequently far away from wetlands. In contrast reaches with the lowest seepage (S4, S5, S6 at Logan Northwest Field canal, S3 at Hyde Park and Logan Northfield canal, and S1, S2, S3, S4 at Benson canal) are located in silty clay and silty clay loam soils (clay content in these areas is around 32 – 52%), with low permeability, in shallow ground water area and with very mild slopes. The remaining reaches are located mainly on silt loam and loam soils with intermediate permeability.

- Exceptions to the previous observations are the S1 reach at Logan Northwest Field canal and the S2 reach at the Crocket canal. Both of these reaches presented high seepage loss although they are located in a shallow groundwater area. Dissimilarities observed in these reaches (in contrast with other reaches in shallow groundwater) are: high hydraulic conductivity, these two reaches are located on the top of steep slope terrains close to the Logan river, and the type of soil is gravelly loam (same type of soil as reaches with the highest seepage) while the others reaches are located over silty clay and silty clay loam soils. The high seepage observed might be a result of the interaction of the surface water with the shallow groundwater through a high permeable soil, in which the underground flow direction possibly is affected by the topographical position, and by the interaction with the Logan River, a natural drainage.

- In contrast, the Nibley Blacksmith Fork canal is located in gravelly loam soil (same type of soil of reaches with the highest seepage), surrounded by some wetland, the terrain in the area is not as steep as the area with reaches with the highest seepage. The reaches in this canal have lesser seepage losses than other reaches in the same type of soil, and the furthest downstream reach (S3) presented net seepage gains. The different behavior might be due to the topography, possible influence of the groundwater table, wetlands, and conveyance properties of this canal.

- In the Crocket canal it was observed that reach S1 presented the highest gaining-losing stream. This reach is located in the bottom part of a steep slope in the Logan Canyon, in gravelly loam soil (same type of soil of reaches with the highest seepage), with high hydraulic conductivity, with no visual presence of springs or pipes. This gaining may be a response of some interaction between groundwater coming from irrigated areas in the upper part of the canyon and the wetted perimeter of the canal.

- Also, it was observed that reaches at the Logan Northwest Field, Benson, Cow Pasture, Southwest Field and the S3 reach of the Logan and Northfield canals are all located in the shallow groundwater region and surrounded by wetlands. It is highly possible that gaining-losing streams might be present in this area. In fact, in the present study some reaches in this area were found to have gaining and gaining-losing behavior (e.g. S4, S5, S6 at the Logan Northwest Field canal, S1 and S3 in the Benson canal, S3 in the Hyde Park and Logan Northfield canals). Variations of seepage in these streams may be seasonal and highly dependent on the shallow groundwater table behavior and local underground water pathways.

Additionally, it was observed that the sealing of bottom and walls of the earthen canals changed along the canal and during the irrigation season. Thus, at the head of the canals the bottom was usually somewhat stony, while downstream accumulation of sediment and vegetative growth were observed. Also, in some sections the sediment in the streambed was removed (apparently due to higher flows in the canals). Thus, permeability of the streambed may be highly variable along the canal during the irrigation season, and might differ from the representative values given on the soils map.

Although a kind of pattern between the estimated canal seepage and the type of soil, shallow groundwater and topography was observed, the previous approach to understand seepage behavior in the reaches that were evaluated suffer from the lack of knowledge of the real conditions of the factors present in the canal (e.g. groundwater table, permeability, wetted perimeter, and others, are unknown). Thus, a simple extrapolation of the seepage observed in the reaches to the whole canals is inaccurate. In fact, according to the United States Geological Survey (1977) to extrapolate measured seepage to the influenced area is necessary to know the next information: soil types, conveyance properties (mean flow, wetted perimeter, and longitudinal bed slope), and geo-hydrologic settings, referred to the water table position in relation with the canal. Deeming the lack of knowledge of those factors, and considering that some observed factors (such as channel surface sealing, vegetation wetted perimeter, depth of water, and others) varied in the same reach in time and space, the losses should be understood as the seepage for the given reach under the given conditions during the time the measurements were performed. Consequently, further studies are required to understand canal seepage behavior in Cache Valley, and further information about the behavior of factors affecting canal seepage is required in order to extrapolate the measured seepage to others reaches in the canals.

## CONCLUSIONS

Canal seepage in the canal systems that were studied manifests spatial and temporal variations. Monthly comparison of seepage losses within the reaches did indicate a higher seepage loss during the late July and August period. Spatial variation indicates that within canals most of the canals presented a descending trend of the mean seepage loss as the reaches go downstream. Between canals it was observed that reaches located in the east part of Logan City presented higher seepage losses than reaches in the canals on the west side. A superposition of the seepage and GIS maps showed a pattern between the estimated canal seepage and the surrounding type of soil, the saturated hydraulic conductivity, the presence of the shallow groundwater and the topography. However, further study and information is required in order to extrapolate the measured seepage to other canal sections. Also, reaches with the highest seepage losses were identified to be S1, S2 and S3 in the Hyde Park and Smithfield irrigation canals, S1 and S2 in the Logan Northern irrigation canal, S2 in the Crocket canal, and S1 in the Logan Northwest Field canal, where five of the seven reaches mentioned presented flowing water beside the canal, and one reach has been implicated with regard to flooding problems in a residential area. Also, seepage gaining and gaining-losing streams exist in these canals.

The current meter used in the project (FlowTracker® ADV®) was useful during the data collection since it facilitated: the determination of the approximate boundary between dead and flowing water, the verification of perpendicularity of tag line and flow, the verification of submerged laterals, and the measurement of low flow velocities. Additionally, a low SNR was detected at the end of the Benson canal, although the water had visible suspended particles. This reach had low flow velocity (0.09 m/s), and no evidence of hydraulic jumps for a distance of 2.5 km in the upstream direction.

## RECOMMENDATIONS

- Reaches with significant losses should be evaluated in greater detail in order to determine precise locations of seepage. The ponding method can be used to determine a more precise location of the cracks (if any), and tracer studies can be use to verify if the water in the basements of residential areas and beside some canals come from the irrigation canals.
- Highly vegetated sections could not be measured with the proposed methodology. However it could be used after maintenance activities (weeding) have been performed.
- Further studies of the factors affecting seepage in the canals are required in order to improve the understanding of the seepage behavior found in the present study.

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