RELATIONSHIPS BETWEEN SEEPAGE LOSS RATES AND CANAL CONDITION PARAMETERS FOR THE RAPID ASSESSMENT TOOL (RAT)

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ABSTRACT

A rapid assessment tool (RAT) is being developed for evaluating irrigation network performance. As part of that development, the relationship between condition rating factors and seepage loss measurements was examined. The statistical analysis was based on 32 ponding test sites in the Lower Rio Grande Valley (LGRV). The results indicate that seepage losses from the lined canal segments can be modeled as a function of a rating factor describing the spacing of large cracks in the lower part of the canal cross-section. Cross-section appears to be a moderating variable in relating seepage loss to canal condition. Separate ratings are proposed for overall canal condition and seepage loss condition for lined canals. There was no statistical relationship between seepage loss and condition rating factors for unlined canals. The overall condition of the lined canal was correlated with the rating of canal bank condition. Presently the RAT is the only reported rating scheme that utilizes Geographic Information System (GIS) to display the rated conditions.

INTRODUCTION

A challenge to improving water resource management in irrigated regions is ageing and/or under performing irrigation infrastructure. Many of these systems suffer from both high seepage and operational losses. These losses reduce supplies and cause water logging and soil salinization problems. Irrigation districts are therefore being forced to examine management, maintenance, rehabilitation and modernization (MMRM) strategies with the goal of improving performance. Rehabilitation or modernization needs of irrigation systems are related to the structural condition, hydraulic performance, seepage loss rate and the level of obsolescence of the infrastructure. A critical aspect of MMRM strategies is the application of innovative methodologies to quickly and inexpensively relate the condition of the assets to the technical performance of the scheme. These methodologies enable scheme planners and managers to then prioritize investment options based on the condition of different scheme and scheme components.

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The Texas A&M University is currently developing a Rapid Assessment Tool (RAT), to analyze the status of irrigation water distribution networks. The RAT is a combination of infrastructure condition rating, seepage loss tests along with both mapping and analyses using Geographic Information Systems (GIS), (Fipps and Leigh, 2000). During phase 1 of the RAT development, Fipps and Leigh (2000) proposed an initial condition rating system for lined and unlined canals. This paper outlines the continued development of the rating methodology including relationships between the canal condition and seepage losses. The objectives of this work are to:

(i) Further develop a condition rating system for irrigation canals and hydraulic structures.
(ii) Determine relationships if any, between the condition rating factors and measured seepage loss rates in lined and unlined canals.

The goal is to develop a modeling system to quickly and inexpensively evaluate irrigation network improvement needs in irrigation districts.

CONDITION RATING SCHEMES FOR HYDRAULIC ENGINEERING INFRASTRUCTURE

The US Army Corps of Engineers (USACE) under their repair, evaluation, maintenance and rehabilitation project (REMR) has developed within the last 15 years, several rating procedures to evaluate the condition civil engineering infrastructure. These include indexing systems for embankment dams (Andersen and Torrey III, 1995), navigation structures (Mckay et al., 1999). Burton et al. (2003) used a simplified procedure for rating the condition, performance and importance of irrigation infrastructure. The method was applied to several irrigation schemes in Albania. The authors reported that initial asset management procedures had to be simplified given the lack of local resources including maps, database software and personnel with suitable experience. Cornish and Skutsch (1997) proposed a detailed procedure to evaluate components and prioritize maintenance and rehabilitation of irrigation networks. The method outlines the development of a priority index based on an assessment of the structural and hydraulic condition, importance and area served by the respective component.

Fipps and Leigh (2000) also developed rating procedures for both irrigation network condition and performance, as part of a Rapid Assessment Tool (RAT), being developed at Texas A&M University. The RAT is the only reported condition rating methodology that utilizes GIS. The methodology is being applied to irrigation networks in the Rio Grande Valley, Texas. Phase 1 of the RAT development involved seepage loss tests, mapping of the existing infrastructure in the LGRV, along with performance rating of canal discharge, head and physical condition. Canal riders in the LGRV irrigation district completed the head condition surveys, while extension personnel evaluated the condition of the irrigation infrastructure. To date, the Biological and Engineering Department has completed seepage tests (ponding method) on 44 canal sections in the LGRV.17 of those tests were conducted on unlined canal sections and 27 on lined sections. A total of 22 of the lined canal sites and 10 of the unlined sites were rated.

RECENT DEVELOPMENT WORK ON THE RAT

The development team reviewed the RAT development phase I results and agreed on the following issues for further work under phase 2:

(i) In lined canals, the seepage losses appeared to be greater for canals rated with higher frequency of large cracks i.e. canals with larger cracks tended to show higher seepage loss rates. Additionally, most of the horizontal cracks occurred below the normal operating level, suggesting that these could contribute to the seepage losses. Thus the contribution to the seepage losses by both crack frequency and distribution over the wetted perimeter was examined.

(ii) In unlined canals, there did not appear to be any clear relationship between the seepage losses, and the rating factors considered. It is possible therefore that the team did not account fully for all the variables that contribute to losses. Silt levels along with maintenance operations were some of the previously excluded factors that were considered in this phase.

(iii) Indicators of possible structural failure of canal elements were not previously considered. These indicators include the extent of canal bank erosion as well as observed seepage levels through the embankment of canals and structures.

(iv) Several natural indicators of seepage losses would also be considered further, including aquatic weed growth along the canal bank as well as in adjacent fields and drains.

(v) Some analytical tools were required to develop useful relationships between seepage losses and the parameters being evaluated. Statistical tools including regression analysis and correlation were therefore used to explain the variability of seepage loss rates.

The team then agreed that the following objectives were critical to the further development of the RAT:

1. Relate canal condition to seepage losses
2. Assess parameters that contribute to the overall condition of the canal.
3. Examine those rating factors the indicate chance of canal bank failure

Some factors relate to more than one objective. For example, visible signs of seepage losses through the canal banks are related to both objectives 1 and 2.

NEW APPROACH TO CONDITION RATING

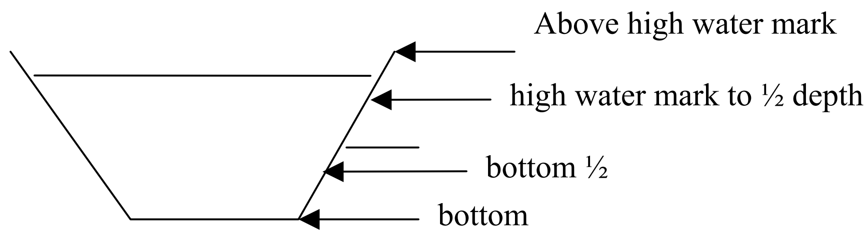

Figure 1: Segments of the lined and unlined canal to be rated.

Based on the experience from the original rating methodology, a new approach was proposed. Instead of rating the overall canal section, cross-section was divided into 4 sub-sections and each rated separately (fig 1). The sub-sections are above high water mark, high water mark to half depth, half depth to canal bottom and canal bottom. The ratings form also expanded to examine several factors including:

- (i) High water marks to estimate the maximum operating depth
- (ii) The presence of aquatic weeds in the irrigation canals and adjoining fields.
- (iii) The level of erosion of the canal embankment.
- (iv) The level of non-aquatic weeds in the irrigation and drainage canals as well as on the embankment.
- (v) An overall rating of the maintenance needs of the canal section as well as the condition of concrete joints.

Table 1: Concrete crack size and frequency rating for lined canals

Crack type	**Size range (in)**	**Size rating**	**Crack Frequency**	**Frequency rating**
Hairline	0<=1/16	0	none	0
Crack	1/16<1/4	1	sparse	1
Pencil	¼<1/2	2	>10 ft apart	2
Finger	½<3/4	3	5 – 10 ft apart	3
Break	>3/4	4	3 – 5 ft apart	4
			less than 3 ft apart	5

All field data collected during the survey, were coded in the statistical package SPSS 11.5. The evaluated seepage loss rates were reported in in/day and (gal/ft^2/day). To develop statistical relationships, the seepage results were plotted against several rating factors including the size and frequency of cracks at different sections of the canal cross-section. The statistical package was then used to develop regression relationships as well as correlation between the measured variables. The Pearson ranked correlation, was used to check for the significant correlations between the parameters.

RESULTS

Table 2: Correlation between different parameters for lined canal

Param.	Test	Bottom Finger	Bottom Break	Lower Finger	Lower Break	Aquat. veg	Seep. (in/day)	Seep. per unit area (gal/ft^2/d)
Bottom finger	Pearson Correlation					.845(**)		
	Sig. (2-tailed)					.008		
Bottom Break	Pearson Correlation				1.00(**)		.967(**)	.897(**)
	Sig. (2-tailed)				.		.000	.002
Lower finger	Pearson Correlation				.666(**)	.761(**)		
	Sig. (2-tailed)				.009	.004		
	N				14	12		
Lower Break	Pearson Correlation		1.000(**)	.666(**)			.967(**)	.897(**)
	Sig. (2-tailed)		.	.009			.000	.002
Aquatic veg.	Pearson Correlation	.845(**)		.761(**)				
	Sig. (2-tailed)	.008		.004				

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The most promising relationships appeared to be between the seepage compared with large cracks in the lower part of the cross-section and bottom of the canal. These are shown in Figures 2 and 3 below.

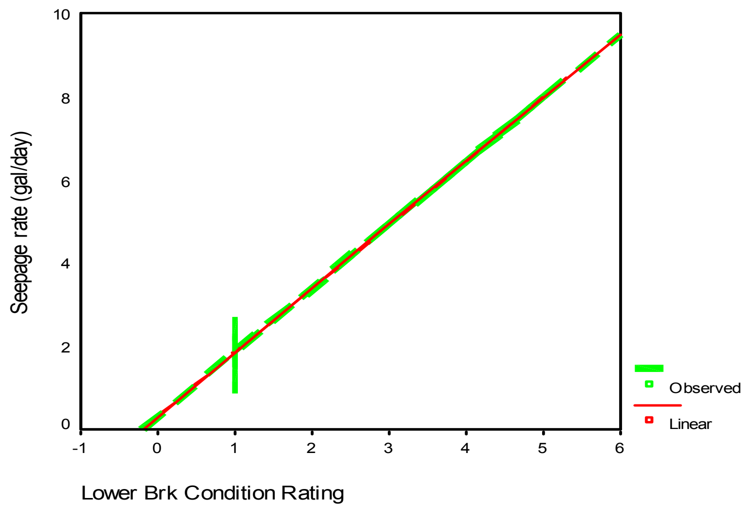

Figure 2. Actual and predicted seepage loss rates (in/day)

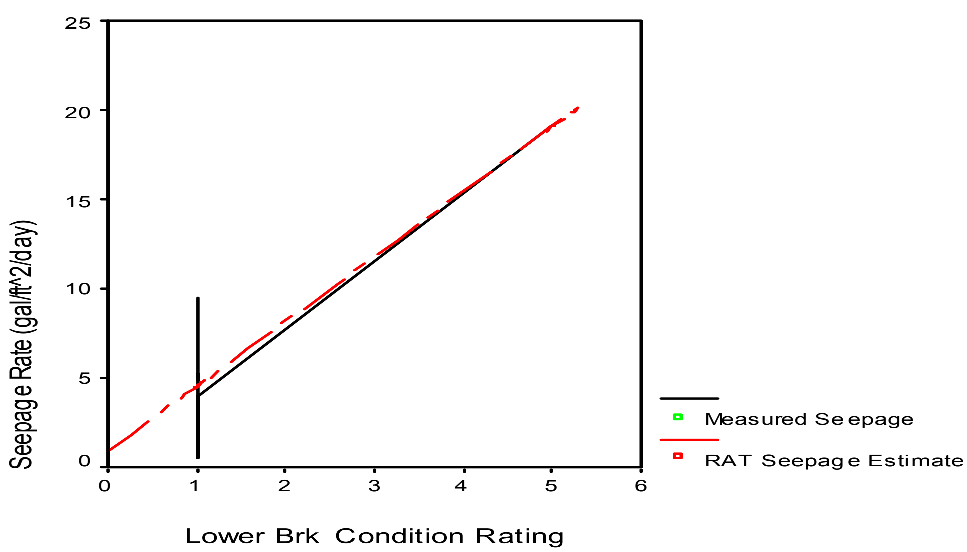

Figure 3. Actual and predicted seepage loss rates (gal/ft^2/day)

The best-fit linear regression model for the data is given by equations 1 and 2 below.

$S1 = 0.32 + 1.530 l_{br}$ adjusted $r^2 = .93$, SE = .61 (1)

Where S1 = seepage loss rate (in/day)

lb_{br} = rating for the frequency cracks > ¾” in the lower half of the canal cross-section.

$S2 = .889 + 3.634\ b_{br}$ adjusted $r^2 = .77$, SE = 2.72 (2)

Where S2 = seepage loss rate (gal/ft^2/day)
lb_{br} = rating for the frequency cracks > ¾" in the lower half of the canal cross-section.

The relationship in equations (1) and (2) indicate that the seepage rates in the lined canals are explained by the frequency of large cracks in the lower cross-sections of the canals. This model is consistent with the sensitivity analysis reported by Rastogi and Prasad (1992) who noted that canal supply depth strongly influences seepage. Therefore, frequent large cracks in the lower section and bottom of the canal should have a greater effect on seepage compared to those at the top of the cross-section. Recent work by Rahimi and Bahootkoob (2002), canal lining failure is caused by a net unbalanced stress due by non-uniform soil swelling pressures. These stresses tend to cause lining failure in the lower third of the side panels.

Generally, canals in the LRGV are raised above ground level and constructed on compacted soil. As a result, neither properties of the surrounding soil nor

Table 3: Pearson correlation of overall rating and other parameters

Parameter	**Pearson correlation**
Pencil cracks above ½ depth	.470(*)
Break in top of canal	.752(**)
Finger cracks in top of canal	.694(**)
Overall repair rating	.616(**)
Joint condition rating	.744(**)

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

As shown in table 3, the overall rating is correlated with the large cracks in the upper section of the canal (0.75), the condition of the joint (0.74) as well as the overall repair rating (0.66). The condition of the joint as well as break-sized cracks at the top of the canal cross-section explained most of the variance in the overall canal rating. However the overall rating did not correlate with the condition rating in the lower section of the canal. Conversely, the seepage loss correlated well with cracks in the lower portion of the canal cross section. Separate overall condition and seepage loss conditions should therefore prove beneficial. The overall condition rating may reflect better the repair requirements of the canal to enhance hydraulic performance and reduce the risk of failure. Alternatively, the seepage loss rating could be considered a subset of the overall rating, to estimate the chance of seepage, largely based on the frequency and size of cracks in the lower portion of the canal cross-section.

DISCUSSION

The results of the statistical modeling indicate that for lined canals, the seepage loss rate depends on the frequency of large cracks in the lower segment of the canal cross-section. While this relationship is supported by the scientific literature, further field assessment and validation would prove useful. In using the RAT to estimate seepage losses from irrigation canals in the LGRV, some care should be exercised in rating the large cracks in the bottom half of the canal. Groundwater levels should also be noted when conducting seepage loss ratings as these levels moderate seepage losses. A minimum depth of 3 meters below the canal bottom is recommended. The overall condition of the lined canal is explained largely by the condition of the expansion joints as well as the size and frequency of cracks in the top half of the canal. A useful approach therefore is to have separate rating for both the overall maintenance needs and the level of seepage loss expected.

There was no statistical relationship between seepage loss rates and unlined canal parameters. This could be due to the high variability in the parameters along with the relatively small number of samples. The most recent publications on seepage losses in unlined irrigation canals suggest that losses may be related to large holes in the embankment caused by rodent, insects and rotting roots. This may be moderated by both silt build-up and level of maintenance.

Currently the RAT is the only rating scheme that uses GIS to display results. As the canal network is geo-referenced, the modeled seepage loss relationship can be displayed throughout the network once the rating is completed. This will allow district personnel to view spatially the estimated seepage rates for lined canals and therefore develop suitable plans. Such plans may include a combination of repairs and replacement of canal sections. In case of limited funds, the model suggests that sealing the large cracks (including joints) in the lower sections of the canals should have the maximum impact on seepage reductions in lined canals.

CONCLUSIONS

Development work on the Rapid Assessment Tool (RAT) indicates that seepage loss from lined canals is best explained by the size and frequency of large cracks in the lower sections of the canal. However there was no relationship between the rating factors and seepage losses in the unlined canals. Separate rating for the overall canal conditions and maintenance condition is recommended.

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