USE OF GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN DEFINING MUNICIPAL WATER SUPPLY NETWORKS

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ABSTRACT

Geographical Information Systems (GIS) have been helping the Irrigation District Team (IDEA) of the Irrigation Technology Center to provide services and assistance to the agricultural communities and irrigation districts in the Lower Rio Grande Valley of Texas. During the summer and fall of 2003, we took advantage of the GIS program started in 1997 that included mapping of the irrigation districts and assembling basic attribute data on the water distribution networks. In cooperation with the 14 irrigation districts in Hidalgo and Cameron Counties, we conducted a study to identify the extent of the municipal water supply networks (MSN) defined as those portions of the water distribution networks and control structures of irrigation districts that transport raw water to municipal treatment plants.

This study was a time and labor intensive process and involved frequent visits to the irrigation districts for the collection and review of field data and analysis. This paper presents the procedures and methods used to produce the first initial estimates of the MSN. The characteristics of the MSN include the static volume (or capacity), evaporation and seepage losses from reservoirs, resacas (oxbow lake) and canals, and leakage from pipelines. Also discussed are alternate operating scenarios and future recommendations to improve estimates for seepage losses and leaks and to take a regional approach to planning distribution network improvements.

BACKGROUND

In the early 20th century, the newly established land development companies started carving-out irrigation canals to serve the million plus acres of agricultural lands in the Lower Rio Grande Valley of Texas. The farmers and the growing towns depended on water from the irrigation distribution networks for their daily consumption. Today 14 of the 28 irrigation districts continue to pump water from the Rio Grande River to one or more of the 39 municipal water treatment facilities through the gravity-flow canals and underground pipelines.

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Generally, the amount of municipal water in the distribution networks at any one time is small compared to the amount of agricultural water (90% of water rights held by agriculture). In essence, the agricultural water fills the distribution networks and the municipal water is "piggy-backed on top" of it. Thus, in the absence of agricultural water, municipal water deliveries can become problematic.

During the late 1990s, the irrigation districts were plagued by regional and local droughts, causing water supply shortages and several districts to run out of all available water allotted for irrigation purposes. Those districts that served the municipalities could no longer charge (fill-up) the distribution networks necessary to transport the raw water to the takeout points without tremendous pumping costs and accruing negative balances charged against the districts' agricultural water accounts.

The municipal water supply network (MSN) is defined as those portions of the irrigation distribution networks, which also carry municipal water. The extent of the MSN is based on the locations of existing control structures that can be closed to isolate the MSN from downstream portions of the irrigation districts. During the summer and fall of 2003, the Irrigation District Team (IDEA) of the Irrigation Technology Center conducted a study of the extent, capacities and loss of water of the MSN. This study can be used as a step to help start addressing future problems that may hinder irrigation and municipal water supplies deliveries alike.

INTRODUCTION

In 1997, we began a GIS program that included mapping irrigation districts in the Lower Rio Grande Valley and assembling basic attribute data on the water distribution networks. The development of this GIS resource has played a key role in the planning and completion of this study.

The study was done in the following steps:

- identification and verification of the districts with municipal water deliveries;
- production of review maps for each of the 14 districts;
- initial meeting with irrigation districts to:
  - A. review maps,
  - B. identify on the maps the locations of municipal takeout points and downstream control structures, and
  - C. collect available data on sizes, dimensions and capacities of MSN components;
- with district staff, conduct field reconnaissance and measurements as needed;
- mapping and computing the surface areas of reservoirs and resacas using aerial photographs and GIS mapping tools;

- determining the lengths of MSN components from GIS-based maps;
- processing data, completing analysis, and production of tables and maps for districts to review;
- meetings with district personnel to review data and analysis;
- follow-up field measurements and other efforts as needed to develop complete data sets and analysis;
- finalizing MSN estimates under normal operational conditions, including:
  A. static volume,
  B. evaporation, and
  C. seepage losses;
- feasibility assessment of analyzing MSN requirements assuming no agricultural water deliveries; and
- formation of recommendations for further analysis.

IDENTIFICATION OF THE MUNICIPAL SUPPLY NETWORK

We first obtained a GPS survey from the Rio Grande Water Master office, which contained the latitudes and longitudes of municipal water treatment facilities in Hidalgo and Cameron Counties, and each of the irrigation districts that supplied raw water to the division points. Next, we imported this data into *ArcGIS*, and produced GIS maps of each district showing the district boundaries and water distribution networks in relation to the plant locations. The municipal supply systems that carry water from the district takeout point to the plant were unavailable.

For the next several weeks meetings were scheduled with district personnel to verify, on the maps, the exact location of the takeout points for each treatment plant, and also to identify the nearest control structures needed for isolating the MSN from the remainder of the distribution network. From the meetings, we learned that the districts had limited knowledge of what systems could be eliminated to obtain the most direct path to the takeout points.

EXTENT, CAPACITIES AND SURFACE AREAS

Our GIS-based maps and databases include canal type (lined, unlined) and top widths for most canal segments in the region (for more information on these maps, see http://idea.tamu.edu). However, we have not assembled other attribute data such as canal shape, slide slopes, bottom width, and the actual water span widths and depths at different operating levels. All of this information was needed for this study, but few of the districts had this information readily available. Out of the 14 districts, only one district had all needed information, and only two of the remaining districts had a significant amount of the necessary information.

With limited district personnel, we took measurements of canal water-span widths and depths during normal operation conditions of most canal segments within the MSN. The segments were selected and measured according to size variations and in relation to the control structure locations, which isolate the MSN components. Figure 1 shows portions of four (4) districts and segments for which field measurements were taken. Segment lengths were calculated using GIS mapping tools.

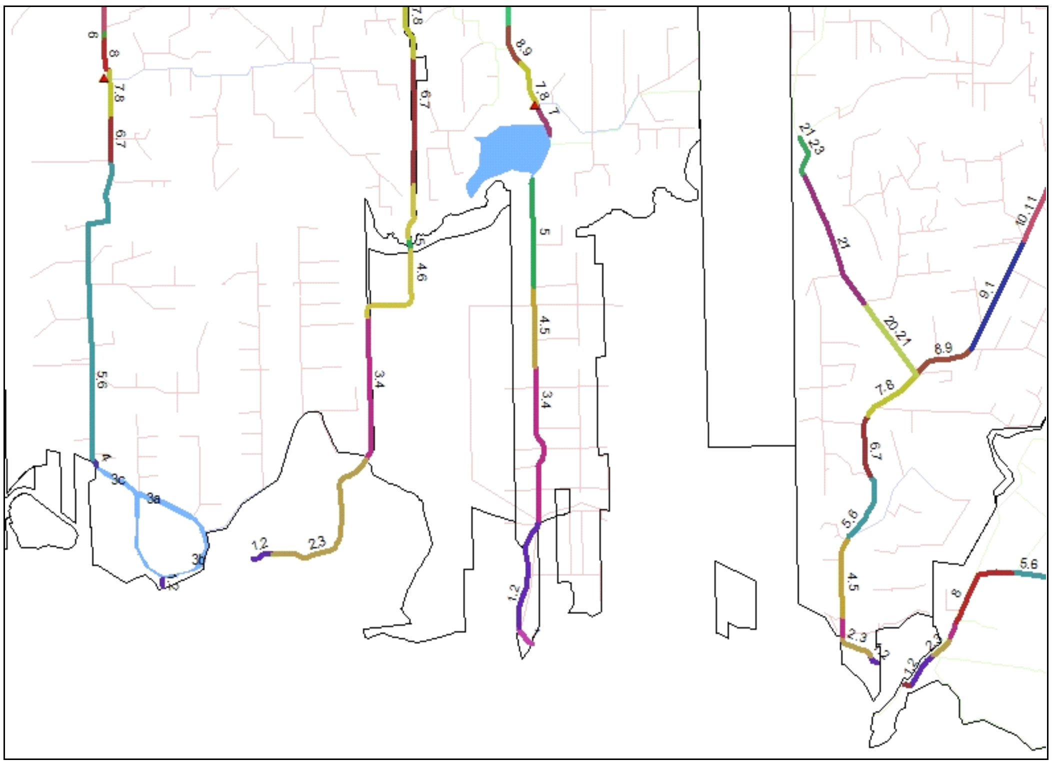

Figure 1. Shows portions of four (4) irrigation districts with MSN segments and segment reference numbers for which depth and width measurements were taken

The next step was to combine canal width and depth measurements with canal shape information to determine the capacities of each segment. However, only three of the 14 districts had information available on canal shapes. Thus, we had to assume canal shapes to complete this portion of the analysis. We used the following two shapes:

- a parabolic shape to produce a low volume estimate
- a rectangular shape to produce a high volume estimate

Most lined canals have a trapezoidal shape that will have a volume that is greater than a parabolic but less than a rectangle. Very large, unlined canals tend to be rectangular, while smaller unlined canals develop a more parabolic shape.

Next, using aerial photographs, we mapped the boundaries of all reservoirs and resacas, and for districts without capacity data, took depth measurements and calculated surface areas and total storage volumes.
Table 1 summarizes the characteristics of the MSN. *Static volume* is defined here as the volume of water needed to fill the MSN to normal operating levels for agricultural water deliveries. *Static* means that water is not flowing in the system (an analogy is the filling a bath tub with water). Usually, water is not static in distribution networks, but continuously moves. This *transient* capacity will be somewhat higher than the static estimates provided here.

Table 1. Summary of the municipal water supply network characteristics.

component	**width/ diameters**	**total length (miles)**	**surface area (acre-feet)**	**static volume (acre-feet)**
lined canals	4 - 80 ft	92	229	721 - 866
unlined canals	10 - 150 ft	168	1,137	4,382 – 6,527
pipelines	14 - 72 in	25		27
resacas			377	2,484
reservoirs			3,845	8,216
TOTALS		**285**	**5,588**	**15,830 - 18,120**

Figure 2 shows the irrigation district service area boundaries, locations of the water treatment plants and takeout points, and the extent of the MSN.

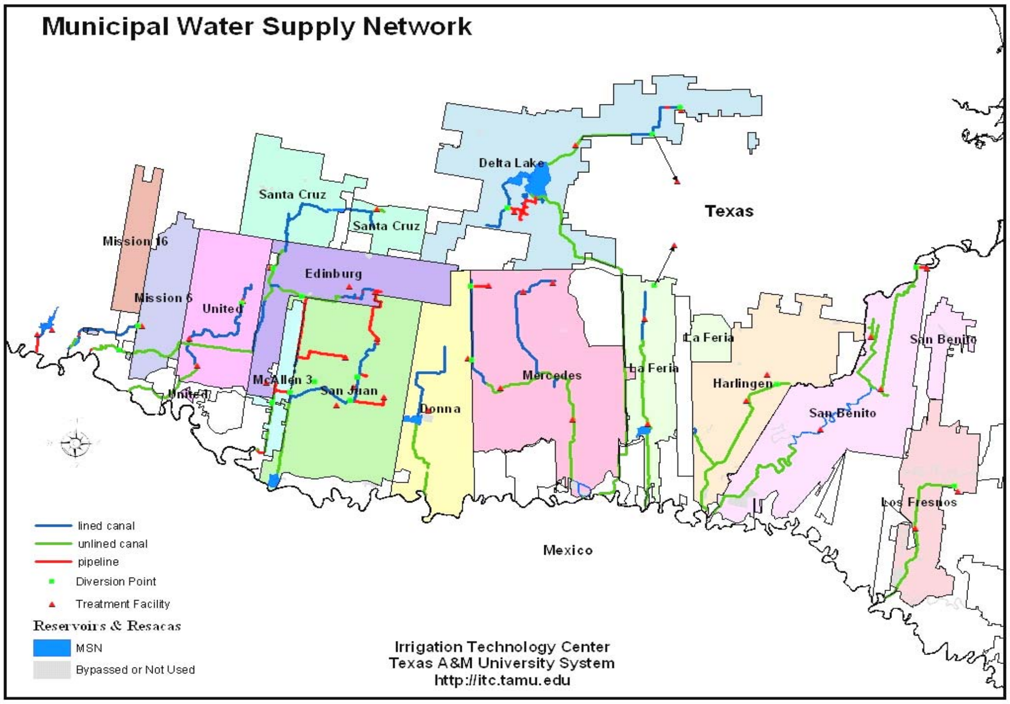

Figure 2. The Municipal Water Supply Network

ADDITIONAL ESTIMATIONS AND OPERATING SCENARIOS

The estimates assume that the MSN is operating at normal levels used for agricultural water deliveries. We have good confidence in the volume and evaporation estimates. More work is needed to improve seepage loss estimates and narrow the range shown below.

We did not attempt an analysis of the MSN for the case of only municipal water deliveries (i.e., in the absence of agricultural water). The data to complete such an analysis is not currently available, and collecting this data and performing the analysis would be a time and labor intensive effort. To evaluate the value of such an analysis, we recommend that a pilot study be done on one to two districts to determine if further analysis is warranted.

Evaporation

To estimate evaporation from canals and resacas, we used the following equation:

Evaporation = 0.8 x (peak Class A pan evaporation) x (surface area)

From National Weather Service data, the peak Class A pan evaporation rate occurs in July and is equal to about 0.25 in/day.

For determining evaporation from reservoirs, we used the following equation:

Evaporation = (peak lake evaporation rate) x (surface area)

From the Texas Water Development Board website, we selected an average peak lake evaporation rate of 0.33 in/day for these calculations.

Table 2 gives the estimated evaporation rates for the MSN. Delta Lake accounts for 62% (65 ac-ft/day) of the total evaporation from the reservoirs.

Table 2. Maximum daily evaporative losses of the municipal water supply network.

component	**surface area (acres)**	**evaporation (ac-ft/day)**
canals, resacas	1743	0 - 29
reservoirs	3845	0 - 106
TOTAL	**5588**	**0 - 135**

Seepage Losses and Leaks

Most of the 14 districts in the MSN charge for water losses based on a percentage, ranging from 15 - 30%. One district has a higher charge for municipal deliveries when there is no agricultural water, and two districts use rates based on the gallons delivered. A percentage is not useful for calculating seepage losses. Instead, we need a rate such as gal/ft^2/day, which is the most common measurement of seepage loss rate.

Since 1998, we have conduced 52 ponding tests to determine the seepage and total losses of irrigation canals in the Lower Rio Grande River Basin. Table 3 provides a summary of test results. The results labeled *high with leaks* were in canals that, in addition to seepage losses, had leaks caused by cracks and holes in the canal embankment, and/or leaking valves and gates within the test segment.

Table 3. Expected seepage and total losses (gal/ft^2/day) from MSN canals, reservoirs and resacas based on ponding tests conducted in the Lower Rio Grande Valley			
component	**low**	**High**	**high with leaks**
unlined canals	0.15	3.14	4.71
lined canals	0.25	4.62	6.93
reservoirs/resacas	0.15		

While only a few of our ponding tests were conducted on canals within the MSN (Figure 2), we expect that losses in the MSN will be similar to test results. To determine MSN seepage and loss rates, we combined the rates given in Table 3 with the actual dimensions of MSN components.

Table 4 gives MSN losses for three cases: *low*, *high* and *high with leaks*. The low case assumes the "low" loss rates from Table 3 and an assumed parabolic shape for canals with an unknown shape. Likewise, the high case assumes the "high" loss rates from Table 3 and an assumed rectangular shape for canals with unknown shapes. However, we do not expect many of the segments within the MSN to have leaks, thus seepage is more likely to be within the range of 42 to 826 ac-ft/day.

Table 4. Estimated seepage losses and leaks of the municipal water supply network (ac-ft/day).			
component	**low**	**High**	**high with leaks**
unlined canals	27	556	834
lined canals	9	171	257
reservoirs/resacas	5	81	81
pipelines	1	18	18
TOTALS	**42**	**826**	**1190**

We have tested only one (1) pipeline for leaks. Leakage from pipelines depends on such factors as the type of materials, joints (if used), and pressures (or how full pipe flows). Older, concrete pipes with no rubber seals are likely to have high loss rates, while newer PVC pipelines will have very little. The pipeline leakage in Table 4 is a first estimate only. More work is needed to confirm this estimate.

The No Agricultural Water Case

In the absence of agricultural water, the operational levels may be lower when supplying just municipal water. In such situations, the static volumes and losses may be lower than given in Tables 2, 3 and 4. This is because seepage loss rates are usually lower at shallower depths and the wetted perimeter and associated areas decrease very rapidly as the water level is reduced.

However, there will still be a minimum operational level. Many of the municipal takeouts depend on gravity flow from canals, which requires a relatively high operating water level. Similarly, for pump takeouts, a minimum water depth must be maintained above the pump for proper operation.

Of the 14 districts, only four (4) had such data readily available. As a result, most of the operational requirements would need to be determined in the field or obtained from the water utilities.

In addition, the ***transient volumes*** within the MSN at these lower operating levels would need to be considered. These volumes include the flow and depth of water needed to overcome resistance to flow caused by friction losses in canals and pipelines, and restrictions and friction losses caused by water control structures. The information needed for this analysis includes the types, elevations, and operation requirements of control structures (gates, siphons and culverts), and slopes and elevations of the MSN canals and pipelines. Such data is not currently available and would take a considerable effort to obtain (note: for the static volumes reported in Table 3, since depths were measured at normal operating levels, "transient" volumes are considered).

SUMMARY AND RECOMMENDATIONS

An initial analysis of the municipal water supply network (MSN) in the Lower Rio Grande Valley was completed. The extent of the MSN was based on the locations of existing control structures that can be closed to isolate the MSN from the remaining portions of the irrigation water distribution networks. Volume and loss calculations were completed for normal operating levels used for agricultural water deliveries.

There are 39 municipal treatment plants that take water from the water distribution networks of 14 districts in Hidalgo and Cameron Counties. As of November 2003, the MSN consisted of approximately:

- 92 miles of lined canals
- 168 miles of unlined canals
- 25 miles of pipelines
- 377 acres of resacas
- 3845 acres of reservoirs

We also produced the following estimates:

- the static volume (or capacity) is between 15,830 and 18,120 ac-ft
- evaporation from reservoirs, canals and resacas of the MSN ranges from 0 to 135 ac-ft per day
- Delta Lake accounts for 62% of the peak reservoir evaporation, or 65 ac-ft/day
- seepage losses range from 41 to 1190 ac-ft/day
- leakage from pipelines ranges from 0.25 to 18 ac-ft/day

Recommendations

- Improve the seepage loss and leakage estimates of pipelines and canals
- Conduct a pilot study on the *no agricultural water scenario* (i.e., only municipal water delivery) to determine if this analysis is warranted. Initially select one or two districts for this intensive data collection and analysis effort
- Take a regional approach in planning and implementing programs and projects to change the distribution networks to reduce water losses in the MSN and improve the dependability of water supplies.