# ISSUES AND APPROACHES TO COUPLING GIS TO AN IRRIGATION DISTRIBUTION NETWORK AND SEEPAGE LOSS MODELS

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## ABSTRACT

Geographic Information Systems (GIS) is increasingly being used in water resources primarily because of its ability to store, analyze and display spatial data. There are several possible approaches to coupling GIS with simulation models, depending on the objective, availability of data and resources, and the skill of the modeler. This paper outlines some methods and challenges related to applying GIS to simulation modeling of irrigation distribution networks. Two examples are presented: a GIS-based irrigation distribution network model currently under development at Texas A&M, and an analysis of seepage canal seepage losses using GIS. Main issues and challenges include user considerations, proper geo-referenced data, GIS software cost, availability of skills, and the difficulties of coupling existing models with GIS.

## BACKGROUND

A few researchers have linked GIS with simulation models for irrigation management. For example, Gupta et al. (2003), for example, used the interpolation techniques of *ArcInfo* to generate a topographic map of an irrigation command area in India. The digitized map data was then used as an input into hydraulic model. Ines, et al. (2002) used GIS and crop growth models to estimate irrigation water productivity. In both cases, data analysis and model simulations were done external to GIS, and GIS was used to input and store spatial data, and to display results.

There are several possible approaches to coupling GIS with models which vary depending on purpose, availability of resources, and the skill of the modeler. Possible approaches to integration of GIS with simulation models include:

<u>1. Loosely coupled</u>
The simulation model is run independently of GIS, and linkage is achieved using external code, or via Visual Basic within *ArcGIS*.

<u>2. Closely coupled models through a user interface</u>
Models are linked to a GIS coverage data model through a user interface. For example, a *ArcGIS* database is used to provide the site-specific information and/or to identify model data files that are required for model assembly.

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3. Closely coupled through a relational database

A geo-database is a relational database that stores geographic data. At its most basic level, the geo-database stores both spatial and attribute data and the relationship between them. These allow the user to build more complex data models including modeling the flow in geometric networks. Geodatabases are built using ArcCatalog software from ESRI.

4. Modeling using tools within GIS

Several tools are available in within GIS to develop models and carry out spatial analysis. These form part of GIS analysis using raster algebra. Examples include:

- Geo-statistical functions – used to interpolate surfaces based on the spatial location of measured data. This is useful for interpolating geological variables such as rainfall, temperature, and hydraulic conductivity
- Distance functions that allow the user to determine the nearest location to a feature or the least cost path to a particular destination.

## EXAMPLE 1: IRRIGATION DISTRIBUTION NETWORK MODEL

Over the past three decades, there has been much research in developing computer models and software packages for water resources planning and management (Wurbs, 1994). However, there has been little work on modeling of irrigation distribution networks, and most existing models lack GIS database connectivity.

The most widely know distribution models include:

- Steady, a steady-state canal hydraulic model (Merkley, 1994)
- CanalMan, a hydraulic simulation model of unsteady flow in branching canal networks (Merkley, 1997)
- HEC-RAS, river hydraulic models of one-dimensional steady and unsteady flows (Brunner, 2001).

Of these three, only HEC-RAS has the ability to import three-dimensional river schematic and cross section data created in a GIS or CADD (Computer Aided Drafting and Design) system. After completing a hydraulic analysis, the computed water surface profiles can be exported back to the GIS or CADD system for development and display of a map.

The Texas A&M Approach

A distribution network includes many elements, including mains, laterals, turnouts, gates, valves, and other control and management structures. These elements are complex and encompasses large amount of information that vary with time. GIS is ideal for storing, displaying and analyzing this data. We believe that GIS is the key in making distribution network models practical, and will enhance spatial data management, visualization and analysis with hydraulic models.

We are developing a new, combined open channel, pipeline distribution network model using In OOP (Object-Oriented Programming) C++ programming language and GIS functions being built with *ArcGIS*.

GIS is used to provide input data to the model and to display the output or results of the model. In *ArcView*, attribute tables have been set up which describe map features (stored in dBase tables or .dbf files). We are experimenting with two methods for using GIS for managing input and output data:

Export and import as text files

The original *ArcView* (.dbf) data files can be exported as text (.txt) files. Using standard data input commands, models can be programmed to extract needed data from the text files. After the simulation is completed, the results are written to output text files. Then *ArcView* can join the output text files with original .dbf files to generate new dBase tables.

Export and import as dBase tables

Original *ArcView* .dbf files can be exported to a database using SQL. The SQL server manages GIS data in a centralized mode. The SQL server then exports useful data to the models. The models send back the calculation results to the SQL server. ArcView can join the .dbf files from the SQL server to generate new dBase tables for the map.

## IRRIGATION DISTGRICT NNETWORK MODEL PROTOTYPE

### Model Description

Open-channel branching irrigation distribution networks are analyzed and modeled generically. The generic model is based on a canal system as shown in figure 1. This layout is divided into three parts: upstream, middle, and downstream. Gradually varied flow is assumed in the upstream and downstream sections, while uniform flow is assumed in the middle section.

For the example shown in Figure 1, at the upstream end is a square sluice gate with the opening $G_o$ and sill height h. Under the gate, the water is assumed to flow freely. At the downstream end is a dam with a water depth of $y_d$ immediately behind the dam. Flow may be specified in one or more turnouts in each lateral. A C++ program has been coded to simulate the flow in this branching distribution network.

### Model Verification

The model has been validated with the data measured from an irrigation system in Jamaica. The details of the verification will not be discussed in this paper.

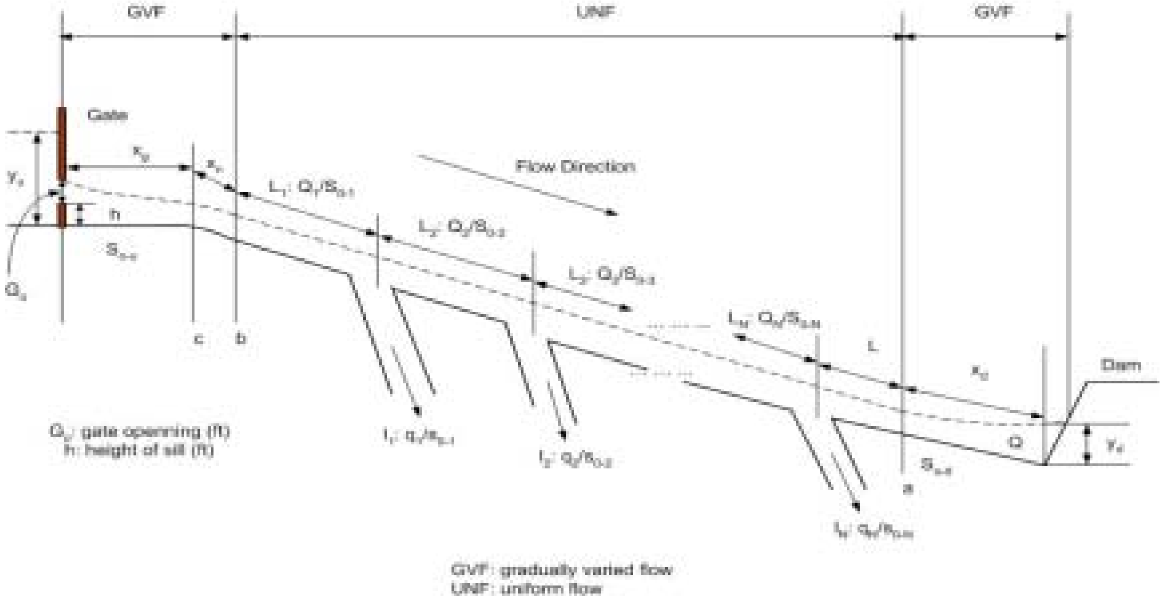


Figure 1. Generic Layout of Branching Open-Channel Irrigation Distribution Network

A GIS map was made with *ArcGIS* (*ArcMap* with *ArcCatalog*). This map consists of following three shape files:

1. Fields:

Polygon shape files which represent the fields with or without different kinds of crops, hypothetically crop 1 and crop 2 in the map.

2. Canals

This is a polyline shape file to represent irrigation canal segments (main, lateral, turnout, etc.). Each of the canal segments has a record in a dBase .dbf table to store the data, such as system ID, name, length, canal shape, roughness factor, bottom slope, side slope, and bottom width. These data are needed for the open-channel model to implement.

3. Structures

This is a point shape file to represent irrigation regulation structures along the system (weir, gate, flume, etc.). Each of the structures has a record in a dBase .dbf table to store the data such as, structure ID, name, width, and calibration factors. These data are also required in the model. The model output or results are written to a dBase table which is then used to produce shape files and the new information on the map.

Figure 2 shows a schematic of the distribution network and some input data; JFIgure 3 shows the simulation results segment. With the model results, *ArcGIS* can produce maps of discharge and depth profiles, including depth around the structures and settings of the structures such as gate opening.

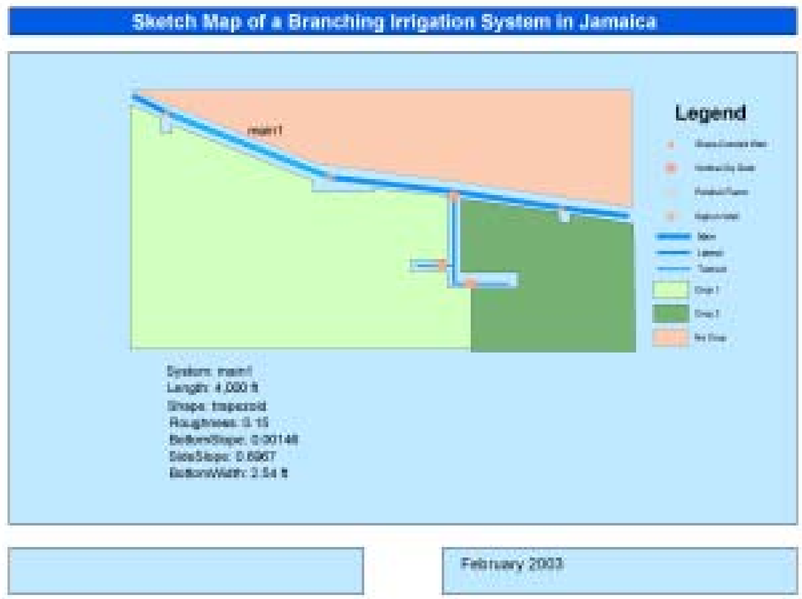


Figure 2. Schematic of Irrigation Distribution Network with model input data

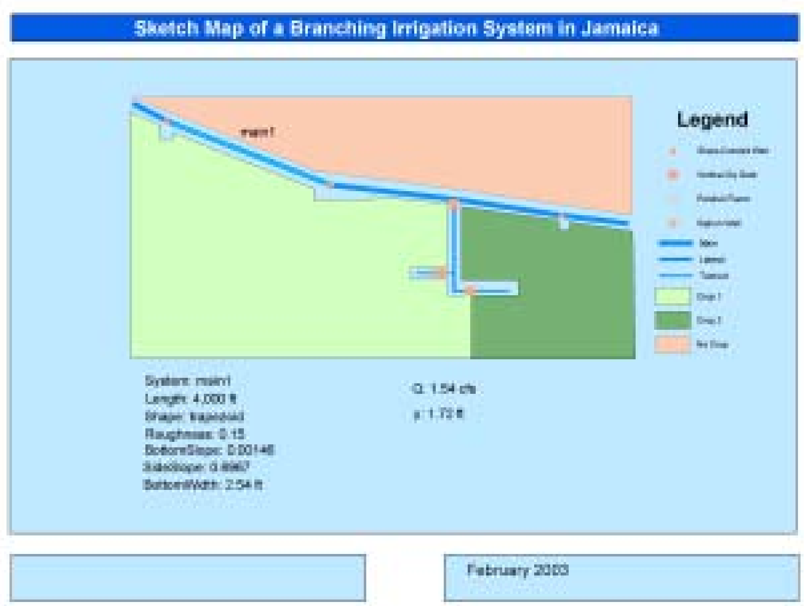


Figure 3: Schematic of Irrigation Distribution Network with results of model implementation

## EAMPLE 2: MODELING USING GIS TOOLS

GIS was used in determining the most suitable or “least cost” path for conveying water in a distribution network. In the least cost path analysis, the eight neighbors of a cell are evaluated and the path then moves to the cell with the smallest accumulated value. A cost surface represents a factor or combination of factors that affect travel across an area. Different cost surfaces can be combined as long as they are ranked on a common scale. Weights can be assigned to each factor based on the relative importance of that factor.

In this example, the conveyance capacity of open canal is dependent on factors including:

- Canal condition – type and quality of lining, presence of weeds
- Soil – infiltration rate which contributes to seepage losses
- Geometry – side slope, top and bottom width defines capacity
- Slope – provides the driving force

These factors were combined to develop least path cost surfaces as shown in Figure 4. The total cost raster is shown in Figure 5. The least cost path for conveying water from the source to a location at the lower end of the network is shown in Figure 7**.**

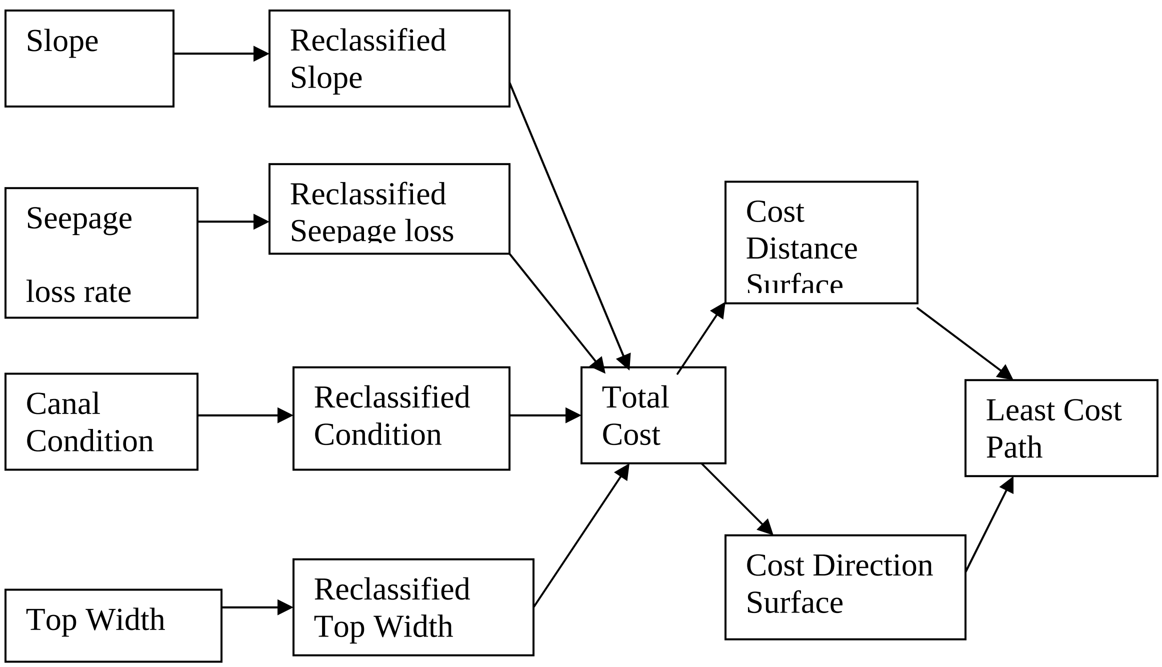


Figure 4: Flow chart for calculating cost surface

Least cost path analysis is expected to form part of broader studies, to determine the most cost effective canals for rehabilitation. This would account for other factors including rehabilitation costs, and crop productivity on different soils.

Data generation and analysis
The dataset for this analysis was generated from measurements and data from the Lower Rio Grande Valley in Texas:

- Seepage loss rates were generated from ponding tests conducted in the project area.
- Canal condition is based on a rating system under development at Texas A&M. Canals were rated on a scale of 1 – 5, based on a visual inspection of the level of cracks, and weeds in the canals. The lower value indicates small number of cracks and low weed infestation.


Figure 5: Total cost raster surface for water conveyance


Figure 6: A least cost path alternative given equal weight to each factor.

The seepage loss tests and canal condition rating form part of the Rapid Assessment Tool (RAT) being developed at Texas A&M University assess the rehabilitation needs of the canal network.

## ISSUES AND CHALLENGES

GIS Integration with existing hydraulic models.
While several good hydraulic models exist, their codes are not always compatible with new GIS applications. Persons who need models that are closely coupled to GIS may need to develop their own code. While very time consuming, it would avoid the integration problems reported in the literature. An added advantage is that these new codes and models can be made available on the World Wide Web and thus transferred rapidly and inexpensively to users.

Data availability and data quality.
The usefulness of models and GIS depends heavily on the availability of good and quality data. This includes properly georeferenced spatial data of system components including canals, along with attribute data such canal capacity. Some data including digital elevation models of different areas in the United States are available on public domain, and is available via the Internet. This may not be the case in other countries where digital data may not be as well developed or not readily available. Accurate seepage loss measurements are both time-consuming and costly to generate, but are necessary for suitable analysis. Accurate data is also needed to properly calibrate and validate models.

User considerations.
This is a most import aspect of model integration. Model integration should result in "user friendly" products that satisfy the demand of the user, combined with proper support.

Cost of data, hardware and software.
GIS modeling requires the use of fast computers having large data storage capacities. While the required computer hardware is becoming increasingly more powerful, and relatively low-priced, this may not be the case with computer software.

Availability of skills.
The use and integration of GIS in irrigation applications require specialized knowledge, which can only be acquired through training and human resource development. As such skills are not always available in irrigation districts, the opportunity exists therefore for major human resource development solutions to match the development of spatial technology.

Integration with other spatial technologies.
The availability of global positioning systems (GPS) and remote sensing can enhance both data accuracy and the easy of collecting data. GPS allows for accurate georeferencing and measurement. Alternatively satellite imagery can produce both land use and seepage loss data, which are critical for analysis in irrigated agriculture.

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