IMPROVING OPEN CHANNEL NETWORK OPERATION

USING GATE CONTROL SUPPORT MODEL

DEVELOPED WITH ARCGIS GEOPROCESSING TOOLS

A Thesis

by

MOSTAFA ESKANDARI HALVAEI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Biological and Agricultural Engineering

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Using Gate Control Support Model

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Approved by:

Chair of Committee,	Raghavan Srinivasan
Committee Members,	Kelly Brumbelow
	Vijay Singh
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ABSTRACT

Improving Open Channel Network Operation

Using Gate Control Support Model

Developed with ArcGIS Geoprosessing Tools. (August 2010)

Mostafa Eskandari Halvaei, B.S., University of Tehran

Chair of Advisory Committee: Dr. Raghavan Srinivasan

Many efforts have been conducted for improving the operation and management of open channel networks. Implementing simulation models and software is an effective step in achieving better operation of control structures in open channel networks. The purpose of this study was to develop a tool in ArcGIS for assisting the open channel network managers in operating flow control structures. This model presents a time schedule for gate operation based on the demands at turnouts through the water usage schedule of the network. The developed model was designed to be added as a tool to ArcToolbox in ArcGIS. Any ArcGIS user who has access to ArcView or ArcInfo can add this tool to ArcToolbox. Using ArcGIS Geoprocessing tools, ModelBuilder, Scripting and ArcToolbox tools, the proposed model, "Arc-Canal", was created. Arc-Canal is implementable for irrigation networks that open channel network are digitized in ArcGIS. Simulation is for the gravity flow in open channels without any pump in the network. Calculations are based on steady flow. All hydraulic calculations for water level, gates, and weirs are based on the methods defined in "Open-Channel Hydraulics"

(Chow 1959). Most of the available flow simulation models are complicated individual software for which user needs to be trained to install and use it. Also most of these software are not free accessible. Arc-Canal is an easy to use tool that anyone with the knowledge of working with ArcGIS can run it. By adding the tool to ArcToolbox and following the described naming method, and entering the required data, model is ready to run. The developed model is a free access tool. Most of the channels in open channel networks in south Texas have mild bottom slope and flow is steady gravity flow. It is desired that the developed model will be a tool to assist irrigation districts in south Texas.

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CHAPTER I

INTRODUCTION

FAO (2009) reported that as global populations grow and as the demand for food

increases in a world with a fixed water supply, there are efforts underway to learn how to

produce more food with less water through improvements in irrigation

methods and technologies, agricultural water management, crop types, and water

monitoring. In 2000, the world population was 6.2 billion. The UN (2009) estimates that

by 2050, there will be an additional 3.5 billion people, with most of the growth

in developing countries that already suffer water stress. WBCSD (2009) estimated that

69% of worldwide water use is for irrigation.

The management improvement would be the subsequent step for the irrigation

networks after structural improvements like canal lining and water control structures

application. Preparing scientific irrigation schedules, automating water control

structures, quantifying the exact water demands and usages, and verifying the water

losses through the irrigation distribution network are the issues that network managers

might overcome to minimize water loss.

Simulating the irrigation networks and using software developed for gate

automation represent scenarios for irrigation network management and water control

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This thesis follows the style of *Journal of Irrigation and Drainage Engineering*.

structure operations to improve the water usage efficiency. There are several flow simulation models for irrigation distribution networks simulating steady, unsteady, or both flow conditions. Most of the flow simulation models can incorporate a variety of water control structures such as gates, weirs, and flumes.

ArcGIS is an integrated collection of GIS software products that provides a standards-based platform for spatial analysis, data management, and mapping. One of the desktop level products of ArcGIS is ArcView. ArcView can display spatial data, create layered maps, and perform basic spatial analysis. Most of the irrigation districts use ArcGIS in order to present their properties, lands, and the water distribution networks graphically, and also often build databases for importing their properties' data to databases.

Geoprocessing is a GIS operation used to manipulate GIS data in the way that takes an input dataset, performs an operation on that dataset, and returns the result of the operation as an output dataset. The fundamental purposes of geoprocessing are to allow the user to automate GIS tasks and to perform spatial analysis and modeling. Geoprocessing allows the user to quickly and easily turn his ideas into new software that can be executed, managed, modified, documented, and shared with the ArcGIS user community. ModelBuilder and scripting are two tools of geoprocessing. Model Builder is an application that users can use to create models with ArcToolbox tools and features, perform analysis, and also document and distribute models so they can be useable by others.

In this study, I developed a model simulating the steady flow in open channel networks to help the open channel network managers operate gates based on more accurate schedules. I named my developed tool "Arc-Canal". Arc-Canal provides the gates' position preference and channel flow profile at each reach. Arc-Canal is developed with the following ArcGIS geoprocessing tools: ModelBuilder, Scripting, and ArcToolbox tools.

1.1. Objectives

Create a tool in ArcGIS that simplifies simulating steady flow in open channels and generating gates' operation schedule, which does not need any extra knowledge of using ArcGIS, encouraging ArcGIS users to take Arc-Canal advantages.

Using the flow simulation models seems necessary to reach a better irrigation distribution networks operation management. Better management improves the efficiency of the irrigation and results in better irrigation scheduling. Most of the irrigation districts and water distribution offices use and are familiar with ArcGIS. This idea originated from the necessity of using the flow simulating models and irrigation district offices being familiar with ArcGIS.

The main outcome of this project is a tool in ArcToolbox that prepares a schedule for the operation of all gates in an open channel network. The result of this tool can be shown in three methods: (1) A table presenting all gates operation schedule. This view is the main view of the output of this model; (2) Network Gates Positions for a

specific time. For this method input is Time and the output is a table that shows each gates' position for the selected time; (3) Single Gate Operation Schedule. For this method input is Gate ID and the output is a table presenting times and the position of the selected gates.

Besides the main tool, Arc-Canal contains two other minor tools; (1) Discharge Calculator, for specific time for all or a specific reach. For this tool inputs are Time and Reach ID and the output is the flow rate, Q (cfs) (2) Water Profile Plot, for a specific time for a specific reach. For this tool inputs are Time and Reach ID, and the outcome of this model is a table that presents water depth and distance from channel upstream. Users are also able to view the results graphically.

My efforts focus on presenting better managements for irrigation scheduling, by improving gate controlling, delivering more accurate water amount at demands, making less water waste and decreasing the operation time that cause saving money from spending less for power and labor. The overall goal of this research is improving the irrigation distribution network efficiency and management. The result of this improvement is preparing easy to use tools for irrigation networks managers.

CHAPTER II

LITERATURE REVIEW

Flow simulation models are programs represent the behavior of the flow in
certain conditions. Simulation of flow is to gain insight into the flow behavior.
Simulation models for open channel flows have been commercially available for more
than 2 decades (Clemmens et al. 2005). Developed flow simulation software has been
designed to simulate the steady or unsteady flow conditions and some of them are
designed to simulate both flow conditions. Beside flow simulation software many people
have worked on developing automatic canal control systems and automatic gate control
algorithms. Wide varieties of control algorithms had already been developed or were
under development in 1998 (Malaterre et al. 1998). The most economical option for
improving the performance of the irrigation networks is better system operation and
management; and for making better management it is very helpful apply the flow
simulation models and testing different management scenarios to find the best
management scenario (Islam et al. 2008).

In late 1980s, the ASCE task committee on irrigation canal system hydraulic
modeling was formed to evaluate the available computer programs for simulating
unsteady open channel flow and published the report presenting the committee findings
in 1993 (The ASCE Task Committee on Irrigation Canal System Hydraulic Modeling
1993). This committee investigated the available simulation models on in 1993: CANAL
from Utah State University, SNUSM from a former Bureau of Reclamation engineer in

Arizona, MODIS from Delft Institute of Technology, Delft, The Netherlands, DUFLOW from The Netherlands Public Works Department, Hague, The Netherlands, USM from the Bureau of Reclamation, Denver, and CARIMA from SOGREAH consulting engineers, Grenoble, France. The ability of the models that the committee was more interested in was ability to simulating water level and flow variations in canal systems with many gates and weirs (The ASCE Task Committee on Irrigation Canal System Hydraulic Modeling 1993). As a result of evaluations, four problems limited the use of computer models for canal system management were published; Models are not well publicized and are not readily distributed to prospective users, most if not all canal-system models are poorly and inadequately documented, there is a significant lack of end-user confidence, and few models have been coupled with adequate and/or sufficient data to provide a necessary level of calibration and verification (The ASCE Task Committee on Irrigation Canal System Hydraulic Modeling 1993).

Following the ASCD task committee, another committee was formed to evaluate canal control algorithms (Holly and Merkley 1993). Investigators tested each algorithm with the canal simulation model which they had access to the source code or the source code developer of the model. The results were presented in a special issue of the Journal of Irrigation and Drainage Engineering (Clemmens 1998). The simulation models used to analyze control algorithms were: SIC used by Malaterre (1998), Deltour and Sanfilippo (1998), CANAL used by Merkley and Walker (1991), CASIM used by Liu et al. (1998), CanalCAD used by Burt et al. (1998), ICSS used by Lin and Manz (1992), and Mike 11 used by Clemmens et al. (1997).

Several studies on automatic canal control systems and gate control automation in open channel networks have been done, and the methods and algorithms have been performed on many of available unsteady flow simulation software. Although many of these automation studies have been conducted by institute that created the simulation model, these simulation models were not created with gate control in mind and thus one has to be intimately familiar with the source code in order to implement sophisticated control features (Clemmens et al. 2005). Of the unsteady flow simulation models created with the automatic gate control in mind, only three of them have the capability of automatic gate control based on the algorithms written by user; CanalCAD from the Univ. of Iowa, Hydraulics Lab, Mike 11 version 3.2 from the Danish Hydraulic Institute, and SOBEK from Delft Hydraulics (Clemmens et al. 2005).

Clemmens et al. (2005) found CanalCAD, Mike 11 version 3.2, and SOBEK useful for canal automation studies but they mentioned that it was required to develop a new canal model having more convenient methods for determining canal properties. Their results show that CanalCAD is easier to use, but it has more limitations than MIKE 11 version 3.2 and SOBEK (Clemmens et al. 2005).

CanalCAD (Holly and Parrish 1992) was the first unsteady flow simulation software that was developed primarily to test automatic canal-control algorithms (Clemmens et al. 2005). CanalCAD is a simulation model developed for designing, analyzing and operating irrigation canals for both steady and unsteady flow and the computations are based on full, one-dimensional, dynamic de St. Venant equation. It uses the implicit Preissman scheme where all nodes are assigned values or both depth

and discharge. The solution starts with known conditions at a given time and solves for the values at a future time. CanalCAD is the only program that offers predefined options for simulating gravity offtakes (Clemmens et al. 2005). CanalCAD has a user customized access for gate control algorithms and a user friendly menu for canal definition and results processing. This simulation software cannot handle branching canals, however branching and looping through a reservoir is allowed. Parrish and Khalsa (1997), Burt et al. (1998), and Wahlin and Clemmens (2002) used CanalCAD in their researches.

MIKE 11 is modeling software for simulating flow, water quality and sediment transport in estuaries, rivers, irrigation canals and other surface water bodies developed by the Danish Hydraulic Institute. "MIKE 11 GIS" is side software for MIKE 11 which is an extension to ArcMap. It takes advantage of ArcMap's many GIS functionalities and provides the user with a number of useful tools in relation with MIKE 11 modeling. Bautista et al. (2006) studied the canal automation controlling a single in line canals. The study case of this research was Salt River Project (SRP). For this study the Danish Hydraulic Institute (DHI) developed a Mike-11(version 3.2, DHI 1992) model of SRP's Arizona Canal (Rungo 1995). Tests were conducted on the Upper Arizona Canal to verify the ability of the model to simulate transients (Clemmens et al. 1997). Computed water levels matched actual water levels and water level trends compared favorably in all pools; hence differences can be explained by gate calibration inaccuracies (Bautista et al. 2006).

SOBEK is a general software package for the integral simulation of processes in one dimension and two dimensions, i.e. in a river, an estuary, a canal or in a sewer network. It is a powerful instrument for flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, ground-water level control, river morphology, salt intrusion and surface water quality. The SOBEK model has interaction with MATLAB software. Water levels from SOBEK passed to MATLAB and gate position changes are passed back to SOBEK. Wahlin and Clemmens (2006) used two types of controllers for studying the branching canal networks automation; linear quadratic regulator delay (LQR) and model predictive control (MPC). In branching canal network it is not an effective control strategy to control the whole system by controlling each canal separately (Wahlin and Clemmens 2006). The researchers used SOBEK unsteady-flow simulations to evaluate both the LQR and MPC feedback-control algorithms. At that time, SOBEK did not have a function that allows the user to model radial gates (Wahlin and Clemmens 2006). The available boundary conditions in SOBEK are either water surface elevations or flow rates. In SOBEK, changes in gate hydraulic regime occur more suddenly than in real life, causing numerical oscillations and potential instability (Wahlin and Clemmens 2006).

In the late 1980s, the irrigation division of Cemagref Montpellier in France developed the first version of mathematical model of hydraulic simulator for steady and unsteady flow in canal networks and named it SIC (Simulation of Irrigation Canals). The main goal of the software was to represent the behavior of the canal system and designing and managing the canals. In SIC model, the simulation of the flow is based on

the one-dimensional Saint Venant equations, and also subcritical calculations (subcritical flows can be modeled at cross structures and limited locations). Litrico et al. (2008) reviewed several methods to convert discharge into gate opening for the control of an open channel equipped with regulation gates. The researchers developed a method to take into account the dynamic behavior of the pool-gate interaction by using a simple linear model for the pools' dynamics. SIC simulation model was used in Litrico et al. (2008) study for comparing the exact solution obtained from a full nonlinear simulation of SIC model with three approximations results of nonlinear methods of the researchers studies. Litrico et al. (2008) claimed that their proposed method enables users to better estimate the gate opening necessary to get a desired average discharge.

Although, in reality it is not possible to operate the gates all the time and open and close them base on the discharge required upstream and downstream, this limitations comes from the mechanical limitations of the gates and also the power consumption (Litrico et al. 2008), in the design of controllers for irrigation canals, it is well known that using the discharge as the control variable enables us to partially decouple the pools (Malaterre 1995; Schuurmans 1997; Malaterre et al. 1998; Malaterre and Baume 1999).

The principle objectives of the SIC model are provide a research tool for understanding the hydraulic behavior of the canal; to practice the operational management rules in order to improve the current procedures of management of the canal; evaluating the influence of possible modification on certain parameters of canal design to improve and maintain the capacity of a channel; to test the automatic operational procedures and to evaluate their effectiveness.

In 1995, US Department of Defense, Army Corps of Engineers released to public software model the hydraulics of water flow through natural rivers and other channels called HEC-RAS. This software performs one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling. Islam et al. (2008) developed the new steady and unsteady flow simulator for irrigation open channels (branched or looped) for improving the performance of the irrigation networks, named it CanalMod. Authors mentioned that steady flow calculations could be done directly with flow formulas but for unsteady flow calculations it is required to use numerical modeling; in this research the Saint-Vanent equations for unsteady flow were solved using weighted four-point Preissmann scheme. The commonly used boundary conditions in open channel flow modeling are discharge hydrograph at the upstream boundary and stage hydrograph, rating curve or constant depth at the downstream boundary (Islam et al. 2008). The computational and processing modules of the CanalMod are written in "C" programming language and the data editor is written in "Visual Basic". Islam et al. (2008) used HEC-RAS model simulation results for comparison and confirmation of the CanalMod simulation results; CanalMod simulation results and simulation results of the HEC-RAS model were almost identical.

CanalMan (Merkly 1995) is the hydraulic simulation software for simulation of flow in branching canal networks but not loop canal systems, for analysis, operational and training activities. CanalMan developed at Utah State University, Logan, Utah, USA. The model has the ability of operation both in manual and automatic mode and generates the proposed operating schedule. One of the outstanding capabilities of this

model is taking the local gate automation algorithms applied by the user. The local gate automation schemes designed in the simulator can be calibrated and used by the user. During the simulation it is possible to change the input and see the effect of change on the results. The canal cross section can be either trapezoidal or circular in CanalMan. The Saint-Venant equations constitute a system of two nonlinear, hyperbolic, partial differential equations that have traditionally been used to model the water flow in open channels (Hashemi et al. 2007). Canelon (2009) applied three different linear equation solvers for solving the Saint-Venant equations in CanalMan simulation software: (1) Gaussian elimination with no pivoting (the original solver in CanalMan), (2) LU decomposition with partial pivoting, and (3) Gauss-Jordan elimination with full pivoting. It was demonstrated that the application of partial and full pivoting to the solution of the linear set of equations during Newton–Raphson iterations can make the difference between convergence and divergence of the solution, and should be applied as needed. Implementing the pivoting strategies, especially full pivoting affected the execution speed of CanalMan and made it faster (Canelon 2009).

Attempts to automate gates have met with limited success and there is still much room for improvement in automation methods (Chittaladakorn and Merkley 2005). Chittaladakorn and Merkley (2005) developed a classifier system for automatic operation of canal gates and tested that through simulation modeling. The classifier system contains of lots of rules and appropriate responses to the rules. Each rule has a condition and one associated action. The classifier system can be applied to the control of computer simulated system or to a real system. Chittaladakorn and Merkley (2005)

developed a GBML (Genetics-Base Machine Learning) classifier system to search for a finite set of operational rules for open channel irrigation delivery system and tasted it through simulation.

GIS is a general-purpose technology for handling geographic data in digital form. Its abilities include: preprocessing data into a form suitable for analysis, supporting spatial analysis and modeling directly, and postprocessing results (Goodchild 1993). McKinney and Cai (2001) describe a concept and methodology of connecting GIS with water resources management model. Through the developed model users interact with GIS interface, and they can apply their changes and decisions to the model while the model is running behind the GIS. Authors point it out as one of this model advantages. The concept and methodology of connecting GIS to models in other fields that have a spatial dimension and hence to which GIS can provide a powerful additional component of the modeler's tool kit is applicable (McKinney and Cai 2001). The concept and methodology described in this paper is also applicable to connect GIS with models in other fields that have a spatial dimension and hence to which GIS can provide a powerful additional component of the modeler's tool kit.

Python is a programming language whose design philosophy emphasizes code readability (Python Foundation 2007). ESRI sees Python as the language that fulfills the needs of its user community. Some advantages of Python are as follows (ArcGIS Desktop 9.3 Help 2009):

- Python is simple to learn because of its clean syntax and simple, clear concepts.
- Python supports object-oriented programming in an easy-to-understand manner.

- Documenting Python is easy because it has readable code.

- Complicated data structures are straightforward to work with in Python.

- Python is simple to integrate with C++ and Fortran.

- Python can be seamlessly integrated with Java.

- Python is free from the Web and has a widespread community.

CHAPTER III

MATERIALS AND METHODS

ArcGIS Geoprocessing was used for developing "Arc-Canal". By applying available tools of ArcToolbox and scripting the hydraulic functions and adding the scripts, I developed Arc-Canal in ModelBuilder. Scripts for the proposed model are in Python and Visual Basic programming languages.

The developed model is for simulating the flow only in branching open channel networks and not a loop one. The calculations are based on the steady flow. Canals in this model can be in trapezoid or rectangular shape. Water control and measurement structures, which the developed model handles, are sluice gate, radial gate, sharp crested weir and broad crested weir. Each canal section between water control or measurement structures, channels branching point or turnouts, with unique channel width, side slope, manning roughness factor, and channel bottom slope called "Reach". Time of traveling water from upstream of each reach to the end of that reach is considered in calculations. Simulations run based on having all canals full of water.

It is required to have all demands volume and time at turnouts in advance to be able to run the model and get an accurate gate operation schedule based on demands.

3.1. Initializing the Model

To start running the developed model, "Arc-Canal", ArcMap – ArcView must be open. First, the user needs to add the developed tool to ArcToolbox. Click the

Show/Hide ArcToolbox Window button on the Standard toolbar to open the ArcToolbox window. To add a toolbox, right-click the ArcToolbox folder in the ArcToolbox window and click Add Toolbox, and then click on Arc-Canal and click Open.

Before running the Arc-Canal, the user needs to add the required layers to ArcMap and also follow the naming methods of reaches, flow control and measurement structures in the network. There are two shapefile layers that user must add;

1) A Shapefile Feature Class with Geometry Type of Line, including all the reaches in the network, named "Reach". Based on the assumptions of the model the Reach layer can include only branching canal network, not any loop channel network.

2) A Shapefile Feature Class with Geometry Type of Point, including all the water control structures and water measurement structures in the network, named "Structure".

For the proposed model, specific naming method for reaches, water control and measurement structures have been defined. By creating any feature in a shapefile layer, a new row adds to the attribute table of that layer which has a field named "Id". Naming the reaches and structures means changing the value of the "Id" field in a way that model can use them.

3.1.1. *Reach Naming*

The first and main reach at upstream will have the Id of "1". Every reach Id will be the Id of the reach that starts from the end point of it, plus one more digit at right side starting from 1 up to 9. So the next reaches connected to the end point of the first reach

will have the Id of "11", "12", "13", up to "19". The Id of reaches starting from the end point of reach with the Id of "11" will be "111", "112", up to "119" and the Id of reaches starting from the end point of reach with the Id of "12" will be "121", "122", up to "129" and so on.

3.1.2. *Structures Naming*

Each structure's Id is the same Id of the reach ends to that structure. So if a reach at the upstream of any structure has an Id of, for example, "1121", that structure will have the Id of "1121". Since the first gate at the upstream of the first reach is not connected to any other reach, the Id of first gate connected to the upstream of the first reach will be "0". Another part of naming the structures is defining the type of the structures. The user must add a new field to the attribute table of the structures with the name of "Type", and fill with different brief letters for different structures as below: "g" for gates, "t" for turnouts, and "w" for weirs.

Now the user must open the Arc-Canal tool and first run 5 Step models to create the Gates Operation Schedule which is the main result of the developed tool. Then the user can run any of the other models: Flow Profile Calculator, Single Gate Operation Schedule, and Network Gates Position.

3.2. Gates Operation Schedule

Step 1:

By clicking on the "Step 1" model, a window will be opened presenting the Step 1 model for creating a geodatabase file (Figure 3.1), and it asks to define the location of the Personal GDB.
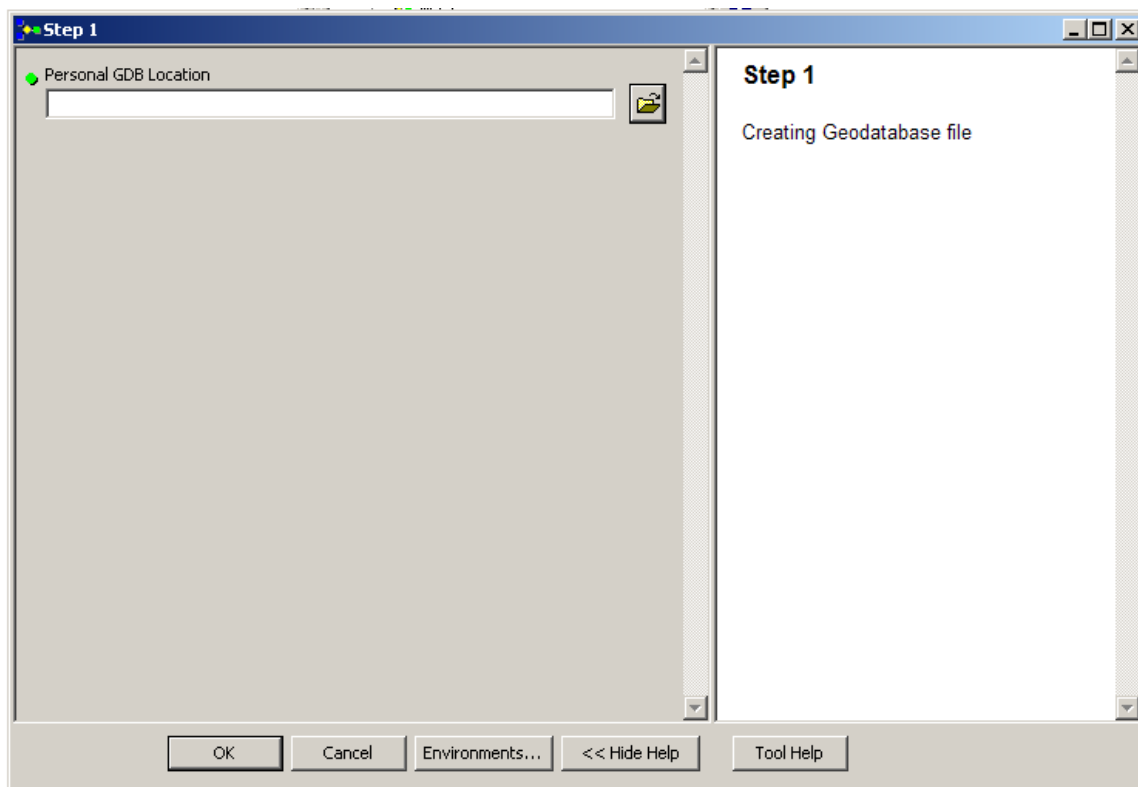

Figure 3.1. Step 1 model for creating a geodatabase file

User may brows the same folder that the Reach and Structure layers are located.

Step 2:

The next step is running the "Step 2" model. By clicking on the "Step 2" model, a window will be opened presenting the Step 2 model for creating tables the user needs to fill out later (Figure 3.2). For running this model user must select the Reach layer as a first parameter of the model and select the Structure layer as a second parameter of the model. The user also needs to check the location and the geodatabase name that the result tables are going to be created in. The outputs of this model are four tables (personal geodatabase tables). Reach_characteristics, Gate_characteristics, Weir_characteristics, and TurnOut_DemandSchedule are the tables that "Step 2" model creates. All 4 tables created by the model will be added to the project layers. The user needs to switch to the Source view on Table of Contents in order to view the tables.
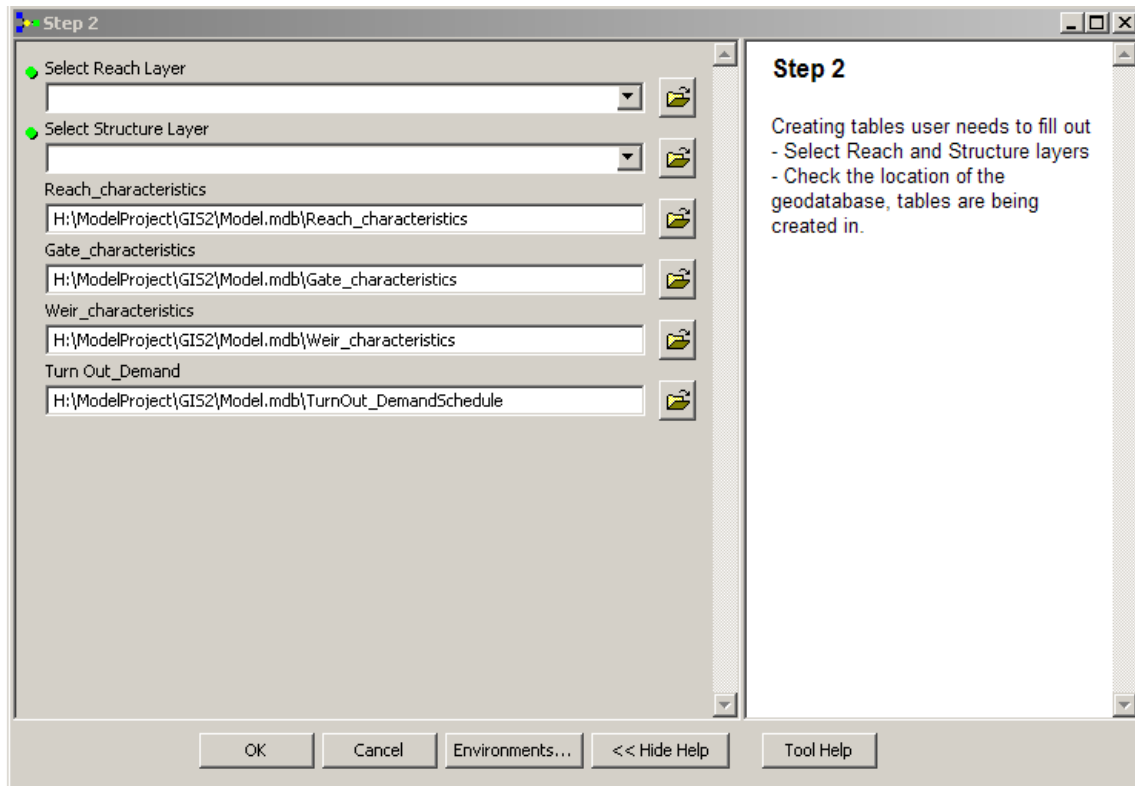
Figure 3.2. Step 2 model for creating tables user needs to fill out

After running the "Step 2 " model, the user needs to open all four created tables

and fill required data for all fields of tables. The Reach_characteristics table presents the

reaches physical characteristics in six fields having the value of "<Null>". The

"Reach_characteristics" table below (Figure 3.3) is result of my test project. Every reach

has a row in this table with its own Id number in the "Id" field. "L_ft" which is the

length of reach, "b_ft" which is the bottom width of reach, "n" which is roughness factor

of reach, "So" which is the bottom slope of reach, "z" which is side slope of reach, and

"Ymax_ft" which is the maximum water level reach can carry.

Figure 3.3. Test project "Reach_characteristics" table

The Gate_characteristics table presents the physical characteristics of gates and turnouts by fields; "C", which is the coefficient of discharge, and field "L", which is gate width. "Gate_characteristics" table below (Figure 3.4) is result of my test project. Every gate or turnout has a row in this table with its own Id number in the field of "Id".

Figure 3.4. Test project "Gate_characteristics" table

The Weir_characteristics, table presents the physical characteristics of weirs by field; "h_ft", which is the height of weirs above the reach's bottom, and the field "L_ft", which is weir width. The "Weir_characteristics" table below (Figure 3.5) is the result of my test project. Every gate or turnout has a row in this table with its own Id number in the "Id" field.

Figure 3.5. Test project "Weir_characteristics" table

TurnOut_DemandSchedule table presents the turnouts water demand schedule including the opening day and hour, duration of water taking and also the rate of water. Every turnout has a row in this table with its own Id number in the field of "Id". "Q" is the discharge in cfs, and "OpeningDay" is the day of the turnout opening. This day is not a date; the day that the first turnout opening happens is "1", and other turnout opening days are counted from day "1". "OpeningHour" is the time of opening in 24 hour of the day. "DemandDuration_hr" which is the number of hours that turnout is open. If any turnout has more than one operation, the user can add a new row to the table with the

same Id number in "Id" field and fill the demand information in other fields.

"TurnOut_DemandSchedule" table below (Figure 3.6) is result of my test project.

Figure 3.6. Test project "TurnOut_DemandSchedule" table

Step 3:

Step 3 is a Toolset including different models. The user needs to continue running this set of models from the first one to the point that the number after letter M in the name of model is equal to the number of digits of the largest reach Id in network. For example if the largest reach Id in the network is 11213, it has five digits so the last model user needs to run in step 3 is M5-3.

By running any M -1 model, a window will be opened (Figure 3.7) that asks to check the geodatabase location and run the model. By running any M -1 model, a new table will comes to the layers in Table of Contents.
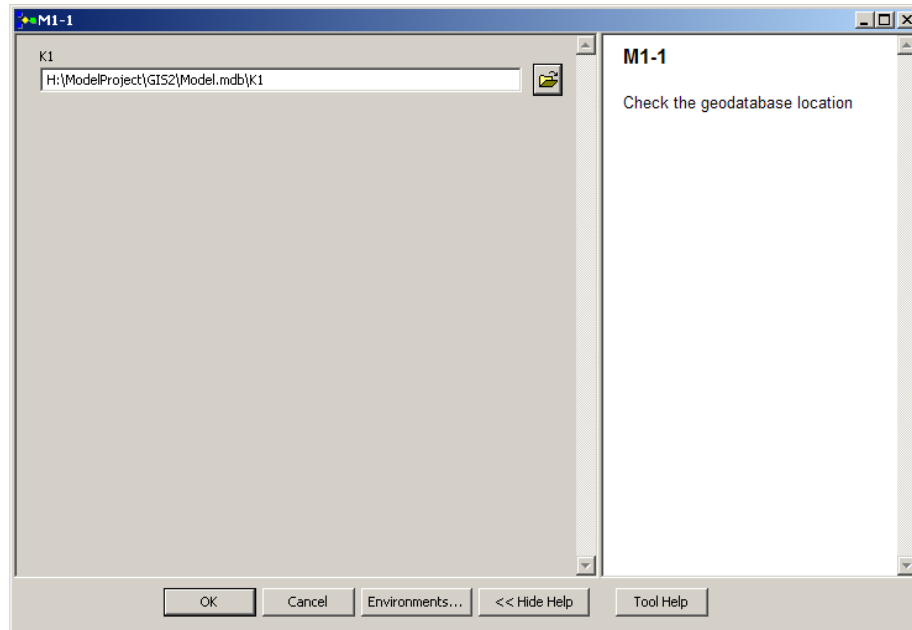
Figure 3.7. M -1 models window

By running M -2 models, a window will be opened (Figure 3.8) that asks to click on OK.
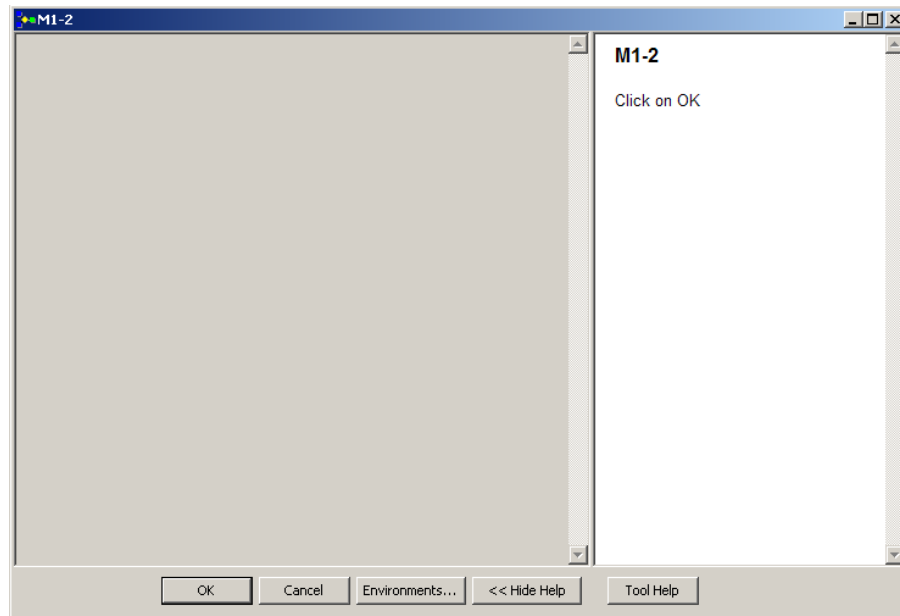

Figure 3.8. M -2 models window

By running any M -3 models, a window will open (Figure 3.9) that asks to check the geodatabase location and run the model. By running M -3 models, a new table will come to the layers in Table of Contents.
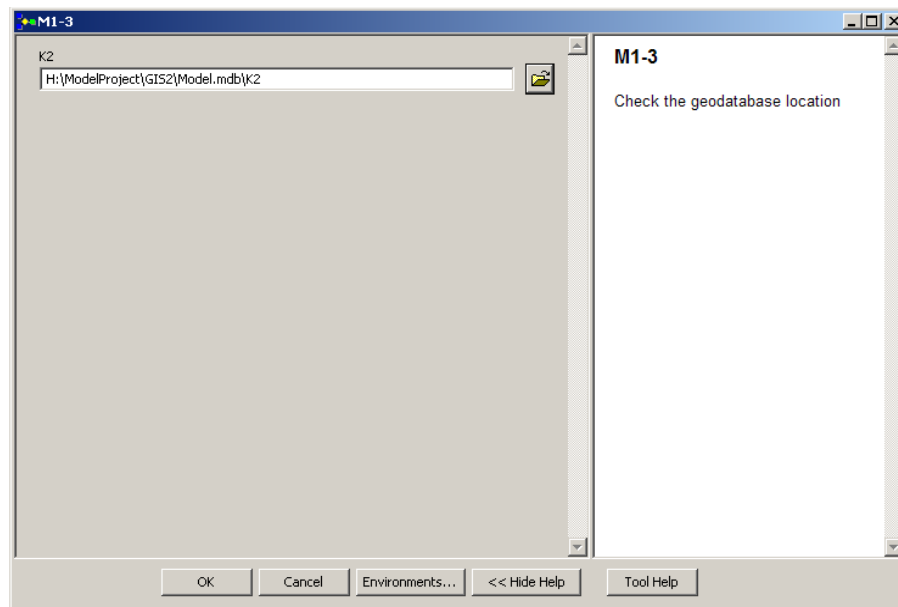

Figure 3.9. M -3 models window

After running all required M models from Step 3 Toolset, tables that their name starts with letter "K" following a number will be added to the Table of Contents. The user does not need to open or edit them, but the user should not delete them. These tables are required for the next steps.

Step 4:

Next step is running the "Step 4" model. By clicking on the "Step 4" model (Figure 3.10), a window will be opened presenting the Step 4 model that asks to check

the geodatabase location and run the model. This model creates the "Operation" table, including all gates operation times.
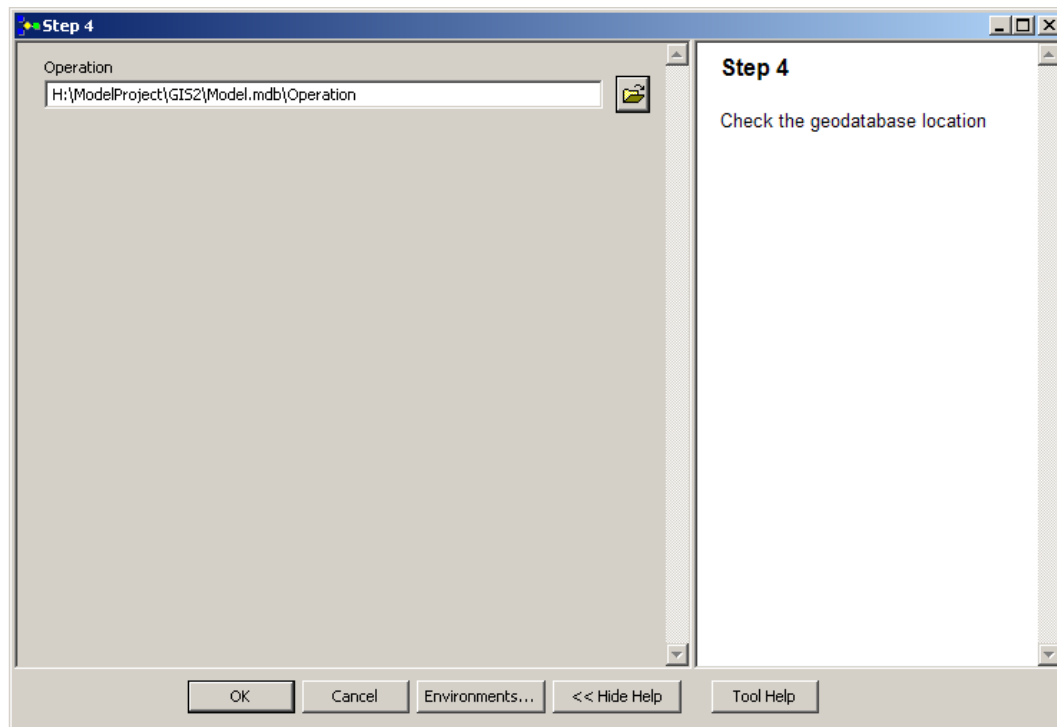

Figure 3.10. Step 4 model window

Step 5:

Next step is running the "Step 5" model. By clicking on the "Step 5" model, a window will open presenting the Step 5 model that asks to enter the Reservoir Water Level and check the geodatabase location, and then run the model (Figure 3.11).
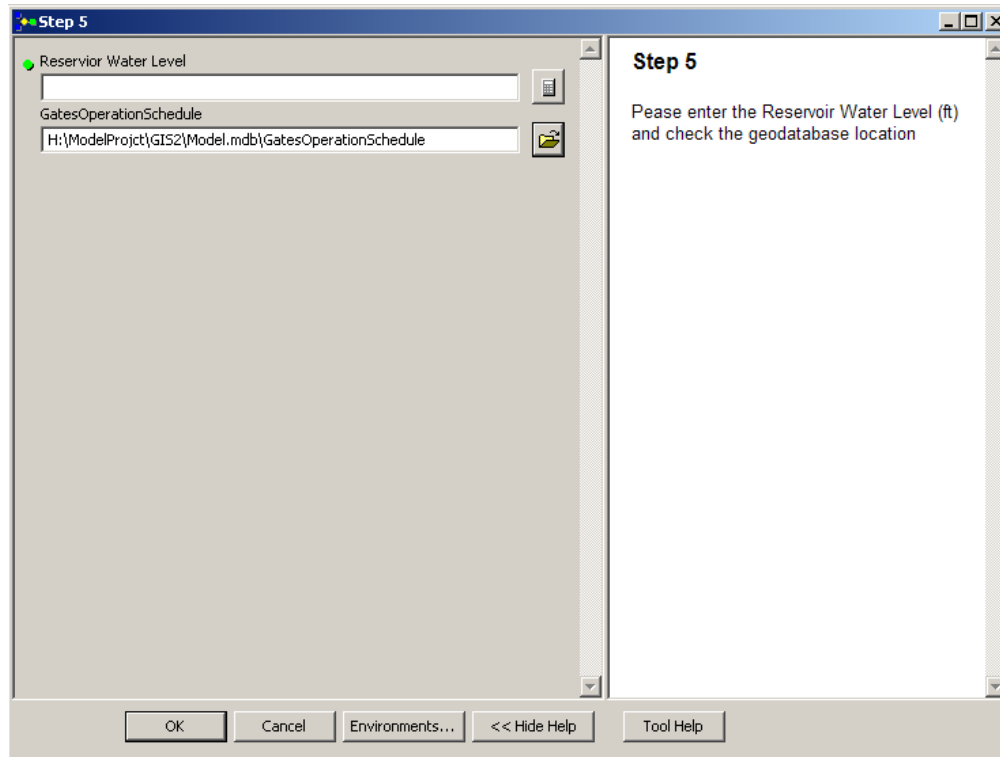
Figure 3.11. Step 5 model window for entering reservoir water level

This model creates "GatesOperationSchedule" table including "Operation Days" field which is the day of operation, "OperationHours" field which is operation hour, and "Operation _ft" which is the amount of opening or closing of the gates in foot unit. The positive numbers means opening of the gate and negative numbers means closing of the gate. The other field in this table is the "Id" field which which is the Id of the gate that must open or close. "GatesOperationSchedule" table is the final result of developed model. "GatesOperationSchedule" table below (Figure 3.12) is result of my test project.

Figure 3.12. Test project "GatesOperationSchedule" table

3.3. Flow Profile Calculator

One of the models available in Arc-Canal toolbox is the Flow Profile Calculator. By clicking on this model, a window pops up (Figure 3.13) that asks user to enter the Id of the reach and the Time the user wants to calculate the flow profile. Id must be an integer same as one of the reach Id, available in the digitized open channel network in the project. The unit of Time must be in hours and can be a float number.
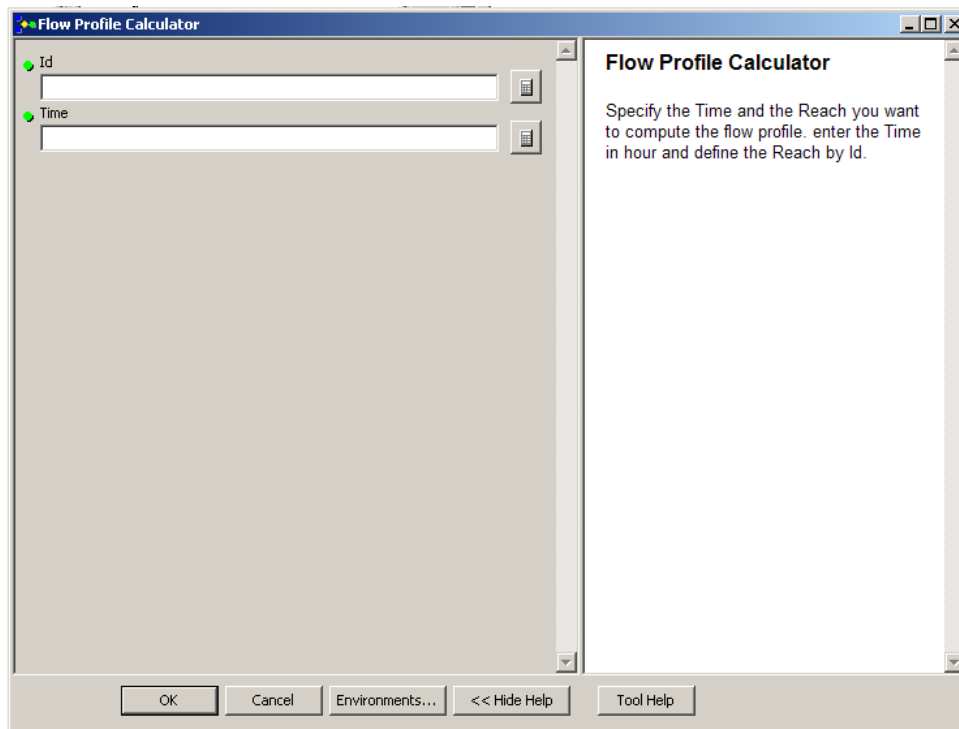
Figure 3.13. Flow Profile Calculator model

This model creates the "Profile" table that includes field "y", which is the depth of flow from bottom of the channel in foot, and field "x" which is the distance from the downstream of the reach in foot. The "Profile" table below (Figure 3.14) is result of my test project.

Figure 3.14. Test project "Profile" table

Users may like to create a graph from the created Profile table and see the results

graphically. By clicking on Tool, then Graphs, and then Creat..., Create Graph Wizard

gets open and can create graph for any profile table user created. Figure 3.15 presents a

graph I created for one of profile tables of my test model project.
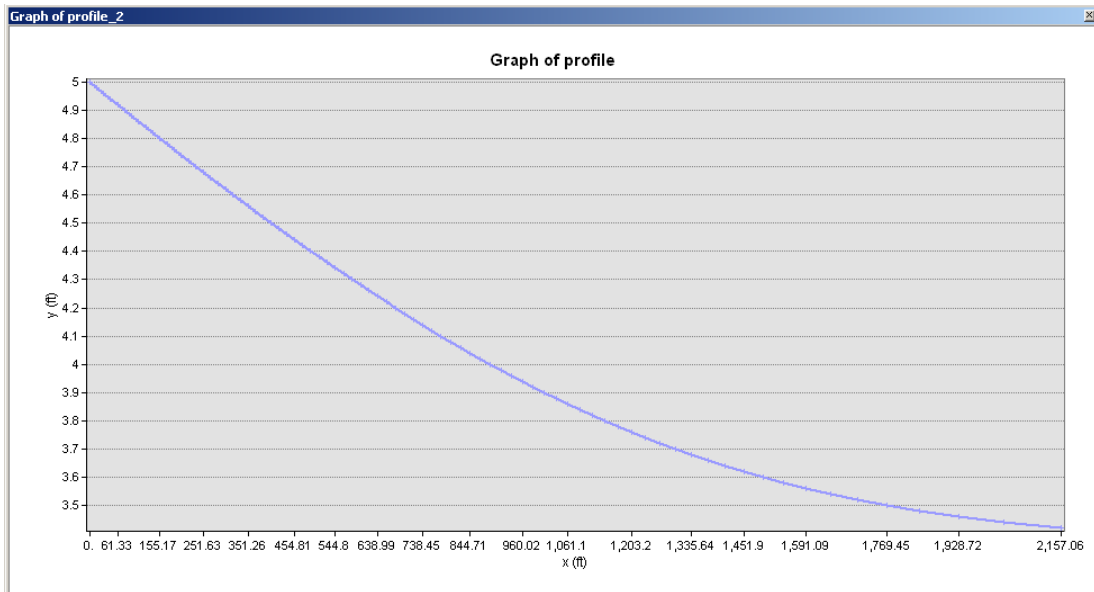
Figure 3.15. Test model sample profile graph

3.4. Single Gate Operation Schedule

One of the models available in Arc-Canal toolbox is Single Gate Operation Schedule. By clicking on this model, a window pops up (Figure 3.16) that asks user to enter the Id of the gate the user wants to have the operation schedule of only that gate. Gate Id must be an integer same as one of the gate Id available in digitized open channel network in project.
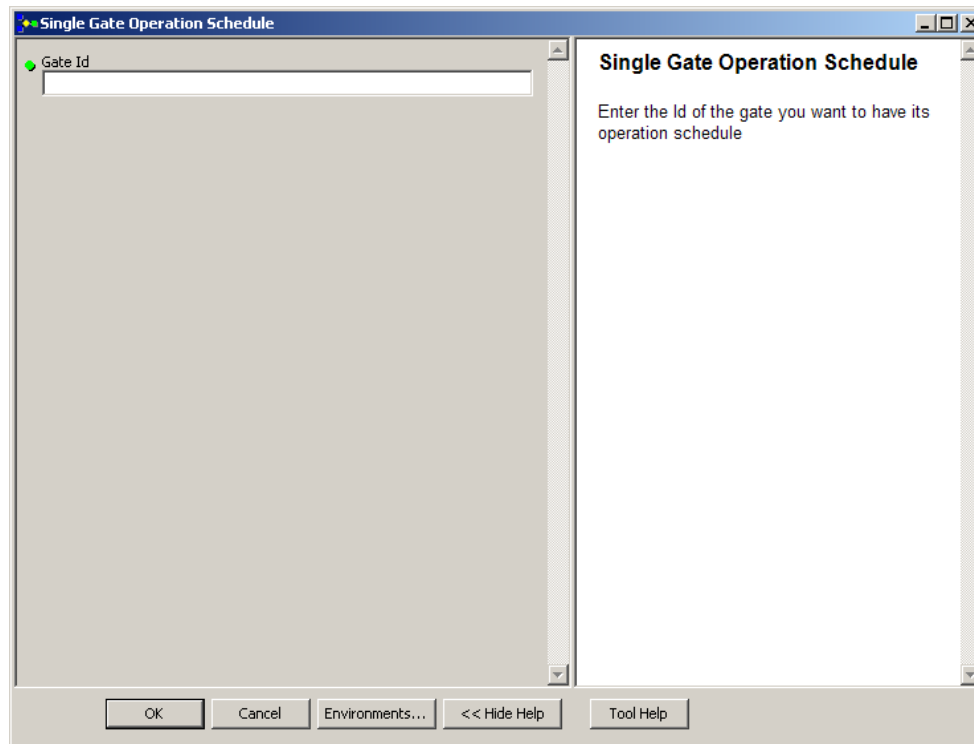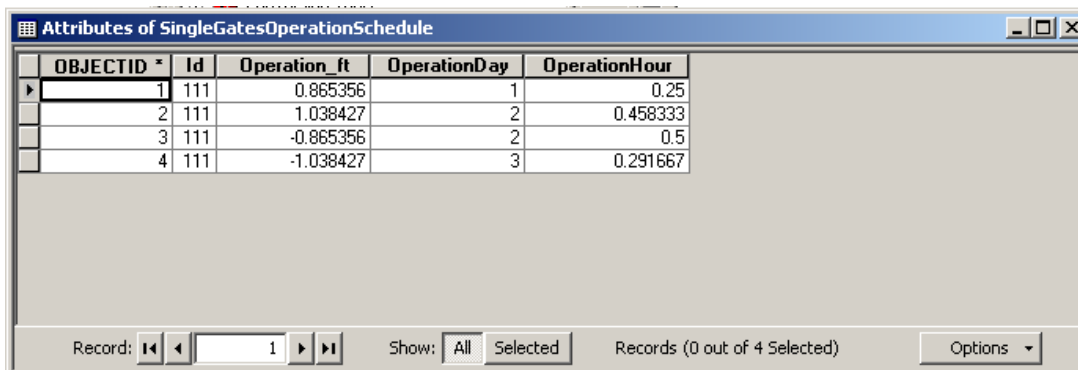
Figure 3.16. Flow Profile Calculator model

This model creates "SingleGateOperationSchedule" table including field "Id" which is the Id of the gate, "Operation Days" field which is the day of operation, "OperationHours" field which is operation hour, and "Operation _ft" which is the amount of opening or closing of the gates in ft unit which positive number means opening of the gate and negative number means closing of the gate. "SingleGateOperationSchedule" table below (Figure 3.17) is result of my test project.

Figure 3.17. Test project "SingleGateOperationSchedule" table

3.5. Network Gates Position

One of the models available in Arc-Canal toolbox is Network Gates Position. By clicking on this model, a window pop up (Figure 18) that asks user to enter the Time the user wants to have the position of all gates in the network. The unit of Time must be in hour and can be a float number.
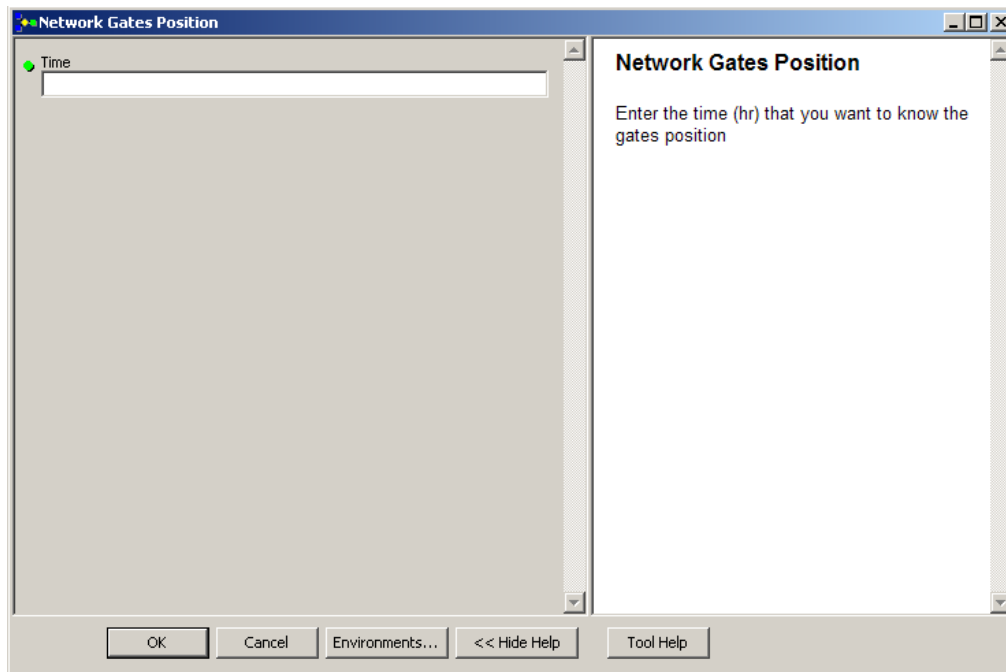
Figure 3.18. Network Gates Position model

This model creates "NetworkGatesPosition" table including field "Id" which is the Id of the gate, "Gate Position" field indicates the amount of gate opening at the specified time in foot. "NetworkGatesPosition" table below (Figure 19) is result of my test project.

Figure 3.19. Test project "NetworkGatesPosition" table

3.6. Methods of Computations

3.6.1. *Discharge Computation*

Calculation of discharge at channel cross section is based on Manning formula (U.S. units);

$$Q = \frac{1.468}{n} A.R^{\frac{2}{3}}. S^{\frac{1}{2}} \tag{1}$$

where Q is discharge (cfs); A is cross-sectional area (ft^2); R is hydraulic radius (ft); S is friction slope; and n is roughness coefficient.

In order to calculate A, P, and R, water depth from the bottom of the channel (h), Channel Bottom Width (b), Channel Side Slope (z), Channel Roughness Factor (n) are required.

$$A = h\,(b + h.z) \tag{2}$$

$$P = b + 2\sqrt{z^2 + 1} \tag{3}$$

$$R = \frac{A}{P} \tag{4}$$

3.6.2. *Normal Depth Computation*

The normal depth may be computed by a uniform-flow formula (Chow 1959). Chow (1959) presents three different methods using manning formula for determining normal depth: Algebraic Method, Graphical Method, and Method of Design Chart. I used the trial and error approach from Algebraic Method in my model. Using Manning formula and taking the known data to the right side of equation, model calculates the right side value.

$$n. Q/1.468 \sqrt{S} \tag{5}$$

Where Q is the discharge of flow (cfs); S is friction slope; and n is roughness coefficient. Then model assumes a value of y and computes the section factor.

$$A. R^{2/3} \tag{6}$$

Where A is cross-sectional area (ft^2) and R is hydraulic radius (ft). Model makes several such trials until the computed value is very close to the right side of the equation. Below are the codes I developed in Python programming language for computing the normal water level.

```
y2 = float(30)
y1 = float(0)
Yn = (y2+y1)/2

from math import sqrt

F1 = n*Q/1.49/sqrt(So)

A = (b+z*yn)*yn
P = b + 2*yn* sqrt(1+pow(z,2))
R = A/P
F2 = A*R**0.66666

while abs(F1 - F2)>e :
    A = (b+z*yn)*yn
    P = b + 2*yn* sqrt(1+pow(z,2))
    R = A/P
    F2 = A*R**0.66666

    if F2<F1 :
        y1 = yn
    if F2>F1 :
        y2 = yn
    yn = (y1+y2)/2
print '---------------------'

print 'yn= ', yn
```

3.6.3. *Critical Depth Computation*

Chow presents three different methods for determining critical depth: Algebraic

Method, Graphical Method, and Method of Design Chart (Chow 1959). I used the trial

and error approach from Algebraic Method in my mode. At the critical state of flow the

specific energy is a minimum (Chow 1959). There for:

$$\frac{dE}{dy} = 1 - \frac{V^2}{gD} = 0 \qquad (7)$$

Where E is specific energy in channel (ft); V is velocity in channel (ft/s); D is hydraulic

depth; and g is gravity. When discharge and channel characteristics are know, D and V

are function of y, and can be written as below:

$$D = \frac{y(b+zy)}{b+2zy} \tag{8}$$

$$V = \frac{Q}{y(b+yz)} \tag{9}$$

where Q is discharge, b is channel bottom width, z is channel side slope. Substituting the

above expression for D and V in equation (7) and simplifying,

$$\frac{Q^2}{g} = \frac{y^3(b+2y)^3}{b+2zy} \tag{10}$$

After calculating the left side of the equation (10), by trial and error for y value and

calculating the right side of equation (7), the best value found for y resulting closest

value of the right side of the equation to the left side. Below are the codes I developed in

Python programming language for computing the critical water level.

```
y2 = float(30)
y1 = float(0)
yc = (y2+y1)/2

from math import sqrt

RS = pow(Q,2)/g
LS = pow((yc*(b+z*yc)),3)/(b+2*z*yc)

while abs(RS-LS)>e:
    if LS<RS :
        y1 = yc
    if LS>RS :
        y2 = yc
    yc = (y1+y2)/2
    LS = pow((yc*(b+z*yc)),3)/(b+2*z*yc)


print '----------------------'
print 'yc= ', yc
```

3.6.4. *Underflow Gates Computation*

Certain control gates in canals may be called underflow gates from the fact that water passes underneath the structure. Common examples are sluice gate and radial gate (Chow 1959). By the energy equation, it can be shown that the discharge through a underflow gate may be expressed as

$$Q = CLh \sqrt{2g(y + \alpha \frac{V^2}{2g})} \tag{11}$$

where C is the coefficient of discharge, L is the length of the gate, h is the height of gate opening, y is the upstream depth of flow, and $\alpha V^2/2g$ is the velocity head of the approach flow (Chow 1959). The outflow of the gate may be either free or submerged, depending on the tailwater depth (Chow 1959). For the purpose of the experimental studies, the

velocity head term in equation (11) may be omitted, and its effect may be included in the coefficient C; thus

$$Q = CLh\sqrt{2gy} \tag{12}$$

where C is a coefficient depending on the geometry of the structure and on the upstream and downstream depth (Chow 1959).

3.6.5. *Weirs Computation*

Many experimental formulas for the discharge over weirs have been developed; most such formulas can be expressed in the general form (Chow 1959).

$$Q = CLH^{1.5} \tag{13}$$

where C is the discharge coefficient, L is the effective length of the weir, and H is measured head above the crest, excluding the velocity head for sharp crested weir and the elevation of upstream water surface above the weir crest for broad crested weir. According to a well known weir formula of Rehbock, the coefficient C in equation (13) is approximately

$$C = 3.27 + 0.40\frac{H}{h} \tag{14}$$

Where h is the height of weir (Chow 1959). Below are the codes I developed in Python programming language for computing H, measured head above the crest, excluding the velocity head for sharp crested weir and the elevation of upstream water surface above the weir crest for broad crested weir.

```
H1 = float(0)
H2 = float(y1-h)

Q = float(543)
H = H2
C = float(3.27+0.4*H/h)
Q2 = C*L*H**1.5

while abs(Q-Q2)>d:
    if Q2 > Q :
        H2 = H
    if Q2 < Q :
        H1 = H
    H = (H1 + H2)/2
    C = float(3.27+0.4*H/h)
    Q2 = C*L*H**1.5

print 'H=',H, 'Q2=', Q2, 'C=', C
```

3.6.6. *Flow Profile Computation*

Gradually varied flow profile computation methods are generally classified to three methods: graphical integration method, the direct integration method, and the step methods (Chow 1959).

The graphical integration method has a straightforward procedure and easy to follow, however applying this method to actual problems becomes very laborious (Chow 1959). In the method of direct integration, the differential equation of gradually varied flow cannot be expressed explicitly in term of water level for all types of channel cross sections; hence, a direct and exact integration of the equation is practically impossible (Chow 1959). Application of step method divides the channel into short parts and carries the computation step - by - step from one end of each part to the other end (Chow 1959).

Some step methods appear superior to other methods in certain respects, but no one method has been found to be the best in all applications (Chow 1959).

Direct step method is one of the step methods applicable to prismatic channels (Chow 1959). Direct step method calculates the length of each short part of the channel Δx based on the specified water levels y. It means the inputs in this method are water levels y, and the results are length of short parts of channel Δx. Calculations in direct step method are backward, and it begins from the downstream of the channel toward the upstream. Disadvantage of direct step method is not being able to calculate the water level y at specific location of the channel.

In this study, I am using the direct step method for computing the flow profile (Chow 1959) along some modification for calculating the water level y of the beginning of channel.

Equating the total head at two ends of every short part of the channel may be written:

$$S_0 \ \Delta x \ + \ y_1 + \propto_1 \frac{{V_1}^2}{2g} \ = \ y_2 + \propto_2 \frac{{V_2}^2}{2g} + \ S_f \ \Delta x \qquad (15)$$

where y is the depth of flow (ft); Δx is channel short part length (ft); V is the mean velocity (ft/s); α is energy coefficient; S_0 is the bottom slope; and S_f is friction slope. Solving the above formula for Δx:

$$\Delta x \ = \ \frac{E_2 - E_1}{S_0 - S_f} = \ \frac{\Delta E}{S_0 - S_f} \qquad (16)$$

where E is specific energy (ft) or assuming that $\alpha_1 = \alpha_2 = \alpha$,

$$E = \ y + \propto \frac{V^2}{2g} \qquad (17)$$

The friction slope is expressed like below when the manning formula is used:

$$S_f = \frac{n^2\ V^2}{2.22\ R^{4/3}} \tag{18}$$

At the beginning of the calculation the length of the channel is asked and the backward flow depth calculation will continue step - by - step by reducing the flow depth and calculating the distance from downstream until the calculated distance gets bigger than the channel length. At this point a new iteration will start and tries to calculate the flow depth for the distance from the downstream close to the channel length with difference smaller than a specified error amount.

Below are the codes I developed in Python programming language for computing the flow profile. These codes can generate all three types of mild slope, M1, M2, and M3.

```
A = (b+z*y1)*y1
V = Q/A
P = b + 2*y1* sqrt(1+pow(z,2))
R = A/P
E1 = y1 + a*pow(V,2)/2/g
Sf1 = (n*V/R**(0.6666))**2/2.22

print '\n\n', '.....................','\n'
print 'y','        ', 'x'
print y1,'     ', 0

y2 = y1 - dy
A = (b+z*y2)*y2
V = Q/A
P = b + 2*y2* sqrt(1+pow(z,2))
R = A/P
E2 = y2 + a*pow(V,2)/2/g
dE = E1 - E2
E1 = E2
Sf2 = (n*V/R**(0.6666))**2/2.22
aveSf = (Sf2+Sf1)/2
Sf1 = Sf2
dx = dE/(So - aveSf)
x = x + dx
```

```python
print y2,'    ', x


while x<X :
        y1 = y2
        y2 = y1 - dy
        if y2<yn:
             y2 = yn
        A = (b+z*y2)*y2
        V = Q/A
        P = b + 2*y2* sqrt(1+pow(z,2))
        R = A/P
        E2 = y2 + a*pow(V,2)/2/g
        dE = E1 - E2
        Ef = E1
        E1 = E2
        Sf2 = (n*V/R**(0.6666))**2/2.22
        aveSf = (Sf2+Sf1)/2
        Sff = Sf1
        Sf1 = Sf2
        dx = dE/(So - aveSf)
        xf = x
        x = x + dx
        if x<X and y2>yn:
             print y2,'    ',x


ym = float(3.36)
xc = xf

while abs(X-x) > e :
    ym = (y2+y1)/2
    A = (b+z*ym)*ym
    V = Q/A
    P = b + 2*ym* sqrt(1+pow(z,2))
    R = A/P
    E2 = ym + a*pow(V,2)/2/g
    dE = Ef - E2
    Sf2 = (n*V/R**(0.6666))**2/2.22
    aveSf = (Sff+Sf2)/2
    dx = dE/(So - aveSf)
    x = xf + dx
    if X<x :
        y2 = ym
    if X>x :
        y1 = ym

if ym > yn :
    print ym,'    ', x
```

```
if ym < yn :
    print ''
    print ym,'    ', x-dx
    print ''
    xc = xc + 100
    while xc<X:
        print yn,' ', xc
        xc = xc + 100
    print ''
    print yn,' ',x
```

3.6.7. *Gate Operation Schedule Computation*

Gate Operation Schedule includes two separate parts, one is the time of gate operation and the other one is the amount of opening or closing. Amount of gates opening or closing is based on the gate initial opening level and the required opening level. The calculation of the gate openings described earlier in "Underflow Gates Computation".

Purpose of calculating the gates operation time is avoiding the flow spill over the channels but keeping the water level always at the maximum possible level in all channels. Time of gates operations depend on the channels previous condition whether there was water flowing in channel or not, and also possible maximum water level in every channel. Model calculates the initial volume of the water in each reach using the current flow profile of the reach. Then the model calculates the required volume of the water for each reach based on the new flow profile from the next demand change at any turnout. Model calculates the difference in the volume of the water form one stage to the next stage and calculates the time required to take action in advance for keeping the

water level in maximum level by changing the reach upstream gate position and letting less or more water enter to the reach.

Calculation of volume of water in each reach with different discharges passing the reach is based on flow profile of the reach calculated by flow profile computation. Similar procedure for calculating the integral of a curve has been used for calculating the volume of the water under flow profile. For calculating the integral of a curve, area below the curve calculated by adding the area of rectangulars with small widths and height resulted from averaging height of two side points. In a same way, the area of flow profile cross sections calculated based on the water level of the point, and then the average area between every two points calculated. By multiplying the distance between every two points by the average area of those two points and adding all results, the total volume of the water below the flow profile get calculated. Since the flow profile calculator model computes the distance from downstream of the reach for every 0.05 foot of water level from the maximum water level of every reach, the calculated volume below the flow profile is acceptably close to the exact volume of water below the flow profile.

The operation time difference of gates at upstream and downstream of each reach, which can be called water travelling time, is calculated by dividing the calculated water volume difference of initial and new flow profiles, by the new discharge rate of reach. The goal of calculating the water traveling time is keeping the water level at downstream of the reach always at the maximum level.

CHAPTER IV

MODEL VERIFICATION AND RESULTS

4.1. Hypothetical Case Study and Results

Since beginning to develop Arc-Canal, I created a hypothetical case study to run the developed models and test them. The hypothetical case study includes all possible flow measurement and control structures. The hypothetical case study includes two turnouts, three gates, one weir, and also one point where dimensions of the canal cross section are changed and the reach is broken to two reaches. Then I initialized the model. I added the Reach and the Structure layers and I followed the naming methods described earlier. Figure 4.1 illustrates the scheme of hypothetical case study.
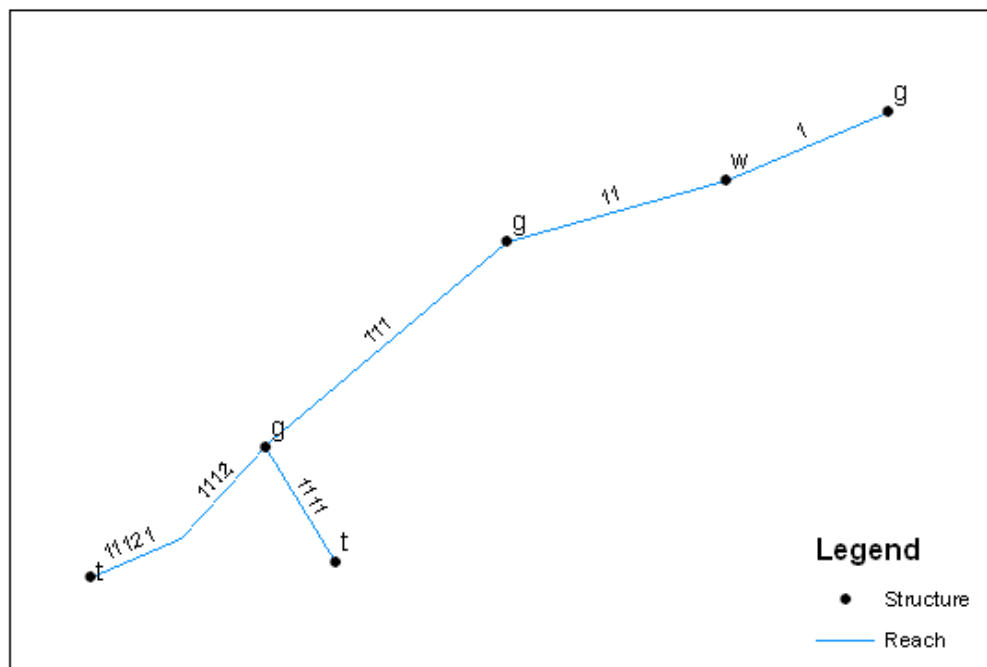
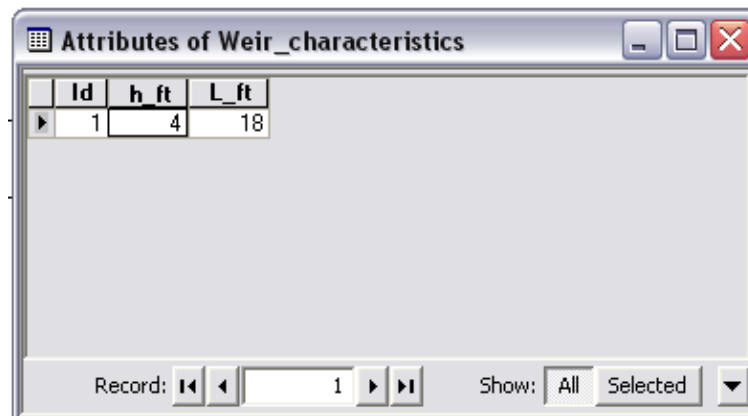

Figure 4.1. Hypothetical case study

I ran the five step models described on section 3.2.Gates Operation Schedule to create the GatesOperationSchedule table. Meanwhile the Reach_characteristics, the Gate_characteristics, the Weir_characteristics, and the TurnOut_DemandSchedule were created and I filled them with required data. Figures 4.2 through 4.5 illustrate the filled tables.

Figure 4.2. Reach_characteristics table
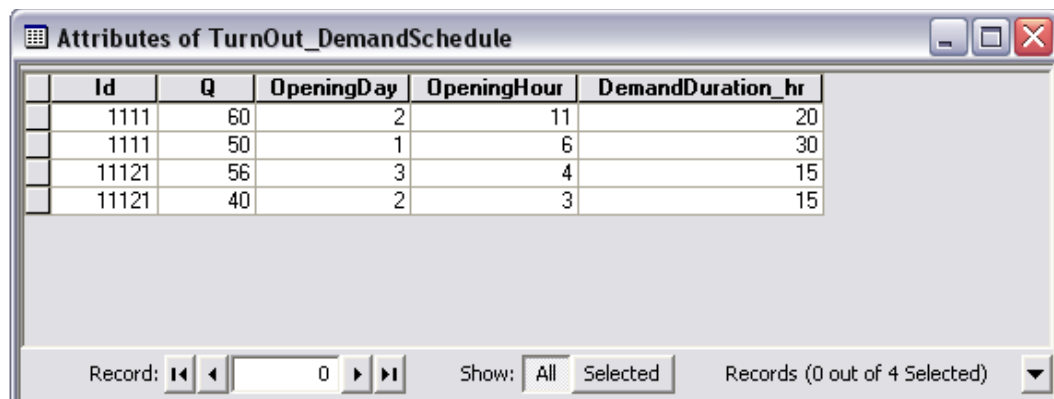
Figure 4.3. Gate_characteristics table

Figure 4.4. Weir_characteristics table

Figure 4.5. TurnOut_DemandSchedule table

After running all five step models, the GatesOperationSchedule table was created. Figure 4.6 illustrates the GatesOperationSchedule table.

Id	Operation_ft	OperationDay	OperationHour
0	0.207685	1	0.579138
0	0.290759	2	0.776765
1111	0.865356	1	0.25
11121	0.398056	2	0.125
1111	1.038427	2	0.458333
11121	0.557278	3	0.166667
1111	-0.865356	2	0.5
11121	-0.398056	2	0.75
1111	-1.038427	3	0.291667
11121	-0.557278	3	0.791667
111	0.70656	1	0.233333
111	0.847872	2	0.444444
111	-0.70656	2	0.483333
111	-0.847872	3	0.277778
11	0.327074	1	0.144444
111	0.565248	2	0.034578
11	0.392488	2	0.37037
111	0.791347	3	0.102079
11	-0.327074	2	0.394444
111	-0.565248	2	0.659578
11	-0.392488	3	0.203704
111	-0.791347	3	0.727079
11	0.261659	1	0.923466
11	0.366322	3	0.022714
11	-0.261659	2	0.548466
11	-0.366322	3	0.647714
0	-0.207685	2	0.204138
0	-0.290759	3	0.401765

Figure 4.6. GatesOperationSchedule table

Then I ran the Flow Profile Calculator model to generate couple of flow profiles for different reaches for different times. All flow profiles matched the flow profile types; M1, M2, and M3 and there were not any strange pattern on the generated flow profiles.

I ran the Single Gate Operation Schedule for all gates in the network one by one and the results on the tables were matched with the GateOperationSchedule table I generated before.

Finally I ran the Network Gate Position model for different operation times. Then I compared different gate positions for different times with each other and checked to not have any gate position change while there was no operation happening. The gates positions match the gates operation.

4.2. Comparison of Arc-Canal Results with Chow (1959)

Chow (1959) gave an example of computing an open channel flow profile in chapter 10, Methods of Computation. The example was solved with different methods of flow profile computation; Graphical-integral Method, Direct integration, and Direct Step Method. In this example a trapezoidal channel has b = 20 ft (channel bottom width), z = 2 (channel side slope), So = 0.0016, and n = 0.025 carries a discharge of Q = 400 cfs and the backwater profile created by a dam which backed up the water to a depth of 5 ft immediately behind the dam. The result of all three methods Chow (1959) used is very close. The flow profiles calculated with different methods for this example are for the channel length of almost 2400 ft.

The computation of the developed model for the same example compared with Chow's (1959) direct step method computations results in table 4.1. The RMSE (Root Mean Squared Error) of the developed model results and Chow (1959) results is 0.0022, which indicates that the computation of the developed model is very close to what Chow (1959) computed. Figurer 4.7 presents the comparison of the flow profile generated from the developed model and computation results of Chow (1959).

Table 4.1. Comparison of water level calculation results of Chow (1959) and developed model

| x – distance to the channel downstream end /ft	y – computed water level profile by Chow (1959) /ft	y' – computed water level profile in this study /ft	(y-y')2
0.00	5.00	5.0000	0.00E+00
155.00	4.80	4.8002	1.74E-09
318.00	4.60	4.5996	7.56E-09
491.00	4.40	4.3993	2.53E-08
679.00	4.20	4.1991	4.59E-08
891.00	4.00	3.9988	9.00E-08
1146.00	3.80	3.7985	1.56E-07
1304.00	3.70	3.6980	2.92E-07
1500.00	3.60	3.5979	3.40E-07
1623.00	3.55	3.5480	3.17E-07
1777.00	3.50	3.4978	3.95E-07
1898.00	3.47	3.4669	7.98E-07
2050.00	3.44	3.4367	9.20E-07
2187.00	3.42	3.4161	1.30E-06
2375.00	3.40	3.3959	1.45E-06
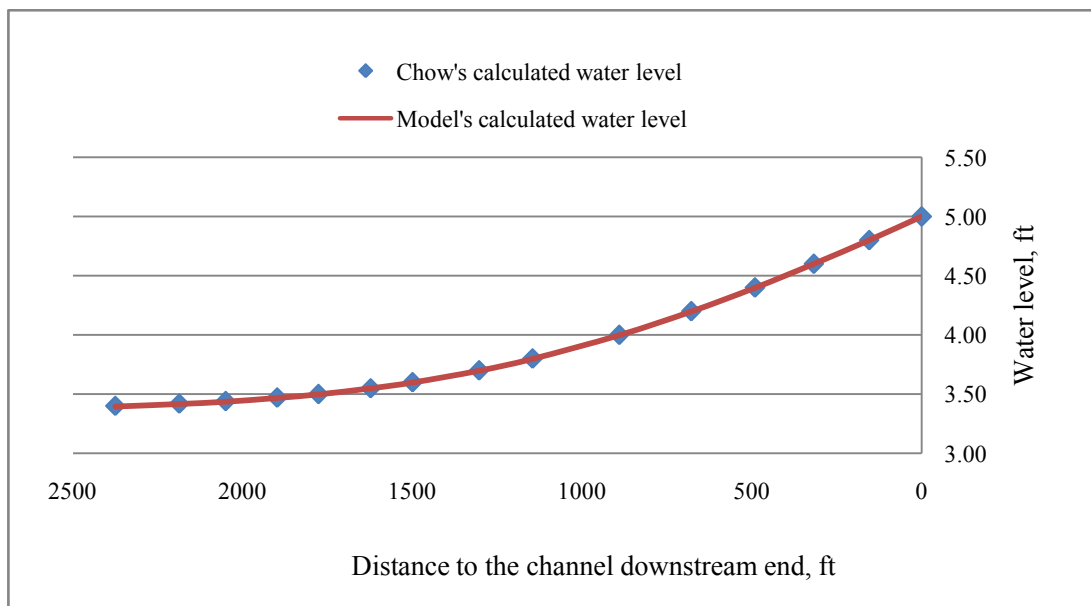
Figure 4.7. Comparison of flow profile calculation results of Chow (1959) and developed model

4.3. Comparison of Arc-Canal Results with Field Data

To determine the accuracy and the possible error in Arc-Canal, a real field data was collected and I run the model for the collected data. Available collected data did not include all the required inputs of the model, but they matched the assumptions of the model. I took the manning roughness factor from Haan et al. (1994) and I calibrated gates discharge coefficient using the available measurements of the gates. Selected open channel network for testing the developed model is part of Harlingen Irrigation District at Lower Rio Grande Valley located in south Texas (Figure 4.8).
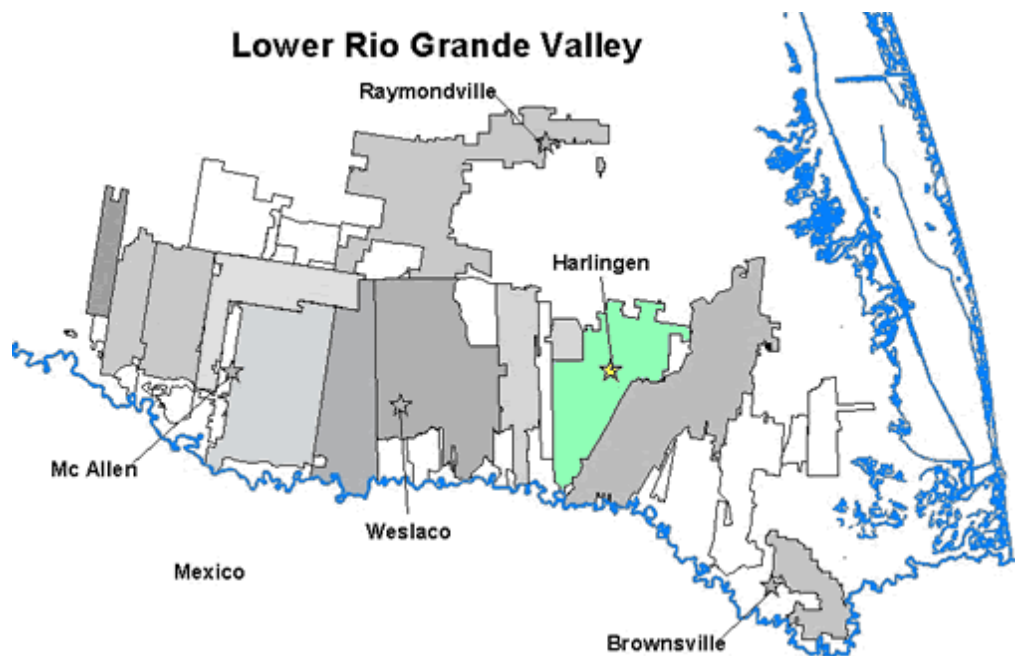

Figure 4.8. Harlingen Irrigation District at Lower Rio Grande Valley located in south Texas

The selected part of the open channel network for testing the developed model includes two turnouts (Id = 11 and Id=12) and two gates, one gate at the upstream of main channel (Id=0) and the other one at the beginning of the lateral (Id=11) (Figure 4.9).
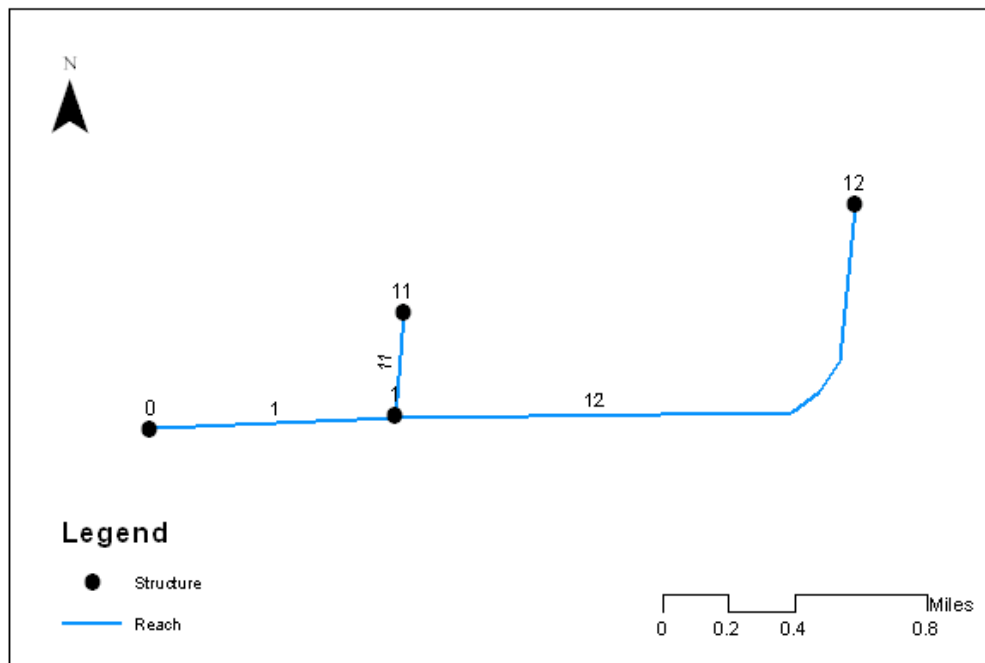
Figure 4.9. Selected part of the open channel network for testing developed model

Model results were compared with the collected data from the study area for the time period that each turnout has one opening and closing. A group of measured data was used to initialize the model and to fill the required tables for beginning to run the models. After following the required steps of the models described earlier, the model created the "GatesOperationSchedule" table. Then I ran the Flow Profile Calculator

model for the same times that water level was measured in the channels. There were five measurement points that water depth at each point was measured twenty times. Totally one hundred water depth measurements from channels were collected. Then I ran the Flow Profile model for the times measurements were conducted and found the water depth Arc-Canal calculated for those points at those times. I compared the collected measurements and calculated data and calculated the difference. The Average Root Mean Squared Error of all hundred measurements for different measurement points and times from Arc-Canal results and field measured data was 0.172 (%17.2).

Table 4.2 presents the field measured data, results calculated by the model, and the difference for all measurement points for time: day 2, 16 hr.

Table 4.2 Comparison of field measured data and calculated results by the model for time: day 2, 16 hr.

Reach Id	Measured water depth / ft	Calculated water depth / ft	Water depth difference / ft
1	3.1	3.102	0.202
11	1.7	1.631	0.069
11	2.1	1.983	0.117
12	2.3	2.401	0.103
12	2.7	2.571	0.129

Figure 4.10 shows the computed flow profile of reach 1 for time: day 2, 16 hr.. The reach length is about 4224 ft.

Figure 4.10. Computed flow profile of reach 1 for time: day 2, 16 hr.

Figure 4.11 shows the computed flow profile of reach 11 for time: day 2, 16 hr.. The reach length is about 1584 ft.
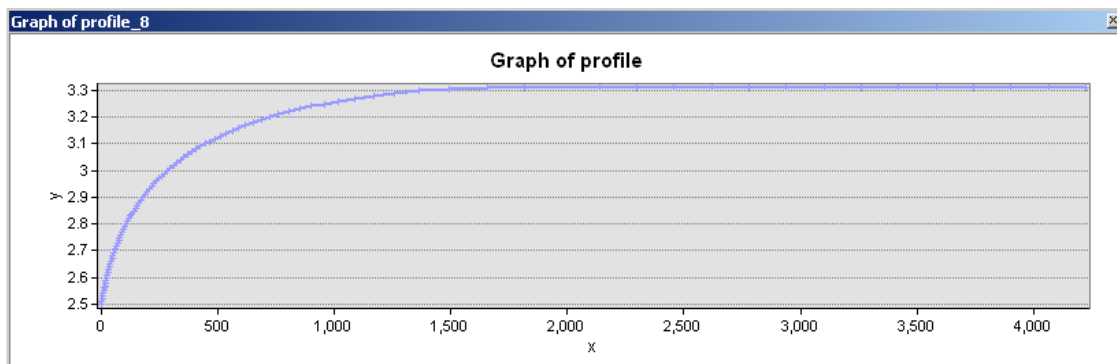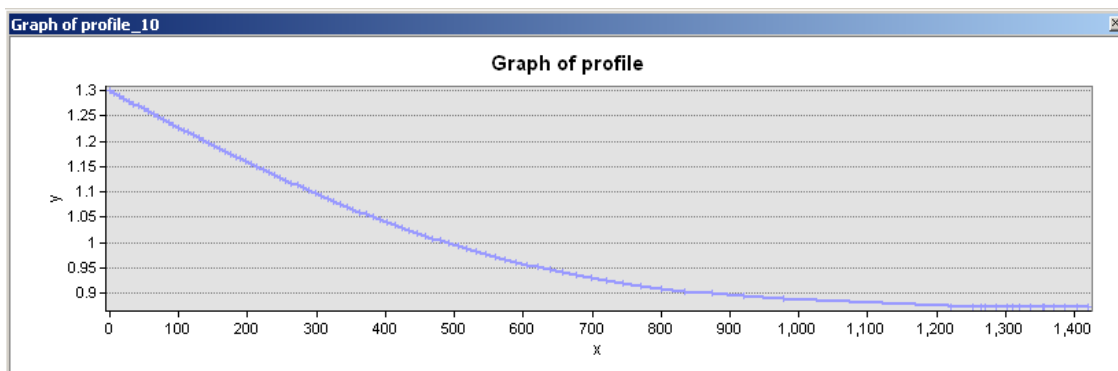

Figure 4.11. Computed flow profile of reach 11 for time: day 2, 16 hr.

Figure 4.12 shows the computed flow profile of reach 12 for time: day 2, 16 hr. The reach length is about 9504 ft.
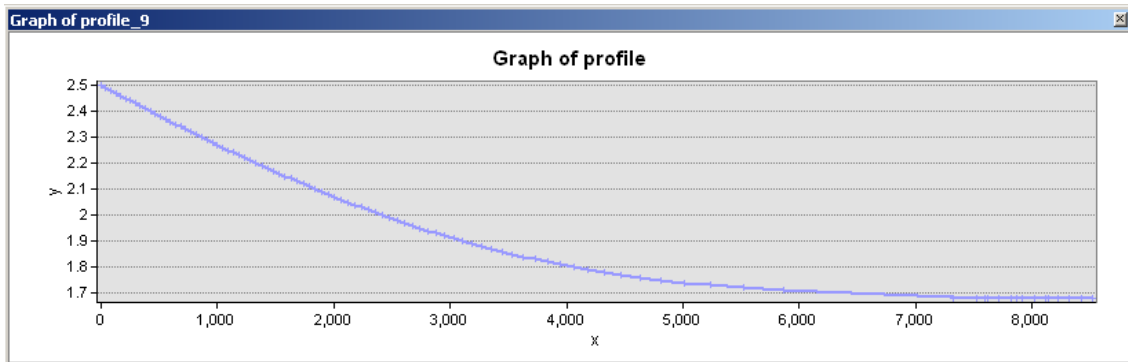
Figure 4.12. Computed flow profile of reach 12 for time: day 2, 16 hr.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In this study I developed a tool for generating a gate operation schedule and modeling the flow profile in irrigation distribution networks. The modeling tool assumes steady flow in the branching open channel networks. All hydraulic calculations for water level, gates, and weirs are based on methods defined in "Open-Channel Hydraulics" (Chow 1959). The model must be added to ArcToolbox and the user needs to follow the specific naming method for reaches and structures for the channels and structure layers.

The developed model can be a very useful tool and easy to use for irrigation districts managers. Any ArcGIS user who had experience working with ArcView may use this model, and any more knowledge is not required. Comparing the results of the model with reference computation (Chow 1959) for open channel flow profile shows that the results from the model are very close, and flow profile calculations of the model had a 0.002 RMSE. Also, comparing field measurements from Harlingen irrigation district at south Texas with the results from the developed model validate the accuracy of model.

The outcome of this study will be able to play an important role in water management for planning, analysis and development for modern management of irrigation systems for irrigation districts in the Lower Rio Grande Valley of Texas and any other similar areas.

5.2. Recommendations

The model I created in ArcGIS can be improved in different aspects. One of the main improvements for the developed model could be adding a pipeline option to the model. Having a pipeline option in the model will vary the usage of the model and will make it useable for irrigation networks that are a combination of open channel and pipeline. There are available models for simulating pressured flow in pipelines, like EPANET, and some other models simulate flow both in open channels and pipeline. But there is not a model developed in ArcGIS for simulating the flow for networks that are combination of open channel and pipeline flow.

Another improvement might be making the model to include a pump in the network. One of the assumptions of the current model I developed is not having any pump through the channels, which may limit the users. Also developing the model to give more options of flow control and measurement structures to the user may be helpful.

Another improvement for the current model may be adding a new option to the current model, presenting the flow profile as a video clip for the operation time using ArcScene.

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