WinSRFR 4.1 User Manual

Eduardo Bautista, Ph.D.

James L. Schlegel

Theodor S. Strelkoff, Ph.D.

USDA-ARS

Arid Land Agricultural Research Center

21881 N. Cardon Lane, Maricopa, AZ, USA

WinSRFR 4.1, Software and User Manual

Eduardo Bautista, James L. Schlegel, Theodor S. Strelkoff

USDA-ARS U.S. Arid Land Agricultural Research Center

Maricopa, AZ USA

September, 2012

Abstract

WinSRFR is a software package for the hydraulic analysis of surface irrigation systems. The software integrates four different components: 1) an unsteady flow simulation engine that can be used to predict the surface and subsurface flow of water for a known system geometry, infiltration and roughness conditions, and boundary conditions; 2) tools for evaluating the performance of irrigation systems and for estimating infiltration and roughness conditions from field-measured data; 3) tools for designing irrigation systems, and 4) tools for optimizing the operation of existing irrigation systems. The software was developed for both practical uses and research. WinSRFR Version V. 4.1 introduces a reprogrammed simulation engine, SRFR 5. The engine was reprogrammed to facilitate the future development of simulation capabilities. New features of interest to practical users include: batch simulation capabilities, simulation of one-dimensional infiltration with the Green-Ampt equation, modeling of surge irrigation, enhancements to the user interface, and enhanced graphical and numerical outputs.

Table of Contents

Figures

Tables

Part I. Basics

1 Welcome to WinSRFR

WinSRFR is a software package for the hydraulic analysis of surface irrigation systems. Intended users are irrigation specialists, consultants, extension agents, researchers, university level instructors and students, and farmers with moderate to advanced knowledge of surface irrigation hydraulics.

The software offers four analytical functionalities, which are identified in this document as WinSRFR Worlds. These functionalities are:

- Event Analysis: Irrigation event analysis and parameter estimation functions
- Simulation: SRFR's simulation functions for testing and sensitivity analysis
- Physical Design: Design functions for optimizing the physical layout of a field
- Operations Analysis: Operations functions for optimizing irrigations

These functionalities are accessible through the four color-coded World buttons (Figure 1). Pressing one of these buttons will launch the corresponding World Window, shown in the same figure.

1.1 Release History

Version	Release Date	Key Features
1.1	Sept. 2006	Integrated the functionality of the DOS programs SRFR, BASIN, and BORDER into a single Windows application. WinSRFR 1.2, released May 2007, addressed several issues & bugs in the first release.
2.1	Dec. 2007	Provided Merriam-Keller analysis support for all infiltration functions and all field cross sections, support for design and operations of furrow irrigated fields. contour functionality across all field cross sections and integration of the latest SRFR simulation engine
3.1	2009	Replaced the Physical Design and Operations Analysis procedures based on static databases of pre-computed unsteady flow solutions with volume balance solutions tuned with zero-inertia simulation results. The new procedures: • Expand the range of options used to specify infiltration characteristics for physical design and operational analysis problems • Expand the physical design and operational analysis functionality to

included close-ended borders and furrows, level furrows, and furrows with cutback

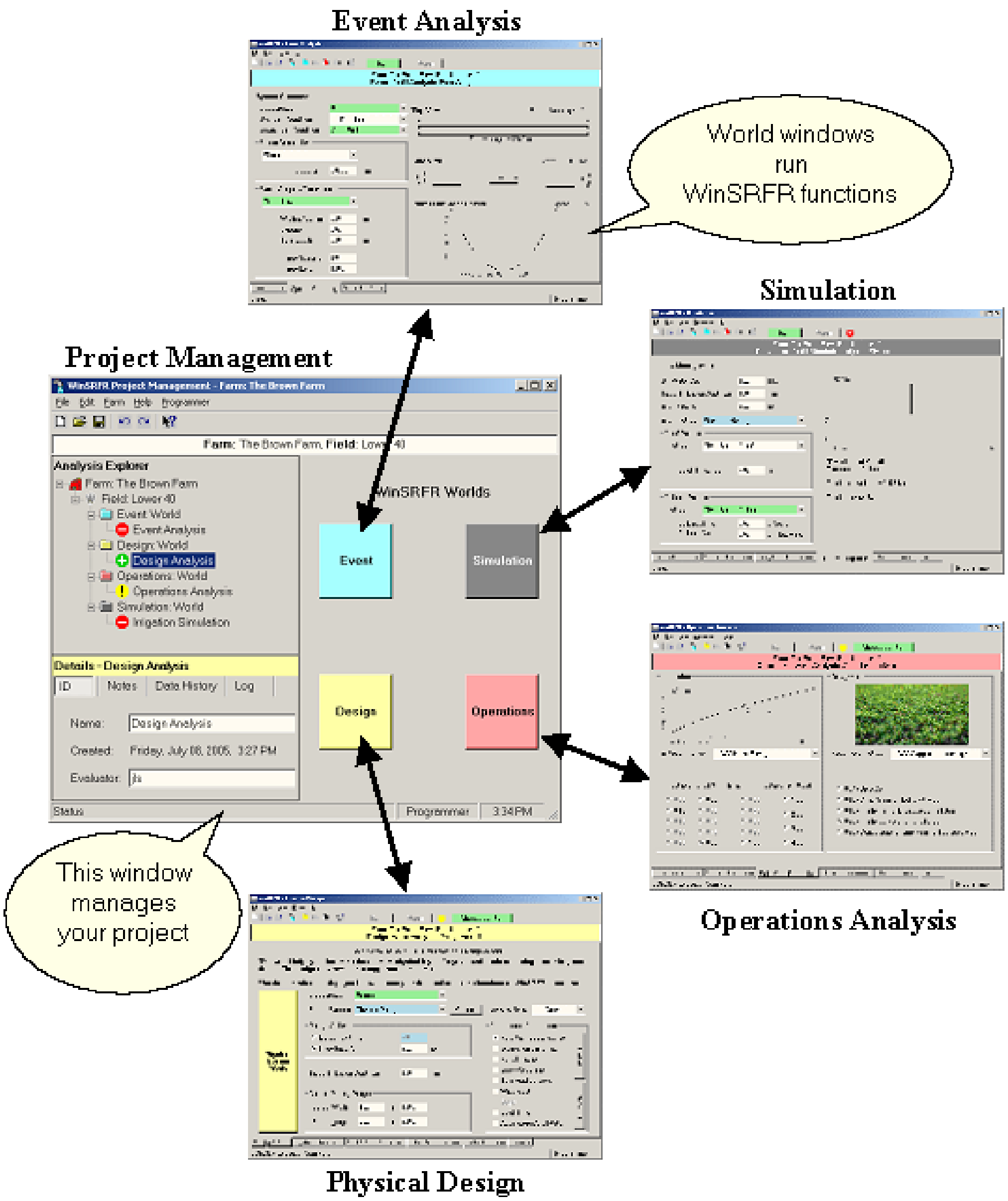


Figure 1. WinSRFR's Four Worlds of Functionality

What is new in Version 4.1

- The simulation engine was rewritten using an object-oriented architecture. The recoding effort was undertaken primarily to facilitate code maintenance and development.
- Routines that deal with complex boundary conditions, such as front-end recession and re-advance, were modified. These changes have resolved some computational difficulties encountered with previous versions of the software,
- In the Simulation World, System Geometry and Soil-Crop Properties Tabs, the user can now specify spatially variable properties (infiltration, roughness, cross-section).
- In the Simulation World, Soil-Crop Properties Tab, infiltration in border/basin irrigation systems can now be modeled with the Green-Ampt equation,
- Users can now run multiple simulations from .txt and .csv files and run the simulation programmatically, from a user-written driver program.

1.2 Credits and Acknowledgments

WinSRFR was developed and is supported by:

USDA	- United States Department of Agriculture
ARS	- Agricultural Research Service
ALARC	- Arid-Land Agricultural Research Center

Mr. J.L. Schlegel was the lead software developer for WinSRFR. Mr. D. Bourne and Mr. J. Cooperwood were software developers for the project. The unsteady flow simulation engine was developed by Dr. T.S. Strelkoff. Basin design and operational procedures were developed by Dr. A.J. Clemmens, Dr. A.R. Dedrick, and Mr. R.J. Strand. Border design and operational procedures were developed by Dr. T.S. Strelkoff, Dr. A.J. Clemmens, Dr. M. Shatanawi, Mr. B.V. Schmidt, and Mr. E. J. Slosky. Furrow design and operational procedures were developed by Dr. A.J. Clemmens. Procedures for event analysis were developed by Dr. E. Bautista and Dr. A.J. Clemmens. USDA-NRCS provided significant input and feedback during the development of this software package. In particular, USDA-ARS acknowledges the contributions of Mr. Clarence Prestwich, Irrigation Specialist, National Water & Climate Center, USDA-NRCS.

Comments and questions can be directed to:

email: james.schlegel@ars.usda.gov

US mail: WinSRFR

James Schlegel

Arid-Land Agricultural Research Center

21881 N. Cardon Lane

Maricopa, AZ 85138

1.3 Installation

1.3.1 Operating System and Hardware Requirements

WinSRFR was developed using Microsoft's .NET Framework 2.0 for the Windows operating system. To ensure proper installation and operation, the application must be installed on a personal computer configured as follows:

Supported Operating Systems

- Windows 7
- Windows XP
- Windows Vista

Additional Software Requirements

- Microsoft's .NET Framework 2.0 (Installed by the WinSRFR Installer if necessary)

Storage Requirements

- 20 MB for the program. Project files can each be several MB in size.

Monitor

- 800 x 600 resolution or better

1.3.2 Installation / Uninstallation Procedures

The installation program AlarcWinSrfr41Setup.exe will decompress all needed files, register libraries with the Windows operating system, and create needed directories. By default, the program will install under the C:/Program Files folder and create a /USDA/WinSRFR 4.1 subdirectory. Other USDA-ARS developed software may also install under the folder /USDA.

The program must be uninstalled using the Add/Remove Programs command under the Windows Control Panel. This is needed in order to correctly unregister the application and all its associated files.

1.3.3 Settings for international (non U.S.) installations

WinSRFR was developed using a U.S. Windows installation. Windows allows the user to adapt the display of numbers and dates using the Control Panel/Regional and Language Options /Regional Options Tab. The Regional Settings for some non-U.S. locations can cause WinSRFR to misinterpret numbers entered through the user interface. At this time, the only way to avoid this problem is by displaying numbers using the U.S. settings (use period as the decimal symbol, comma as the digit grouping symbol, and minus as the negative sign symbol). The numerical display can be customized using the Customize button in the Windows Regional Options Tab.

1.3.4 Accessibility Issues

WinSRFR is designed to meet the accessibility guidelines set forth in the Certified for Windows logo handbook:

- Support standard system size, color, font, and input settings. This provides a consistent user interface (UI) across all applications on the user's system.
- Ensure compatibility with the High Contrast option for users desiring a high degree of legibility. When this option is selected several restrictions are imposed upon the application. For example, only system colors selectable through Control Panel or colors set by the user may be used by the application.
- Provide documented keyboard access to all features. This allows the user to interact with the application without requiring a pointing device, such as a mouse. See Keyboard Navigation.
- Provide notification of the keyboard focus location. It should always be apparent both to the user and programmatically which part of the application has the focus. This requirement also enables use of the Magnifier and Narrator accessibility aids.
- Convey no information by sound alone. Applications that convey information by sound must provide other options to express this information.

  WinSRFR has been tested with these Microsoft supplied accessibility aids:

- Magnifier - Magnifies a portion of the computer's desktop for easier viewing
- Narrator - Reads the names, values and actions associated with displays and controls

1.4 Compatibility

WinSRFR 4.1 is backward compatible with files created with previous versions of the software (1.1, 2.1, 3.1). However, project files created or saved with WinSRFR 4.1 are not compatible with earlier versions. Thus, if a project file created with 3.1 is opened and saved with 4.1, that project will no longer be accessible with 3.1.

1.5 Disclaimer

The software can be used to analyze both practical and theoretical irrigation problems. Analytical procedures are based on mathematical representations of irrigation systems, using a combination of physical principles and empirical relationships. Users need to interpret results judiciously, however, as they depend on uncertain inputs and assumptions that may be violated in the field. The United States Department of Agriculture and the Agricultural Research Service accept no liability or responsibility of any kind resulting from installation and use of this software.

1.6 Manual Conventions

Input box, option button, drop-down list item	**Example**
Drown-down list, Tab Page	**EXAMPLE**
Menu item	Example
Keyboard sequence	**Example**
Hyperlink	Example

1.7 Notation

Flow Variables

Ay	Cross-sectional flow area
Az	Infiltration area (Infiltration volume per unit length)
BW	Bottom width of a trapezoidal furrow cross section
C	Constant of the power law relationship for a parabolic furrow
FS	Furrow spacing
H	Water surface elevation
L	Field length
M	Exponent of the power law relationship for a parabolic furrow
Q	Inflow rate
R	Hydraulic radius
R	Cutoff ratio (user input) - Ratio of advance at cutoff to field length.
S0	Field bottom slope
Sf	Friction slope
Sigmay, σy	Surface shape factor
SS	Side slope of a trapezoidal furrow cross section
T	Time
Ta	Advance time
Tco	Cutoff time
TL	Advance time to end of the field
TR	Recession time
TW	Top width of flow

W	Border/basin/furrow set width
W100	Flow width at 100 mm (4 in)
WP	Wetted perimeter
X	Distance
XR	Cutoff ratio (simulation output) - Ratio of advance at cutoff to field length or Tco to TL.
Y	Flow depth
Ymax	Maximum flow depth
z	Infiltration depth (Infiltration volume per unit area)
τ	Opportunity time

Infiltration and Roughness Parameters

k	Empirical constant
a	Empirical exponent
b	Empirical steady-state infiltration rate.
c	Empirical instantaneous infiltration depth, attributable to soil macropores and cracks
z_c	Characteristic infiltration depth
τ_c	Characteristic infiltration time
τ_{100}	Characteristic infiltration time for 100 mm infiltrated depth
τ_b	Branch Time; for infiltration given by the Branch function, the time at which infiltration rate becomes constant
n	Manning roughness coefficient
χ	Sayre-Albertson chi

Performance Measures

ADlq	Low-Quarter Adequacy (ADlq = Dlq / Dreq)
ADmin	Minimum Adequacy (ADmin = Dmin / Dreq)
AE	Application Efficiency (AE = Dz / Dapp)
D(x)	Function describing the final infiltrated depth as a function of distance along the field.
Dapp	Average depth of applied water (applied volume/area).
Ddp	Average depth of deep percolation (deep percolation volume/area)

Dinf	Average depth of infiltrated water (infiltrated volume/area)
Dlq	Low quarter average infiltrated depth average infiltration depth for quarter of the field receiving the least amount of water (not necessarily contiguous).
Dmin	Minimum infiltrated depth.
DP%	Deep Percolation fraction (DP% = Ddp / Dapp)
Dreq	Required application depth.
Dro	Average depth of runoff, or, runoff volume expressed as an equivalent average depth.
DUlq	Low-Quarter Distribution Uniformity (DUlq = Dlq / Dinf)
DUmin	Minimum Distribution Uniformity (DUmin = Dmin / Dinf)
Dz	Infiltrated depth contributing to the irrigation target
PAElq	Potential Application Efficiency of the Low Quarter(attainable AE when inflow rate and cutoff time are such that Dlq = Dreq; see definition for AE)
PAEmin	Potential Application Efficiency of the Minimum (attainable AE when inflow rate and cutoff time are such that Dmin = Dreq; see definition for AE)
RO%	Runoff fraction (RO% = Dro / Dapp)
Verr	Volume balance error

Miscellaneous

NaN	Not a Number - displayed when a parameter does not contain a valid value.
TBD	To be determined – displayed when a text box is awaiting for a value computed by the program

2 Overview of the WinSRFR Functionality

Engineering studies of surface irrigation systems begin with an evaluation of current performance. The analysis, based on field-measured data, determines the fate of the irrigation water: how much water was applied, how much infiltrated, the distribution of infiltrated water along the field, how much water contributed to satisfy the irrigation requirement, and how much was lost by deep percolation and runoff.

If performance is judged to be inadequate, then the operation of the current system needs to be examined. Such an analysis would compare the performance tradeoffs of different combinations of inflow rate and cutoff time for the assumed average field conditions (infiltration, roughness, and target application depth). The analysis helps identify a range of operational recommendations for improved performance. Alternatively, the analysis may demonstrate that performance cannot be substantially improved with the existing physical configuration and, thus, indicates the need for an alternative system layout.

An analysis of alternative system layouts may consider changes to the dimensions of the field (length and width) with the available flow rate, and/or to the bottom slope (if soil conditions allow). Similar to operations analysis, design analysis must compare the performance tradeoffs of different combinations of design variables and must be conducted based on representative field conditions.

Field conditions and the available inflow rate can be expected to vary during the irrigation season or over the course of multiple seasons (bottom slope). Hence, both operational and design analyses need to include sensitivity analyses to assess the expected performance degradation with likely variations in field conditions. The ultimate objective is to identify operational and/or design recommendations that are robust, i.e., recommendations that result in acceptable levels of irrigation performance under the expected range of field conditions.

WinSRFR functionalities were developed to support this analytical process. These functionalities, referred to as Worlds in the software, are Event Analysis, Operation Analysis, Physical Design, and Simulation. The following paragraphs provide an overview of these functionalities. The Simulation World has pivotal role in the application and, hence, is discussed first.

2.1 Hydraulic Simulation

The Simulation World is used to predict the surface flow and infiltration of as a function of distance along the field and time. Required inputs are the field geometry, field infiltration and hydraulic resistance conditions, and the given upstream (inflow hydrograph) and downstream (open or closed) boundary conditions. The simulation engine can be configured to model basins, borders, and furrows, all under the assumption of one-dimensional flow. This means that all flow characteristics vary only with distance along the field length and time, i.e. not across the field width. For borders and basins, the model is applicable to situations where the side-fall is negligible in comparison with the applied depth, infiltration and roughness are relatively uniform across the field width, and inflow is distributed uniformly along the upstream boundary. When water flows into a border/basin from a source point, this last requirement is clearly not satisfied. Nevertheless, the analysis is still applicable as long as water spreads across the field over a relatively short distance. With furrows, simulations consider only a single furrow and, therefore, neighboring furrows are assumed identical. Any variation in properties from furrow to furrow must be modeled separately. Outputs include the advance and recession curves, flow and depth hydrographs at specified locations, water surface profiles at specified times, and a variety of performance measures such as application efficiency, distribution uniformity, and adequacy of the irrigation. These outputs are available graphically or as tabulated values.

The Simulation World serves different functions within the WinSRFR framework:

- It provides support for computations conducted by the other three Worlds. The simulation engine is used in the Event Analysis World to verify infiltration parameter estimates (computed with the post-irrigation volume balance and two-point method estimation procedures). In Operations and Design, the simulation engine is used to calibrate the volume balance computations and to verify the accuracy of the selected solution point.

- The Simulation World is a tool for conducting sensitivity analyses, starting from a selected operational or design recommendation.

- The Simulation World can be used to examine problems that cannot be handled by the available design and operational procedures, but without the benefit of the performance contours. The Simulation World offers greater flexibility than the Operations Analysis and Design Worlds for defining system inputs, including field geometry, infiltration, hydraulic roughness, and boundary conditions. Users can assign constant field properties or prescribe variations in these properties with distance along the flow direction (infiltration, roughness, cross-section, slope). The Simulation World also offers options for specifying infiltration and hydraulic roughness that are not available in the other Worlds.

- The underlying simulation engine (SRFR) is a research tool and offers an application program interface (API) that can be accessed programmatically with a user-written driver program . SRFR classes and their functionality are available to the programmer through the API. The API is described in the document SRFR 5.0-API.docx and is available from the authors upon request.

The simulation engine solves the one-dimensional unsteady open-channel flow equations coupled with empirical/semi-empirical equations describing infiltration and channel roughness. The governing equations represent the physical principles of conservation of mass and momentum. Given the relatively low velocities and Froude numbers that characterize surface-irrigation flows, the simulation engine actually solves truncated forms of the momentum equation. The zero-inertia (force equilibrium) version assumes only pressure gradients, friction, and gravitational forces acting on the flow. This form of the equations can be applied to all practical field conditions with results similar to those computed with the full unsteady flow equations. The kinematic-wave version ignores also the pressure gradient force and assumes that frictional forces are in balance with gravitational forces, i.e., that flow is at normal depth everywhere. Such an assumption is reasonable with relatively large slopes and when there are no backwater effects (hence, is applicable only to open-ended systems). Under those conditions, results computed with the kinematic wave nearly match those computed with the full hydrodynamic or the zero-inertia equations. Numerical solutions of these models have the advantage, relative to the hydrodynamic equations, of being more robust and computationally faster.

2.2 Event Analysis

Procedures in the Event Analysis world are used to evaluate the performance of irrigation events described by field measured data. They are also used to estimate the extant infiltration parameters needed for evaluation, simulation, physical design, and operational analysis. These procedures use the mass balance principle to determine the disposition of the irrigation water. Three evaluation procedures currently are provided:

2.2.1 Infiltration profile analysis from probe penetration data

Probe penetration analysis is an evaluation technique that relies on measurements of the post-irrigation depth of the infiltration wetting front. This depth is determined by driving a metal probe through the wetted profile at several locations along the field, and is applicable in heavy to medium-textured soils. The water penetration depth is used to estimate the post-irrigation depth of infiltration water contributing to the irrigation target, Dreq. Dreq is calculated considering the depth of water needed to replace the root zone soil water deficit and leaching requirements. The analysis requires measurements of inflow and outflow, a description of the root zone's available water capacity, and pre-irrigation soil water deficit. The applied and outflow volumes (for open-ended systems) are used to calculate a post-irrigation mass balance. Outputs of the analysis are: a) the applied, runoff, and infiltrated depth totals; b) infiltration depth profile; and; c) performance measures, including application efficiency and uniformity. Since infiltration parameters are not determined with this procedure, insufficient information is provided for further analysis in WinSRFR (that is, the user cannot perform operation evaluation, design, or simulation). Thus, it is not useful for providing quantitative recommendations for improvement.

2.2.2 Merriam-Keller post-irrigation volume balance (Merriam and Keller, 1980)

The Merriam-Keller procedure is a method for estimating the final infiltration depth profile and the average infiltration characteristics of the evaluated furrow, border, or basin from a post-irrigation volume balance. The infiltration characteristics of the field are described with a of a user-selected infiltration formulation. The analysis yields estimates for the parameters of the selected infiltration formulation. Section 6.2.2 discusses the infiltration expressions that can be used with the Merriam-Keller analysis. The method can be applied to basins, borders, and furrows. The method matches the observed infiltration volume, calculated from the difference of measured inflow and outflow, with the numerical integral of the post-irrigation longitudinal infiltration depth profile. Infiltration depth at discrete points along the field is calculated from observed intake opportunity times, computed from the measured advance and recession times. Originally, the method used the resulting mass balance relationship to solve for the constant k of the Kostiakov infiltration equation, with the exponent a given from ring infiltrometer measurements or experience. WinSRFR implements the Merriam-Keller procedure for a variety of infiltration equations. Since the method solves for infiltrated volume at the end of irrigation, only one infiltration coefficient (or family) can be determined. WinSRFR solves for k. Other terms used with the other equations have to be entered by the user (e.g., the steady state term b and the storage term c). In addition to the outputs described above, the analysis produces an estimate of the field's infiltration function. The accuracy of the estimated function can be verified via simulation. A trial-and-error approach needs to be used to determine the combination of parameters (the given a, b, c and the resulting k) that will most closely reproduce the observed advance and recession trajectories, and the observed runoff hydrograph, if one was measured.

2.2.3 Elliot and Walker's two-point analysis of advance data

Elliott and Walker's (1982) Two-Point Method is a procedure for evaluating the average infiltration characteristics of a field from two advance distance-time observations. The method was developed for sloping, free-draining furrow irrigation systems and uses exclusively the Extended Kostiakov infiltration equation to describe the field's infiltration characteristics (see Section 5.3.2.1 for a description of infiltration equations used by WinSRFR). WinSRFR's implementation allows the user to apply the method to sloping borders as well. The method uses the two advance distance-time pairs to set up two volume balance equations. Solution of these equations yields estimates for two of the parameters of the Extended Kostiakov equation, k and a. Inputs required by the analysis are: a) the measured inflow; b) advance times to two distances along the field (half the field length and full field length are recommended); c) a measured steady-state outflow rate or, alternatively, an estimate of the steady state infiltration rate; d) an estimate of the Manning roughness coefficient, used to calculate upstream flow depth; and e) for furrows, a description of the furrow cross sectional area (side slope and bottom width for trapezoidal furrows, power-function constant and exponent for parabolic shaped furrows). Outputs of the analysis, as indicated above, are k and a. The WinSRFR 4 implementation of the Two-Point method incorporates improvements suggested by Bautista et al. (2012) for the calculation of the surface volume. If runoff measurements are available, then the function can be validated via simulation. In such cases, a trial-and-error approach is recommended to find the function that leads to the best match with the observed irrigation event, by adjusting the value of b.

2.3 Operational Analysis

The Operations Analysis World is used to examine potential irrigation performance as a function of inflow rate and cutoff time. Required inputs are the geometric configuration of the system, infiltration, hydraulic roughness, and the irrigation requirement (target application depth). The outputs consist of performance contours. These are analogous to the constant-elevation curves on topographical maps, which illustrate peaks and valleys in the landscape; performance contours illustrate the peaks and valleys in performance as a function of the operational variables. With these contours, the user can:

- Rapidly examine how the operational variables affect individual performance indicators, such as application efficiency, distribution uniformity, deep percolation, and runoff losses.
- Identify solutions (combinations of inflow rate and cutoff time) that meet the irrigation requirement (Dreq). To this end, two different criteria can be applied:
- Solutions can be found for which the minimum infiltrated depth (Dmin) (the minimum infiltration value along the final infiltration profile) matches the irrigation target (Dmin = Dreq)
- Solutions can be found for which the low –quarter infiltration depth (the average depth for the quarter of the field receiving the least infiltration) matches the irrigation target (Dlq = Dreq)
- Examine the performance tradeoffs for solutions that satisfy the requirement. In this regard, the contours can be used to identify solution regions that are likely to be very sensitive to slight differences between the actual field conditions and those assumed in the analysis, including solutions that may lead to incomplete advance.

The Operations World offers a tool – the Water Distribution Diagram - that can be used to inspect individual points in the solution region. With this tool, the user can navigate a selected performance contour and easily visualize the resulting changes in the final infiltrated profile and performance.

Operations Analysis procedures are applicable to furrow and border/basin irrigation systems, with either an open or closed downstream end. Different options are available for specifying infiltration and hydraulic roughness conditions, but the analysis assumes that those properties are uniform along the field. Similarly, the analysis assumes a uniform cross section and bottom slope. The analysis can assume a constant inflow rate or a cutback configuration.

The performance contours are built from simulation results computed at discrete points in the user-defined solution region (a range of discharges and cutoff times). Contour lines are then developed by interpolation amongst the discrete set of results. A large number of simulation results must be computed to build the performance contours. To reduce the computational burden, WinSRFR develops the simulation solutions at discrete grid points using volume balance calculations calibrated with unsteady simulation results. Calibrated volume balance methodology is discussed in the WinSRFR Technical Reference. Calibration is performed at a user-selected grid point within the solution region. Volume balance solutions closely match the unsteady simulation results near the calibration point, but can be increasingly inaccurate away from the calibration point. The software allows the user to contrast the volume balance and unsteady simulation performance predictions at any point within the solution region.

2.4 Physical Design

The Physical Design World is similar to Operations Analysis, except that it is used to find field layouts (length and width for a known available inflow rate, or length and unit inflow rate for a given width) that produce acceptable levels of performance. Required inputs are the target application depth, field slope, soil and crop characteristics, and available inflow. Outputs consist of a set of performance contours, functions of the design variables. In contrast with the Operations Analysis World, all solutions displayed in the Physical Design contours match the minimum infiltration value to the target depth.

With these contours, the user can:

- Rapidly examine how the design variables affect individual performance indicators (potential application efficiency, distribution uniformity, deep percolation, runoff losses, etc.).
- Identify ranges of solutions that will deliver acceptable levels of performance.
- Examine the performance tradeoffs of different solutions. As in Operations Analysis, the contours can be used to examine the potential sensitivity of solutions to slight differences between the actual field conditions and those assumed in the analysis.

Procedures in the Physical Design World apply to furrow and border/basin systems with an open or closed downstream end. As in Operations Analysis, the software offers various options for specifying infiltration and hydraulic roughness conditions. The analysis assumes either a constant inflow rate or a time-based inflow cutback. The analysis also assumes a constant slope and cross-section along the field.

Design analyses often involve examining alterations to the field slope. For those types of comparisons, the user needs to create design scenarios with different slope values.

The solution region (e.g., the range of lengths and widths) to be explored is user-specified. The software computes design solutions at grid points of the solution region, using the same procedures as in Operations Analysis (volume-balance calculations calibrated by unsteady simulation results). Contour lines are then developed by interpolation.

3 Creating and Managing Projects and Scenarios

Systematic irrigation studies generally consist of one or more evaluation, operational, design, and/or simulation analyses. WinSRFR projects will generally involve a combination of Event, Operational Analysis, Design, and/or Simulation analyses. A study may also require developing multiple scenarios of a particular type, say Simulation, to test the effect of varying one or more parameters. A scenario is defined in this document as a particular data set associated with a particular type of analysis. Thus, a WinSRFR project consists of a collection of analytical scenarios.

Projects and their corresponding scenarios are created and managed through the main user interface component, the Project Management Window. Individual scenarios within a project are edited and executed through the World Windows. World Windows are also used to view and extract outputs. World Windows are specific to each type of analysis and, thus, differ in their required inputs and resulting outputs.

This chapter explains the process of creating and managing projects and scenarios through the Project Management Window. It then describes the basic structure of World Windows. Finally, the section discusses data structures and their relationship to project-file organization and management

3.1 Project Management Window

The **PROJECT MANAGEMENT WINDOW** (Figure 2) is the first form displayed by the application. It consists of three graphical controls:

- The **ANALYSIS EXPLORER**
- The **ANALYSIS DETAILS**
- The **WINSRFR WORLD BUTTONS**

3.1.1 Analysis Explorer

The **ANALYSIS EXPLORER** is the main tool for managing WinSRFR projects (Figure 3). It displays a hierarchical tree-view of the data in a project. The **ANALYSIS EXPLORER** works like the Windows Explorer. Items in the hierarchy are selected by single-clicking on them. Double-clicking opens the item. An open-folder can be closed (collapsed) by double-clicking. Only one project can loaded into WinSRFR at a time.

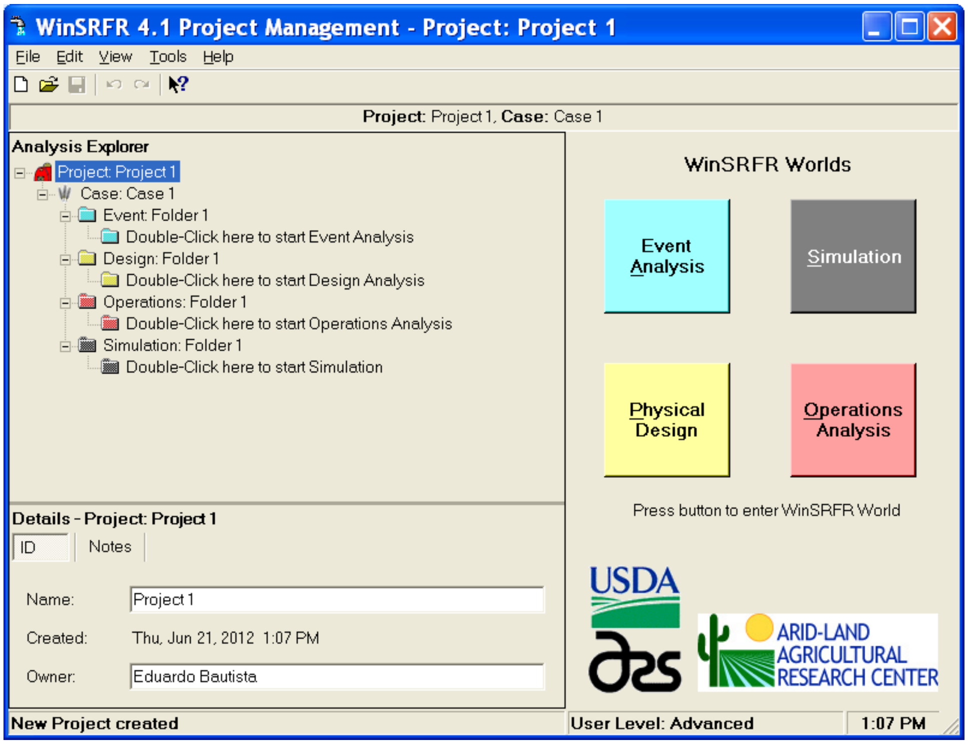


Figure 2. The Project Management Window.

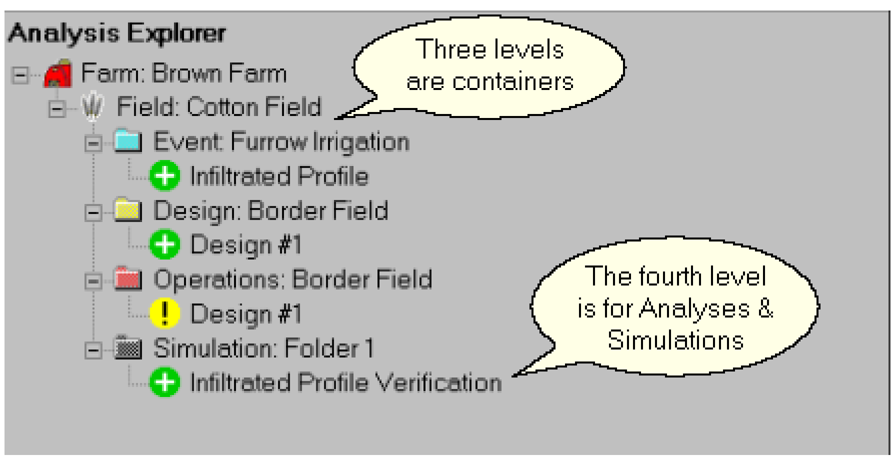


Figure 3. The Analysis Explorer

3.1.1.1 Analysis Explorer Folders

The top three levels in the **Analysis Explorer** are folders that help organize analytical scenarios. Scenarios reside at the fourth (i.e. right-most) level.

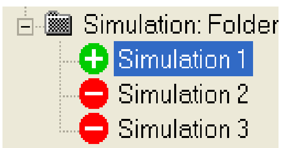
- The top level container is the **Project Folder**; only one Project per file is allowed.

- The next level (or branch) are **Case Folders**. A Project consists of one or more Cases. This folder level merely provides flexibility when organizing data within a Project file. For example, each Case within a project can be used to store information from individual fields within a farm.

For practical analyses, a project file is likely to be associated with a particular farm, and a case with a field within a farm. Hence, WinSRFR and this manual use the concepts of Project and Farm folder interchangeably. Similarly, Field and Case Folders are synonymous terms. The user can select which terminology to use from the Edit/Nomenclature menu item.

- The last level in the folder hierarchy is the **World Folder**. These folders store analyses or simulations by functionality, i.e., a Simulation Folder can only store Simulation scenarios, a Design Folder only Design scenarios, etc.. A Case (Field) Folder can contain one or more World Folder of any type. Thus, a Case Folder can contain two Simulation folders, each containing a related set of simulation scenarios.

3.1.1.2 Scenarios



Analytical scenarios reside at the fourth level. A scenario consists of field inputs, execution criteria, and computed outputs.

3.1.1.3 Creating and saving projects

A new project is created automatically when the application launches. New projects contain a single Case folder, and an empty folder for each type of World. Projects are saved to a .srfr file using the File/Save As or File/Save commands. A single project is contained in a .srfr file. Saved projects can be opened using a File/Open command, by selecting from a list or recently opened projects, from the list of Example projects (provided with the installation file), or the program can be configured (see section 4.2.2) to open the most recently saved project. Only one project can be opened at a time. However, data from two different projects can be viewed on the same screen by running a second instance of WinSRFR. This procedure can also be used to copy data from one project to another.

3.1.1.4 Creating, copying, moving, and deleting folders and scenarios

Folders and scenarios can be created (Start New Analysis), deleted (Remove), moved (Cut/Paste) or cloned (Copy/Paste) using context menus. A context menu is invoked by selecting the item on which the operation is to be performed and then pressing the right mouse button. The context menus will differ depending on the selected level within the Analysis Explorer.

Folder and scenario objects can only be pasted to the appropriate type of container. Thus, when copying a scenario from one folder to another, select the scenario when copying, and then select a folder for pasting. Similarly, scenario folders can only be pasted to Case (Field) folders while Case folders can only be pasted to the upper level of the Explorer hierarchy (the project). WinSRFR restricts paste operations by displaying a Paste... command only in the context menu of containers that can accept the most recently copied scenario or folder.

When World folders are first created, they are empty. An empty folder displays an icon with the label "Double-click here to start...". A scenario can be initiated by double-clicking on that icon.

3.1.1.5 Execution status of scenarios

- The icon associated with a Scenario displays its execution status. The green plus icon indicates the analysis was completed successfully and results are available. The yellow exclamation point indicates the run failed to produce valid or a complete set of results. A red minus icon indicates that the scenario has not been executed. If a scenario is successfully run and its data is subsequently modified, then the status icon will revert to red minus.

> **NOTE:** The application occasionally fails to refresh the Analysis Explorer after executing a scenario or after clearing all results. Click on View/Refresh or **F5** to update the Analysis Explorer.

3.1.2 Analysis Details

The Analysis Details pane is used to identify and document projects. The pane displays two editable (**ID** and **NOTES**) and two non-editable (**DATA HISTORY** and **LOG**) data fields. These fields are accessed by clicking on their respective tabs (Figure 4). Since a project consists of a collection of scenarios, users can document individual case folders, world folders, and scenarios within a project. The ID and Notes fields can be used for this purpose. In addition, the Data History and Log fields provide information on the history of individual scenarios.

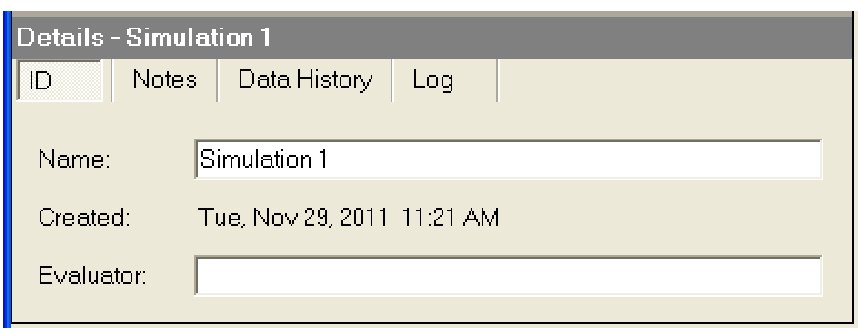


Figure 4. The Analysis Details pane

- **ID:** This field is an identifier for the Farm, Fields, World Folders, and Analyses. When first created, these items are named using the default naming scheme. The user can provide a more meaningful identifier, but each ID must be unique within its containing folder (i.e., two analyses within a World Folder or World Folders within a Field cannot have the same name).
- **NOTES:** Users can enter a detailed description of a project, folder, or scenario in this field. Documentation data is not required, but is highly recommended.
- **DATA HISTORY:** This field is available only for scenarios. This field is useful for diagnosing data compatibility problems. It records when the scenario was first created and gets updated whenever an existing scenario is cloned to create a new scenario. It is non-editable.

- **LOG:** This field is available only for scenarios. It contains a log of the last five runs for the selected scenario. It is non-editable.

3.1.3 WinSRFR Worlds Buttons

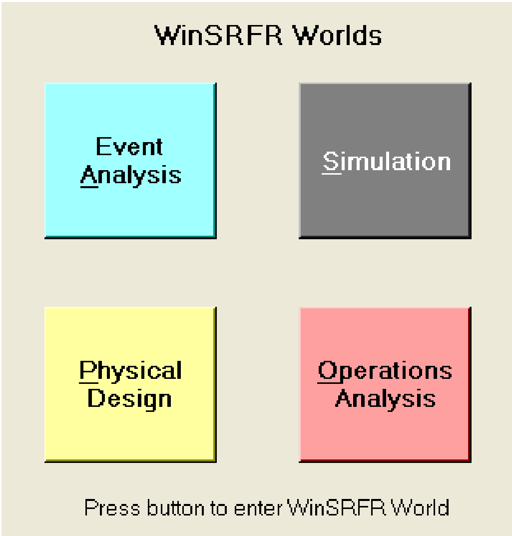


Figure 5. World Buttons

The WinSRFR World Buttons are short-cuts. The application will create an initial scenario in the corresponding World whenever one of these buttons is pressed. Pressing any of these buttons will also open an existing scenario, if the project contains only one scenario of the requested type. World Buttons and their corresponding World Window are identified using the color scheme shown in Figure 5.

3.2 World Windows

World Windows provide access to the analytical functionalities of WinSRFR. They share a common layout, which is explained in the following paragraphs. Details of data inputs expected by these Windows are explained in Chapter5.

The title bar of each World Window (Figure 6) displays the software version and the World Name. Below the menu is the Scenario Identification bar. It displays the name of the currently loaded scenario and its path within the Analysis Explorer. This Scenario Identification bar is color coded, to match the colors of the World buttons in the Project Management Window.

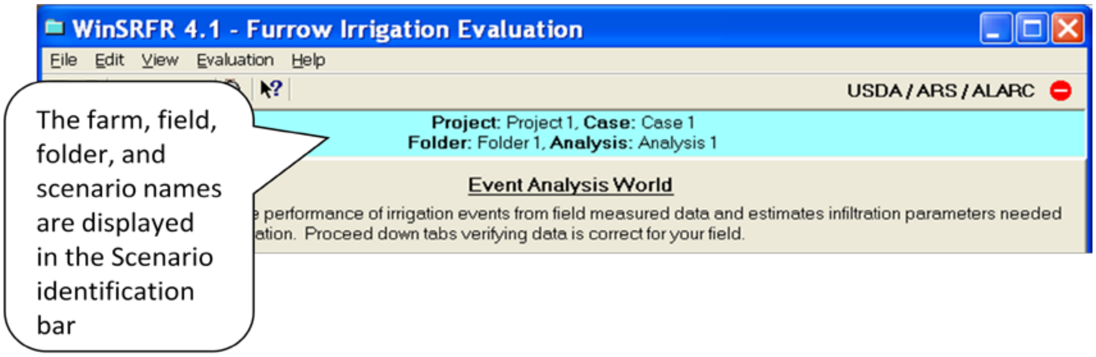


Figure 6. World Window: scenario identification

Data for each scenario are provided through a series of tabbed pages (Figure 7). The left-most **START TAB** is used to select the irrigation system that will be analyzed (basin/ border, or furrow), specify other preliminary information, and select a specific type of analysis, if applicable. Those selections limit the data options that are displayed in other tabs.

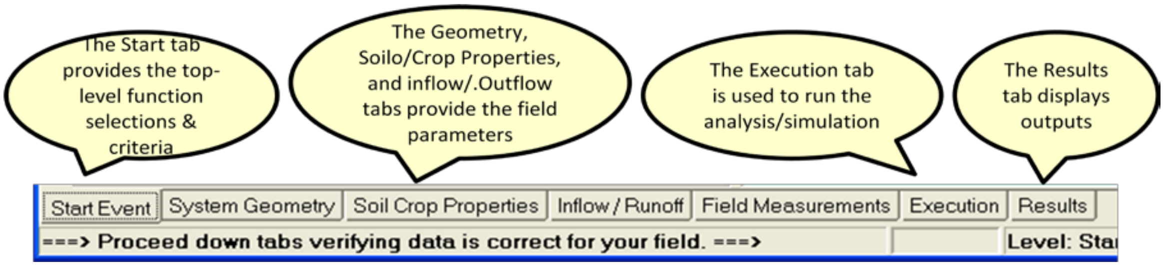


Figure 7. World Window: tab pages

The next three tab pages, **SYSTEM GEOMETRY**, **SOIL / CROP PROPERTIES**, In**FLOW/RUNOFF**, are common to all Worlds. As their names suggest, these tab pages organize data inputs into logical groups: inputs that define the geometry of the system, inputs that define roughness and infiltration properties, and inputs that define water inflows and outflows (inflows and outflows are technically known as system boundary conditions).

Figure 7 shows a **FIELD MEASUREMENTS** Tab following Inflow/Runoff. This tab page is exclusive to the Event Analysis World and is used to enter data specific to the analysis. The Operations and Design page do not have this tab page, while Simulation replaces it with the Data Summary tab

The **EXECUTION** tab is the next-to-last tab in all Worlds. Execution criteria can be set or edited from this page. The right-most bottom tab page, **RESULTS**, displays the results generated by the analysis, if the execution is successful. When results are available, the World Window displays a second row of tabs near the top of the page (Figure 8). The outputs produced depend on the type of analysis.

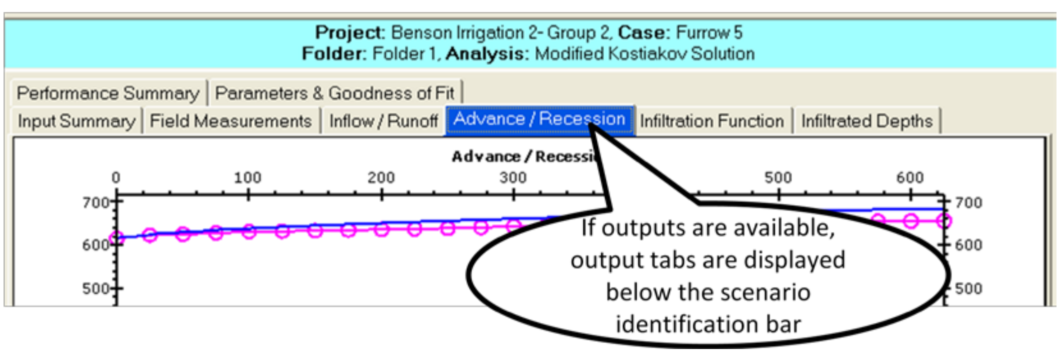


Figure 8. World Windows: output tabs

3.3 Data Organization and File Management

3.3.1 Data Organization

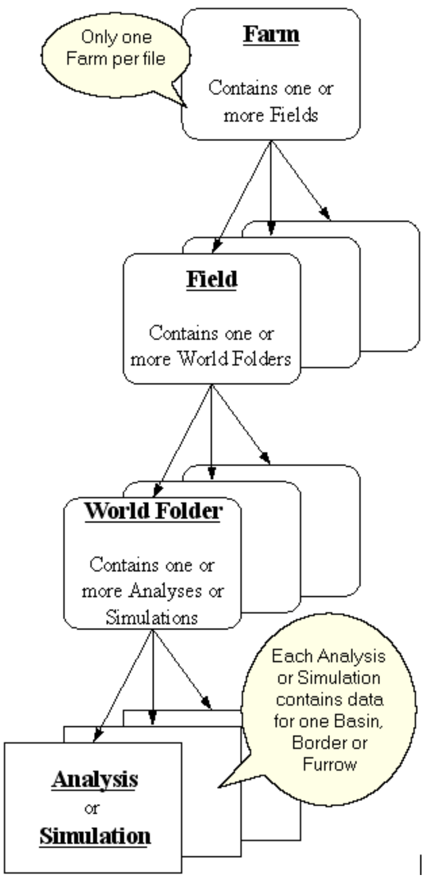


Figure 9. Data object hierarchy

From a programming standpoint, all WinSRFR data structures are objects. All objects are organized hierarchically in memory, using the structure illustrated in Figure 9. The top level of this hierarchy is a Farm (Project). A Farm object holds one or more Fields objects which in turn, hold one or more World Folders. World folders can only contain specific types of scenarios. Thus, Event Analysis scenarios can only be created in an Event Analysis folder, simulations in a Simulation folder, etc. New scenario objects can be instantiated from existing scenarios using copy and paste. All data structures within a scenario are copied and pasted; even data that may not be supported in the new analysis world. For example, the Simulation World supports tabulated cross section data while the Event Analysis world does not. If a scenario from the Simulation World is pasted into an Event Analysis folder, the tabulated cross section is included but is not used by the Event Analysis World. After pasting a scenario from one world into another, the pasted data should be carefully checked in the new world.

As in the case of information stored in memory, WinSRFR stores project data to a .srfr file hierarchically. In addition to storing input and output data set for individual scenarios, a .srfr file stores data needed to recreate all project objects. The file is not viewable or editable without the WinSRFR user interface and files can be very large, even with a small number of scenarios.

3.3.2 File Management, Compatibility, Recovery, and Management of File Size

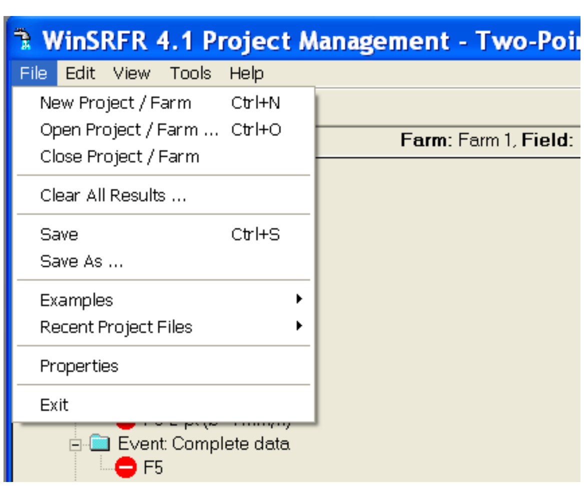


Figure 10. File management commands

WinSRFR uses conventional File management commands (New, Open, Close, Save, Save As) (Figure 10). When using the Open command, WinSRFR automatically resets the default directory data file path to the location of the mostly recently opened file, unless a file is opened from either the Examples or the Recent Projects Files list.

Because of the hierarchical structure of the data, and the fact that new data structures have been added to objects as the software has evolved, WinSRFR data files are backward but not forward compatible. When opening a file created with a previous version, the new unused data fields will be populated with default values.

When saving a project, WinSRFR creates a backup file (with the extension name .sfbk) in the directory of the current project (Figure 11). This file can be used to recover an existing project if the file gets corrupted. All data added to a project since the last save operation will be lost, however.

Figure 11. Project backup file

File corruption problems have been noted when saving large project files. Thus, when dealing with large projects, it is advisable to reduce the file size prior to saving using the `File/Clear All Results` command. This command will clear all results and associated data structures, but preserve all input data including execution settings. If a fatal exception occurs while working on a project, WinSRFR generates a diagnostic file. The default location for that file is a subdirectory of the installation folder. The user can use the User Preferences to change the location of this diagnostic file. Please provide a copy of this file when contacting the developers to report a fatal exception.

3.4 Tools

The Tools menu in the Project Management Window provides access to the following program features:

- DATA COMPARISON TOOL
- CONVERSION CHART

3.4.1 Data Comparison

The Data Comparison Tool (Figure 12) is used to compare, graphically and numerically, results from different scenarios. The Data Comparison form has three sections. The Data Selection section is used to select the data types to be displayed using the provided checkboxes. The Data Explorer is used to select the scenarios to be displayed. It replicates the structure of Analysis Explorer for the particular project. Scenarios with valid outputs are identified with checkboxes and, therefore, only those scenarios can be selected. Scenarios without outputs or with invalid outputs are displayed with a status icon (similar to the ones used by the Analysis Explorer). Results are presented in the tabbed pages, on the right-hand side of the form.

The Goodness-of-fit checkbox is used to compare numerically the results of two scenarios. These comparisons generally involve Event Analysis and Simulation scenarios (field observations vs. predictions). The metrics used for comparison are the same ones used to verify Merriam-Keller analysis results, in the Event Analysis World.

The sequence of colors used to display different series is user-selectable. Use `Edit/User Preferences /Color` command to edit this color scheme. You will need to exit the Data Comparison Tool and return to the Project Management Window. As explained in the Data Exchange section, all graphical outputs can be copied and pasted to other applications as bitmaps using the clipboard. They can also be exported to a file using various graphical formats. The underlying numeric data can also be exchanged using the clipboard. All results can be printed using menu commands.

To clear selections, uncheck the corresponding boxes in the Data Explorer. You can also click on the menu command `Edit/Clear All Selections` to simultaneously unselect all analyses.

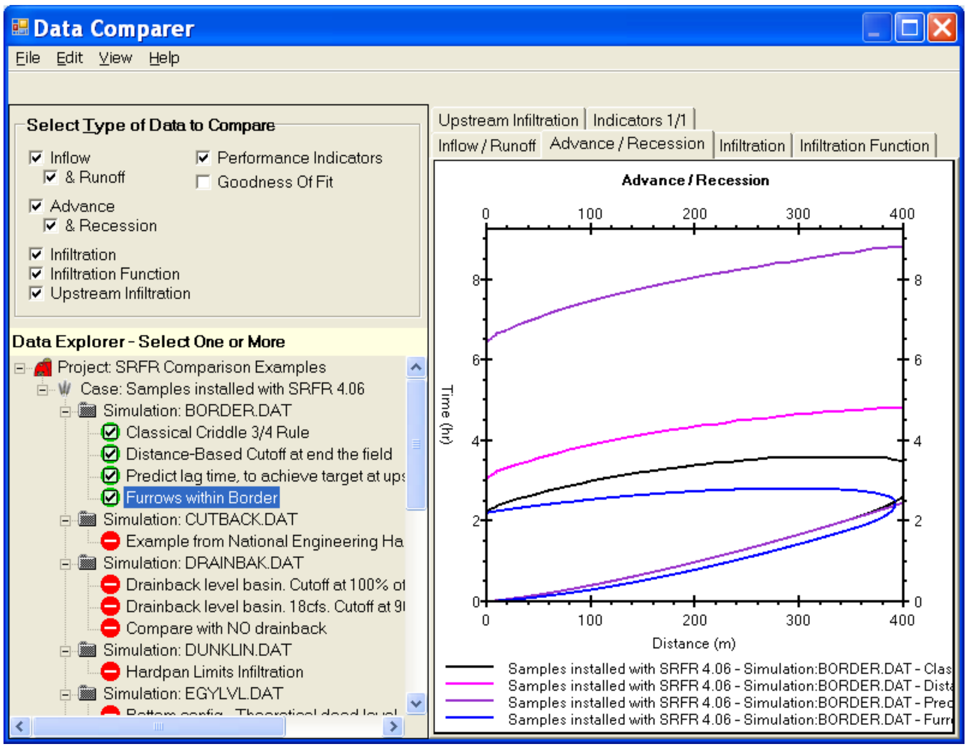


Figure 12. Data comparison tool

3.4.2 Units Conversion Chart

The Conversion Chart (Figure 13) is used to convert values from one unit system to another. Conversions are provided for

- Length
- Area
- Depth
- Volume
- Flow Rate

To convert a value, select the appropriate tab, enter the value in one of the provided input boxes, and press Enter (or click the OK button) to update the value displayed in the other input boxes on that tab.

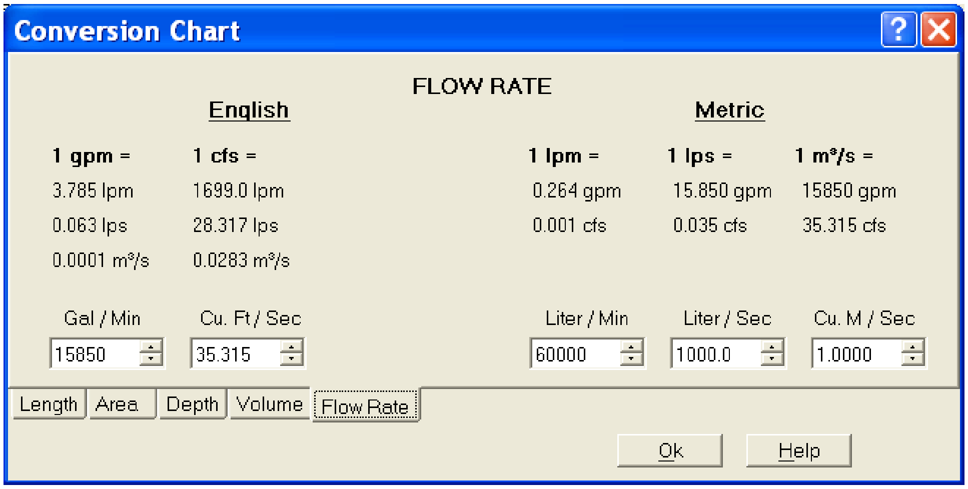


Figure 13. Conversion chart

4 Working with the Graphical User Interface

WinSRFR's Graphical User Interface (GUI) was developed using standard Windows structural elements, interaction elements, conventions, and services. This chapter discusses the main architectural features of the GUI, the help system, GUI configuration options, and use of the Windows clipboard to exchange data with other applications.

4.1 Visual and Navigation Elements

Forms and data controls are the central GUI elements used to organize, display, and interact with the data. Program commands are issued using command buttons and/or the menu system. Users can navigate through the application using the mouse and/or keyboard commands.

4.1.1 Forms

The two main forms used by WinSRFR, the **Project Management Window** and **World Windows**, were described in the previous chapter. The **Project Manager** is the parent form for all controls used by the program, including World Windows. The **Project Manager** can be moved within the display screen, resized, or minimized independently of open World Windows. Closing the **Project Manager** will close all open **World Window** forms and the application. Settings (location and size) of the **Project Manager** form are not saved between WinSRFR sessions.

Scenarios are opened using a **World Window** form. The form provides controls for data editing and validates the user-provided inputs. Only one World Window of each type (e.g., one Simulation World Window) can be opened at any time. World Window forms can be moved within the display screen, resized, and minimized.

Additional forms used by the application are launched from the **Project Manager** or from **World Windows**. These forms are used to define tabular inputs, modify program settings, or to display program outputs (such as the **Data Comparison Tool**). Many of these additional forms are modal, meaning that the user needs to provide the needed inputs and close the form before returning control to the parent form (a **World Window** or the **Project Manager**). Some of these forms cannot be resized or minimized, but all can be moved around in the display screen.

4.1.2 Data input and edit controls

WinSRFR input controls include input boxes, option buttons, check boxes, drop-down lists, and data tables. Use and limitations of input boxes and data tables is discussed next.

4.1.2.1 Input boxes

Input boxes are used mostly to enter numeric values. These controls are actually text boxes and display data using a format specified by the application. The format depends on the units typically used for the particular variable. As a result, the input boxes may not display data exactly as entered. For example, and since the input box for field length displays only two significant figures, a field length specified as 150.5555 m will be displayed as 150.56 m (Figure 14). Note, however, the data will be preserved in memory and file exactly as entered.

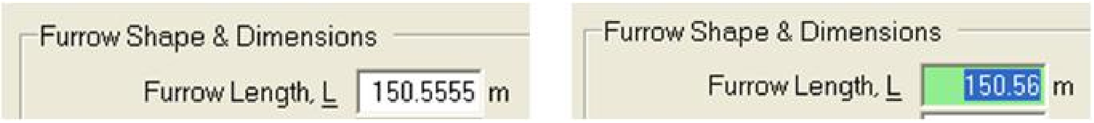


Figure 14. Input boxes and their effect on numerical inputs

All numerical input boxes have a units label to their right (Figure 14). When entering data, the provided value will be assumed to have been given in the units specified by the label. If the user has data in units that differ from the units displayed, it may be possible to change the text box to accept the user's data units. Right-click on the units text to the right of the text box to display a menu of alternate units available for that control. Select the units that match the data to be input. Most numerical text boxes offer at least two different choices for units. If the user has data in units different from those offered by WinSRFR, then those data will have to be converted to WinSRFR-compatible units. WinSRFR has a built-in unit conversion tool (invoked by pressing the function key **F7** when viewing the Project Management window) that can assist with unit conversions. All inputs provided to input boxes are converted to SI units prior to program execution or to executing a File/Save command.

4.1.2.2 Data Tables

Data Tables are used for entry and display of tabular data. They appear in Window's forms as well as in Dialog Boxes. Data can be entered manually, pasted from the clipboard or imported from a file. Tabular data can be copied to the clipboard and exported to a file.

The number of columns in data tables is defined by the application and corresponds to the data items required to define a particular input, for example field elevation as a function of distance along the field. The maximum number of rows is user-defined and corresponds to the number of items in the table. Depending on the data, some tables require either one or two rows of data at a minimum. The user cannot edit the independent variable (location or time) of those required rows of data, but only the dependent variable (e.g., field elevation, discharge).

When directly editing a data table, menu commands are used to add or delete table rows, as needed. Those commands are available through either the form (Edit/Data table name) or the context menus. **Tab** or **Arrow** keys are used to navigate through the cells in a data table.

The process of importing tabular data into WinSRFR is illustrated in Figure 15. The file to the left (a .txt file) contains data ready to be imported into an elevation data table, which is displayed to the right. Data columns in the .txt file are tab-separated. The first line in this file displays the units applicable to each column of data. If this line is present, those units will be used when the data is imported. If this line is missing, the units currently being displayed by WinSRFR will be used instead. (In this example, the unit label line is redundant because the data is given in meters and the table is expecting values in meter). Unit labels recognized by WinSRFR are listed in Table 1.

The data can be imported by copying the data from the .txt file (**Ctrl-C**) to the clipboard and then pasting into the WinSRFR table, using the corresponding context menu (**Right-Click**, Paste Table). Alternatively, the File/Import From File command can be used. The application will stop an import operation if there are more columns in the imported data set than in the data table but will proceed with fewer columns in the data set than required. In the latter case, the application will then enter the available data in the first column of the data table and zeroes for the missing data. The application determines the number of rows needed by the data table to handle the available data. Blank rows will be ignored. Error message(s) will be displayed if the data is not valid or incompatible with the current setup, such as when a data row is incomplete.

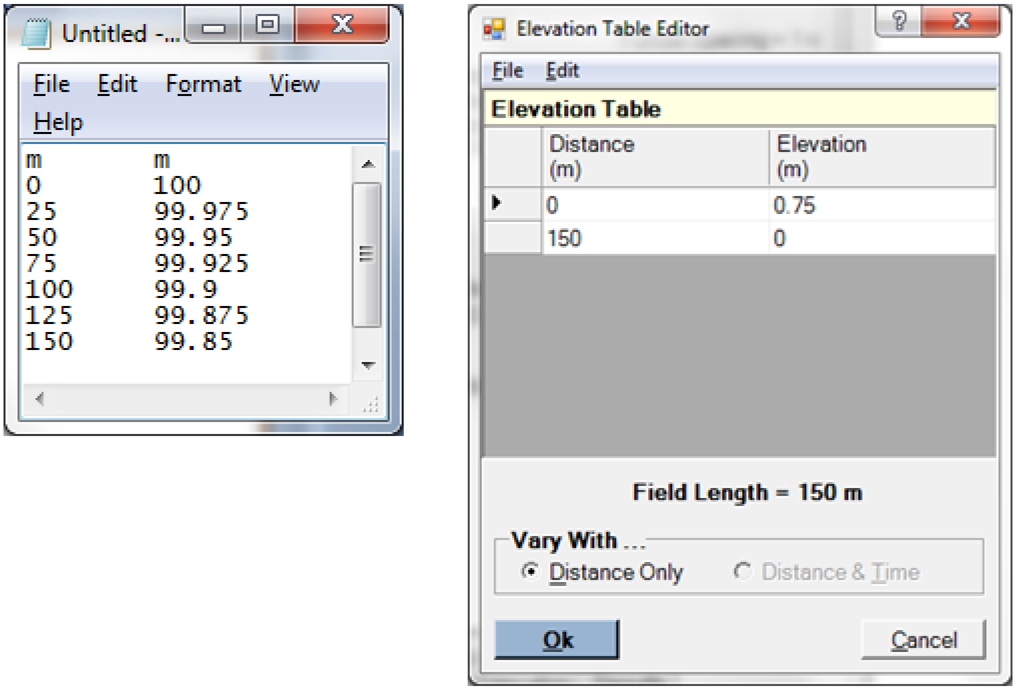


Figure 15. Importing data from a text file to a data table using the Windows clipboard

Table 1. Unit labels for importing tabular data into WinSRFR

Variable	Unit Labels
Length	"m", "ft"
Depth	"m”, mm", "cm", "in", “ft”
Side Slope	"H/V"
Slope	"m/m", "m/100m", "ft/ft", "ft/100ft"
Time	"sec", "min", "hr", _
Flow Rate	"cms", "lps", "lpm", "cfs", "gpm"
Percentage	"%"
Soil Water Holding Capacity	"mm/m", "in/ft"

Data can also be imported from spreadsheet files and other applications capable of creating tab-delimited files, but only using the copy/paste mechanism, or by saving the data as a tab-delimited .txt file. As in the example, a spreadsheet can be provided with a line to identify the units corresponding to each data column.

WinSRFR tabular data can be exported to a .txt file and imported back into a different WinSRFR scenario. While it is easier to use copy and paste commands to transfer tabular data between scenarios, this command is useful in that it provides a mechanism for creating a data template in a text editor or a spreadsheet. Except when working with small data tables, users generally will find that editing tabular data is awkward with a WinSRFR data table because of their limited data editing capabilities. Thus, when dealing with large tables, the recommended approach is to edit the data outside WinSRFR and to import those data using one of the above procedures. Note that data files created by an export operation contain additional header information relative to the example. That additional information is ignored during an import operation.

4.1.2.3 Color coding of data controls

The color scheme of WinSRFR input controls identifies the source/state of the data (Figure 16). This color scheme applies exclusively to text and drop-down boxes. The background color for these controls is identified in Table 2:

New scenarios are created with default values entered for all pertinent variables. Default values are displayed in text and drop-down box controls using the standard Window background color. Most analyses will require users to modify these values. User-Entered Data (i.e., different from the default values), are displayed with a green background color. Because World Windows share a common layout but have different input requirements and produce different outputs, input controls in one World represent output controls in a different World. This is the case, for example, with Furrow Length, an input in Simulation, but an output in Physical Design. This data field will be displayed in blue, once the value is calculated by the application. If design calculations are successful, this field displays the value associated with the selected solution point.

Blue drop-down lists are used also to indicate that WinSRFR offers only one choice for that variable under the given conditions. Such is the case for the Solution Model selection option (**SIMULATION WORLD/ EXECUTION TAB/SOLUTION MODEL**). This control displays the option selected by the application, if the user level is Standard User. However, if the user level is Advanced, then the application will display the options available to the user.

User-selected options may be incompatible with other user-selected options or with program-defaulted values. If these selections are considered by the application to be in error, they will be displayed in red with an adjacent red icon. Hover the mouse over the red error icon next to the input control to display a tooltip describing the error

Table 2. Color coding of data controls

If the value in the control is …	… then the background color is
Defaulted:	Standard window color
User-Entered:	Green
Calculated or only one choice:	Blue
Warning:	Yellow
In Error:	Red

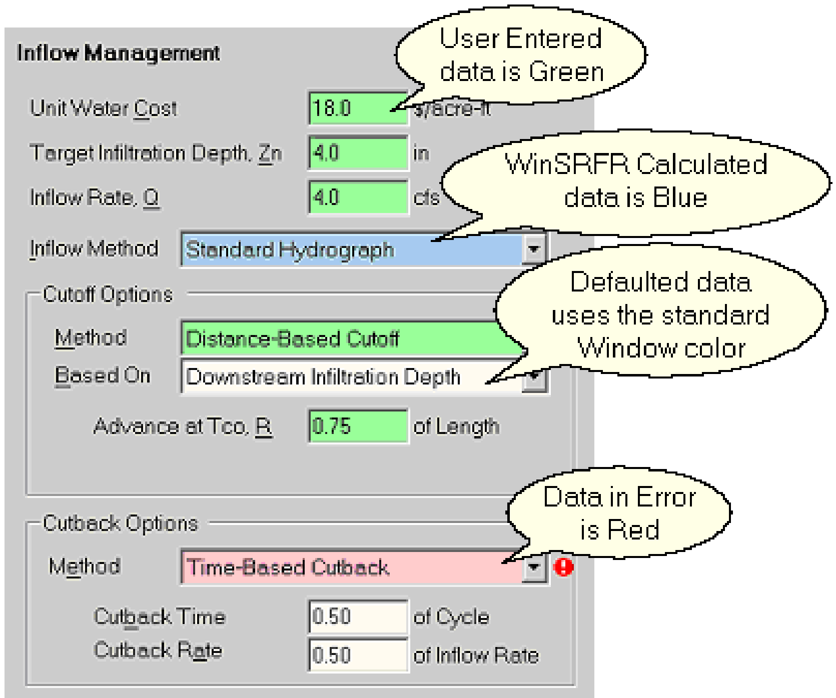


Figure 16. Color coding of data controls

4.1.3 Menus and command buttons

WinSRFR uses a combination of command buttons and menus to issue commands. Command buttons are displayed in the background color of the form or in blue.

The WinSRFR menu system includes form menus and context menus. Form menus are always visible, such as the menus in the Project Manager and in a World Window. They are organized in logical groups, similar to those found in other Windows applications (File, Edit, View, Help, etc.). Context menus are hidden and are displayed by right- clicking on a particular control. Context menus are used by:

- **Analysis Explorer**. The available commands (Figure 17) are used to edit the project data objects.

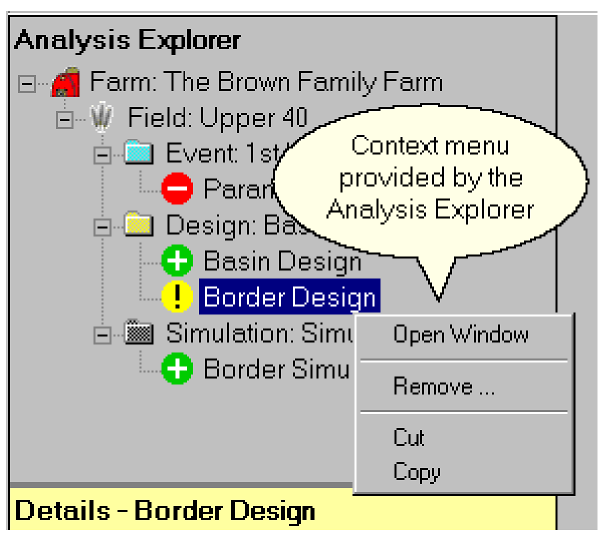


Figure 17. Context menu for the Analysis Explorer

- **Input boxes** (e.g., the **FURROW LENGTH** input control, in the **SYSTEM GEOMETRY TAB**). The corresponding commands (Figure 18) are used to exchange data with the Windows Clipboard.

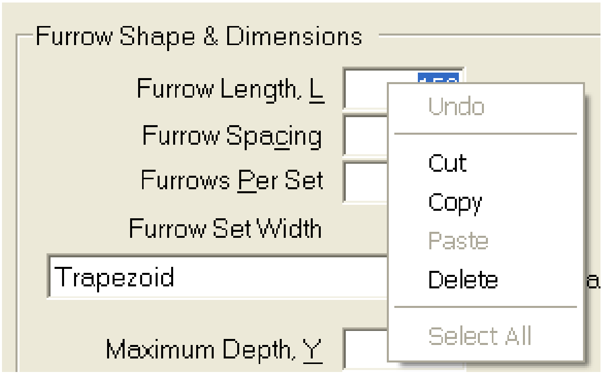


Figure 18. Context menu for a text box

- **Data entry tables**. Two context menus are available for data tables (Figure 19). The first is invoked by right-clicking on the upper-left corner of the data table and is used to exchange data with the Windows clipboard. The second is called by clicking on the left side of the table and is used to add or delete table rows.

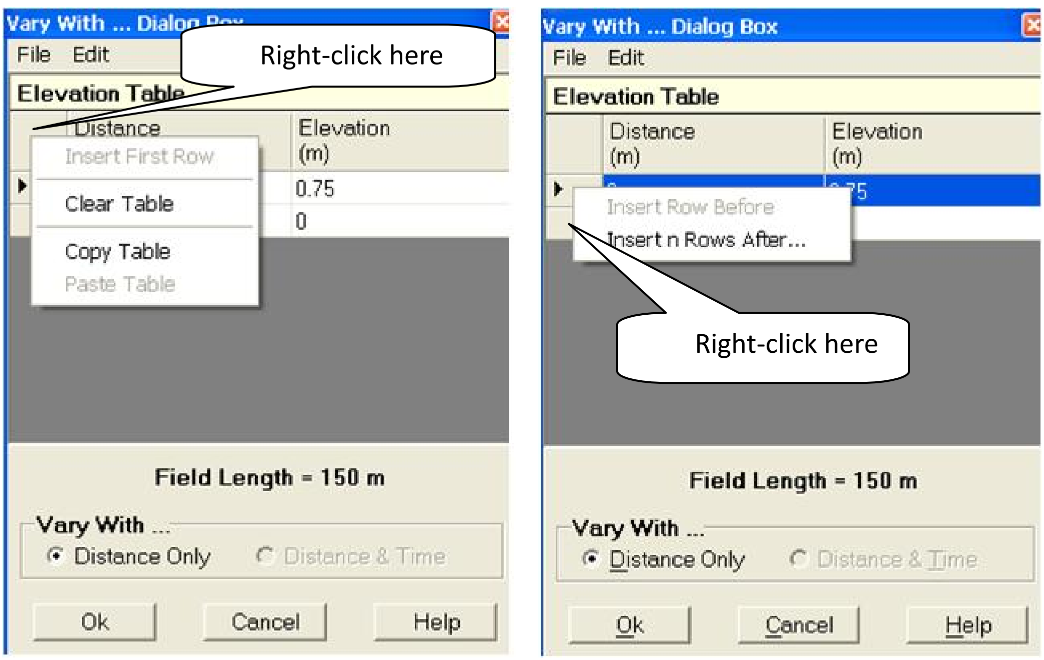


Figure 19. Context menus for data tables

- **Units labels**. These menus are associated with input boxes (e.g., the units label for Furrow Length) are used to select a units system for displaying the data in the control (Figure 20).

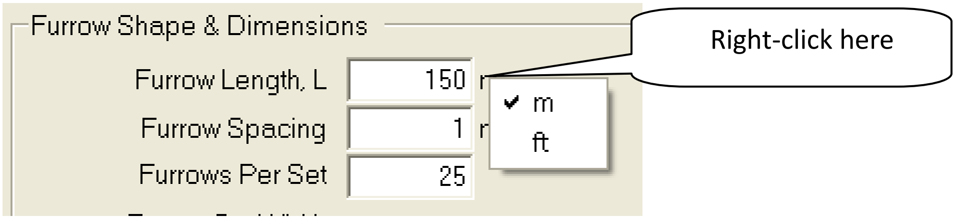


Figure 20. Context menus for unit labels

- **Graphical outputs**. These menus (Figure 21) are used to copy graphical and numerical data to the Windows Clipboard. When viewing contours, they are also used to select a solution point.

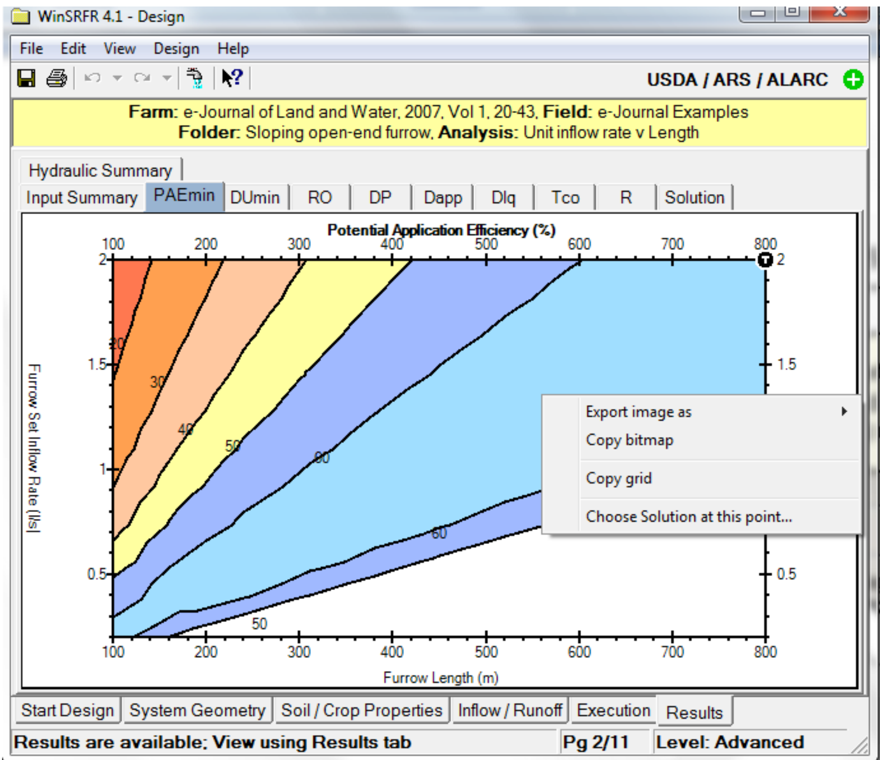


Figure 21. Context menus for graphical outputs

4.1.4 Navigation

WinSRFR allows users to interact with the application using either a pointing device (mouse) or the keyboard.

4.1.4.1 Mouse navigation

The application employs conventional mouse commands, e.g., a left-click pressed on a command button or menu item issues a command, pressing on a selection control (tab control, option button, check box, or drop-down list), enables that selection, while pressing on an input control or form will bring the focus to that form or control. A mouse right-click brings up a context menu, if one exists.

4.1.4.2 Keyboard navigation

Keyboard navigation requires a sequence of keyboard inputs to, first, select a control and, second, to perform an action with that control – edit its content, open its content, or execute an associated command. Commonly used commands are available through Function and Control key combinations. Keyboard navigation for different types of input controls is summarized in Table 3. Table 4 summarizes the use of Function/Control keys.

Table 3. Keyboard navigation for different types of input controls.

Menus	
	Select. Press and release the `Alt` key. This selects the first menu in the menu bar and underlines the activation keys for all menu items. **Click.** Use the arrow keys (↑, ↓, →, ←) to traverse the menu to select the item you want then press the `Enter` key, or press the underlined activation key for the desired menu item.
Tab Pages	
	Select. Use the `Tab` key to move focus to the tabs. Use the arrow keys to select the tab page.
Numeric Controls	
	Select. To select a numeric input control, use the `Tab` key to move the focus to the control. `Tab` moves the focus forward while `Shift-Tab` moves the focus backward. Alternatively, use `Alt` as you would the `Shift` key to select the numeric control. Most controls have an associated activation key; this is the letter underlined in the control's label. For example, `Alt-W` will select the control with W underlined. The `Tab` key may be needed to select a particular control if it is in a group of controls that share a single label. **Edit.** To edit the value of a numeric entry control:2) When a numeric control has focus, its value is usually highlighted. You can simply type in a new value at this point or use the arrow keys to position the cursor to a point where you can edit the current value. 3a) Press `Enter`. The new value will be entered and the focus will stay on the control or 3b) Press `Tab`. The new value will be entered and the focus will move to the next control. *When using keyboard control, units labels cannot be changed!*
Drop-down lists and Option Buttons	

	Select. Use the `Tab` key to move the focus to the control. `Tab` moves the focus forward while `Shift-Tab` moves focus backward, or use the `Alt` as you would the shift key to select the control. Most controls have an associated activation key; this is the letter underlined in the control's label. For example, `Alt-S` will select the control with "S" underlined. The "Tab" key may be needed to select a particular control if it is in a group that shares a single label. **Edit**. To edit the value of a selection control, use the arrow keys to move through the selections.
Check Box Controls	
	Select. Use the `Tab` key to move the focus to the desired check box. **Edit**. Use the `Space bar` to change the state.
Command Buttons	
	Select. Use the `Tab` key to move the focus to the button. `Tab` moves the focus forward while `Shift-Tab` moves focus backward or; use `Alt` as you would the `Shift` key to press the button. Most buttons have an associated activation key; this is the letter underlined in the button's label. For example, `Alt-A` will press the button with "A" underlined. **Execute**. Use the `Space Bar` to 'press' the button.
Analysis Explorer	
	Select. Use the `Tab` key to move the focus to the Analysis Explorer. `Tab` moves the focus forward while `Shift-Tab` moves the focus backward. Use the arrow keys to move around in the explorer. The ↑ and ↓ arrow keys move through the visible items. The ← key moves up through the items closing levels as it goes. The → key moves down through the items opening levels as it goes. **Open Item**. Once you have selected an Analysis or Simulation item, press the `Enter` key to display it in its corresponding WinSRFR World or Press the `Spacebar` to display the Context Menu associated with the item. Use the arrow keys to select the Context Menu item then press "Enter" to activate that item. Press the escape key, `Esc`, to remove the Context Menu.

Table 4. Summary of Function and Control key commands

All Windows	
F1	Help
F5	Refresh display
Ctrl-X	Cut
Ctrl-C	Copy
Ctrl-V	Paste
Ctrl-S	Save
Ctrl-Y	Redo
Ctrl-Z	Undo
Results Tab	
Ctrl-F	Full page layout
Ctrl-G	Graphics layout
World Windows	
Ctrl-P	Print
Ctrl-R	Run the Analysis or Simulation
Ctrl-W	Display the main WinSRFR Project Management Window

4.2 User Settings

User settings modify the range of analytical options offered by the program, the display of visual elements, and the response of the application to certain user commands.

4.2.1 User Level

The WinSRFR Simulation World offers many options for configuring irrigation systems. With the Edit/User Level menu command, users can restrict the options available for an analysis, and hence, those that are displayed on the user interface.. Three user levels are available:

- Standard
- Advanced
- Research

This command is available only through the Project Manager Window. The setting is stored in the Windows registry and is saved for future sessions.

Most practical analyses can be conducted with the options offered at the Standard User Level. Advanced User Level options are less commonly used and some of those options require substantial knowledge by the user of the underlying computational procedures. Furthermore, some Advanced Level User options are still experimental. The Research User Level is available only for research and code development, and thus is not made available to the general public. Options available at the Advanced and Programmer user levels are summarized in Appendix A.

4.2.2 User Preferences

Users can set default values for the colors, fonts, units, etc. of the GUI using the `Edit/User Preferences` menu command (Project Manager). These preferences are stored in the Current User section of the Window's Registry and can be set differently for different users sharing the same PC. New projects are created with these default options, but some of those options can be overridden for individual projects. Those particular settings are then stored with the project file.

User Preferences are organized in tab groups, as follows:

- **Startup:** Startup options and default information for new projects
- **Views:** Options for enabling / disabling and controlling WinSRFR views
- **Files:** Paths to commonly used files / folders
- **Dialogs:** Options controlling whether or not certain dialog boxes are displayed
- **Units:** Units system and default units selection
- **Graphs:** Colors and options to use for graphs
- **Contours:** Colors and options to use for contours

1) Startup

The Startup tab (Figure 22) is used to set:

- **FARM (PROJECT) NAME:** Default name used when a new Farm / Project is created
- **FARM (PROJECT) OWNER:** Default name used for the Farm/Project Owner
- **EVALUATOR:** Default name of person running WinSRFR; used when a new Analysis / Simulation is created
- **OPEN PREVIOUS FILE AT STARTUP:** If checked, reopens at startup the most recently opened project file

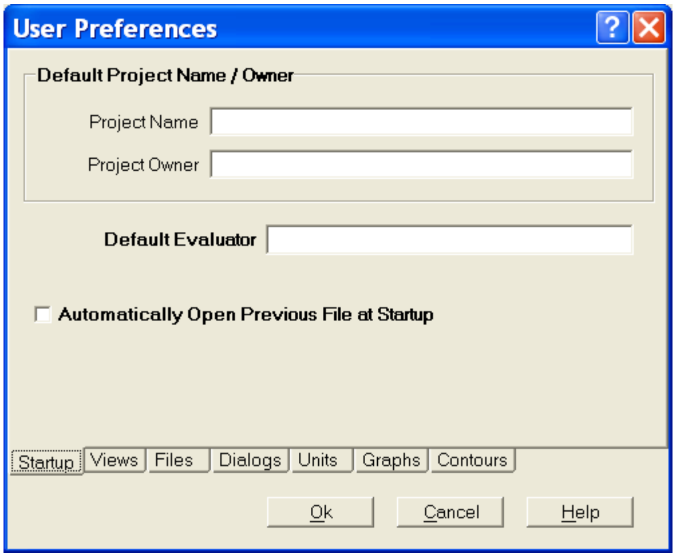


Figure 22. Dialog box for User Preferences

2) <u>Views</u>

The Views tab (Figure 23) displays the following options:

- **RESULTS DISPLAY:** Determines how graphical outputs will be displayed

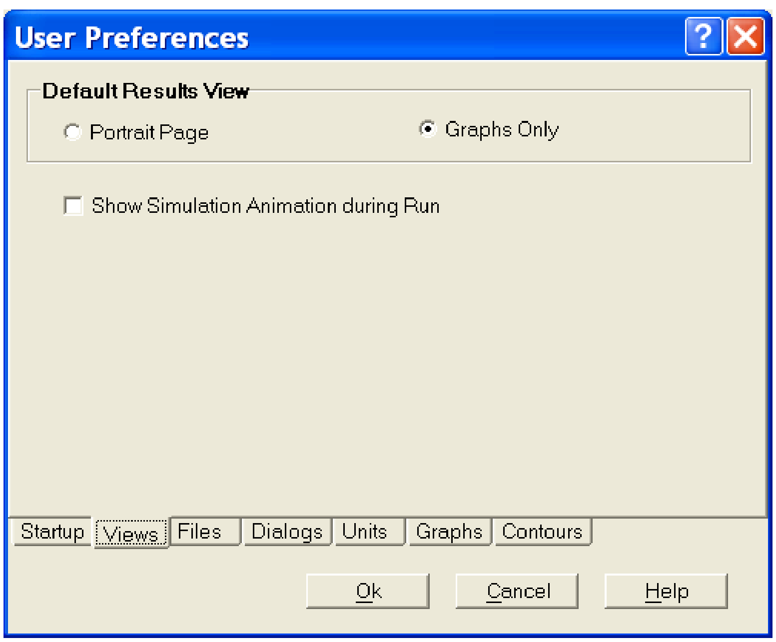


Figure 23. User Preferences/Views tab

- **Portrait Page:** Both graphical and text outputs are displayed on a Portrait page (Print Preview-like view)
- **Graphs Only:** Graphical outputs fill the available window; text outputs are displayed on a Portrait page
- **SHOW SIMULATION ANIMATION:** If checked, the Simulation Animation Window will automatically display when running a Simulation.

3) Files

File management options are set through the Files tab (Figure 24):

- **LOG & DIAGNOSTIC FILE FOLDER:** Path to the folder for WinSRFR's log and diagnostics files. By default, the pathname is set to the folder provided by Windows for application data: C:\Documents and Settings\...\Application Data\USDA\WinSRFR 4.1. The user can change to any path desired, for easier access.
- **DATA FILE FOLDER:** Path to the folder for WinSRFR's data files. By default, the pathname is set to the folder provided by Windows for application data: C:\Documents and Settings\...\Application Data\USDA\WinSRFR 4.1 The user can modify this to any path desired.

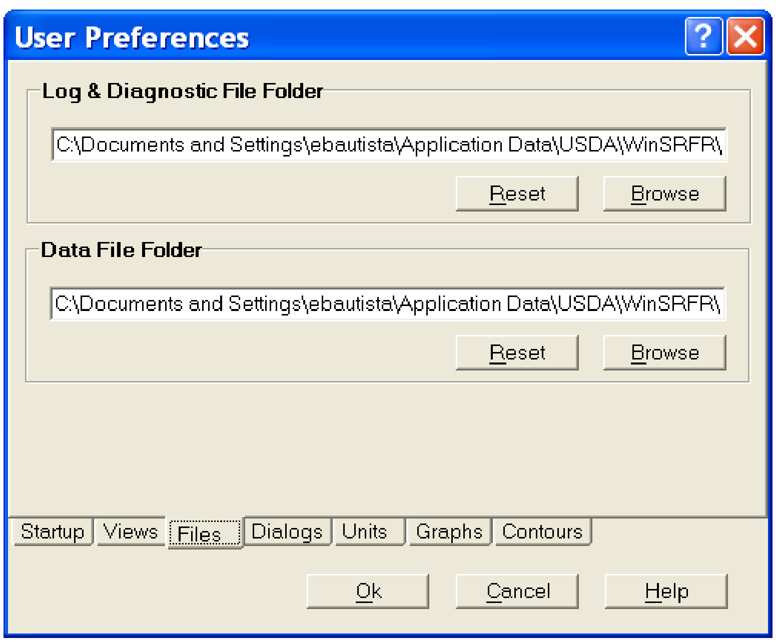


Figure 24. User Preferences/Files tab

4) Dialogs

The Dialogs tab (Figure 25) defines when and how some dialogs forms will be displayed:

- **SOLUTION MODEL AND CELL DENSITY** When setting up a simulation, the application checks the inputs, determines which Solution Model and Cell Density are most appropriate for the given data, and sets values for those two simulation parameters. This option controls how these application-suggested inputs are handled.

- **Unconditionally Accept** Automatically accepts recommended values without confirmation
- **Require Confirmation** Prompts the user to verify the program- recommended selection for the simulation-engine controls.

  The Solution Model and Cell Density parameters are explained in Section 7.2. For most applications, the user should allow the application to set these parameters. Thus, the recommended setting is **Unconditionally Accept**.

- **INFILTRATION FUNCTION:** Controls the processing of infiltration parameters when changing the infiltration formula in the World Window/Soil and Crops Properties tab. The assumption is that in some cases the user will want to keep the existing values but in others will want to keep the shape of the function, independent of the parameter values.
- **No Matching:** Preserves the displayed parameter values, if applicable.
- **Auto Matching:** Automatically fit the parameters to match the shape of the previously defined infiltration function. The infiltration formula matching procedures are described in Section 5.3.2.4.
- **Confirmed Matching:** Displays a dialog box with a chart of the currently defined function and the alternative function, along with controls that can be used to manipulate the shape of the alternative function. The same matching procedures are used as with Auto Matching.

The recommended setting for this feature is **Confirmed Matching** (Section 5.3.2.4).

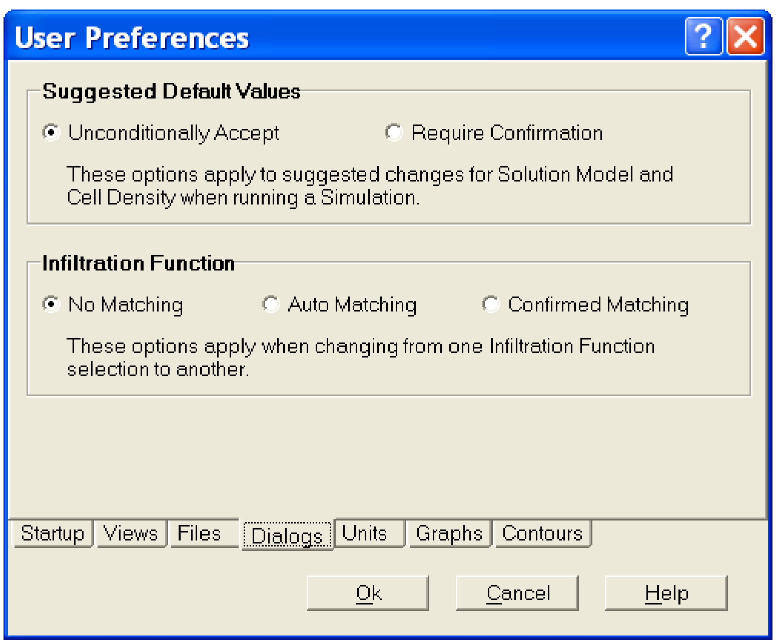


Figure 25. User Preferences/Dialogs tab

5) Units

Data stored in memory and in the .srfr file are in SI units; however, the user interface can be configured to display variables, in both input and output forms, in English or metric units (Figure 26). Specific variables are displayed using units typically used in practice. For example, if working in English units, field lengths are displayed in ft and depths in inches.

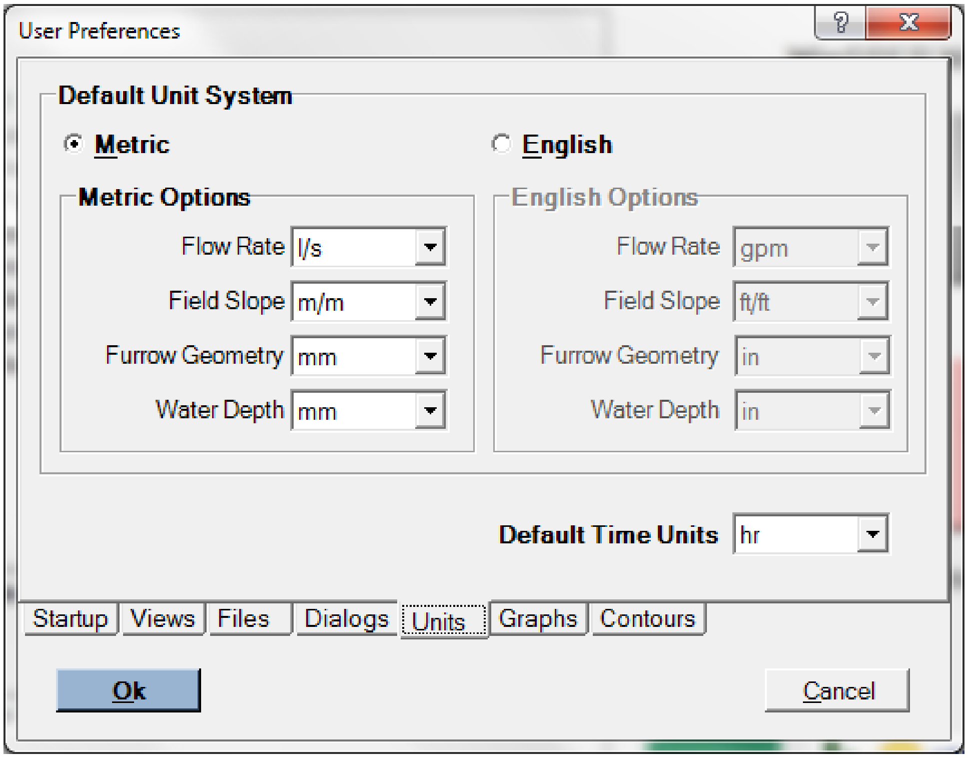


Figure 26. User Preferences/Units tab

- **DEFAULT UNIT SYSTEM:** Selects **Metric** or **English** as the default units system upon startup
- **Metric/English Options:** Drop-down lists are provided for selecting units for **Flow Rate, Field Slope, Furrow Geometry,** and **Water Depth**
- **DEFAULT TIME UNITS:** Selects hours (**hr**) or minutes (**min**) as the default time units

Two mechanisms are available for overriding the default units:

- **Setting units for the active project**: use the Edit/Units menu item. This setting is stored in the project file. It does not affect the unit system of other WinSRFR projects or of new projects (which will continue to use the default system).
- **Setting units for individual inputs**: use the context menu for individual input-item control. Numeric input controls that display units provide context menus to select the units for that individual input control. **Right-click** the mouse on the units label to display the context menu. These individual settings are not stored with the file and apply only to the current session.

6) Graphs

The Graphs tab (Figure 27) controls the sequence of colors used to plot series of lines or curves on a graph. It also controls the display of the text in a graph.

- **LINE COLORS:** Selects the color order of plotted data series
- **GRAPH OPTIONS:** Turns on/off the display of graph text (**TITLE**, **SUBTITLES**, **AXIS LABELS**) and selects **Font** type and **Size**.

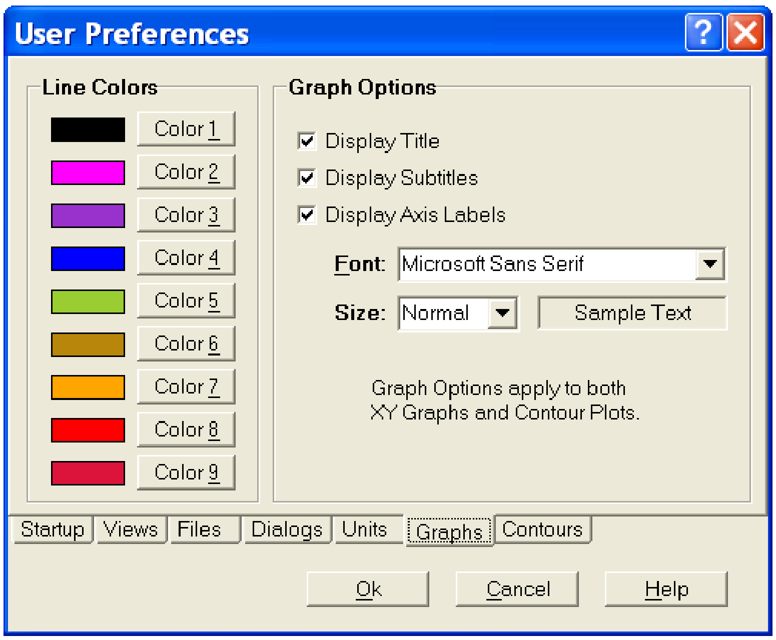


Figure 27. User Preferences/Graphs tab

7) Contours

The Contours tab (Figure 28) sets default options used to generate contour graphs in the Operations Analysis and Physical Design Worlds.

- **CONTOUR FILL COLORS:** Selects the color scheme to use to fill the contour levels. The available options are an-application-defined **Color Scale**, **Gray Scale**, **User Defined** color scale, and **No Fill** (only contour lines are displayed).
- **CONTOUR OPTIONS:** Controls the display and calculation of various contour elements
- **Calculate Minor Contours:** Decreases the interval at which contours are calculated and displayed
- **Display Fill Color Key:** Turns on/off the display of a contour color legend
- **Display Contour Labels:** Turns on/off the display of contour labels
- **Display Grid Points:** Turns on/off the display of the contour grid points
- **Calculate Standard Contours:** Selects low-order interpolation procedures for contour calculations

- **Calculate Precision Contours:** Selects high-order interpolation procedures for contour calculations

For individual projects, options that affection the calculation of contours can be overridden in the Execution tab of the Operations and Design Worlds.

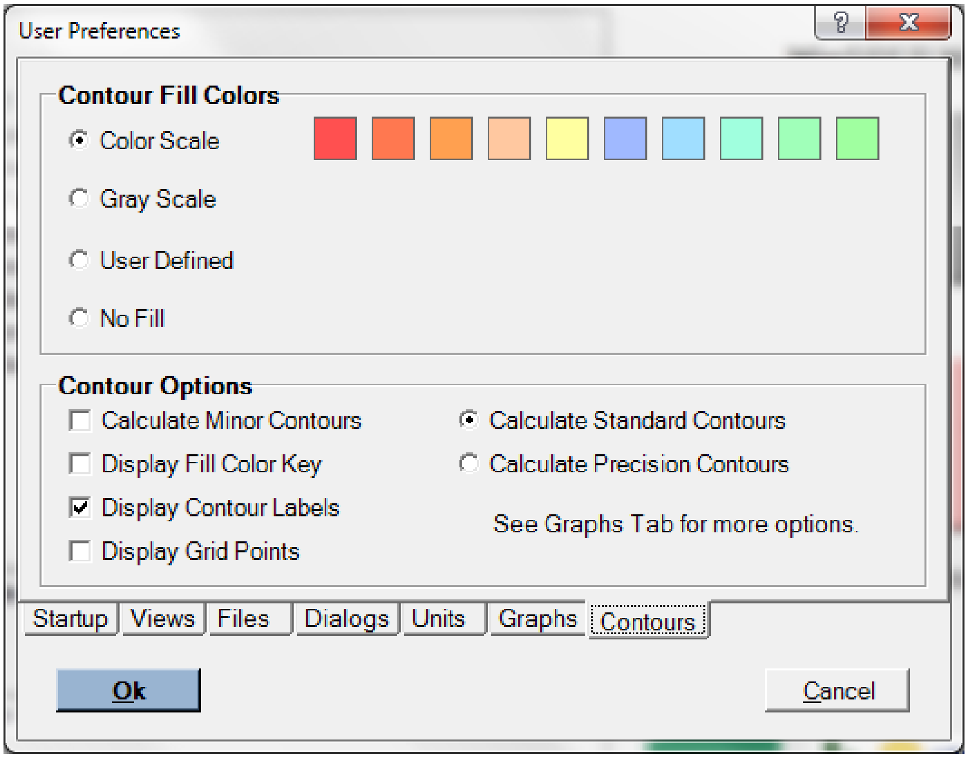


Figure 28. User Preferences/Contours tab

Nomenclature Defaults

Use the `Edit/Nomenclature` menu command to select nomenclature used to refer to the two top level data containers displayed by the Analysis Explorer. The available choices are

- `Farm / Field`
- `Project / Case`

4.3 Help and Application Messaging

Guidance in the use of this software is provided through a Help system. In addition, using a Messaging system, the application provides feedback to the user in response to inputs or to conditions imposed on a scenario.

4.3.1 Help

The WinSRFR Help System provides general and context-specific HTML help for its forms and controls. The same content is also available in the form of a PDF Manual. The Help System consists of several mechanisms, summarized in the following table.

Table 5. WinSRFR Help System.

Help **menus**	General help and some context-sensitive help can be accessed through Help menu commands. Example of general help is help for working with the user interface.
PDF Manual	The PDF manual can be viewed at any time by using the Help/View PDF Manual command.
F1 **Key**	Pressing the F1 key displays context –sensitive help for the form or tab page that has focus.
Help Buttons	Most dialog boxes have a Help button in the upper right corner.
What's This? **Help**	This help is activated by selecting the Help/What's This? menu command or by clicking on the What's This? toolbar button [ICON]. Clicking on a control (e.g., a tab page, a text box, etc.) provides information about the input required by that control.
Tooltips	World Windows display an error icon next to an input control if a problem is detected with the data. Tooltips provide information about the error and are displayed by hovering the mouse over the error icon. In the example, the message is that the entered value is negative.

4.3.2 Error & Warning Messages

Incorrect or inconsistent inputs inevitably lead to computational incidents or at least to faulty results. WinSRFR tries to prevent computational incidents by identifying suspect data. Computational incidents can occur with apparently valid and consistent inputs, if the application cannot handle the flow conditions defined by the data. If an incident does occur, or if peculiarities in the inputs or outputs are detected, the application provides diagnostic information which may help correct the problem.

1) Data Entry Errors

Input boxes and tables provide a first level of data validation and error messages. The application rejects inputs if the data type is incorrect (e.g., entering text values in numeric fields). If the input provided to a numeric input box has no physical meaning (such as zero or negative values for data that can only have positive values), the background color of control will turn to red and an error icon will appear next to the control. A tooltip can then be used to display an error message. The application may also trap data that is inconsistent with other data items. For example, entering a table of distance and field elevations with a field length that is not compatible with the value given in the Furrow or border length text box will generate an error message. These errors will prevent an analysis from executing.

2) Setup Errors & Warnings

Setup Errors & Warnings are displayed in the Execution Tab of all World Windows, prior to running an analysis.

Setup Errors. Assuming that a Data Entry Error is not immediately corrected and the user changes the focus to the Execution tab, a setup error message will be generated. Data tables do not always generate Data Entry Error messages. In addition, inputs may be incomplete or incompatible. All inputs provided for a scenario are validated when the user switches to the Execution tab or attempts to run the analysis (by pressing **CTRL-R**). At that point, those incorrect or incompatible inputs generate a Setup Error message.

Figure 29 is an example from the Event Analysis World – post-irrigation volume balance analysis with the Merriam-Keller procedure. This procedure is intended to evaluate the performance of an irrigation event, but as an intermediate step computes an infiltration parameter estimate. The figure shows two different error messages displayed by the application. The first message states that there is an error with runoff data – in this case, the input data states that the irrigation system has an open downstream end, and thus produces runoff, but no runoff data has been provided. The second error message is related to the calculation of the infiltration parameter k. This parameter is undefined until the user presses the button Accept a and Estimate k button, and the calculation is completed successfully. The value of k will be displayed on the form when this calculation is completed. The Verify and Summarize Analysis button will not be enabled until these two error messages are cleared.

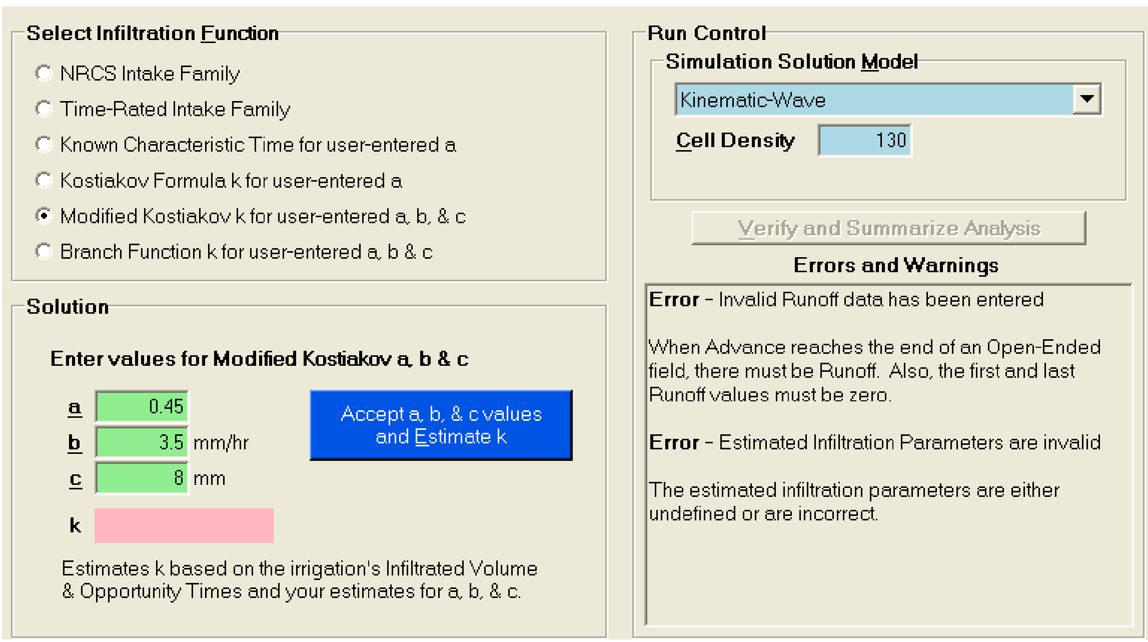


Figure 29. Example setup error displayed by the Event Analysis World

Warnings. These messages are generated prior to execution when an analysis can be executed with the given inputs, but the application detects potential anomalies with the data. Such would be the case of the example shown in Figure 30. The example involves simulation of an irrigation system with a slope of less than 0.004 (m/m or ft/ft) using the kinematic wave engine. The kinematic wave model cannot be recommended with very mild slopes. Standard users will never see this warning because the application automatically selects a simulation engine based on a given slope. The warning will be issued only if an advanced/expert user chooses to override the selection made by the application.

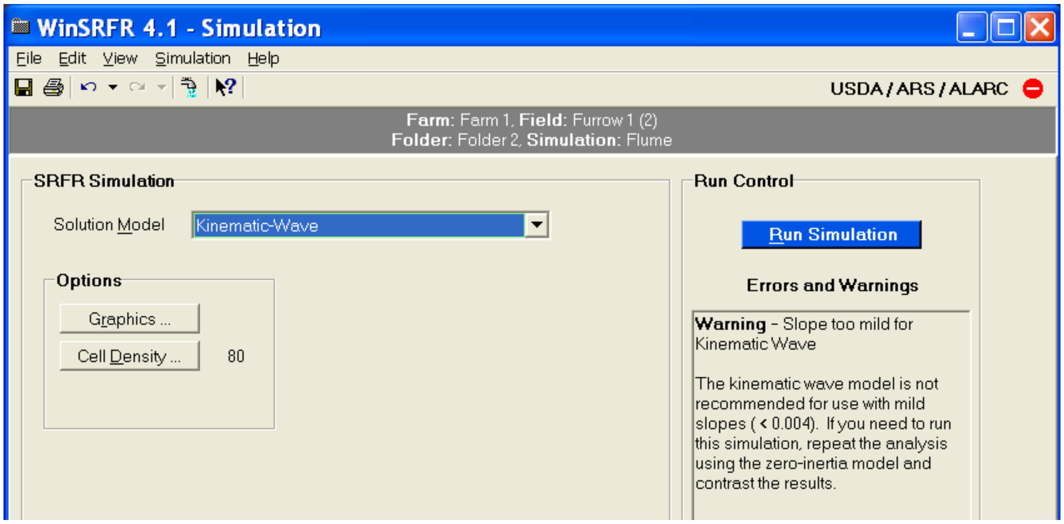


Figure 30. Example of setup warning.

3) Execution Errors & Warnings

Execution Errors. A WinSRFR analysis involves the application of numerical methods and requires numerous calculations. A given set of conditions can result in a computational incident – for example calculation of a negative flow area or a failure to converge. Extensive exception-handling routines are built into the WinSRFR simulation engine and other computational procedures. Some of those routines allow the application to reinitiate the calculations after making numerical adjustments. The application provides no feedback to the user when the exception is resolved and computations are completed successfully. If the application is unable to correct the problem, calculations stop and an Execution Error message is displayed. The error-handling routines provide diagnostic information about the error. Rarely does an exception cause an unexpected program termination but in those cases an error file is generated.

Outputs generated by the application may still be available to the user, but of course only up to the point in the calculations where the exception occurred. Those available outputs will be displayed by the application. For example, if an exception causes a simulation to terminate, partial simulation results can still be viewed through the Simulation Animation Window.

Execution Warnings. Setup Warnings are carried through to the output summary screens as Execution Warnings. Thus, these messages reemphasize the need to interpret the results carefully when peculiarities arise in the problem setup. Other Execution Warnings are generated when results fail to satisfy a constraint defined by the scenario data. For example, in the Simulation World the computed flow depth at some distance along a furrow is computed greater than the maximum furrow depth. The simulation engine handles these situations, without further user input, using hydraulic principles (the flow section is extended vertically under the assumption that neighboring furrows are experiencing the same flow conditions). A Warning Message is provided because users may not appreciate the problem, given only the simulation results.

4.4 Data Exchange

WinSRFR supports data exchange using cut/copy/paste and import/export.

1) <u>Within a Single WinSRFR Project</u>

To move data within WinSRFR, use the cut/copy/paste commands to copy and paste entire Fields, World Folders or individual Analysis/Simulation Objects.

2) <u>Between Two WinSRFR Projects</u>

To exchange data between WinSRFR data files, run two instances of the WinSRFR program and open the two files of interest. Use the cut/copy/paste commands to copy and paste entire Field or World Folders or individual Analysis/Simulations.

3) <u>With Other Windows Applications</u>

Cut/copy/paste commands can be used to copy tabular data from a text file or spreadsheet to WinSRFR, or from WinSRFR to spreadsheets/text editor software (see section 4.1.2.2). You can also copy WinSRFR graphical outputs to Windows applications that accept bitmaps, gifs, tiffs, etc.

4.5 Undo/Redo

The Edit/Undo menu command allows the user to restore a scenario to a previous condition. The Undo command only works prior to execution of an analysis. Once the analysis is run, for example by pressing the Run Simulation command in the Simulation World, the sequence of inputs provided to the scenario is erased from memory.

The Edit/Redo menu command serves to restore an input erased by an Edit/Undo command.

Part II. Working with Scenarios

Equation Chapter 5 Section 1This section provides detailed instructions for setting up WinSRFR scenarios, describes the analytical options offered by the application, and provides guidance for the interpretation of results. Subsections are organized according to the functionalities of the program. Each subsection includes an example study. The chapter can be read sequentially. Alternatively, the hyper-links provided below can be used to navigate to the topic of interest. Topics and subtopics:

- Irrigation System Basic Properties
- System Geometry
- Soil/Crop Properties (hydraulic roughness and infiltration characteristics)
- Inflow/Runoff
- Irrigation Event Analyses
- Probe Penetration Analysis
- Merriam-Keller Analysis
- Elliot-Walker Two-Point Analysis
- Design Analysis
- Furrow Design
- Basin / Border Design
- Operations Analysis including:
- Basin / Border / Furrow Operations
- Simulation

5 Defining Basic Properties of the Irrigation System: Common Input Tabs

Basic irrigation system properties needed by any type of analysis (Event Analysis, Simulation, Operations, Design) are defined using the first four World Window tabs, namely:

1) **START**
2) **SYSTEM GEOMETRY**
3) **SOIL/CROP PROPERTIES**
4) **INFLOW/RUNOFF**

These four tabs are referred to as common input tabs in this manual.

5.1 Start

The Start tab is the first tab displayed in a newly created scenario. As an example, Figure 31 illustrates the Start tab for the Physical Design World. **SYSTEM TYPE**, **Required Depth**, and **Unit Water Cost** are inputs required by all Worlds and will be explained in the following paragraphs. Below the common inputs are analytical options specific to each World (in the figure, those options are displayed in the Design Contours frame). These World-specific options will be explained in chapters 6-9.

- **SYSTEM TYPE:** All analyses begin by selecting the irrigation System Type. This selection determines the range of options displayed by other tabs. The remaining tabs do not need to be edited in any particular order. The available choices are:
- **Basin/Border:** Systems in which a field is divided into wide strips separated by berms or dykes. The field elevation fall across each strip is zero or small in comparison with the fall in the direction of flow. Because the width of flow is many times greater than the depth of flow, infiltration can be assumed one-dimensional.
- **Furrow**. Systems consisting of a series of evenly-spaced narrow channels. Since the width of flow in each channel is not much larger than the depth of flow, lateral flow contributes significantly to the infiltration process. Hence, infiltration is assumed two-dimensional.
- **IRRIGATION WATER USE**
- **REQUIRED DEPTH:** The Required Depth is the depth of water needed to replace the soil water deficit. This target is used to calculate application efficiency AE, the ratio of infiltrated water depth contributing to the irrigation target to the average depth of applied water. Event Analysis and Simulation World calculations can be carried out without properly defining the Required Depth, but the analysis will not produce an AE estimate. Operational and Design analyses cannot be executed without first defining a Required Depth.

- **UNIT WATER COST:** The unit water cost is used to calculate the total cost of applied water for an irrigation event. This input is not required for hydraulic calculations, but only as supplementary information.

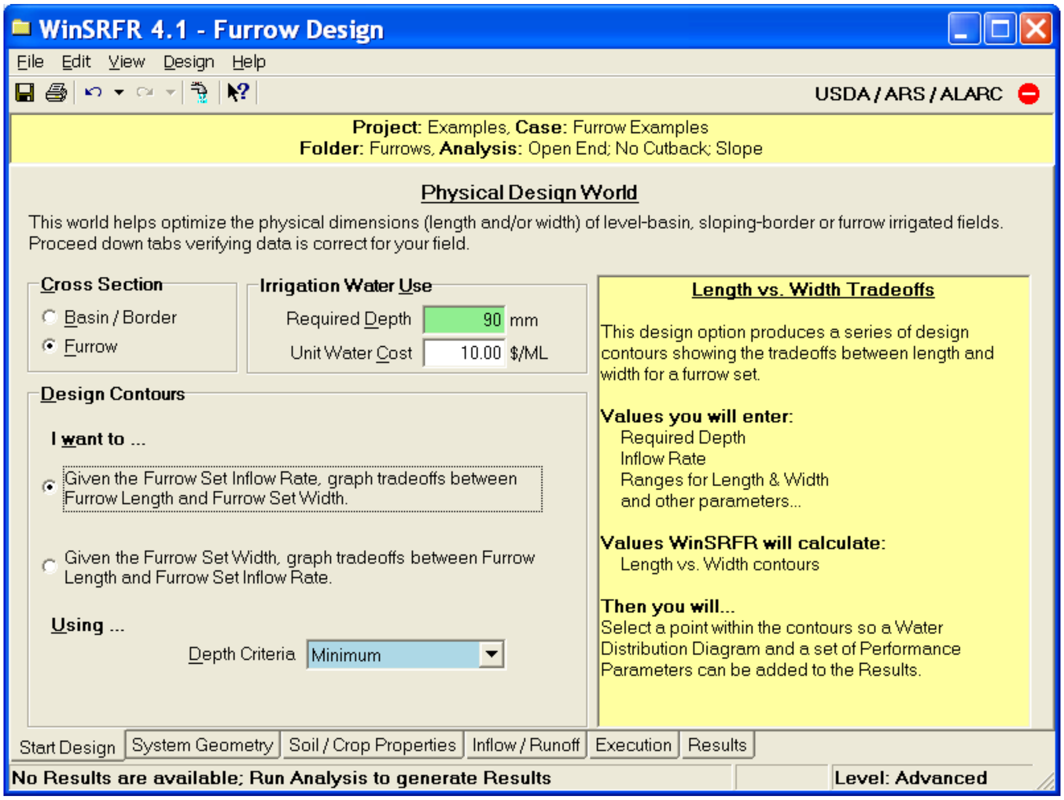


Figure 31. Example Start Tab: Physical Design World.

5.2 System Geometry

The geometry of an irrigation system is defined by its dimensions (length and cross-section), and bottom description. This information is entered using the **SYSTEM GEOMETRY TAB** (Figure 32). Different input controls will be displayed by the form depending on the selected **SYSTEM TYPE**. The Operations Analysis and Design Wolds offer a limited set of system geometry configuration options in comparison with the Event Analysis and Simulation Worlds.

5.2.1 Border/Basin Dimensions

Inputs required to define the dimensions of basins and borders, are shown in Figure 32:

- **Length:** Length of the system in the direction of flow. Current WinSRFR procedures assume one-dimensional flow. Thus, they are most applicable to rectangular irrigation units (borders, basins, and furrow sets). In practice, irrigation units are often not rectangular, but procedures for extending the one-dimensional analysis to two-dimensional systems have not yet been developed. At this time, when dealing with trapezoidal irrigation units, we recommend entering the average, and testing the results using the minimum and maximum field lengths

This input box is not user-editable in the Design World, because field length is an output of the analysis. It initially displays the message TBD (To Be Determined). This is updated after the design produces a set of results.

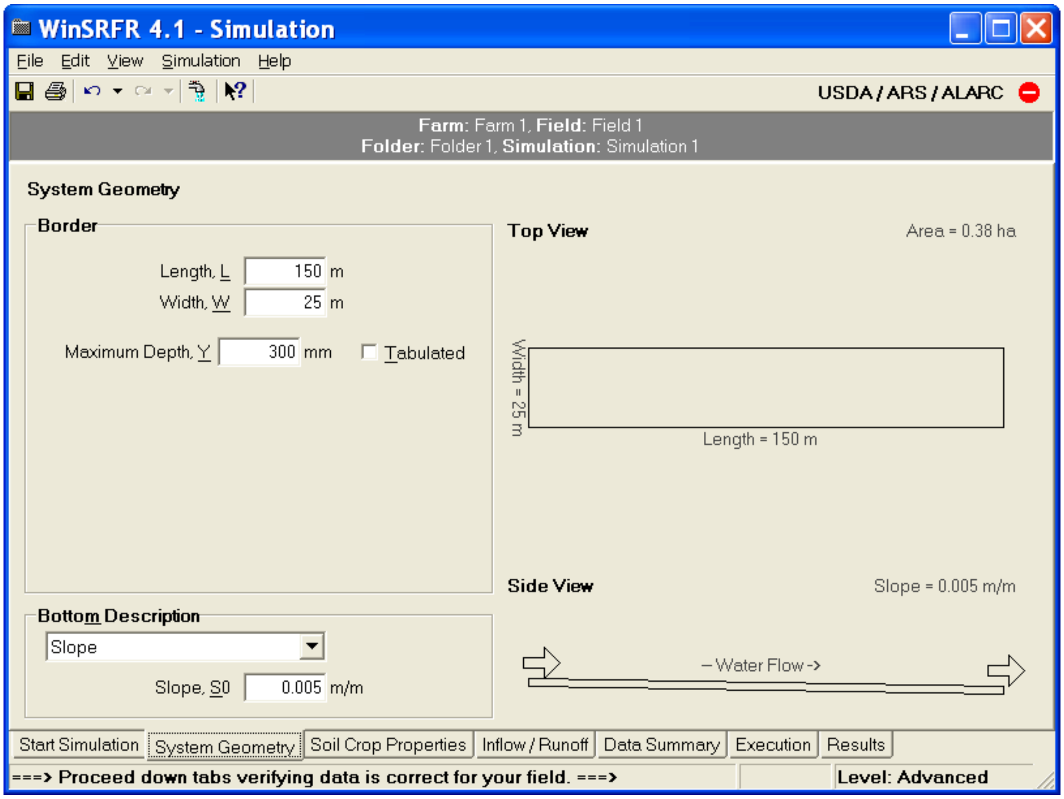


Figure 32. System Geometry tab

- **Width:** This is the breadth of the system, perpendicular to the direction of flow. Besides determining the inflow rate per unit width in a border/basin, this variable is also used to compute the average infiltrated depth (infiltrated volume/unit length/unit width). The Border Width control is disabled in the Design World if the selected design option is to compute the Length and Width of the system for a given inflow rate.

- **Maximum Depth:** This is the maximum depth of flow, defined by the height of the basin/border berms. This parameter has no effect on WinSRFR calculations[1], but the application issues a warning when the computed flow depth exceeds this value because the calculated performance measures are unreliable. Results may still be useful, if the overflow condition lasts for a relatively short time. Use the Simulation Animation Window to inspect the evolution of the surface flow profile in relation to the given Maximum Flow Depth.

[1] The simulation engine allows the calculations to continue by extending the channel vertically. See the WinRFR Technical Reference for more details.

5.2.2 Furrow Dimensions

- **Length:** Length in the direction of flow. See comments for border length.
- **Spacing:** This is the distance between furrow centers. Furrow spacing is used to compute the average infiltrated depth (volume/unit length/unit width) in the irrigated field. Thus, when modeling a furrow system in which every other furrow is irrigated, twice the nominal furrow spacing should be entered, to calculate a representative average application depth
- **Number per set:** This input is the number of furrows in an irrigation set and must be given as an integer value. WinSRFR divides the total inflow rate by the number of furrows per set to obtain the unit inflow rate qin (inflow per furrow). Ultimately, all hydraulic calculations (simulation, event analysis, design, and operations analysis) consider a single furrow. This control is enabled or disabled in the Design World, depending on the selected design option.
- **CROSS-SECTION:** This drop-down list is used to define the shape of the furrow. It offers the following choices:
- **Trapezoid:** With a trapezoidal section, the flow top width TW at a given flow depth Y is given by the relationship

$$TW = BW + 2*Y*SS \tag{1.1}$$

- where BW is the Bottom Width and SS the Side Slope (Horizontal/Vertical). Relationships for flow area, wetted perimeter, and hydraulic radius follow from this definition. Input boxes for the two parameters, BW and SS, will be displayed (Figure 33) when the Trapezoid option is selected. Also, the application will update the Cross Section graph, shown on the bottom-right hand corner of the System Geometry tab.

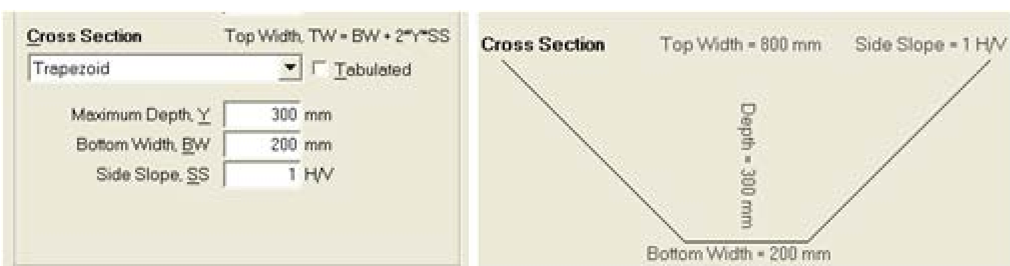


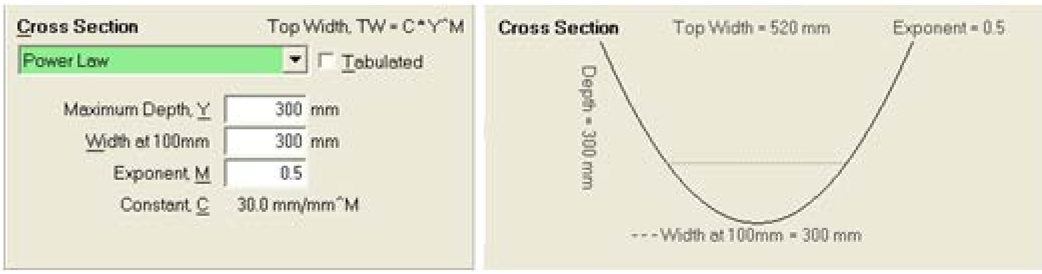
Figure 33. Parameters of a trapezoidal furrow cross section.

- **Power Law:** A power law (i.e., parabolic) section is defined by a relationship of the form

$$TW = C*Y^M \tag{1.2}$$

- where TW and Y are as previously defined, and C and M are empirical parameters. The units of C depend on the units of Y and TW while M is dimensionless. When this option is selected, the form displays controls for the top width value at Y = 100 mm (4 in, if working in English units) and the exponent M (Figure 34) will be used to compute C. The Cross Section graph is updated when making this selection. As with the trapezoidal section, relationships for flow area, wetted perimeter, and hydraulic radius follow from the top width definition.

•



•

Figure 34. Parameters of a parabolic furrow cross section.

- **Trapezoid from Field Data:** This option allows the user to enter field data and calculate the corresponding trapezoidal section parameters. An Edit Data button will appear when this option is selected. Pressing this button will launch the Cross Section Editor, described further below. Upon closing the Cross-Section Editor, the Bottom Width and Side Slope input boxes will display the calculated parameters.
- **Power Law from Field Data:** This option is similar to the previous one, except that it launches the Cross Section Editor with power law options selected.
- **Maximum Depth:** The maximum flow depth, as defined by the height of the furrow walls. A warning will be issued if the computed flow depth exceeds this value. See comments for borders.

Furrow cross-sections cannot be defined precisely. A typical furrow cross-section is irregular and does not exactly conform to the geometric choices offered by the program – trapezoid or power law. Furthermore, the cross-section may vary along the length of run (i.e., the channel is non-prismatic). Despite these limitations, most practical analyses can be conducted by assuming a prismatic channel with a trapezoidal or parabolic cross-section. Research studies may consider a non-prismatic channel. In those cases, the geometric parameters can be varied with distance, but not the cross-section type.

5.2.2.1 Cross-Section Editor

The **CROSS SECTION EDITOR** (Figure 35) is used to compute the furrow cross-sectional parameters from field-measured data. Calculations proceed as follows. The user first identifies the type of cross sectional data available for the analysis. This selection is made with the **FURROW CROSS SECTION DATA** input control The program can handle either furrow width vs. depth data (using the **Width Table** or **Depth/ Width Table** options), or transverse length vs. depth data, in an X-Y coordinate system (**Profilometer Table** option). Next, the user provides the cross-sectional data. Different input controls will be displayed depending on the **FURROW CROSS-SECTION DATA** selection. The data can be entered manually, imported from a text file, or imported via the Windows clipboard. The program automatically fits the data, based on the selected **FURROW SHAPE** (**Trapezoid** or **Power Law**). The program also displays, on the right-hand side of the editor (Figure 35), a graph of the field-measured (thin line) and fitted cross sections (thick line). In the example, the given data are contrasted with a power-law fit. The computed parameters can be accepted at that point if the user is satisfied with the program-generated fit. If the fit is unsatisfactory, then the user can test a different section with **Furrow Shape**, and/or manually modify the computed parameters (with the controls in the **Parameters** frame). Pressing the **Save Data and Close** button closes the Dialog Box, accepts the results, and transfers the computed parameters (and section type, if that option was changed) to the **Geometry Tab**. Specific options are explained next.

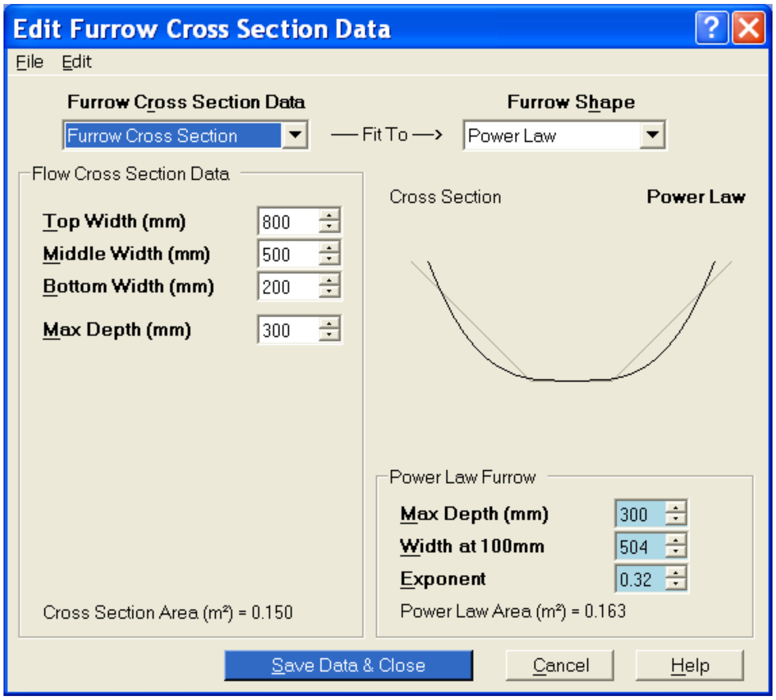


Figure 35. The Furrow Cross-Section Editor, illustrating the determination of cross section parameters from three width values

> **Note:** the following paragraphs employ the term DEPTH to refer to the vertical distance from the furrow bottom to an arbitrary elevation. This definition, then, is equivalent to water depth within the furrow.

- **Furrow Cross Section Data**.
- **Width Table:** This option (Figure 35) requires the user to provide furrow widths (the transverse cross-section length) at the bottom, middle, and top of the furrow. The input controls associated with these values are labeled accordingly in the frame **Width Data**. **Max Depth** is the maximum flow depth given in the Geometry Tab. This is a practical way of characterizing the furrow cross section. Widths do not need to be measured with great precision if several data sets are collected along a furrow, and then averaged. Figure 36 illustrates three measurements of a furrow cross-section that do not exactly conform to a trapezoid or parabolic geometry.
- **Depth/Width Table**: This option is similar to the previous one (Figure 36), except that the user selects the number of data pairs (2 or more), and the depths at which the widths are given. This option should be used if the user has carefully measured depth vs. width data. For practical studies,

measurements should be obtained at various locations and averaged. The Dialog Box displays a table for data entry.

•

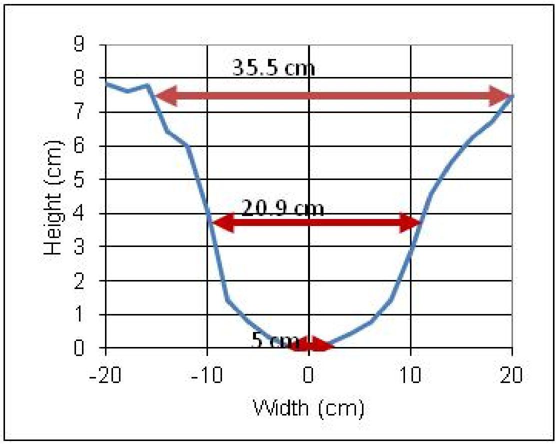


Figure 36. Furrow depth-width data.

Figure 37. Profilometer

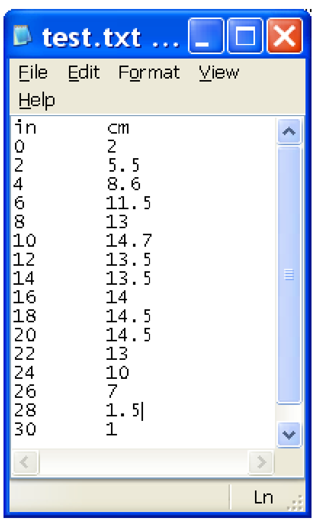


Figure 38. Text file with profilometer data.

- **Profilometer Table:** A profilometer is a device that is used to measure distances from an arbitrary plane above the furrow to the furrow surface. These measurements are taken at multiple points along the furrow width in an X-Y coordinate system (Figure 37). The application refers to the Y values as rod depths and the interval between X values as rod spacing. Profilometer data can be analyzed with this option. Analysis of profilometer data assumes an approximately symmetrical geometry, a coordinate system with the origin in the middle (X) and top (Y) of the furrow, and a constant rod spacing. Hence, X ranges from negative to positive values while Y values are only positive.

The data can be entered manually, imported using copy and paste, or imported from a file. The above described coordinate system needs to be employed when entering data manually. The number of measurements (**No. of Rods**) and the **Rod Spacing** need to be entered prior to entering the rod depths. Data can be imported with a different coordinate system, for example, with the origin at the left, bottom corner. The application will then make the necessary transformations.

Figure 38 is an example of a text file with profilometer data ready for import. In the example, the X values are given in inches and the Y values in cm, as indicated by the column labels, and the X origin is at the left. If the rod spacing is not constant, the data will not import correctly. If the application fails to determine the correct rod spacing from the data, that value will have to be corrected manually in the **Rod Spacing** input box (Figure 39). In cases where the Y data is inverted, the application will issue a warning, import the data, and convert it to a coordinate system compatible with its calculations.

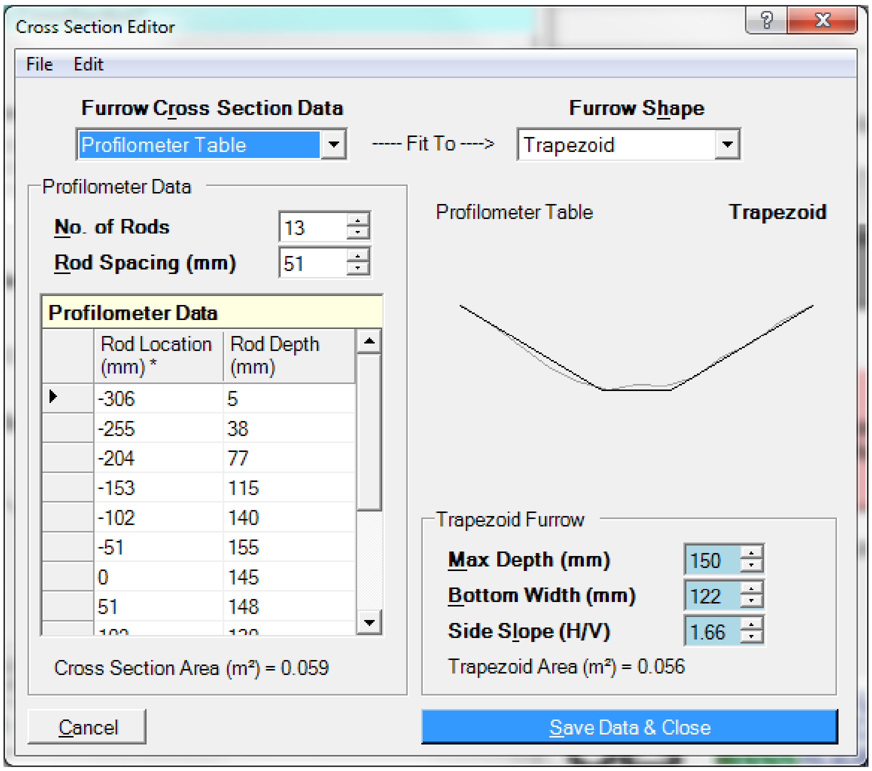


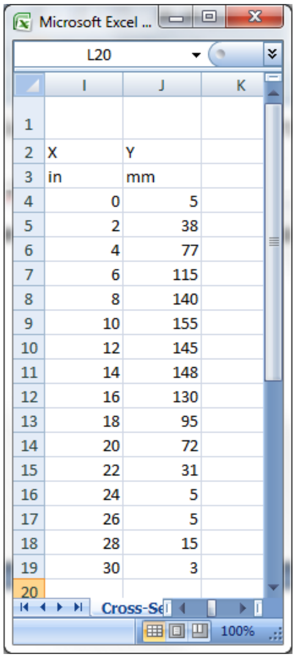
Figure 39. Cross-Section Editor showing imported profilometer data.

5.2.2.2 Profilometer Examples

The following examples are included in the Cross-Sections.srfr file and the Cross-sections.xls file.

Cross-section 1

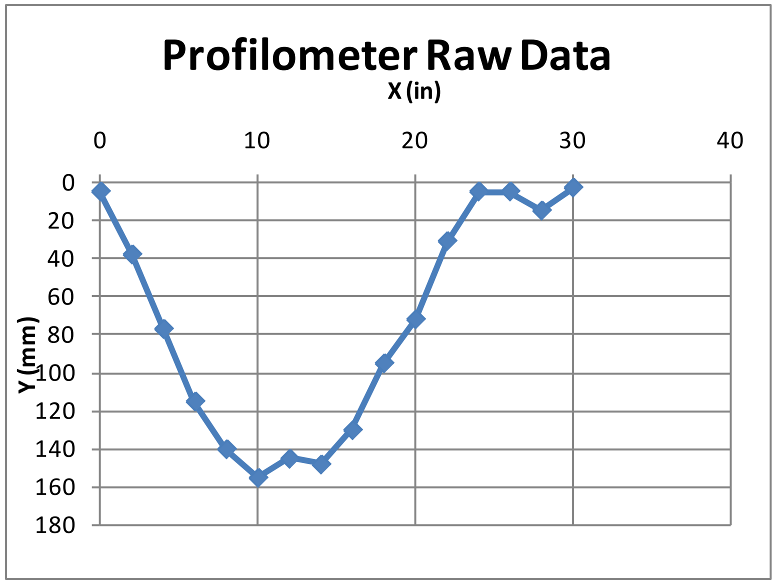
The data for this example are illustrated in the following two images:



Microsoft Excel ...

L20

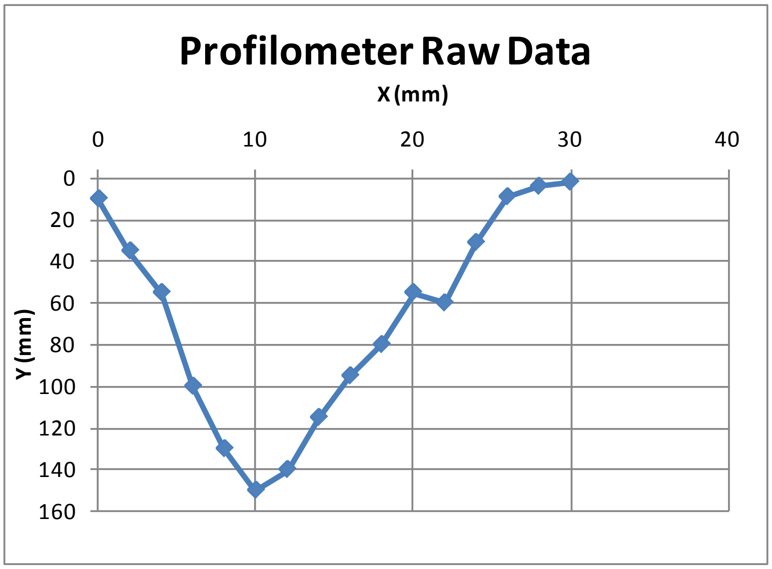
	I	J	K
1			
2	X	Y	
3	in	mm	
4	0	5	
5	2	38	
6	4	77	
7	6	115	
8	8	140	
9	10	155	
10	12	145	
11	14	148	
12	16	130	
13	18	95	
14	20	72	
15	22	31	
16	24	5	
17	26	5	
18	28	15	
19	30	3	
20			



Enter the raw data (with unit labels) into the profilometer data table. For this example, the profilometer had its horizontal scale marked in inches and the vertical one in centimeters. The data can be imported from a spreadsheet (or text file) in combined units if the table has unit labels in the first row. The software will issue a warning indicating that it cannot fit the data satisfactorily due to the irregularity of the data. From the photo and the plotted data, it should be clear that the right three points belong to the furrow bed. Eliminate the last three rows to make the data more symmetrical. The software will adjust the center of the furrow with the remaining data and find the best fit parameters. These data are as well described by a parabolic or trapezoidal shape.

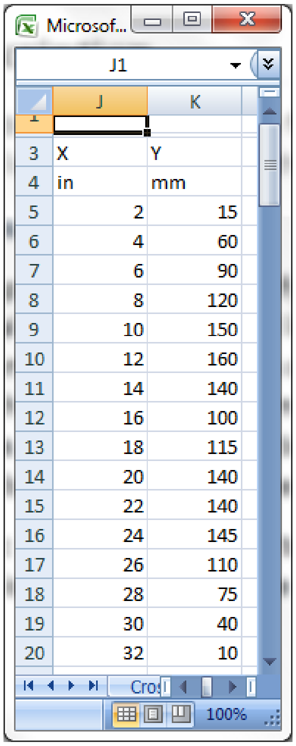
Cross-section 2

	X	Y
3	in	mm
4	0	10
5	2	35
6	4	55
7	6	100
8	8	130
9	10	150
10	12	140
11	14	115
12	16	95
13	18	80
14	20	55
15	22	60
16	24	31
17	26	9
18	28	4
19	30	2

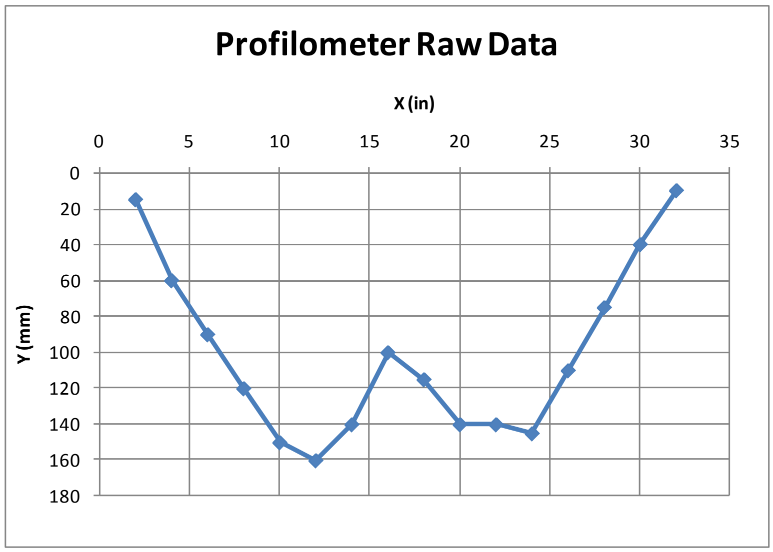


These data are more irregular than those Cross-section1. The furrow is clearly non-symmetrical. Enter the data in the table. The program issues a warning. Eliminating the last five points makes the more symmetrical, but the fit is still not as good as with the example of the previous page. The data is better described by a parabola than by a trapezoid.

Cross-section 3



	J	K
3	X	Y
4	in	mm
5	2	15
6	4	60
7	6	90
8	8	120
9	10	150
10	12	160
11	14	140
12	16	100
13	18	115
14	20	140
15	22	140
16	24	145
17	26	110
18	28	75
19	30	40
20	32	10



The raw data can be fitted to a trapezoid. This initial fit is identified in the SRFR file and the accompanying Excel file as Cross-Section_A. The furrow has a hump in the middle and at small flow depths, this irregularity will cause substantial errors in the calculated flow area. An approximate geometry can be developed by considering three separate flow sections and then fitting the resulting flow areas as a function of depth to a trapezoid. Calculations are explained in the Cross-sections.xls spreadsheet.

5.2.3 Bottom Description

Five options are available for describing the field bottom. These are accessible using the **Bottom Description** drop-down list. The options are the same for furrows as for basins/borders.

- **Bottom Description**:
- **Slope:** This option is used to specify a constant average slope for a field. The slope can be entered as total vertical drop / field length or as total vertical drop per 100 units of field length (for example, in the U.S., it is customary to specify slope as ft/100ft). Click on the units label to change the unit system used for input. An input box will be displayed to enter the slope value. This is the only option displayed in the Physical Design or Operational Analysis Worlds, as those procedures assume a constant bottom slope.
- **Slope Table:** This option is used to enter a table of longitudinal distances vs. slope. The table can consist of a single row, the slope at distance zero. Additional rows are locations where the slope changes. The Edit Table button appears when this option is selected. Pressing the button launches

the Slope Table dialog. See section 4.1.2.2 for more information on how to work with Data Tables. The Slope Table option is available only in the Event Analysis and Simulation Worlds. Procedures in the Design and Operational Analysis Worlds only allow a constant field bottom slope.

- **Elevation Table:** This option is used to enter a table of vertical field elevations vs. distance. Each row in the table represents a surveyed elevation-distance pair. At a minimum, elevations at the upstream and downstream ends of the field are entered with the downstream location matching the stated field length. The simulation engine interpolates field elevation at the points between survey stations. As with the Slope Table, elevation values are edited in the Elevation Table dialog, an option available only for Event Analyses and Simulations.

- **Average From Slope Table:** This option assumes a constant average slope for the field. Its value is computed from a user-entered table of slope values , as in option (2). After entering a Slope Table, the user can switch at any time between this option and the Slope Table option, but only in the Event Analysis and Simulation Worlds.

- **Average From Elevation Table:** This option assumes a constant average slope for the field. Tabular data is entered as in the Elevation Table option (3). The user can switch at any time between this option and the Elevation Table option when operating in the Event Analysis or Simulation Worlds.

5.2.4 Advanced/Research Options

Basins/ Borders:

- **Tabulated:** This option is available for simulation only. Check this box if the berm height is variable with distance. Use the Border Depth Table to specify the variation in maximum depth as a function of distance.

- **BORDER DEPTH TABLE**. This table is displayed when the Tabulated box is checked. Maximum depth needs to be specified at least at the upstream end of the field. The application assumes a linear variation in depth between locations with a specified depth.

Furrows:

- **Tabulated:** This option is available for simulation only. If checked, it enables modeling non-prismatic furrows. The application displays the **CROSS SECTION TABLE** when this box is checked.

- **CROSS SECTION TABLE:** This table is used to specify the location of changes in cross-section, and the corresponding cross-sectional parameters. Only one cross-section type (trapezoid or power law) is allowed when using tabular data. The application assumes a linear variation in cross-section in between locations with a cross-section definition. The cross-section needs to be defined at least at the upstream end of the field.

  The **CROSS-SECTION TABLE** can be used in combination with the **EDIT CROSS SECTION DATA** dialog box to define furrow cross-sectional parameters from field data at selected locations. To do this, right-click on the location for which geometric parameters will be calculated. Then, select the `Cross-Section from Field Data` option in the context menu. Details on using the cross-section editor are provided further below. When specifying tabular cross sectional data in combination with the Edit Cross Section Data dialog box, the software saves the resulting geometric parameters but not the input data for each location. Those inputs should be saved to a text or spreadsheet file if they are to be preserved for future use.

5.3 Soil / Crop Properties

The Soil / Crop Properties tab is used to specify the field's hydraulic roughness and infiltration characteristics. The configuration options displayed by this tab depend on:

- The system type (furrows vs. basins/borders) – different infiltration options are available for basins and borders as opposed to furrows; hydraulic roughness options are the same for both system types
- The World that the user is working in – The Event Analysis, Operational Analysis, and Design Worlds offer a limited set of configuration options in comparison with those available for the Simulation World. Infiltration is an output of Event Analysis and is not a configuration option.
- The User Level - The Research level includes options that are for research purposes only.

5.3.1 Hydraulic Resistance

The soil surface and submerged vegetation exert a resistive drag force on the flowing water. WinSRFR calculates this drag force by the formula,

$$S_f = {V|V|}\big/{C^2 R} \tag{1.3}$$

In this expression, S_f is the friction slope, i.e. the resistive drag force divided by the weight of the stream, each per unit length of channel. Under typical surface irrigation conditions, S_f is equal to the slope of the water surface; it is proportional to the flow velocity V, and inversely proportional to the hydraulic radius R (area divided by wetted perimeter, a measure of their relative importance), and an empirical parameter describing the roughness characteristics of the channel, the Chezy coefficient C.

5.3.1.1 Standard options

The default method for calculating C in WinSRFR is with the Manning formula,

$$C = c_u R^{1/6} / n \tag{1.4}$$

in which the user provides a value for the empirical roughness coefficient n. The user can select n from a predefined list of values recommended by the USDA-NRCS surface irrigation design guides. Those values are displayed as option buttons (**NRCS Recommended Value**) in the Roughness frame. Alternatively, a locally calibrated value of n can be provided in the **User- Entered Value** input box.

The Manning n has dimensions of length to 1/6 power, but the same numerical value is used when working in either English or metric units. Conversion to appropriate units is accomplished with the constant c_u. This and other inputs are provided by the simulation engine as part of the calculations.

Typical calculations with the Manning formula assume that n encompasses the effect of soil-surface and vegetation drag on the irrigation stream. Large values of n imply a large friction slope and, therefore, large flow depths for the same flow rate. The value of n is assumed to be a function of the surface characteristics, and thus independent of flow rate and depth.

The Manning formula is used exclusively by the Event Analysis, Operations Analysis, and Physical Design Worlds, and is the only option available for Standard and Advanced Users in the Simulation World. Research-level users have access to more options.

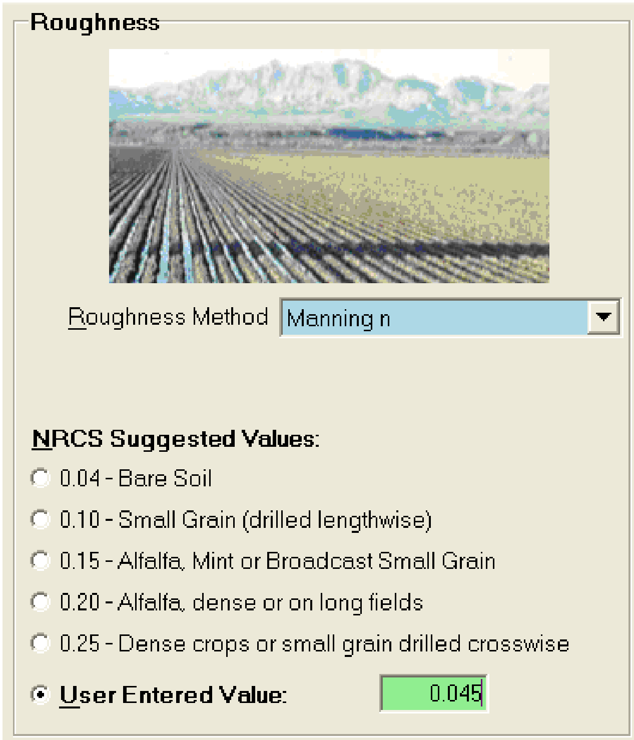


Figure 40. Calculation of hydraulic resistance with the Manning formula

> **NOTE:** The Two-Point Method is the only Event Analysis procedure that uses the Manning n for calculations. The Merriam-Keller method does not use n, but requires a reasonable estimate of the parameter in order to verify the results via simulation. An n value is not required for the Probe Penetration Analysis, unless the data is copied to another World for further analysis.

5.3.1.2 Advanced Options

- **Tabulated:** This check-box control allows the user to specify spatial variations in roughness with distance. This option can be used, for example, to model situations where there are substantial variations in vegetation density along the field. If enabled, the Roughness frame will display the Tabulated Roughness control. This table is used to specify roughness coefficient values as a function of distance. When the Tabulated

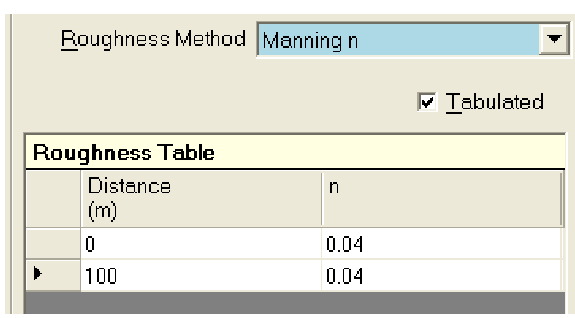


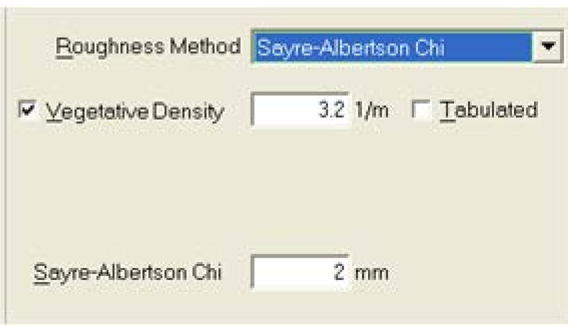
Figure 41. Modeling variable roughness with the Tabulated option.

Roughness table is first launched, it displays a roughness value at the field inlet (distance = 0). This value applies to the entire length of the field, unless a new roughness coefficient is indicated at a given distance. New values apply from the specified location up to the next roughness location or to the end of the field.

-

The table works with any roughness formulation but only one formulation can be used for a simulation. If Vegetative Density is enabled (Research Level option), the user can also specify variations in that parameter. The Tabulate Roughness table cannot be used in combination with the option buttons for specifying recommended values for the Manning n. Those values have to be provided manually.

5.3.1.3 Research Options



Researchers have long recognized that the empirical Manning n varies with flow depth for the soil and vegetation drag characteristics. Hence, the Research User Levels offer additional hydraulic roughness calculation options, which are attempt to model the effect of flow depth on hydraulic resistance. Practical experience with these options is limited.

Figure 42. Research options for calculation of hydraulic resistance.

- **ROUGHNESS METHOD:**
- **Power Law Manning Formula**: Option 2 calculates C much like option 1, but allows the Manning n value to vary as a power law of water depth , i.e.,

$$n = C_n * Y^{A_n} \tag{1.5}$$

If this option is selected, the Roughness frame will display input boxes for the empirical parameters Cn and An. Here Cn is a value of the Manning n determined under reference conditions , and An the exponent of the power-law relationship. Options 2 is equivalent to option 1 (Manning) when An = 0.

- **Sayre-Albertson:** The third method for calculating the Chezy C is with the logarithmic Sayre-Albertson relationship.

$$C = 6.06\sqrt{g}\,\log_{10}(R / \mathrm{X}) \tag{1.6}$$

With this expression, the user needs to enter the absolute roughness of the soil surface, given by the variable X (Figure 42). Note that in contrast with the Manning n, X needs to be specified in appropriate length units.

- **Vegetative density:** The soil surface exerts a resistive force only at the flow boundaries. The vegetation exerts additional resistance drag over the entire depth of submergence, depending heavily on the density of growth. This vegetative density (with dimensions of length^{-1}) is measured as frontal cross-sectional area per unit plan area of the flow channel (typically a border strip, or basin) per unit depth. Advanced users can incorporate the drag of submerged vegetation separately from soil drag, if field data are available. This is done by clicking on the Vegetative Density checkbox (Figure 42). This will enable the input box for vegetative density. Evaluation of vegetative drag, which can be substantially greater than the drag of the soil surface, is still in an experimental stage. No guidance can be provided at this time for selecting a value for this parameter.

5.3.2 Infiltration

Infiltration is the process by which water is absorbed into the soil. In a one-dimensional view of the irrigation stream, in which all variables are functions of distance and time only, the pertinent infiltration variable is the volume infiltrated per unit length $A_z(x, t)$ $[L^3/L]$. The simulation engine calculates A_z as

$$A_z = WP \cdot z \tag{1.7}$$

In this expression, WP [L] is the transverse length of the soil-stream interface through which the infiltration takes place, and z is the volume infiltrated per unit length per unit width of the soil surface [L3/L2]. For convenience, WP is identified in the software as the Wetted Perimeter, although it is not always a true wetted perimeter. WinSRFR uses mostly empirical equations to calculate z. With empirical formulations, z is assumed to be a function of opportunity time only (opportunity time is the time that stream water has been present at a particular point along the field). New to WinSRFR 4.1 is the calculation of infiltration with the approximate, semi-physical Green-Ampt equation, used with basins and borders but not width furrows..

Equation (1.7) assumes that water infiltrates in the direction normal to the soil surface. This is a reasonable assumption in border strips and basins; then, water infiltrates essentially vertically, direction only and the WP is constant and equal to the border/basin width W. Eq. (1) represents furrow infiltration less adequately because of the contribution of horizontal flow to total infiltration, and because WP varies with distance and time as the depth of the stream rises and falls with the passage of the stream. Options for calculating z and WP are discussed in the following paragraphs, along with the uses and limitations of these options.

Infiltration conditions are specified in WinSRFR, by

- Selecting an Infiltration Function (a method for calculating z) and entering values for the parameters of the selected formula.
- With furrow irrigation, selecting an approach for calculating Wetted Perimeter.
- Most irrigation analyses assume spatially uniform infiltration conditions, but new in WinSRFR 4.1 is the ability to model variations in infiltration properties along the field. This is done with the Tabulated checkbox control.
- A hardpan soil layer will limit the depth of infiltrated water. This effect can be modeled with the Limiting Depth Option.

Controls for these inputs are displayed on the right-hand side of the Soils and Crops tab page (Figure 43). The form also displays a graphical representation of the infiltration function and the time needed to infiltrate the required infiltration depth. These controls are displayed for Simulation, Operational Analysis and Physical Design. They are not displayed, for Event Analyses because Infiltration is an unknown and an output of the analysis (the Event Analysis World displays controls for infiltration parameters in the Execution Tab). The infiltration calculation concepts discussed in the following paragraphs apply to all WinSRFR Worlds.

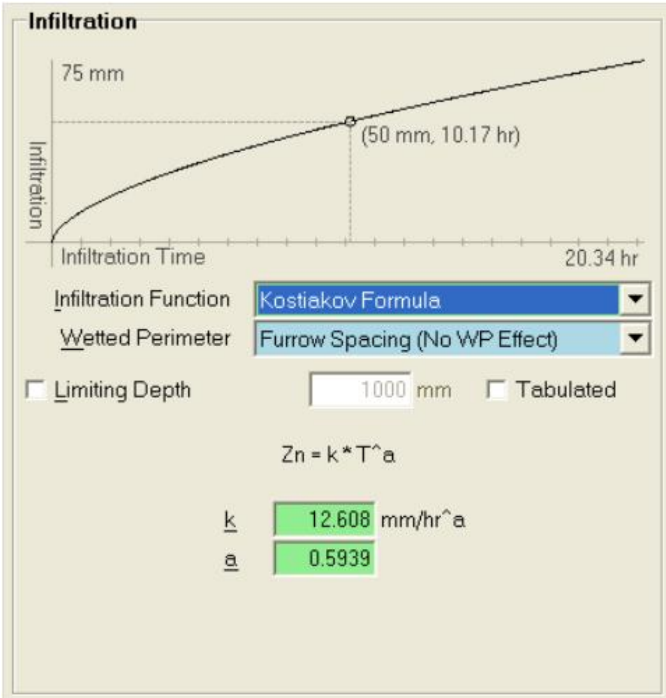


Figure 43. Inputs needed to define infiltration conditions.

5.3.2.1 Infiltration function

Table 6 lists the formulations used by WinSRFR to calculate z. Required parameters and their dimensions (in square brackets) are also listed in the table. The **INFILTRATION FUNCTION** drop-down control is used to select a formula. Input boxes for the corresponding parameters are displayed in accordance with the selection. If the selected infiltration option is an NRCS Intake Family, option buttons are displayed instead. Parameter values must be provided in the units indicated next to the input boxes. Where appropriate, units for these inputs can be changed by right-clicking on the units label, as described in Section 4.1.2.1. Comments on the infiltration depth formulations follow.

- **Kostiakov Formula:** Equation (1.8) is widely used in irrigation studies. The parameters for this expression (**k**, **a**) are derived from field infiltration evaluations and are empirical. This expression will model a declining infiltration rate with time if the exponent **a** is restricted to $0 < a < 1$. This restriction on the value of **a** applies as well to variations of the Kostiakov relationship, namely Eqs. (1.9)-(1.14). The parameter k has dimensions of length/time^a. Typical units for k are in/h^a or mm/h^a.
- **Modified Kostiakov Formula:** The Kostiakov equation.(1.8) can represent the process inaccurately at long times in soils with a well-defined steady-state infiltration rate. This problem can be overcome by adding to it the product bτ. In principle, b represents the long-term infiltration rate. In practice, b is a fitting parameter determined from infiltration measurements. The equation is commonly identified in the literature as the Kostiakov-Lewis equation. In many field situations, infiltration is dominated by water flow through cracks and macropores. To account for this effect, the Kostiakov equation was further modified in the SRFR program (Strelkoff et al., 1998) by adding a constant c. The infiltration represented by c is assumed to take place instantaneously. This

document and the software refers to this combined expression as the Modified Kostiakov formula (1.9). Thus, inputs that need to provided are $\mathbf{k}$, $\mathbf{a}$, $\mathbf{b}$, and $\mathbf{c}$. These inputs need to be provided in consistent units.

Table 6. Infiltration formulas used by WinSRFR

Name	Formula	Eq. Number	Inputs
Kostiakov (Kostiakov, 1932)	$z = k\tau^a$ in which τ = opportunity time	(1.8)	k [L/T^a] – constant a [.] – exponent
Modified Kostiakov (Mezencev, 1948; Strelkoff et al., 1998)	$z = k\tau^a + b\tau + c$	(1.9)	k [L/T^a] - constant a [.]- exponent b [L/T] – steady infiltration rate c [L] – instantaneous infiltration depth (through cracks and macropores)
NRCS Intake Family (USDA-SCS, 1974; USDA-SCS, 1984)	$z = k\tau^a + c$	(1.10)	Family number (selected with option button).
Characteristic Infiltration Time	$z = k\tau_c^a$	(1.11)	τ_c [T] – characteristic infiltration time, the time needed to infiltrated z_c z_c [L] – characteristic infiltration depth (typically, the required application depth Dreq) a – exponent
Time-Rated Intake Family (Merriam and Clemmens, 1985)	$z = k\tau_{100}^a$ in which $a = 0.675 - 0.2125 \log_{10}(\tau_{100})$	(1.12) (1.13)	τ_{100} [T] – characteristic infiltration time for a depth of 100 mm (4 in) .
Branch (Clemmens, 1981	$\begin{cases} z = k\tau^a + c, & \tau \le \tau_b \\ z = z_b + b\tau, & \tau > \tau_b \end{cases}$	(1.14)	k [L/T^a] a [.] b [L/T]

			c (L)
Green-Ampt (Green and Ampt , 1911)	$z = \tau K_s + \Delta\theta\Delta h \ln\left(1 + \frac{z}{\Delta\theta\Delta h}\right) + c$ in which $\Delta\theta = \phi - \theta_0$, $\Delta h = h_s - h_f$, h_s = ponded depth	(1.15)	Φ (L/L) – Effective porosity θ_0 (L/L) – Initial water content h_f (L) – Wetting front pressure head K_s (L/T) – Hydraulic conductivity C (L) – Instantaneous infiltration depth (through cracks and macropores)

- **NRCS Infiltration Families:** The former USDA- Soil Conservation Service, SCS proposed the use of the infiltration family concept as a way of categorizing infiltration behavior for similar soils (USDA-SCS, 1974; USDA-SCS, 1984). The corresponding infiltration equation is given by Eq.(1.10), in which k and a are specific to each family but c is constant for all families (7 mm or 0.28 in. in English units). Because of the similarity between the infiltration families presented in the 1974 and 1984 publications, WinSRFR combines them into a single set. A family number is selected using option buttons. The values of the parameters displayed on the form depend on the selected unit system.

- **Characteristic Infiltration Time:** The characteristic infiltration time concept is based on the premise that the opportunity time needed to infiltrate application requirement Dreq, or some other convenient application target, determines to a greater extent the final water distribution and the performance of an irrigation event. Thus, if a reasonable estimate for the opportunity time is available, it can be used to derive an approximate infiltration function for a particular analysis. Such estimate may be available from experience on that particular field. WinSRFR implements this concept using the Kostiakov relationship. The user specifies the opportunity time (**Characteristic Infiltration Time**, τ_c,) the **Characteristic Infiltration Depth**, z_c, (Dreq or another convenient depth value), and a value for the exponent **a** for Eq. (1.11) (gleaned from previous experience with soils in the area). The parameter k is calculated by the program, in appropriate units.

> NOTE: The Characteristic Infiltration Time concept can be used with any infiltration formulation to obtain an approximate infiltration function with uncertain parameter values. The concept is used in the Operations Analysis and Physical Design chapters

- **Time-Rated Intake Family:** This formulation is similar in concept to the Characteristic Infiltration Time, but applies exclusively to a target depth of 100mm (4 in). The **Characteristic Infiltration Time** t_{100} (in hours) is the only input that needs to be provided. The exponent a is calculated with Eq. (1.13), and is then used to determine the constant k. Equation (1.13) is empirical and was derived from an analysis of multiple field-measured-infiltration data sets, as with the NRCS family.

- **Branch Function:** The Modified Kostiakov equation implies a continuous decay in infiltration rate. In some soils, the infiltration rate decreases over a relatively short time, and then becomes constant. This behavior can be modeled with the Branch Function, which as shown by Eq. (1.15), consists actually of two functions. The branch time τ_b is the time at which the rate predicted with the first branch matches the constant final infiltration rate, b, of the second branch. The program calculates τ_b from the user provided values for **k**, **a**, **b**, and **c**. These parameters need to be given in consistent units.

- **Green-Ampt:** The Green-Ampt formula, Eq. (1.15), was derived from the principles of flow in porous media (Green and Ampt, 1911, Warrick, 2003). It applies to cases of one-dimensional infiltration, namely borders and basins. The formulation used by the software assumes a homogeneous texture and uniform initial water content. Required inputs are displayed in Figure 44.

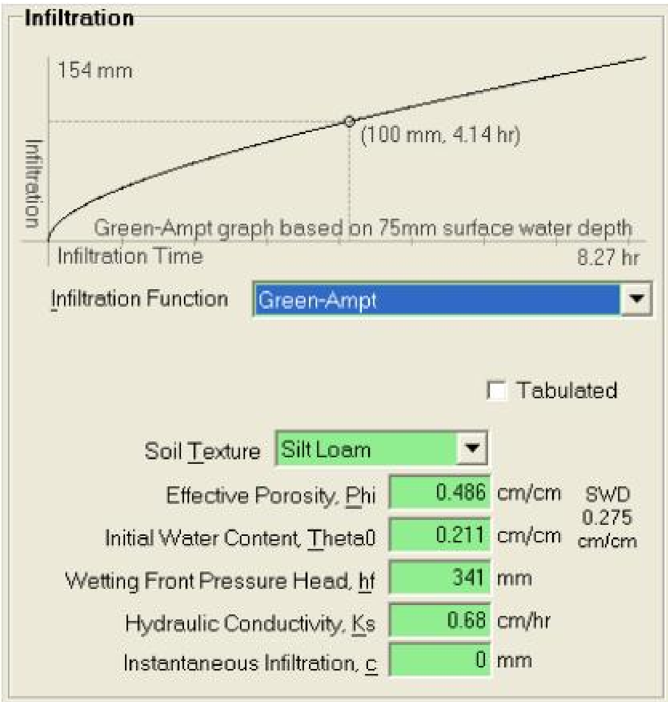


Figure 44. Inputs for the Green-Ampt infiltration formula.

- **Effective porosity:** This parameter is defined as the total porosity minus the residual water content, expressed volumetrically (volume/volume).
- **Initial Water Content:** Volumetric water content of the dry soil. The difference between the Effective Porosity and the Initial Water Content is the soil water deficit (volume/volume).
- **Wetting Front Pressure Head:** This parameter is a measure of the suction exerted by the soil at the boundary between the wet and dry soil. Several authors have proposed that it be calculated as weighted average of the soil pressure vs. hydraulic conductivity relationship (Bouwer, 1964; Morel-Seytoux and Khanji, 1974; Neuman, 1976). Enter this value as a pressure head (pressure/specific weight of water = length).
- **Hydraulic Conductivity**. Conductivity through the saturated soil profile. Because of the effect of air entrapment, this value is often assumed to be half of the saturated hydraulic conductivity (Bouwer, 1966). This parameter has dimensions of length/time.
- **C:** As in empirical infiltration formulations, the parameter c in the Green-Ampt method represents an infiltration depth (a length) attributable to cracks and macropores. Typical Green-Ampt calculations do not include this parameter. WinSRFR uses this value to offset the infiltration opportunity time used in the calculations, under the assumption that the infiltration rate will be reduced by this initial instantaneous infiltration depth. For details on this assumption and the implications for Green-Ampt predictions see Clemmens and Bautista (2009).
- **Soil Texture:** Whenever possible, Green-Ampt parameters should be determined for the specific conditions at hand, supported by field data. In the absence of measurements, the Soil Texture drop-down control can be used to display estimates for the parameters from general knowledge of the

soil texture (see Note below). The values displayed by the Soil Texture drop down control were derived from Rawls et al. (1982) (see also Kozak and Ahuja, 2005). The Effective Porosity (Phi) and Wetting front Pressure (hf) are average values originally reported in those publications. The hydraulic conductivity is the reported average value for saturated hydraulic conductivity divided by 2, as explained earlier. The value displayed for initial water content is the midpoint between the water content at field capacity (-1/3 bar soil pressure head) and permanent wilting point (-15 bar).

If percent sand, silt, and clay information is available for a location, estimates for the Green-Ampt parameters can be derived using the relationships proposed by Saxton and Rawls (2006).

5.3.2.2 Wetted Perimeter

WETTED PERIMETER: This drop-down list (Figure 45) displays the four methods offered by WinSRFR for calculating the effect of wetted perimeter on furrow infiltration. Furrow Spacing (option 1) is the primary (and default) method. It is available to Standard and Advanced Users and is the only method currently available for Event Analyses, Operational Analyses, and Physical Design. The Simulation World offers all four methods.

In the Simulation World, the choices offered by the program for calculating WP depend on the method selected to calculate z. If more than one method is offered, the user has to make the selection based on the available data, specifically the method used to measure furrow infiltration and the parameters of the selected infiltration function. The program has a default option for calculating WP for each z calculation method. Significant judgment is required if selecting an alternative method.

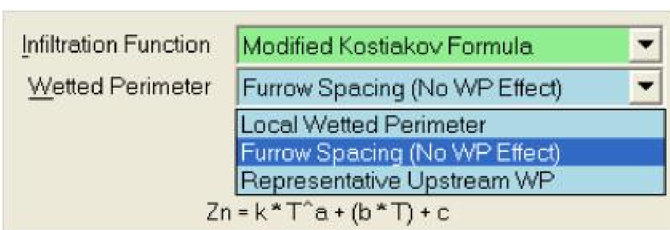


Figure 45. Wetted perimeter options for furrow infiltration calculations.

-
- **Furrow spacing:** Most furrow-infiltration evaluation methods, including those used by WinSRFR (Merriam-Keller and Elliot-Walker Two-Point Methods), compute Az [L^3/L] directly, instead of using Eq.(1.7) (i.e., independently of the width of the actual infiltrating surface). The reason is that field data needed to characterize wetted perimeter variations with time and along the field, and their influence on infiltration, are typically not collected. As a result, furrow irrigation models (e.g., SIRMOD - Walker, 2003) typically require that infiltration conditions be specified directly, i.e., as Az. For example, if the Modified Kostiakov function is used to fit the infiltration data, the resulting function is of the form

$$Az = K\tau^a + B\tau + C \tag{1.16}$$

The dimensions of the uppercase parameters K, B, and C are, then, [L^2/T^a], [L^2/T], and [L^2], respectively, in contrast with the dimensions of the lowercase parameters k, b, and c in Table 6, WinSRFR uses the above-described approach as the primary method for representing furrow infiltration. To make the data entry compatible with Eq.(1.7), AZ is represented as the product of furrow spacing and z. The parameters of z (k, b, c) then, are simply the parameters of Az divided by furrow spacing (except for the dimensionless parameter a). The Merriam-Keller and Two-Point procedures in the Event Analysis World use this calculation to derive the parameters for z. The calculation has to be done manually by the user if an infiltration function is derived with different software or from published results.

Use of the above-described approach for modeling furrow infiltration neglects the effect on the infiltration process of varying wetted perimeter with time and distance along the furrow. The assumption is reasonable when depth variations along the furrow are expected to be small (as in blocked-end furrows, or in graded furrows with a large runoff rate relative to the inflow rate). Note, however, that an infiltration function derived for a particular spacing cannot be extrapolated to other furrow spacing conditions, i.e., we cannot simply divide by the original spacing and multiply by a new spacing. Embedded in the parameters are lateral-infiltration effects that depend on the original spacing conditions.

- **NRCS empirical wetted perimeter:** The NRCS infiltration families were originally developed for border/basin irrigation (with dimensions of volume/unit length/unit width). They were adapted to furrow irrigation by assuming a linear relationship between one- and two-dimensional infiltration, with an empirical wetted perimeter WP_{NRCS} as the proportionality constant (USDA-SCS, 1984; Walker et al., 2006; Strelkoff et al., 2009):

$$A_z = z \cdot WP_{NRCS} = z(WP_g + \Delta WP) \tag{1.17}$$

The empirical wetted perimeter WPNRCS has two components. WP_g is an approximation to the geometric wetted perimeter at the inlet, and thus is a function of inflow rate Q, bottom slope S_0, and Manning roughness n. The term ΔWP is a constant equal to 0.213 m (0.7 ft) that attempts to account for horizontal infiltration, in addition to the infiltration that occurs in the direction normal to the infiltrating surface. With this formulation, the relative contribution of horizontal infiltration diminishes as the flow becomes wider and deeper. This is consistent with the actual behavior of infiltration in furrows. This formulation is supported by the study of Fangmeier and Ramsey (1978) and more recent studies on infiltration from strip sources (Warrick and Lazarovitch, 2007; Warrick et al., 2007).

The NRCS Empirical Wetted Perimeter does not use a measured wetted perimeter as WPg, but instead relies on the following approximate relationship.

$$WP_g = c_1 \left(\frac{Qn}{S_0^{0.5}} \right)^{0.4247} + c_2 \tag{1.18}$$

In this expression c_1 and c_2 are constants that depend on the system of units. Equation (1.18) was developed to facilitate calculations, based on typical furrow geometries - bottom widths between 0.06 and 0.15 m (2.4 and 6 in), side slopes (H/V) between 1:1 and 2:1 (USDA-SCS 1984), WinSRFR interprets Q as the average discharge rate over the total period of inflow, except in cut-back scenarios in which -- like in the original USDA-SCS publication -- before- and after-cutback values are inserted in the formula -- with consequent reductions in wetted perimeter after cutback. Likewise, the bottom slope that WinSRFR enters in the formula is the average bottom slope for the entire length of run. For zero slope cases, S0 is replaced with an empirical estimate of the friction slope Sf (USDA-SCS, 1984):

An important limitation of the NRCS empirical Wetted Perimeter is that geometric wetted perimeters can vary substantially within the range of geometry data, while Eq. (1.18) computes the same value for any geometry with a given Q, S_0, and Manning n (Perea et al., 2003). Clearly, Eq. (1.18) should not be used outside the original data range. Another limitation is that it was developed for sloping furrows and is not well suited for small slopes. Despite these limitations, these procedures were implemented in the WinSRFR software because they are supported by field-measured data and continue to be used by NRCS personnel in combination with the infiltration families.

- **Representative Upstream Wetted Perimeter:** Like the NRCS option, this method assumes a linear relationship between one- and two-dimensional infiltration, but with the actual upstream wetted perimeter as the proportionality constant. The method does not account for lateral infiltration but includes well-defined procedures for calculating the upstream flow depth and wetted perimeter at zero and small slopes (Bautista et al., 2009a). This approach is essentially equivalent to the method presented by Walker et al. (2006) for adjusting furrow infiltration parameters on the basis of parameters computed at a reference flow rate (and wetted perimeter). That adjustment is based on a relationship of the form

$$Z = Z_r \left(\frac{WP}{WP_r} \right)^b \tag{1.19}$$

in which Zr is the infiltration relationship derived at a reference flow rate with WPr the corresponding wetted perimeter. Walker et al. (2006) assumed b =1. However, results presented by Blair and Smerdon (1985) suggest b > 1 while those of Oyonarte et al (2002) suggest b < 1. In the absence of additional guidance, WinSRFR currently assumes b = 1.

- **Local wetted perimeter:** This method intends to account for flow depth variations in time and space in calculation of Az (Bautista et al., 2009a). It computes the incremental infiltration $\delta Az_{i,j}$ in the course of a time step Δt_j at a particular location x_i as the product of the increment in z and the current wetted perimeter, averaged over the time step $\overline{WP}_{i,j}$.

$$Az_{i,j} = Az_{i,j} + \delta Az_{i,j} = Az_{i,j} + \left\{ z(\tau_{i,j}) - z(\tau_{i,j-1}) \right\} \cdot \overline{WP}_{i,j} + c\left(WP_{i,j} - WP_{i,j-1} \right) \tag{1.20}$$

The last term applies only when $WP_{i,j} > WP_{i,j-1}$. Use of this formula is presently limited because the parameters of z cannot be readily estimated by conventional volume-balance procedures, including those currently provided by WinSRFR. In addition, use of this formula is not recommended when infiltration through macropores and cracks is substantial because such a process is more likely to be a function of furrow spacing than of wetted perimeter.

- **TABULATED:** The Tabulated check box control (Figure 46) is used to specify spatial variations in infiltration properties. When this box is checked, the program displays a tabular data control.

- **INFILTRATION TABLE:** This table (Figure 46) is used to specify infiltration parameters as a function of distance. When first launched, this control will display infiltration conditions at the field inlet (distance = 0). If we want to impose a change of conditions, say at 100 m, then a row needs to be added to the table with distance = 100 (assuming the program is displaying metric units). Infiltration conditions at the inlet apply up to distance = 100 m. The new function applies for the rest of the field. Additional rows can be added to the table if more variation needs to be specified. If Limiting Depth is checked, then this parameter can also vary with distance. The **Tabulated Infiltration** control does not allow the user to use different infiltration formulations with distance. It does not allow either to modify the units of the input parameters.

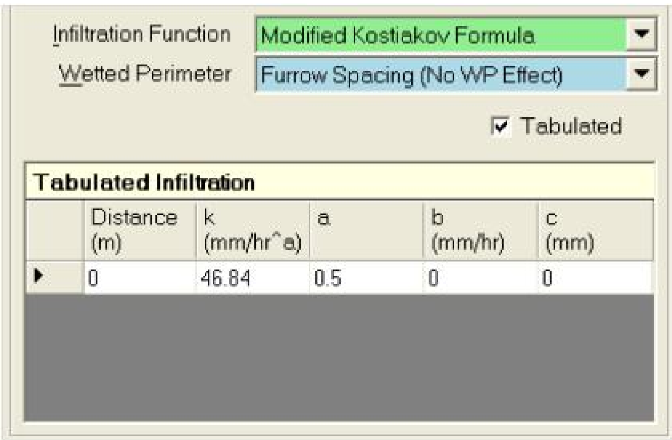


Figure 46. Tabulated infiltration

> Note: With this option, calculations assume abrupt changes in infiltration conditions. Gradual variations in infiltration conditions, which can occur in practice, cannot be treated at this time. Large infiltration variations occasionally cause computational problems. These problems can sometimes be overcome by increasing the computational cell density.

- **Limiting Depth:** The Limiting Depth option (Figure 47) is used in cases where infiltration is limited by a hardpan layer. In such cases, cumulative infiltration depth will not increase beyond a user-specified value. The input box for the limiting value is enabled whenever the Enable Limiting Depth box is checked. The assumption in using this method is that the user knows what depth of water can be infiltrated before the wetting front reaches the hardpan; it is not the soil depth at which the hardpan is located, but depends on the soil porosity. If the Tabulated infiltration option is enabled, then the Tabulated Infiltration table will include a column for Limiting Depth data.

Figure 47. Limiting Depth infiltration calculation option.

5.3.2.3 Selection of the infiltration calculation method

The **Infiltration Function** control displays only a subset of the options shown in Table 6, depending on system type and World. The Kostiakov, Modified Kostiakov, and Characteristic Time options can be used for simulation, operation, and design, and with either furrows or borders/basins. The intake families (NRCS; Time-Rated) can be used for simulation with any system, but for design and operational analyses can be used only for borders and basins. The branch function is available for simulation for all systems, but not for design or operational analyses. The Green-Ampt formula applies to one-dimensional infiltration problems and, thus, can be used to predict infiltration only in borders/basins. Currently it can be used only for simulation. In summary, at least three options are available for calculating z for any type of analysis.

Depending on the specific field conditions, the selected infiltration formulation can have a profound effect on the results. Thus, even when the calculation options are limited, the selection can be challenging. This selection generally will be dictated by the available data. If Evaluation World tools are used to estimate an infiltration function from field data, then that estimate should be used as a foundation for subsequent operational, design, and simulation studies. If published data are available for the location or estimates have been derived from field evaluations, then those results could be used as the foundation for a study. In the absence of field data, users will have to rely on experience and published data to derive a reasonable estimate for the infiltration conditions at a site. The intake families are particularly useful for this purpose. Table 2-6 of the National Irrigation Guide provides some guidance for selecting an NRCS intake family as a function of soil textural type. The Time-Rated Intake Family and Characteristic Time concepts can be used to produce rough estimates of infiltration conditions, better when bolstered by experience with a particular soil.

Infiltration information available for a particular study may not be compatible with the calculation options offered by WinSRFR. For example, a user may have infiltration data for a site given in the form of the Branch function, and wants to use that function in a design study. The Design World does not accept the Branch Function. There are also cases where the selected infiltration function may result in computational anomalies. This is particular true in cases where the infiltration function includes a c term. Sometimes, those computational anomalies can be corrected by approximating the infiltration function with a different function that excludes the troublesome term. These two problems can be overcome, sometimes, by recognizing that different infiltration functional forms with apparently very different parameters can predict very similar infiltration depths, at least for a limited time. The Infiltration Formula Matching control and the NRCS Intake Family Options are used to convert a known infiltration function to a different functional form. More details on these tools are provided in the Infiltration Formula Matching and Approximate NRCS Infiltration Family sections.

Selection of an option for modeling furrow infiltration with the **Wetted Perimeter** option is limited. The NRCS Empirical Wetted Perimeter (USDA-SCS, 1984) is used in combination only with the NRCS Intake Families. Similarly, the Representative Upstream Wetted Perimeter is used always in combination with the Time-Rated Intake Families. In both cases, the dimensions of the published parameter values are volume per unit length per unit width, so they always need to be multiplied by a wetted perimeter value to compute the infiltration volume. For other infiltration formulas, the WP can be computed with the furrow spacing, representative upstream wetted perimeter, or local wetted perimeter options. Note, however, that this choice is not arbitrary because the parameter values depend on the nominal wetted perimeter used to compute infiltration. For example, WinSRFR's Event Analysis procedures calculate, first, the infiltration parameters needed to compute Az (with Eq. (1.7)), and then use the furrow spacing to convert those parameters to their equivalents for computing z (volume/length/width). If the WinSRFR estimated parameters are used in simulation, the user should not arbitrarily change the Wetted Perimeter option to, say, Representative Upstream Wetted Perimeter, as the resulting W, when multiplied z, will not yield the correct value of Az

Table 7 summarizes the infiltration function and wetted perimeter combinations allowed by WinSRFR:

Table 7. Infiltration function and wetted perimeter combinations used by WinSRFR

Infiltration Function	Wetted Perimeter Options
• Kostiakov, • Modified Kostiakov, and • Branch	• Furrow spacing, or • Representative upstream wetted perimeter, or • Local wetted perimeter
• NRCS infiltration families	• NRCS empirical wetted perimeter
• Time-Rated infiltration families	• Representative upstream wetted perimeter, or • Local wetted perimeter
• Characteristic Time	• Furrow spacing

Infiltration conditions cannot be determined with great precision, even when estimates are derived from field measurements. Field evaluations are of limited duration and generally involve a few furrows or borders, not entire fields. Infiltration conditions vary spatially and from one irrigation event. Consequently, hydraulic studies of irrigation systems must test the sensitivity of the recommended design or operational strategy to likely variations in infiltration conditions.

5.3.2.4 Conversion tools

Since not all analytical procedures support the infiltration formulations provided by the software, infiltration functions sometimes need to be approximated by an alternative function. The following tools are available to make these conversions:

1) Infiltration Formula Matching

The default (installation) setting for the **User Preferences/Dialogs/ Infiltration** configuration option (Section 4.2.2) is Confirmed Matching. This setting enables the infiltration formula matching mechanism of WinSRFR. It also causes the program to launch the **Infiltration Formula Matching** dialog box (shown below) in response to changes in the Infiltration Formula drop-down control. This dialog box will be discussed shortly. The infiltration formula matching-mechanism fits an infiltration equation with a given set of parameters to an alternative equation with, a different set of parameters. The calculations are based on the Required Depth of infiltration. The two functions will match exactly at this infiltration value, match approximately for smaller times, and diverge for longer times. The conversion is a useful mechanism when copying scenarios from the Event Analysis or Simulation Worlds to Operational Analysis or Physical Design, since the latter two Worlds offer a reduced set of options for defining infiltration conditions. Evidently, this conversion is irrelevant if the user is defining infiltration conditions for the first time. In those cases, the user can accept the conversion and enter the desired parameter values.

The **Infiltration Function Editor** (Figure 48) is used to manually fit the parameters of the new infiltration function to mimic the behavior of the original function. The fitting is done with the aid of plots of the original and new infiltration functions, displayed on the Soil Crop Properties tab. Pressing the OK button accepts the new function and the fitted parameters. Pressing Cancel aborts the operation and restores the original infiltration function and its parameters.

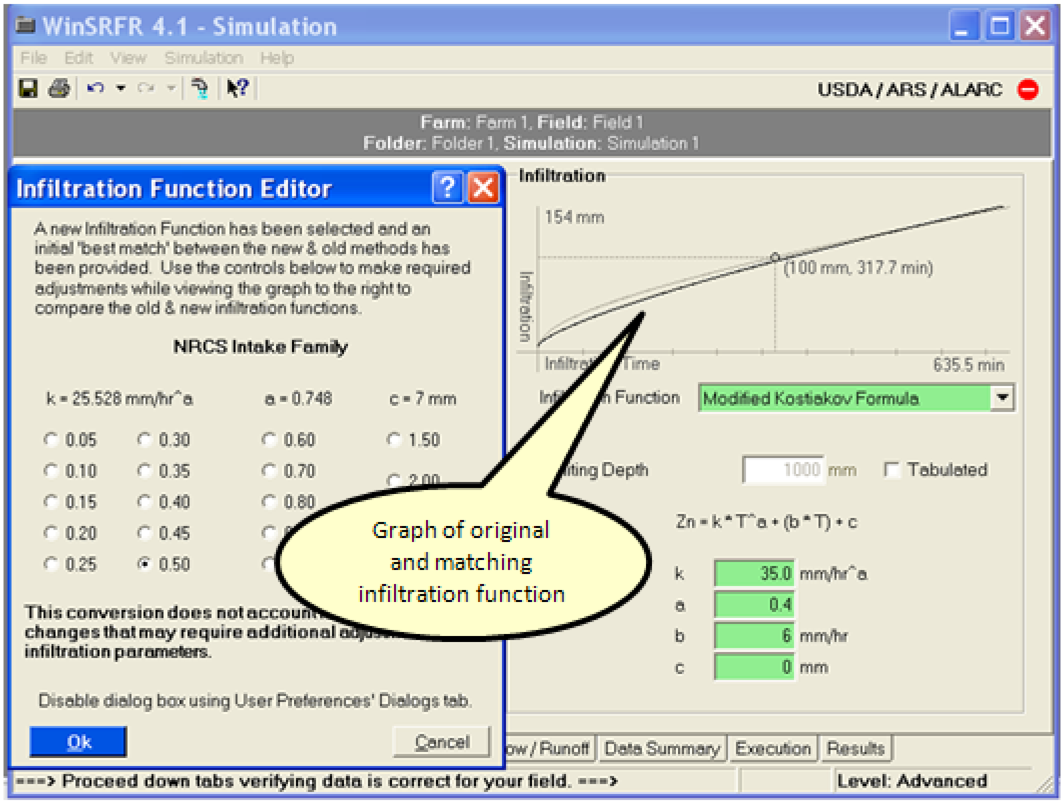


Figure 48. Infiltration function editor.

The infiltration formula matching does not account for nominal wetted perimeter effects in furrows and, therefore, these formula conversions should not be used if they also require a change in the calculation of the nominal wetted perimeter. With furrows, formula matching is allowed only for infiltration formulations that use the same wetted perimeter option, as described in the previous section. The program will issue a warning when attempting a conversion that will invalidate the inputted infiltration parameters.

The **User Preferences/Dialogs/ Infiltration/ Automatic** Option enables the infiltration formula matching mechanism but performs the action automatically (the dialog box is not launched). The user has no control over the output and cannot compare the shape of the original and fitted functions.

The **User Preferences/Dialogs/ Infiltration/ No Matching** option disables the infiltration formula matching mechanism. The new infiltration formula selection is adopted and the current infiltration parameter values are preserved as displayed in the Soil and Crop Properties Tab. If the original infiltration formula has more parameters than the alternative equation, the additional parameters are ignored.

In general, it is recommended that the Preferences/Dialogs/Infiltration be set to **Confirmed Matching**. The reason is that not all infiltration formulations offered for Event Analysis and Simulation are available for Operations Analysis and Physical Design. When copying scenarios between Worlds, the user will be forced to find a formulation that is acceptable for the desired type of analysis and that fits the original function If Confirmed Matching is enabled. This will not happen with the No Matching option. In those cases, the user may inadvertently create scenarios with different infiltration conditions.

2) <u>NRCS Intake Family Options</u>

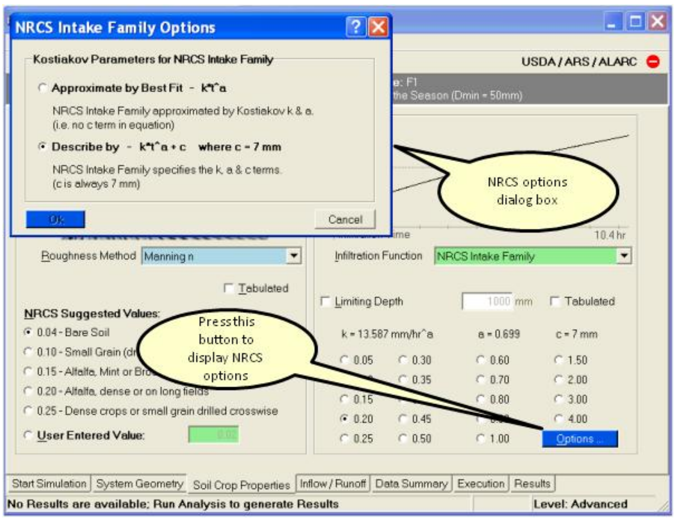


Figure 49. NRCS Intake Family options.

The NRCS Intake Families can cause computational difficulties in the Simulation World when the inflow rate to a field is small relative to the contribution of the c term in the function $z = k\tau^a + c$. Because of these potential difficulties, WinSRFR allows the user to represent the NRCS Intake Families using the standard formulation, or with an approximate fit based on the function $= k\tau^a$ (c=0). This option is selected using the **OPTIONS** button in the lower-right hand side of the Soil/Crop Properties tab (Figure 49).

5.4 Inflow/Runoff

The Inflow/Runoff tab is used to define the inflow (Q) to the system (upstream boundary condition) and the outflow from the system (downstream boundary condition). The Simulation World offers the broadest range of options for specifying the field inflow and only subsets of those options are accommodated by other Worlds. Options offered by the Simulation World also depend on the selected User Level. The following discussion is largely based on the more detailed options available in the Simulation World.

5.4.1 Standard User Upstream Boundary Conditions

Two options for entering inflow information are available to Standard Users. Those options are selectable from the **INFLOW METHOD** drop-down list.

- **INFLOW METHOD**
- **Tabulated Inflow:** This Standard option allows the user to enter a table of measured time vs. discharge values. This option is available in the Event Analysis and Simulation Worlds, but not for Physical Design or Operational Analysis. As with other tabular data, hydrographs can be entered manually, by importing a text file, or from a spreadsheet using copy/paste. Menu commands

available for entering hydrograph data are also similar to those available for other tabular inputs. The tab sheet generates a plot of the hydrograph, as a check on the input data. Procedures that use the tabulated inflow hydrograph assume a linear variation in flow rate with time in between measured values.

> Cutoff time needs to be specified for Simulation and Post-Irrigation Volume Balance Analysis (Merriam-Keller method). With tabular inflow data, this is done by inserting a zero flow rate value at the end of the table. The software interprets a non-zero flow rate value at the end of the table as an incomplete hydrograph. Two-Point Method Analyses can be executed with an incomplete hydrograph, as will be explained in section 6.3.

- **Standard Hydrograph:** This option is used to specify, nominally, a constant inflow rate and a prescribed cutoff time. Additional options are provided to configure the cutoff time (Cutoff Options) and the inflow rate (Cutback options). Upon selecting Standard Hydrograph, When selected, WinSRFR displays an input box for the Inflow Rate, cutoff time, and frame boxes that are used to specify cutoff and/or cutback options.
- **CUTOFF OPTIONS**: The Cutoff Options drop down list is used to specify a cutoff time. It is displayed only when the Inflow Method is a Standard Hydrograph. Input controls displayed by the form will vary depending on the option selected from this list. Those controls are denoted in the following paragraphs using the notation of this Manual.
- **Time-based cutoff:** Cutoff occurs at the user-specified **Cutoff Time Tco**, the time elapsed since the start of the irrigation. This is the default selection when using a Standard Hydrograph. Inflow rate may vary, however, depending on cutback options described below. This is the only cutoff option offered for Event Analysis, Operations Analysis, and Physical Design.
- **Distance-based cutoff:** Cutoff occurs at the advance distance Xco = R * L, where R is the **Cutoff Location** (a fractional value < 1.0) and L the field length given in the System Geometry Tab. This option, together with the next three options, is offered for Simulation only.
- **Distance and Infiltration Depth:** Cutoff occurs when a desired **Infiltration Depth z**, expressed as a fraction of Dreq (z = Rz * Dreq) has accumulated at a prescribed downstream **CUTOFF LOCATION** (Xco = R * L). Note that infiltration will ultimately exceed the given infiltration depth, depending on the time needed for water to recede at the prescribed location.
- **Distance and Opportunity Time:** Cutoff occurs when a given infiltration **Opportunity Time** (total elapsed time minus the advance time) has been experienced at a given downstream **Cutoff Location** (Xco = R * L).
- **Upstream Infiltrated Depth:** In the case of furrows and basins, cutoff occurs when the **infiltrated depth** at the head end of the field matches the prescribed infiltration depth, expressed as a function of Dreq (z = Rz * Dreq). Ultimate infiltration will exceed the prescribed depth, depending on the lag time between cutoff and initial recession. In the case of graded border strips, WinSRFR attempts to calculate a cutoff time that will ultimately infiltrate the prescribed depth at the head end of the field. The algorithm relies on a dimensionless database of previously run simulations to predict the lag time necessary to achieve this objective.
- **CUTBACK OPTIONS:** The **CUTBACK OPTIONS** drop down list is used to specify a cutback option. It is displayed only in combination with a Standard Hydrograph, and thus with the Cutoff Options. Input

controls will vary depending on the selection. Those controls are denoted in the following paragraphs using the notation of this Manual.

- **No Cutback:** This is the default selection for the Standard Hydrograph.
- **Time-Based Cutback:** Inflow rate is reduced at the specified **Cutback Time** and to the **Cutback Rate** Qcb, expressed as a fraction of the initial Q (Qcb = RQ * Q)
- **Distance-Based Cutback:** Inflow rate is reduced to the specified **Cutback Rate** when the advancing stream reaches the specified **Cutback Location**.

The time-based cutback option depends on cutoff time and, therefore, is undefined when using any distance-based cutoff. In the Design and Operations worlds, no cutback is allowed for borders/basins, and only time-based cutback is allowed for furrows.

5.4.2 Advanced/Research Upstream Boundary Conditions

Advanced/research boundary conditions include three additional options for specifying cutoff, and options for modeling surge and drainback irrigation systems. They are available for simulation only.

5.4.2.1 Cutoff options

- CUTOFF OPTIONS:
- **Distance and Infiltration Depth:** Cutoff occurs when a desired **Infiltration Depth z**, expressed as a fraction of Dreq (z = Rz * Dreq) has accumulated at a prescribed downstream CUTOFF LOCATION (Xco = R * L). Note that infiltration will ultimately exceed the given infiltration depth, depending on the time needed for water to recede at the prescribed location.
- **Distance and Opportunity Time:** Cutoff occurs when a given infiltration **Opportunity Time** (total elapsed time minus the advance time) has been experienced at a given downstream **Cutoff Location** (Xco = R * L).
- **Upstream Infiltrated Depth:** In the case of furrows and basins, cutoff occurs when the **infiltrated depth** at the head end of the field matches the prescribed infiltration depth, expressed as a function of Dreq (z = Rz * Dreq). Ultimate infiltration will exceed the prescribed depth, depending on the lag time between cutoff and initial recession. In the case of graded border strips, WinSRFR attempts to calculate a cutoff time that will ultimately infiltrate the prescribed depth at the head end of the field. The algorithm relies on a dimensionless database of previously run simulations to predict the lag time necessary to achieve this objective.

5.4.2.2 Surge Irrigation

This option is new to WinSRFR 4.1 and is available for Simulation only. In surge irrigation, water is applied in pulses (on-off cycles). The following inputs are required to define a surge simulation problem:

- SURGE STRATEGY. The Surge Strategy defines the duration of the on-off cycles. Four strategies are available. Additional input controls are displayed, depending on this selection.
- **Uniform Time**. Surges take place at constant on/off time intervals. The Off-Time is assumed equal to the On-Time, defined in the **Surge On-Time** input box. The number of surges is calculated from the cutoff time. . This option produces equal on-off times on both sides of the surge valve.

- **Uniform Location**. With this option, during the advance phase, the on-time for a surge depends on the time needed for water to advance to a prescribed location. The advance increments are uniform. The off-time is equal to the on-time for the left-side of the surge valve, but equal to the on-time of the next advance surge for the right-hand side of the valve. The constant advance increment is calculated by dividing the field length by the **Number of Surges**. Thus, if field length is 100 m and 4 surges are requested, the program will calculate surges to 25, 50, 75 and 100m. After advance is complete, surging continues with **Uniform Surge-On Time**, and off-time equal to the on-time.

- **Tabulated Time**. Surge by Uniform Location presents the practical challenge of detecting the advance front. A practical alternative is to use on-times of increasing duration in an effort to produce nearly constant advance distances. This is the surge strategy used in commercial surge valves. The **Tabulated Surge Times** table is used to define the increasing on-time surges. This table is also used to enter the uniform on-off times for post-advance.

- **Tabulated Location**. This option works much like the Uniform Location option, except that the advance increments can be defined arbitrarily. The **Tabulated Surge Locations** table is used to define the fractional surge distances. As with the Uniform Location option, a **Uniform Surge On-Time** is entered for the post-advance phase.

Practical surge irrigation systems use a surge valve to switch the water flow from one irrigation set, located on one side of the valve, to a second set located on the other side. This has the effect of turning the water on and off for each set. The on-time for each set is the same, but the off-time is different except when the on-time is constant and equal to the off-time (Uniform Time surge strategy). As a result, irrigation performance may change slightly from the first to the second set. If the performance of the second set needs to be examined, then conduct an analysis for the first set with the Tabulated Time, Uniform Distance, or Tabulated Distance surge strategies, and use the output to define a surge problem for the second set, using the Tabulated Time strategy.

- **Inflow Rate:** This value is entered in the corresponding input box. Inflow rate is assumed constant during each surge.

- **Cutoff Time:** Time at which inflow stops. Cutoff time overrides the defined surge strategy. Hence, if cutoff time is reached in the middle of a surge, the surge will be terminated.

  Cutoff time does not need to be specified (i.e., the Cutoff Time input box is not displayed) when the Surge Strategy is Tabulated Time, because the end time for the last surge is assumed to be the cutoff time.

- **SURGE INFILTRATION METHOD:** WinSRFR offers two empirical choices for modeling the effect of surge on infiltration, selected with option buttons. The effect of surge on infiltration is still not well understood and, thus, results need to be interpreted carefully.

- **Blair-Smerdon**. This option assumes that the infiltration rate will continue to decrease during the off-time, just as if water was flowing continuously (Blair et al, 1984). Hence, the opportunity time at any point is a function of the total time. This option works with any infiltration formulation.

- **Izuno-Podmore**. With this option, the infiltration rate during the second and subsequent surges is set to the steady infiltration rate (Izuno and Podmore, 1985; Izuno et al, 1987). This option will work only with the Modified-Kostiakov and Branch functions. In both cases, the steady infiltration rate term b must be non-zero.

5.4.2.3 Drainback irrigation

Drainback irrigation is a Simulation World option. With these systems, the surface volume is allowed to drain back into the supply channel after cutoff. The resulting runoff increases the inflow available to the next basin to be irrigated. These systems typically have a blocked downstream end and zero or slightly adverse slope.

The rate at which water drains off the field depends on the water-surface elevation in the supply channel. Thus, drainback calculations change the upstream boundary condition from a specified inflow rate to a specified upstream flow depth. Initially, the upstream flow depth is assumed equal to the flow depth calculated by the program (the water surface elevation in the supply channel is equal to the water surface elevation at the field inlet). The software assumes that the water level in the supply channel decreases linearly with time. Eventually, the water level in the channel matches the field invert. At that point the boundary condition is zero flow depth and outflow stops. The required inputs are:

- **Drainback**. This check box enables drainback calculations.
- **Draw-Down Time**. The time needed for the supply water level to drop to the field invert. This value needs to be measured in the field, as it depends on the characteristics of the supply channel.

The drainback option, as currently implemented, only simulates the first basin in a drainback system. Other basins (except the last) can be modeled by adding the drainback outflow to the inflow rate from the supply channel. The last basin in a system receives this combined flow as well, but cannot drain back into the supply channel. Thus, drainback has to be turned off when simulating the last basin in a drainback system.

5.4.3 Downstream Boundary Condition

Flow calculations depend on whether the irrigation system has an open or blocked downstream end. The system will produce runoff if the water advances to the end of the field and the downstream end is open. Use the Downstream Boundary Condition option buttons to select an appropriate condition. This is the only input that needs to be provided for Simulation, Operations, and Physical Design analyses.

Evaluation procedures (Event Analysis) also require a description of the outflow, in the form of an outflow hydrograph. Runoff rate measurements as a function of time are provided through the Runoff Table. Analyses that use those data assume a linear variation in flow rate with time in between the observed values. The Post-Irrigation Volume Balance Analysis (Merriam-Keller) requires a complete outflow hydrograph in order to correctly calculate a final volume balance. A complete hydrograph is indicated by entering a zero flow rate in the last row of data in the Runoff Table. A non-zero value indicates an incomplete outflow hydrograph. A Two-Point-method evaluation can be carried out without a complete hydrograph.

6 Event Analysis (Field Evaluation)

Event Analysis procedures are used to evaluate the performance and infiltration parameters of irrigation systems from field-measured data. Three procedures are selectable from the **START EVENT** tab:

- Probe penetration Analysis
- Post-Irrigation Volume-Balance Analysis (Merriam-Keller Method)
- Two-Point Method Volume-Balance Analysis (Elliott-Walker Method)

6.1 Probe Penetration Analysis

This method can be applied to all types of systems, and with any type of downstream boundary condition. In border/basin irrigation, it is assumed that the infiltrated profile is uniform across the width. With furrows, the wetted profile depth will be different below the furrow top than below the bottom, so probe measurements are taken at both locations to determine an average penetration depth. Since infiltration parameters are not determined with this procedure, insufficient information is provided for further analysis in WinSRFR. Infiltration characteristics must be determined by other means, to perform operational analyses, design studies, or simulations.

6.1.1 Inputs

Common data

Table 8 summarizes the Common Data for Probe Penetration Analysis. Note that some Common Data are not required for this analysis. If the results of a Probe Penetration Analysis are to be used for subsequent Simulation, Operations, or Design studies, then, it is recommended that data be provided for the non-required inputs as well. This will ensure the consistency of data for all scenarios developed from the original Probe Penetration scenario.

If inflow/outflow data are not given, a final volume balance will not be calculated and deep percolation losses will not be estimated. These data do not affect the calculation of the infiltrated profile.

Table 8. Probe Penetration Analysis: Common Data

Input	Required	Use
System Geometry Tab		
Length	Yes	Calculation of the infiltrated profile from the probe measurements
Width	Yes	Final mass balance calculation; only used if a final mass balance can be calculated with the data provided.

Overflow depth	No	None
Slope	No	None
Soil and Crop Properties Tab		
Hydraulic Roughness	No	None
Infiltration	No	None (disabled)
Inflow/Runoff Tab		
Inflow	No	Calculation of final mass balance. Distance-based cutoff and cutback options are disabled. Time-based options are still valid.
Outflow	No	Calculation of final mass balance

Probe Measurements tab

The probe measurement tab, illustrated in the figure below, consists of three sections:

- Soil Water Depletion (SWD) Table
- Irrigation Target Calculation Section
- Post-Irrigation Infiltrated Depths Table

1) Pre-Irrigation Soil Water Depletion (SWD) table

The pre-irrigation soil water depletion table calculates the depth of water needed to refill the soil profile[2]. The analysis requires prior knowledge of the Available Water Capacity of the soil, which depends on soil texture (AWC - the water held between field capacity and permanent wilting point), and the volumetric water deficit. The table allows entering deficit data from a single field location. Thus, if measurements from multiple locations are available, they should be combined into a single set of values. Table 9 describes the variables used by the SWD table. The table consists of seven columns, four of which are for inputs and three for outputs. Three of the input columns are required, while one is not. The AWC can be determined from soil physical measurements or estimated from published values[3]. The Soil Water Deficit (SWD) is measured from soil samples extracted with an auger. For conventional field studies, SWD can be estimated with the procedures described in USDA-NRCS (1998)[4].

[2] USDA-NRCS Irrigation Guide (1997), exhibit 9-2

[3] See for example Saxton, K. 2006 the Soil Water Characteristics - Hydraulic Properties Calculator. USDA-ARS/Washington State University

[4] USDA-NRCS. Estimating Soil Moisture by Feel and Appearance. Program Aid no. 1619. April 1998

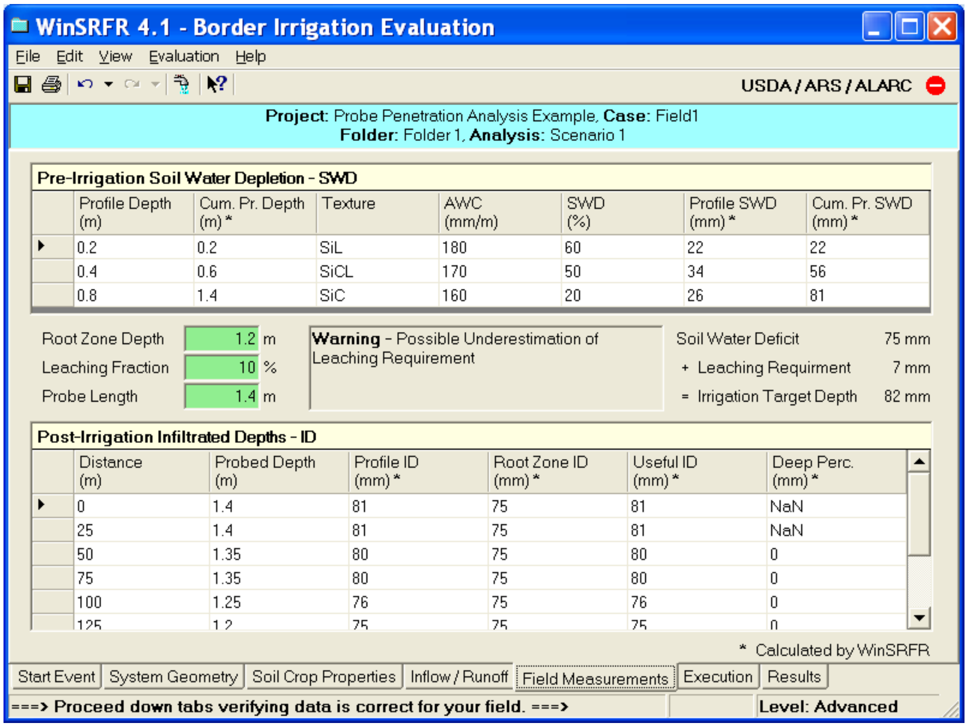


Figure 50. Probe Penetration analysis: Field Measurements tab.

Table 9. Probe Penetration analysis: Summary of variables for pre-irrigation soil water depletion table

Variable	Input or Output	Required?	Description
Profile depth	input	Yes	Soil depth profile for which available soil water holding capacity and water deficit data are available
Cum profile depth	output		Sum of depth profiles
Texture	input	No	Soil textural description. This field is used only for descriptive purposes, not in the calculations
AWC	input	Yes	Available Water Capacity. The depth of water (L/L) that the given soil profile can store. The AWC can be estimated from tables or databases that relate soil texture to AWC.
SWD	input	Yes	Soil Water Deficit. The volumetric soil water deficit in the given soil profile, expressed as a percent. For routine applications, the deficit can be estimated with the touch and appearance method (NRCS, 1998)

Profile SWD	output		Profiled Soil Water Deficit. Deficit in the given soil layer, expressed as an equivalent depth of water
Cum SWD	output		Cumulative Soil Water Deficit. Sum of Profile SWD.

2) Irrigation Target Calculation section

The Irrigation Target Calculation Section determines the irrigation requirement, taking into account the soil water deficit and leaching needs. Required inputs are:

- **Root Zone Depth:** The depth of the soil profile explored by the crop
- **Leaching Fraction:** The Leaching Requirement (a depth) is the product of the leaching fraction and the Root Zone SWD. The Irrigation Target Depth is the irrigation requirement, the sum of Root Zone SWD and Leaching Requirement.
- **Probe Length:** This value is used for post-irrigation depth calculations, explained in the next section. The probe should be longer than the root zone depth; otherwise the root-zone infiltrated depth will be underestimated. The program issues warnings in such cases.

In typical evaluations, the cumulative soil profile will be equal to the root zone depth; the Root Zone SWD will then be equal to the deficit calculated in the SWD table. The Root Zone SWD will be less than the cumulative SWD only in cases where the cumulative soil profile is deeper than the root zone. In those cases, deep percolation losses can be estimated. The root zone deficit cannot be fully determined if the probed soil profile is shallower than the depth of the root zone. Similarly, the root zone deficit cannot be calculated if the user does not provide a root zone depth. For crops with deep root zones in which only the upper soil layers are used to manage irrigation water, then the root zone depth can be defined as the depth of the management layer.

The Warning Box alerts the user to potential problems or inconsistencies with the inputs provided in the pre- or post-irrigation tables. Additional warning/error messages are provided in the Execution Tab.

3) Post-Irrigation Infiltrated depths table

The Post-Irrigation Infiltrated Depths table (ID Table) consists of six columns two of which are required inputs, and four computed values, defined in Table 10.

With the probed depth, probe length, and the SWD Table, the program determines the depth of water stored in the root zone (root zone infiltrated depth). If both the probe depth and cumulative profile depth (used to compute the soil water deficit data) are greater than the root zone depth, then the analysis will estimate the depth of water contributing to the leaching requirement, and the depth of percolation losses.

Table 10. Probe Penetration analysis: Summary of variables for post-irrigation infiltration depths table

Variable	Input or Output	Description
Stations	input	Distance along the field where water penetration is measured
Probed depth	input	Depth of water penetration
Profile ID	output	Infiltrated depth in the soil profile
Root Zone ID	output	Infiltrated depth in the soil profile within the crop's root zone
Useful ID	output	Infiltrated depth in the soil profile contributing to the irrigation requirement (soil water deficit + leaching requirement)
Deep percolation	output	Infiltration depth in excess of the requirement

6.1.2 Execution

Execution Tab

All calculations needed for this analysis are conducted as the user enters the needed data in the Probe Measurements Input Tab. The Execution Tab has only one input control, the **Summarize Analysis button**. The only function of this button is to prompt the program to generate all printable output forms. The tab will also display warning messages, to indicate possible problems with the analysis due to the nature of the data, or error messages, when required data is missing or inconsistent. The analysis will not be completed if errors are detected in the data.

6.1.3 Outputs

Outputs generated by the Probe Penetration Analysis are described in the following table.

Table 11. Probe Penetration analysis: summary of outputs

Output Tab Name	Type	Description
INPUT SUMMARY	Table	Summary of geometry, crop and soil properties, and boundary conditions
SOIL WATER DEFICIT (SWD)	Table	Same table as the SWD table in the Probe measurement tab
INFILTRATED DEPTH (ID) INPUTS	Table	Same table as the ID table in the Probe measurement tab

PERFORMANCE ANALYSIS TABLE	Table	Displays the average infiltration estimate generated from the profile measurements and from the post-irrigation volume balance (if the data is provided). Also displays the computed irrigation performance indicators
INFLOW AND RUNOFF	Graph	Inflow-outflow hydrographs. Generated if the data were provided
INFILTRATION DEPTHS	Graph	Displays the root zone deficit, the irrigation requirement, and the measured root zone and useful infiltrated depths

6.1.4 Example

The following examples are found in the example file "Probe Penetration Analysis Example.srfr".

Scenario 1

A summary of the input data can be viewed from the Input Summary tab sheet (not shown here). Part of the Soil Water Depletion output tab is displayed in Figure 51. The SWD is calculated using three soil layers, each with different textural properties, and therefore with different AWC. The table calculates the SWD for individual soil profiles, and then the total SWD for the cumulative soil profile.

Because the cumulative profile depth (1.4 m) and the probe length (1.4 m) are both greater than the root zone depth (1.2 m), the analysis can yield the root zone deficit prior and subsequent to the irrigation. The analysis can also yield the depth contributing to the leaching requirement, although not in its entirety, because the irrigation target is 82 mm (75 mm of Root Zone SWD and 7 mm Leaching Requirement). This is illustrated with the data obtained at the two measurement stations closest to the upstream end of the field, where the measured probe penetration is equal to the probe length (Figure 52). For these stations, water could have infiltrated beyond the probed depth. Because the wetted profile length cannot be quantified from the given data at the given stations, the corresponding cells are labeled NaN (Not a Number).

The analysis (Figure 52) shows that the root zone was refilled except at the downstream end of the field, where a small deficit was measured, while leaching requirements were likely met only at the upper end of the field. While deep percolation losses cannot be quantified directly from the probe data, they can be estimated from the final mass balance (input and outflow data are provided for this example). The example file provides two additional scenarios for which a final mass balance cannot be calculated. The user is encouraged to change the depth of the soil profiles included in the SWD table, the root zone depth, and the probe length, and view the effect of those changes on the results in either of these scenarios.

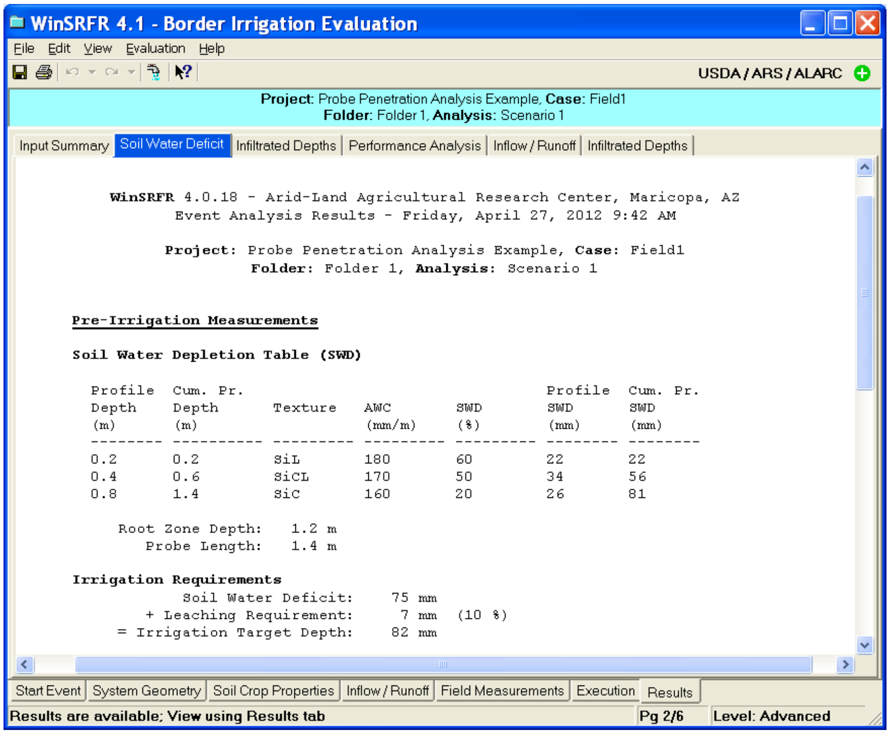


Figure 51. Probe penetration analysis: Soil water deficit output tab

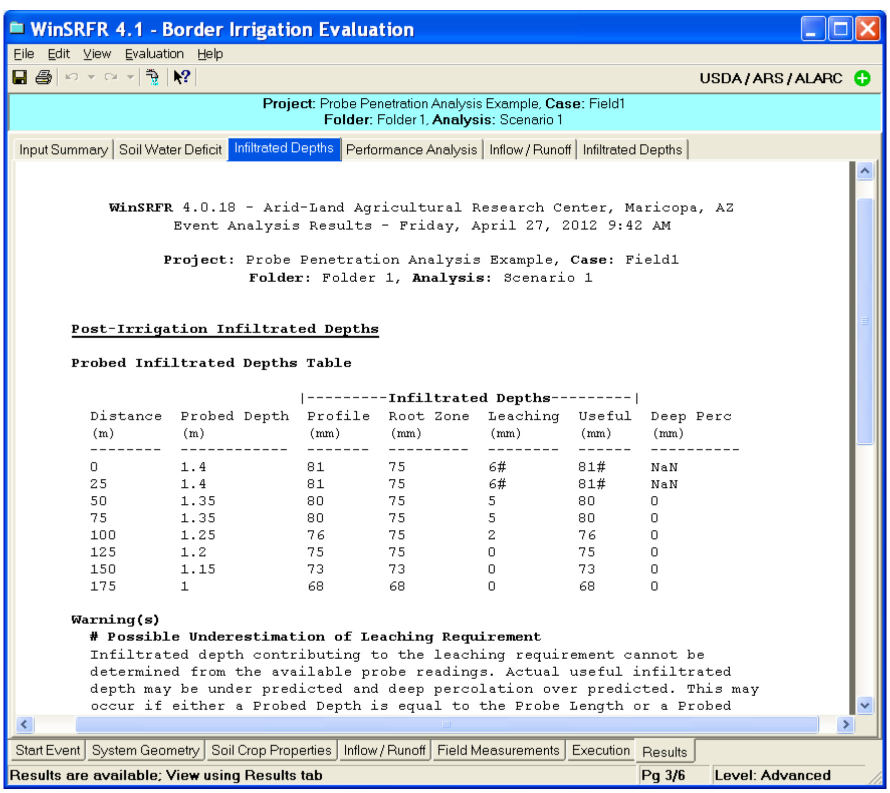


Figure 52. Probe Penetration analysis: Infiltrated depths output tab

Scenario 2

This example differs from the previous one in that the soil depth is less than the probe length. The data allows the determination of the final infiltration profile and deep percolation losses. Application efficiency cannot be determined, however, because no runoff data is available.

Scenario 3

This scenarios differs from the first in that the probed soil depth was equal to the probe length at various locations along the field. The depth to which water penetrated cannot be determined with certainty. Thus, the final infiltration distribution and deep percolation losses cannot be estimated.

6.2 Merriam-Keller Post-Irrigation Volume Balance

This method is applicable to all types of systems, and with any type of downstream boundary condition.

6.2.1 Inputs

Common data

Common data requirements are summarized in Table 12. Note that not all data provided in those tables are required to complete an analysis. If the data will be used in subsequent simulation, design, or operations analyses, it is recommended to enter the unused inputs for completeness. This will ensure consistency of data for all scenarios developed from the original evaluation.

Distance-based cutoff and cutback options are inapplicable with this procedure and are disabled. Time-based cutoff and cutback options remain valid.

Table 12. Merriam-Keller post-irrigation volume balance: Common data

Input	Required	Use
System Geometry tab		
Length	Yes	Calculation of the infiltrated volume
Width/Set Width	Yes	Calculation of the final mass balance
Overflow depth	No	None
Slope	Yes	With furrows, used to determine the wetted perimeter for fitting the NRCS and Time-Rated infiltration families; also needed for validation (used by the simulation engine)
Soil/Crop Properties tab		
HYDRAULIC	Yes	With furrows, used to determine the wetted perimeter for fitting the

ROUGHNESS		NRCS and Time-Rated infiltration families; also needed for validation (used by the simulation engine)
INFILTRATION	No	Output generated by the method
Inflow/Runoff tab		
Inflow	Yes	Calculation of the final volume balance
Runoff	Yes	Calculation of the final volume balance

Advance-Recession tab

Advance and recession data are entered through two tables in the Advance and Recession Tab page (**Figure 53**). Data are entered as a time series (distance vs. advance/recession time). A third table displays calculated Opportunity Times. In typical Merriam-Keller evaluations, the same distance values are used to measure advance and recession times. If advance data are provided at different distances than the recession data, WinSRFR calculates the opportunity times at all the given distances and

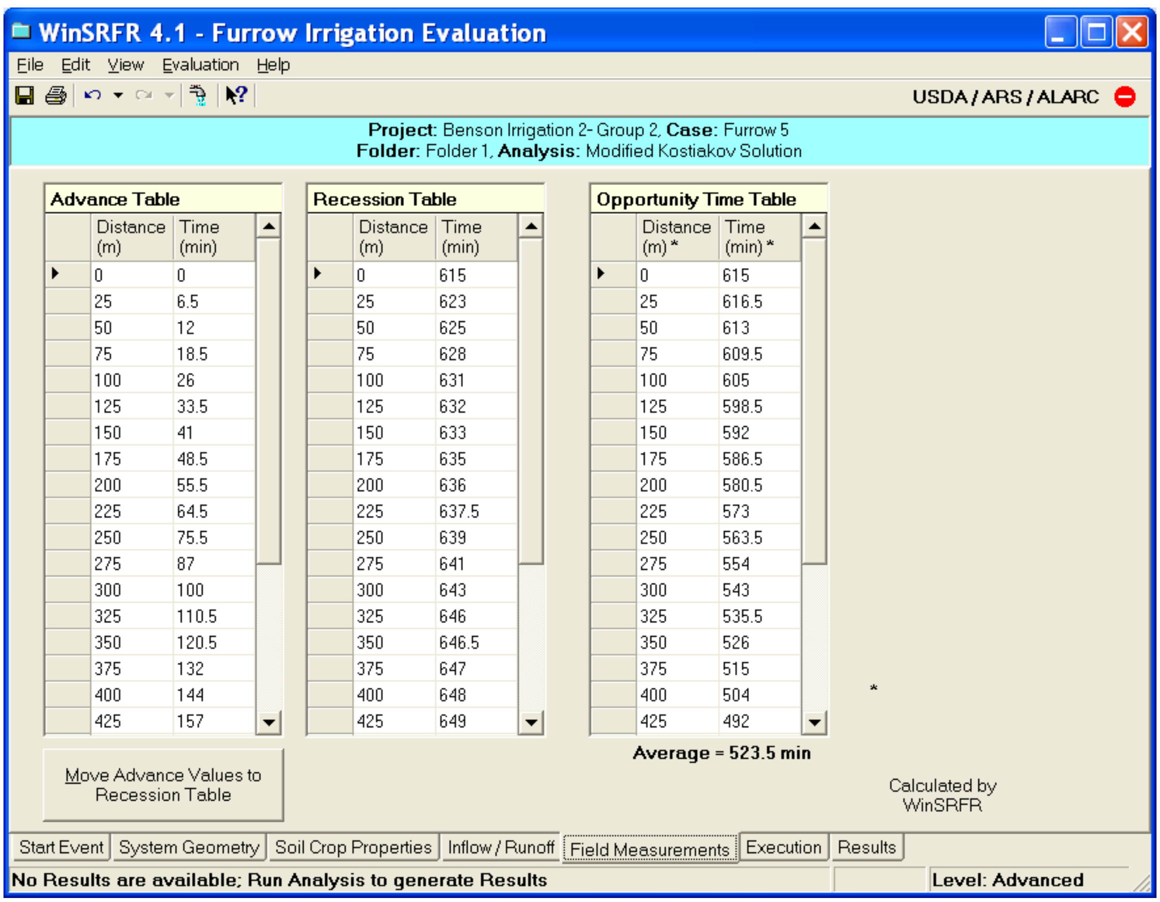


Figure 53. Merriam-Keller post-irrigation volume balance analysis: Advance/Recession tab

interpolates the missing time values (advance and/or recession). Tabular values can be entered manually, imported from a text file, or can be copied-and-pasted from a text file or from an electronic spreadsheet (see Data Table Entry for details on how to work with WinSRFR tables). When entering the data manually, the user can copy the station distances (X) from the advance table to the recession table by pressing the button "Move Advance Values to Recession Table." The program expects the user to provide time values at least at the upstream and downstream ends of the field and automatically enters the field length. Hence, the field length must be specified before entering data in these tables.

Because water can advance irregularly across the width of borders and basins, determining an advance time to a given station can be difficult in these types of systems. For those cases, the user can try to estimate the fraction of wetted border/basin as a function of time and use those values as surrogates for advance distance.

6.2.2 Execution

Execution Tab

This tab (Figure 54) displays three input sections:

- Select Infiltration Function
- Solution
- Run control

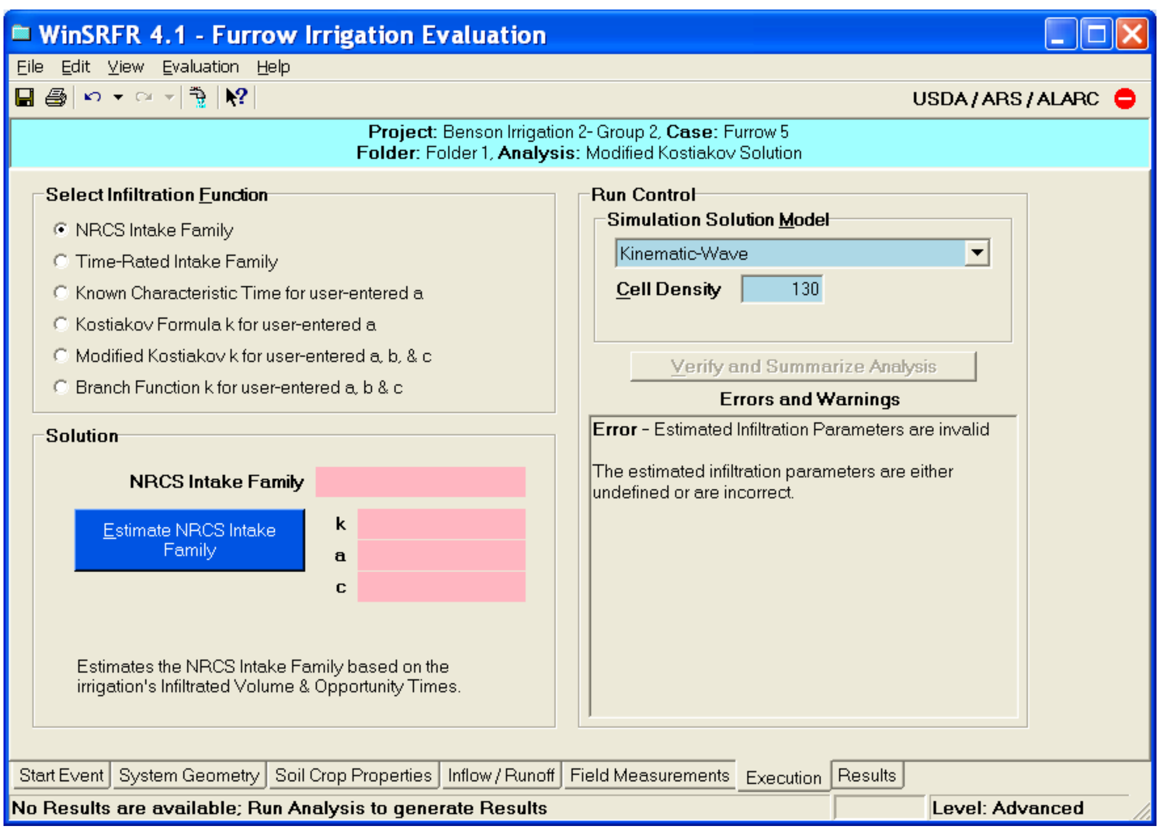


Figure 54. Execution tab for the Merriam-Keller post-irrigation volume balance analysis

SELECT INFILTRATION FUNCTIONS: Option buttons in this section select the infiltration equation to be used in formulating the post-irrigation volume balance. This choice will affect the number of parameters that the user will have to estimate independently and provide as input to the program. Infiltration function choices, required parameter inputs, and the resulting parameter estimates are displayed in Table 13:

Table 13. Merriam-Keller post-irrigation volume balance: infiltration options displayed by the Execution tab

Infiltration option	Required inputs	Estimated parameters
NRCS Intake Families	**None**	Infiltration family (k, a)
Time Rated Intake Families	**None**	Infiltration family τ_{100} (k,a)
Known characteristic infiltration time	**a**	k (z_c, t_c)
Kostiakov Function	**a**	k
Modified Kostiakov Function	**a, b, c**	k
Branch Function	**a, b, c**	k

When dealing with infiltration families, the program determines the two needed parameters. For all other infiltration functions, the program calculates only the constant k. With the Characteristic Time function, WinSRFR uses the user-specified target depth as the characteristics depth z_c. WinSRFR then calculates the characteristic time t_c based on z_c, the user specified a, and the program-calculated k.

These infiltration function choices apply to any irrigation system type. In WinSRFR, all furrow infiltration calculations require selecting an infiltration formula and also an effective wetted perimeter option. While the Simulation World (see Hydraulic Simulation/Common Inputs) offers several wetted-perimeter choices for a given infiltration function, for estimation, the choices are restricted to the combinations shown in Table 14, and hence, to the selection of the wetted perimeter option handled by the software without user intervention.

Advanced/Research User Option

- **RUN CONTROL:** Run Control displays two controls that affect the validation simulation run. For most applications, WinSRFR will select appropriate values for these options (see Section 7.2). These options may be useful in cases where the validation simulation fails.
- **Simulation** Solution Model: Selects the simulation engine used for simulation.
- **Cell Density:** Specifies the number of cells used to spatially discretize the computational domain.

Table 14. Merriam-Keller post-irrigation volume balance: wetted perimeter options available for different infiltration functions

Infiltration function	Wetted perimeter option
NRCS Intake Families	NRCS empirical wetted perimeter
Time Rated Intake Families	Representative upstream wetted perimeter
Known characteristic infiltration time	Furrow spacing
Kostiakov Function	
Modified Kostiakov Function	
Branch Function	

6.2.3 Outputs

Outputs generated by the analysis are the following:

Table 15. Merriam-Keller post-irrigation volume balance: Summary of outputs

Output Tab Name	Type	Description
INPUT SUMMARY	Table	Summary of common inputs
ESTIMATED FUNCTION	Table	Summary of advance-recession data and estimated infiltration function
PERFORMANCE ANALYSIS	Table	Efficiency and uniformity indicators, based on the estimated function and the observed opportunity times
GOODNESS-OF-FIT	Table	Statistics computed from observations and simulation results
INFLOW & RUNOFF	Graph	Inflow and outflow hydrographs (time vs. discharge)
ADVANCE/RECESSION	Graph	Advance and recession trajectories (distance vs. time)
INFILTRATION FUNCTION	Graph	Estimated infiltration function (time vs. depth)
INFILTRATED DEPTHS	Graph	Infiltration profile, computed from the measured opportunity times and the estimated function, and average infiltrated depth (from volume balance)

These outputs can be used to compare the simulation results with the field measured data and evaluate the goodness-of-fit of the estimated function. Differences between predictions and observations can be reduced by adjusting the user-entered infiltration parameters and/or by selecting an alternative infiltration function. For example, when using the Kostiakov equation, the user needs to provide a value for the exponent a. In the original Merriam-Keller methodology, this value was measured with ring infiltrometer tests. In the absence of such measurements, the user may chose to test reasonable values of the parameter a until finding one that gives a good match between observations and predictions. Experience, published information, and judgment should be used in selecting a range of values of a to test, and in making adjustments to parameters, because a set of parameters that minimizes the differences between observations and predictions may not necessarily provide a realistic representation of the infiltration process. Referring again to the Kostiakov infiltration function example, a best fit can sometimes be found with a near-zero value for the exponent a. Such a small value of the exponent implies an infiltration rate that goes almost instantaneously to zero. The evaluator has to decide whether such a function represents the process realistically, whether the results are related to troublesome data, or whether a different infiltration model needs to be adopted.

A major difficulty in making adjustments to the infiltration function is that other inputs required for estimation and validation (e.g., hydraulic roughness) may also be uncertain. Therefore, the analysis may also require conducting sensitivity tests for those other uncertain parameters, in addition to the user-entered infiltration parameter estimates.

6.2.4 Example

An example can be found in the file Merriam-Keller Analysis Examples.srfr.

The example's data were reported by Elliott (1980) as Benson Farm, Irrigation 2, Group 2, Furrow 5 (Benson 2-2-5). The data set includes advance and recession data at 25 m intervals, field elevations at each of these stations, cross-sectional data measured with a profilometer at about 100 m intervals, and inflow and outflow hydrographs. Because these hydrographs were not measured until final cutoff and runoff times, respectively, these times were assumed in accord with the measured recession data. The analysis assumes a prismatic channel so the cross-sectional measurements were averaged and used to define the geometrical parameters (see section Fitting furrow cross-sectional data).

The Event Analysis folder, Folder 1, contains three scenarios based on the Benson 2-2-5 data. Each scenario is based on a different formula selection, the NRCS Infiltration Families, the Time-Rated Infiltration families, and the modified Kostiakov equation. A different wetted perimeter option also applies to each of these infiltration function choices, as explained above. The post-irrigation volume balance problem has a unique solution when formulated in combination with the NRCS or Time-Rated families (because the parameters of those functions are pre-determined and uniquely related to each other) but has multiple solutions when formulated in combination with the Modified Kostiakov equation. The Modified Kostiakov solution given in the example file is one of many possible solutions. Other solutions can be found by modifying the values of the parameters, a,b, and c, which in turn will produce a different value for k. While the parameters have in principle no physical meaning, they should provide a realistic representation of the infiltration process and must be chosen judiciously, as explained above.

The resulting infiltration functions and validation results can be inspected from the output tabs for each scenario. However, instead of analyzing those results individually, the Data Comparison tool (Tools/Data Comparison) can be used to compare estimation results with each other and with the field data (Figure 55). To make these comparisons, simulation scenarios were generated from each of the estimated infiltration functions, by copying the event scenarios and pasting them into the simulation folder Folder 1. They can then be selected for display with the Data Explorer Control of the Comparison Tool.

The figures illustrate key comparisons that can be conducted with the Data Comparison tool:

- Advance and recession trajectories
- Inflow and runoff hydrographs
- Upstream infiltration
- Final infiltration profiles

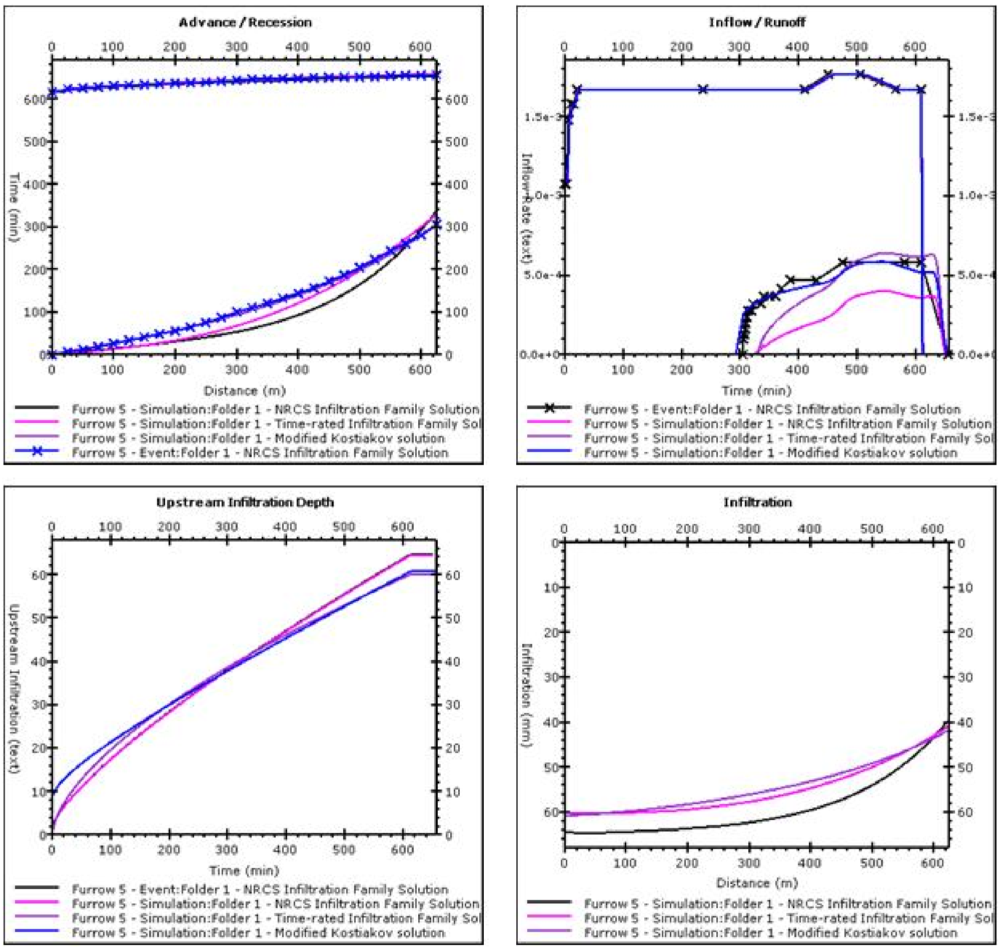


Figure 55. Outputs generated for the MK post-irrigation volume balance analysis: Advance/recession trajectories, inflow/runoff, upstream infiltrated depth, and final infiltration profile.

The estimated functions predict the observed advance, recession, and runoff data with different degrees of accuracy, even though all of them satisfy the post-irrigation volume balance relationship. Advance and runoff predicted with the Modified Kostiakov solution are closest to the observed values. The average infiltrated depth simulated with the Modified Kostiakov function is also the one that most closely matches the average infiltrated depth measured on the field. Note that because the estimated functions use different wetted-perimeter options to calculate the infiltration volume per unit length, they need to be compared on the basis of the Upstream Infiltration (an explanation for the concept of Upstream Infiltration is given in Table 19; see also Sections 5.3.2.2 and 5.3.2.3 for explanations on the use of wetted perimeter on furrow infiltration calculations). This graph shows that the estimated functions differ mostly in the resulting infiltrated depth at short times.

The estimated infiltration functions are uncertain because of the uncertainty of the inputs and the inherent variability of infiltration properties in time and space. These and other potential results can be used to frame the range of likely infiltration conditions for the problem. Performance analysis results should be interpreted with caution because of the uncertainty of the infiltration estimates. Similarly, subsequent operational and design analyses should be conducted taking into account the uncertainty of the estimation results.

When validating the Merriam-Keller solution, output errors generated by the simulation engine will occasionally prevent WinSRFR from completing the goodness-of-fit analysis. Such problems can occur, for example, when inflow is not constant with time or when variable field elevations are specified. For those cases, the analysis can still be completed manually, by copying the scenario into a simulation folder, performing an unsteady simulation with the estimated function, and then comparing the observed and predicted results using the data comparison tool (the comparison tool will generate goodness-of-fit measures when comparing measured and predicted data).

6.3 Two-Point Analysis

This procedure was developed for sloping, free-draining furrows. The method can produce reasonable infiltration function estimates when the surface storage volume is very small relative to the infiltrated volume at the time that advance is measured. It is not recommended for other types of surface-irrigation systems and should be used with caution even with sloping, free-draining furrows.

6.3.1 Inputs

Common Data

Common data requirements are summarized in Table 16. Note that not all data provided in those tables are required to complete an analysis. If the data will be used in subsequent simulation, design, or operations analyses, then the recommendation is to enter the unused inputs, for completeness. This will ensure the consistency of data for all scenarios developed from the original evaluation.

Table 16. Elliott-Walker two-point analysis: common data

Variable	**Input / Output**	**Use**
System Geometry tab		
Length	Input	Calculation of the infiltrated volume during advance
Width/Set Width	Input	Calculation of the final mass balance during advance
Overflow depth	Input	Not required, used by the validation simulation
Slope	Input	Needed for validation
Soil / Crop Properties tab		

Hydraulic Roughness	Input	Needed for validation
Infiltration	Output	Output generated by the method
Inflow / Outflow tab		
Inflow	Input	Calculation of the applied volumes at the measured advance times
Outflow	input	Calculation of final infiltration rate, if selected. Comparison to measured outflow.

Distance-based cutoff and cutback options are inapplicable with this procedure and are disabled. Time-based cutoff and cutback options are valid.

Field Measurements tab

Two advance distance-advance time pairs are required in the **FIELD MEASUREMENTS TAB** (Figure 56). The recommended approach is for the advance-time measurement stations to be located at half and full field length. The form displays a few intermediate results that can be used to detect possible data anomalies.

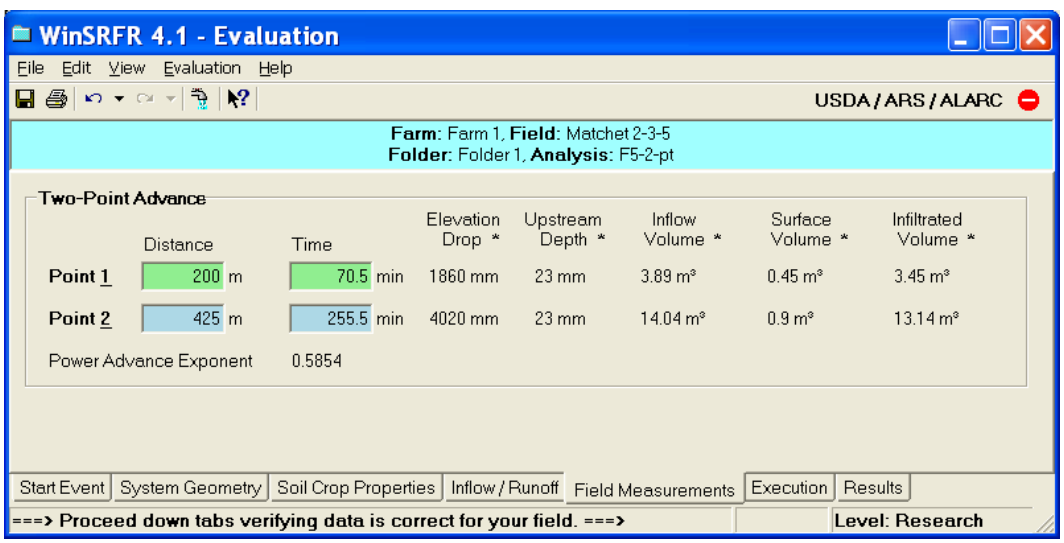


Figure 56. Two-point analysis: Field measurements tab .

6.3.2 Execution

Figure 57 displays the Execution tab for the Two-point analysis. Required inputs are:

- **Steady infiltration rate b:** This is the velocity at which water infiltrates (volume/area/time) under steady-state conditions. An estimate for this parameter may be available from published data or field evaluations conducted under similar soil conditions. An effective method for measuring this parameter is with a ring or blocked furrow infiltrometer.

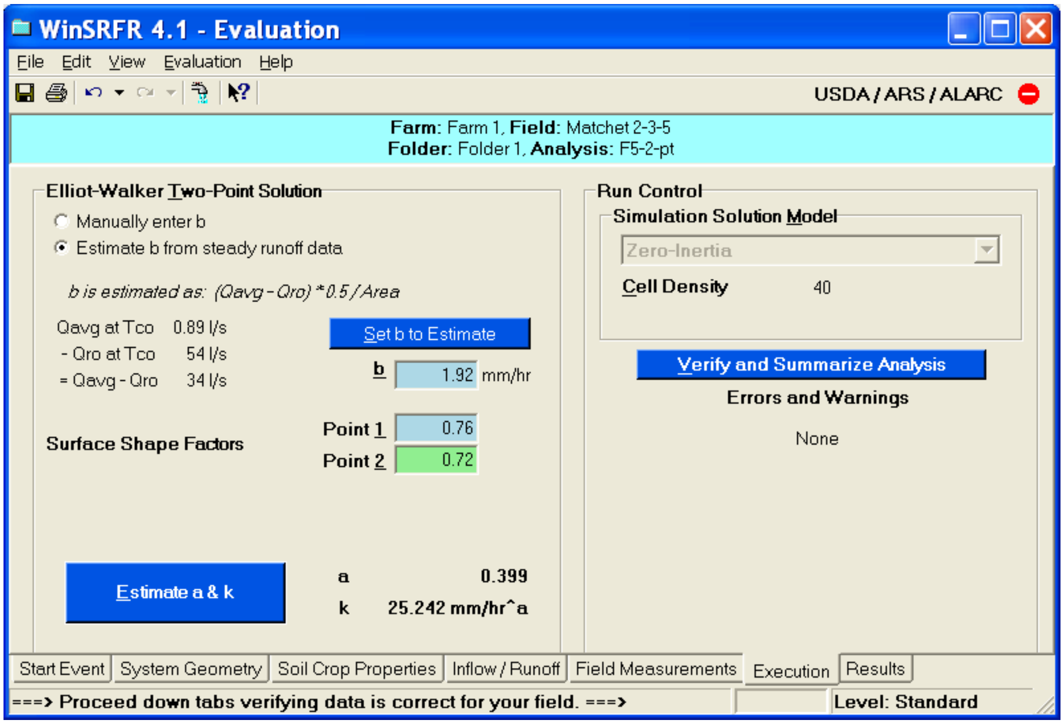


Figure 57. Two-point analysis: Execution tab.

- **Estimate b from steady runoff data:** This button will be enabled only if the irrigation system is free-draining (open downstream boundary) and the Runoff Table (see Section 5.4.3) contains valid data. When this button is pressed, the application will compute an estimate b and display it in the input box Steady infiltration rate b. The user can still enter an alternative value, if so desired. The estimate is calculated from the available inflow and runoff data, using a variation of the method proposed by Walker and Skogerboe (1987, p. 105):

$$b = \psi \frac{\overline{Q_{in}} - Q_{ro}(t_{co})}{LW} \tag{1.21}$$

In this expression $\overline{Q_{in}}$ is the average inflow rate up to the cutoff time Tco, Qro is the outflow rate measured at or prior to Tco, L the field length and W the width (in the case of furrows, the furrow spacing). In the original method, the parameter b (identified as f_0 in that publication) has dimensions of volume/length/time. Also, the original method assumes that Qro is measured at steady-state. The infiltration rate often continues to decline for times much longer than the duration of typical irrigation events. Hence, Eq. (1.21) assumes that the system is not at steady-state and reduces the value of b with the empirical parameter ψ (ψ= 0.5).

- **SURFACE SHAPE FACTORS:** These parameters are used to determine the surface volume at the given advance times using the formula:

$$V_y(t) = \sigma_y A_0(t) x_A(t) \tag{1.22}$$

In Eq. (1.22) t is the advance time to distance x_A, V_y is the computed surface volume, A_0 the upstream flow area, and σ_y the surface shape factor. Conventional application of the two-point method assumes a value of σ_y between 0.7 and 0.8, and the same value is used for the two advance times (Walker and Skogerboe, 1987). WinSRFR sets σ_y = 0.76 but the value is editable, and different values can be used at the two advance times (**Point 1**, **Point 2**). Bautista et al (2012) examined the evolution of σ_y with advance distance under different flow conditions. Their results can be used to develop advance-distance- dependent estimates of σ_y.

- **Estimate a & k:** Pressing this button will prompt the application to conduct the calculations. The Errors and Warnings window will generate messages if the application detects missing or inconsistent data. If calculations are successful, the resulting a and k will be displayed and the Verify and Summarize Analysis button will be enabled.
- **Verify and Summarize Analysis:** Pressing this button will prompt the application to, first, validate the estimated infiltration function and then to summarize the analysis and generate all pertinent output forms. The estimated function is validated by conducting an unsteady flow simulation and comparing the simulation results with the observations. Validation results may suggest adjustments to the steady-infiltration parameter b or to the shape factors. Judgment needs to be used in making those adjustments as they can result in an unrealistic representation of the infiltration process (e.g. negative parameters).

Advanced/Research User Option

- **RUN CONTROL:** Run Control displays two controls that affect the validation simulation run. For most applications, WinSRFR will select appropriate values for these options (see Section 7.2).
- **Simulation** Solution Model: Selects the simulation engine used for simulation.
- **Cell Density:** Specifies the number of cells used to spatially discretize the computational domain.

6.3.3 Output

Outputs generated by the Two-Point Analysis are the following:

Table 17. Elliott-Walker two-point analysis: Summary of outputs

Output Tab Name	Type	Description
INPUT SUMMARY	Table	Summary of common inputs
ESTIMATED FUNCTION	Table	Summary of advance-recession data and estimated infiltration function
PARAMETERS & GOODNESS-OF-FIT	Table	Efficiency and uniformity indicators, based on the estimated function and the observed opportunity times . Statistics computed from observations and simulation results
INFLOW & RUNOFF	Graph	Inflow and outflow hydrographs (time vs. discharge)

TWO-POINT ADVANCE	Graph	Advance and recession trajectories (distance vs. time)
INFILTRATION FUNCTION	Graph	Estimated infiltration function (time vs. depth)
INFILTRATED DEPTHS	Graph	Infiltration profile, computed from simulation with the estimated function

6.3.4 Example

The following example can be found in the file Two-Point Analysis.srfr.

The evaluation was reported by Elliott (1980) as Matchett Farm, Irrigation Number 2, Group Number 3, Furrow 5 (Matchett 2-3-5). The furrow is 425 m l(1395 ft) long and has an average slope of nearly 1%. The data set contains advance times, recession times, field elevations, and cross-sections measured at 25 m (82 ft)intervals. Also included are detailed inflow and runoff hydrographs, and some flow depths and corresponding top widths. Since the available data can be used to run a more comprehensive Merriam-Keller analysis, part of the available data is summarized in the folder Complete Data, scenario F5. This scenario will be used to examine Two-Point method results.

The folder “2Pt” contains three Two-Point scenarios. Each scenario uses as input: the average field slope; average cross-sectional parameters calculated from the cross-section data(see Section 5.2.2.1); an assumed value for the Manning n (0.04); the complete inflow hydrograph; the advance times measured at 200 m and 425 m for its calculations and a single outflow flow value measured just prior to cutoff time[5]. With these data, the application will compute b = 0, 1.92 mm/h (0.08 in/h) (by pressing Estimate b from steady runoff data). Computations are very sensitive to b and there is substantial uncertainty in the determination of this parameter (Bautista et al. 2009b). Hence, the following analysis compares the infiltration function computed with three values of b: b = 0, 1.92, and 3.84 mm/h for the first, second, and third scenarios, respectively. In the absence of any information that could be used to determine b, a user may simply assume a Kostiakov infiltration function (b = 0). b = 3.84 mm/h (0.16 in/h)is simply the value that would have been computed with Eq. (1.21)but with ψ = 1. Solutions were computed for each of these scenarios. The executed scenario was then copied and pasted into the simulation folder 2Pt (2). The simulation was run for each case.

Use the Data Comparison Tool (Section 3.4.1) to compare the observed and simulated advance for the F5-2pt (b = 0 mm/h) scenario. To do this, select the F5-2pt (b = 0 mm/h) scenario in the “2Pt” folder and its counterpart in “2Pt (2)” folder with the Data Explorer. Then, uncheck the Recession box (in Select Type of Data to Compare). Finally, select the Advance tab. You should see that the simulation matches the two advance observations very closely.

Next, select the two other simulation scenarios, b = 1.92, b = 3.84 in the Data Explorer. The objective is to compare the predicted advance for all scenarios with the observations. Inspect now the graphs displayed in the Infiltration Function, Inflow/Runoff, and Infiltration tabs. This example should make it clear that we cannot judge the goodness-of-fit of the infiltration function estimated with the

[5] The Runoff Table for these examples actually contains two rows. The first row corresponds to zero discharge at the final advance time. These two values are used to graph the runoff hydrograph in the Inflow/Runoff tab and subsequently in all output forms.

Two-Point method by simply comparing the simulated advance with the two advance measurements. The three estimated infiltration functions predict infiltration as a function of time similarly only for times less than the final advance time, but diverge for longer times. As a result, all three solutions match the advance data equally well but produce very different infiltration functions, runoff hydrographs, and final infiltration profiles (Figure 58).

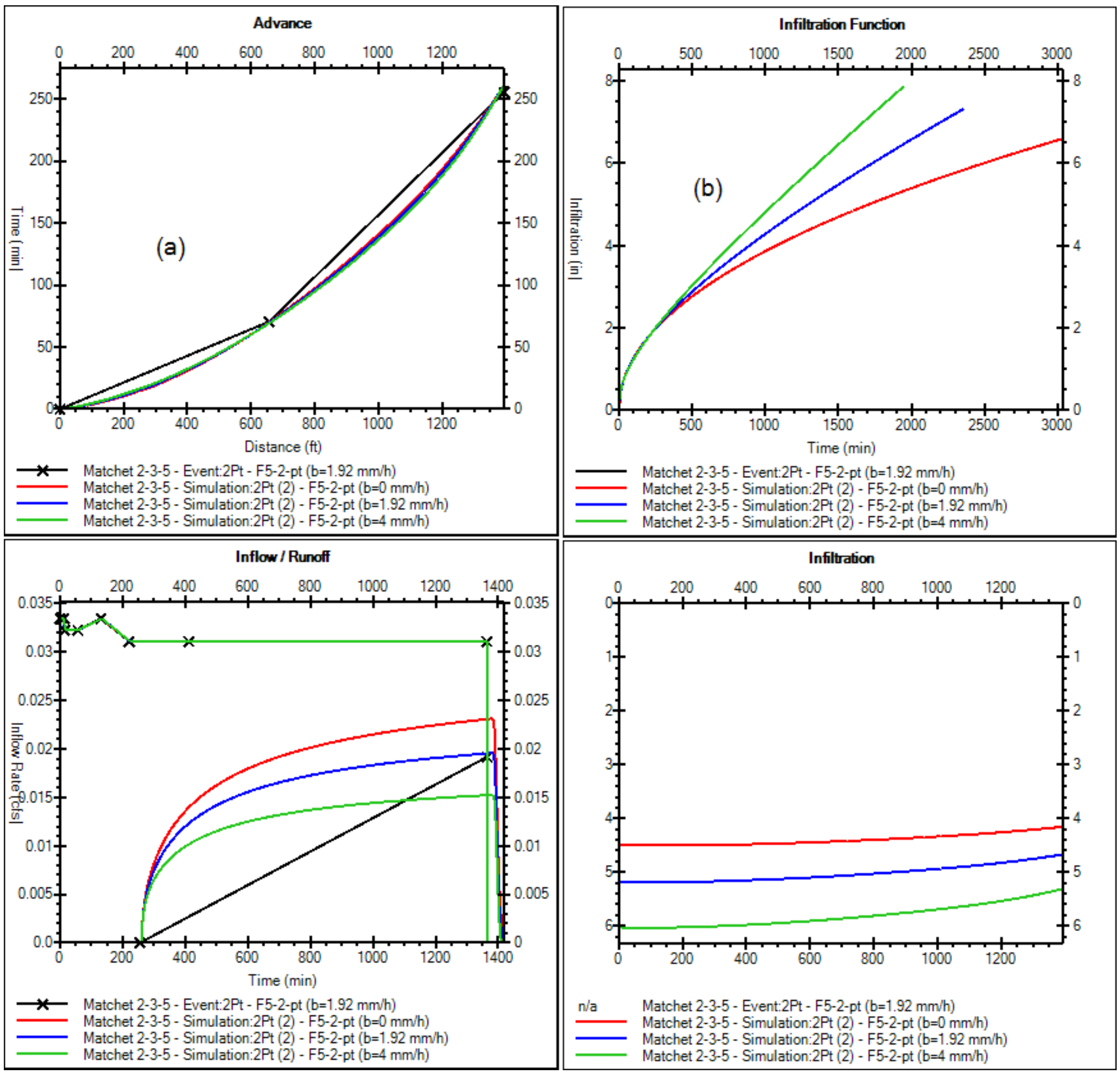


Figure 58. Two-Point analysis results for the Matchett 2-3-5 example.

The single outflow measurement used in the calculations provides an additional measure of goodness-of-fit for the three proposed solutions. Click on the Inflow/Runoff tab. You should see results similar to those depicted in Figure 58c. The two values provided in the Runoff Table are represented as symbols joined by a line. The runoff rate at 1364 min is visible on the right hand side of the graph. Clearly, the solution computed with b = 1.92 mm/h predicts this single runoff rate value most closely.

While the data offered by a typical Two-Point Evaluation is very limited, there are additional steps that can be taken to further validate the results. A strategy for validation of these types of analyses is described in Bautista et al. 2009b). Some specific procedures are described next.

The Two-Point solution can be sensitive to the assumed values for σ_y. This parameter depends primarily on the field bottom slope, but also depends on the unknown infiltration characteristics. Thus, a more accurate determination of this parameter requires prior knowledge of the parameters that the Two-Point procedure is trying to calculate. The application provides feedback on this parameter, in the Results/Estimated Function tab. That form provides details of the calculations, including the shape factors used for calculations, and the shape factors resulting from the simulation. Large differences between these values imply very different surface volumes between computed by the Two-Point method and the unsteady simulation engine. In those cases, the simulation with the calculated infiltration function may not match the observed advance very well. Results may be improved by substituting the shape factors calculated by the application back into the Execution tab, and recomputing the solution. For this example, the shape factors reported by the application are 0.762 and 0.705. Substituting these values back into the Surface Shape Factor input boxes should produce only values for the parameters k and only slightly different from those computed with 0.76 for both advance points. In addition to the surface shape factors, surface volume calculations are sensitive to the assumed hydraulic roughness parameter. In the absence of flow depth measurements, recession measurements, or a detailed runoff hydrograph, the only way to test the adequacy of our assumption is to test the sensitivity of the solution to n. Sensitivity tests are illustrated in the two scenarios contained in the folder "Sensitivity Tests." The results of these Two-Point scenarios (with n = 0.02 and n = 0.06) were transferred to the "Sensitivity simulations" folder. Compare these results with those obtained with the original solution (n = 0.04). You should observe slight differences in the predicted recession, runoff, and final infiltration profile. Despite these differences, estimates of application efficiency and distribution uniformity are essentially the same. Also, the resulting infiltration functions predict similarly at least for infiltration depths less than about 150 mm (6 in).

The Two-Point method assumes that the two advance observations are representative of the entire advance trajectory. Since the advance of water over a field can be erratic, when conducting a Two-Point evaluation it may be prudent to collect two or three intermediate advance measurements, instead of measuring only the advance half-way through the field. The additional effort of collecting one or two more advance measurements is minor but provides valuable information for validating the estimated infiltration function. If those additional data are available, they can be used to repeat the Two-Point analysis using a different intermediate point. If the advance is well-behaved, then results computed with different combinations of advance measurements should be comparable. Calculations with advance measurements at 250 m and 425 m are shown in the scenario F5-2pt, in the "250 X 425 m" event analysis and simulation folders. Again, results do not exactly match those obtained with the original analysis [F5-2pt (b= 1.92 mm/h)], but the differences are minor for practical purposes.

For this example, the Two-Point solutions can be contrasted with the detailed advance, recession, and runoff measurements available in the Complete Data set scenario. Evidently, the Two-Point method would not be recommended for parameter estimation if such an extensive data set is available. Execute the F5-Merriam-Keller scenario, using the inputs provided. Compare then this event analysis scenario with the simulation scenario generated with b = 1.92 mm/h. These results should confirm that that particular two-point solution reproduces the observed irrigation event fairly well.

7 Hydraulic Simulation

Hydraulic simulation is used to predict the surface and subsurface flow of water, the final longitudinal distribution of infiltrated water, and the performance of the irrigation system. Solutions are computed with simplified forms of the unsteady open-channel flow equations.

7.1 Inputs

The Start Simulation Tab displays only the common inputs System Type, Required Depth and Unit Water Cost. No other selections are offered by this tab.

Common Inputs

The Simulation World offers the largest range of irrigation-system configuration options. Table 11 summarizes the common inputs:

Table 18. Simulation: Common data

Input	**Required**	**Use**
Start Simulation tab		
System Type	Yes	Defines range of geometric and infiltration configuration options
Required Depth	Yes	Not required for simulation but needed to calculate the post-irrigation performance indicators. Performance indicators such as Application Efficiency are calculated relative to the specified target infiltration depth.
Unit Water Cost	No	Used to calculate cost of applied water and of potential losses
System Geometry Tab		
Length	Yes	See section 5.2 System geometry.
Width/Set Width	Yes	See section 5.2 System geometry.
Furrows per set	Yes	See section 5.2 System geometry.
Maximum depth	Yes	See section 5.2 System geometry.
Bottom Description	Yes	See section 5.2 System geometry
Slope	Yes	See section 5.2 System geometry
Soil and Crop Properties Tab		

Hydraulic Roughness	Yes	See section 5.3 Soil/Crop Properties.
Enable Vegetative Density	Yes	See section 5.3 Soil/Crop Properties. Advanced option.
Infiltration Function	Yes	See section 5.3 Soil/Crop Properties.
Wetted Perimeter	Yes (furrows only)	See section 5.3 Soil/Crop Properties.
Enable Limiting Depth	No	See section 5.3 Soil/Crop Properties. Advanced option.
Inflow/Runoff Tab		
Inflow Method	Yes	See section 5.4 Inflow Management.
Inflow Rate	Yes	See section 5.4 Inflow Management.
Cutoff Options	Yes	See section 5.4 Inflow Management.
Cutoff Time	Yes	See section 5.4 Inflow Management.
Cutback Options	Yes	See section 5.4 Inflow Management.
Downstream Boundary Condition	Yes	

Data Summary Tab

The Data Summary tab (Figure 59) summarizes the data input from System Geometry, Soil / Crop Properties and Inflow Management. The Data Summary tab can be used to edit input values but not input options. For example, if the Kostiakov function is used to specify infiltration properties, then the parameters of that function can be edited, but the user cannot change to a different infiltration formulation. To change selections or edit tabular data use the appropriate Common Data tab.

7.2 Execution

A simulation is run by pressing the Run Simulation button in the Execution Tab (Figure 60) or by pressing CTRL-R. Prior to execution, the user can adjust the follow inputs:

- Solution Model
- Graphics
- Cell Density

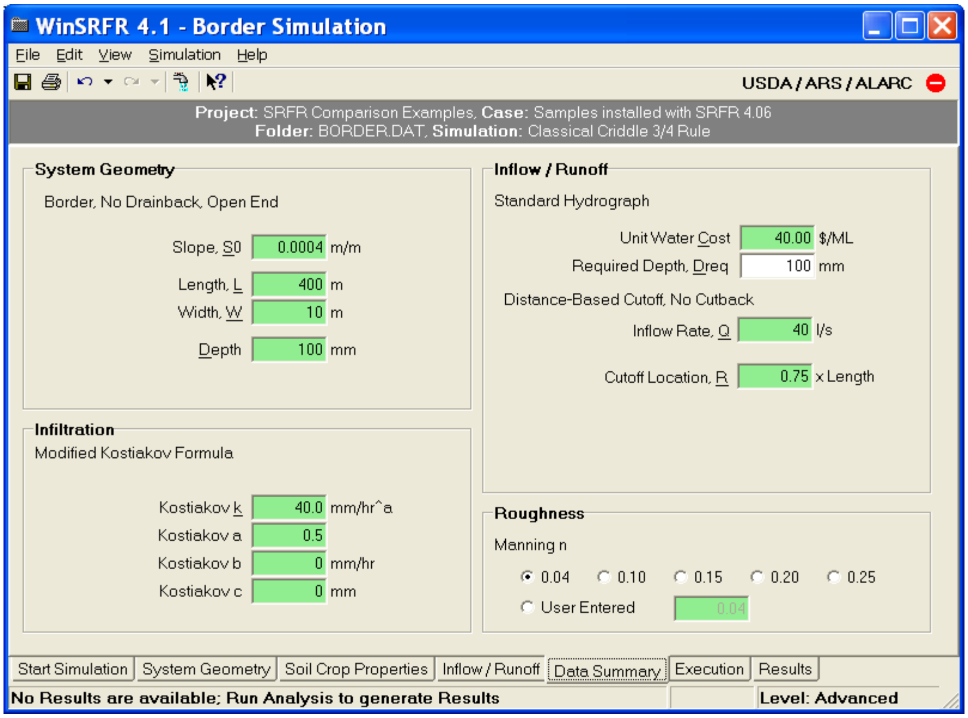


Figure 59. Simulation: Data Summary tab

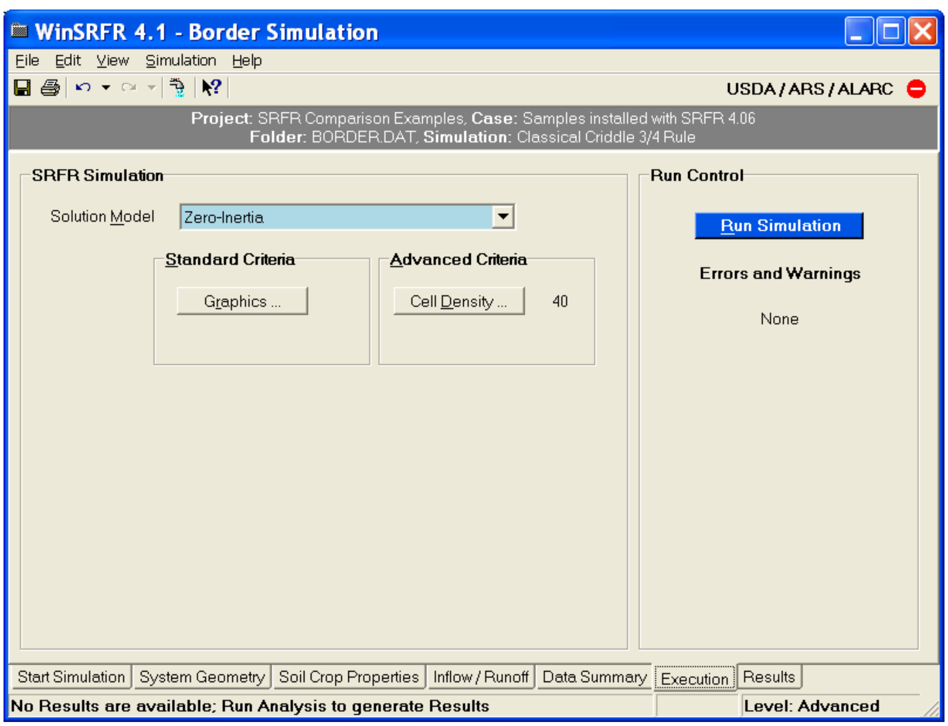


Figure 60. Simulation: Execution tab

Solution Model. Two solution models are used by WinSRFR, **Zero-Inertia** and **Kinematic-Wave**. Both models are subject to limitations. In theory, the zero-inertia model is accurate in comparison with a full hydrodynamic model under typical irrigation conditions. However, it experiences computational problems when the bottom slope is steep. The kinematic wave model is based on the assumption that flow depths are at normal depth everywhere along the field. It is as accurate as zero-inertia or a hydrodynamic model under conditions at which the normal depth assumption is valid – steep slopes - and experiences fewer computational problems. However, because it assumes a unique relationship between discharge and depth, the kinematic wave model cannot model irrigation systems with a closed downstream boundary, which exhibit backwater effects.

For most applications, users will not have to make a selection for the solution model. WinSRFR selects the zero inertia model whenever the field bottom slope is smaller than 0.004 [L/L]. It will also use the zero-inertia model for steeper slopes if the downstream end is closed. For all other cases, it will use the kinematic wave model. An Advanced user can override these selections except when the downstream boundary is closed. In that case, the only choice is zero-inertia. The simulation engine will issue a warning if selecting a model that is not recommended for the given data.

Graphics. As part of the simulation output, the application plots a set of depth hydrographs and flow depth/water surface elevation profiles. By default, the application plots the hydrographs at five equally spaced locations and the profiles at three times. The number of displayed graphs can be edited with the Graphics button. Upon pressing this button, the Simulation Graphics Dialog Box will be displayed. The dialog box has two editable tables (Figure 61):

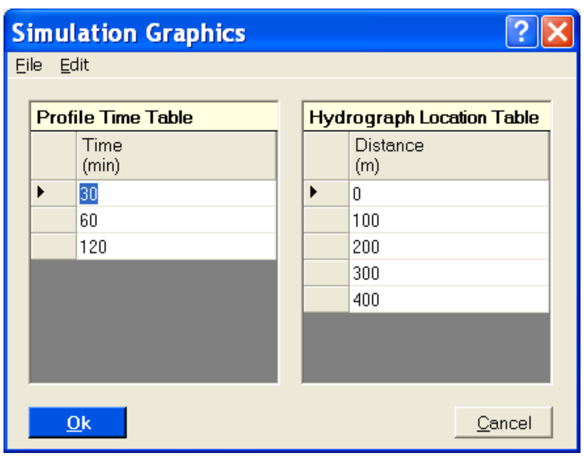


Figure 61. Simulation graphics dialog box

- The **Profile Time Table** specifies the times at which WinSRFR captures and displays surface profile data.
- The **Hydrograph Location Table** specifies the locations at which WinSRFR captures and displays a flow rate/depth hydrograph data.

Edit these tables to select the locations and times at which the corresponding graphs will be generated. The profile time table data will be preserved

NOTE: With open-end systems, the zero-inertia model sets the depth at the downstream boundary equal to zero after water reaches the end of the field. For those cases, WinSRFR will appear to display one less depth hydrograph than requested in the hydrograph location table. To view the evolution of flow depths near the downstream boundary, include a distance just upstream of the boundary.

NOTE: The Hydrograph Location Table expects the field length to be given in the last row of data. If the table contains any other value, the program will set the hydrograph locations to default values (0, 20%, 40%, 60%, and 100% of the field length).

Cell Density. Cell density is the number of spatial increments used to divide the stream for the numerical simulation. This option is mostly a legacy of older numerical schemes in which the user had to manipulate the computational grid to ensure numerical accuracy. The simulation engine has built-in logic that adapts the spatial and temporal discretization depending on the particular flow conditions. In fact, most simulations will produce spatial cell densities different from the nominal cell density value (shown to the right of the Cell Density button) because the program modifies the computational grid on the fly, during the calculations. For most practical problems, the cell density recommended by the program will generate numerically accurate results. Still, a good practice is to repeat the simulation with a higher cell density than in the original run, to verify the results. Pressing the Cell Density button will bring up the Simulation Density Dialog box (Figure 62). Very low cell densities can lead to problems with numerical accuracy. Very large cell density values are not recommended either because of the increased computational time (with little or no gain in accuracy).

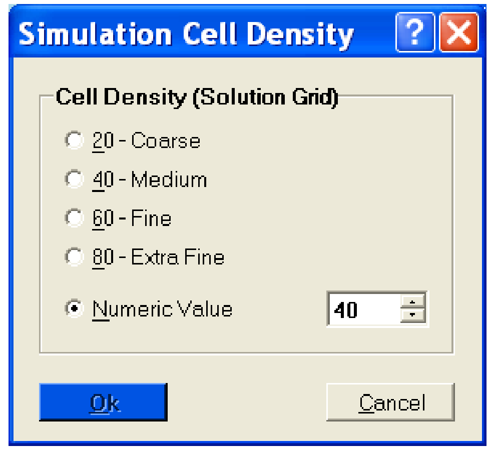


Figure 62. Simulation Cell Density dialog box

7.3 Outputs

The set of tabular and graphical outputs generated by a simulation are summarized in Table 19. Graphical outputs can be copied and pasted to other Windows applications, or can be exported to file in a variety of formats. The underlying data for the graphical outputs can also be copied and pasted to other applications that accept tab-separated text.

Table 19. Simulation: Summary of outputs

Tab	Type	Description
Summary	Table	Summary of inputs and computed performance measures
Hydraulic Summary	Graph	Combined graph displaying the inflow/outflow hydrographs, advance/recession trajectories, and the final infiltration profile.
Advance /Recession	Graph	Advance and recession as a function of time. The Advance tab displays advance data alone.
Infiltration	Graph	Depth of infiltrated water as a function of distance. The infiltration (Ordered) tab arranges these values in descending order
Upstream Infiltration	Graph	Plot of infiltration depth as a function of time, computed from the simulation results. For borders/basins, it is calculated as the infiltrated volume per unit length divided by the border width. Therefore, it will be equal to the

		specified infiltration function. For furrows, it is calculated as the infiltrated volume per unit length divided by furrow spacing. It will be equal to the specified infiltration function only when using the furrow spacing as the nominal wetted perimeter option.
Hydrographs (Flow & Depths)	Graph	Flow rate/depth as a function of time at specified hydrograph locations
(Depth/Elevation) Profiles	Contour graph	Water surface depth/elevations as a function of distance computed at the times specified in the Profile Times table.

Examples of the Hydraulic Summary, Infiltration, and Hydrographs (depth) graphical outputs are depicted in Figure 63.

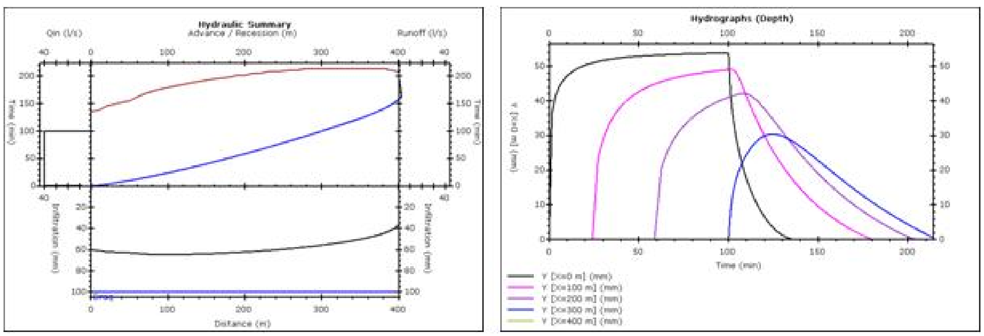


Figure 63. Simulation graphical outputs: Hydraulic summary and flow depth hydrographs

7.4 The Simulation Animation Window

The results of a successful simulation can be viewed with the Simulation Animation Window (Figure 64). This tools is enabled via the `Simulation/View Simulation Animation Window` menu item or as a user preference option (`Edit/User Preferences/Views/Show Simulation Animation`). The tool has controls that allow the user to replay the simulation and save the output. Individual frames can be saved (`File/Save Frame as`) in different graphical formats, while complete simulations can be saved (`File/Save Animation as`) as an Animated GIFF file.

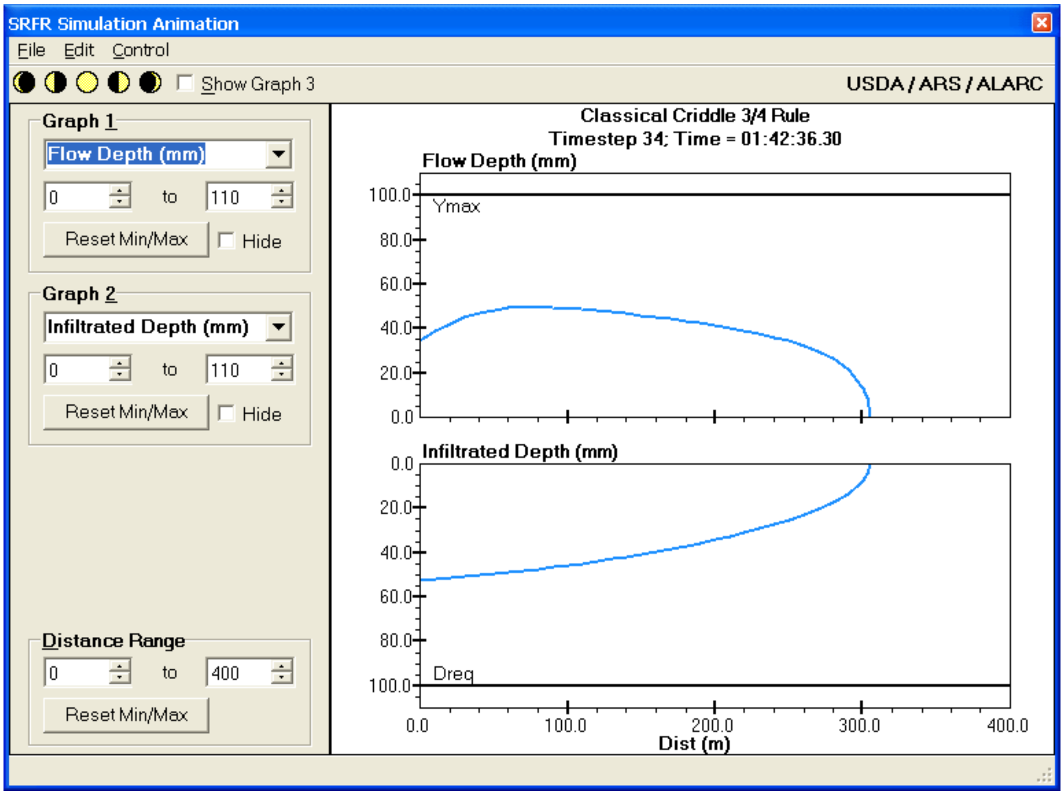


Figure 64. The Simulation Animation Window

By default, the Animation displays the time evolution of the surface flow profile in the upper part of the screen and the infiltrated profile in the lower part. The window can be configured to display other flow variables and to include a third graph. Controls are provided as well for adjusting the vertical and horizontal axes, to facilitate the inspection of results. The Simulation Animation Window is particularly useful for examining overflow conditions or computational anomalies.

The Animation Window displays simulation data that is still in memory and that will not be stored to file. This means that if an open project contains multiple scenarios and valid results are available for all of those scenarios, the Animation Window will show only the results of the most recently run simulation.

7.5 Simulation Network

New to WinSRFR 4.1 is the **Simulation Network**. This tool, available only for Advanced users, can be used to inspect the detail of hydraulic simulations. It is mainly a research tool, but can be used also to identify computational anomalies. The Simulation Network will be displayed upon issuing the menu command `Simulation/Simulation Network` or by pressing the keyboard combination **F7**.

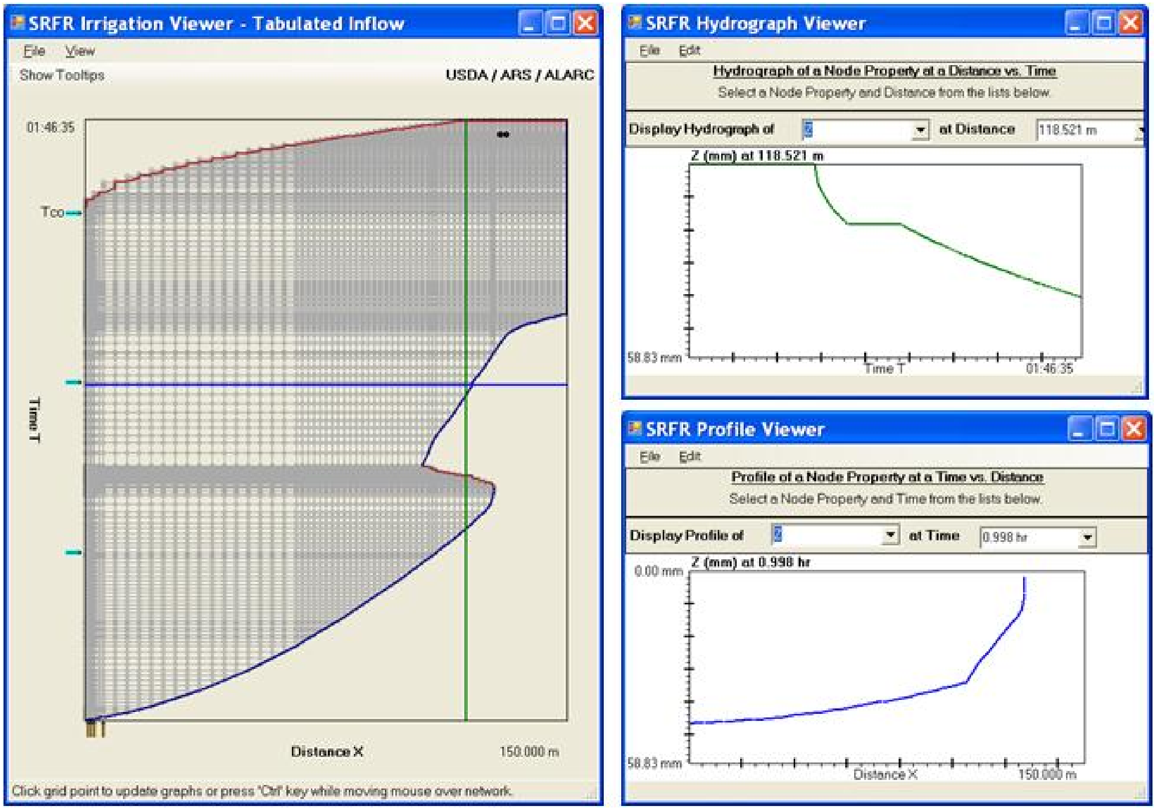


Figure 65. Simulation Network.

The Simulation Network tool has three components (Figure 65). To the left is the **Irrigation Viewer**, which depicts the computational grid. To the right are the **Hydrograph** and **Profile viewers**. The **Hydrograph Viewer** displays a user-selected hydrograph (a time series) at a selected location along the stream. In this example, the illustrated time series is z (infiltrated depth) at a distance of about 118 m. In contrast, the **Profile viewer** shows a user-selected flow profile (a space series) at a selected simulation time. In the example, the space series is the infiltrated profile approximately 1 h after the start of the irrigation. The blue and green intersecting lines on the Irrigation Viewer identify the currently plotted time and space series. Locations and times for which flow data are available depend on the computational grid generated by the numerical solution. The selected location and time can be changed by clicking on the **Irrigation Viewer** or by using the right-most drop down control on the respective viewer. Pressing the **CTRL** key while navigating with the mouse over the Irrigation Viewer forces the hydrograph and profile viewers to update their display dynamically.

The variable to be displayed with the hydrograph or profile viewers can be changed by clicking on the left drop down-control (**Display Hydrograph of** … /**Display Profile of**…). Infiltration, flow depth, water surface elevation, and discharge are some of the variables that can be inspected. The example illustrated in Figure 65shows that with the given inflow hydrograph, advance stopped after some time and front-end recession ensued. The flow rate increased to the point where advance restarted and eventually reached the end of the field. Hence, the peculiar shape of the infiltration time series at the selected point.

The **Irrigation Viewer** has a View menu command. The View/Inputs command displays inputs to the simulation and is useful for diagnosing potential problems with the inputs. Note, however, that all inputs are shown in SI units. The View/Animation Window command is used to animate user-selected results. The other two menu items are used to reopen the hydrograph and profile viewers, in case either one is closed.

Similar to the Animation Window, the Simulation Network can only display the results of the most recent simulation, i.e., data that is still in memory. Although the detailed data is not saved with the project's .srfr file, both viewers allow the user to copy/export the graphical results or the underlying data (use the Edit menu or right click on the viewer to bring up a context menu). Thus, detailed simulation results can be saved to a text or spreadsheet file.

7.6 Examples

The SRFR Examples.srfr file contains examples that illustrate the use of several simulation configuration options. The file contains two case folders, one for standard options and the second for advanced options. The User Level has to be set to Advanced before attempting to view the scenarios in this second folder. These examples are briefly described in the following bullets.

Standard options

- **BORDER.DAT** Folder: These examples demonstrate options for specifying a distance-based cutoff, i.e., it forces the simulation to stop the inflow when the advancing stream reaches a specified distance from the field inlet. For specific instructions on how to specify cutoff based on distance, infiltration depth, or opportunity time, see Section 5.4.1. Run these examples and compare the results using the Comparison Tool.
- Classical Criddle ¾ Rule - Specifies a distance-based cutoff 3/4 of the way down the field.
- Distance-Based Cutoff at end the field - Triggers cutoff when the water reaches the end of the field.
- Predict lag time, to achieve target at upstream end - Attempts to satisfy the irrigation requirement at the upstream end. To account for the lag time between cutoff and final recession, the target upstream infiltration depth is set at 95% of the requirement, Dreq.
- **CUTBACK.DAT** Folder: This example shows the use of cutback irrigation. Guidance for using the cutback options are provided in Section 5.4.1.
- Example from National Engineering Handbook - Uses Time-Based Cutoff with Distance-Based Cutback.
- **VARIABLE INFILTRATION** Folder: These examples illustrate simulations with variable infiltration. Data are entered with the Infiltration Table.
- Variable infiltration/Modified Kostiakov: example models spatially variable infiltration with the Modified Kostiakov formula
- Variable infiltration/Green-Ampt: Similar to the previous example, except that it models spatially variable infiltration with the Green-Ampt formula
- Average infiltration/Modified Kostiakov: Similar to the Variable infiltration/Modified Kostiakov scenario, except that infiltration is spatially averaged.

- Average infiltration/Green-Ampt: Similar to the Variable infiltration/Green-Ampt scenario, except that infiltration is spatially averaged.
- **EGYLVL.DAT** Folder: These examples show how to configure the field bottom based on field elevations as a function of distance instead of using a single constant slope value. The examples also illustrate the effect of field bottom non-uniformity on irrigation performance. Run the examples and use the Comparison Tool to compare the results.
- Bottom config - Theoretical dead level – Constant slope (level furrow) for comparison.
- After laser leveling - Elevation Table describes the furrow bottom after laser leveling.
- After traditional land leveling - Elevation Table describes the furrow bottom after traditional land leveling.
- **FILTER.DAT** Folder: Examples are based on a filter strip design problem. The main feature illustrated is the use of a tabulated hydrograph to specify the field inflow. The main objective was to determine if the inflow would be contained within the filter strip under uncertain infiltration conditions.
- Gary Conaway file - Border with a steep slope using Tabulated Inflow.
- Same, with 1.5 NRCS Family - Same field with different NRCS Intake family defining Infiltration.
- And now, with 0.20 NRCS Family - Same field with yet another NRCS Intake family defining Infiltration.
- **OVERFLOW.DAT** Folder: Examples shows handling of overflow conditions (water depth exceeding the furrow/border height). View the results with the Animation Tool.
- Izadi Test 1 - No overflow for comparison.
- Same with 118mm furrow depth; overflows - Shallow furrow that overflows down the field.
- Same with 108mm furrow depth; overflows upstream - Shallow furrow that overflows near the upstream end of field.
- Overflowing borders - Border that overflows.
- **TOMSHOPS.DAT** Folder: Examples are for a field with a steep slope. Such slopes can cause computational problems.
- Tom's hops. 660 ft run on 7% slope. - Long steep furrow irrigation.
- Test case of Tom's - Cuts field length by 1/2.
- **TWIN.DAT** Folder: Examples combine distance and Infiltration Depth cutoff options with a bottom configuration based on a slope versus distance table.
- Cutoff when target infiltrated at furrow end - Distance & Infiltration Depth cutoff.
- Example 1 with broken bottom. Same average - Adds Slope Table for uneven slope with two slope segments.
- Example 1 w/ broken bottom. Slope decrease then increase - Adds Slope Table for uneven slope with three slope segments.

- **READVANCE.DAT** folder: this examples demonstrates the ability of the program to handle front-end recession and re-advance. These conditions are created by substantial variations in inflow rate with time. Use the **SIMULATION ANIMATION WINDOW** to view the front-end recession and re-advance.
- Tabulated inflow

Advanced options

- **SURGES.DAT** folder: these examples illustrate surge irrigation configuration options. See Section 5.4.2.2 for details on how to configure inflow for surge irrigation.
- Uniform times – Equal and constant surge on/off times
- Tabulated times – Surge on/off times follow a user-prescribed time schedule.
- Uniform locations – Surge on/off times are determined based on constant advance distance increments during the advance phase. Constant on-off times apply during the post-advance phase.
- Tabulated locations – Surge on-off times are determined based on user-prescribed advanced distances. Constant on-off times apply for the post-advance phase.
- **DRAINBAK.DAT** Folder: These examples demonstrate drainback irrigation systems (see Section 5.4.2.3). The user specifies a drawdown time, following cutoff, that is an estimate of the time required for the excess surface storage to fully drain from the field. Individual examples combine the drainback option with a particular cutoff options.
- Drainback level basin. Cutoff at 100% of basin length - Drainback at upstream end of field with Cutoff when Advance reaches end of the field.
- Drainback level basin. 18cfs. Cutoff at 90% of basin length - Increases Inflow Rate while decreasing Cutoff location.
- Compare with NO drainback - Removes Drainback from the previous example.
- **SIMULATION ENGINE** Folder: The purpose of these scenarios is to contrast the kinematic wave and zero-inertia solutions and also to show the effect of cell density on results. For all user levels, WinSRFR selects the simulation engine to use depending on the slope and downstream boundary condition. If the slope is greater than or equal to 0.004 and the downstream boundary is open, then the kinematic wave model is selected. The zero-inertia is selected otherwise. Also, WinSRFR automatically selects the cell density depending on the data. Advanced users can override this selection. In these examples, water does not advance to the end of the field.
- Kinematic wave Slope=0.003. With this scenario, WinSRFR will select zero-inertia. Manually change the engine to kinematic wave. The default cell density is 40.
- Zero-inertia Slope=0.003. This scenario duplicates the previous scenario but uses the zero-inertia engine for calculations. The program should default to zero-inertia. Set the cell density to 40, if needed. After calculations are completed, contrast these results with the first scenario. Repeat these two simulations using cell densities of 60 and 80. Things to notice about the results are, first, that results are almost the same, which is expected since the slope is nearly at point where the program would change the simulation engine. The kinematic wave model tends to produce recession predictions that are not as smooth as the zero-inertia model. Finally, the zero-inertia

results are essentially insensitive to the cell density, at least within the range of conditions of the test. The kinematic wave model is slightly sensitive. This sensitivity may not be an issue for typical problems in which cutoff occurs after final advance. It is always good practice to check the model used by the calculations and the cell density and to run some sensitivity tests.

- Kinematic wave Slope = 0.01/Zero Inertia Slope = 0.01. These two scenarios are similar to the previous ones except that the slope is set to 0.01. The application will select the simulation engine to kinematic-wave with a slope value of this magnitude. Run these examples and inspect the results displayed in the Profiles (depth) tab. The depth profiles computed by the zero-inertia model exhibit substantial oscillations. This problem is not uncommon when using the zero-inertia model with steep slopes and can cause computations to ultimately fail.
- **DUNKLIN.DAT** Folder: This example illustrates the use of the Limiting Depth option for Infiltration calculations. The limiting depth is an infiltration depth, not a soil depth. Thus, the assumption is that the user knows how many inches or millimeters of water will infiltrate before infiltration ceases due to the hardpan effect.
- Hardpan Limits Infiltration - Effect of hardpan using Enable Limiting Depth option for Infiltration.

8 Operations Analysis

The Operations Analysis World is used to develop recommendations for system inflow rate and cutoff time. The methods in this World can be applied to furrows, borders, and basins, either with an open or closed downstream end. The procedures are applicable to graded or level systems, but calculations assume a uniform field slope. The analysis can be conducted assuming a constant inflow rate or a flow cutback strategy (furrows).

The Operations Analysis World offers two analytical alternatives, which are selected with the **Operations Contours** option buttons (Figure 66).

- Option 1, applicable to all systems, is to **Develop Performance Contours as a Function of Inflow Rate and Cutoff time for the known (Border/Furrow set) Width**.
- Option 2, applicable to furrows only, is to **Develop Performance Contours for Furrows per Set and Cutoff Time, for the Known Inflow Rate**. This option assumes that the farm operator is trying to use the full capacity of the irrigation delivery system.

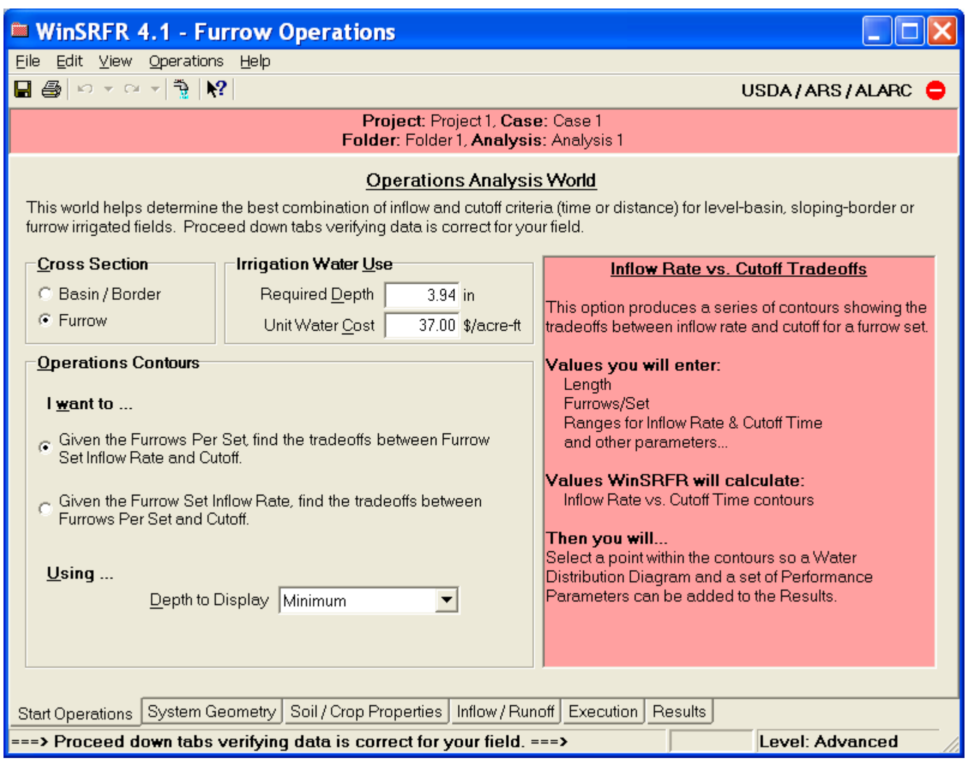


Figure 66. Operations Analysis Start tab

Solutions are generated based on one of the following criteria for infiltrated depth, selected via the **Depth to Display** drop-down control.

- **Minimum**: the minimum depth in the final infiltration profile matches the known irrigation requirement (Dmin = Dreq); thus, the requirement is met everywhere.

- **Low-quarter**: the low quarter depth in the final infiltration profiles matches the know irrigation requirement (Dlq =Dreq); a deficit will be tolerated in some areas of the field.

The two analytical options are closely related and require the same inputs. Thus, the inputs discussed in the following section apply to both options.

8.1 Inputs

Similar to other Worlds, an Operations Analysis begins by specifying the **System Type** and the **Required Depth**. The System Type limits the set of options that can be displayed in the System Geometry, Soil/Crop Properties, and Inflow/Runoff tabs (Table 20). The table also identifies outputs generated by the analysis. Those data fields do not need to be specified when setting up the common inputs.

Table 20. Common inputs for Operations Analysis.

Input	Input/Output	Use
System Geometry tab		
Length	Input	
Border width	Input	
Furrows per set	Input /Output	When analyzing furrow systems, this variable is an input when using option 1 and an output when using option 2
Maximum depth	Input	Used indirectly, the simulation engine (which is used in calibration and when computing a solution point)
Slope	Input	Design analysis assumes a constant slope, which can be given as a single value, or calculated from a user-entered table of elevations (slopes) with distance
Soil/Crop Properties tab		
HYDRAULIC ROUGHNESS	Input	Design analysis uses only the Manning roughness option, user-entered or selected from a table of NRCS recommended values
INFILTRATION	Input	With borders/basins, the Kostiakov, Modified Kostiakov, Characteristic Infiltration Time, NRCS Infiltration Family, and Time-Rated Infiltration Family can be selected. With furrows, the infiltration function choice is restricted to Kostiakov, Modified Kostiakov, and Characteristic Infiltration Time. The only wetted perimeter option available for operations analysis is furrow spacing.
Inflow/Runoff tab		
INFLOW METHOD	Input	A standard hydrograph is the only available option

Inflow Rate	Output	The text box displays the inflow rate associated with the selected solution point
Cutoff Options	Input	Time-based cutoff is the only available option
Cutoff Time	Output	Calculated value, text box will display the cutoff time of the selected solution point
Cutback Options	Input	With furrows, the design can be based on constant inflow or inflow with cutback; option unavailable for borders/basins
Cutback Time	Output	Text box displays cutback time for the selected solution point
Cutback Rate	Input	The entered value is multiplied by the initial inflow rate to determine the cutback rate

8.2 Execution

The **Execution Tab** (Figure 67) displays four sets of inputs:

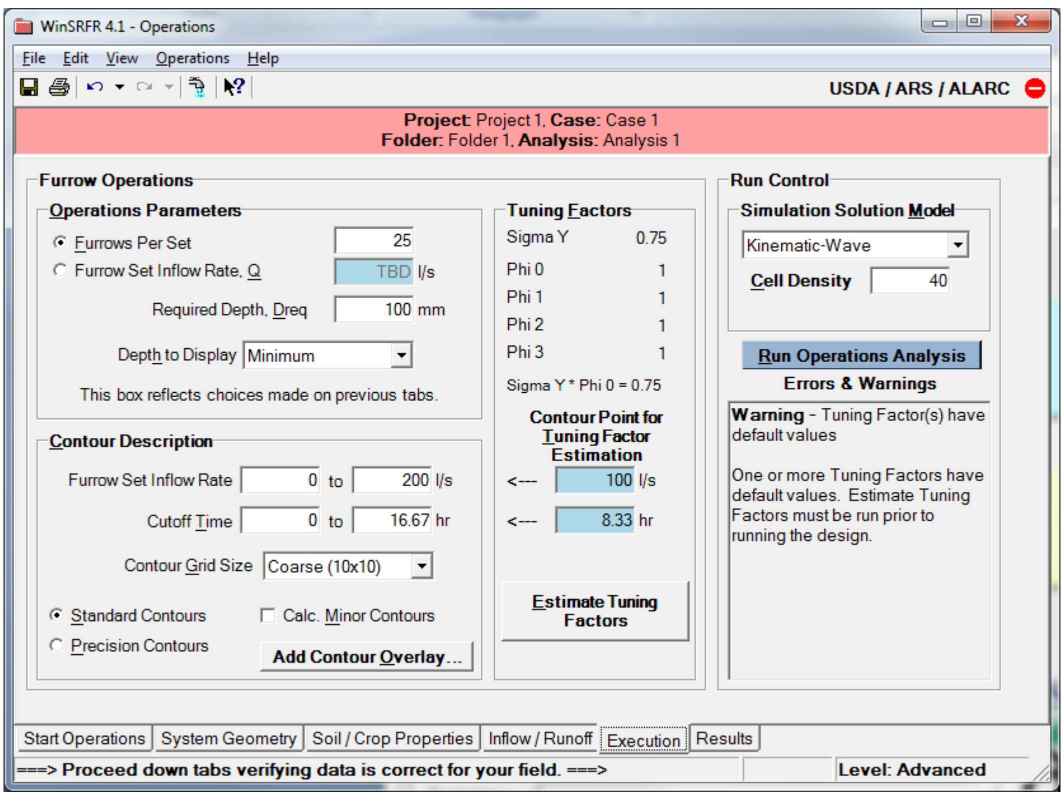


Figure 67. Operations Analysis Execution tab.

- **Operations Parameters.** This section displays the analytical options available for Operations Analysis (same as in the Start tab) and the Depth Criteria.

- **Contour Description.** The main input in this section is the range of the decision variables to be examined, i.e., the solution region. Minimum and maximum values for Inflow Rate and. Cutoff Time (Option 1) or Furrows per set and Cutoff time (Option 2) need to be given. Development of an acceptable contour graph for a specific problem can take a few iterations – for example, if the initially provided range of flows and times is too small, water will not reach the end of the field and contours will not be generated. Start by defining a broad range and gradually zoom into a region of interest.
  Other parameters in this section control the contouring calculations and are set by the application by default. The effect of these parameters on the results depends on the particular problem. An analysis should begin with the default options and calculations should be refined when developing a final product. Four computational inputs can be specified in the Contour Definition section:

- **Contour Grid Size:** WinSRFR calculates performance results at discrete points on a rectangular grid. Results from those discrete points are used to generate the contours, by interpolation. The density of the grid can be modified with the **Contour Grid Size** drop-down control. Selectable options are **Coarse**, **Medium**, and **Fine**. A finer grid will result in more accurate contours but will also increase the computational time.

- **Standard:** Selects a low-order interpolation scheme for the computation of the contours.

- **Precision Contours**. Selects a high-order scheme for the calculation of the contours. High-order interpolation may be needed in cases where the standard computations produce jagged contours. This is an option of last resort, as it increases the computational time by an order of magnitude. Before attempting this option, make sure the tuning parameters have been computed, and increase the contour grid size.

- **Calc. Minor Contours:** If checked, minor contours will be calculated and displayed in the contour graphs. For cases where contours are closely spaced, minor contours may make results difficult to read. Contours need to be recomputed after checking this option.

- **Add Contour Overlay:** This selection will bring up a new input form that is used to generate a contour overlay, in addition to the standard outputs. An overlay combines two or more sets of performance contours and allows the user to examine the relationship between those indicators. Since an overlay is generated after the contours are calculated, it can be modified without recalculating the contours. In that case, select a new overlay and press **F5** to refresh the results. Only one overlay can be generated for every scenario. The recommendation is to overlay only two sets of contours, to facilitate the examination of results.

- **Tuning Factors.** WinSRFR generates performance contours using volume balance calculations calibrated with unsteady simulation results. A point in the solution region must be used for calibration. The accuracy of the contours depends on the location of that single tuning point. Inputs in the **Tuning Factors** section are the X-Y coordinates of the tuning point (e.g., a flow rate and cutoff time combination if using Option 1). Initially, place the tuning point in the middle of the contour region. After entering the coordinates, press the **Estimate Tuning Factors** button. The calibration will not execute if the tuning point results in an application depth that is less than Dreq. Also, calculations will fail if the stream cannot reach the end of the field. In those cases, the program will ask the user to provide an alternative location. In general, the selection should increase the applied depth (e.g., increase Q, Tco or both). If the calculations are successful, the program will display completion messages along with the computed parameters in the boxes labeled **Phi0-Phi3**. Note, however, that successful calculations do not always produce quality results.

Two mechanisms are available to assess the quality of the tuning. The first is to examine the value of the parameters Sigmay and Phi0, and their product Sigmay*Phi0. Sigmay is calculated by the program and generally will have a value between 0.6 and 0.8. If the product Sigmay*Phi0 > 1.0, and thus, Phi0 is much larger than 1 (1.3 or larger), then an alternative tuning point needs to be tested. Generally, a good tuning point will result in Phi0 < 1.1.

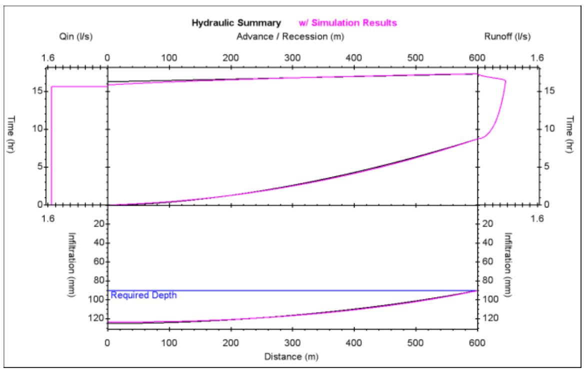


Figure 68. Solution point: advance, recession, and infiltration profile computed with the volume balance solution and unsteady simulation results.

The second mechanism is to complete the calculation of the contours (**RUN OPERATIONS ANALYSIS**) and examine the results displayed in the **HYDRAULIC SUMMARY** tab. The graph in this tab overlays the volume balance predictions (advance, recession, final infiltration profile) with the corresponding unsteady simulation results for any selected solution point. Initially, the selected solution point is the Tuning Point. The two sets of results should be in reasonable agreement. An example is presented in Figure 68 for an open-end irrigation systems. Note that, since the volume balance solution cannot predict the shape of the runoff hydrograph, only the simulated runoff is displayed. If the volume balance and unsteady simulation results do not match very well, then a different tuning point needs to be selected and contours recalculated. The **HYDRAULICS SUMMARY** tab will be updated whenever an alternative solution point is selected, as will be explained in the Examples section.

For best results, the tuning point should be located near solutions that satisfy the Depth Criteria; however, those solutions will not be evident until the contours are calculated. Hence, development of a useful set of contours will require at least a couple of iterations. Note that an adequate calibration may not result in accurate performance predictions everywhere in the solution region. Results may be inaccurate in regions where the advance is very slow and the resulting distribution uniformity is poor. Since these are undesirable solutions, the contour inaccuracies are inconsequential for purposes of the analysis. The contours generally will be accurate in regions with useful solutions.

The Tuning Factors are used differently depending on the system type (Table 21). In general, Phi0 matches the advance time to the end of the field and Phi1 matches the downstream recession time. The infiltrated volumes are then matched using Phi2 & Phi3. The calibration of Phi0 requires an initial estimate for the surface shape factor **SIGMAY**. That estimate is generated by the program and displayed above **PHI0**.

The tuning calculations are specific to the given set of inputs. Changes to any particular input invalidate the current tuning results. If data for the scenario are modified, recalibrate the solution point prior to re-computing the contours.

Table 21. Use of Tuning Factors for Operational/Design analyses as a function of System Type

Tuning Factor	Description
Furrows (Open or Blocked End)	
Phi 0	Adjusts the advance time to the end of the field to match the SRFR Simulator
Phi 1	Adjusts the cutoff time (Tco) so the recession times at the end of the field match
Phi 2	Adjusts the recession at the head of the field so the infiltrated volumes match
Phi 3	Unused
Level Basin (Blocked End)	
Phi 0	Adjusts the advance time to the end of the field to match the SRFR Simulator
Phi 1	Adjusts the cutoff time (Tco) so the recession times at the end of the field match
Phi 2	Unused (the recession time at the head of the field is calculated so the infiltrated volumes match)
Phi 3	Unused
Sloping Border (Open or Blocked End)	
Phi 0	Adjusts the advance time to the end of the field to match the SRFR Simulator
Phi 1	Adjusts the cutoff time (Tco) so the recession times at the end of the field match
Phi 2	Adjusts the recession time at the head of the field to match the SRFR Simulator
Phi 3	adjusts the slope of the recession curve to match the infiltrated volumes

Additional comments on the quality of the calibration procedure are provided later in this chapter when discussing the **SOLUTION POINT** tab.

- **RUN CONTROL.** This section identifies the simulation engine used for calibration, zero-inertia or kinematic wave. This choice is set by the program and cannot be modified by the user (Standard users).
- **RUN OPERATIONS ANALYSIS:** After completing the tuning process, press this button to compute the contours. Messages indicating the progress of the calculations will be displayed at the bottom of the **EXECUTION** tab. Warning/error messages may be displayed at the end of the calculations,

generally to alert the user to solutions that do not satisfy the problem's requirements (e.g., solutions that fail to advance to the end of the field). Those messages are provided for informational purposes need to be closed to allow the program to display the contours.

8.3 Outputs

The outputs of the operations analysis (Table 22) are displayed by the **RESULTS** tab. For definitions of the performance indicators, see the Terminology section.

Table 22. Summary of Operations Analysis outputs

Tab	Type	Description
INPUT SUMMARY	Table	Summary of inputs
AE	Contour graph	Application Efficiency
DUMIN	Contour graph	Distribution Uniformity of the Minimum
RO	Contour graph	Runoff
DP	Contour graph	Deep Percolation
DAPP	Contour graph	Applied Depth
DMIN OR DLQ	Contour graph	Minimum or Low-quarter infiltrated depth
R	Contour graph	Advance Ratio = Advance Distance at Cutoff Time/Length if R ≤ 1, Cutoff Time/Final Advance Distance Time if R>1
SOLUTION	Graph	Final infiltrated profile and performance summary for the selected solution point
DREQ=DMIN	Graph	Graph that illustrates the application efficiency and cutoff time of the set of solutions satisfying the Dmin = Dreq condition
HYDRAULIC SUMMARY	Graph	Comparison of volume balance and unsteady flow simulation predictions for the selected solution point. Overlaid outputs include • Plot of advance/recession times with distance, • inflow and outflow with time, • plot of final infiltration depth with distance

Details of the information provided by the performance contours are discussed in the Examples section of this chapter.

> **NOTE:** Use the Edit/User Preferences command to customize the display of performance contours. After making the desired changes, press F5 from the Operations Analysis window to update the display.

8.3.1 Navigating the contours - The Water Distribution Diagram

The performance contours provide an overview of performance changes as a function of the decision variables. Additional details can be obtained by navigating over the contours with the cursor. The standard Windows arrow cursor will be replaced with a cross-hair cursor and display the coordinates and of the point and its performance value.

The contour graph can be inspected with greater detail by launching the **WATER DISTRIBUTION DIAGRAM**. This is done by right-clicking on the contour graph and selecting the `Choose Solution at this Point` menu command. The diagram displays the predicted final infiltration profile and also a summary of performance measures for any user-specified decision variable combination. The diagram can be updated dynamically while navigating over the contour region. To do this, move the **OPERATIONS ANALYSIS** window to one side of the screen and the **WATER DISTRIBUTION DIAGRAM** to the other side of the screen, so that the two windows overlap as little as possible. Move then the cursor over the contour graph while holding down the **CTRL** key. The contour graph coordinates for the selected point are displayed at the bottom of the **WATER DISTRIBUTION DIAGRAM** window, in the **CONTOUR POINT** box. Those coordinates can be set manually. After selecting a point, press the **SAVE AS SOLUTION** button. This command will update the results displayed in the **SOLUTION** and **HYDRAULIC SUMMARY** tabs. Use the latter tab to assess the quality of the results computed with volume balance in comparison with unsteady simulation at the solution point.

8.4 Examples

Two operational analysis scenarios are presented in the *Operations Analysis.srfr* file. These scenarios illustrate the use of the two analytical options discussed in the introduction to this chapter. They need to be executed by pressing first the Estimate Tuning Factors button and then Run Operations Analysis button in the Execution tab.

8.4.1 Examine performance as a function of inflow rate and cutoff time

This example examines a 1968 ft long X 131 ft wide (600 m X 40 m) border, with a slope of 0.002. The border is assumed to have a roughness of 0.15 and infiltration properties given by the NRCS 0.6 Infiltration Family, with a target application depth of 3.5 in (90 mm). Examine the corresponding infiltration depth vs. time curve, shown in the **SOIL/CROP PROPERTIES** Tab, and note that the time needed to infiltrate the irrigation requirement (referred to as the Characteristic Infiltration Time τ_c) is 3.54 h. The border is irrigated for 4 hours when the maximum flow is available, 10 cfs (~285 l/s) but the supply rate can be less, sometimes as low as 6 cfs (170 l/s). Assuming 12 identical borders in the field and a maximum of 48 hours to irrigate the field, the analysis aims to determine:

- The current and maximum application efficiency that can be attained with the existing system
- The performance that can be expected with different Q and Tco combinations, and

- How performance (and management) will change if a blocked end is added to the current system.

The scenario “Existing border, open end” analyzes operations with the current system. Although the maximum available inflow rate is 10 cfs, the contours were developed for a slightly greater flow range, to illustrate some interesting hydraulic characteristics of the system. The calibration point is located in the middle of the contour region (Q =9 cfs, Tco = 4 h). The calibration is adequate based on the criteria outlined in section 8.2. Examine the results Tuning Factors (**Execution** tab) and the **Hydraulic Summary** tab graph to confirm that the calibration is adequate.

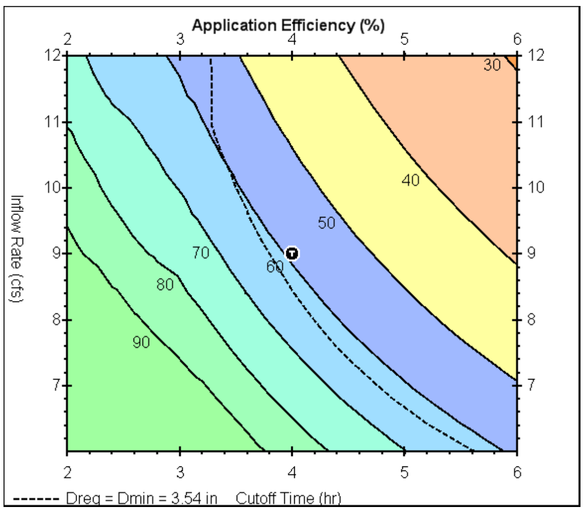


Figure 69. Operations analysis: application efficiency contour

Figure 69 depicts the Application Efficiency contour for this initial scenario (**AE** tab). The black dot with a T in the middle of the contour identifies the tuning point. Small values of inflow rate (Q) and cutoff time (Tco) result in applied depths (Dapp) less than the irrigation requirement, and consequently, large values of AE. Underirrigation is extensive in this part of the solution region. As both Q and Tco, increase, the irrigation requirement Dlq = Dreq is eventually satisfied. Those solutions are represented by the dotted line crossing through, mostly, the 60% contour. For this example, AE cannot exceed ~ 63%, which is typical of free-draining systems. Solutions to the right of the dotted line result in minimum infiltration depths in excess of the irrigation requirement. AE decreases in this part of the solution region, with not benefit to the crop.

An interesting characteristic of the dotted line (solutions that satisfy Dmin = Dreq) is that Tco is nearly constant, about 3.3 h, for inflow rates greater than about 11 cfs, but variable with smaller flows. With large inflow rates, the advance time to the end of the field is short relative to τ_c, the opportunity time needed to infiltrate Dreq. Under those conditions, the point of minimum infiltration is the field inlet and Tco is essentially dictated by τ_c. If Q < 11 cfs, advance time to the end of the field is larger than τ_c and the point of minimum infiltration is at the downstream end of the field. Thus, Tco increases with increasing advance time to the end of field.

Use the **Water Distribution Diagram** to, first, examine the behavior of the infiltration profile along the Dmin = Dreq line and, second, to select the current operation (Q = 10 cfs, Tco = 4h) as the solution point. The current operation results in an AE of about 53%. Save the current operations as the solution point (**Save as Solution point**). This action will update the **Solution** and **Hydraulic Summary** tabs, and will also mark the location of the solution point on the contours with a second black circle. Remember to compare the volume balance and unsteady simulation results for the solution point in the **Hydraulic Summary** tab. This step must be undertaken for any selected solution point. If you want to compare the results numerically, copy (i.e. clone) the scenario into the Simulation World, run the simulation, and display the original Operations Analysis scenario and the cloned Simulation scenario with the **Data Comparison Tool** (**Project Management** window, **F6**). Use the **Indicators** tab in the **Data Comparison Tool** to compare pertinent water distribution measures such as Dro, Dinf, Dmin, and Dlq.

Solutions satisfying the Dmin = Dreq criteria can be more easily inspected with the **Dmin = Dreq** tab. The graph shows AE, DP, RO, Dumin (or DUlq), and Tco as a function of Q. AE varies very gradually over the Q range of interest. As Q increases, uniformity improves and deep percolation decreases, but at the expense of more runoff. Navigate this graph just as you would navigate the performance contours and get more detailed information on the Q-tco combinations of interest. The **Water Distribution Diagram** can be used in combination with this graph, just like with the performance contours. The illustration shows that near-constant AE (~63%) can be obtained with Q between 6 and about 9.5 cfs, as long as the applied volume (i.e., the cutoff time) is properly controlled. Considering the constraint on the time available to irrigate the entire field, an inflow rate of 8.4 cfs and a cutoff time of 4 h can satisfy this constraint with an AE of 63%.

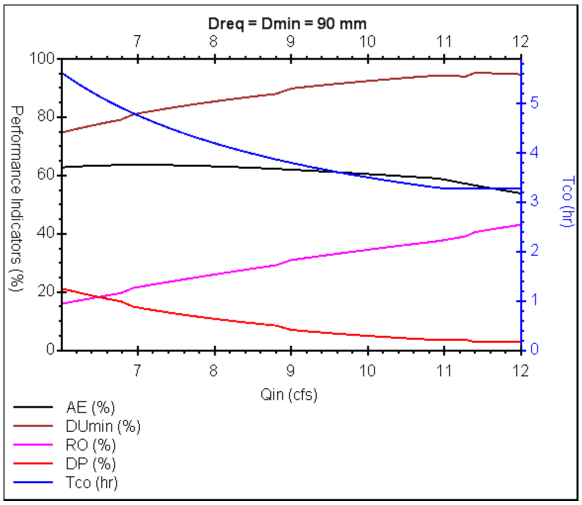


Figure 70. Operations analysis: system performance for solutions satisfying Dreq = Dmin.

An additional constraint placed on this problem is the available Q, which sometimes is limited. Considering the 48 h constraint on the time needed to irrigate the entire set, it may not be possible to satisfy Dmin=Dreq with low flows. Of interest is to assess the magnitude of the infiltration deficits that would result in those cases. This problem can be examined by overlaying the Dmin contour on the AE contour. Return to the Execution tab, press **Add Contour Overlay**, and make the corresponding selections. Return to the **Results** tab and press **F5** (or View/Refresh) to update the display. View the results in the **Overlay** tab. If a Dmin of 3 in is acceptable at the downstream end of the field (i.e., if a deficit of 0.5 in can be tolerated by the crop with little loss in production), then there is some flexibility in managing the system. For example, Dmin = 3 can be achieved with Q = 6.9 cfs and Tco= 4h, for an AE of about 76%.

An important consideration in selecting an operational strategy is the location of the advancing front at cutoff time. The location can be inspected with the **R** tab. Considering the uncertainty of inputs, early cutoff occurs relative to final advance increases the likelihood that water will not reach end of the field. The cutoff ratio R is greater than 1.0 when cutoff occurs after advance is complete and less than 1.0 in the opposite case. For this example, solutions that satisfy Dmin=Dreq lie slightly above the R=1 contour. Hence, for this system final advance distance is a good surrogate of cutoff time for inflow rates less than 9.6 cfs. Distance based cutoff is a practical management strategy and is particularly useful when the inflow rate is variable or cannot be measured with great precision. The Dapp contours show on the other hand that solutions that satisfy the Dmin=Dreq criteria nearly follow a constant Dapp = 5.5 in contour (especially for Q < 9 cfs). This shows that high levels of performance can be attained within a range of inflow rates, but only if the same volume of water is applied.

8.4.2 Examine performance as a function of furrow set size and cutoff time

This scenario examines the performance of a low-gradient, blocked-end furrow irrigation system. The decision variables are furrows per set and cutoff time for a known inflow rate. In contrast with the previous example, the selected Depth Criteria is Dlq. The furrow is 656 ft long, the slope 0.02%. The cross-section is trapezoidal with bottom width of 5.9 in and side slope of 1.5. The field is 400 furrows wide. The characteristic infiltration time for the required depth, 3.94 in, is nearly 3.5 h. Infiltration is modeled with the Modified Kostiakov equation. Manning n is assumed equal to 0.045. The flow rate is 3.53 cfs. In the Start tab, the selected analytical option is to set the Inflow Rate and graph performance as a function of Furrows per Set and Cutoff Time. The solution region to examine is 20-100 for Furrows Per Set and 2- 6 h for Cutoff Time.

Calibrate the example with a tuning point Furrows per set = 55, Tco = 4 h and evaluate the quality of the tuning using the criteria outlined earlier.

The resulting AE contour graph (Figure 71) shows a white area for large values of Furrows per Set. Navigate with the cursor over this area. The program will display a message indicating that advance cannot be completed with the selected solution point. A blanked out region in the Operations and Design contours identify undesirable solutions. Solutions that satisfy the depth criterion are indicated with a dotted line. Those solutions suggest that an AE of nearly 90% can be achieved.

Use the **Water Distribution Diagram** to navigate the area between the dotted line (Dlq=Dreq) and the boundary of the white region. These solutions will produce high AE but at the expense of underirrigation near the downstream end of the field. Solutions below the dotted line satisfy the requirement everywhere but result in increasing deep percolation losses as furrows per set decreases and/or cutoff time increases.

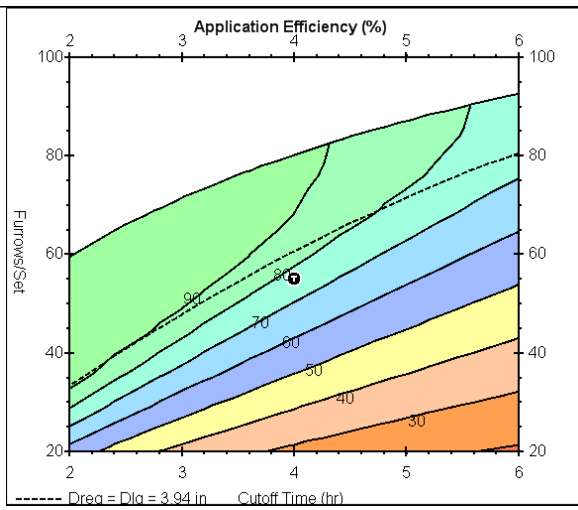


Figure 71. Operations analysis: application efficiency contour with cutoff time and furrow set size as decision variables

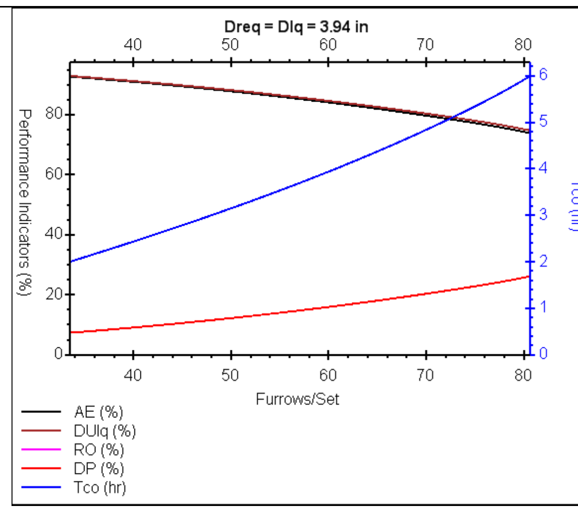


Figure 72. Operations analysis: solutions satisfying Dlq = Dreq and the resulting performance

View the relationship between AE and DUlq with the help of the **Dlq=Dreq** tab (Figure 72). For irrigation systems with no runoff, solutions that satisfy the depth requirement have an AE nearly equal to DUlq. Hence, for this irrigation system AE and DUlq both increase with decreasing set size (i.e, with increasing inflow rate per furrow). While this might suggest using even a smaller set size than shown in the graph, the inflow rate per furrow is limited by maximum flow depth and erosive velocity considerations. Using the Water Distribution Diagram, select and save a solution point on the left hand side of the graph (e.g., 33 furrows per set, Tco = 2h). With this solution, the unit inflow rate is about 48 gpm and the computed flow depth exceeds the furrow maximum depth. As a result, the program will issue a warning. To examine the overflow condition in more detail, launch the Animation Window

(View/Animation Window). Use also the Animation Window to examine flow velocities. The program does not issue a warning about erosive velocities because those conditions are soil dependent. For suggested tolerances on flow velocity under furrow irrigation, see the USDA publication NEH-Ch5 Furrow Irrigation (USDA-SCS, 1978). Overall, the results show that there is some flexibility in choosing a set size. If both AE and DUlq are required to be between 85% and 90%, that objective can be met with set sizes between 43 and 58 furrows. Considering the field width, the field can be irrigated using 7 to 9 sets.

9 Physical Design

The Physical Design World is used to determine the dimensions of an irrigation system for a known field slope, inflow rate, infiltration, roughness characteristics, and irrigation depth requirement. The design procedures can be used to analyze furrows, borders, and basins, either with an open or closed downstream end. Procedures apply to graded or level systems. Calculations are based on the following assumptions:

- uniform field slope;
- a constant inflow rate (although furrow calculations allow flow cutback);
- spatially uniform infiltration and roughness conditions;
- wetted perimeter effects on infiltration are negligible (furrows only);
- the prescribed irrigation requirement has to be satisfied at the point of minimum infiltration.

Similar to other Worlds, the first step in Physical Design consists of selecting a System Type and defining the Required Depth (Start tab). The next step is to select an analytical method with the **DESIGN CONTOUR** option buttons. The two available options are:

- Option 1. **Develop Performance Contours as a Function of Length and Width for a Given Inflow Rate**. This approach is used when the inflow is fixed or when the design wants to always take advantage of the maximum available flow rate.
- Option 2. An alternative approach is to **Develop Performance Contours as a Function of Length and Inflow Rate for a Given Width**. This approach is most useful when the width is set by land-grading operations or when examining design relationships on a per unit width basis (i.e., when examining relationships for an individual furrow or for a border/basin section 1 m (or 1 ft in English units) wide.

At this time, Physical Design is based exclusively on the Minimum Depth Criteria (i.e. solutions satisfy the condition Dmin = Dreq).

9.1 Common Inputs

Common inputs for Physical Design are summarized in the following table:

Table 23. Common inputs for Physical Design

Input	Input/Output	Use
System Geometry tab		
Length	Output	The Length box will be disabled for input but will display the length for the selected solution point, after the analysis is run

Width/Set Width	Input or Output	The Width input box will be disabled if the Design Contour option is to plot Length and Width for a given inflow rate. The box will display the width for the selected solution point. The box will be enabled if the selected Design contour option is to plot length vs. inflow rate for a given width
Maximum depth	Input	Used by the simulation engine when calibrating the tuning point
Slope	Input	Design analysis assumes a constant slope
Soil / Crop Properties tab		
HYDRAULIC ROUGHNESS	Input	Design analysis uses the Manning roughness option only
INFILTRATION	Input	With borders/basins, the Kostiakov, Modified Kostiakov, Characteristic Infiltration Time, NRCS Infiltration Family, and Time-Rated Infiltration Family can be selected. With furrows, the infiltration function choice is restricted to Kostiakov, Modified Kostiakov, and Characteristic Infiltration Time. The only wetted perimeter option available for design is furrow spacing.
Inflow/ Outflow tab		
INFLOW METHOD	Input	Only a standard hydrograph is available for design,
Inflow Rate	Input or Output	Specifies the constant inflow rate assumed for design, or the initial flow rate assuming cutback examining depth and width alternatives for a given inflow rate. Otherwise, the box displays the inflow rate associated with the selected solution point
CUTOFF OPTIONS	Input	Analysis assumes time-based cutoff only
Cutoff Time	Output	Calculated value, text box will display the cutoff time of the selected solution point
CUTBACK OPTIONS	Input	With furrows, the design can be based on constant inflow or inflow with cutback

9.2 Execution

The **EXECUTION** Tab inputs are very similar to those required for Operations Analysis.

- **DESIGN PARAMETERS**. This section displays the analytical options of the Start tab. The form will display an input box for the variable that is fixed for design (Inflow Rate or Width). Changes to these variables will be reflected in the Inflow/Runoff or System Geometry tabs, respectively.
- **CONTOUR DEFINITION.** Minimum and Maximum values for the parameters to be plotted:

- **Length**

- **Width** (Option 1) or **Inflow Rate** (Option 2).

  For a new scenario, the software will display a recommend range for the decision variables, but the user should specify those values based on practical constraints. For example, if the total field length and width are both 400 m, the analysts may want to enter 400 m as the maximum (border/furrow set) length and width. Development of a contour graph for a specific problem is in general a two step process. An initial graph is developed based on a broad range for the decision variables, to gain an overview of the system's performance relationships. The range can be reduced to develop a second contour graph, focusing on a particular region of interest, to improve the accuracy of results.

Other inputs required by this section were explained in the Operations Analysis chapter.

- **TUNING FACTORS.** The inputs are the X-Y coordinates of the tuning point. In contrast with Operations Analysis, the recommended approach is to place the initial tuning point at the longest length and midway through the width or inflow rate range. Pressing the **ESTIMATE TUNING FACTORS** button will start the calibration process. The tuning will fail if water fails to reach the end of the field. If unsuccessful, the program will ask the user to provide an alternative tuning point location. For those cases, reduce the width coordinate first (or increase the inflow rate, if using design option 2). If problems persist, reduce the length. Similar to the procedure followed with Operations Analysis, the calibration requires inspecting the results displayed in the **HYDRAULIC SUMMARY** tab and making sure that volume balance and unsteady simulation results are relatively close. Ideally, the tuning point should be inside the contour of highest PAEmin, at the longest length. That location will not be evident until the contours are computed. Thus, at least a couple of iterations will be needed to identify an acceptable tuning point. For Design Analysis, the product Sigmay*Phi0 provides a measure of the quality of the calibration, without having to inspect the **HYDRAULIC SUMMARY** results. If this product is greater than 1.0, the tuning point results in relatively slow advance and poor performance. Such a point is undesirable for calibration.

- **Run Design.** After completing the tuning process, press this button to compute the performance contours. Messages indicating the progress of the calculations will be displayed at the bottom of the **EXECUTION** tab. WinSRFR will display warning/error messages if it computes solution regions that do not satisfy the problem's requirements (e.g., that do not satisfy the condition Dmin=Dreq). Those messages are provided for informational purposes and can be closed to allow the program to display the contours.

9.3 Outputs

The outputs of the design analysis are displayed in tabbed pages and are summarized Table 24. Definitions for the performance indicators are provided in the Terminology section. Tools for Navigating and editing the design contours are the same as those available for Operations Analysis.

Table 24. Physical Design outputs.

Tab	Type	Description
INPUT SUMMARY	Table	Summary of inputs
PAEMIN	Contour graph	Potential Application of the minimum
DUMIN	Contour graph	Distribution Uniformity of the Minimum
DP	Contour graph	Deep Percolation
DAPP	Contour graph	Applied Depth
DLQ	Contour graph	Low-quarter infiltrated depth
TCO	Contour graph	Cutoff Time
R	Contour graph	Advance Ratio = • Advance Distance at Cutoff Time/Length if R ≤ 1, • Cutoff Time/Final Advance Distance Time if R>1
SOLUTION	Graph	Infiltrated profile and performance summary for the selected solution point
HYDRAULIC SUMMARY	Graph	Comparison of volume balance and unsteady flow simulation predictions for the selected solution point. Overlaid outputs include • Plot of advance/recession times with distance, • inflow and outflow with time, • plot of final infiltration depth with distance

9.4 Examples

Design examples are provided in the file *Design Examples.srfr*. The file contains four case folders, Sloping Furrows, Sloping Furrows (2), Sloping Borders, and Level Basins. The first folder contains scenarios based on the Length vs. Width design option. The scenarios in other folders illustrates only the Length vs. Inflow rate option. The case Sloping Furrow is detailed and aims to illustrate how to use the Design, Operations, and Simulation World tools for analyzing a design. All other scenarios are examined with less detail; the main goal is to explain differences in the contours produced for different types of systems. All scenarios have a recommended tuning point. For each, go to the Execution Tab and press the Estimate Tuning Factors button using the recommended tuning point and contour ranges. After the tuning calculations are complete, press the Run Design button. Review the quality of the calibration using the criteria outlined in the Operations Analysis section. Alternative tuning points should be tested, contours computed, and results compared with those generated with the recommended tuning point

Sloping Furrows/ Length v. width

These following inputs apply to this scenarios:

- Slope=0.2%
- Furrow Spacing = 1 m, bottom width = 150 mm, Side slope = 2
- Manning n = 0.04
- Dreq = 90 mm,
- Infiltration is given by the Kostiakov equation (k = 30.1 mm/h^a and a = 0.51). From the given Dreq, it follows that the Characteristics Infiltration Time τ_c = 8.56 h.

The example analyzes alternative layouts for a field 600 m long X 600 m wide. The available inflow rate Q is 150 l/s. The recommended tuning point is 600 m X 100 m. The objective is to identify a layout with high performance, low risk for overtopping and hydraulic erosion, and robust performance - that does not degrade substantially if actual field conditions differ from those assumed in the design.

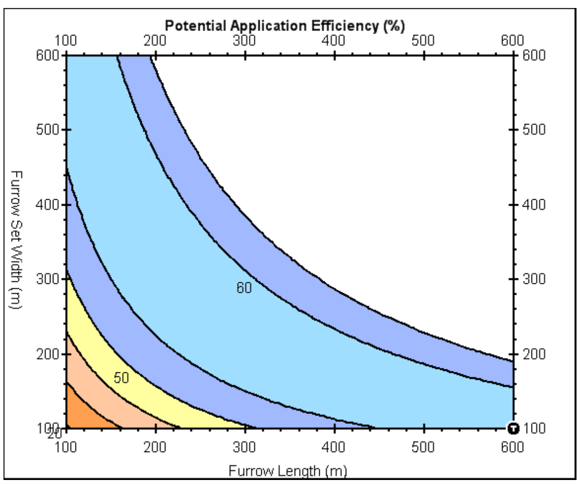


Figure 73. PAEmin contours for a design scenario with the length vs. width option and a known inflow rate.

In contrast with Operations Analysis, the Design World produces contours of potential application efficiency of the minimum (PAEmin). Hence, every solution in the contour region satisfies the condition Dmin = Dreq. The contours for this example (Figure 73) illustrate the fundamental relationship between PAEmin and the design variables for a given flow rate. PAEmin is low at small values of length and width, reaches a peak value (about 64%), and then declines as the area of the irrigation set continues to increase. Higher levels of PAEmin are difficult to attain with free-draining systems because the irrigation requirement at the downstream end of the field cannot be satisfied without incurring runoff losses. The potential efficiency can be improved by relaxing that requirement, for example, by targeting a design that satisfies Dlq = Dreq. A procedure for adjusting the design to satisfy this alternative requirement will be described further below.

A more complete understanding of performance tradeoffs as a function of the design variables can be developed by examining the DUmin (distribution uniformity), RO (runoff) and DP (deep percolation) contours (not shown). Solutions near the bottom-left corner of Figure 73 produce high distribution uniformity but large runoff losses. Solutions near the top-right corner produce a very non-uniform final infiltration profile and large deep percolation losses. That part of the contour region is left blank by the software because those solutions represent poorly posed mathematical problems, meaning that small changes in the inputs can cause significant changes in the calculated advance and performance. Advance to the end of the field is difficult to guarantee in those cases. A PAEmin contour is also, essentially, a DUmin contour. Hence, designs that fall on the PAEmin = 64% contour are also designs for which DUmin = 0.80. The relationship between these two performance indicators can be easily examined by creating a contour overlay.

The contour region with PAEmin > 60% (Figure 73) is wide and extends across the range of lengths and set widths examined. The implication is that that similar levels of performance can be achieved with a wide range of field configurations. It is important to note however, that calculations neglect wetted perimeter effects on infiltration. These effects cannot be quantified with the software but can be expected to vary with the unit inflow rate and, thus with field length. If infiltration conditions are determined with field evaluations, then infiltration and performance predictions will be most reliable for flow conditions close those observed during the evaluation.

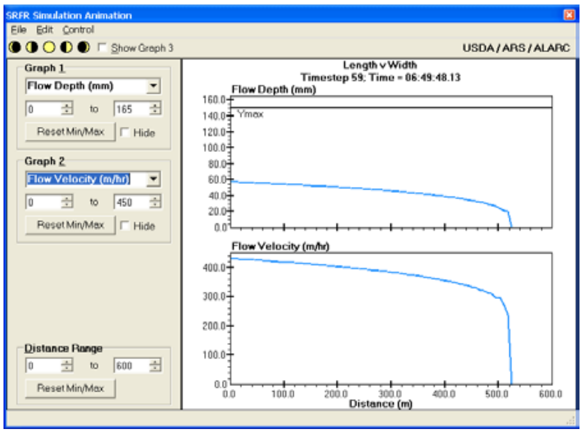


Figure 74. Using the Simulation Animation Window to display the flow depth and velocity for a selected solution point.

Farm operators generally try to maximize field length because it reduces the cost of the conveyance system and of operating farm equipment. However, longer fields require a higher unit inflow rate and present a higher risk of overtopping and hydraulic erosion. The **SIMULATION ANIMATION WINDOW,** shown in Figure 74 (F8) can be used to examine the depth and velocity profiles of any proposed solution. In this example, an initial solution of interest is an irrigation set 600 m long X 100 furrows wide. With this design, the upstream flow depth does not exceed 60 mm, which is less than half the depth of typical furrows. On the other hand, the flow velocity at the upstream end of the field is nearly 440 m/h (0.12 m/s or 0.4 ft/s), and thus less than the 0.15 m/s (0.5 ft/s) tolerance recommended by USDA-NRCS (1997)[6].

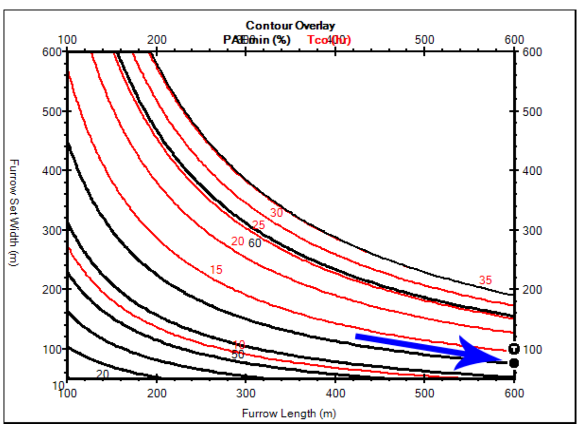


Figure 75. Overlay of PAEmin and Tco contours.

An irrigation set 600 m long X 100 furrow wide requires a 15 h cutoff time. The system will be easier to manage if Tco = 12h. Designs that satisfy this constraint can be easily examined with an overlay off the PAEmin and Tco contours (Figure 75). The figure shows that the two sets of contours run nearly parallel to each other. This means that all design combinations that produce maximum performance have nearly the same cutoff time (Tco = 15 h) while designs with Tco =12 h will necessarily result in a lower PAEmin (60%). As mentioned before, the design can be relaxed by targeting a minimum infiltrated depth less than the requirement. Thus, the following paragraphs examine how to identify a solution based on the requirements Tco = 12 h and Dlq = Dreq.

[6] This value is a broad guideline. Lower velocities may be required with highly erodible soils. The susceptibility of soils to water erosion depends on soil texture and structure, chemistry, and slope. In general, the potential for erosion has to be evaluated under local conditions. The USDA National Irrigation Guide provides additional guidance.

The process begins by selecting a design that nearly meets the above indicated requirement. One possible solution is a set 600 m long X 75 furrows wide, which is identified in Figure 75 with an arrow. Use the Water Distribution Diagram to select that combination as the solution point. The resulting Tco is 12.5 h while the potential performance is PAEmin = 60% , DUmin = 0.86. Use the **Simulation Animation Window** again to check the upstream flow depth and velocity conditions for this design.

The next step is to create an operational analysis scenario from that solution. Copy the design scenario into an operational analysis folder. This will create a scenario similar to the scenario "600 m X 75 furrows" in the "Selected solutions" folder.

From the Start tab, select the **Low Quarter** option in **Depth to Display**. The contour calculations will identify solutions that satisfy Dlq = Dreq. Also, select the contouring option **Develop contours as a function of inflow rate and cutoff time for a known set width**. Execute the Operational Analysis scenario. In the example file, the contouring range was set to 90-195 l/s for inflow rate and 10-18 h for cutoff time . These very wide ranges were selected in order to illustrate some important tradeoffs in performance. After calculations are complete, select the Dreq = Dlq tab (Figure 76). The AE curve displayed in this graph represents, in effect, PAElq as a function of Q for the

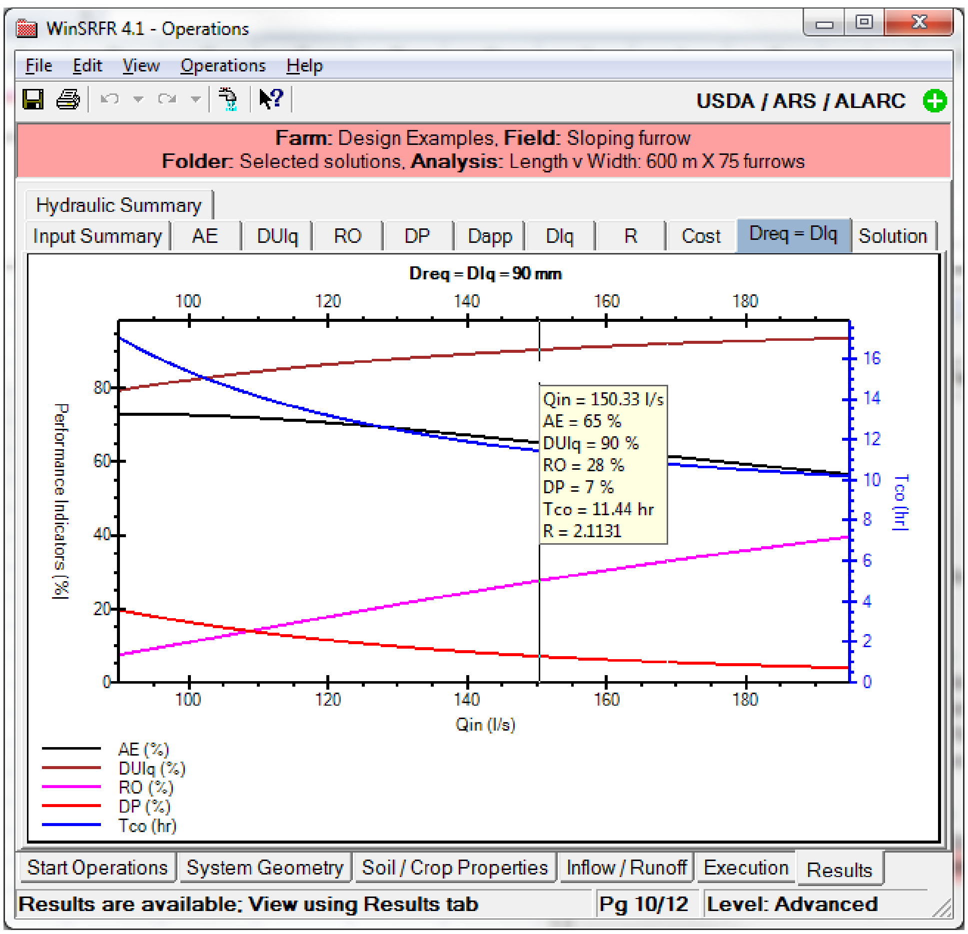


Figure 76. Dlq = Dreq graph for the design example.

given field layout. When navigating this graph with the mouse, the application displays balloon help with performance details for any selected solution point. This tool can be used to find solutions that satisfy a specified inflow rate or cutoff time. If the operation has to be based on the available flow (Q = 150 l/s), then Tco is 11.5 h, and the resulting PAElq and DUlq are, respectively, 65% and 0.91. If a 12 h Tco is enforced, then inflow rate has to be adjusted to 139 l/s. This combination improves PAElq slightly (67%) but at the expense of some loss in uniformity (DUlq = 0.90). AE can be improved even further by reducing the inflow rate, but this will also produce further reductions in DUlq and, more importantly, increase Tco. For example, if Q = 90 l/s, PAElq improves to 72% while Tco increases to 17 h. This represents a 40 h increase in the duration of the irrigation cycle for the entire field relative to the solution with Q = 139 l/s. The Q = 90 l/s solution has another undesirable property that will be discussed in the following section: it is relatively sensitive to inflow variations. Given the requirements of the problem, the proposed operation for the selected design (600 m X 75 furrows) is Q = 139 l/s and Tco = 12 h.

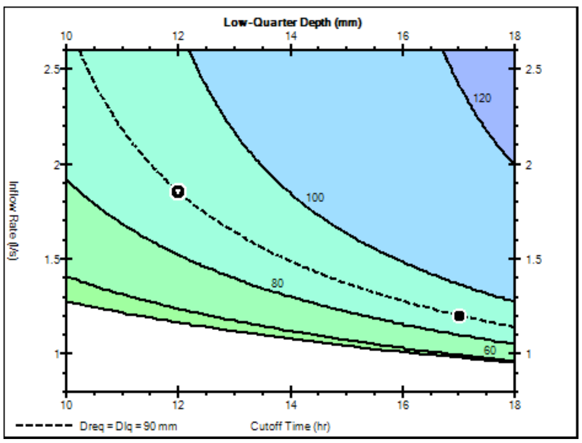


Figure 77. Dlq contour graph for the design example, based on a single furrow.

In furrow irrigation, the flow rate delivered to individual furrows will vary depending on how the inflow into individual furrows (i.e., the unit inflow rate qin) is controlled. According to Trout and Mackey (1988), this variability, expressed as a coefficient of variation (CV), can be as much as 15% when using siphon tubes, 25% when using gated pipe, and 29% when using feed ditches. Furrow-to furrow inflow variations will cause variations in applied water for the same cutoff time. It is of interest is to know the degree of under-irrigation that may result from this variation in applied water. This problem can be examined with the help of a Dlq graph (Figure 77) developed for an individual furrow (see the scenario "600 m X 1 furrow" in the Selected Solutions folder)[7]. The Dlq graph can be interpreted as a graph of adequacy of the low-quarter (ADlq = Dlq/Dreq). If the selected solution is Q = 139 l/s (for an average qin = 1.85 l/s and Tco = 12 h), and if it is assumed that (a) qin is controlled with siphon tubes (with a coefficient of variation of 15%); (b) that qin is statistically characterized by a normal distribution, and; (c) that infiltration conditions are spatially uniform, then qin will be greater than 1.4 l/s for 95% of the furrows[8]. This means that the Dlq of 95% of the furrows will be 74 mm or better (ADlq = 74/90 = 0.82).

Figure 77 can also be used to examine the implications of seeking a high application efficiency with a low Q value. In principle, the solution Q = 90 l/s, Tco = 17 h , (for an average qin = 1.2 l/s) can deliver a PAElq of 72%. However, that solution is located in a region where the contours are closely spaced, and thus, where performance is very sensitive to inflow rate and other uncertain design inputs. With that

[7] This graph is essentially identical to the Dlq graph of the "600 m X 75 furrows" scenario, with y values scaled by a factor of 75.

[8] The standardized deviate $z = (X - \mu)/\sigma$ for a normal distribution corresponding to a cumulative probability of 0.05 is $z = -1.645$ (where μ is the mean of the population and σ the standard deviation). If the mean qin is 1.85 l/s and CV = 15%, then $\sigma = 0.278$ l/s. Solving for X yields $X = \sigma z + \mu = 1.4$ l/s.

solution, and assuming the same variability in qin is as before, 21% of the furrows can be expected to have an ADlq less than 0.82[9] and in many of these furrows water may fail to reach the downstream end.

The proposed design assumes known, average infiltration and roughness conditions. In practice, those inputs cannot be determined precisely, and they vary within a field and throughout the irrigation season. This variability can compromise the performance of the irrigation system. Development of statistical measures of irrigation performance as a function of those uncertain inputs is desirable, but that requires knowledge of the statistical distributions of infiltration and roughness conditions. In the best of cases, those conditions will be determined from a limited number of field evaluations. More often, though, the available information will be generic, such as the infiltration family description provided by the USDA-NRCS soils database or the Manning roughness coefficients recommended by NRCS for different soil/crop conditions. The alternative, then, is to conduct simple sensitivity analyses with the proposed solution. The following discussion on sensitivity analyses will focus exclusively on infiltration, since it is the input that is more difficult to estimate.

It is impractical to try to define the range of infiltration conditions for sensitivity analysis from the parameters of infiltration formulations. A simpler alternative is to define that range using the concepts of Characteristic Infiltration Time (τ_c) and Characteristic Infiltration Depth (z_c). Then, variation is defined from the depth (volume per unit area) that can be infiltrated with a given opportunity time or alternatively, the opportunity time needed to infiltrated a target depth. In fact, most studies have examined infiltration variability in these terms rather than in terms of infiltration parameters.

The scenarios in the simulation folder "Sensitivity Analysis: 600 m X 75 furrows" show how to define different infiltration conditions by varying z_c for a given τ_c. The tests consider only variations from furrow-to-furrow (or border-to-border) and ignore the potential variability along the length of run. The design infiltration conditions are defined by the Kostiakov equation with k = 30.1 mm/h and a = 0.51. With Dreq = z_c = 90 mm, it follows that τ_c = 8.56 h. Assuming that the Kostiakov exponent a is constant for that field, a range of infiltration conditions can be defined by varying τ_c and calculating the resulting Kostiakov constant k. In the examples z_c varies by 0.5, 0.75, 1.0, 1.25 and 1.5 times the design value (45, 67.5, 90, 112.5, and 135 mm). The infiltration parameters needed to represent these infiltration conditions can be calculated by hand. Otherwise, WinSRFR can calculate the parameters by setting the infiltration function to **Characteristic Infiltration Time** (Soil and Crop Properties tab) and then entering the corresponding z_c in the **Characteristic Infiltration Depth** box. The resulting range for k is 15.05 mm/h^a < k < 45.16 mm/h^a. Use the Data Comparison Tool to compare the resulting infiltration functions.

Table 25 summarizes the performance indicators generated with these tests. Low infiltration rates (in particular z_c = 45 mm) lead to significant under-irrigation even though advance times are very short. The problem is, of course, that with a smaller z_c the characteristic infiltration time increases substantially (to 33 h in the case of z_c = 45 mm). With free-draining irrigation systems, the irrigation requirement simply cannot be satisfied if the characteristic infiltration time is larger than cutoff time . Higher than expected infiltration rates (z_c greater than the design value) result in much larger final advance times and lower values of DUlq, but the effect on AE is minor while the irrigation requirement is essentially

[9] If Q = 90 l/s (Tco = 17 h), then μ = 1.2 l./s and σ = 0.18 l/s. Using the Water Distribution diagram, select the solution with qin = 1.055 l/s and Tco = 17 h. That is the minimum inflow rate needed to produce a Dlq of at least 74 mm, and thus an ADlq of 0.82. To solve for the fraction of the population receiving less than this value we calculate z = (1.055 -1.2)/0.18 = -0.8055. From statistical tables, the cumulative probability for z = -0.8055 is 0.21.

satisfied, even with z_c = 135 mm (ADlq = 0.95). The proposed operational solution (Q = 139 l/s, Tco = 12 h) produces large runoff losses relative to deep percolation under the design infiltration conditions. This limits the effectiveness of the design when infiltration rates are low. A solution that balances runoff and deep percolation losses (Q = 150 l/s, Tco = 14 h) will perform better with lower than expected infiltration rates, but evidently will not perform as well if infiltration rates are larger than expected.

Table 25. Results of sensitivity tests for the design example.

z_c Mm	Dinf mm	Drz mm	Ddp mm	Dro mm	Dlq Mm	AE %	DUlq	ADlq	TL h
45	54	54	0	79	53	41	0.98	0.59	2.6
68	79	79	0	54	75	59	0.95	0.83	4.08
90	101	90	11	32	90	67	0.9	1	6.17
113	120	90	30	13	97	68	0.81	1.08	8.88
135	132	88	44	1	86	66	0.65	0.95	12.22

Overall, the analysis shows that the proposed physical configuration and operational solution will tolerate some variation in infiltration conditions from those assumed in the design. This has implications when dealing with furrow-to-furrow infiltration variability for a single irrigation event, or when dealing with changes in infiltration conditions from one irrigation event to the next. Furrow-to-furrow infiltration variability will cause variations in the time to advance to the end of the field. If average advance matches more-or-less the design advance time and the range of observed advance times is close to the range of predicted advance times, then it should be clear that the design is performing properly. Differences in advance time cause the ratio of deep percolation to runoff losses to shift, but do not necessarily cause changes in AE and ADlq. Some extreme under- or over irrigation can be expected for individual furrows, but those cases can be expected to be few if infiltration conditions follow a typical normal distribution. Adjustments to the inflow rate of individual furrows will mostly help reduce runoff losses. If average advance times depart from the design values from one irrigation event to the next, then adjustments to the inflow rate and cutoff time may be needed to meet the irrigation requirement. This is particularly true if advance times or infiltration rates are substantially lower than anticipated in the design.

In the above-presented example, z_c varied by ± 50%. Should a smaller or larger range of conditions be tested? This question is difficult to answer with our current understanding of infiltration variability. Few studies have quantified infiltration variability at the scale of entire furrows over a field and an irrigation season. Those studies, which reflect the combined effect of variable infiltration properties and variable inflow rate on final infiltration, suggest a coefficient of variation between 15 and 30% for infiltration depth for a fixed opportunity time. With such limited information, testing z_c within a range of ± 30 to 60% of the design value does not seem unreasonable. A surrogate measure of infiltration variability is the variability of advance times measured on a series of furrows (or borders/basins). If that type information is available for the field of interest of for a field with similar characteristics, then it could be used to define the range of infiltration conditions for a sensitivity analysis.

Scenario: Unit inflow rate v. Length, Kostiakov infiltration equation

This purpose of this example is to contrast the contours produced with the Length vs. Inflow Rate design option with those produced with the Length vs. Width design option. Inputs are the same as in the previous example. Rather than basing results on the total inflow rate Q, the analysis examines the flow in a single furrow. In some cases it is easier to examine the performance of irrigation systems in terms of unit flow rate. A recommendation for set width can then be developed by dividing the available flow rate by the recommended unit inflow rate. The subject scenario examines lengths in the range 100-800 m and unit inflow rates in the range 0.2-2 l/s. The recommended tuning point is 800 m X 2 l/s.

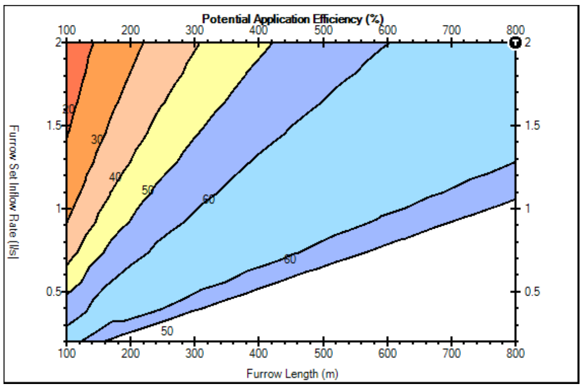


Figure 78. PAEmin contours generated with the Length vs. Inflow Rate design option.

The PAEmin contour graph for this example (Figure 78) shows how the unit inflow rate has to increase with increasing length to reach the maximum PAEmin and the same peak levels of performance are attainable width different lengths; PAEmin = 64% and DUmin = 0.8. Results also show that for a given length, near optimum performance can be achieved with a wide range of flow rates and, thus, that there is some flexibility in setting the unit inflow rate. For example, with a furrow 300 m long, PAEmin of 60% or greater can be attained with Q between 0.5 and 1.0 l/s. Larger inflow rates will result in higher uniformity but also larger runoff losses. Again, it is useful to inspect other performance contours generated with this scenario to better understand the relationship between performance indicators and extant design variables.

Scenario: Unit inflow rate v. Length, Modified Kostiakov infiltration equation

This companion scenario analyzes the same problem as above but uses the Modified Kostiakov infiltration equation to model infiltration. The following Modified Kostiakov parameters were assumed: k =26 mm/h^a, a= 0.35, b = 4 mm/h. Use the Data Comparison Tool to contrast the infiltration equation in this scenario with the equation in the previous scenario. The two equations follow each other closely for times less than t_c but diverge thereafter, because of the contribution of the steady infiltration-rate term.

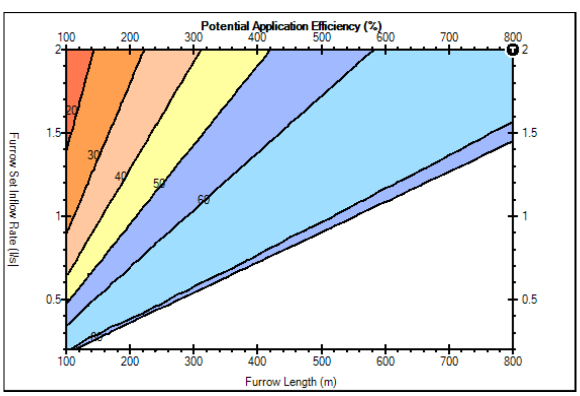


Figure 79. PAEmin contour graph for the design example: Inflow-rate vs. Width, Modified Kostiakov infiltration equation.

The PAEmin contour for this example is shown in Figure 79. The contours are indistinguishable from the previous figure, but only in the upper left-hand portion of the graph. Results do not match as length increases and Q decreases. The contour region with PAEmin > 60% is narrower than suggested by the results calculated with the Kostiakov equation. The reason for the difference is that the infiltration function is being extrapolated for longer times in the bottom –right region of the contour graph whereas the Kostiakov relationship inherently under-predicts infiltration rates at long times. This example shows that that physical design and operational analyses will be more conservative if based on the Modified Kostiakov equation, especially if the irrigation event will involve long application times.

Scenario: Sloping Borders

These examples examine the performance of sloping-border irrigation systems as a function of length and inflow rate per unit width. An open-end and a closed-end border are included. Infiltration conditions for both examples are the same, with infiltration given by the Modified Kostiakov formula with k = 38 mm/h^a, a = 0.4, and b = 20 mm/h. The target infiltration depth is 90 mm. The opportunity time needed to infiltrate this depth of water is 2 h. Hydraulic resistance is described by the Manning equation with n = 0.15. The open-end system has a slope of 0.002 while the slope for the blocked-end system is 0.001. Contour graphs were generated for the same plotting ranges (100-500 m and 1-10 l/s) and the same tuning point (400 m, 10 l/s).

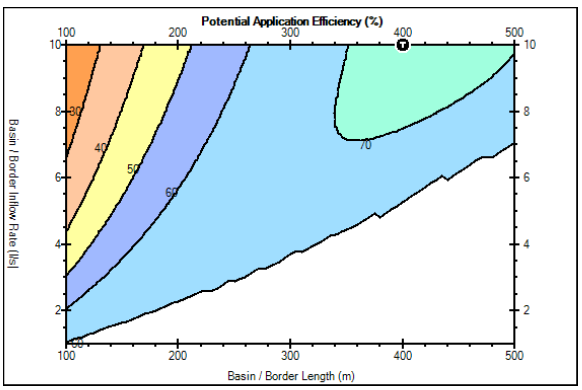


Figure 80. PAEmin contours for open-end, sloping border design example.

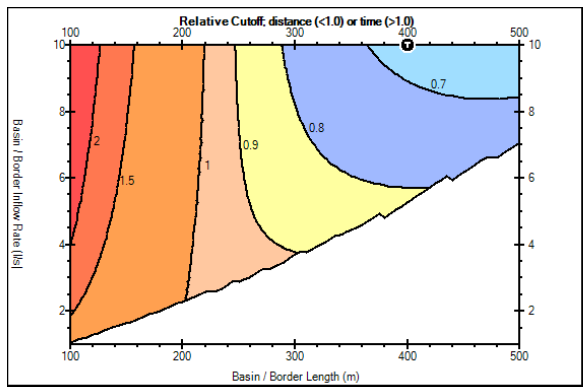


Figure 81. R contours for the open-end, sloping border design example.

Scenario: Sloping Border-Open End

Figure 80 shows the PAEmin contours for the open-end scenario. The relationship between PAEmin and the design variables is similar to the one presented earlier for sloping furrows. The unit inflow rate has to increase as field length increases to achieve peak levels of performance. The border width will be determined then from the available flow, which for a design problem generally will be fixed. Thus, longer fields will require a narrower border. Another limitation to selecting a long field for the design is the potential for erosion, which as has been discussed above, can be examined with the help of the software. Assuming that these two issues are not a concern, a third factor that should be considered is the relative cutoff time. With border irrigation it is not uncommon for cutoff to occur prior to time advance is completed (TL). However, as the ratio of advance distance at cutoff time (x_A) to field length (L) decreases, advance predictions become increasingly unreliable. This problem can be examined with the R contours (Figure 81). Within the contours, R is equal to x_A/L if $Tco \le T_L$, and equal to Tco / T_L if $Tco > T_L$. Increasing field lengths require smaller values of R. This is a consequence of the larger volume of surface storage that results from applying a higher inflow rate. A theoretical limit has been suggested for the minimum acceptable value of R (0.85) for level-basin systems but a comparable criterion has not been developed for sloping borders. Considering potential variations in inflow rate and infiltration conditions, a conservative design approach is to try to get the value of R as close to 1 as possible. For this scenario, a field length of no more than 220 m will result in a value of R equal to or greater than 1. To achieve the best performance with a field 400 m long, inflow has to be cutoff before water advances to 70% of the field length.

Figure 82 is the PAEmin contour graph for the same example but with a blocked end. Evidently, higher levels of better PAEmin can be attained when runoff losses are eliminated. In fact, results suggest a PAEmin of 90% for a 300 m long border with inflow qin = 7.5 l/s/m. Note, however, that the range of flow rates that will deliver maximum performance is very narrow. This means that the expected levels of performance shown the graph will likely not be realized if design conditions (flow rate, infiltration, etc.) are not exactly as assumed in the design. However, this is not a severe problem because performance will still be better than without a blocked end.

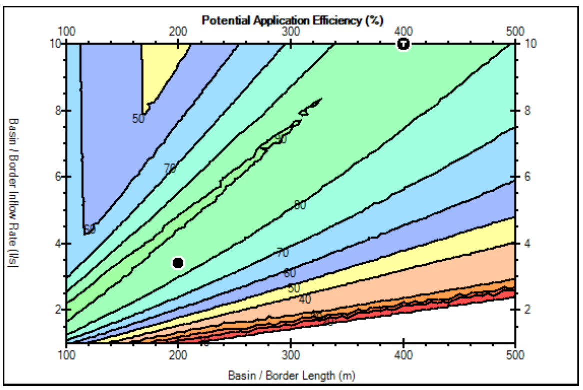


Figure 82. PAEmin contours for the closed-end, sloping border design example.

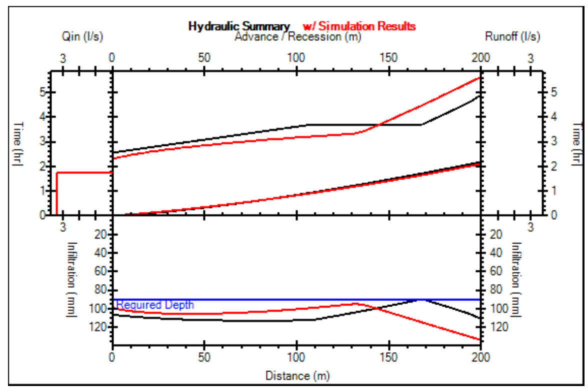


Figure 83. Hydraulic Summary for a selected solution point, closed-end sloping border design example.

Volume balance procedures used to generate the contour plot are less accurate for closed-end sloping border systems than for other systems[10]. Consequently, it is particularly important in these cases to inspect the Hydraulic Summary tab and compare the hydraulic performance computed with the volume balance and unsteady flow solution for any selected solution point. Figure 83 is the Hydraulic Summary Tab generated for the solution point L = 200 m, qin = 3.4 l/s/m. For this point, the volume balance recession predictions differ noticeably from the unsteady flow computations and this affects the final infiltration profile. However, the final performance-indicator values (AE, DUmin, etc.) are not very different. For other points in the contour region, advance predictions can differ substantially and in those cases performance calculations will be unreliable. In general, large differences between the volume balance and unsteady flow solutions are an indication of solutions with undesirable hydraulic characteristics. Those solutions should be avoided.

An important feature of solutions for closed-end systems is that the recommended design may not produce a minimum depth at the downstream end of the field, as is typically the case with open-end systems. This is illustrated with the selected solution point of Figure 83. In this case, the point of

[10] With sloping border systems, the surface profile after water reaches the end of the field is difficult to predict. In addition, advance time predictions becoming increasingly uncertain when R is much less than 1.

minimum infiltration is at about 130 m from the inlet (according to the unsteady simulation results - red line) and most of the deep percolation occurs at the downstream end. In other cases, the point of minimum infiltration can be located at the upstream end of the field. This variation in the location of the point of minimum infiltration explains the rapid variations in performance suggested by Figure 82 as a function of the design variables. Changes in the infiltration profile with length and inflow rate can be easily examined with the Water Distribution Diagram, as explained previously. Large percolation losses at the downstream end of a field are also an indicator of large flow depths that can potentially overtop the border berms and submerge the crop for long times. Either the Simulation Animation Window or the Simulation Network can be used to inspect the evolution of flow depths at the downstream end of the field. This feature points to an important challenge when designing these types of systems. Actual field conditions different from those assumed in the design can cause substantial increases in the ponding depth at the downstream boundary and prolonged periods of inundation that could be damaging to the crop.

Scenario: Level Basins

With level systems, there is significant risk that water will not reach the end of the field when the advance distance at cutoff time is less than 85% of the total length. This limit was developed from theoretical simulation studies. Thus, basin design is different from other systems in that WinSRFR plots results only for combinations of the design variables that result in advance ratios R greater than 0.85.

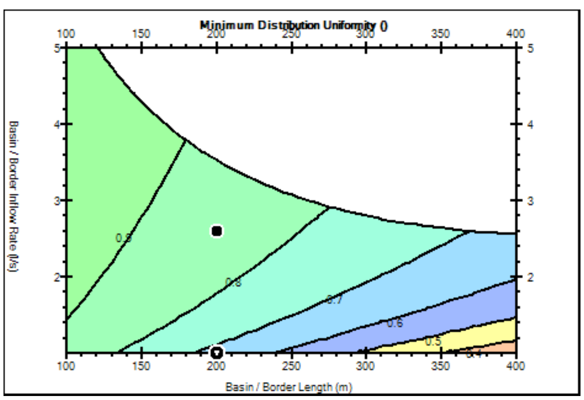


Figure 84. PAEmin contours for level basin example (Dead-Level).

Figure 84 illustrates the PAEmin contour graph for the example Dead-Level scenario in the Level Basin case folder. Infiltration is modeled with the Modified Kostiakov equation and the characteristic infiltration time is nearly 5 h. The white area represents solutions that require an R < 0.85. Navigating with the cursor over this area will generate a message that the limit line has been exceeded. The behavior of R as a function of the design variables can be easily examined with the R contours. Notice that the contours show more gradual changes in performance that for the graded border case of Figure 82. The reason is that with level basins, the point of minimum infiltration is always at the downstream end.

Finding an appropriate calibration point may be more challenging with level basins than with other systems. The software will not allow a calibration point to be located in an area where the R < 0.85 and will suggest an alternate location. As in the closed-end, sloping border case, it is important to compare volume balance and unsteady simulation results at any desired solution point. The volume balance procedures are more accurate for level basins than for graded borders, but recession time predictions can be slightly inaccurate.

The Level-Basin case folder contains a second scenario labeled Low-Gradient. The inputs are the same as for the Dead-Level example except for the value of slope, which is equal to 0.0002. Systems with these very small slopes are common in the southwestern USA and are often referred to as level-basin systems, while those systems with actual zero slope are referred to as dead-level systems. The objective of this example is to show the impact that this small slope has on performance in relation to the dead-level example.

Figure 85 illustrates the PAEmin contours for this example. These contours are, in principle, similar to those of Figure 84, except for the fact that the software does not leave blank the area with solutions with small R. The results suggest , however, higher levels of performance that with the dead-level example. The same solution point was selected from both contours, L = 200 m and qin = 2.6 l/s/m. Run these scenarios and compare the resulting performance indicators. Before selecting a low-gradient over a dead-level design under the given conditions, it is important to compare their sensitivity to potential variations in infiltration conditions.

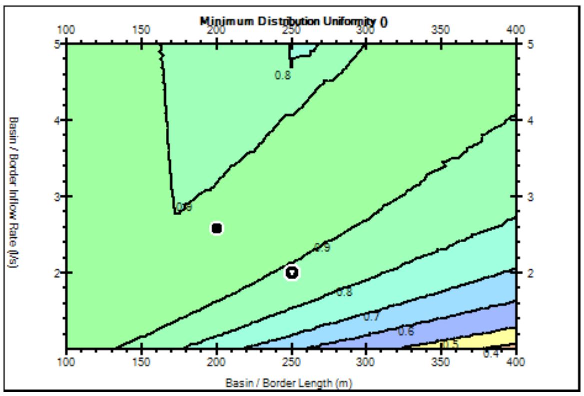


Figure 85. PAEmin contours for level basin example (Low-Gradient)

Part III. Advanced Features

10 Working with Scripts

New in WinSRFR 4.1 is the ability to run batch simulations. Two approaches are available. One is to develop an external application that calls the simulation engine, SRFR 5. SRFR 5 has an Application Programming Interface (API) that exposes many of its objects to users. Programming expertise is required to use this approach. The second approach, discussed in this section, is to use scripts, a rudimentary programming language internal to the application. The scripting language of WinSRFR is a mechanism for communicating with the user interface. It was developed for research purposes prior to the development of SRFR 5 and its programmable API. Scripts are easy to use and no programming experience is required. However, since scripts interact with the user interface, a batch job implemented with scripts will necessarily run more slowly than one implemented directly with the SRFR 5 API. Selecting the best approach for a particular batch job will depend on the job data input/output requirements and whether those requirements can be met with scripts, the number of simulations that need to be executed, and the time needed to develop an application that calls the SRFR 5 API. With a little bit of experience, batch job can be generated in just a few minutes with scripts.

There are two types of scripts. Command Line Scripts are used to set computational options, such as selecting between furrow/ basin/border, set singled-valued inputs such as field length or a flow rate value for a standard hydrograph, and running a simulation. They cannot be used to input series data, such as a tabulated inflow hydrograph (discharge vs. time). Command Queries retrieve outputs and save them to a file. Singled-valued and series outputs can be extracted with Command Queries.

Scripts are provided to WinSRFR as text tables. These tables, called Tabulated Scripts, can be written as either tab or comma-delimited files (with a .txt or .csv extension, respectively). Any spreadsheet program can be used to create a tabulated script .csv file while any text editor can be used to create and edit .txt files. Separate tabulated scripts are needed for input and output.

10.1 Run Multiple Simulations Dialog

A batch job is executed from the Simulation World by selecting the `Simulation/Run Multiple Simulations` menu command. This will bring up the **RUN MULTIPLE SIMULATIONS** dialog. Required inputs are:

- **Input File**: Enter the name of the tabulated script input file in this field. This is a read-only file. It is used to specify the inputs for each simulation in a batch job. Optionally, it also specifies the names of files to which time-series outputs (e.g., Advance, Recession and Infiltration) will be saved.

- **Output File**: Enter the name of the tabulated script output file in this field. This is a read/write file that will be modified during execution of the batch job. The file specifies the single-valued outputs that that will be saved after each simulation. Outputs from each run are appended to the end of this file.

- **Pre-Clear Results** . This check box determines what will happen with previously computed results in the output file. If this box is cleared, old outputs will be preserved and new outputs will be appended to the end of file. If the box is checked, old results will be removed before storing new results.

- **Stop on First Error.** This check box determines how the application will handle warning messages from the SRFR engine. The SRFR engine will issue those messages when the simulated event lasts longer than a week or when the allowable number of computational time steps is exceeded. If the box is checked, the application will allow the SRFR engine to generate a warning. Then, execution of the batch job cannot continue until the user responds to the message. If the box is cleared, the messaging system will be disabled. The application will terminate the particular simulation, write an error report to the output file, and continue the batch job without further user input.

10.2 The Scripting Language and the Script Recorder

A script is a text string used to build and parse a command. The syntax is defined by the Command and Query script languages. These languages can be displayed with the Script Recorder, which is accessible from the Simulation World's File menu (`Scripting/View Command Language` or `Scripting/View Query Language`).

Figure 86 is a screenshot of the Script Editor displaying part of Command Script language. The lines preceded by an apostrophe are comments. Other lines are elements of the script language. The first word in each line is a keyword that represents a variable name. Keywords are closely related to the variable names displayed by the user interface and, thus, are self explanatory. As will be described in the following sections, keywords are used as column headers in a tabulated script. The remainder of each line identifies either the data type or the possible value(s) for that variable. For example,

- CrossSection Basin | Border | Furrow: CrossSection is the keyword (column header) while Basin, Border or Furrow are the values that can be assigned to that variable as data in the tabulated script file. Hence, the Command Script "CrossSection Basin" sets the system type to Basin.
- Slope double: Slope is the keyword and, thus, a column header. The data for this variable is a double-precision value. The script "Slope 0.004" sets the field slope to the value 0.004.

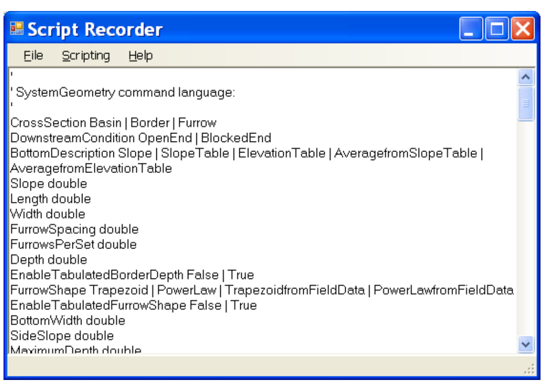


Figure 86. Script Editor displaying a part of the Command Script Language

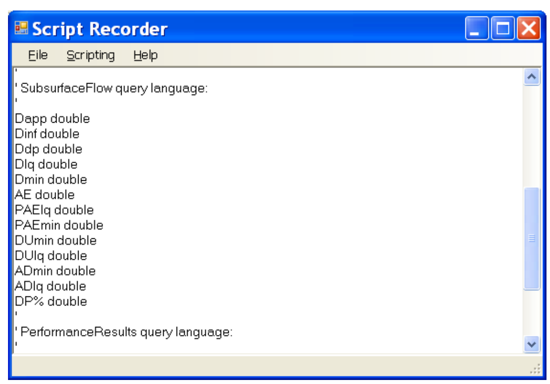


Figure 87. Script Editor displaying part of the Query Script Language.

An example of the Query Language is displayed in Figure 87. The Query language depends on the outputs generated by a simulation and, thus, is viewable only after running a simulation. As in the Command Language, the first word in each line is the keyword. The rest of the line describes the type of data returned by the query, for example:

- Dapp double: Dapp is a keyword and double indicates that a double value will be returned.

10.3 Input File

Tabulated script files contain data (text) that is translated by the application (specifically, by its Command Interface) into scripts. The structure of a tabulated input file is the same for both comma-separated or tab delimited files. Figure 88 illustrates a .csv file written with Microsoft Excel©.

A tabulated script file can specify every single input required for a batch job, or only those inputs that will be varied. In the figure, only two variables are changing as part of the job - length and inflow rate. "Length" and "InflowRate" are script language keywords. All other variables, such as slope, infiltration parameters, hydraulic resistance parameters, cutoff time, etc., do not change during the execution. The data for those variables can be entered through the tabulated script file (represented by a column of constant data), or through the user interface.

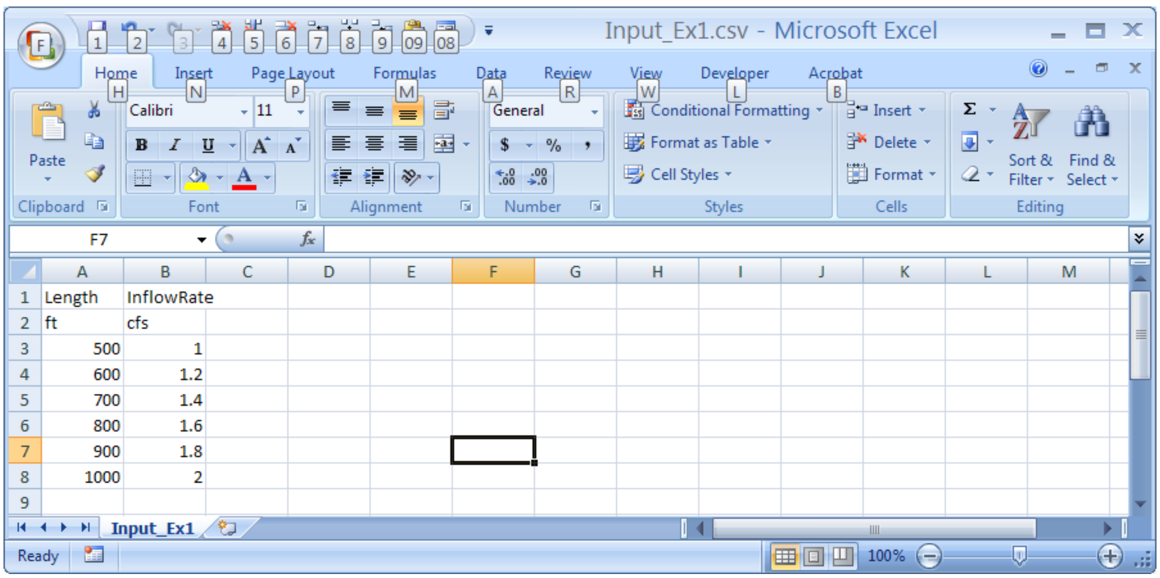


Figure 88. Tabulated script input file.

The first row in the tabulated script input file lists the keywords that will be specified during a batch job, one per column. The second row may contain data (variable values) or unit information. If all of the data is given in project units[11], units information is not needed and data can be entered starting in row 2. If the units of one or more variables are different from the project units, then they must be declared using the unit identifiers of Table 1. For example, if furrow length is an input variable, and the project units for length are m, then those data will be assumed to be given in m unless the unit label indicates they are given in ft. Units can be declared in two ways. They can be included next to the variable name, enclosed in parentheses. Alternately, they can be specified in row 2, but without parentheses. If the latter approach is taken, data will be provided starting in row 3, as in the example. Only one unit declaration method can be used in a file.

[11]Project units are the units set with the Edit/Units command. These are different than the units selected under User Preferences (which set the default units for new projects) or the units selected for individual input controls.

A Command Line Script is built by the application by combining the keyword with its arguments - the value and the unit label (if given). The example of Figure 88 defines six simulation runs. The first data row in the example is translated by the command interpreter into the following Command script:

- Length 500 ft
- InflowRate 1 cfs

The first script sets the field length to 500 ft while the second sets the inflow rate to 1 cfs. After finding the last data item in a row, the application inserts a Command script that causes the simulation to execute (Simulation Run).

Several things need to be kept in mind when writing Command tabulated scripts.

The simulation engine will not be able to access data specified with Command scripts if other current configuration options, specified either through the user interface or by other Command scripts, do not provide a path to those data. For example, “InflowRate 1 cfs” will write a 1 cfs value to the Inflow Rate input box. This box can be viewed in the user interface, and thus accessible to the simulation, only when the **INFLOW METHOD** is **Standard Hydrograph**. If the **INFLOW METHOD** is set to **Surge**, then the simulation will operate on the value displayed in the surge Inflow Rate input box (SurgeInflowRate).

Several input controls trigger a procedure (an OnChange Event) when their value changes. That procedure changes the display of other configuration options and/or populates other input controls. An example is, of course, the System Type option buttons (Furrows vs. Basins/Borders). OnChange Events do not execute when values are written with scripts. As a result, input controls variables are not repopulated. This means that the values of variables associated with those controls have to be specified with scripts. As an example, when the **Green-Ampt** **INFILTRATION FUNCTION** is selected, the **SOIL CROP PROPERTIES** Tab displays a **SOIL TEXTURE** drop-down box. Selections with this control from the user interface changes the values of the Green-Ampt parameters. The command script “SoilTexture Clay” will change the value of the data structure associated with the **SOIL TEXTURE** input control, but will not force the input boxes for the Green-Ampt parameters to be repopulated. These inputs have to be provided with scripts. The same problem occurs when defining infiltration with the NRCS intake families or the Time-Rated intake families.

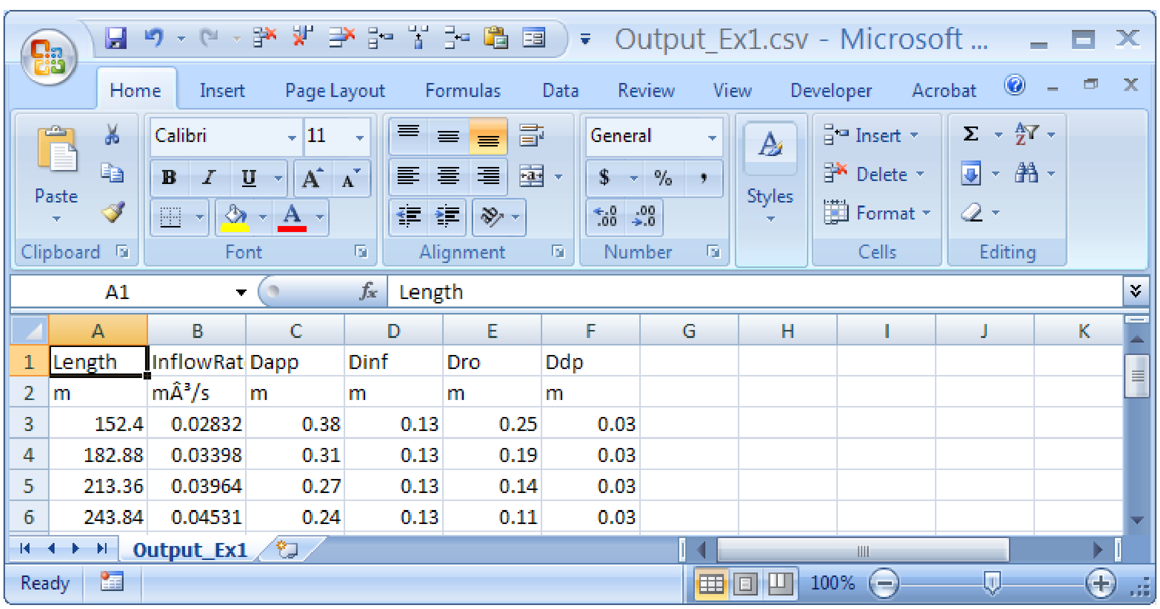
Batch jobs are designed to test a range of conditions. Those conditions may, inadvertently, include scenarios that cause computational problems and trigger the messaging system of SRFR. For example, a simulation with advance-distance based cutoff will run into problems if the inflow rate is too small for the given infiltration conditions and field length. This situation will eventually cause the number of computational time steps to exceed a limit internal to the application. When this happens, SRFR stops the computations and offers the user the choice of increasing the number of time steps or end the simulation. The batch job will not proceed until the user responds. Problems of this type can arise even when cutoff is time based. When running large batch jobs, the SRFR messaging system needs to be disabled (see section 10.1). Care must be exercised when running simulations in which cutoff is determined on the basis of advance.

Lastly, section 4.3 discussed the messaging system of WinSRFR. The application validates the inputs and will not allow a simulation, evaluation, operational analysis, or design scenario to execute if the data are incompatible. A scenario with incompatible data will cause the batch job to be terminated. Incompatibilities are more likely to occur when running batch jobs that include furrows and basins/border, as furrows have many more configuration options. In general, batch jobs should deal with only one type of system.

10.4 Output File

The tabulated script output file (Figure 89) is used to build Command Queries for singled-valued results. These tabulated scripts are simpler than the input scripts. Only output keywords are required in row 1, one per column. Project units will be used on output and will be listed in the second row with requested results. Each simulation run will append a new row of results to the end of the file. The sample Input File described previously will produce six rows of results added to this file. In Figure 89, the tabulated script is used to extract the applied depth (Dapp), the average infiltrated depth (Dinf), the runoff depth (Dro), and the deep percolation depth (Ddp). For documentation purposes, input data should also be included in the output file, especially when running multiple batch jobs. Inputs specified through the user interface can be included in the output file. In the example, Length and InflowRate are displayed in the output file along with the results of interest.

The only variables that can be listed in a Query script file are those that will be available as the product of a simulation. They can be listed in any order because the scripts are simply reading data from the available data structures.



	A	B	C	D	E	F
1	Length	InflowRat	Dapp	Dinf	Dro	Ddp
2	m	mÂ³/s	m	m	m	m
3	152.4	0.02832	0.38	0.13	0.25	0.03
4	182.88	0.03398	0.31	0.13	0.19	0.03
5	213.36	0.03964	0.27	0.13	0.14	0.03
6	243.84	0.04531	0.24	0.13	0.11	0.03

Figure 89. Tabulated script output file, after execution of the batch job.

10.5 Extracting Series Results

Scripts can be used to extract computed time and space series. This information must be provided through the Input File because the output file is reserved for singled-value results. Series data that can be extracted are:

Table 26. Series results that can be extracted with Tabulated Scripts.

Keyword	Description
Advance	The advance trajectory (distance X vs. time T)
Recession	The recession trajectory (distance X vs. time T)
Infiltration	Final infiltration profile (infiltrated depth Z vs. distance X)
Hydrograph	A time series (a user-selected flow variable vs. time T)
Profile	A space series (a user-selected flow variable vs. distance X)

Different types of hydrograph and profile data can be extracted, as will be noted in the following paragraphs. Series data are saved to individual .txt files, one for each combination of scenario and output series .

Figure 90 illustrates the structure of a tabulated script that extracts the advance and recession trajectories, and the final infiltration profile. The series type is specified in row 1, using the keywords of Table 26. A single argument will be provided either in row 2 or 3, depending on whether row 2 is used to specify input units. The single argument is the base name of the output files that will be used to save the results. During execution of the batch job, a counter-generated number is appended to the base name. Hence, in the example, the batch job will generate six files AdvCurve#.txt and six files InfCurve#.txt, where # is a number between 1 and 6. Series are saved using project units. Thus, restatement of units is not required.

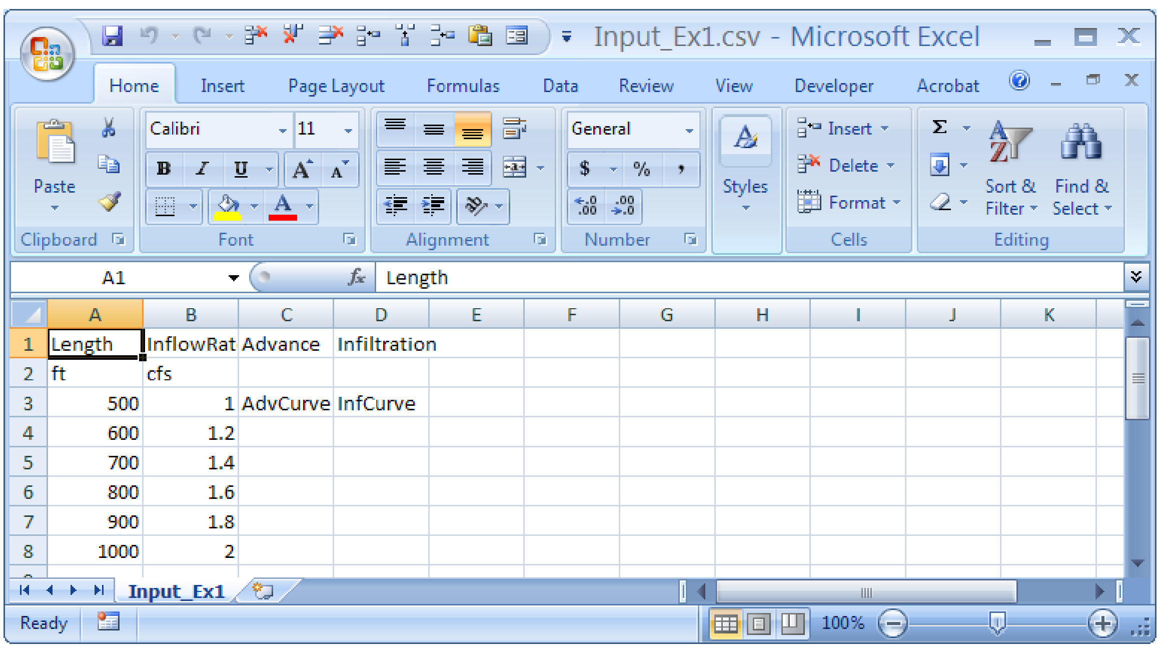


Figure 90. Structure of a tabulated script that extracts the advance and final infiltration series.

A script that extracts a hydrograph or profile series requires two more arguments. The first is the name of the requested flow variable. Flow variable names recognized by the application are shown in Table 27.

Table 27. Flow variables that can be extracted as a hydrograph or profile series.

Variable name	Description
Y	Surface-flow depth
AY	Surface-flow area
Z	Infiltrated depth (volume per unit length per unit width)
AZ	Infiltrated volume per unit length
Zwp	Infiltrated depth adjusted by the wetted perimeter
Q	Flow rate
V	Flow velocity

The second argument specifies either the location of a hydrograph, or the time for the requested profile data. This information is provided in row 1, next to the Hydrograph or Profile keyword. Figure 91 illustrates the structure of a script that extracts a flow-depth hydrograph located at a distance of 50 ft from the inlet, and an infiltration profile at 1 hour into the irrigation. Note that no space is left between the distance/time value and its units label. As in the example of Figure 90, the first row of data is used to enter the name of the text files used for output.

An example that shows how to extract series results is included in the examples directory. The WinSRFR file is Test_batchSimulations.srfr, the script input file Input_SeriesExample.csv and the output script file Output.csv.

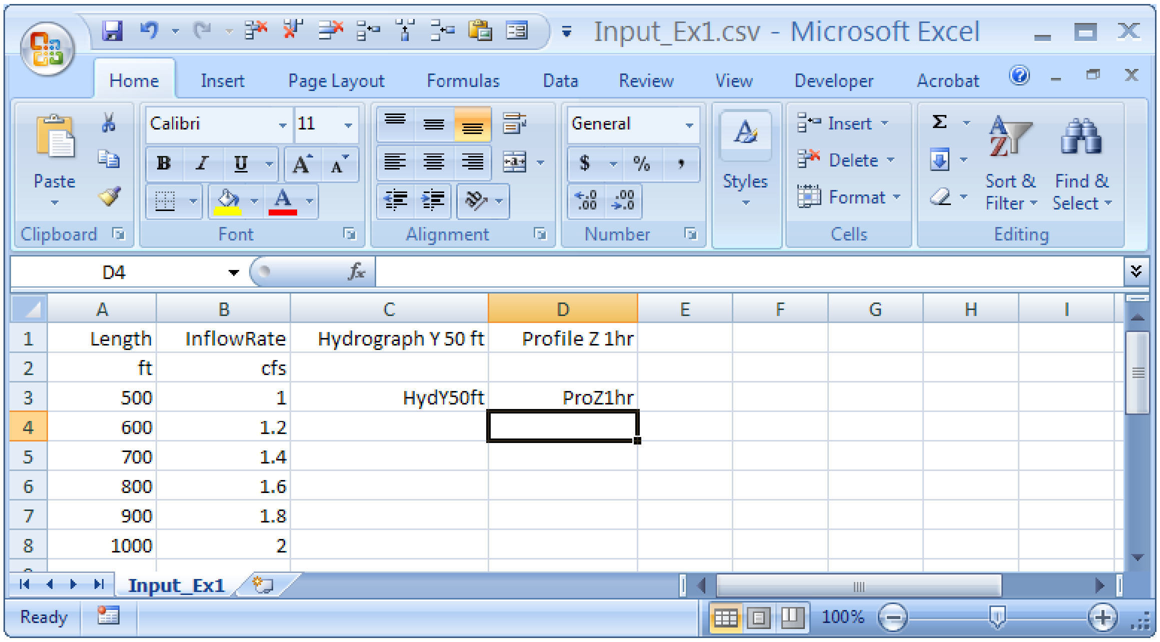


Figure 91. Structure of a tabulated script that extracts one hydrograph and one profile series.

10.6 Viewing the Scripting Language

Use the script Recorder to view the Command and Query languages. The scripting language is updated dynamically on the basis of the data structures required by a particular configuration (Command Language) or the data structures generated by a successful simulation (Query language). Hence, slightly different subsets of the language will be displayed by the Script Recorder depending on how the system is configured[12]. Appendices B and C are examples of subsets of the Command and Query languages. Most language elements included in the scripting language are included in those examples.

10.7 Recording, playing, and loading scripts.

The record, play, and load scripts functions were developed to support the development of applications intended to interact with the WinSRFR user interface. These functions are available from the `Scripting` menu. Tabulated scripts and the availability of the SRFR 5 API now make those functions of limited value for programmers. However, they can be used to help in learning the scripting language.

- `Record Scripts`: Use the Record Script menu item to start the Script Recorder's recording function. Use the WinSRFR user interface to edit the data. Each data change will generate a Command Line script that will be appended to the end of the Script Recorder screen. A sequence of scripts can be saved to a file. Stop Recording turns this function off.

[12] The scripting language also contains commands for variables that are not used currently and are not accessible through the user interface.

- `Play Scripts:` A saved script file can be loaded in into the Script Recorder and then executed with the Play Script menu item.
- `Load Scripts`: The Load Script menu item creates equivalent Command Lines scripts based on the inputs currently available to the user interface. For example, Load Script /System Geometry loads the commands necessary to define the System Geometry setup currently in memory.

11 The SRFR 5 Application Programming Interface

The functionality of the SRFR 5 simulation engine can be accessed through its API. Figure 92provides an overview of the SRFR 5 object hierarchy. The diagram identifies those objects that are exposed by the API. Properties and methods of those objects can be called programmatically.

Interested users are asked to submit a formal request for the SRFR 5 API documentation.

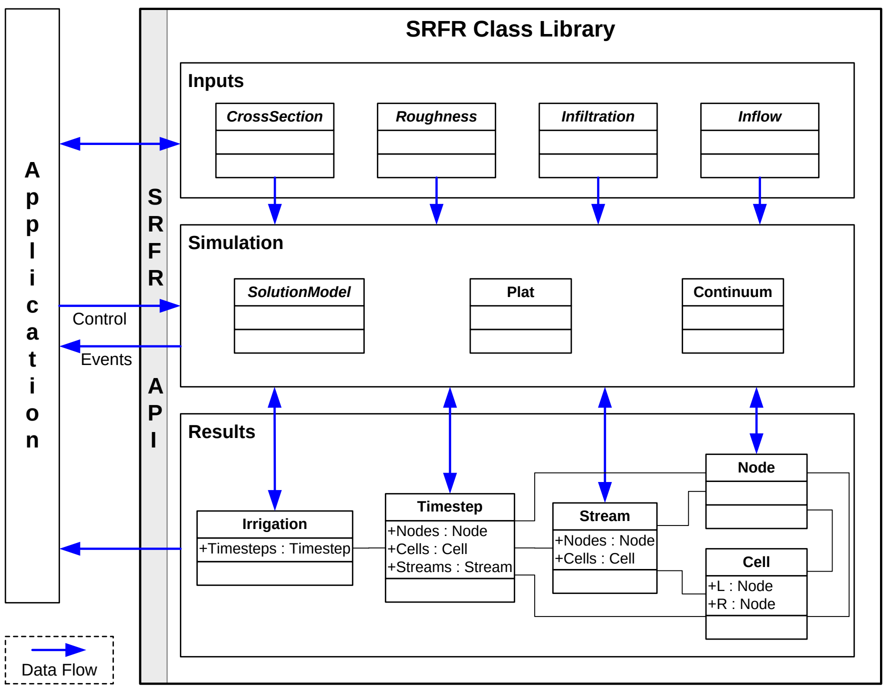


Figure 92. SRFR 5 Class Library

Part IV. References and Appendices

12 References

Bautista, E., Clemmens, A.J., Strelkoff, T.S., Schlegel, J. Modern analysis of surface irrigation systems with WinSRFR Agric. Water Manage., 96 (7): 1146-1154. (2009a)

Bautista, E., Clemmens, A.J., Strelkoff, T.S. Structured application of the two-point method for the estimation of infiltration parameters in surface irrigation J. Irrig. & Drain. Eng. 135 (5): 566-578. (2009b.)

Bautista, E., Strelkoff T. S., Clemmens A. J. Errors in Infiltration Calculations in Volume-Balance Models. J. Irrig. & Drain. Eng. 138(8): 727-735. (2012).

Blair, A.W. Smerdon, E.T. Effect of wetted perimeter on infiltration in furrows. Proc. Development and Management Aspects of Irrigation and Drainage Systems. Irrig. &Drain Div. Conference, ASCE. (1985).

Blair, A.W., Smerdon, E.T. Modeling surge irrigation infiltration. J. Irrig. & Drain. Eng. (ASCE), 113 (4): 497-515. (1987)

Bouwer, H. Unsaturated flow in ground-water hydraulics. J. Hydr. Div. ASCE. HY5: 121-144. (1964)

Bouwer, H. Rapid field measurement of air entry value and hydraulic conductivity of soil as significant parameters is flow system analysis. Wat. Res. Res. 2(4): 729-738.

Clemmens, A.J., Evaluation of infiltration measurements for border irrigation. Agric. Water Manage. 3, 251–267. (1981.)

Clemmens, A.J. Bautista, E. Toward physically based estimation of surface irrigation infiltration. J. Irrig. & Drain. Eng. 135(5):588-596. (2009).

Elliott, R.L. Furrow irrigation field evaluation data. Summers, 1977 to 1979. Dept. of Agricultural and Chemical Engineering. Colorado State University, Fort Collins, CO. (1980).

Fangmeier, D.D., Ramsey, M.K. Intake characteristics of irrigation furrows. Trans. ASAE 21 (4) 696–700, 705. (1978.)

Green, W. H., and Ampt, G. "Studies of soil physics, Part I—The flow of air and water through soils." J. Agric. Sci., 4, 1–24. (1911).

Kostiakov, A.N., On the dynamics of the coefficient of water percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. Trans. 6th Comm. Int. Soc Soil Sci. Part A, 17–21. (1932.)

Kozak, J.A., Ahuja, L.R. Scaling of infiltration and redistribution of water across soil textural classes Soil Sci. Soc. Am. J, 69 (3), pp. 816-827. (2005)

Izuno, F. T., Podmore, T. H. Kinematic wave model for surge irrigation research in furrows. Trans. ASAE, 28 (4): 1145-1150. (1985)

Izuno, F. T., Podmore, T. H., Duke, H. R. Infiltration under surge irrigation. Trans. ASAE, 28 (2): 517-521. (1985)

Merriam, J.L., Clemmens, A.J., Time rated infiltrated depth families. In: Keys, C.G., Ward, T.J. (Eds.), Development and Management Aspects of Irrigation and Drainage. Proc. Specialty Conference, Irrig. & Drain. Div., ASCE, San Antonio, TX, July 17–19, pp. 67–74. (1985.)

Merriam, J.L., Keller, J., Farm Irrigation System Evaluation: A Guide for Management. Agricultural and Irrigation Engineering Department, Utah State University, Logan, UT, 271 p. (1978.)

Mezencev, V.J. Theory of formation of the surface runoff. Meteorol. Gidrl. 3: 33-40. (In Russian) (1948)

Morel-Seytoux, H.J., Khanji, J. Derivation of an equation of infiltration. Wat. Res. Res. 10(4): 795-800. (1974).

Neuman, S.P. Wetting Front Pressure Head in the Infiltration Model of Green and Ampt. Wat. Res. Res. 12(3) : 564-566. (1976)

Oyonarte, N. A., Mateos, L., & Palomo, M. J. Infiltration variability in furrow irrigation. Journal of Irrigation and Drainage Engineering, 128(1), 26-33. (2002).

Rawls, .J., Brakensiek, D.L., Saxton, K.E. Estimation of soil water properties. Tr. ASAE. 25(5): 1316-1320. (1982)

Saxton, K.E., Rawls, W.J. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal, 70 (5), pp. 1569-1578. (2006)

Strelkoff, T.S. “SRFR: A computer program for simulating flow in surface irrigation: Furrows-basins-borders.” WCL Rep. No. 17, Water Conservation Laboratory, Phoenix. (1990.)

Strelkoff, T.S., Clemmens, A.J., Bautista, E. Field properties in surface irrigation management and design J. Irrig. & Drain. Eng. 135 (5): 525-536. (2009)

Trout, T. J., & Mackey, B. E. Furrow inflow and infiltration variability. Trans. ASAE, 31(2), 531-537. (1988).

Walker, W.R., Skogerboe, G.V. *Surface Irrigation: Theory and Practice*. Prentice Hall. (1987).

Walker, W.R. SIRMOD III—Surface Irrigation Simulation, Evaluation, and Design. Guide and Technical Documentation. Dept. of Biological and Irrigation Engineering, Utah State Univ., Logan, UT. (2003).

Walker,W.R., Prestwich, C., Spofford, T. Development of the revised USDA-NRCS intake families for surface irrigation. Agric. Water Manage. 85 (1–2), 157–164. (2006.)

Warrick, A.W. Soil Water Dynamics. Oxford University Press. (2003).

Warrick, A.W., Lazarovitch, N., Furman, A., Zerihun, D. Explicit infiltration function for furrows. J. Irrig. & Drain. Eng., 133(4): 307-313. (2007).

Warrick, A.W., Lazarovitch, N. Infiltration from a strip source. Water Res. Res. 43 (3): W03420. (2007).

USDA-SCS (US Department of Agriculture, Soil Conservation Service), National Engineering Handbook. Section 15. Border Irrigation. National Technical Information Service, Washington, DC, Chapter 4. (1974.)

USDA-SCS (US Department of Agriculture, Soil Conservation Service), National Engineering Handbook. Section 15. Furrow Irrigation. National Technical Information Service, Washington, DC, Chapter 5. (1984.)

USDA-NRCS (US Department of Agriculture, Natural Resources and Conservation Service), National Engineering Handbook. Part 652. Irrigation Guide. National Technical Information Service, Washington, DC. (1997).

USDA-NRCS. Estimating Soil Moisture by Feel and Appearance. ftp://ftp-fc.sc.egov.usda.gov/MT/www/technical/soilmoist.pdf. (1998).

13 Appendix A: Standard, Advanced, and Research Level User Options

TAB	OPTIONS	USER LEVEL		
		Standard	Advanced	Research
Geometry				
	Furrow shape and dimensions vary with distance (Tabulated)	FALSE	TRUE	TRUE
	Slope	TRUE	TRUE	TRUE
	Slope Table	TRUE	TRUE	TRUE
	Elevation table	TRUE	TRUE	TRUE
	Average from elevation table	TRUE	TRUE	TRUE
	Average from slope table	TRUE	TRUE	TRUE
Soil and crop properties				
	Manning n	TRUE	TRUE	TRUE
	Manning An/Cn hydraulic roughness	FALSE	FALSE	TRUE
	Sayre-Albertson hydraulic roughness	FALSE	FALSE	TRUE
	Space- variable hydraulic roughness	FALSE	TRUE	TRUE
	Vegetative density used for hydraulic roughness calculations	FALSE	FALSE	TRUE
	All infiltration formulations (simulation)	TRUE	TRUE	TRUE
	All wetted perimeter options (simulation)	TRUE	TRUE	TRUE
	Limiting infiltration depth	FALSE	TRUE	TRUE
	Infiltration properties vary with distance	TRUE	TRUE	TRUE
	Use approximate NRCS Intake Family	FALSE	TRUE	TRUE
	Time offset used to calculate infiltration, when c >0	FALSE	FALSE	TRUE
Inflow- Runoff				
	Standard hydrograph	TRUE	TRUE	TRUE
	Tabulated inflow	TRUE	TRUE	TRUE
	Surge irrigation	FALSE	TRUE	TRUE
	Cablegation	FALSE	TRUE	TRUE
	Upstream drainback	FALSE	TRUE	TRUE
	Cutoff option- distance and infiltration depth	FALSE	TRUE	TRUE
	Cutoff option- distance and opportunity	FALSE	TRUE	TRUE

	time			
	Upstream infiltration depth	FALSE	TRUE	TRUE
	Downstream boundary condition	TRUE	TRUE	TRUE
Execution				
	Solution model	FALSE	TRUE	TRUE
	Cell density	FALSE	TRUE	TRUE
Simulation Menus				
	Run multiple simulations	FALSE	TRUE	TRUE
	Scripting	FALSE	TRUE	TRUE
	View simulation network	FALSE	TRUE	TRUE
	View simulation debug windows	FALSE	FALSE	TRUE

14 Appendix B: Example of Script Command Language

```
'
' SystemGeometry command language:
'
BottomDescription Slope | SlopeTable | ElevationTable | AveragefromSlopeTable | AveragefromElevationTable
DepthDescription integer
Slope double
Depth double
Length double
Width double
FurrowShape Trapezoid | PowerLaw | TrapezoidfromFieldData | PowerLawfromFieldData
FurrowSpacing double
BottomWidth double
SideSlope double
MaximumDepth double
WidthAt100mm double
Exponent double
CrossSection Basin | Border | Furrow
Drainback False | True
DownstreamCondition OpenEnd | BlockedEnd
ElevationVariation integer
SlopeVariation integer
FurrowsPerSet double
EnableTabulatedBorderDepth False | True
EnableTabulatedFurrowShape False | True
'
' SoilCropProperties command language:
'
InfiltrationFunction CharacteristicInfiltrationTime | NRCSIntakeFamily | TimeRatedIntakeFamily | KostiakovFormula | ModifiedKostiakovFormula | BranchFunction
WettedPerimeterMethod LocalWettedPerimeter | FurrowSpacing(NoWPEffect) | NRCSEmpiricalWettedPerimeter | RepresentativeUpstreamWP
EnableLimitingDepth False | True
LimitingDepth double
CharacteristicInfiltrationDepth double
CharacteristicInfiltrationTime double
Kostiakova-CharTime double
Kostiakova double
Kostiakovk double
ModifiedKostiakovA double
ModifiedKostiakovK double
ModifiedKostiakovB double
ModifiedKostiakovC double
TimeRatedIntakeFamily double
Brancha double
Branchk double
Branchc double
Branchb double
NRCSIntakeFamily 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | 1.50 | 2.00 | 3.00 | 4.00
RoughnessMethod Manningn
EnableVegetativeDensity False | True
VegetativeDensity double
```

ManningN double
ManningCn double
ManningAn double
SayreAlbertsonChi double
NRCSSuggestedManningN 0.04 | 0.1 | 0.15 | 0.2 | 0.25 | 0.33
ErodibilityA double
ErodibilityB double
ErodibilityTauc double
ErodibilityBeta double
FullScaleG double
ErosionResolution Single | Field | Coarse(5) | Fine(9)
ErosionFit Piece-WiseLinear
ErosionCoefficient double
WaterTemp double
KinematicViscosity double
SedimentConcentration double
SedimentTime double
SedimentDistance double
EnableErosion False | True
EnableTabulatedInfiltration False | True
SoilTextureSelection Sand | LoamySand | SandyLoam | Loam | SiltLoam | SandyClayLoam | ClayLoam | SiltyClayLoam | SandyClay | SiltyClay | Clay
Green-AmptC double
EnableTabulatedRoughness False | True
TimeOffsetC False | True
EffectivePorosity double
InitialWaterContent double
WettingFrontPressureHead double
HydraulicConductivity double
NrcsToKostiakovMethod ApproximateByBestFit | DescribeByNRCSFormula
UserEnteredManningN double
Surge2+InfiltrationMethod Blair-Smerdon | Izuno-Podmore
'
' InflowManagement command language:
'
RequiredDepth double
UnitWaterCost double
InflowRate double
InflowMethod StandardHydrograph | Surge | TabulatedInflow
CutoffMethod Time-BasedCutoff | Distance-BasedCutoff | DistanceandInfiltrationDepth | DistanceandOpportunityTime | UpstreamInfiltrationDepth
CutoffTime double
CutoffLocationRatio double
CutoffInfiltrationDepth double
CutoffOpportunityTime double
CutoffUpstreamDepth double
CutbackMethod NoCutback | Time-BasedCutback | Distance-BasedCutback
CutbackTime double
CutbackLocation double
CutbackRate double
DrawDownTime double
Cost double
SurgeStrategy UniformTime | UniformLocation | TabulatedTime | TabulatedLocation
NumberofSurges integer
SurgeOnTime double
SurgeCutoffTime double
SurgeInflowRate double
SurgeCutbackTime double
SurgeCutbackRate double
FurrowSet integer
TotalInflow double
PeakOrificeFlow double

```
CutoffFlow double
PipeSlope double
PipeDiameter double
OrificeDiameter double
OrificeSpacing double
PlugSpeed double
Hazen-WilliamsPipeCoefficient double
OrificeOption EquivalentDiameter | PeakFlow
EnableFertigation False | True
'
' SurfaceFlow command language:
'
Overflow boolean
OverflowTime double
AdvanceTimetoFieldEnd double
PercentageRunoff double
RunoffDepth double
FlowDepth double
GrossAppliedDepth double
DrainbackDepth double
NRCSWettedPerimeter double
RepresentativeWettedPerimeter double
SimCutoffTime double
XaR double
OverflowDist double
SimAverageInflowRate double
VolumeError(%) double
MaxAdvanceDistance double
MaxAdvanceTime double
'
' SubsurfaceFlow command language:
'
ApplicationEfficiency double
MinimumPAE double
MinimumDistributionUniformity double
MinimumAdequacy double
AverageDepth double
MinimumDepth double
Low-QuarterDepth double
DeepPercolationDepth double
AppliedDepth double
Low-QuarterPAE double
Low-QuarterDistributionUniformity double
Low-QuarterAdequacy double
PercentageDeepPercolation double
'
' PerformanceResults command language:
'
XaR double
RVerr double
ErrorCount integer
'
' UnitControl command language:
'
SelectedTab StartSimulation | SystemGeometry | SoilCropProperties | Inflow/Runoff | DataSummary | Execution | Results
ProductName string
ProductVersion string
'
' SrfrCriteria command language:
'
SolutionModel Zero-Inertia | Kinematic-Wave
```

CellDensity integer
NondimensionalMode integer
GraphicProfile integer
RlLeft double
RlRight double
RyBottom double
RyTop double
RfsX double
RfsY double
RfsH double
RfsZ double
Rdfct double
Vdb1 double
Dtlrat double
IT40 integer
YtRec double
Qcoavg double
Nyubc integer
Niwait integer
Ndxkg integer
Idt integer
AutoRdt double
UniformityWeighting integer
StopWhenStagnant boolean
Rdtstg double
R0 double
R1 double
Fiflt double
Imax integer
TStop double
Rcmxr double
Rmmxr double
Jhi integer
Jlo integer
JMax integer
JCountMax integer
DiagFlags integer
StartI integer
StartJ integer
StartK integer
EndK string
DisplaySelections integer
DiagAux2Flags integer
DiagAux3Flags integer
DiagAux1Flags integer
DiagExpFlags integer
EnableDiagnostics False | True
'

15 Appendix C: Example of Scripting Query Language

```
'
' SurfaceFlow query language:
'
Overflow boolean
Tov double
TL double
RO% double
Dro double
Ymax double
DappG double
Ddb double
WPnrcs double
WPrep double
Tco double
XR double
Xov double
Q0avg double
Verr% double
XadvMax double
TadvMax double
'
' SubsurfaceFlow query language:
'
AE double
PAEmin double
DUmin double
ADmin double
Dinf double
Dmin double
Dlq double
Ddp double
Dapp double
PAElq double
DUlq double
ADlq double
DP% double
'
' PerformanceResults query language:
'
ErrorCount integer
'
' UnitControl query language:
'
ProductName string
ProductVersion string
RunCount integer
```