

A Software for Hydraulic Analysis of Linear-Move and Center-Pivot Irrigation Systems: *LincSys*, I. User Interface and Computational Module

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Abstract

LincSys is a software for simulating the hydraulics of linear-move and center-pivot irrigation systems. The term *LincSys* is a mnemonic for the phrase 'linear-move and center-pivot systems'. The *LincSys* software is comprised of a pair of executable files: a hydraulic simulation module, *HydrSimLaterals.exe*, and a graphical user interface (GUI), *LincSys.exe*, through which the user interacts with the hydraulic module. The user interface and the computational module are coupled through an application programming interface. The simulation module of *LincSys* is based on a numerical solution of the continuity and energy balance equations for one-dimensional steady pipe flow. The model can simulate the hydraulics of linear-move and center-pivot systems that use the following emission devices to meter outlet discharges along the lateral: (i) drop-tubes fitted with pressure reducing valve and emitter assemblies, (ii) drop-tube and emitter assemblies, or (iii) emitters placed directly on lateral outlet ports. The GUI of *LincSys* consists of a tabbed form with four windows, namely, the Systems-Projects, Input, Output, and Charts tabpages. Each tabpage provides access to a subset of the program functionalities, consisting of: project management, help utilities, displaying and enabling the editing of input data, conducting simulation, and displaying output data and charts. *LincSys* employs a mix of standard Windows user interface controls to enable users to issue commands, navigate the user interface, and access program functionalities. Note that this manuscript is part I of a two-part paper and it describes the hydraulic simulation module and the GUI of *LincSys*. Part II presents application examples and a brief summary of results of model evaluation.

Keyword: *LincSys* • Graphical user interface • Computational module • System configuration options • Sample project

Introduction

Center-pivot and linear-move systems are used to irrigate a wide variety of crops under a range of conditions [1]. Currently, center-pivot and linear-move systems, collectively, account for about half of the irrigated acreage in the U.S. and are expanding [2]. Thus, the development of accurate and flexible mathematical models that can be used in the hydraulic analysis, design, and management of these systems has become increasingly important.

Flow in center-pivot and linear-move systems are generally considered steady. Accordingly, forms of the energy conservation and continuity equations applicable to one-dimensional steady pipe flow [3] can be used to describe the hydraulics of such systems. Studies on the hydraulic analysis and design of center-pivot irrigation systems were conducted by various authors [4-11]. A design and evaluation model, CPED, was developed for center-pivot systems [12].

The design of linear-move irrigation systems was described in reference [6]. Furthermore, the results of a simulation study, conducted using a version of the CPED model, on variable water application with linear-move systems was presented in reference [13]. Published studies on the hydraulics of linear-move

irrigation laterals are limited. However, the geometric features and hydraulic components of linear-move and center-pivot irrigation systems are generally the same. The main differences between these systems are the mobility or lack thereof of the inlet-end support tower, the mode of motion of the lateral, and the need for a separate guidance mechanism for linear-move systems. These differences are considered not to have appreciable effect on the basic hydraulic principles governing flow in these systems and applicable equations [10]. Thus, in practice the hydraulics of these systems is considered identical.

A software for simulating the hydraulics of linear-move and center-pivot irrigation systems, called *LincSys*, is presented in this manuscript. The term *LincSys* is a mnemonic for the phrase 'linear-move and center-pivot systems'. The *LincSys* software is comprised of a pair of executable files: a hydraulic simulation module, *HydrSimLaterals.exe* and a graphical user interface (GUI), *LincSys.exe*, through which the user interacts with the hydraulic module. An application programming interface is used to couple the user interface to the computational module. Data exchange between the user interface and the simulation module takes place through space delimited text files.

The hydraulic module of *LincSys* is a numerical model that solves the continuity and energy balance equations (for one-dimensional steady pipe flow) to determine the lateral-wide distribution of total heads and lateral and emitter discharges, along with other derived output parameters, given model inputs [14,15]. Derived model outputs consist of the hydraulic head, lateral pressure head, emitter head differential (i.e., the difference in total head across an emitter), and also the uniformity of emitter head differential and emitter discharge profiles. Model input parameters include the inlet head, lateral diameter, pipe hydraulic resistance characteristics, number of spans, lateral elevation profile, distance of outlet ports from lateral inlet, and the hydraulic characteristics of pressure reducing valves (where applicable), emitters, and of pipe appurtenances, among others.

A unique attribute of the hydraulic module of *LincSys*, compared to earlier models, is that it takes into account the effects of key lateral features and

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components (such as pressure reducing valves or *prvs* – where applicable, span geometric features, and drop-tubes) on the system hydraulics. *LincSys* can simulate the hydraulics of linear-move and center-pivot systems with the three distinct lateral outlet discharge metering configurations: (i) *prv*-emitter assemblies fitted to the lower ends of drop-tubes; (ii) emitters attached directly to drop-tubes; or (iii) emitters placed directly on lateral outlet ports. Note that the term emitter is used here in the broader sense to describe various water emission devices used in linear-moves and center-pivots, including high pressure sprinklers placed directly on lateral outlet ports and low pressure spray-nozzles fitted to droptube-*prv* assemblies. Furthermore, the more concise phrase of, system configuration options, will henceforth be used in this document to refer to the lateral outlet discharge metering configuration options.

The GUI of *LincSys* consists of a tabbed form with four windows, namely, the Systems-Projects, Input, Output, and Charts tabpages. Each tabpage provides access to a particular set of program functionalities, consisting of: help utilities, project management, preprocessing (displaying and enabling the editing of input data and input data file handling), processing (conducting simulation runs), and postprocessing (displaying output data and charts and output data and charts file handling).

The help utility of the *LincSys* software provides resources that the user can access through tooltips, a dedicated Help menu that can be activated from the Systems-Projects window, and a set of text files placed in various folders in the course of program installation. *LincSys* employs standard Windows Forms controls, namely control buttons, textboxes, a listbox, DataGridView table, a toolbar, a dropbox with menu, label controls, and chart control to allow users to issue commands, navigate the user interface, and access program functionalities.

The *LincSys* software can be downloaded from the Yuma Agricultural Center, University of Arizona, Yuma Center of Excellence for Desert Agriculture website [16]. Electronic version of the user's manual can be accessed through the help menu of the program or downloaded from the same webpage.

Note that this manuscript is part I of a two-part article and it describes the hydraulic simulation module and the features, layouts, and functionalities of the GUI of *LincSys*. Part II presents results of application examples and model evaluation [17].

System description

A linear-move or a center-pivot irrigation system is a self-propelled machine consisting of a lateral that applies water to crops in the form of precipitation as it moves across the irrigated field. While a linear-move system travels in a straight-line irrigating a rectangular field, a center-pivot system rotates about a pivot point fixed to a permanent base and irrigates a circular area, although various accessories can be used to irrigate parts of the field corners.

A sketch of a typical linear-move system, obtaining its supply from a canal, with an intake apparatus, a pump, and a power unit attached to its inlet-end is depicted in Figure 1a. The lateral is comprised of a series of arched spans connected, at their lowest points, with flexible joints that allow relative movement between adjoining spans. Each span has multiple regularly or variably spaced outlet ports. Figure 1b depicts the details of a droptube, pressure reducing valve (*prv*), and emitter assembly (also described here as precision applicator) often used in these systems to meter outlet discharges across a lateral at a preset rate. A center-pivot irrigation system equipped with precision applicators is depicted in Figure 1c.

A quick comparison of Figures 1a and 1c shows that the structural elements, hydraulic components, and geometric features of center-pivots are the same as those of linear-move systems. The principal differences between these systems are the mobility of the inlet-end support tower (i.e., stationary or mobile), the mode of motion of the lateral (i.e., circular or linear/straight-line), and if there is a need for a separate guidance mechanism or not. These differences are generally considered not to have appreciable effect on the basic hydraulic principles governing flow in these systems and applicable equations. Thus, in practice the hydraulics of these systems is considered identical.

Although Figure 1 depicts only systems that use precision applicator

assemblies for metering outlet discharges along the lateral, the computational module of *LincSys* is capable of simulating the hydraulics of laterals with three different system configuration options: (i) systems that use *prv*-emitter assemblies, fitted to drop-tubes, as emission devices to meter outlet discharges at a pre-set rate across the lateral (labeled here as Droptube-*Prv*-Emitter or precision applicator configuration), (ii) systems that use emitters attached to drop-tubes to meter outlet discharges across the lateral (named as Droptube-Emitter configuration), and (iii) systems in which emitters are placed directly on the lateral (described here as Emitter-On-Lateral system configuration).

The *LincSys* software: availability, installation, and user interface

Overview: *LincSys* is a computer program for simulating the hydraulics of linear-move and center-pivot irrigation systems. The name *LincSys* is a mnemonic for the phrase 'linear-move and center-pivot systems'. The *LincSys* software is comprised of a pair of executable files: a hydraulic simulation module, HydrSimLaterals.exe, and a graphical user interface (GUI), *LincSys*.exe, through which the user interacts with the hydraulic module. The GUI of *LincSys* was developed with the Basic computer programming language in the Visual Studio Integrated Development Environment [18] and it is based on the Windows Forms for .Net Framework Ver. 4.8. The hydraulic simulation module was developed as a standalone numerical model in 2017 by the same authors and was written in the C++ computer programming language within the Visual Studio Integrated Development Environment [19].

The user interface and the computational module are coupled through an application programming interface that uses the *CreatProcess* function. Data exchange between the user interface and the simulation module is effected through space delimited text files. Input data, edited within the user interface, is transferred to the simulation module and output data from the simulation module is relayed back to the user interface using space delimited text files.

Computational module of *LincSys*

From the perspective of hydraulic modeling, the pipeline that conveys water across a linear-move or a center-pivot machine is essentially an irrigation lateral. Nonetheless, these laterals differ from the conventional irrigation laterals of solid-set or set-move systems in the following respects: they move across the field as they apply irrigation water, they are comprised of arched spans placed on an elevated platform, and are often equipped with precision applicators that are suspended from the lateral at a suitable above ground clearance. Assumptions pertaining to the effects of lateral movement and span curvature on lateral hydraulics, a description of the full range of *prv* operating modes in the context of irrigation laterals, and the approaches used in *LincSys* to model *prv* effects on lateral hydraulics (in the systems that are fitted with *prvs*) can be obtained from earlier publications by the current authors [14,15]. Thus, the discussion here focusses on providing brief descriptions of the schematization of a linear-move or a center-pivot lateral as a branched hydraulic network and the formulation and numerical solution of the hydraulic simulation problem of these laterals as implemented in the computational module of *LincSys*.

Irrigation lateral as a branched hydraulic network: For the purpose of hydraulic modeling, a linear-move or a center-pivot lateral is treated here as a branched hydraulic network consisting of links delimited by nodes (Figure 2a). Lateral pipe segments and outlet discharge metering apparatuses are considered as hydraulic links (note: a lateral (pipe) segment is a section of the lateral pipe that is delimited at both ends by computational nodes). In Figure 2a, horizontal line segments represent lateral pipe segments, whereas outlet discharge metering apparatuses (i.e., droptube-*prv*-emitter assemblies, droptube-emitter assemblies, or emitters, as the case may be) are depicted as vertical lines. Note that the link discharges, Q , are system unknowns and need to be determined as part of the hydraulic simulation.

Computational nodes can be points along the lateral at which two or more links are joined (Figure 2b). These include points where drop-tubes or emitters connect to lateral outlet ports (offtake nodes), other points along the lateral where lateral elevations are defined but no outlet ports exist (non-offtake nodes), and span joints. The total head, H , at each of these nodes are system

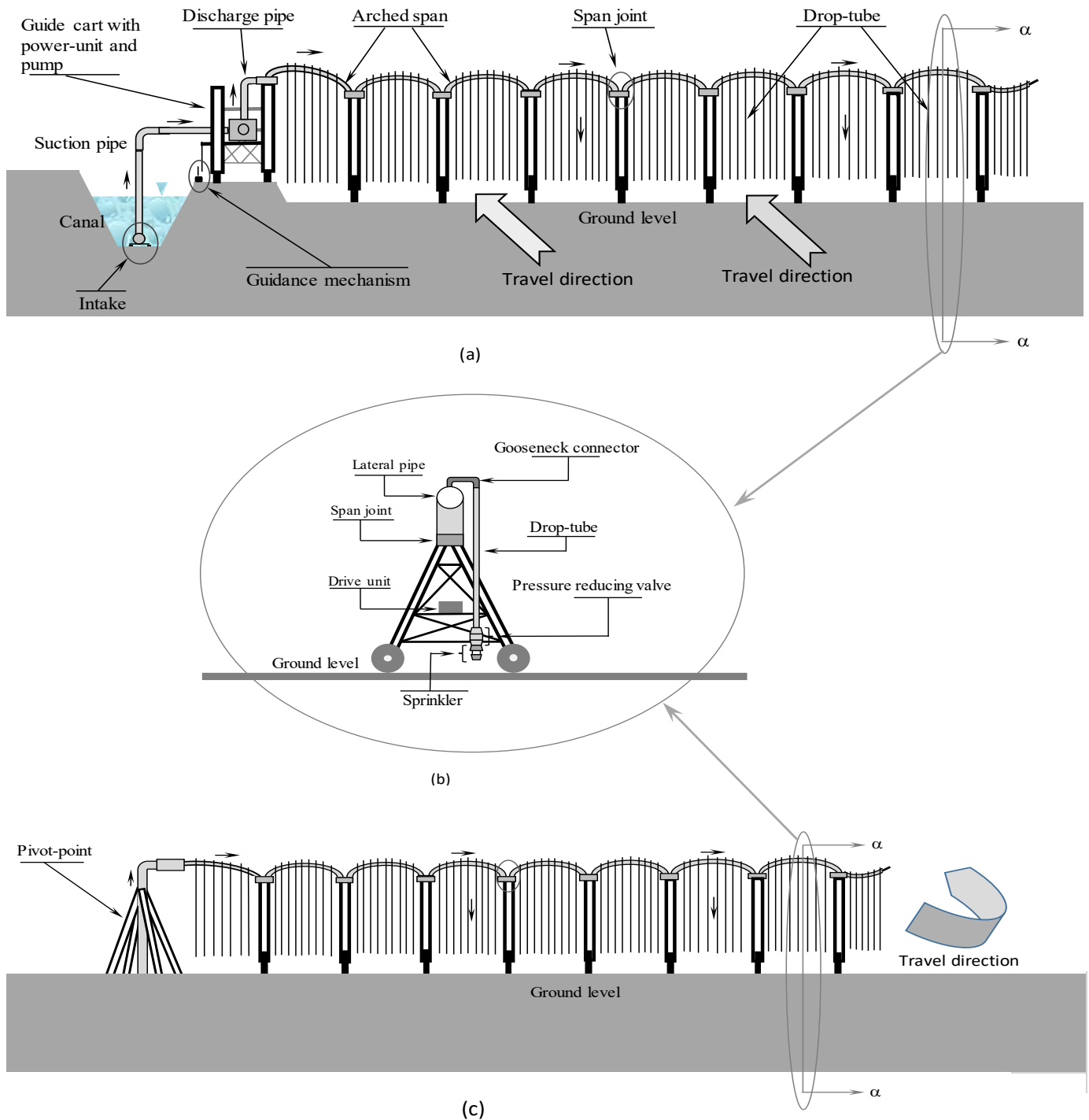


Figure 1. (a) Sketch of a linear-move system obtaining its water supply form a canal and (b) Elevation view of the support tower showing details of drop-tube fitted with a prv-emitter assembly, and drive unit (from section at α - α , Figures 1a and 1c), and (c) Sketch of a center-pivot irrigation system

unknowns and need to be determined as part of the hydraulic computation. In addition, the lateral inlet and the exit ends of each emitter are also considered as nodes. However, these nodes either have a known total head (as in the case of the lateral inlet) or have total heads that can be defined in terms of the discharge and elevation of individual emitters, thus the heads at these nodes do not need to be specifically treated as unknowns of the hydraulic simulation problem. Details on the topological schematization of the lateral as a branched hydraulic network are provided in earlier publications by the same authors [14,15] and in the user's manual of *LincSys*, which can be downloaded from the same website as that of *LincSys*.

Specification of the lateral hydraulic simulation problem: The problem of interest here is hydraulic simulation of a linear-move or a center-pivot lateral

that uses any one of the three system configuration options (described earlier) and is operated under steady flow condition. Thus, the modeling objective is to determine all the link discharges and the nodal heads along the lateral, given the elevation profile and the geometric and hydraulic parameters of the lateral, including the total head at the inlet. Forms of the energy conservation and continuity equations, applicable to one-dimensional steady flow [3] in stationary and straight pipelines, are used here to model the hydraulics of these laterals.

Accordingly, a continuity equation is written for each junction node (a computational node along a lateral, excluding the inlet end node) and an energy balance equation is formulated across each link. For a general lateral hydraulic simulation problem these equations can be coupled to form a system of nonlinear equations that can be solved iteratively [20]. However,

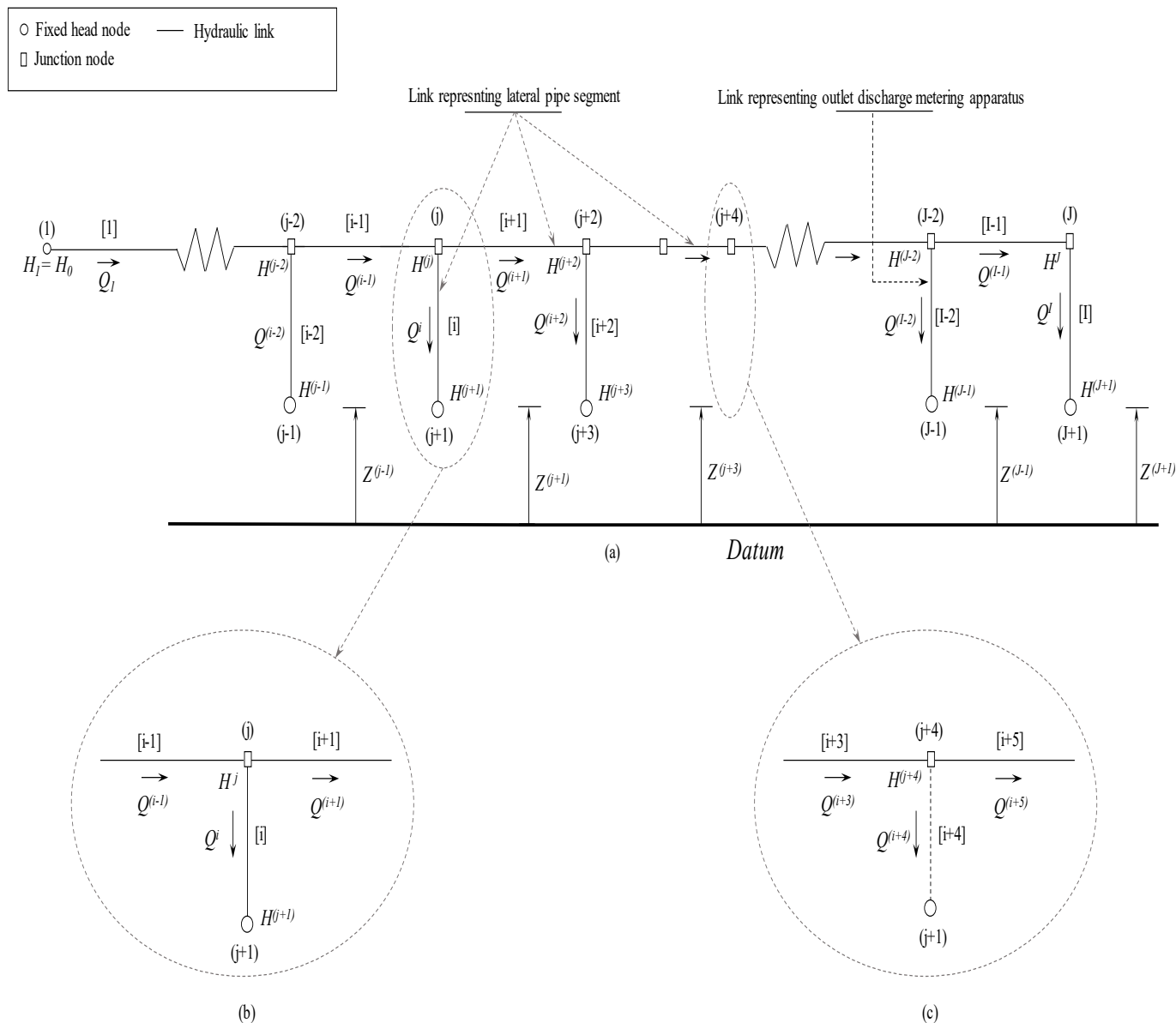


Figure 2. (a) Schematics of a linear-move or center-pivot lateral as a connected series of links delimited by nodes, (b) an offtake junction node and attached links, and (c) a non-offtake junction node (i.e., a node without an outlet) and attached links. (Note: i) node index and jj is link index, Q is link discharge; H and Z are nodal head and elevation, respectively, and H_0 = total head imposed at the lateral inlet. Furthermore, for computational convenience, it is assumed here that a virtual link with zero discharge is connected to each non-offtake junction node, Figure 2c)

the hydraulic module of *LincSys* uses computational methods applicable to hydraulic manifolds [21,22], and a modification thereof for systems with *prvs*, to solve the hydraulic simulation problem of linear-move and center-pivot irrigation systems. For details on the formulation and numerical solution of the simulation problem, as implemented in the computational module of *LincSys*, the reader is referred to [14,15] and the user's manual of *LincSys*.

Installation and A quick exploration of the contents of the *LincSys* installation folder

LincSys Ver.1.0 is a public domain software available for installation free of charge from the Yuma Agricultural Center, University of Arizona, Yuma Center of Excellence for Desert Agriculture website [16]. A quick description of the steps in the installation of *LincSys* can be obtained from a power point presentation (Quick Introduction.ppt) or a document (Quick Introduction.pdf) that can be downloaded from the same website as that of *LincSys*.

Following installation, opening the installation folder of *LincSys* with Windows Explorer (or File Explorer) shows that a sizable number of files and a folder have been copied into it. These include the executable files *LincSys*.

exe and *HydrSimLaterals.exe*, the program icon file *LincSys.icon*, and the program configuration file *LincSys.exe.config.xml*. In addition, a host of .Net Framework utility files with a *.Dll (dynamic link library) extension were copied to the installation folder. Furthermore, the user may notice that a folder named Projects was created under the installation folder.

LincSys uses a specific directory structure to track and manage projects, which are created under the Projects folder during installation (note that the term project is used here to refer to all the input and output data files, of a simulation problem, stored in a folder that bears the name of the project). A look at the contents of the Projects folder shows that directly under it there are five subfolders: *DrptubePrvEmitter*, *DrptubeEmitter*, *EmitterOnLat*, *HelpDocAndLiterature*, and *Templates_InputDataFiles*. A more detailed discussion on the contents and formats of each of the files in these folders are presented in the user's manual. A brief description of the contents of each of these folders will now be presented.

The *DrptubePrvEmitter*, *DrptubeEmitter*, and *EmitterOnLat* folders are referred here as system configuration option folders and they contain the *LincSys* project's data corresponding to the *Drptube-Prv-Emitter*, *Drptube-*

Emitter, and Emitter-On-Lateral system configuration options, respectively. Opening any of the system configuration option folders, following installation (say for instance the DrptubePrvEmitter folder), would show that (at installation) it contains fifteen sample projects (i.e., folders), named SampleProject_1, SampleProject_2, ..., SampleProject_15, each with a complete set of input and output data files.

The HelpDoc and Literature folder contains documents used by *LincSys* as help information resources that can be accessed through the Help menu from the user interface. Furthermore, the Templates_InputDataFiles folder contains input data template files for laterals with number of spans ranging between 6 and 12 and are intended for use as templates for creating new *LincSys* projects.

The graphical user interface of *LincSys*: Features and functionalities, a summary

Overview: The GUI of *LincSys* is a tabbed form designed to provide access to the program functionalities, consisting of help utilities, project management, preprocessing (displaying input data, enabling the editing of input data, and input data file handling), processing (conducting simulation runs), and postprocessing (displaying output data and charts and output data and charts file handling).

Standard Windows Forms controls, namely control buttons, textboxes, a listbox, DataGridView tables, a toolbar, a dropdown with menu, label controls, and chart controls are used to issue commands and execute various program functionalities. Note that in this document the user interface controls are referred to with names that are contextually more intuitive and meaningful, in place of the more general technical names used in the programming literature. Table 1 summarizes the names used in this document for the user interface controls along with their technical counterparts.

As shown in Figures 3 to 6, the GUI of *LincSys* is comprised of four tabpages: the Systems-Projects, the Input, the Output, and the Charts tabpage, each providing access to a particular set of software functionality. Details on the features, contents, and layouts of each tabpage, the software functionalities associated with each, and keyboard usage for activating user interface control buttons, navigating the user interface, browsing through and editing input data, and browsing through the output data and output charts are provided in the user's manual of *LincSys*, and also in document on keyboard usage, both of which can be downloaded from a same website as that of *LincSys*. Thus, the following sections present only a brief description of the main features, layouts, and functionalities of each tabpage.

The Systems-Projects tabpage: features, layouts, and functionalities: The Systems-Projects tabpage represents the main access or entry point to the *LincSys* model. It also provides access to program help resources, project management functionalities, and to the other tabpages. The features and layout of the Systems-Projects tabpage is depicted in Figure 3. The tabpage displays a titlebar at the top and a statusbar at the bottom of the window, which present features that serve only informational purpose. The user-interface controls associated with the Systems-Projects tabpage consists of

the tabcontrols, a toolbar, a groupbox with radio buttons, project listbox, and navigation buttons (Figure 3).

The tabcontrols are displayed underneath the titlebar with the Systems-Projects tabcontrol highlighted. Note that the tabcontrols cannot be used to open any of the other tabpages from the Systems-Projects window. However, the Systems-Projects window and the other tabpages can be accessed through the respective tabcontrols from within the Input, Output, or Charts tabpage.

The toolbar, which is displayed right underneath the tabcontrols (Figure 3) of the Systems-Projects window, is designed to provide access to help resources and project management functionalities of *LincSys*, which include creating a new project, copying a project, deleting a project, and renaming a project.

The Systems-Projects window uses radio button controls, placed inside the Systems configuration option groupbox, to enable the specification of the system configuration option (i.e., Droptube-Prv-Emitter, Droptube-Emitter, or Emitter-On-Lateral) for which a simulation is to be conducted. Note that for the example shown in Figure 3, the system configuration option is set to the Droptube-Prv-Emitter option. The project listbox, to the right of the Systems configuration option groupbox, displays a list of existing projects under the currently selected system configuration option. If *LincSys* is opened for the first-time following installation, the project listbox displays the fifteen sample projects corresponding to the currently selected system configuration option. Note that the cursor in the project listbox can be moved up and down through the list of projects to select one for which hydraulic simulation is to be conducted.

Displayed above the statusbar, of the Systems-Projects tabpage, is a set of navigation buttons (Input, Output, and Charts) that serve as the primary access points to the respective windows and an Exit button for closing *LincSys* from the Systems-Projects window.

The Input tabpage: features, layouts, and functionalities: The Input tabpage is the window where the input data for the current simulation session are displayed and can be edited. The features and layout of the Input tabpage, for a system with Droptube-Prv-Emitter configuration option, are depicted in Figure 4. The Input window contains a titlebar, a statusbar, and user interface controls consisting of input boxes and an input data table (to display and enable the editing of input data), navigation buttons, and tabcontrols.

The titlebar and the statusbar are displayed at the top and bottom of the Input tabpage, respectively. The tabcontrols are displayed underneath the titlebar with the Input tabcontrol highlighted (Figure 4). The Systems-Projects tabpage can be accessed from the Input window through the Systems-Projects tabcontrol. The Output and Charts tabcontrols, on the other hand, can be used to open the respective tabpages only if the tabpages were activated through navigation buttons earlier during the current simulation event.

Displayed in the main body of the Input window, below the tabcontrols, is two groupboxes, namely: the System data, summary and the System topology and components, summary; each with input boxes arranged in a pair of columns. Note that the term input box refers here to a Windows Forms user interface control commonly described in the literature as a textbox control (Table 1). The input boxes display and enable the editing of non-tabular input data.

Table 1. Conventional technical names of user interface controls used in *LincSys* and names used to refer to them in this document

Names of user interface controls		Function
Name used in <i>LincSys</i>	Technical name	
Inputbox	Textbox	Displays and allows editing of nontabular project input data
Outputbox	Label	Displays nontabular project output data
Input data table	DataGridView	Displays and allows editing of the hydraulic network topological data, lateral hydraulic and geometric parameters, and elevation profile data in a tabular format
Output data table	DataGridView	Displays the hydraulic network topological data, lateral elevation profile data, and output parameters in a tabular format
Project listbox	Listbox	Displays the list of existing projects under the currently selected system configuration option and allows selection of a project for which simulation is to be conducted
Navigation buttons	Control buttons	Windows Forms control buttons used to navigate the user interface
Groupbox	Groupbox	A windows user interface feature that contains a set of related user interface controls

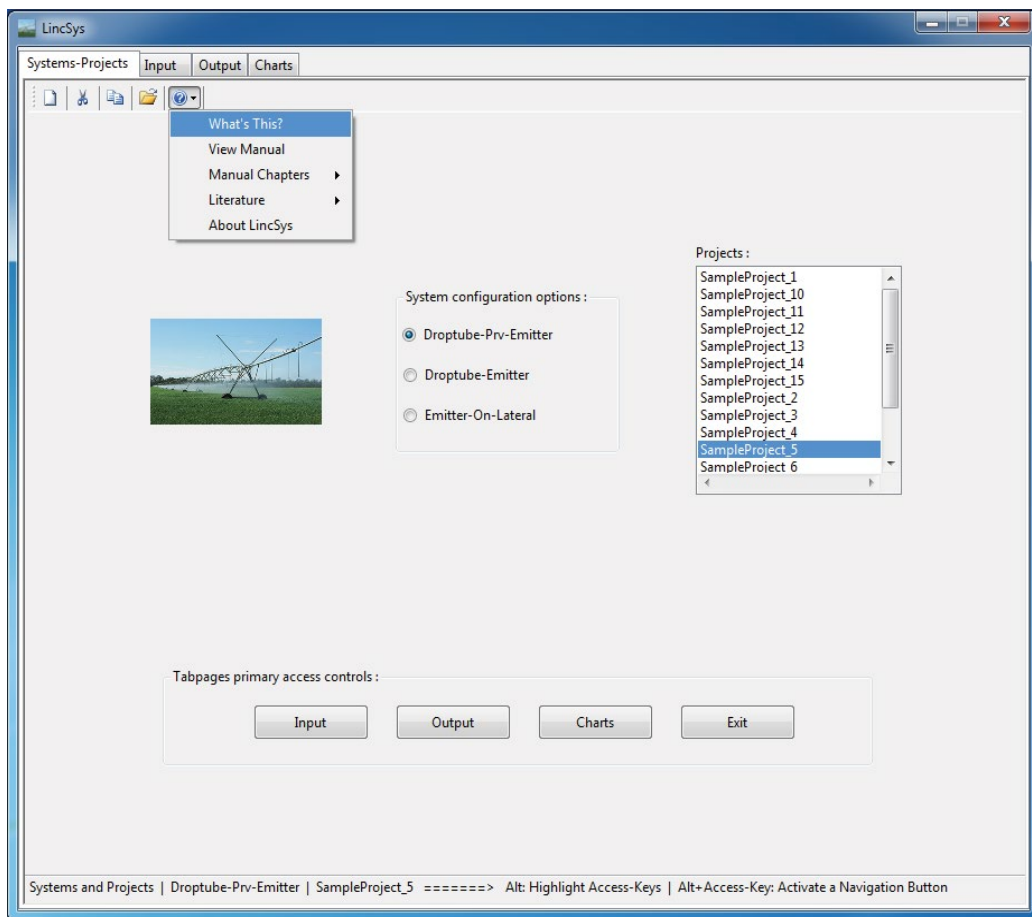


Figure 3. Systems-Projects tabpage: features, layouts, and control elements

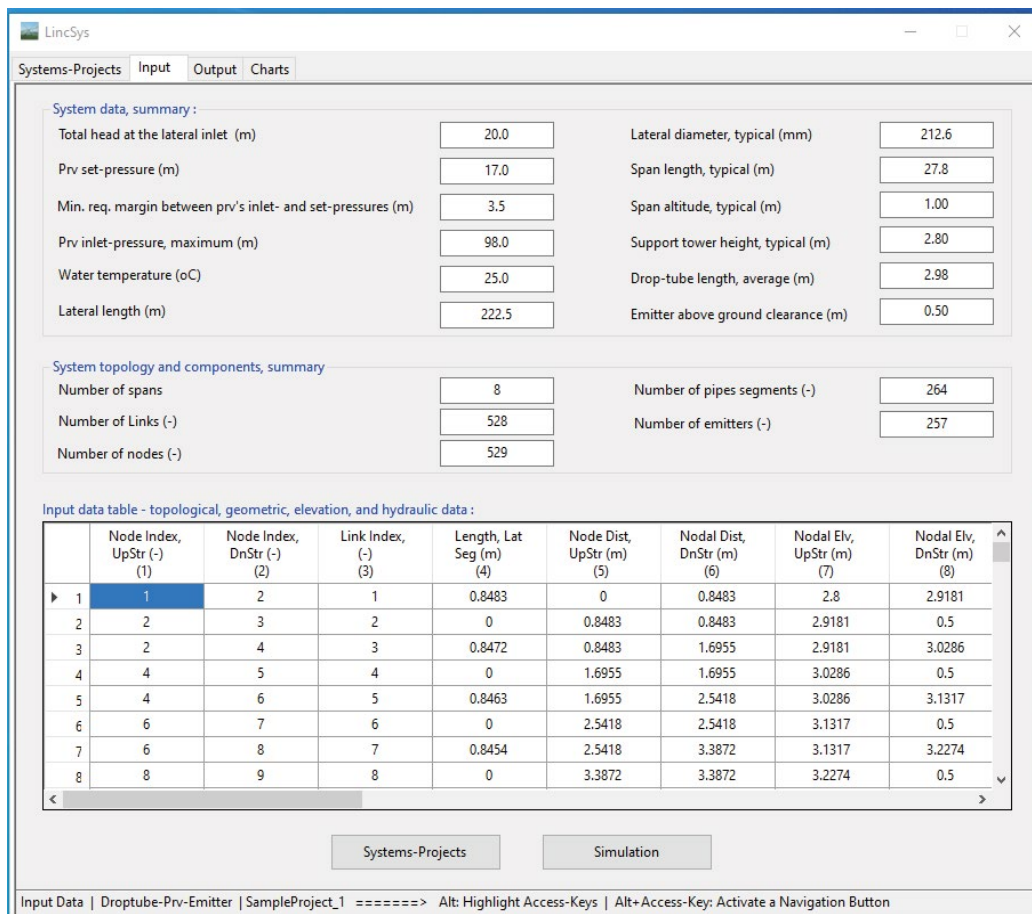


Figure 4. Input tabpage: features, layouts, and control elements

Depicted right under the System topology and components, summary groupbox is a partial view of the input data table, which displays and allows users to edit tabular input data (Figure 4). Note that an input data table is in fact what is described as a DataGridView table in the computer literature (Table 1). The input data table contains twenty-four columns and as many number of rows as there are links in the topological representation of the lateral. The columns in the input data table represent a data type. It could be network topological parameters such as link and node indexes, lateral elevation profile data or input data related to the dimensions and/or hydraulic characteristics of system components such as lateral pipe segments, drop-tubes, emitters, *prvs*, and pipe appurtenances. The row of the input data table, on the other hand, represents data related to a network link and corresponding nodes, including nodal distances from the lateral inlet, nodal elevations, and geometric and hydraulic parameters.

Between the input data table and the status bar, the Input window displays a pair of navigation buttons: Systems-Projects and Simulation. If the Systems-Projects button is activated, then the user interface control will revert back to the Systems-Projects window. Alternatively, a simulation run of the current *LincSys* project can be conducted by activating the Simulation button. Activating the simulation button initiates a process that include input data validation and preparation of the input data in a format that is readable by the simulation module of *LincSys* (*HydrLateralSim.exe*) and then culminates in invoking the simulation module. Following a successful simulation output data will be saved in a series of files in the current project folder and will be displayed in the Output window (note that a list of the input and output data files of *LincSys* along with descriptions of their contents is provided in Table 2). If, on the other hand, the simulation run is terminated because of an already identified runtime error, then *LincSys* prints on the screen a runtime error message identifying possible sources of the error and potential remedies.

Note that the features and layout of the Input tabpage depicted in Figure 4 is for a system with Droptube-Prv-Emitter. For a system with a Droptube-Emitter or Emitter-On-Lateral configuration option, however, only a subset of the nontabular and tabular input data shown in Figure 4 are applicable. For details on this the reader may consult the user manual of *LincSys*.

The Output tabpage: features, layouts, and functionalities: The Output tabpage is the window where the output data from a current or an earlier simulation session are displayed. The features and layout of the Output tabpage are depicted in Figure 5 for a system with Droptube-Prv-Emitter configuration option. The Output tabpage consists of a titlebar, a statusbar, and user interface controls (including output boxes and an output data table), navigation buttons, and tabcontrols.

In the Output tabpage as well, the titlebar and the statusbar are placed at the top and bottom of the window, respectively. The tabcontrols, which are displayed right under the titlebar, are depicted with the Output tabcontrol highlighted. The Systems-Projects tabpage can be accessed from the Output window through the Systems-Projects tabcontrol. The Input and Charts tabcontrols, on the other hand, can be used to open the respective tabpages only if they have been activated through navigation buttons earlier during the current simulation event, either from within the output tabpage or from the Systems-Projects tabpages.

Furthermore, Figure 5 shows that the output tabpage contains three sets of output boxes displaying non-tabular output data, each in a separate groupbox: (i) Emitter discharge and head differential variability indicator parameters, (ii) Emitter discharge and head differential uniformity indicator parameters, and (iii) Additional output parameters. An output box is a Windows user interface element commonly referred to as a label control and its contents are non-editable (Table 1). Note that the output data related to the number of active and passive *prvs*, in the Additional output parameters groupbox, are impertinent to systems with the Droptube-Emitter or Emitter-On-Lateral configuration option, thus they would be deactivated for these options.

The output data table, which is positioned in the middle of the Output window, displays the hydraulic network topological data, lateral elevation profile, and computed hydraulic parameters. The output data table contains twenty columns and as many number of rows as there are links in the topological schematization of the lateral. The columns in an output data table represent data type. It could be network topological parameters such as link and node indexes, nodal distance from the lateral inlet, elevation profile data or computed hydraulic parameter such as discharge, pressure, hydraulic head, and total head profile. A row of the output data table, on the other hand, represents data related to a network link and corresponding nodes, including nodal distances from the lateral inlet, nodal elevations, and computed hydraulic data.

Underneath the Additional output parameters groupbox and above the statusbar, the Output window displays three navigation buttons: Systems-Projects, Input, and Charts. Activating the Systems-Projects button ends the simulation event and program control will revert back to the Systems-Projects page. On the other hand, activating the Input or the Charts button would transfer user interface control to the Input or the Charts window respectively.

The Charts tabpage: features, layouts, and functionalities: The Charts tabpage is designed to display a graphical rendering of a total of eleven computed hydraulic parameters sequentially, each in a separate chart panel. Note that a list of the output chart files and descriptions of their contents is provided in Table 3. Figure 6 depicts the features, layout, and contents of the

Table 2. Input and output data files of a *LincSys* project

File name	Extension	Description of contents
InputData_LinLat	Inp	Input data file. File content consists of network topological and lateral hydraulic, geometric, and elevation data
InputData_LinLat	Xlsx	Excel version of the input data file (InputData_LinLat.Inp)
OutputData_LinLat	Out	The main output data file. File contains network topological and elevation profile data and computed hydraulic parameters
Chart_ElvHglEgl	Dat	Output data file. Its content consists of the lateral elevation profile, computed hydraulic grade-line, energy grade-line, and lateral pressure profile data. <i>LincSys</i> uses data from this file to create: (1) the lateral elevation profile, the hydraulic grade-line, and the energy grade-line chart and (2) the lateral pressure profile chart
Chart_EmitterPrvInletSetPres	Dat	Output data file. The contents of this file consist of <i>prv</i> -inlet pressure, <i>prv</i> -set pressure, computed head differential across emitter, and emitter discharge profile along the lateral. Output data from these file are used by the program to create: (1) the <i>prv</i> -inlet pressure, <i>prv</i> -set pressure, and emitter head differential chart and (2) the emitter discharge profile chart
Chart_FhlHlVelH	Dat	Output data file. Contents of this file consist of the computed lateral discharge, friction head loss in lateral segments, cumulative friction head loss, Darcy-Weisbach friction factor, local head loss in a lateral pipe segment, cumulative local head loss, and velocity head profile data. These data are used by the program to create: (1) the lateral discharge profile chart, (2) chart depicting the profile of friction head loss in lateral pipe segments; (3) the cumulative friction head loss profile chart; (4) the friction factor profile chart; (5) chart depicting the profile of local head losses in lateral pipe segments; (6) the cumulative local head loss profile chart; and (7) the velocity head profile chart
EmitterDischargePressure	Dat	Output data file. Its content consists of emitter discharge, emitter head differential, lateral discharge, <i>prv</i> -inlet pressure, and <i>prv</i> operating status. File contains optional content for users to create professional looking charts with graphical applications.
Lat_hElvHglEgl_Comp	Dat	Output data file. Contains a more complete data on total head, hydraulic head, and pressure head profiles along the lateral. File contains optional content for use in the analysis of the spatial properties of these parameters.
Readme	Txt	Readme file. Contains a concise summary of the content of a sample project folder

Charts window when it is first opened. The Output tabpage contains a titlebar, a statusbar, a chart panel, navigation buttons, and tabcontrols.

At the top of the Charts window is the titlebar and at the bottom the statusbar. Right under the titlebar, the tabcontrols are displayed with the Charts tabcontrol highlighted. While the Systems-Projects tabpage can be accessed from the Charts window through tabcontrols, the Input and Output tabcontrols, on the other hand, can be used to open the respective tabpages only if the tabpages were accessed through navigation buttons earlier during the current simulation event. Directly under the tabcontrols is a rectangular chart panel where graphical outputs are displayed. Note that when the Charts window is first opened, the chart panel displays the graph of the elevation profile of the lateral centerline and the computed hydraulic and energy grade-lines (Figure 6).

Underneath the chart panel, a set of navigation buttons (Output, Previous, and Next) and a Save button are displayed. While the Output button can be used to transfer user interface control to the Output window, the Previous and Next buttons are to be used to browse through the different chart panels. The Save button can be activated to save the currently displayed chart in the Charts subfolder under the current project folder in a Png format.

Concluding remarks and summary

A software, called *LincSys*, capable of simulating the hydraulics of linear-move and center-pivot irrigation systems was developed. The term *LincSys* is a

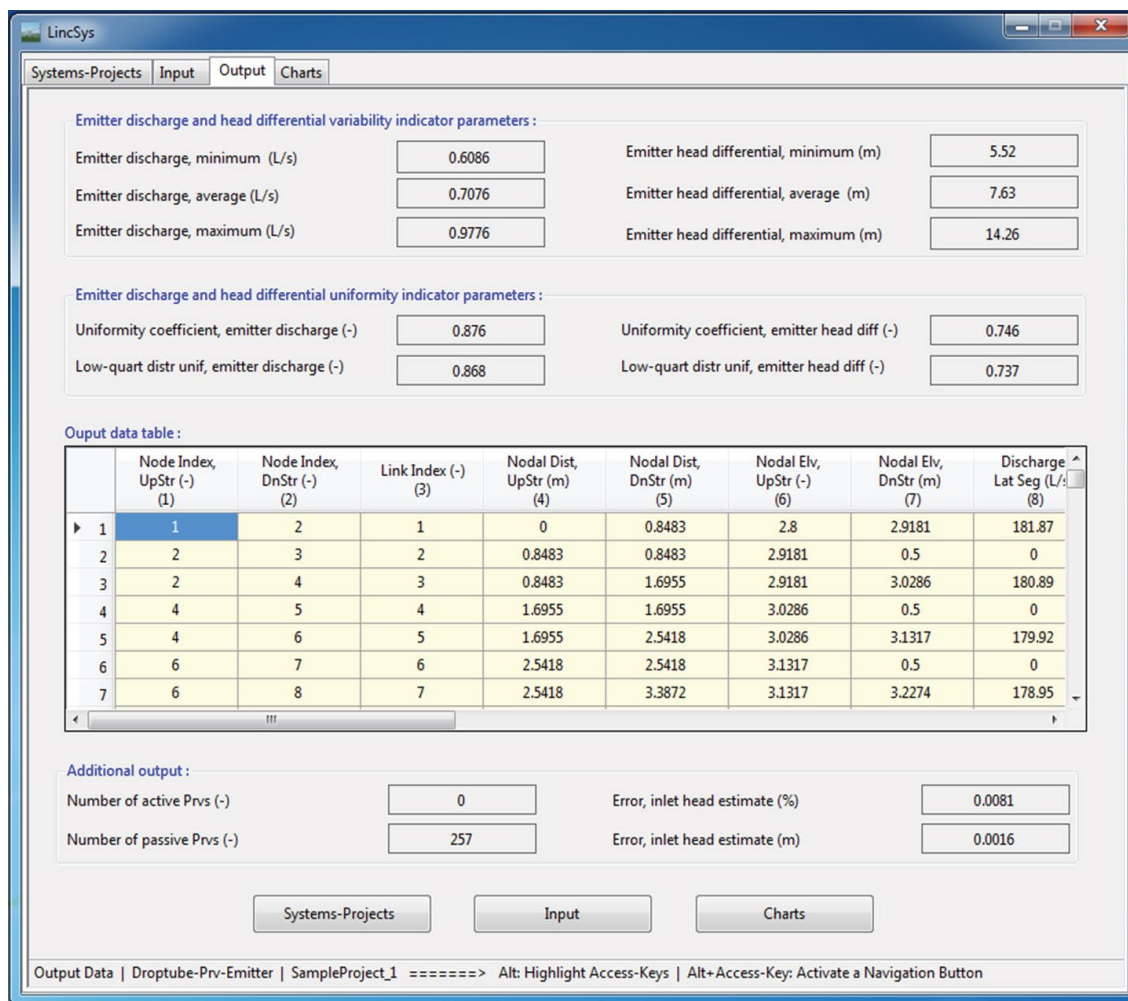


Figure 5. Output tabpage: features, layouts, and control elements

Table 3. List of the chart files of *LincSys* and description of their contents

File name	Description of contents
ChartEglHglElv.Png	Lateral elevation profile, hydraulic grade-line, and energy grade-line chart
ChartEmitDischarge.Png	Emitter discharge profile chart
ChartEmitPrvInletSetPres.Png	Emitter head differential, prv-inlet, and prv-set pressure profiles chart ⁽⁴⁾
ChartFhlCum.Png	Cumulative friction head loss profile chart
ChartFhlPipeSeg.Png	Profile of friction head loss in lateral pipe segments
ChartFrictionFactor.Png	Darcy-Weisbach friction factor profile chart
ChartLatDischarge.Png	Lateral discharge profile chart
ChartLatPressure.Png	Lateral pressure profile chart
ChartLhlCum.Png	Cumulative local head loss profile chart
ChartLhlPipeSeg.Png	Local head loss in pipe segments profile chart
ChartVelHead.Png	Velocity head profile chart

⁽⁴⁾The chart depicts the emitter head differential, prv-inlet, and prv-set pressure profiles for the Droptube-Prv-Emmitter system configuration option. For Drop tube-Emmitter or Emmitter-On-Lateral system configuration option, however, the chart would show only the emitter head differential profile

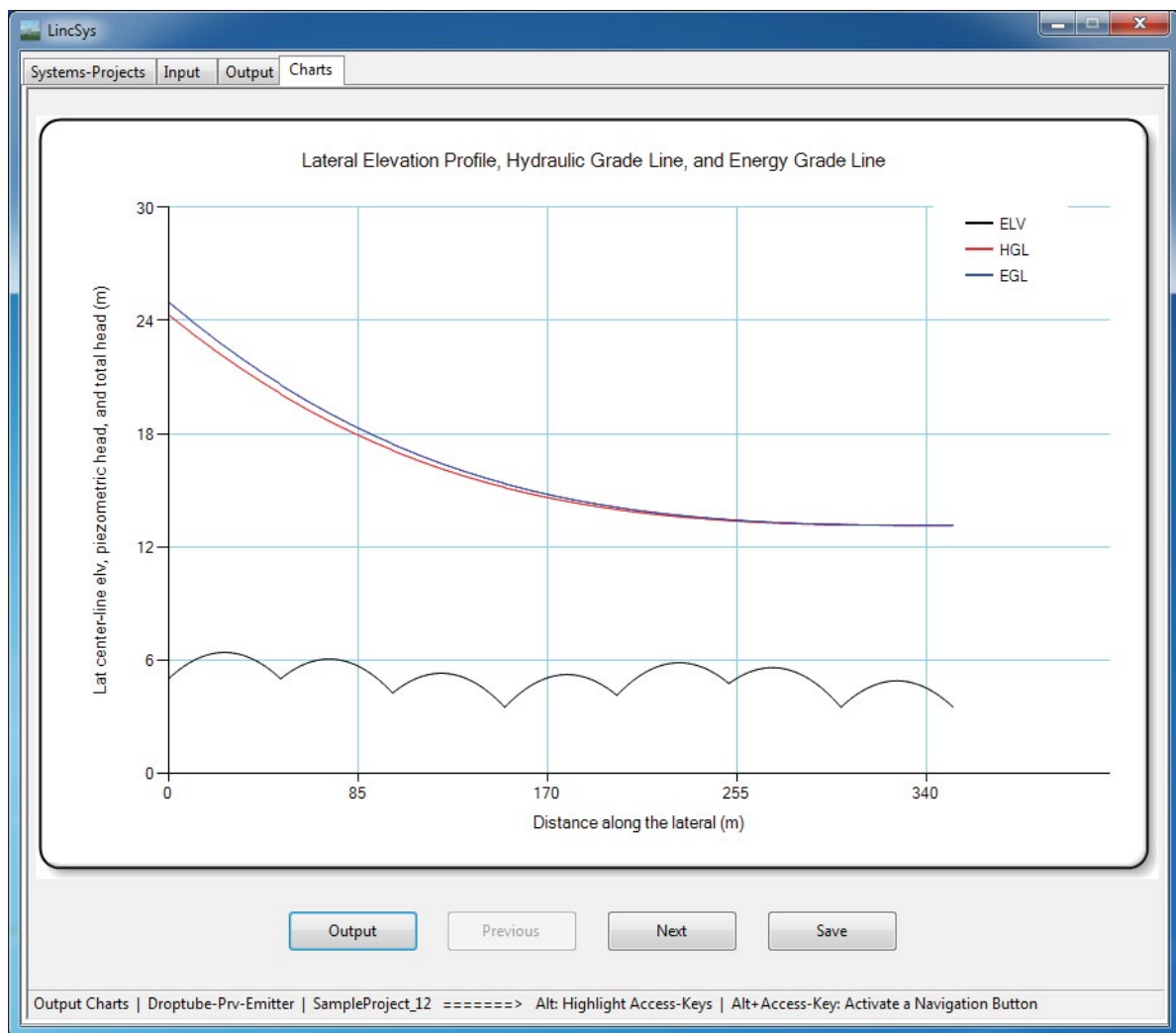


Figure 6. Charts tabpage displaying the lateral elevation profile, hydraulic gradeline, and energy gradeline panel along with features, layouts, and control elements of the tabpage

mnemonic device for the phrase 'linear-move and center-pivot systems'. At the core of the *LincSys* software is a pair of executable files: a hydraulic simulation module, *HydrSimLaterals.exe*, and a graphical user interface (GUI), *LincSys.exe*, through which the user interacts with the hydraulic module. The user interface and the computational module were coupled through an application programming interface and data exchange between them is effected through text files.

The hydraulic module of *LincSys*, *HydrSimLaterals.exe*, is a numerical model that solves the continuity and energy balance equations (for one-dimensional steady pipe flow) to determine the lateral-wide distribution of nodal heads and link discharges and other derived outputs, given model inputs. Derived model outputs consist of the profiles of the hydraulic head, the lateral pressure head, and the head differential across emitters and also the uniformity indicators for emitter head differential and emitter discharge profiles. Model input parameters include imposed inlet head, lateral diameter, pipe hydraulic resistance characteristics, number of spans, lateral elevation profile, distance of outlet ports from lateral inlet, and the hydraulic characteristics of pressure reducing valves (where applicable), emitters, and of pipe appurtenances, among others.

A unique attribute of the hydraulic module of *LincSys*, compared to earlier models, is that it takes into account the effects of pressure reducing valves (*prvs*), lateral geometric features, and of drop-tubes on the system hydraulics. *LincSys* is capable of simulating the hydraulics of linear-move and center-pivot systems with the following emission devices to meter outlet discharges along the lateral: (i) *prv*-emitter assemblies fitted to the lower ends of drop-tubes; (ii) emitters attached directly to drop-tubes; or (iii) emitters placed directly on lateral outlet ports.

The GUI of *LincSys* consists of a Windows Form with four tabpages, namely, the Systems-Projects, Input, Output, and Charts tabpages. Each tabpage provides access to a particular set of program functionalities, consisting of: project management, displaying and enable the editing of input data, conducting simulation run, and displaying output data and charts. The help utility of the *LincSys* software provides resources that the user can tap into through tooltips, a dedicated Help menu that can be activated from the Systems-Projects window, and a set of text files placed in various folders during program installation. *LincSys* employs a mix of standard Windows user interface controls to allow users to issue commands, navigate the user interface, and access the program functionalities in each of the tabpages.

This manuscript is part I of a two-part paper and it presents a brief description of the features, layouts, and functionalities of the GUI of *LincSys* and a synopsis of the computational module. Part II presents application examples and a brief summary of results of model evaluation.

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