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Executive Summary

The following report presents a state-of-the art related to hydraulic models, and the corresponding simulation methods and software tools. These methods and tools are compared, and we also describe the ones considered for the water capture system application, viz. HEC-RAS and SIC.

1 Hydraulic models

1.1 Saint Venant equations

Models that involve water are generally obtained making use of simplifications of the Navier-Stokes Equations, because of the complexity in dealing directly with them. For irrigation canals, one of the most accepted and used model in simulations is the system given by the Saint Venant Equations [18], because of its capacity to represent the characteristics of real interest. However, this system is a nonlinear partial differential equation system, which has analytical solution only in very special cases, forcing the employment of numerical methods to solve it properly. Since the early 60s researchers have devoted important efforts to developing efficient solutions methods for those equations (see [19] for an early review of these methods). Most numerical methods can be included in the finite difference or finite element categories.

As a model for computational simulation it is very accurate, but as model for control, it is clearly not appropriate. Linearizations or simplifications of the Saint Venant equations are used for control purposes.

For modeling intentions, a natural way of partitioning a canal is dividing it into reaches. A reach is a portion of a canal between two gates. So, a normal canal can have several reaches with different characteristics (length, slope, width, etc.). However, all the reaches share a common structure, focusing the problem of modeling an irrigation canal to find a suitable model for reaches.

Making use of Saint Venant equations, a reach can be modelled by two partial differential equations representing a mass balance (continuity equation) and a momentum balance.

Continuity equation

Conservation of mass for a control volume states that the net rate of flow into the volume is equal to the rate of change of storage inside the volume.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q_L \qquad (1)$$

where t is time (s), x is the displacement in the main flow direction (m), q_L is the lateral inflow per unit length (m^3/s/m), $A(x,t)$ is the wetted cross-sectional area of the reach (m^2), and Q the inflow upstream (m^3/s), depending also on x and t.

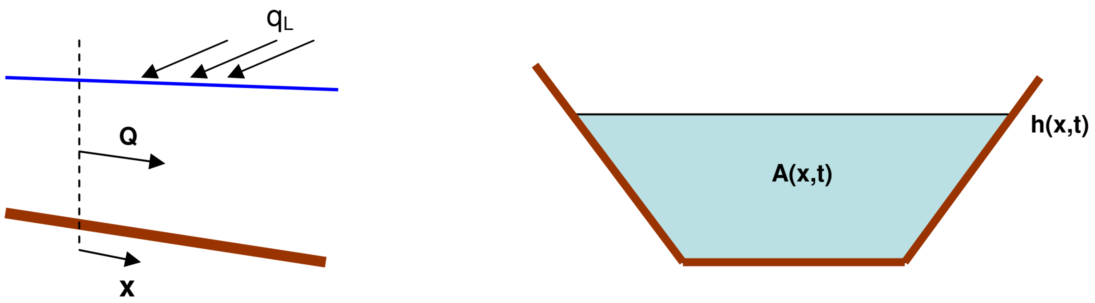


Figure 1. Irrigation canal schematic

Momentum equation

Conservation of momentum is expressed by Newton's second law as the conservation of momentum for a control volume states that the net rate of momentum entering the volume (momentum flux) plus the sum of all external forces acting on the volume be equal to the rate of accumulation of momentum. This is a vector equation applied in the x-direction. The momentum flux is the fluid mass times the velocity vector in the direction of flow. Three forces will be considered: pressure, gravity and friction force. So we get

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x}+gA\frac{\partial Z}{\partial x}+gAS_f-gAS_0=0 \quad (2)$$

with g the gravitational acceleration, Z the water deep, S_0 the longitudinal canal slope, S_f the friction slope. These equations use the following assumptions [1]:

1. The pressure distribution is hydrostatic
2. The velocity is uniformly distributed over a canal section
3. The average canal bed slope is small
4. The flow is homogeneous and incompressible

The momentum equation can be written in terms of the piezometric head ($h=Z_b+Z$) where h is the elevation of the water surface measured from a horizontal datum (i.e. Mean Sea Level) and Z_b is the elevation of the canal bottom above the MSL.

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x}+gA\frac{\partial h}{\partial x}+gAS_f=0$$

Different approaches have been used to model the friction slope such as the Manning-Strickler equation [4]:

$$S_f=\frac{Q^2n^2}{R_f^{4/3}A^2}$$

or the following used in [2]:

$$S_f=\frac{gQ|Q|}{C^2R_fA}$$

with n the Manning Coeficient (s/m$^{1/3}$), C the Chézy friction coeficient (m$^{1/2}$/s) and R_f the hydraulic radius (m) obtained by A over the wetted perimeter. The Manning coeficient can be usually deduced from the canal material.

To solve (1) and (2) the following conditions are needed:

- Initial conditions: $Z(x,0) = Z_0(x)$, $Q(x,0) = Q_0(x)$
- Boundary conditions: $Z(0,t) = Z_i(t)$, $Q(0,t) = Q_i(\mathrm{t})$, $Z(X_f; t) = Z_i(t)$, $Q(X_f, t) = Q_i(t)$.

with X_f the x coordinate at the end of the reach.

An extended approach to model a canal reach is to divide it into a water transport area and a water storage area. Sometimes also, the location of water extractions (off-takes), are placed near the end of a reach, so it is considered that only in the storage area there are lateral inflows/outflows (see Figure 2).

The equations for the transport area are the Saint Venant equations without lateral inflow, and there are an additional one for the storage area (a first order equation of a tank with input and output flows).

1.2 Linearization of hydraulic equations

Two approaches can be considered to obtain a linear model in the case of irrigation canal.

1. To use identification tools. In [5], different linear and non-linear with different order models with low computational demand are tested on a specific canal. In [6], undershot and overshoot gates are also considered.

2. To linearize Saint Venant equations

The linearization of hydraulic equations can be make for easy situations, for example, uniform regimes, where flows and water depth are constant along the reach [7]. A more general way use numerical squemas to obtain linear models.

The following linear model is obtained in [8] from Saint Venant equations. This model is also studied in [3]:

Considering variables around a working point $Z(x,t) = Z_0(x) + z(x,t)$ and $Q(x,t) = Q_0+q(x,t)$, and neglecting all the second-order terms,

$$\frac{\partial q}{\partial x} + B_0 \frac{\partial z}{\partial t} = q_L$$

$$\frac{\partial q}{\partial t} + 2V_0 \frac{\partial q}{\partial t} - \beta_0 q + (C_0{}^2 - V_0{}^2) B_0 \frac{\partial z}{\partial x} - \gamma_0 z = 0$$

where the Manning equation is used, and with

$$\gamma_0 = V_0{}^2 \frac{dB_0}{dx} + gB_0 \left[(1+\kappa) S_0 - (1+\kappa - F_0{}^2(\kappa - 2)) \frac{\partial Z_0}{\partial x} \right]$$

$$\beta_0 = -\frac{2g}{V_0} \left(S_0 - \frac{\partial Z_0}{\partial x} \right)$$

$$\kappa = \frac{7}{3} - \frac{4S_0}{3B_0P_0}\frac{\partial P_0}{\partial Z}$$

$F_0 = \frac{V_0}{C_0}$ Frode number

$C_0 = \sqrt{\frac{gA_0}{B_0}}$ water wave celerity

$V_0 = \frac{Q_0}{A_0}$ water velocity

with the latter three values evaluated in the working point. B_0 is the top width for the equilibrium point and P_0 is the wetted perimeter.

In [8, 3] the Laplace transform is applied and a reordering of equations gives a system in of ordinary differential equations in the variable x with the following structure:

$$\frac{\partial}{\partial x}\begin{bmatrix} q(x,s) \\ z(x,s) \end{bmatrix} = M(x,s)\begin{bmatrix} q(x,s) \\ z(x,s) \end{bmatrix}$$

with *M* a matrix depending on above coefficients and variables (see references). Because matrix *M* depends on the variable *x*, there is not a closed solution to the differential equation, and then, it is necessary to use a numerical integration method to obtain the solution. Only the case where *M* is not dependent on *x* has an analytical solution. This is the uniform regime and is characterized by having the same water depth and the same water flow throughout a canal.

The problem is solved numerically in an efficient way in [9], by discretizing the problem by several uniform regimes.

1.3 Hydraulic models for control

An exhaustive description and references for a set of simplified types of models for control can be found in [3] and [10]. These include Saint Venant model linearizations, infinite order linear transfer functions, finite order nonlinear models, finite order linear models (state-space models), finite order linear models (transfer functions), neural networks based models, fuzzy logic based models and Petri Nets based models.

One of the simplest and used in some Model Predictive Control applications is the Integrator Delay Model. It defines a discrete transfer function H(z) from upstrem inflow $Q_{in}(z)$ and downstream outflow $Q_{out}(z)$ to downstream water level h. It consists of a delay time in series with an integrator part.

$$H(z) = \frac{h(z)}{Q_{in}(z)} + \frac{h(z)}{Q_{out}(z)} = \frac{z^{-k_d}}{A_s(z-1)} + \frac{1}{A_s(z-1)}$$

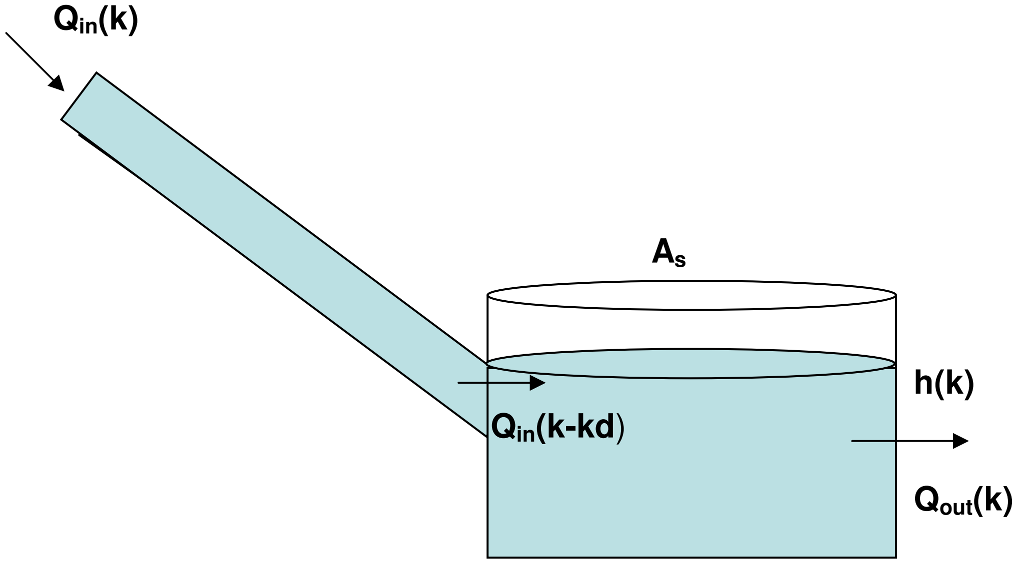


Figure 2. Integrator Delay Model of a canal reach

The main advantage of the model is that it is very simple, compact and therefore fast. The disadvantage is that the parameters delay time and storage area are only valid at one working point. One solution is to work with a model based controller that does not have a fixed internal model, but is time-variant with the operating points. Another way of dealing with the changing operating points is to use multiple models in parallel in the controller. These local models are valid in the different operating points.

1.4 Models of other elements in canals

Besides the model of the reaches, it is necessary to model the different elements placed along the canal to manipulate the flows in the canal systems. These elements are mainly gates, weirs and pumps.

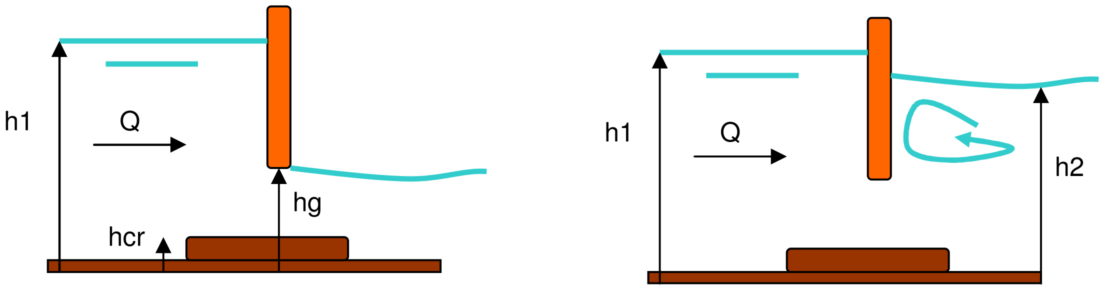
A complete model description of the diferent types of gates, weirs or pumps is out of the scope of the document. A model description of a wide class of these elements can be found in [2] and [3].

In the real canals in Spain that are going to be used in the HD-MPC project as applications in WP6 and WP7 (Postrasvase Tajo-Segura and Canal del Bajo Guadalquivir), the flow is controlled by undershot gates. For this reason, a brief description of the models has been included in this document.

There are two particular working flow conditions when dealing with overshoot gates:

1. The free flow condition
2. The submerged flow condition.

There are several approachess for both conditions (see [3]). Here, the formula due to Bos [11] is presented.



Free flow

Submerged flow

Figure 3. Undershot gate

Free flow

$$Q(k) = C_g W_g \mu_g \left(h_g(k) - h_{cr}\right)\sqrt{2g\left(h_1(k) - h_{cr} + \mu\left(h_g(k) - h_{cr}\right)\right)}$$

Submerged Flow

$$Q(k) = C_g W_g \mu_g \left(h_g(k) - h_{cr}\right)\sqrt{2g\left(h_1(k) - h2\right)}$$

where Q represents the flow through the structure (m^3/s), C_g the calibration coefficient, W_g the width of the gate (m), μ_g the contraction coefficient, h_1 the upstream water level (mMSL), h_2 the downstream water level (mMSL), h_g the gate height (mMSL), h_{cr} the crest level (mMSL), g the gravitational acceleration (=9.81 m/s^2) and k the time step index.

Linearized equations fot both conditions can be found in [2]. Several formulas has been defined theoretically or empirically to determine if the jump is free or submerged (See [3] for some references).

2 Simulation methods for the Saint Venant equations

In order to simulate the variable regime, it is necessary to solve the equations of Saint Venant. The existing models are divided in two types, depending on if they solve the complete equations of Saint Venant or if they realize some simplifications.

In this report we are going to focus on the schemes of resolution for the complete Saint Venant equations, which are the following:

I. Characteristic method

It is a technique for solving partial differential equations. The method is to reduce a partial differential equation to a family of ordinary differential equations along which the solution can be integrated from some initial data given on a suitable hypersurface.

It can be applied to prismatic canals, but its application for no prismatic canals with irregular geometry is of an enormous complexity and has not very reliable results. That is why they haven't been used for fluvial canals.

II. Finite difference method

It uses numerical methods for approximating the solutions to differential equations using finite difference equations to approximate derivatives.

There are two kinds of finite difference methods:

II.1. Explicit finite differences. Within this group we find the following numerical schemes:

- Diffusive or Lax scheme
- Leap-Frog
- McCormack
- Lamba

The explicit schemes present the disadvantage of requiring very small time steps during the calculation so that they are stable. However, this means that they are 'expensive in computation'.

II.2. Implicit finite differences.

Outstanding schemes:

- Preissmann
- Beam and Warming
- Vasiliev

Generally the implicit schemes are more efficient than the explicit ones from the computation point of view, although this is not an advantage when we are modeling a quickly variable flow regime, since the time step has to be reduced to values similar to those of the explicit schemes to be able to represent discontinuities. Nowadays, the majority of commercial models solve the scheme of Preissmann or some variant of it. Some of these models are: HEC-RAS, MIKE-11, SIC, SOBEK, and DAMBRK.

III. Finite element method.

The finite element method is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc.

This method gives optimal results for elliptical or parabolic equations. The Saint Venant equations form a hyperbolic system, this does that the method of the finite elements requires much complexity and long calculation time to reach results that do not improve considerably the obtained with the finite differences.

IV. Finite volume.

The finite volume method is a method for representing and evaluating partial differential equations in the form of algebraic equations (see [12]). Similar to the finite difference method, values are calculated at discrete places on a meshed geometry. "Finite volume" refers to the small volume surrounding each node point on a mesh. In the finite volume method, volume integrals in a partial differential equation that contain a divergence term are converted to surface integrals, using the divergence theorem. These terms are then evaluated as fluxes at the surfaces of each finite volume. Because the flux entering a given volume is identical to that leaving the adjacent volume, these methods are conservative. Another advantage of the finite volume method is that it is easily formulated to allow for unstructured meshes. The method is used in many computational fluid dynamics packages.

All the schemes of resolution of the complete Saint Venant equations have stability problems when the flow is quickly variable. This problem can be solved in two ways: with isolation methods or with direct methods:

- Isolation methods: The purpose is to isolate the discontinuity and to treat it like a contour. In practice this is nonviable because we don't know where the discontinuity will be.
- Direct methods: They are divided in two groups, those that add an artificial term in the equations to increase the diffusion (artificial viscosity) and those that don't add any artificial term. The methods that do not add artificial viscosity are clearly desirable, like the Local Partial Inertia (LPI).

3 Simulation software

In this chapter some software tools used to simulate canals and rivers are mentioned and briefly described. These tools use the *Implicit Finite Differences* method mentioned in Chapter 2:

HEC-RAS: Developed by U.S. Army Corps of Engineers. HEC-RAS (Hydrologic Engineering Centers River Analysis System) allows performing one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling.

MIKE-11: Developed by DHI (Danish Hydraulic Institute). MIKE 11 provides an array of computational methods for steady and unsteady flow in branched and looped channel networks, and flood plains. MIKE 11 is applicable to flow conditions ranging from steep river flows to tidally influenced narrow estuaries, and describes sub critical and supercritical flow locally. MIKE 11 includes advanced formulations for simulating flow through a variety of standard structures as well as complex structures such as operational structure or dam break structures.

SOBEK: By Delft Hydraulic. SOBEK is a 1D and 2D instrument for flood forecasting, drainage systems, irrigation systems, sewer overflow, ground-water level control, river morphology, salt intrusion and water quality.

DAMBRK: Developed by BOSS International. DAMBRK (Dam Break Forecasting Model) is a one-dimensional hydrodynamic flood routing software. The software accounts for dam and bridge failures, storage effects, floodplain overbank flow, and flood wave attenuation. DAMBRK is used for dynamic flood routing, dam safety analysis, and reservoir spillway analysis.

FLDWAV: FLDWAV is an evolution of DAMBRK that incorporates some improvements in aspects like the simulation of structures.

SIC: The SIC model has been developed at the Irrigation Division of Cemagref Montpellier (France). It has been particularly dedicated to irrigation canals. This model has been adapted from another hydraulic model, where some features have been removed, new ones have been introduced, and for which special user-friendly interfaces have been developed. It can be used both by engineers and by canal managers.

3.1 Tools chosen

INOCSA has chosen HEC-RAS and SIC for the third application of the HD-MPC project.

In Chapters 4 and 5 both models are going to be described and in particular HEC-RAS is compared with the rest of software tools. In Section 6.3 a comparison between HEC-RAS and SIC will be presented.

4 HEC-RAS

4.1 General overview

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities (see [13] and [14]).

The HEC-RAS system contains four one-dimensional river analysis components for: 1) steady flow water surface profile computations; ***2) unsteady flow simulation***; 3) movable boundary sediment transport computations; and 4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

The current version of HEC-RAS supports steady and unsteady flow water surface profile calculations; sediment transport/mobile bed computations; and water temperature analysis.

4.2 Unsteady flow simulation

This component of the HEC-RAS modelling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau's UNET model [20]. This unsteady flow component was developed primarily for subcritical flow regime calculations.

The hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures that were developed for the steady flow component were incorporated into the unsteady flow module.

Additionally, the unsteady flow component has the ability to model storage areas and hydraulic connections between storage areas, as well as between stream reaches.

4.3 Equations used for unsteady flow simulation

The physical laws which govern the flow of water in a stream are called, as we mention before, Saint Venant equations:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \qquad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{\beta Q^2}{A}\right)}{\partial x}+gA\left(\frac{\partial h}{\partial x}+S_f-S_0\right)-\beta q v_x+w_f B=0 \qquad (2)$$

These are equations for one-dimensional and unsteady flow in an open canal.

4.4 HEC-DSS and HEC-DSSVue

The U.S. Army Corps of Engineers Hydrologic Engineering Center has developed and released the HEC Data Storage System Visual Utility Engine (HEC-DSSVue), a graphical user interface for the HEC Data Storage System (HEC-DSS) (see [15]).

HEC-DSS is a database system designed to efficiently store and retrieve scientific data that is typically sequential. Such data includes, but it is not limited to, time series data, curve data, spatial-oriented gridded data, textual data and other. The system was designed to make it easy for users and application programs to retrieve and store data.

HEC-DSS originated in 1978 for hydrologic modeling programs, in order to exchange time series data. It includes programming interfaces for C++, Visual Basic and Java. HEC-RAS is interfaced with HEC-DSS.

An assortment of utility programs has been developed to:

1) load and import data from a range of formats
2) export data
3) graph, tabulate and edit data
4) mathematically manipulate data
5) perform various database utilities and maintenance functions. Several of these functions have been incorporated into HEC-DSSVue.

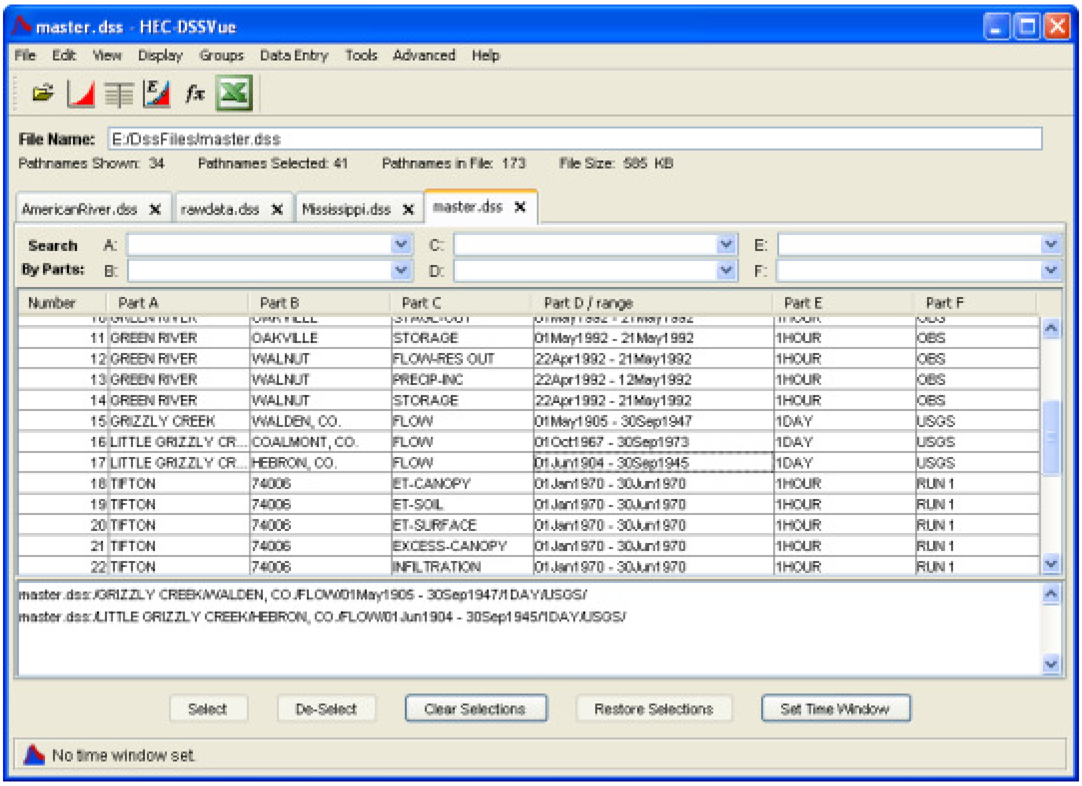
HEC-DSS has been installed on a variety of operating systems including Microsoft Windows, Apple Macintosh, and a variety of Unix flavors.

There are no licenses or fees required for HEC-DSS or its utilities.

HEC-DSS incorporates a modified hashing algorithm and hierarchical design for database accesses that is designed specifically for the storage and retrieval of large sets of data. This includes (but it is not limited to) computed or observed daily flow values, hourly precipitation amounts, rating tables and radar rainfall measurements.

Data in HEC-DSS is stored in blocks or records, and each record is identified by a unique name called a ‘pathname’. A record’s pathname must be given each time that its data is stored or retrieved from a HEC-DSS file. A pathname consists of six parts, which describe the data, including its region, location, parameter, beginning time and version. This convention makes the data self-documenting. Because of this self-documenting nature, there is no need for a data dictionary or data definition file as required with other database systems. In fact, there are not database creation tasks or any database set-up. By just providing a HEC-DSS database file will automatically be generated and configured.

HEC-DSSVue is a Java-based visual utilities program that allows users to plot, tabulate, edit, and manipulate data in HEC-DSS database files [15]. The graphics produced by HEC-DSSVue are highly customizable and can be saved in various formats, including “jpeg” and “png” (portable network graphics), or for printing or copying to the clipboard for inclusion in reports. HEC-DSSVue incorporates over sixty mathematical functions. Along with these functions, HEC-DSSVue provides several utility functions that provide a means to enter data sets into a HEC-DSS database, rename data set names, copy data sets to other HEC-DSS database files, and delete data sets.



File Name: E:/DssFiles/master.dss

Pathnames Shown: 34 Pathnames Selected: 41 Pathnames in File: 173 File Size: 585 KB

Number	Part A	Part B	Part C	Part D / range	Part E	Part F
11	GREEN RIVER	OAKVILLE	STORAGE	01May1992 - 21May1992	1HOUR	OBS
12	GREEN RIVER	WALNUT	FLOW-RES OUT	22Apr1992 - 21May1992	1HOUR	OBS
13	GREEN RIVER	WALNUT	PRECIP-INC	22Apr1992 - 12May1992	1HOUR	OBS
14	GREEN RIVER	WALNUT	STORAGE	22Apr1992 - 21May1992	1HOUR	OBS
15	GRIZZLY CREEK	WALDEN, CO.	FLOW	01May1905 - 30Sep1947	1DAY	USGS
16	LITTLE GRIZZLY CR...	COALMONT, CO.	FLOW	01Oct1967 - 30Sep1973	1DAY	USGS
17	LITTLE GRIZZLY CR...	HEBRON, CO.	FLOW	01Jun1904 - 30Sep1945	1DAY	USGS
18	TIFTON	74006	ET-CANOPY	01Jan1970 - 30Jun1970	1HOUR	RUN 1
19	TIFTON	74006	ET-SOIL	01Jan1970 - 30Jun1970	1HOUR	RUN 1
20	TIFTON	74006	ET-SURFACE	01Jan1970 - 30Jun1970	1HOUR	RUN 1
21	TIFTON	74006	EXCESS-CANOPY	01Jan1970 - 30Jun1970	1HOUR	RUN 1
22	TIFTON	74006	INFILTRATION	01Jan1970 - 30Jun1970	1HOUR	RUN 1

```
master.dss:/GRIZZLY CREEK/WALDEN, CO./FLOW/01May1905 - 30Sep1947/1DAY/USGS/
master.dss:/LITTLE GRIZZLY CREEK/HEBRON, CO./FLOW/01Jun1904 - 30Sep1945/1DAY/USGS/
```

No time window set.

Figure 4. Sample HEC-DSSVue Catalog View

Data sets are selected from a sorted / filtered list of pathnames in a HEC-DSS database file using a mouse. HEC-DSSVue also incorporates the “Jython” standard scripting language, which allows one to specify a routine sequence of steps in a text format, and then execute the sequence from a user-defined button or from a “batch” process.

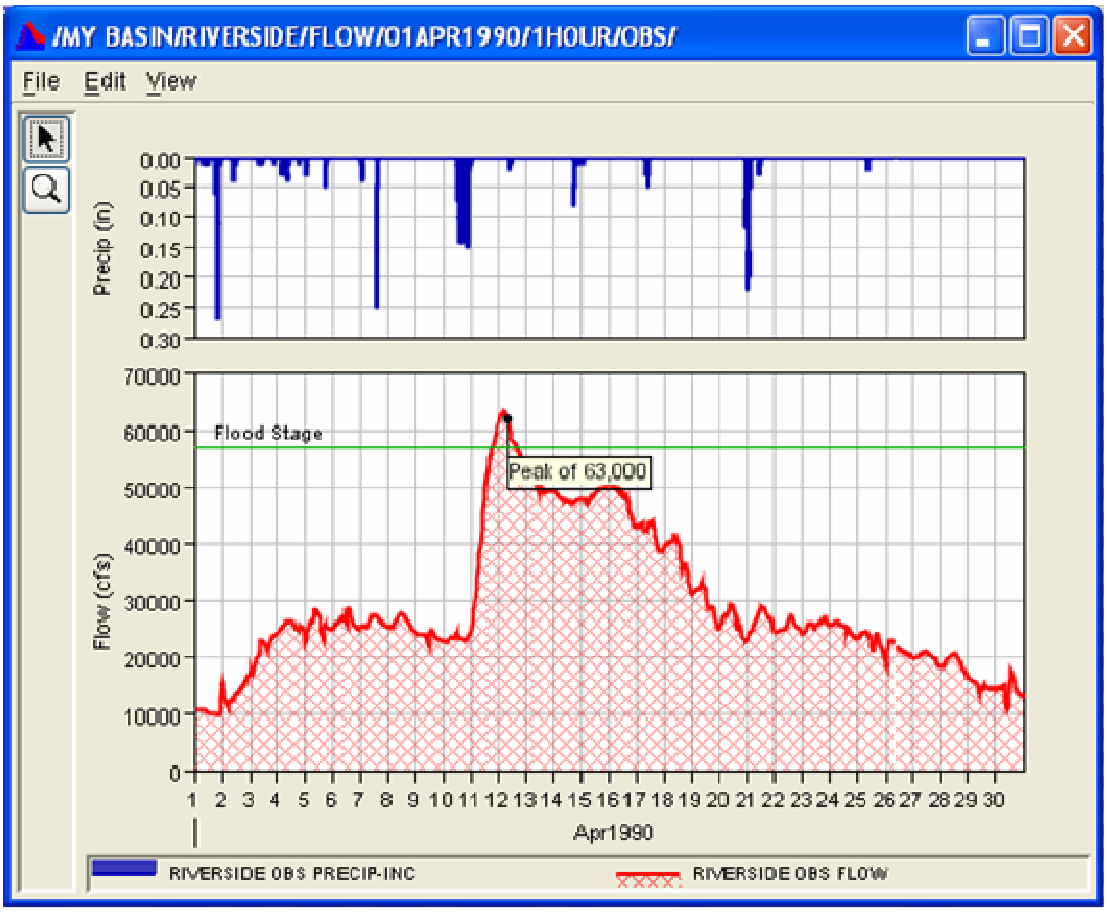


Figure 5. Sample HEC-DSSVue Graphical Display

HEC-DSSVue was written using the Java programming language, which allows it to be run under a variety of different operating systems. Supported systems include Microsoft Windows and Sun Solaris (Unix). It is also available for Linux, but has only been tested on Red Hat Linux.

4.5 Comparing HEC-RAS

This is a brief comparison between HEC-RAS and the rest of Simulation Software Tools:

The Canadian Dam Association (CDA), in its celebrated annual congress in October of 2005, included a study whose objective era to compare **HEC-RAS with FLDWAV and DAMBRK** and to evaluate advantages and disadvantages of each model. FLDWAV is an evolution of DAMBRK that incorporates some improvements in aspects like the simulation of structures, but the numerical scheme is the same in both models (see [17]):

1. Both models have the same theoretical base and use the same numerical techniques in the majority of cases. The use of both models leads to the same results when all the introduced parameters are identical.
2. FLDWAV has more computer options in relation to conditions of contour and capacity to deal with non-Newtonian flow and wind. However HEC-RAS presents more options for the calculation of lateral flows.
3. The experience in the use of both models reveals that the computation time required by FLDWAV is inferior to the one of HEC-RAS.
4. HEC-RAS has better functions of pre and post processing. The data are easier to publish, to modify and to visualize in a screen.
5. Both models have capacity to interact with digital land models (DEM or TIN) by means of surroundings GIS (Geographical information System).

In the last years, this one-dimensional hydraulic model has been mostly used for dams break.

MIKE 11 is a general river modeling system developed by DHI (Danish Hydraulic Institute). MIKE 11 has become industry standard in many countries, including Australia, New Zealand and Bangladesh and in many European countries. MIKE 11 contains modules for run-off simulations, hydrodynamics, flood forecasting, transport and dilution of dissolved substances, sediment transport, and river morphology as well as various water quality processes.

An important disadvantage MIKE-11 compared with HEC-RAS is that MIKE-11 is not free. And it is not very easy to configure by the user without the help of DHI.

MIKE 11 is focused on flood propagation, and has some modules that allow different approaches (steady and unsteady flow, complete equations). MIKE-11 has also the ability to model composite sections, dry beds, weirs, passes under roads and other structures. Together with the hydrodynamic modules, there are other modules that can be used to study sediment transport and water quality. MIKE 11 allows the entry of data from programs that use Geographic Information Systems (GIS) and export the results to them. The **SOBEK** model, by Delft Hydraulics, is focused on rivers, canals and estuaries, is less widespread. It also allows the steady and unsteady approach and has additional modules available for the study of water quality, saltwater intrusion, sediment transport and morphological changes in rivers and estuaries.

HEC-RAS is very interesting against the rest of models due to the following arguments: environmental-friendly, widely used to model hydraulic simulations, easily configurable and free model.

5 SIC

5.1 General overview

SIC software (Simulation of Irrigation Canals) can be used both by engineers and by canal managers (see [16]).

The very first version of this model was developed for the I.I.M.I. (International Irrigation Management Institute) on a real canal located in the South coast of Sri Lanka (Kirindi Oya Right Bank Main Canal). One purpose of this model was to be easily usable by canal managers as a decision support tool, in order to help them in the daily operation and maintenance of their system.

Since this first application was promising, Cemagref, with other partners, decided to develop a new standard version of this software, that could be used on most of the irrigation canals world-wide.

The SIC model has been developed at the Irrigation Division of Cemagref Montpellier (France).

5.2 Technical merit

Computational accuracy

The SIC hydraulic model is solving the complete Saint Venant equations. It uses the classical implicit Preissmann scheme. The implicit coefficient q is set to 0.6. The time step can be selected from 0.01 to 999.99 minutes (default value is 10 minutes). The distance step can be chosen by the user (default value is 200 meters).

Initial conditions

The SIC model is divided into three units. ***Unit 1*** is the topographical unit used to enter topological and geometrical data of the system.

Then, ***Unit 2*** is used to make steady flow computations on this system, given the boundary conditions (discharges, gate openings, etc.).

Then from one of theses steady states, or from a previous unsteady flow state, ***Unit 3*** can perform unsteady flow computations, given the evolution of the boundary conditions in function of time.

In order to easily establish a desired initial steady state (common situation for irrigation canal management purposes), some features have been implemented in Unit 2. For example, if a targeted water elevation is given upstream of a gated cross structure, then the model can automatically compute the required gate opening in order to reach this water elevation. Unit 2 also computes the gate opening at a gated off-take, the crest width or elevation at a weir off-take, in order to match a given targeted off-take discharge, or the real supplied discharge given the offtake dimension and setting.

Internal and external boundary conditions analysis

When describing the system topology, the user has to indicate the locations (called nodes), where an inflow (e.g. headworks) or outflow (e.g. turnouts) will occur. The canal portion between two nodes is called a reach. In Unit 2, a Manning coefficient and a seepage value can be indicated at each data cross-section. This allows to take local changes into account. The downstream boundary conditions are given in terms of rating curves. Cross structures and node devices are described in this Unit 2. They are able to simulate many hydraulic conditions.

At cross structures, the different flow conditions can be simulated: free flow, submerged, piped, open flow, overtopping, and the corresponding transitions from one condition to another one. One cross structure contains up to 5 gates and up to 5 weirs, with different sizes, sill elevations, discharge coefficients, etc.

At nodes, several types of offtakes can be modeled: imposed discharge (e.g. headworks or pumps), gated offtake, weir or pipe with downstream condition (constant elevation, weir, user's defined rating curve), rating curves (turnout discharge function of water level in the main canal, e.g.: weirs). In the case of a gated offtake, weir or pipe the program can also handle the different hydraulic conditions (free flow, submerged, piped and open flow).

Special Hydraulic conditions

The SIC model does not handle advance on a dry bed, nor channel dewatering, nor hydraulic jumps. Supercritical flow can be allowed in unsteady flow computations, through a simplified modelization, if the corresponding option has been selected.

5.3 Modelling capabilities

System configuration

Branching and looping systems can be handled in steady and unsteady flow computation.

Frictional resistance

The channel friction is represented using the Manning (or Strickler) equation. The Manning coefficient can vary from one data cross-section to another.

Boundary condition types

Lots of boundary conditions can be taken into account:

- check gates (up to 5) and weirs (up to 5) in the same cross structure,
- inverted siphons, pumps, drop structures,
- reservoirs in series,
- siphon with gated inlet, etc.

Rating curves can be defined at the downstream boundary conditions and at the offtakes. Discharge hydrographs can be defined at nodes (headworks and offtakes). Stage hydrographs can be defined at the downstream boundary condition.

Turnouts

Through the user-friendly interface, three types of turnouts can be described:

a) Pumps, also called Imposed Discharge. Discharge can be positive (headworks) or negative (turnouts).

b) Gates, weirs or pipes with downstream condition (constant elevation, weir, user's defined rating curve).

c) Rating curves. The model computes the real supplied discharge, depending on the water elevation in the main canal.

Operations duplication

The gate opening operations can be described at each cross structure and turnout. This can be done through the user-friendly interface or through a regulation module.

Automatic Control

Automatic control of any structure (cross structure, offtakes, boundary conditions) is possible inside SIC. First, the measured, controlled and control action variables have to be specified. Some parameters can be specified concerning these variables (e.g. minimum gate movement, minimum and maximum values, measure and control time step, etc.). Second, the design technique has to be specified. The most common techniques are already available (PID, BIVAL, ELFLO, interactive manual control, etc.). An open regulation module is given to the user, where any other type of control can be written in FORTRAN programming language. In addition, an interface with the commercial package MatLab allows to write directly the regulation modules as a Matlab function, and allowing to use any Matlab function (included graphical functions).

5.4 USER CONSIDERATIONS

User interface

Lots of efforts have been devoted to develop a user-friendly interface for the SIC model. It is menu driven and has lots of graphical possibilities (editor and display). The locations where data have to be entered (or results to be visualized) are identified through direct reference to the topological sketch.

Topographical unit:

The network topology is created or modified through a graphical editor, mouse driven (if any, or keyboard if no mouse available). This editor is interactive and checks for errors. Reach geometry is entered using user-friendly interface.

Different types of cross-sections are proposed through the SIC user-friendly interface: offset / elevation, width / elevation, rectangular, trapezium, triangular, culvert, power relationship, circle.

When describing the system geometry, the user has to indicate all the data cross-sections. This data can come from a topographical survey or some design documentation. Each cross-section can be of a different type. If one of these sections contains a cross structure, it has to be indicated at this stage. The cross devices will be described in Unit 2 with all the hydraulic parameters.

The shape of the sections can be visualized in a graphical window. Errors are checked. Sections can be duplicated, inserted, deleted.

Additional computation cross-sections are automatically interpolated in order to fit into the given distance step (default value = 200 m).

6 HEC-RAS and SIC inside Task 7.3.

Inside Task ***7.3. Control and planning of the water capture system***, a simulation platform to test distributed controllers in the field of Water Capture System applications is being developed. Two approaches have been considered:

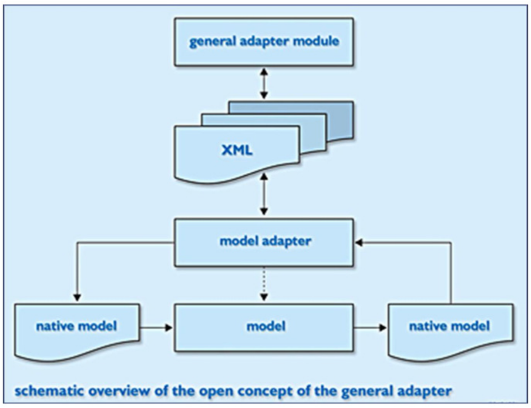
1. Integration of HEC-RAS and Matlab with the FEWS platform
2. Integration of SIC with Matlab

6.1 Integration of HEC-RAS and Matlab with the FEWS platform

The target of Task 7.3. is designing control and planning systems to manage water in canals in order to guarantee flows requested by different types of users (mainly irrigation).

During the first year of the project HD-MPC, INOCSA took the decision of using the software platform DelftFEWS (Flood early warning system):

- FEWS can integrate all the necessary modules for managing water distribution and allows the interchange of information among them
- FEWS will launch the modules in batch
- FEWS will show all data in a friendly interface

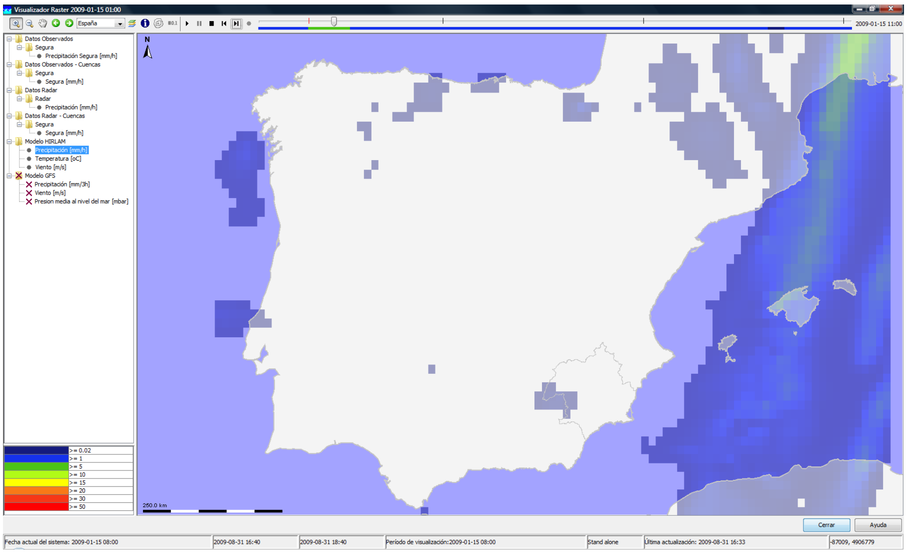


The philosophy of FEWS is to provide an open system that allows a wide range of existing forecasting models to be used. This concept is supported by the general adapter module, which communicates to external modules through an open XML based published interface, effectively allowing "plugging-in" of practically any forecasting model.

An adapter between the native module data formats and the open XML interface is typically required.

Inside the HD-MPC project, the modules to be integrated with FEWS will be:

- Meteorological forecast: For meteorological forecasting, the numerical model HIRLAM from AEMet (State Meteorological Agency of Spain) will be used (see D7.3.1)



Fecha actual del sistema: 2009-01-15 08:00 | 2009-08-31 16:40 | 2009-08-31 18:40 | Período de visualización:2009-01-15 08:00 | Stand alone | Última actualización: 2009-08-31 16:33 | -87009, 4906779

Figure 6. HIRLAM

- Controller (the model predictive control software), thought to be developed in MATLAB
- Hydraulic model: HEC-RAS will be the software in charge of simulating the evolution of water in canals. This software replaces 'the real canals'.

The work to be performed for the integration of HEC-RAS and the CONTROLLER with FEWS consists of the development of an ***adaptation software (model adapter) to convert input/output data from one application to another***.

The most difficult task is the conversion between FEWS and HEC-RAS data, because of the important quantity of data managed by HEC-RAS and the lack of information about input/output data of this software package. The conversion is between XML files generated or read by FEWS and HEC-DSS format, the HEC-RAS database system. The communication between the controller (MATLAB) and FEWS is quite simpler. Some functions written in MATLAB read XML and produce an output in that format.

This adaptation software is being developed by USE and INOCSA, but at the moment it has not been concluded successfully due to some difficulties with HEC-RAS.

6.2 *Integration of SIC with Matlab*

Due to those difficulties mentioned before, another alternative has been considered and it is based on the SIC software package developed by Cemagref (see Chapter 5). The advantage of this tool is an easier integration with Matlab, then the controller can be developed using this tool. The adaptation needs to integrate Matlab and SIC (task already performed), and current work is related to produce a SIC model of the 'Postrasvase Tajo-Segura' (irrigation canals located at the South East of Spain).

6.3 *Comparison between SIC and HEC-RAS*

This is brief comparison of SIC and HEC-RAC based on the characteristic mentioned in Chapters 4 and 5 of this document:

Advantages of HEC-RAS over SIC:

- Accepts batch inputs from excel, so that building a large-scale model is quick and easy.
- Simulates Dry Beds, and Sub/hyper critical flow in the same simulation. This can be important for simulating pools with no tail water.
- HEC-RAS is free.

Advantages of SIC over HEC-RAS:

- Hydro-mechanical gates are already modeled.
- Large example of control algorithms (including design method available).
- SIC has an interface with MATLAB, which is convenient for users to define controllers. HEC-RAS would interchange information with MATLAB but an interface must be developed because it is not included in the package.

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