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Watercom Pty Ltd

DRAINS
User Manual

A manual on the DRAINS program
for urban stormwater drainage system
design and analysis

by

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SUPERSEDED

This manual coincides with DRAINS as at Version 2018.06.
This user manual has been superseded by the DRAINS Help System which contains more current information on using the DRAINS program.

Sydney

June 2018

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WELCOME

This manual provides the information you need to use the DRAINS program to design and analyse urban stormwater drainage systems. Together with the Help system and the examples that accompany the program, it will guide you to understand what DRAINS can do, and how to use it to model many situations. The data files included in the **`ManualExample`** folder among the files supplied with DRAINS, which are also obtainable from www.watercom.com.au, can be used to explore the operation of the program.

The manual covers the operation of DRAINS, incorporating methods from *Australian Rainfall and Runoff*, the main source of hydrological design information in Australia. Unfortunately, the latest 2016 version of ARR (Ball et al., 2016) is incomplete at present, containing some methods that are not completely specified or supported. As this information becomes available, DRAINS will be able to implement the new methods. In the meantime, you can apply established methods such as ILSAX, the rational method, extended rational method and storage routing models, all with 2016 rainfall data.

DRAINS uses hydrological and hydraulic methods developed by generations of engineers. If you have had formal training in water engineering and experience in using models to solve practical problems, you should find the program easy to use and to interpret. If you are a beginner in the fields of hydrology, hydraulics or stormwater system design, or are out of practice, this manual and the Help system will assist you towards understanding the program's operations and outputs.

DRAINS can apply five alternative types of hydrological model (to define flowrates through a drainage system) and two hydraulic modelling procedures (to determine corresponding depths and velocities). It has recently been updated to include new procedures from *Australian Rainfall and Runoff*, 2016.

This manual can be used as a learning guide for DRAINS or as a reference manual that you can dip into. There is an index at the end, and you can use search functions to find topics in the PDF version. Most displays of screens are in Microsoft Windows 10 style; these displays may appear different in XP, Windows 7 or 8 styles, but the contents are the same.

Chapter 1 describes what DRAINS is and does, and how it can be installed.

Chapter 2 provides an example that takes you through the steps of entering data, running the program, and inspecting some of its outputs. Although the drainage system modelled is simple, there are several steps involved, which are set out in the example. The ILSAX hydrological model is applied in this chapter. (This and the other examples supplied run with the demo version of DRAINS, and cover most of the methods available.)

Chapter 3 provides additional examples using the rational method and the extended rational method, older models that are likely to be phased out in future.

Chapter 4 indicated how initial loss – continuing loss models and storage routing models are ds most of the procedures are similar to the ILSAX model operation, there are references to parts of Chapter 2.

Chapter 5 presents the many features of DRAINS. It shows the menus that control operations, the tools used to set up a system, the system components (pits, pipes, etc.) and the data bases that store the characteristics of standard components. It also describes the data required for all components. This chapter is meant to be dipped into, rather than being read completely.

Chapter 6 is about processes. It describes the options within DRAINS for inputting and displaying information, running the program, outputting data and results, and obtaining help.

Chapter 7 describes how DRAINS operates, covering computing and computational aspects. It also describes how DRAINS can be applied to design and analysis tasks, indicating how runs can be made and how results can be interpreted.

Chapter 8 provides the technical background to DRAINS and the methods that it uses. There are explanations and references relating to material on rainfall data, hydrological models, overland flows, pit inlet capacities and pressure change coefficients, detention basins, culverts and bridges.

The examples that were explained in earlier versions of this manual are now included in the DRAINS Help system. They use files that are available at C:\Program Files\Drains or C:\Program Files (x86)\Drains, depending on whether you are using a 32 or 64 bit operating system.

Previous versions of this manual described some features that have become obsolete and have been deleted. To avoid confusion, these descriptions are not given here, but the information remains in the DRAINS Help system to provide guidance when models created by earlier versions of DRAINS are revisited

As DRAINS develops and new features are added, there will be revisions of this manual, available electronically from www.watercom.com.au.

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1. INTRODUCTION TO DRAINS

1.1 Description

DRAINS is a multi-purpose Windows program for designing and analysing urban stormwater drainage systems and catchments. It was first released in January 1998 and is marketed by Watercom Pty Ltd, based in Wooli, NSW.

DRAINS can model drainage systems of all sizes, from small to very large (up to 10 km^2 using multiple sub-catchments[1] with ARR 2016 and ILSAX hydrology, and larger using storage routing model hydrology). Working through a number of time steps during the course of a storm event, it converts rainfall patterns to stormwater runoff hydrographs and routes these through networks of pipes, detention basins, channels and streams. In this process, it integrates:

- design and analysis tasks,
- hydrology (five alternative models) and hydraulics (two alternative procedures),
- closed conduit and open channel systems,
- headwalls, culverts and other structures,
- stormwater detention systems, and
- large-scale urban and rural catchments.

Within a single package, DRAINS can carry out hydrological modelling using ARR2016, ILSAX, rational method and storage routing models, together with unsteady hydraulic modelling of systems of pipes, open channels, and in the premium hydraulic model, surface overflow routes. It includes an automatic design procedure for piped drainage systems, connections to CAD and GIS programs, and an in-built Help system. Figure 1.1 shows areas where DRAINS can be used.

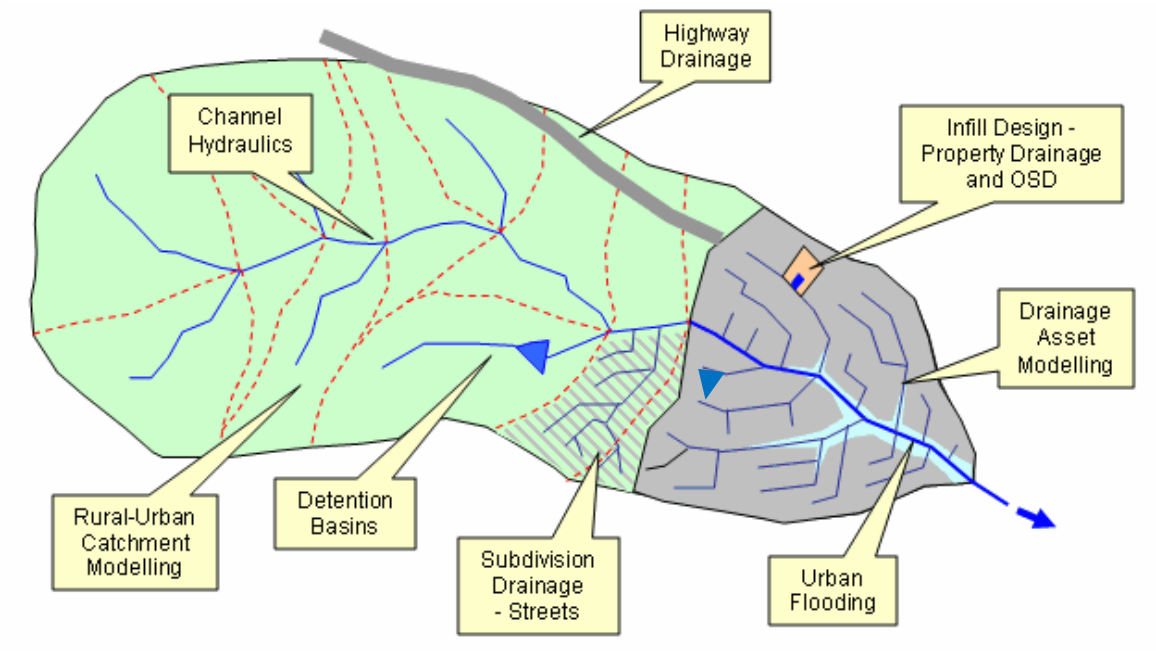

Figure 1.1 DRAINS Applications

Three significant capabilities that DRAINS does not provide are (a) continuous modelling over long periods with wet and dry conditions, (b) water quality modelling, and (c) 2-dimensional unsteady flow modelling.

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[1] Sub-catchments should be at most 5 ha in models that include times of concentration, as this quantity is often inaccurate. Larger areas can be modelled using a number of sub-catchments.

DRAINS is continuously being improved and expanded. It is available in versions for 20, 50 and unlimited numbers of pipes or channels. The ILSAX hydrology or rational method can be chosen. Optional ILSAX or rational method procedures, storage routing models, GIS capabilities and unsteady flow hydraulics in overflow routes are available at extra cost. Current prices for purchase and support are available from Bob Stack of Watercom Pty Ltd on (02) 6649 8005 or bobstack@watercom.com.au.

1.2 Modelling Aspects

1.2.1 Hydrological Models

DRAINS provides the hydrological models shown in **Table 1.1** to convert rainfalls to flowrates applying the procedures shown in **Figure 1.2**. These employ different loss and routing procedures. The rational method is the simplest, only calculating peak flowrates, while the other models produce hydrographs (time series of flows) and volumes to model stormwater detention systems. Some models are applied to relatively small urban sub-catchment areas, while others are usually applied to larger areas.

Table 1.1 Alternative Hydrological Models

Hydrology Model	Application	Loss Procedure	Routing Procedure	Rainfall Input	Output
ILSAX	small urban sub-catchments	Horton	time-area	hyetograph	hydrographs
Rational Method	small urban sub-catchments	runoff coefficient	none	intensity-frequency-duration data	peak flows
Extended Rational Method (ERM)	small urban sub-catchments	runoff coefficient	time-area	hyetograph	hydrographs
Storage Routing – RORB, RAFTS or WBNM	large rural and medium and large urban areas	initial loss - continuing loss	non-linear storage routing	hyetograph	hydrographs
ARR 2016 IL-CL	small to large rural and urban catchments	initial loss - continuing loss	time-area	hyetograph	hydrographs

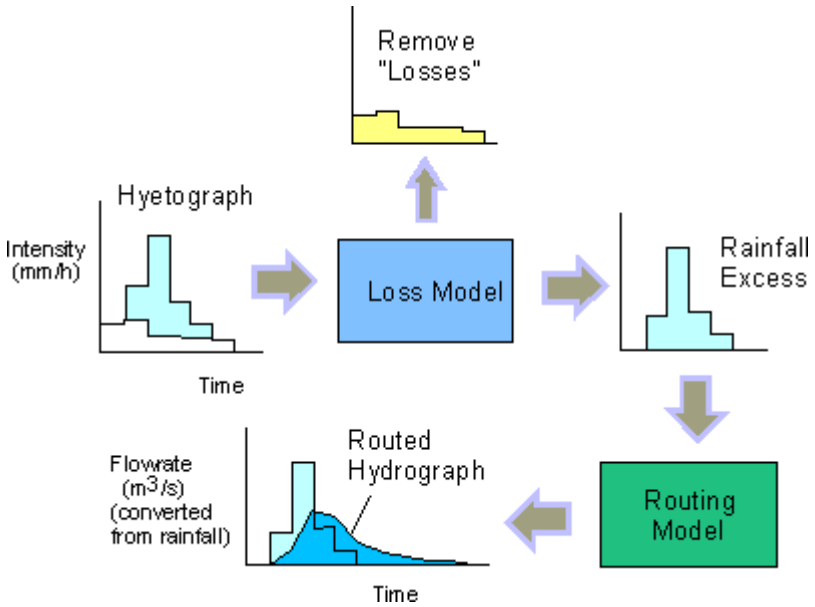


Figure 1.2 Rainfall-Runoff Procedures

These models describe the surfaces or land-uses of sub-catchments in different ways, and give varying results. They are applicable to different catchment sizes. They are described in detail in Section 8.3, and their relative merits are assessed in Section 8.3.7. Most of the examples in this manual employ the ILSAX model.

1.2.2 Hydraulic Calculations for Pipes, Open Channels and Surface Overflows

The procedures in DRAINS originally were intended to be of a medium level of complexity, providing stable, fast and sufficiently accurate methods to compute flowrates and water surface profiles. The needs of users have prompted considerable advances.

The original *basic hydraulic model* combined (i) hydraulic grade lines (HGLs) projected backwards from tailwater levels at drainage system outlets with (ii) a pressure pipe calculation procedure, to calculate flowrates and HGL levels at pits and other locations using a quasi-unsteady process. DRAINS then computed the characteristics of surface overflows outside the pipe system.

This model has been replaced by a one-dimensional unsteady flow procedure. In the *standard hydraulics model*, this is applied to pipe and open channel flows, while in the *premium hydraulic model*, surface overflows are also modelled by full unsteady flow calculations.

1.3 Administration

1.3.1 Support

For support, contact Watercom Pty Ltd at phone/fax (02) 6649 8005 or bobstack@watercom.com.au. Support is usually available for 12 months after purchase of DRAINS or renewal of support.

1.3.2 DRAINS Viewer

In addition to the DRAINS program, a free Viewer is available. Although it cannot set up or run DRAINS models, the Viewer can display inputs from any DRAINS model, and stored outputs from a DRAINS run. It can be used to check DRAINS models created by others. A setup file for this Viewer can be obtained from Bob Stack at bobstack@watercom.com.au.

1.3.3 Installation

If you are setting up the demonstration version, or updating a DRAINS program that is already installed, you only need the setup file, which can be downloaded from the website www.watercom.com.au. There are three choices available. Preferably, DrainsSetup64.exe should be selected.

Click your mouse on the icon for the .exe file and, when prompted, enter the password provided by Watercom Pty Ltd, or enter 'DEMO' to install the demonstration version. Then follow the instructions, acknowledging the Conditions of Use. The USB locks that are currently supplied do not require a driver.

Installations can be made on any number of PCs. Running DRAINS requires that the moveable hardware lock or dongle be connected to the PC's USB port. Locks for servers are also available. Locks are programmed to model certain sizes of drainage network (up to 20, 50 or unlimited links), and where allowed, to implement additional rational method, ILSAX and storage routing model calculations, to import and export data from GIS files and to undertake full premium hydraulic calculations. DRAINS can be uninstalled in the usual way for Windows programs.

The version number of the DRAINS program being used can be found in the **About** DRAINS**….** option in the **Help** menu. The **License Details** item provides information on the capabilities of the attached hardware lock.

The DRAINS Viewer installs in the same way as DRAINS. No password is required.

1.3.4 Training

Training workshops and in-house courses are conducted regularly. Visit www.kustomengineering .com.au for details of current courses. The workshops are conducted by Dr. Geoffrey O'Loughlin (02

9570 6119, 0438 383 841 or geoff.oloughlin@gmail.com) and Dr, Benjamin Kus (0412 327 568 and ben@kustomengineering.com.au). They are communicated to DRAINS users by e-mail, and advertised by mail-outs to organisations involved with urban stormwater management.

1.3.5 Starting DRAINS

Once installed, DRAINS can be opened by:

- using the **Start** menu, selecting Programs and choosing DRAINS,
- clicking on a DRAINS shortcut if one is created on your or taskbar, or
- clicking on Drains.exe in the C:\Program Files\Drains\Program or C:\Program Files\Drains\Program (x86) folders (in 32 or 64 bit operating systems).

When opened, the Main Window of DRAINS appears as shown in Figure 1.3.

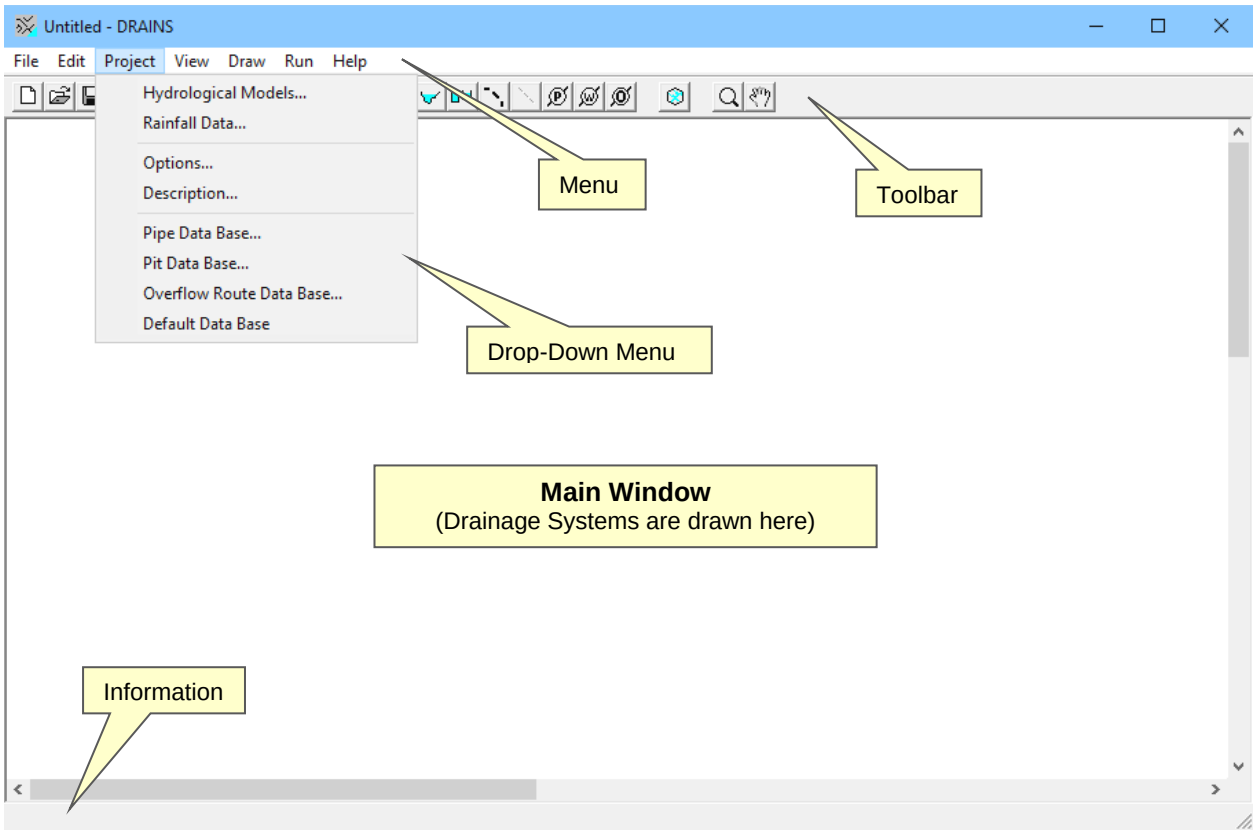
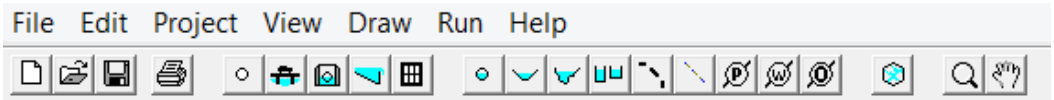


Figure 1.3 The Main DRAINS Window with the Project Menu Selected

You can define a drainage system graphically on this blank screen by drawing components such as pits and pipes, using the facilities in the menus and toolbar located at the top.



To operate DRAINS, you can enter data directly using the keyboard and mouse, or open or import an existing file from the **File** menu. If you are entering an entirely new system, you must follow the steps that are explained in the next section.

2. PIPE SYSTEM MODELLING USING ILSAX

2.1 General

This example illustrates how a pipe system, assumed to be located at Orange, New South Wales, can be set up in DRAINS and how Design and Analysis runs can be made. You can construct the model yourself, following the instructions set out below. The demonstration model of DRAINS can be used for this. Alternatively, you can inspect and run the finished model files Orange1.drn and Orange2.drn provided in the set of examples accompanying this manual. The instructions do not cover all DRAINS options or procedures, but are adequate to set up this working model.

The example can be run with different rainfall inputs, and with various hydrological models. Design rainfall patterns or hyetographs are produced by combining intensity-frequency-duration (I-F-D) relationships with temporal patterns that are available for any site in Australia. There is a choice between using rainfall patterns from *Australian Rainfall and Runoff* 1987 and patterns from the 2016 version. Because ARR 2016 is incomplete, there appears to be a hesitancy to adopt the 2016 procedures, although these are based on much more rainfall data, and are clearly superior. Another factor may be that the 2016 temporal patterns are more complex than the earlier ones, and 10 times more calculations are required.

To avoid repetitions, this example will be set up in four parts:

Section 2.2 inputting hydrological models and other specifications to form data bases;

Section 2.3 inputting model components;

Section 2.4 importing ARR 2016 design rainfalls, running the model, and inspecting results.

Section 2.5 importing ARR 1987 design rainfalls, running the model, and inspecting results;

The ILSAX hydrological model will be applied in these examples, but instructions for using other hydrological models will be provided later.

2.2 Inputting Common Data

2.2.1 General

The hydrological model, rainfall patterns and component data bases should be established first. Most of this information can be changed later, if you wish.

If you open and close an existing DRAINS model, the hydrological model and rainfall from that model will remain. To start afresh, you need to exit from DRAINS and start up again. In this case, the databases for the hydrological model and rainfall data will be empty, while those for pipes, pits and overflow routes will be taken from the file Drains.db1, located in the C:\ProgramData\Drains folder.

2.2.2 Choosing an ILSAX Hydrological Model

The background information for a model is entered using functions in the **Project** menu in the Toolbar. Select **Hydrological Models…** in the **Project** menu. The property sheet in Figure 2.1 appears, showing buttons that can be used to establish hydrological models. (Not all of the options shown may be available with your hardware lock. If you are setting up a new model, the Default model will be a nominal, incomplete Rational Method model.)

All the types of models are described later in this manual, but the ILSAX hydrology is used in this example. Clicking the **Add ILSAX Model** button opens the property sheet shown in Figure 2.2, in which the characteristics of the hydrological model can be entered.

You should enter the name and numbers shown. These will be explained later, but if you require an immediate explanation, press the **Help** button to open the Help screen shown in Figure 2.3. You can explore the various topics using hyperlinks and the Index and Search facilities on the left side of the window.

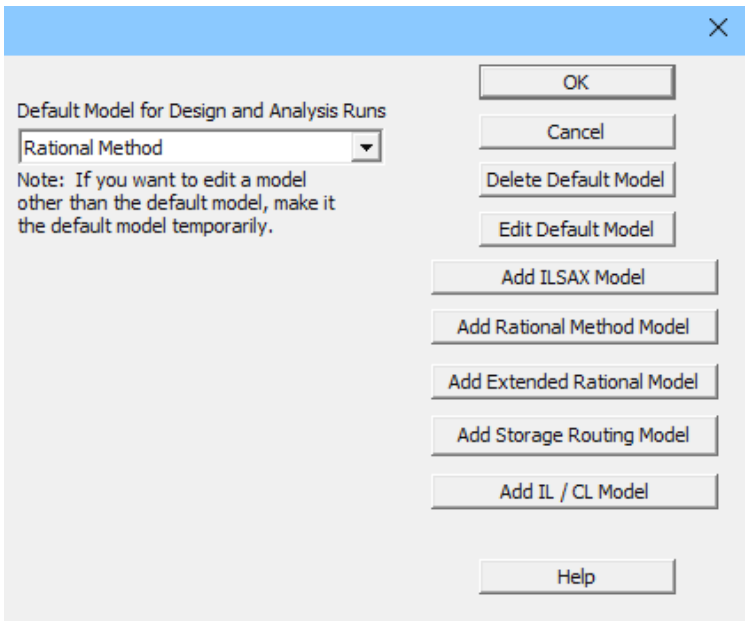


Figure 2.1 The Hydrological Model Specification Sheet

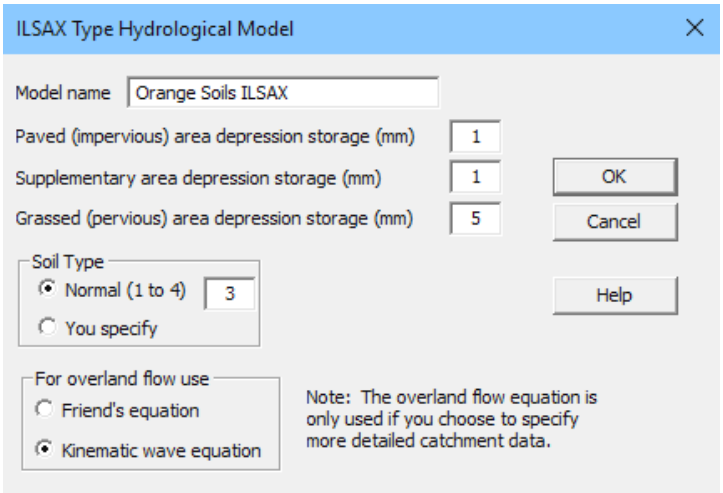


Figure 2.2 ILSAX Type Hydrological Model Property Sheet

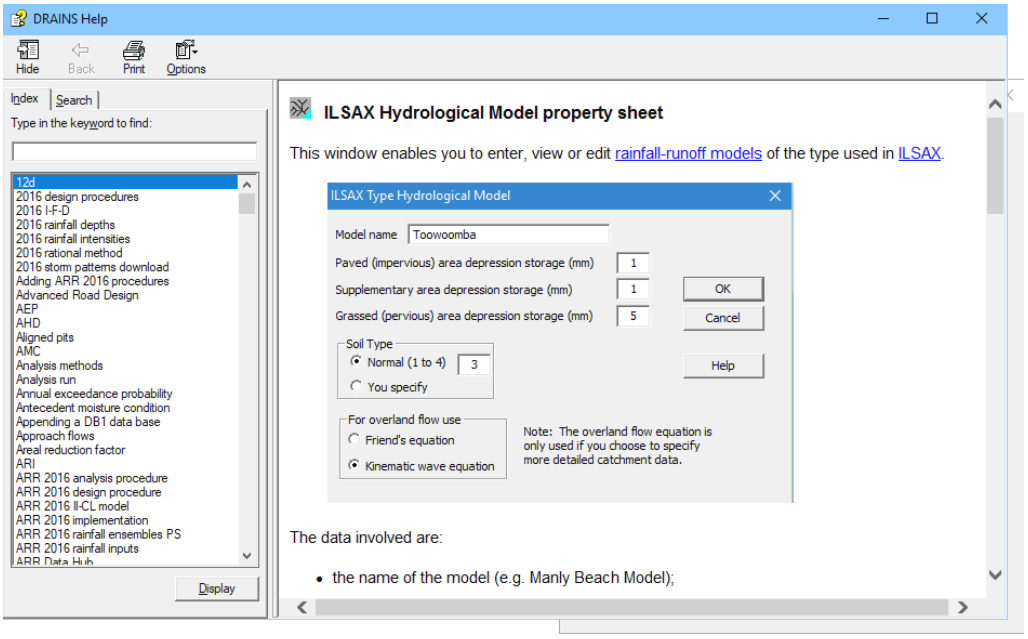


Figure 2.3 Help Window opened from the ILSAX Hydrological Model Property Sheet

You should then click **OK** in the property sheet and again in the Hydrological Model Specification sheet, ensuring that 'Orange Soils ILSAX' is defined as the default model in the drop-down list box at the top left corner of Figure 2.4.

2.2.3 Project Options

The Project Options sheet shown in Figure 2.5 can be opened from the **Project Options …** option in the **Project** menu.

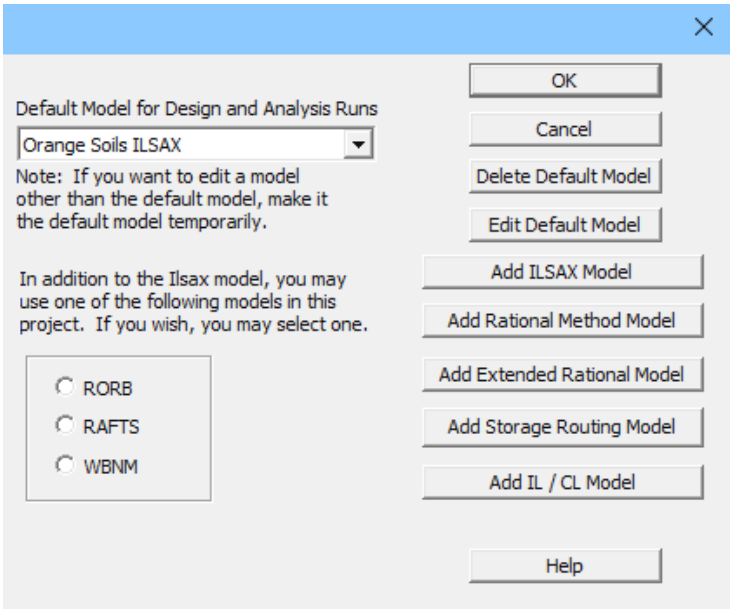


Figure 2.4 Hydrological Model Property Sheet with ILSAX Model Specified

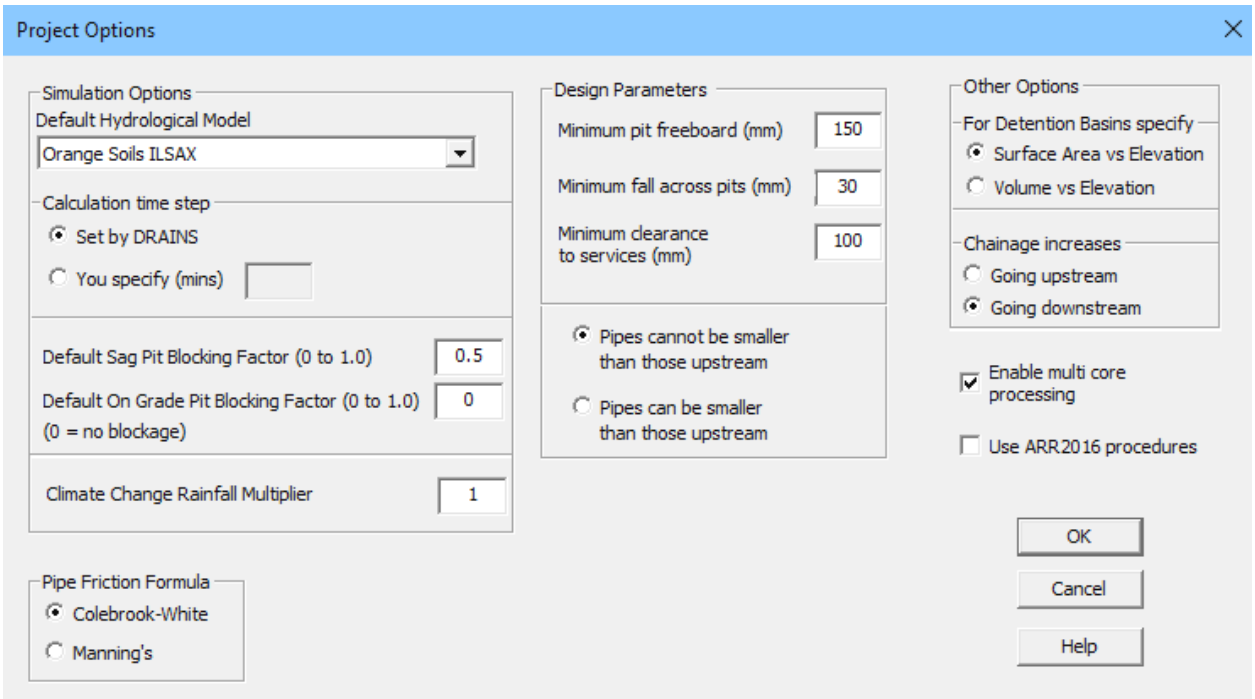


Figure 2.5 Project Options Sheet

This sheets sets the parameters that are used in DRAINS runs, including the types of rainfalls to be applied. The factor that needs to be set in this example is the blocking factor for sag pits at which ponding occurs (0.5). The factor for on-grade pits can be left at 0.0.

2.2.4 Description

An optional three-line description can be entered using **Project** → **Description …** (the **Description …** option in the **Project** menu). These lines appear at the bottom right of the Main Window.

2.2.5 Pipe, Pit and Overflow Route Data Bases

These can be entered separately, but a quick option this is used here is to adopt a standard regional data base. Choosing **Project** → **Default Data** Base opens the window shown below, which enables you to choose a data base. In this case, the latest New South Wales base will be used.

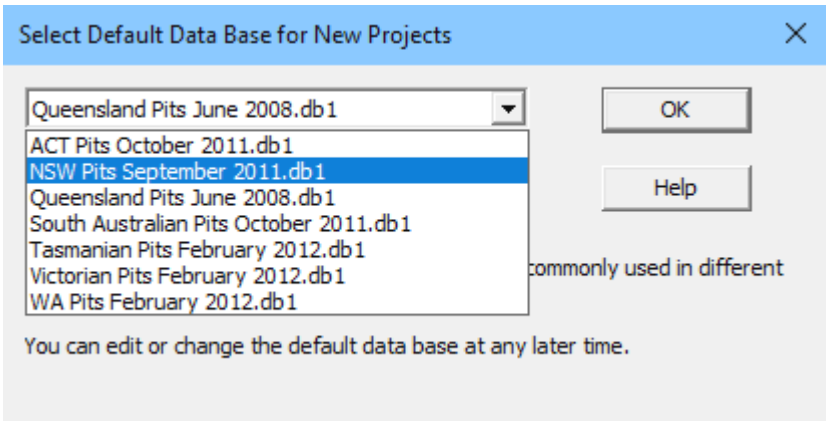


Figure 2.6 Selecting a Default Data Base

As described in Section 5.4.5 to Section 5.4.7, these data bases can be inspected or altered, and new items can be added. The selected data base stays in the .drn file for each model. New pit, pipe and overflow route types can be added, and existing information can be altered, but for programming reasons it is not possible to remove pipe and pit specifications.)

At this point, you should save the file using the **Save** option in the **File** menu, naming it Orange1.drn.

2.3 Inputting System Components

Suppose that the system to be designed is that shown in Figure 2.7, with five stormwater pits and five pipes.

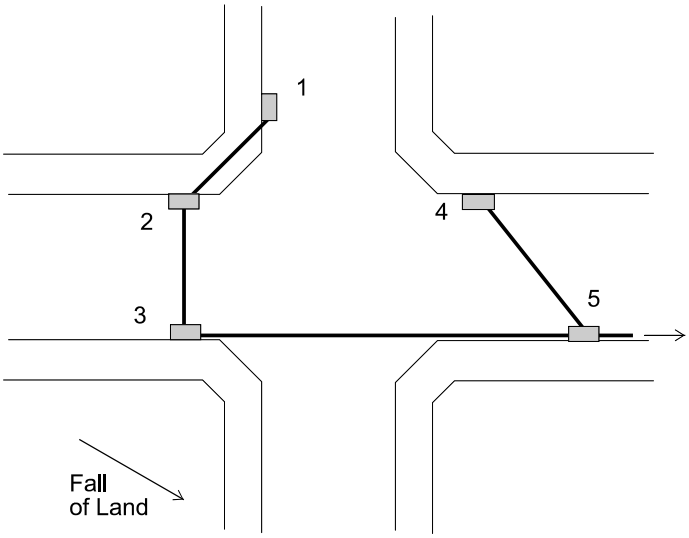


Figure 2.7 A Simple Drainage System

This system can be drawn in the Main Window using five tools from the Toolbar:

As you guide your mouse arrow over the Toolbar items, tool-tips will appear, indicating the purpose of each button. Once you click one of the Toolbar button, the cursor will change to a pencil, which can be used to place that component in the Main Window.

You can use the pit and node tools, and , to draw five drainage pits and three outlet nodes in the Main Window, as shown in Figure 2.8.

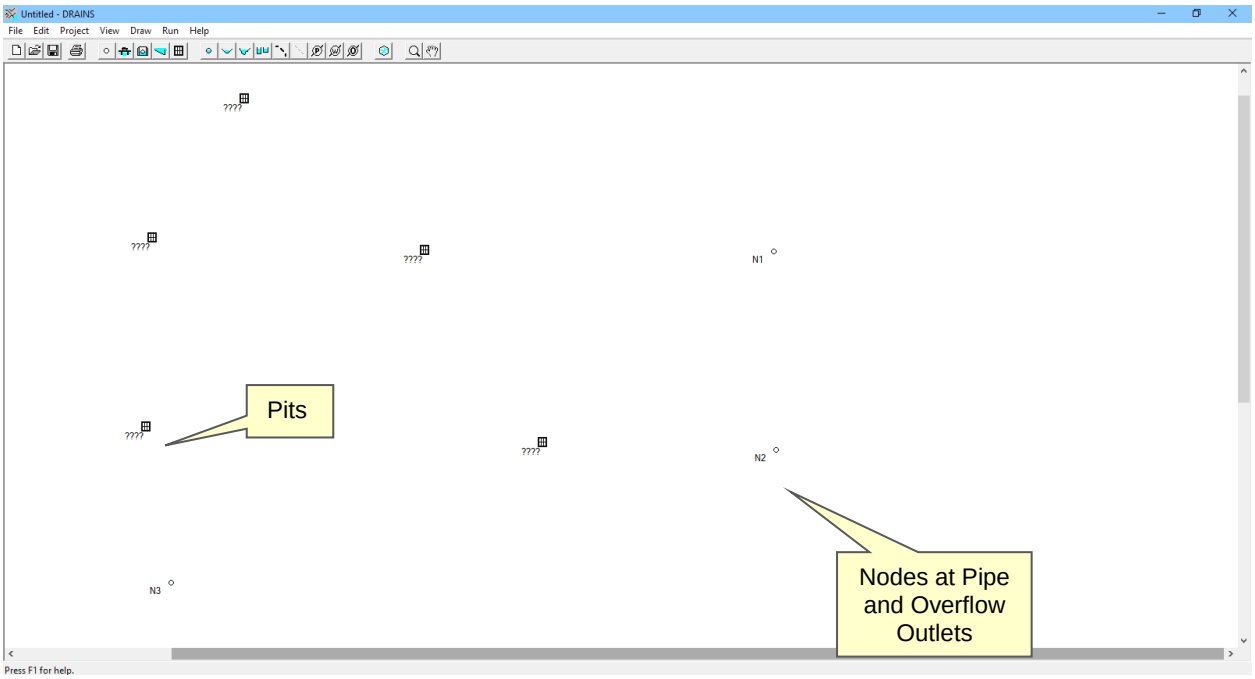


Figure 2.8 Initial Drawing of Drainage System

Pipes can be drawn between these by selecting the pipe tool and clicking on the beginning and end points to locate each pipe. Overflow routes made up of poly-lines can be added using the corresponding tool . Sub-catchments can be added using the sub-catchment tool , making sure that they touch the pits, to produce the system shown in Figure 2.9.

Note that the overflow paths can be drawn as a polyline, ., allowing them to be placed to the side in cases where both the pipe and any overflows travel to the same destination. Points along the overflow route are selected using the left mouse button, and the end-point is defined by clicking the right mouse button.

The names of components (mostly given as ???? to start with) can be dragged to more convenient locations. The components themselves can be moved round the screen. You can select a component by clicking it to make 'handles' appear, holding the left mouse button down on it so that horizontal and vertical arrows appear, and then dragging the component to the required location. A pipe or channel can be moved as a single unit by dragging near its centre. Alternatively, their ends can be moved by dragging the handles.

As well as entering data directly onto a blank Main Window, as shown above, you can insert a background from a CAD drawing file, together with a layout of pits and pipes. A drawing file for the current example, Orange Base.dxf, is shown in Figure 2.10. This can be entered into a DRAINS Main Window, after the hydrological, rainfall and options settings have been defined, using the **Import DXF File…** option in the **File** menu, shown in Figure 2.11. This takes you through a set of dialog boxes in which you must nominate layers containing data on the background, pipes (as lines) and pits (as circles), and other information. The first of these is shown in the lower part of Figure 2.11.

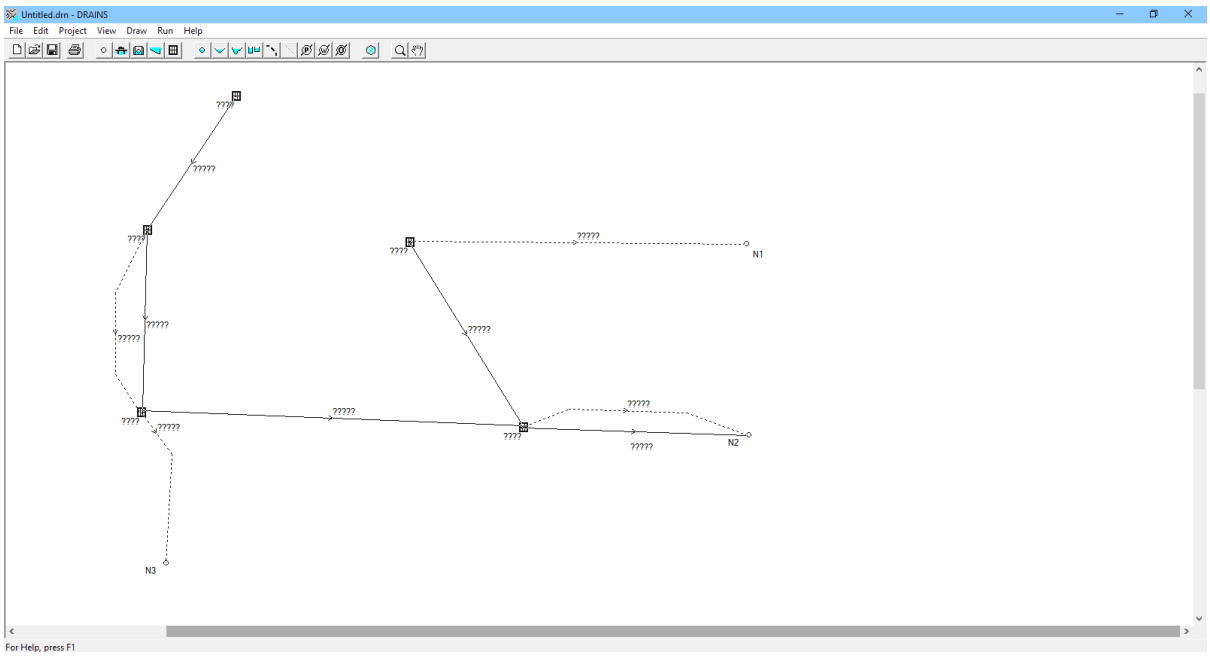


Figure 2.9 More Complete Orange Drainage System Drawing

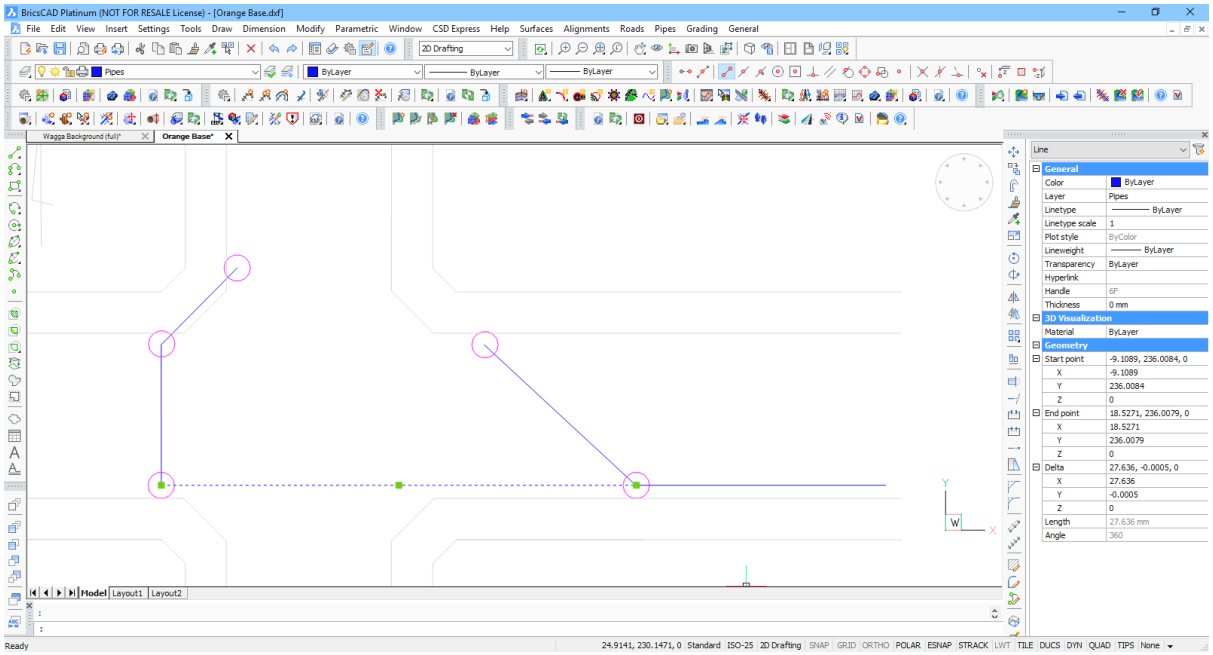


Figure 2.10 CAD Display showing Pipe System Layout and Background

The pipe system appears as shown in Figure 2.12. This model should be saved as file Orange2.drn. This view can be enlarged using the magnifying tool or mouse wheel, and you can pan across the model using the pan tool in the toolbar. All pipe lengths can be scaled by setting the length of one pipe. The other components of the system: pits, sub-catchments, overland flow paths and outlets, can then be added. The background is an image created from vector objects (lines, polylines and arcs) in the nominated layer of the CAD file. It can be switched on and off, and its colour can be changed, using options in the **View** menu.

Data for parts of the drainage system can be entered and edited using property sheets that appear when you right-click a component, and select **Edit Data** from the pop-up menu, as shown in Figure 2.13.

The property sheet for Pit 1 is shown in Figure 2.14. This has two pages, the first with pit properties and another optional page for factors to be applied if pit pressure change coefficients are to be calculated using the *Queensland Urban Drainage Manual* (QUDM) charts (refer to Section 6.4.4). These include an aligned/misaligned choice (explained in the DRAINS Help system) and the width of the pit wall on which the outlet pipe is located.

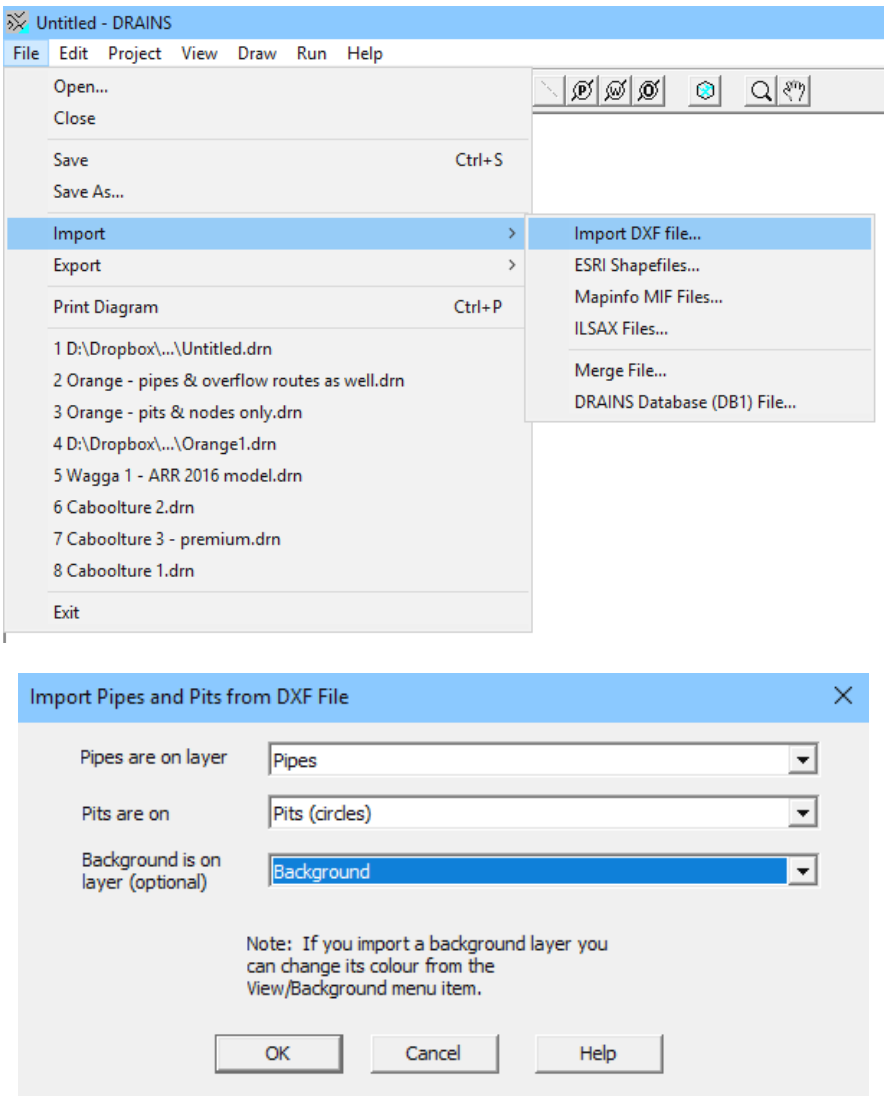


Figure 2.11 Menu and Dialog Box for Nominating CAD Layers

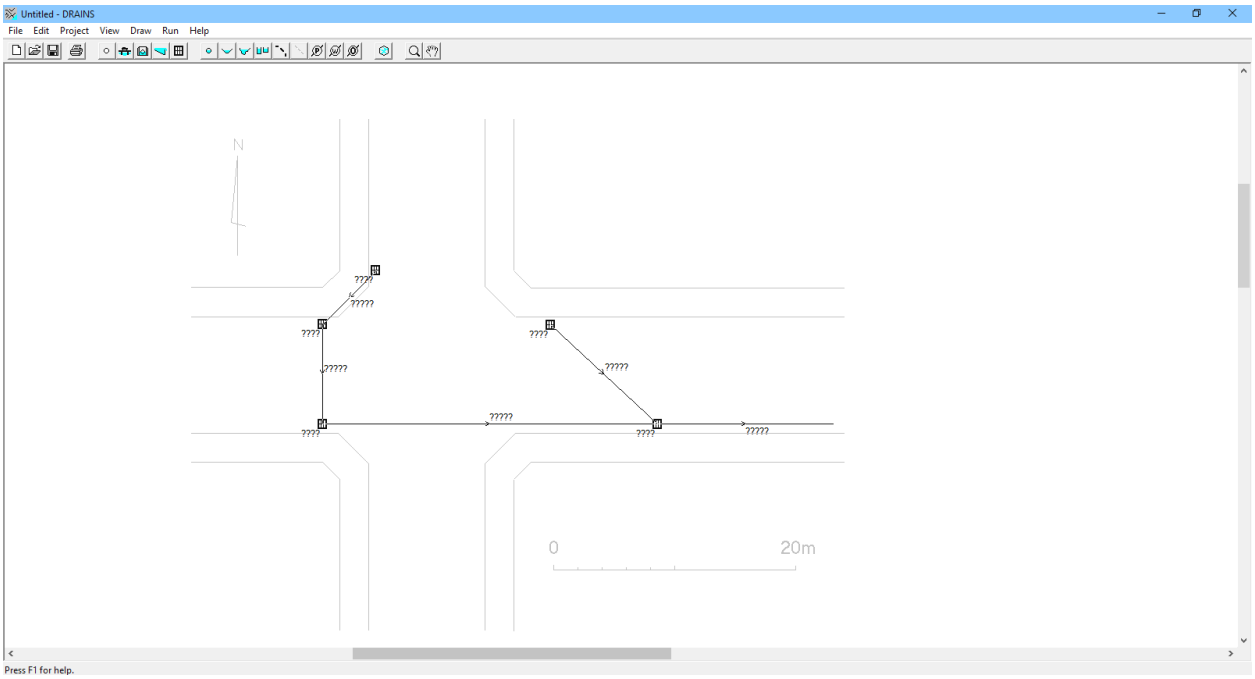


Figure 2.12 Inputted Drainage System from the CAD File

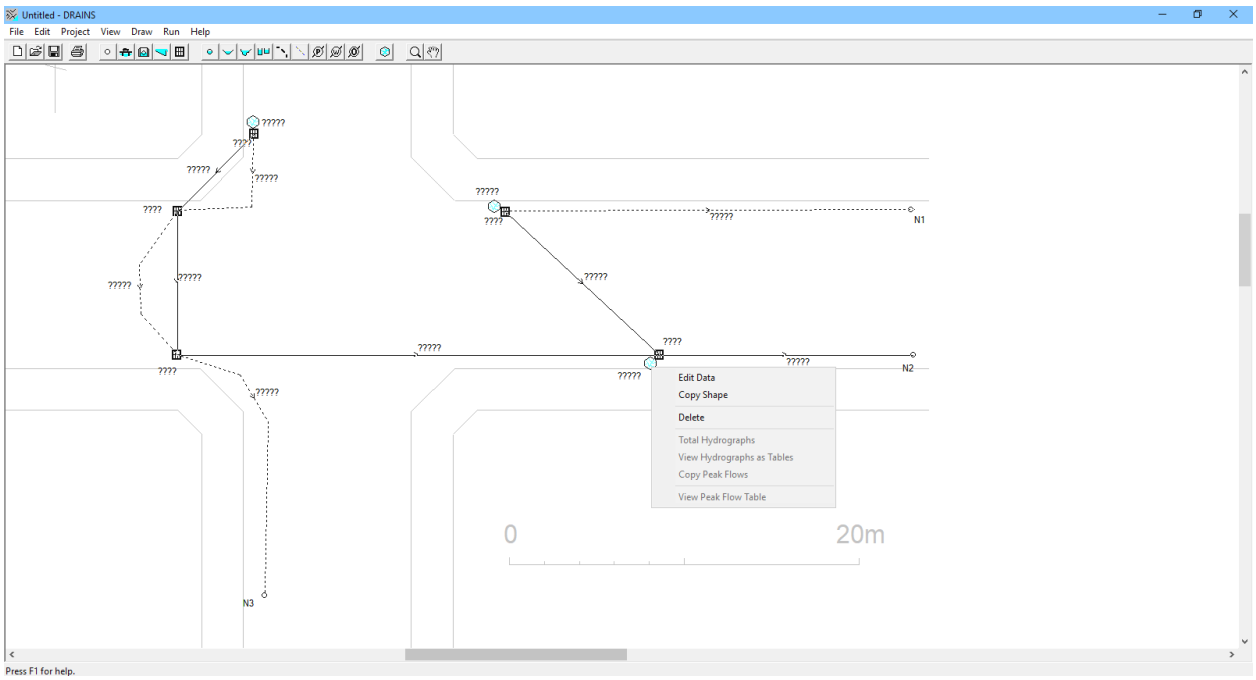


Figure 2.13 Pop-Up (Right Mouse Button) Menu

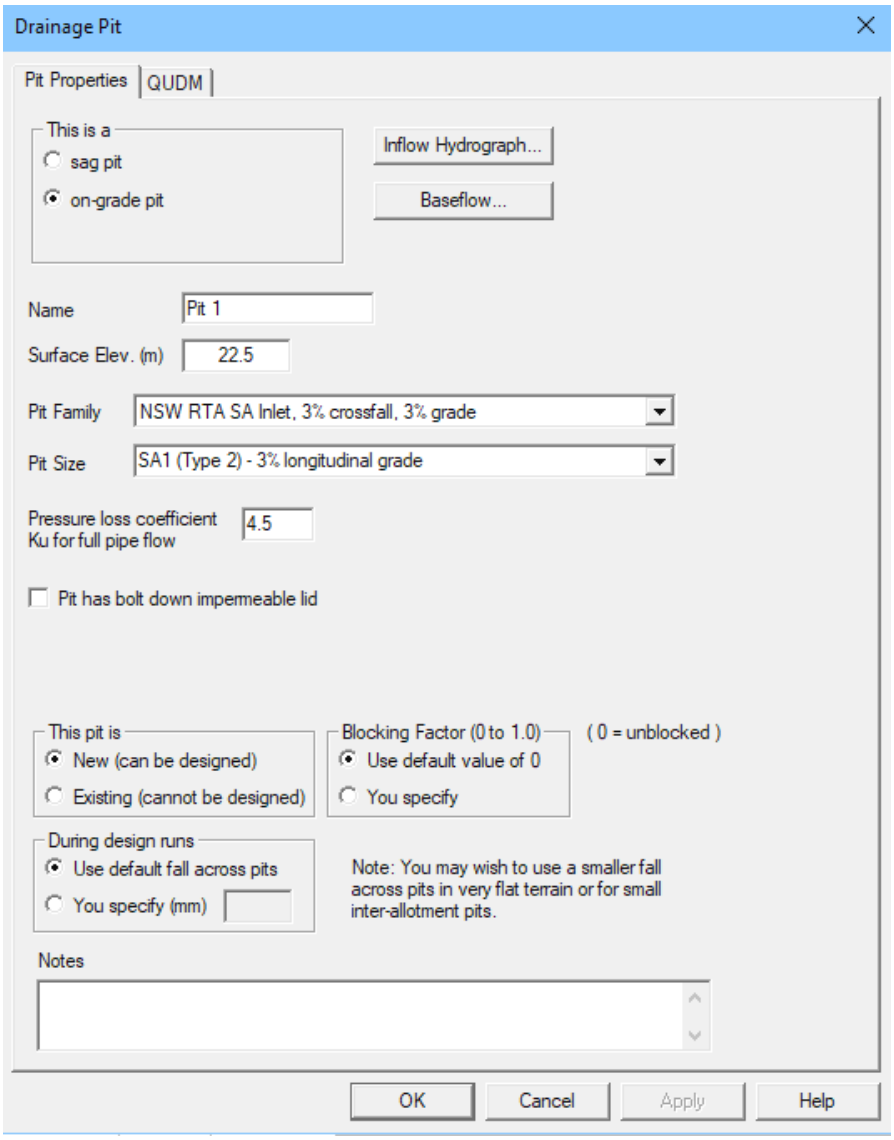


Figure 2.14 A Drainage Pit Property Sheet

When entering data, you can move from box to box using the **Tab** key on your PC's keyboard.

From Figure 2.7 you can see that any overflows from Pit 1 will flow to Pit 2, so that this first pit should be selected as an on-grade pit, located on a slope so that no pond will form over the pit. Note how pit types and sizes are selected from a data base of pit types using two drop-down list boxes.

The pit pressure change coefficient value of 4.5 is suitable for a pit at the top of a drainage line. You can obtain further information about these factors, which influence the water levels in the pipe system, from the Help system and from Section 8.6.6.

After closing the Drainage Pit property sheet, you will find that the pit name has changed and the question marks have disappeared. As data is entered, the allocated names appear in the Main Window. DRAINS will not run until all the required data is entered. Even if the data for all components are entered, question marks will remain if the connections between components are incomplete.

Table 2.1 defines the data for the pits in this system, and also for nodes at the outlets. If you are following this example, enter the appropriate values for the five pits. The names of pits can be up to 10 characters long, and those of other components may be slightly larger. Assume all pits to be NSW RTA (Roads and Traffic Authority, now Roads and Maritime Services) SA2 pits, at the slopes shown in the table.

Table 2.1 Pit and Outlet Node Data for the Orange Example

Name	Pit Type	Longit-udinal Slope (%)	Ponding Volume (m^3)	Ponding Depth (m)	Pressure Change Coeff. K_u	Surface Elev. (m)	Blocking Factor (0=clear)
Pit 1	On-Grade	5			4.5	22.5	0.0
Pit 2	Sag	1, say	2	0.15	0.5	22.3	0.5
Pit 3	On-Grade	1			1.5	22	0.0
Pit 4	On-Grade	3			4.5	22.1	0.0
Pit 5	On-Grade	1			1	21.7	0.0
Outlet 1	Node					21	
Outlet 2	Node					21.5	
Outlet 3	Node					21	

Pit 2 is a sag pit, located in a hollow in which stormwater can form a pond over the pit. For this type of pit, there is an additional page on the property sheet, labelled Pond Properties, where extra information has to be provided - an allowable ponding depth, a maximum ponded volume, and a safe ponding depth in minor storms, here taken to be 0.15 m, 2 m^3, 0.12 m and 0.20 m. Note that sag pits are blue, while on-grade pits are black.

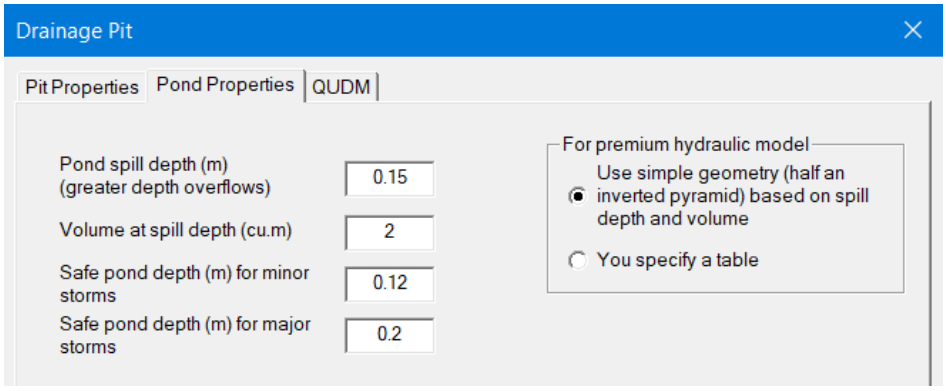


Figure 2.15 A Drainage Pit Property Sheet

Next, you can enter the sub-catchments, as shown in Figure 2.13. The sub-catchment symbol should not be placed over a pit. If this is done, it will snap to the top right corner of a pit, and can then be moved to another location around the pit if you wish. The data for sub-catchments is entered into their property

sheets, which are opened from a pop-up menu in the same way as for pits. The simplest form of the property sheet for the ILSAX hydrological model specified in Figure 2.4 is shown in Figure 2.16.

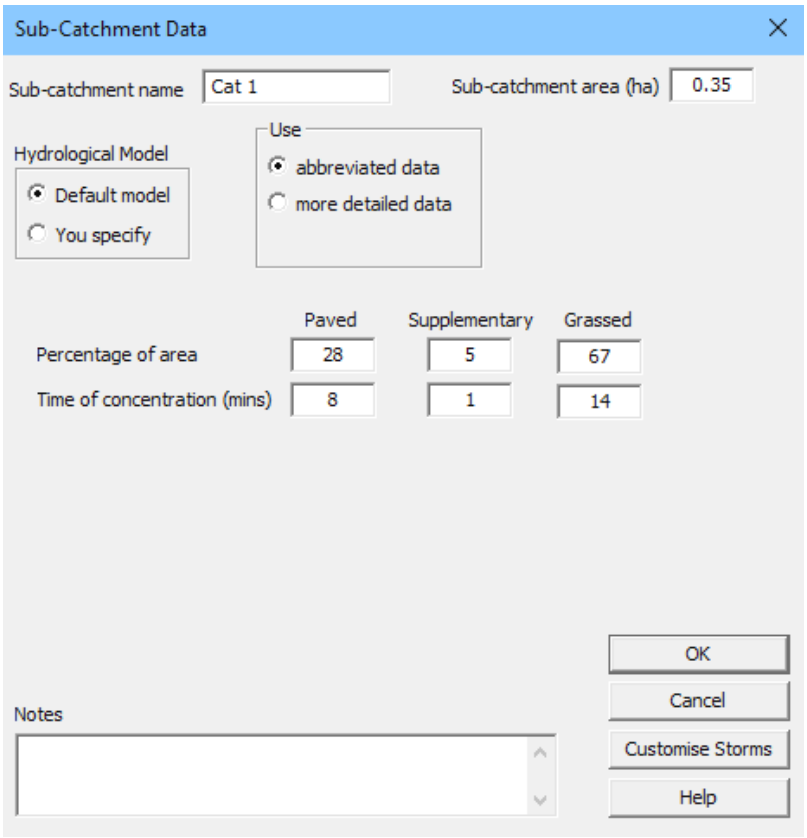


Figure 2.16 The Sub-Catchment Data Property Sheet

The sub-catchment draining to each pit is divided into three types of land-use:

- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system, draining onto the grassed area), and
- grassed areas (pervious areas).

A time of entry (or time of concentration) is assigned to each land-use. For the paved and grassed land-uses, this is the time that it takes for stormwater to flow from the furthest boundary of that area to the point nearest to the pit. The supplementary area time is the time required for runoff to drain onto the pervious area. Times can be calculated using the equations and guidelines presented in Section 8.3.2(d).

The parameters for all sub-catchments are presented in Table 2.2.

Table 2.2 Sub-Catchment Data for Orange Example

Name	**Pit or Node**	**Total Area** (ha)	**Paved Area** (%)	**Suppl. Area** (%)	**Grassed Area** (%)	**Paved Time** (mins.)	**Suppl. Time** (mins.)	**Grassed Time** (mins.)
Cat 1	Pit 1	0.125	28	5	67	8	1	13
Cat 2	Pit 2	0.231	33	5	62	9	1	15
Cat 3	Pit 3	0.025	90	0	10	3	0	4
Cat 4	Pit 4	0.35	75	5	20	9	1	15
Cat 5	Pit 5	0.02	90	0	10	2	0	3

After entering values for Catchment Cat 1, you can enter parameters for the four other sub-catchments. The displayed names of all should change from '?????' to the names you provide - if not, check that the symbol for each sub-catchment touches the symbol for the related pit.

Pipe data is entered by right-clicking on pipes to open their property sheets. You need to click on the object and not on its name. Clicking on the name will open a dialog box (illustrated later in Figure 6.16) that can vary the information shown in the Main Window. Figure 2.17 shows the sheet for the first pipe.

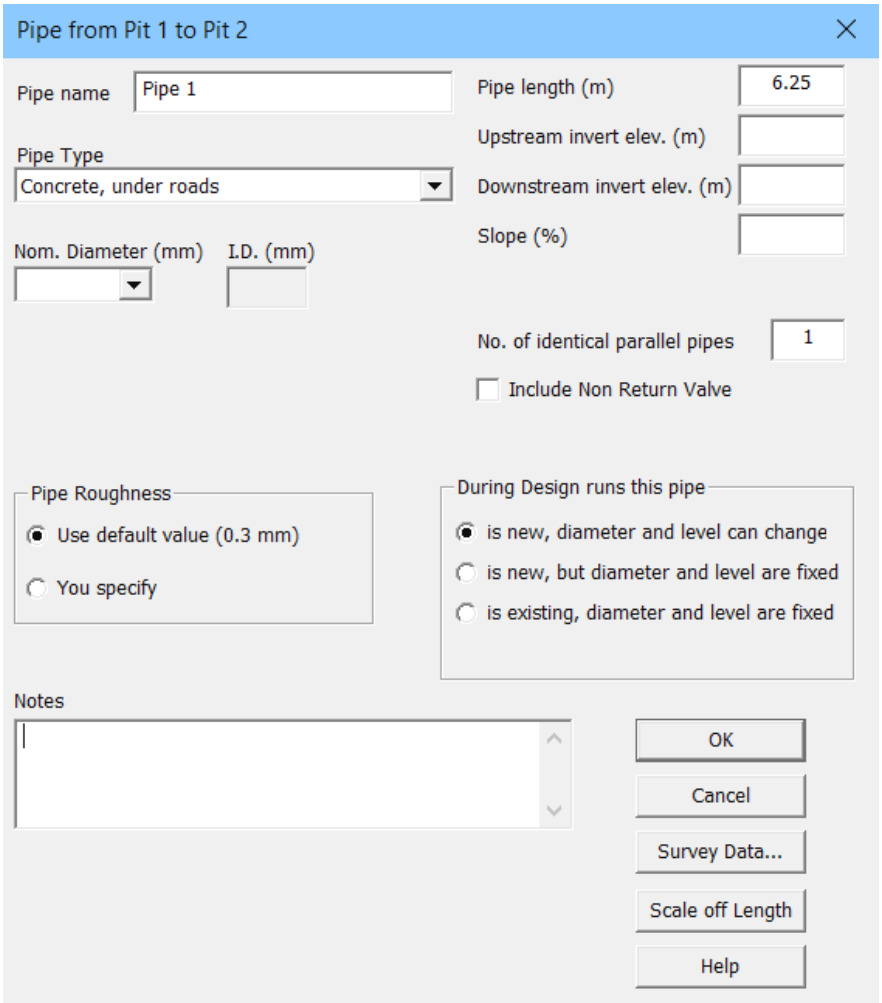


Figure 2.17 The Pipe Property Sheet

It is not necessary to specify invert levels or slopes because DRAINS will calculate these during the design. You must, however, specify the pipe name, length and type, selecting the type from a list box. (If you have inserted a background, pipe lengths can be automatically scaled after the first length is entered.) You can also take the lengths of the remaining pipes from Table 2.3.

Table 2.3 Pipe Data for Orange Example

Name	**From**	**To**	**Length** (m)
Pipe 1	Pit 1	Pit 2	6.25
Pipe 2	Pit 2	Pit 3	8.19
Pipe 3	Pit 3	Pit 5	27.6
Pipe 4	Pit 4	Pit 5	12.03
Pipe 5	Pit 5	Outlet	14.05

When you close the property sheet, you will find that the pipe name is prefixed with '??', indicating that the data are still incomplete.

Overflow routes are the next components to be defined. These may have a number of boxes, depending on the options that can be run with your hardware lock, but in this simple example, it is only necessary to define a name and an estimated time of flow in the first 'Basic Data' sheet, as shown in Figure 2.18.

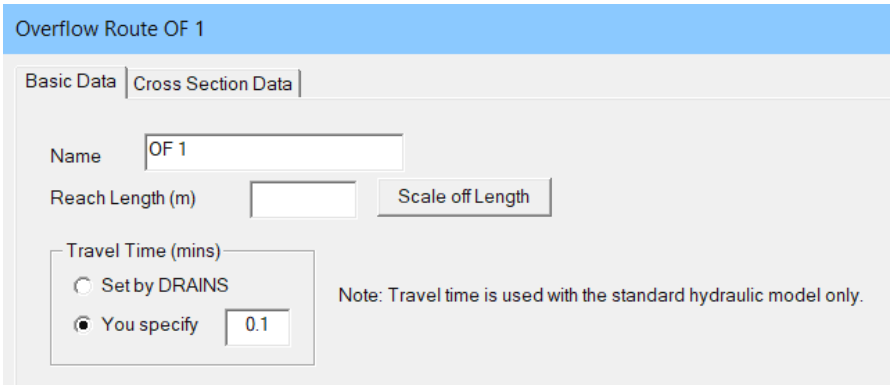


Figure 2.18 The Overflow Route Property Sheet - Page 1 (Top Portion)

On the second page, you must also define overflow route cross-sections from the overflow route data base, with slopes and percentages of downstream sub-catchments, as shown in Figure 2.19. For now, enter the simple values shown in the figure.

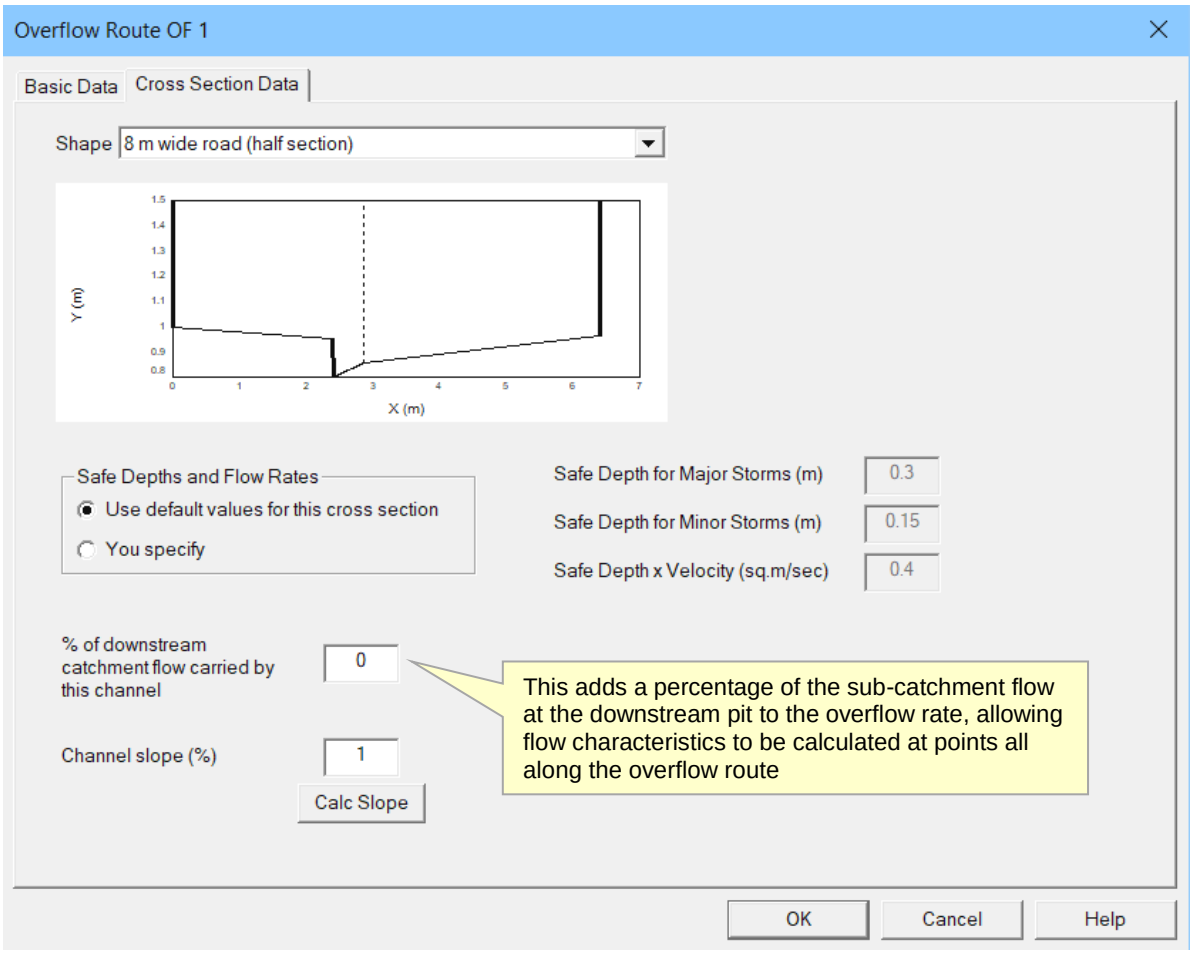


Figure 2.19 The Overflow Route Property Sheet - Page 2

(Note that Figure 2.18 may include additional data entry boxes if the storage routing or premium hydraulic model options are available. Only the information shown above is required in the Orange example.) The overflow route information for this example is shown in Table 2.4.

The percentages of downstream areas are used to define flow characteristics along the overflow route, as explained in Section 5.3.7.

Finally, the outlet names and levels must be defined. Here it is assumed that the main outlet operates as a free outfall. The tailwater level for the pipe system will be the higher of the normal and critical depths for the outlet pipe, unless this is running full. Outlet surface levels are specified in Table 2.1.

Table 2.4 Overflow Data for Orange Example

Name	From	To	Travel Time (minutes)	% of D/S Catchment	Flow Path Slope (%)
OF 1	Pit 1	Pit 2	0.1	0	4
OF 2	Pit 2	Pit 3	0.1	0	3
OF 3	Pit 3	Outlet 3	1	0	3
OF 4	Pit 4	Outlet 2	1	0	1
OF 5	Pit 5	Outlet 1	1	0	1

As these changes are made, you should periodically save the file and tidy it up so that it looks like the arrangement in Figure 2.20. If you have **Property Balloons** switched on in the **View** menu, details of the data for various components can be seen without opening property sheets.

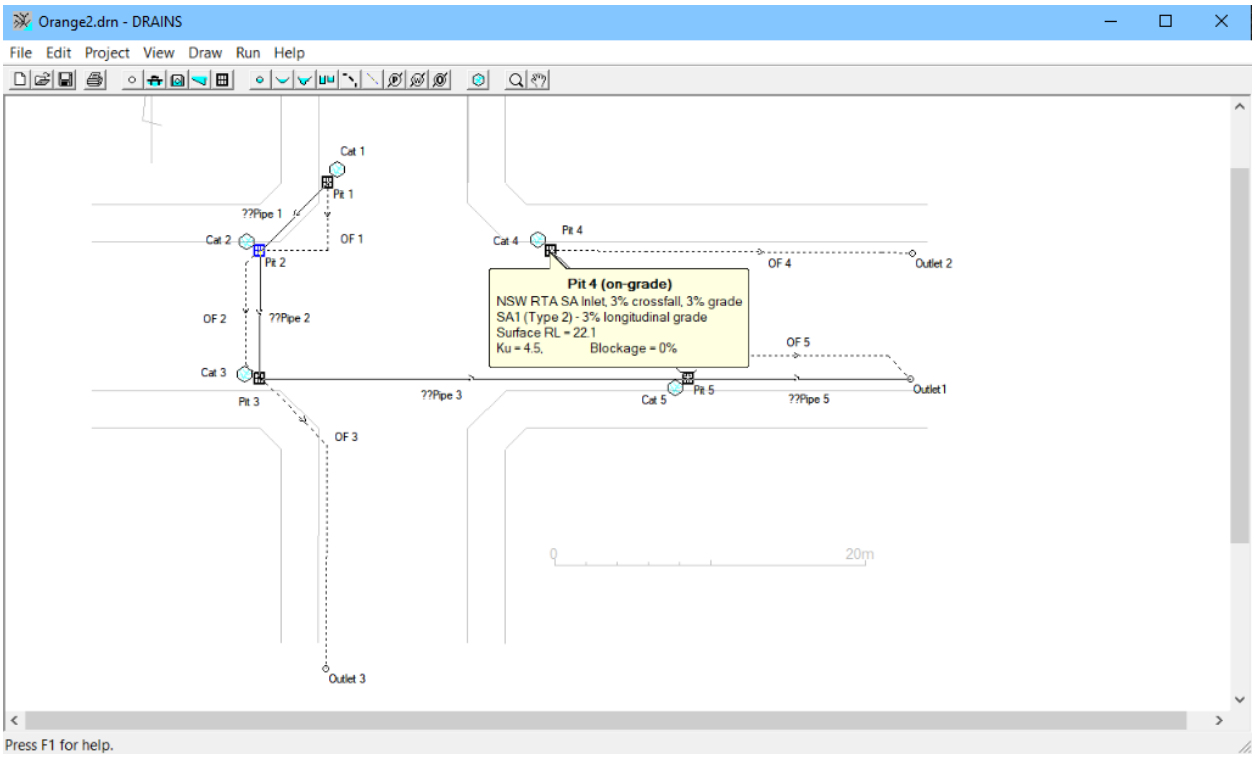


Figure 2.20 Orange Drainage System Ready to Run (with Property Balloon shown)

Be sure to save the file. All the entered data can be altered if required.

2.4 Entering and Running with ARR 2016 Rainfall Data

NOTE: This is no longer the current procedure. Please refer to the the DRAINS Help Topic *'Inputting ARR 2019 rainfalls'*

2.4.1 General

A considerable amount of data needs to be entered to use this model, more than can be practically typed in using the keyboard. However, rainfall data can be entered in a two-stage process – (i) obtaining data from two websites as comma-separated variable (.csv) files, and storing these in a folder, and (ii) inputting the data from the files. DRAINS combines the intensities and temporal patterns into ensembles or sets of 10 patterns for a number of storm burst durations.

The use of ensembles of 10 storms increases the volume of calculations compared to the 1987 patterns which have one pattern for each duration. It also complicates the organisation of results and the identification of critical events. This example will illustrate how this is done in DRAINS, implementing procedures from ARR 2016.

2.4.2 Obtaining Rainfall I-F-D and Ensembles Data

The 2016 rainfall intensity-frequency-duration data supplied on the Bureau of Meteorology website, www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016, can be obtained by entering the latitude and longitude of the project location. The coordinates can be obtained from Google Maps or other sites, but it will be easier to use the ARR Data Hub, data.arr-software.org/, which will also be used to obtain storm patterns.

The Hub is shown in Figure 2.21. The blue pointer can me moved to the site location, and the longitude and latitude will be displayed, as shown in Figure 2.22.

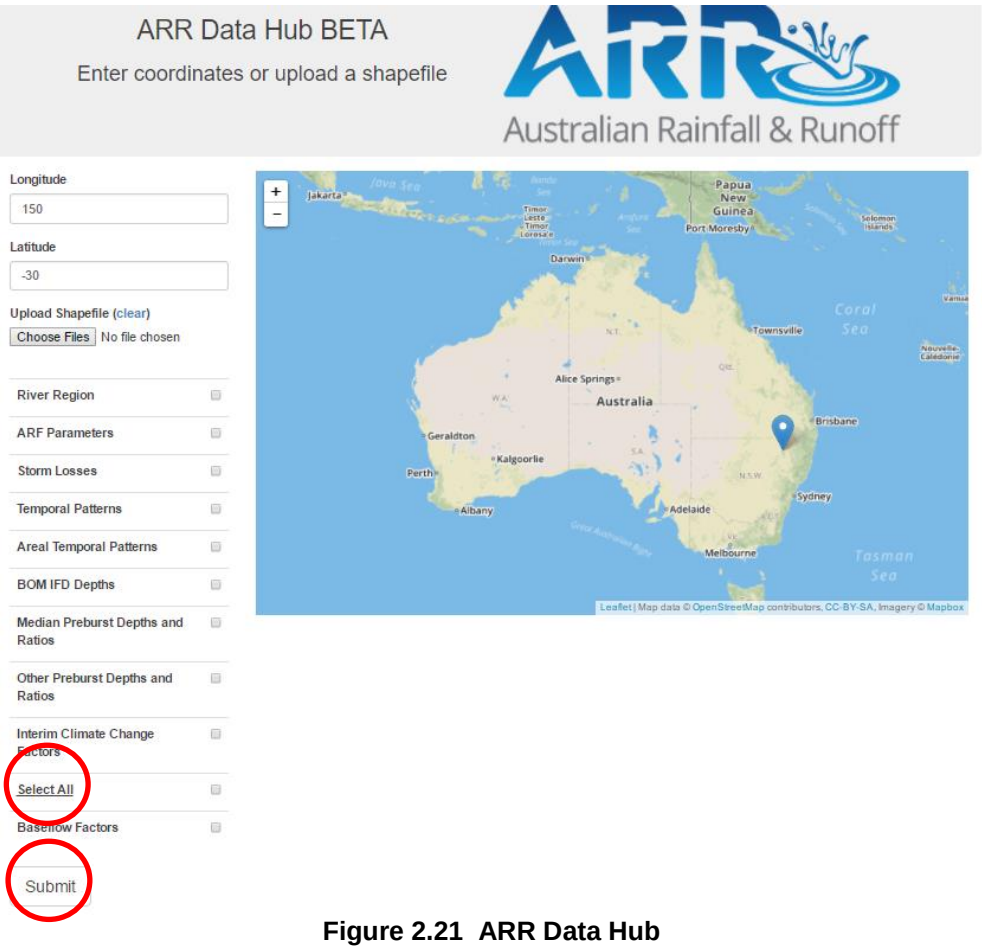


Figure 2.21 ARR Data Hub

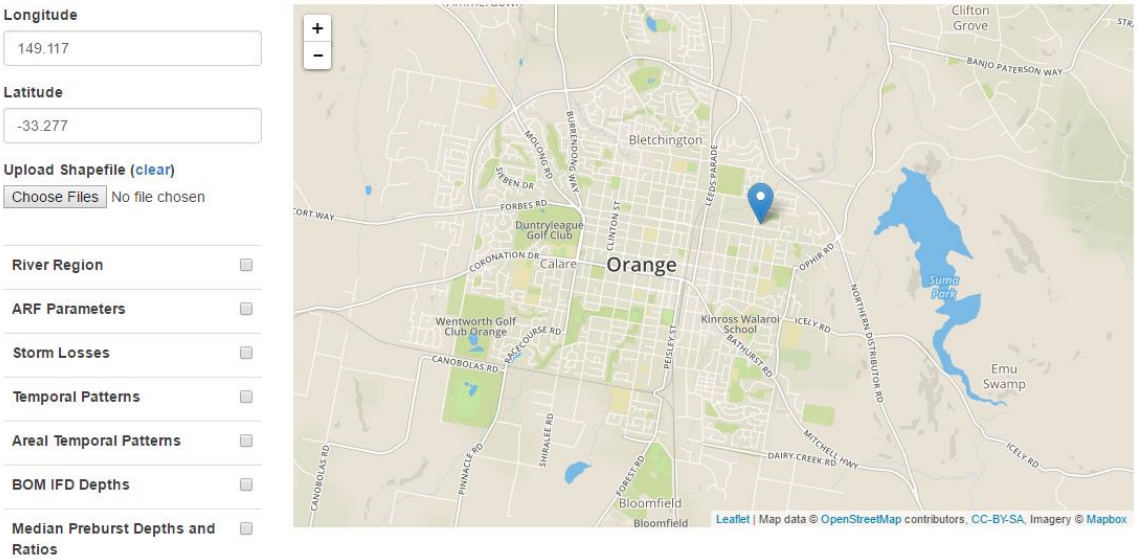


Figure 2.22 Selecting a Site Location and Obtaining Longitude and Latitude

Click on the **Select All** button at the bottom left of the window, and then click the **Submit** button. This will open up a window containing various types of data, shown in Figure 2.23.

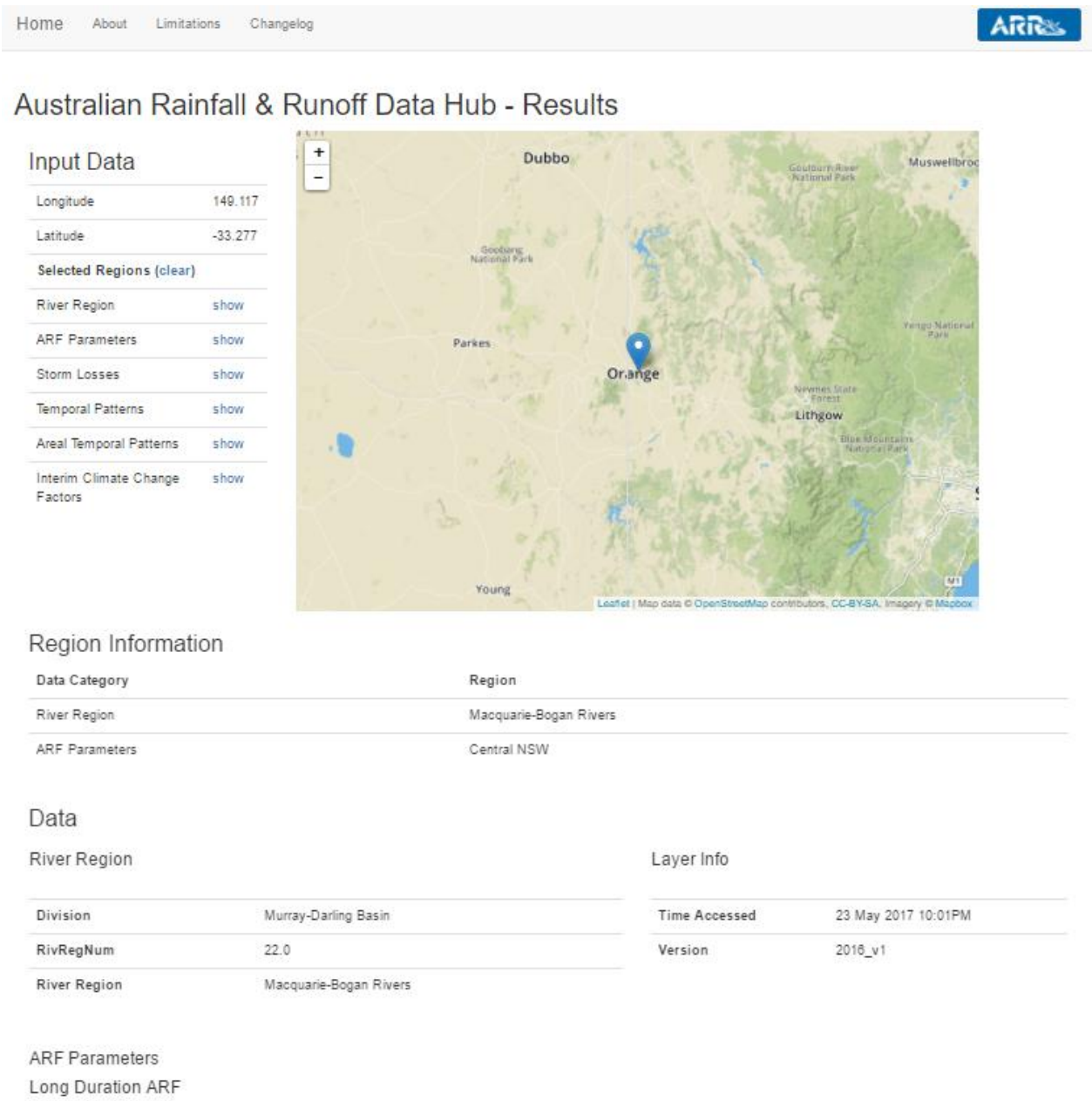


Figure 2.23 Data from the ARR Data Hub

This will open a **Save As** window, shown in Figure 2.24, from which you can save the .zip file into a project folder. Add the project location 'Orange –' to the filename. Go to this folder and extract (unzip) the file's contents into a folder of the same name. This will contain two .csv files.

Now return to the Data Hub and click on the link to the Bureau of Meteorology I-F-D data:

This transfers you to the Bureau website, with the latitude and longitude entered, as shown in Figure 2.25. You will need to click on the two acknowledgements, enter the site name and click the **Submit** button. This opens the window shown in Figure 2.26.

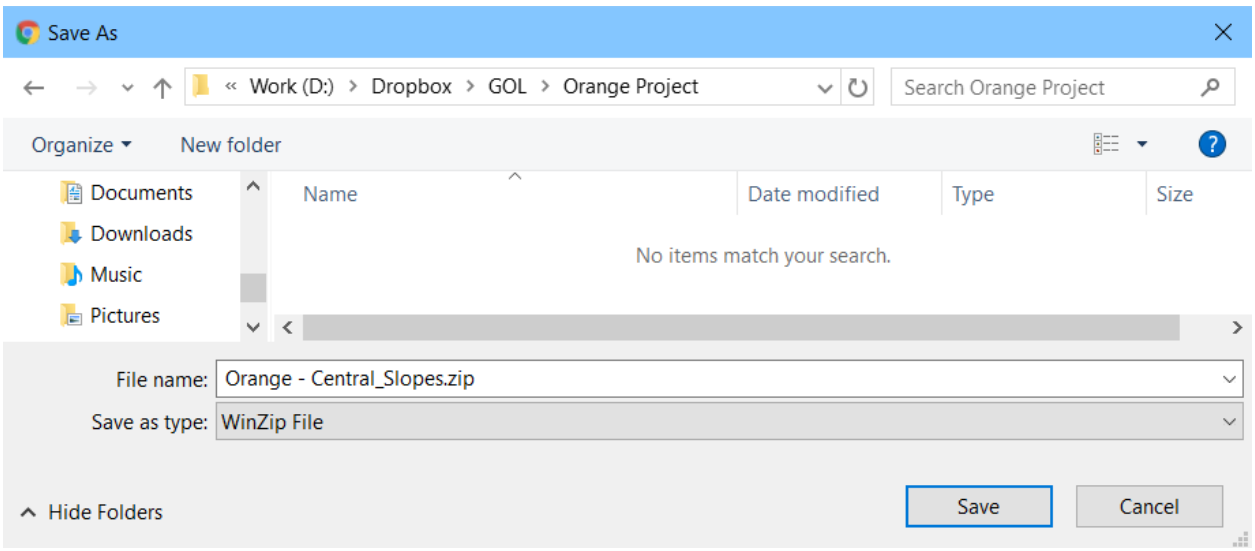


Figure 2.24 Window for Saving Ensembles Files

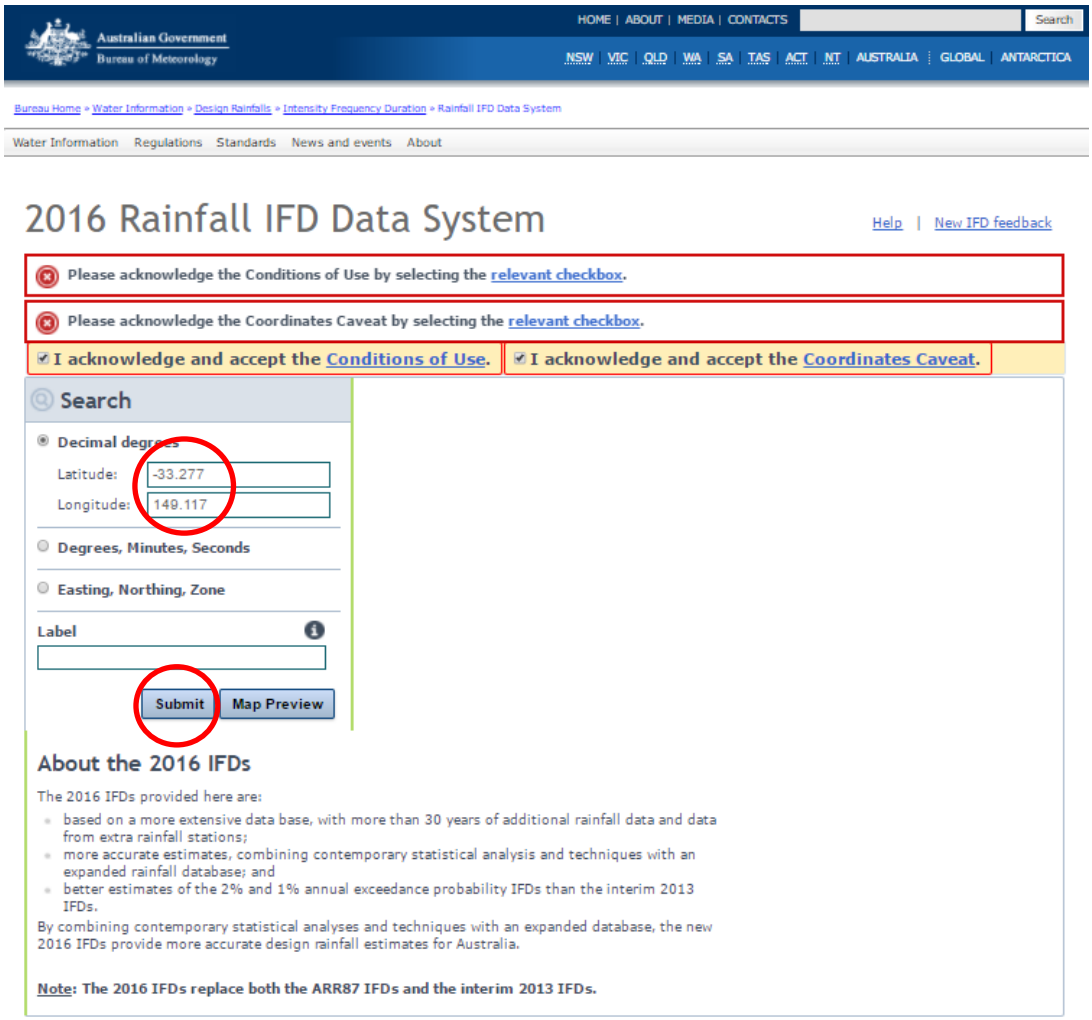


Figure 2.25 BOM 2016 I-F-D Page

This window contains a table of rainfall depths for various AEPs and durations. It is likely that you will want to add additional durations – 20, 25, 45, 90 and 270 minutes for urban drainage systems, and perhaps 540, 1080, 1800 and 2160 minutes for large catchments. To do this, enter times in the **Non-Standard Durations** boxes to the left of the window, as shown Figure 2.27.

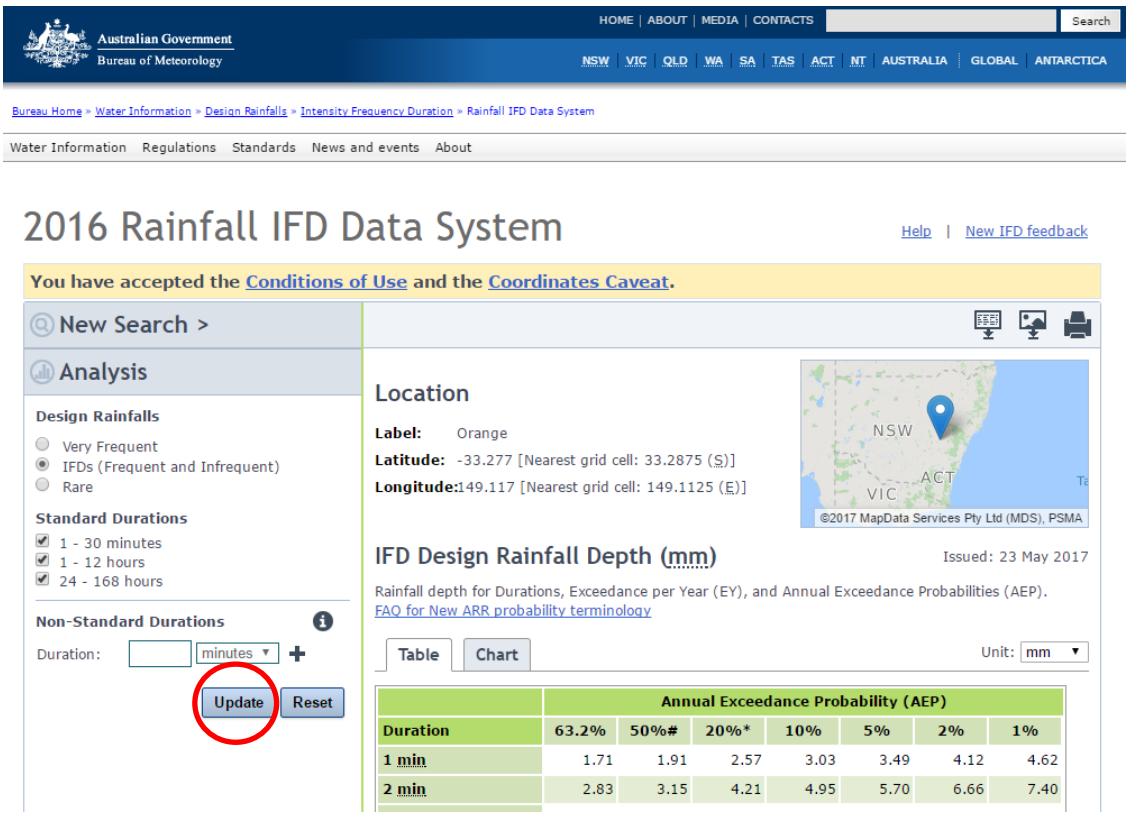


Figure 2.26 BOM 2016 I-F-D Data Page

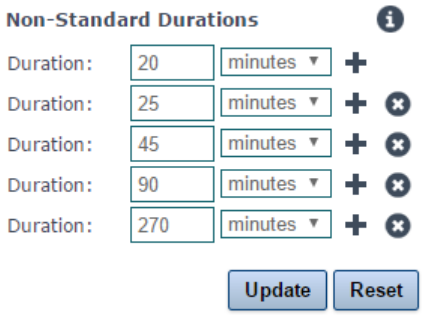
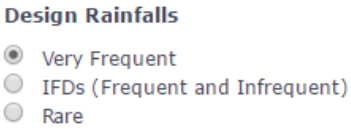


Figure 2.27 Additional Durations

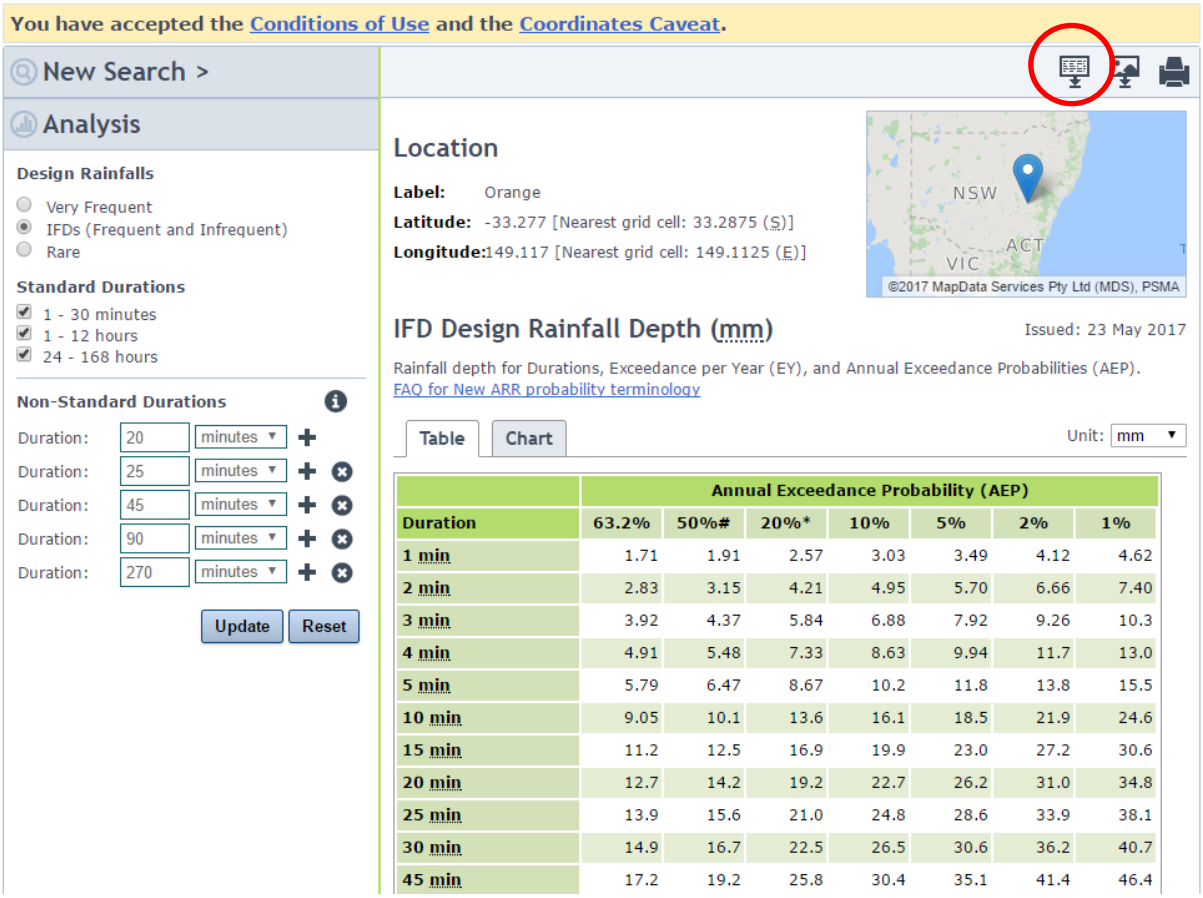
Clicking the Update button will add depths for these durations to the Table, as shown in Figure 2.28.

Now click on the first symbol above the map, which will open a Save As window (Figure 2.29) that you can use to save a .csv file to your project folder. Add the location name to the filename.

This will give you rainfall depths for the AEPs shown, from 1 exceedance per year (1 EY), equivalent to 63.2% AEP, through to 1% AEP. If you wish to use older frequencies such as 2 year and 5 year average recurrence interval (ARI), you can go to the panel at the top left, and click the box for **Very Frequent**, and the click on **Update**.



The screen will change, and new frequencies will appear, as shown in Figure 2.30.



	Annual Exceedance Probability (AEP)						
Duration	63.2%	50%#	20%*	10%	5%	2%	1%
1 min	1.71	1.91	2.57	3.03	3.49	4.12	4.62
2 min	2.83	3.15	4.21	4.95	5.70	6.66	7.40
3 min	3.92	4.37	5.84	6.88	7.92	9.26	10.3
4 min	4.91	5.48	7.33	8.63	9.94	11.7	13.0
5 min	5.79	6.47	8.67	10.2	11.8	13.8	15.5
10 min	9.05	10.1	13.6	16.1	18.5	21.9	24.6
15 min	11.2	12.5	16.9	19.9	23.0	27.2	30.6
20 min	12.7	14.2	19.2	22.7	26.2	31.0	34.8
25 min	13.9	15.6	21.0	24.8	28.6	33.9	38.1
30 min	14.9	16.7	22.5	26.5	30.6	36.2	40.7
45 min	17.2	19.2	25.8	30.4	35.1	41.4	46.4

Figure 2.28 BOM 2016 I-F-D Data Page with Added Durations

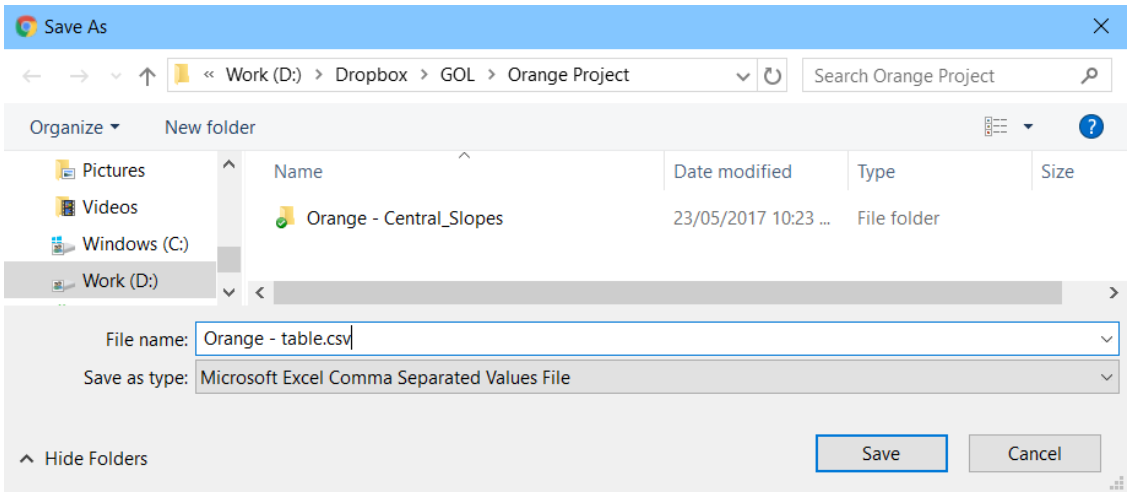


Figure 2.29 Saving BOM 2016 I-F-D Data File

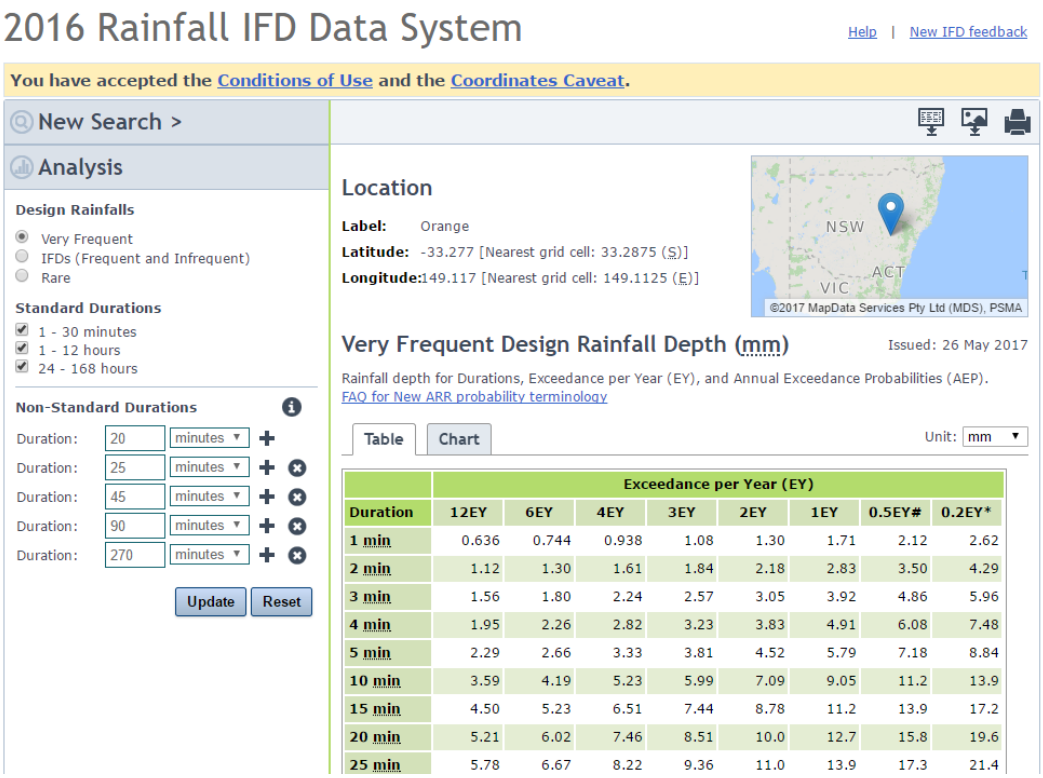


Figure 2.30 BOM 2016 I-F-D Data Page for Very Frequent Rainfalls

You can then use the **Download as CSV** icon above the map to download and save a second I-F-D file, which can be named Orange - Very_frequent_table.csv. This will contain the 0.5 EY and 0.2 EY rainfall depths, equivalent to the 2 and 5 year ARI storms.

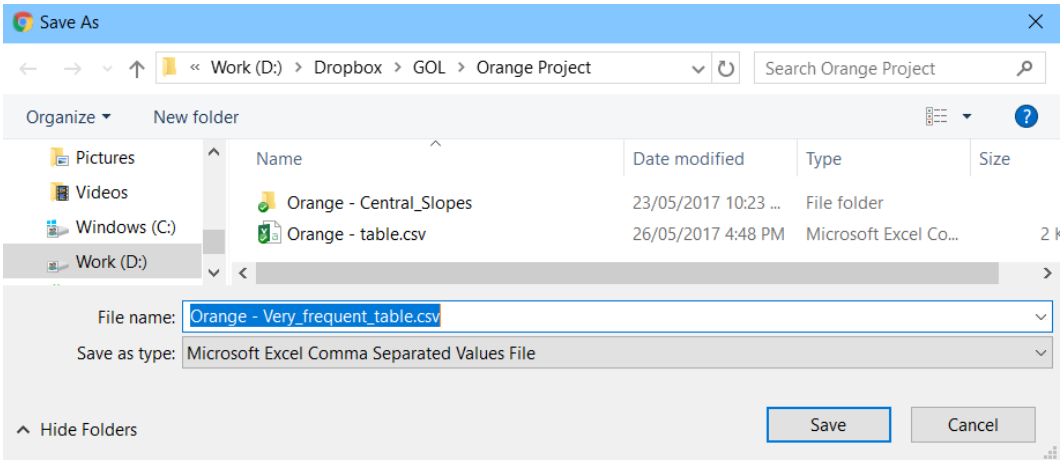


Figure 2.31 Saving Second BOM 2016 I-F-D Data File

2.4.3 Inputting ARR 2016 Rainfall Data into the DRAINS Model

You now need to transfer the data in the saved .csv files to DRAINS. Open the DRAINS model, and go to the **Options …** choice in the Project menu. Ensure that the box labelled **Use ARR2016 procedures** is ticked, and that **Ensembles of Storms** is selected.

Then go to **Project** → **Rainfall Data …**, where you should see the window shown in Figure 2.32.

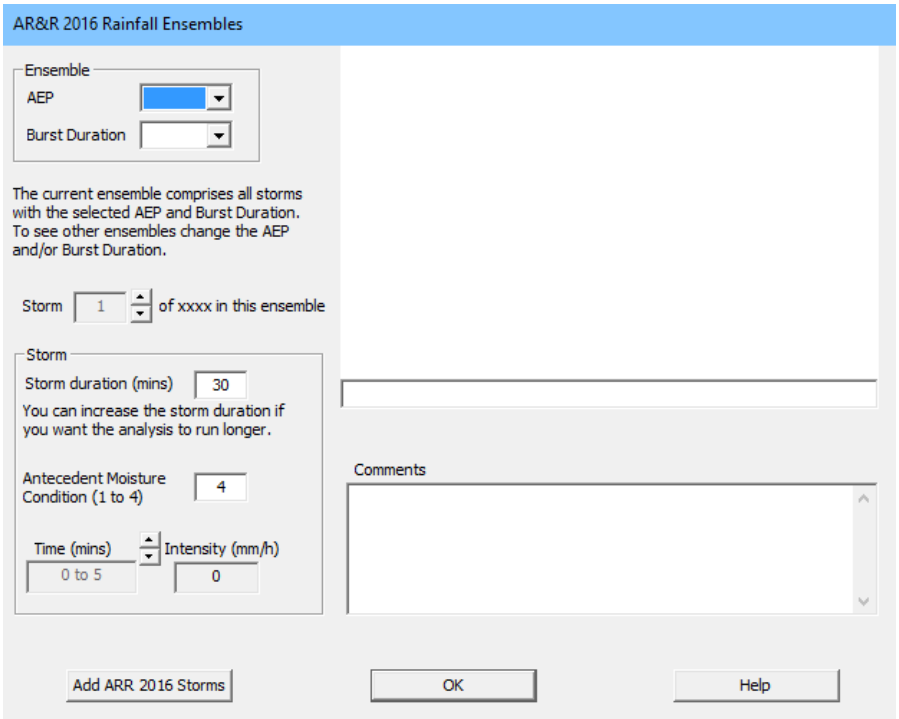


Figure 2.32 ARR 2016 Rainfall Property Sheet

With a new model, this will be empty; with an old one, it will display the previously-entered set of ensemble data. To enter new data, click on the **Add ARR 2016 storms** button, which will display the following message:

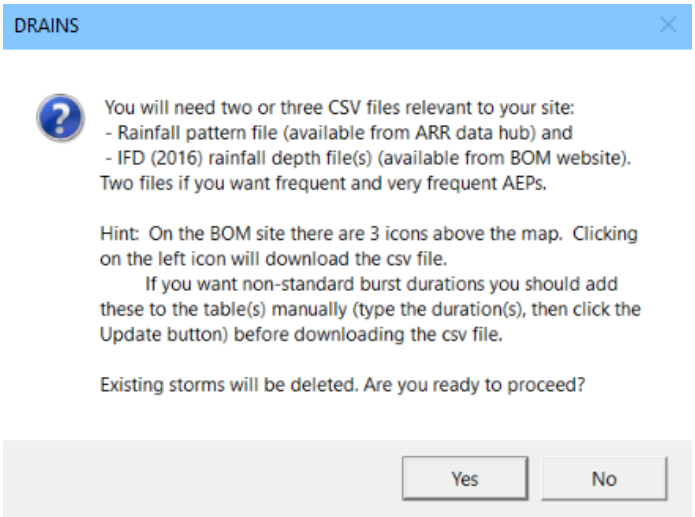


Figure 2.33 Message about Data Inputs

You will need to have the files ready in the folder mentioned in the previous section. When you click **Yes**, a window appears asking you to choose a file containing ensemble data. In this example, this will be the file ending with _increments.csv in the Orange- Central_Slopes folder.

This opens the window shown in **Figure 2.35**, in which you can enter the AEPs and durations that you will need. Since this example is about designing a very small system, you will only need to enter data for two AEPs, and you will not need longer storms.

After you click **OK**, the window in **Figure 2.36** appears. You will need to navigate out of the ensembles folder and select the first of the I-F-D files, Orange - table.csv. Once this is transferred to DRAINS, the message shown **Figure 2.37** appears. When you click **Yes**, the window for inputting files will re-appear and you can enter the Orange - Very_frequent_table.csv file.

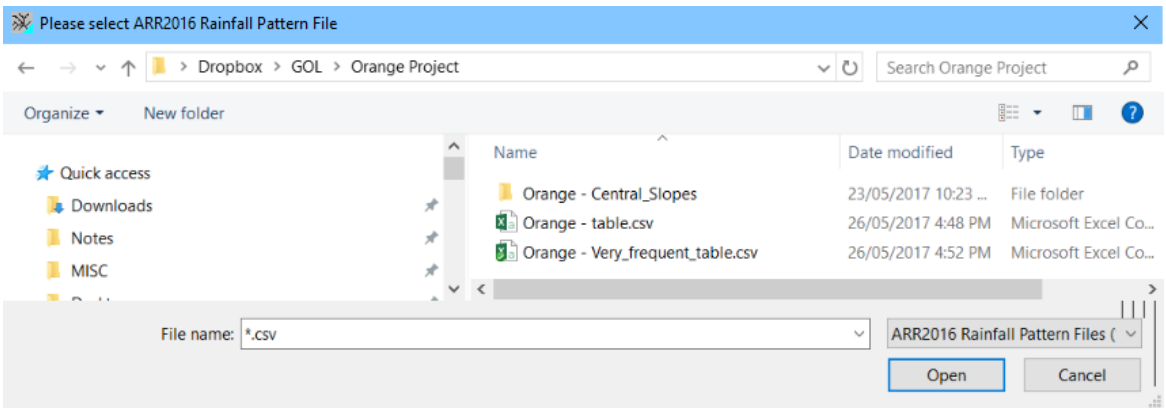


Figure 2.34 Inputting Ensembles Data

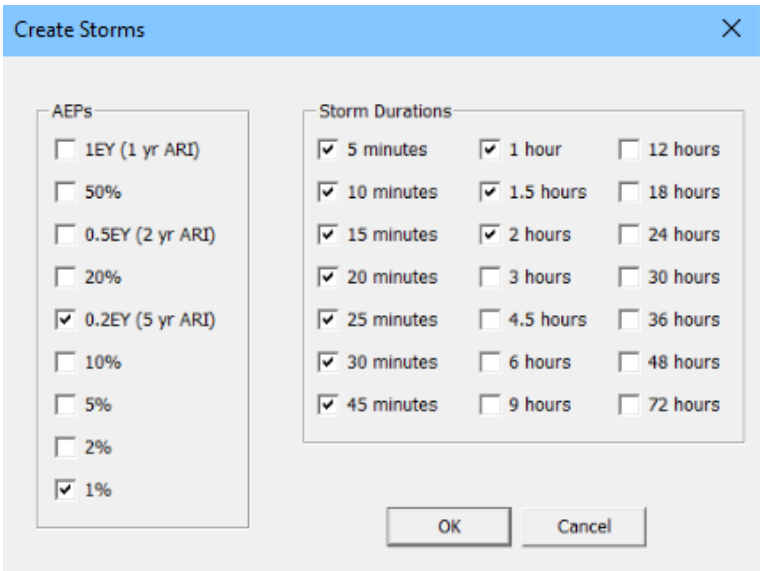


Figure 2.35 Create Storms Dialog Box

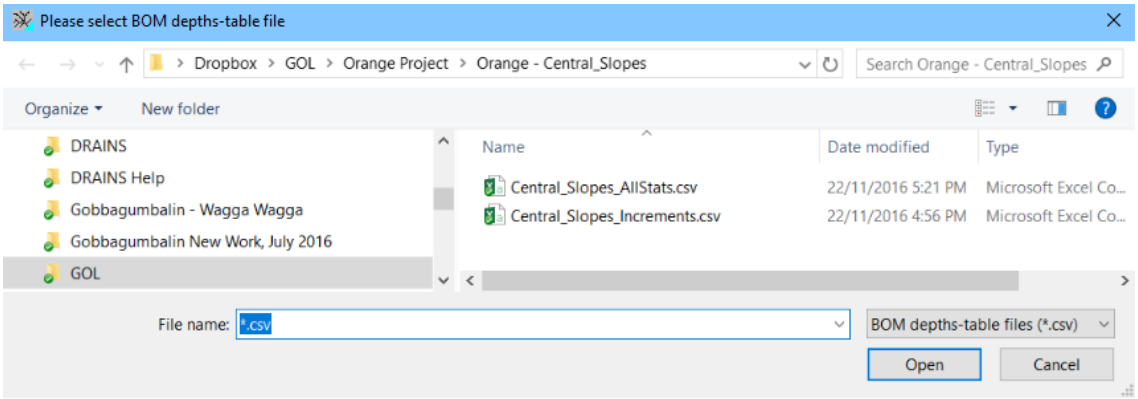


Figure 2.36 Inputting I-F-D Data

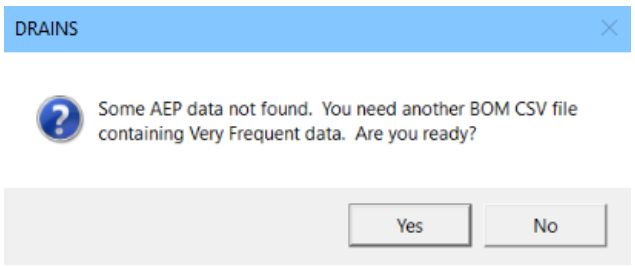


Figure 2.37 Message about Second I-F-D Data File

The property sheet for rainfalls then appears again, this time with the data that has been entered into DRAINS. This can be viewed using the various menus, as shown in Figure 2.38. Click **OK** to leave this window.

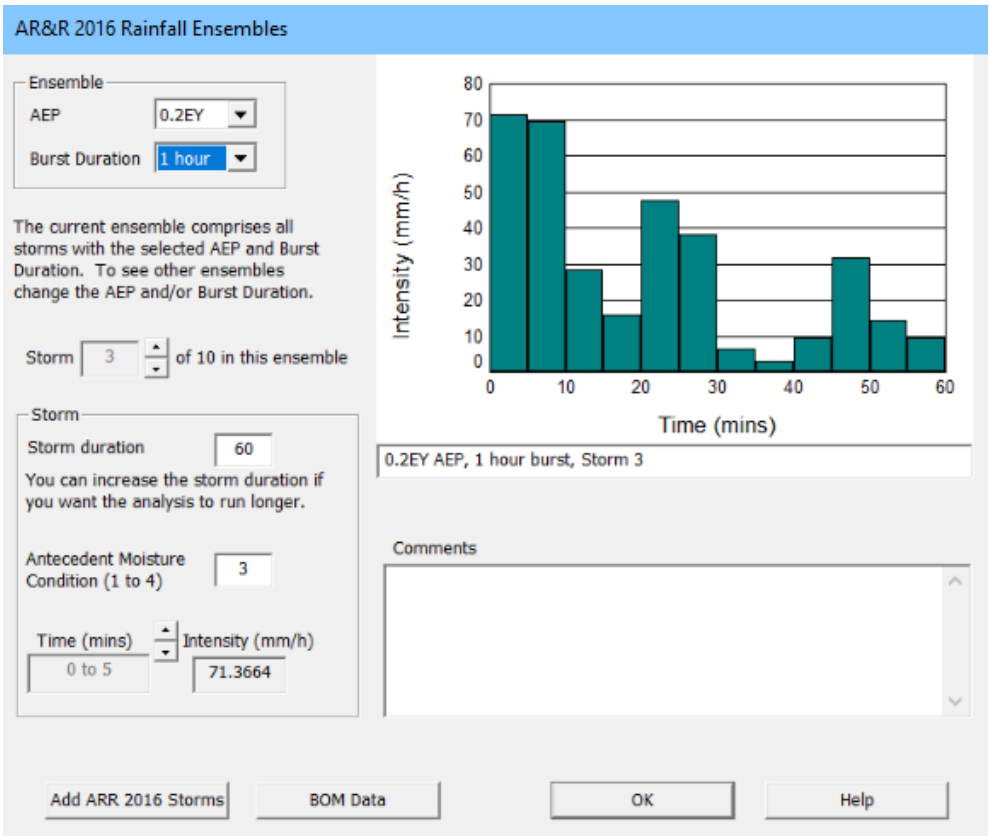


Figure 2.38 Entered Rainfall Burst Patterns

Finally, you will need to select major and minor storms for design. (The design process defines the pipe sizes and depths needed to carry runoff from minor storms satisfactorily, while meeting certain criteria. The system must also 'fail-safe' in runoff from major storms. The system performance can be checked using various major and minor Analysis runs.)

In the **Project** menu, choose the **Select Major/Minor Storms** option. You can make alterations to these if required.

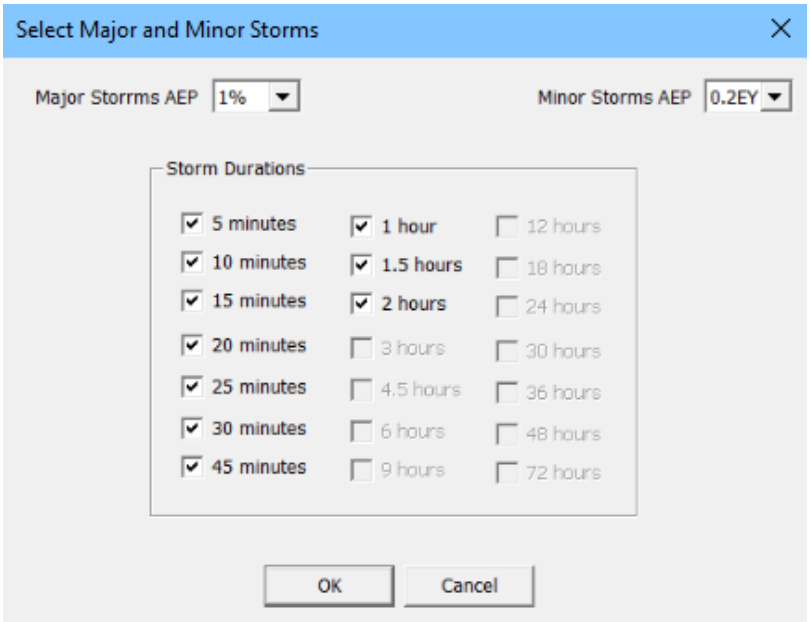


Figure 2.39 Select Major/Minor Storms with ARR 2016 Rainfalls

A considerable amount of rainfall data has been entered – 91 minor storm bursts and 91 major bursts. Some of these are shown in Figure 2.40. ARR 2016 requires that calculations be performed for this number of storms.

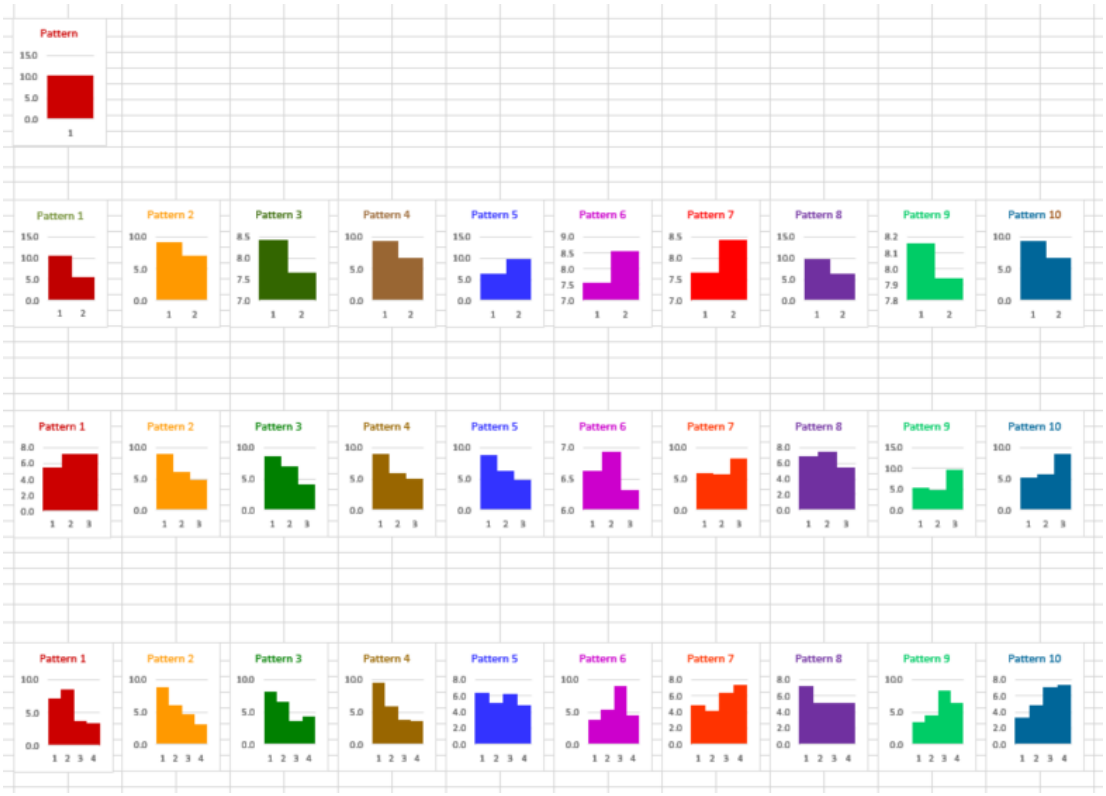


Figure 2.40 Orange Rainfall Bursts for 5, 10, 15 and 20 Minutes Duration and 10% AEP

If you have entered other background data as described in Section 2.2 and defined the drainage system as described in Section 2.3, you are ready to run the model.

2.4.4 Running the DRAINS Design Model

Pipe design in DRAINS is performed on the basis of an allowable flow along each overflow route. The method determines this flowrate, taking into account the flows from of the sub-catchment immediately downstream of each pit. It then works backwards to define a set of pit inlets and pipe sizes that will limit depths in sag pits and overland flows to safe levels in both minor and major storms. Safety requirements are defined in terms of flow depths and velocity-depth products in the Overflow Route Data Base, as shown in Figure 2.19.

The major/minor system is usually employed in Australian drainage design. Pipes are sized to carry flows of a minor ARI, usually 5 or 10 years, and a check is made to ensure the safe working of the system during a major storm event, with an ARI of 50 or 100 years. You can run the program in Design mode from the **Run** menu, shown in Figure 2.41.

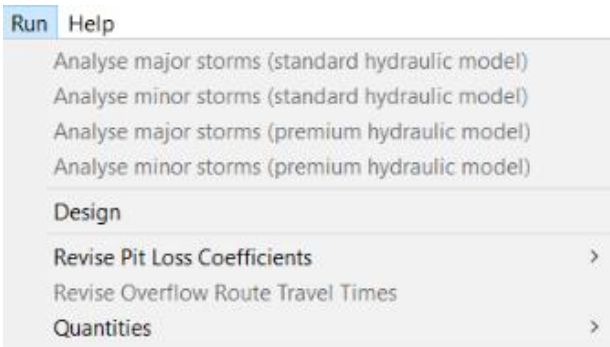
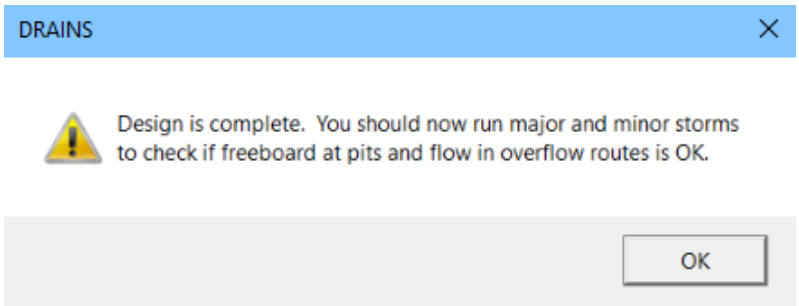


Figure 2.41 Run Options

After a Design run, the message shown below appears, advising that the process is complete and that you should run an analysis with minor or major storms to assess the results.



You can do this by choosing the **Analyse minor storms** and **Analyse major storms** options. The standard hydraulic model is available in all DRAINS model. The alternative premium model requires more detailed information on overflow routes, in order to model them with unsteady flow hydraulics.

When performing an Analysis, DRAINS automatically works with multi-core processing when running with ARR 2016 ensembles. Results of an analysis using minor storm ensembles are shown in Figure 2.42.

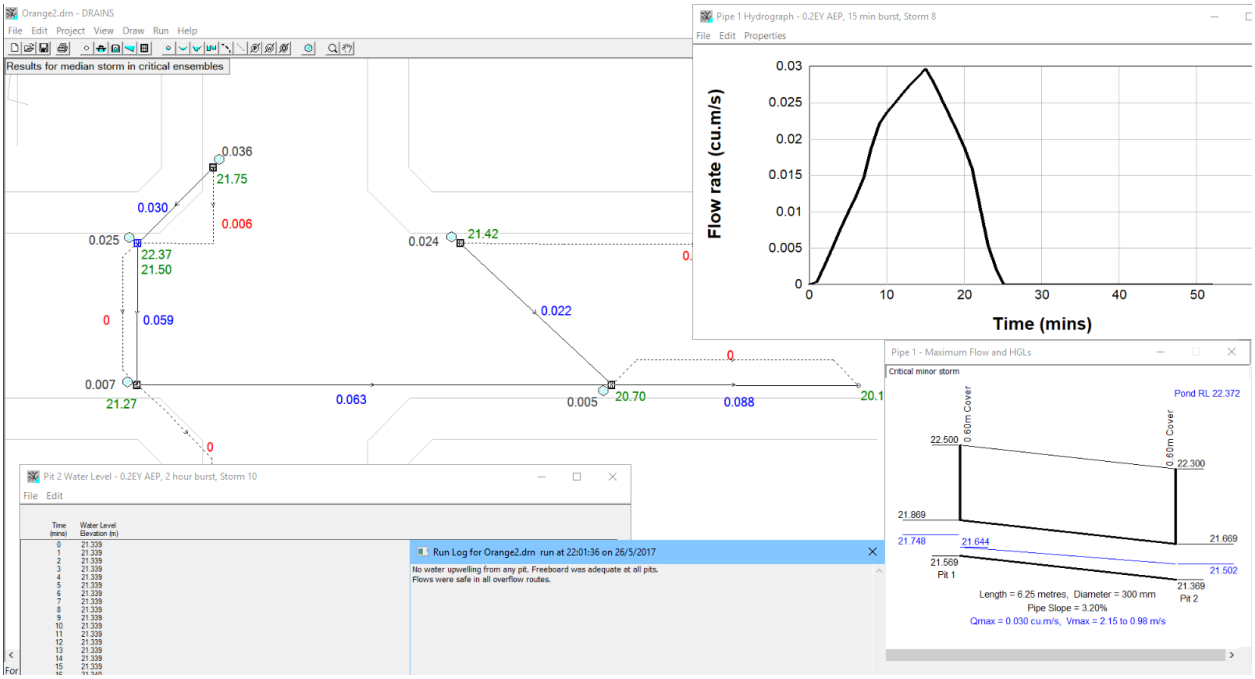
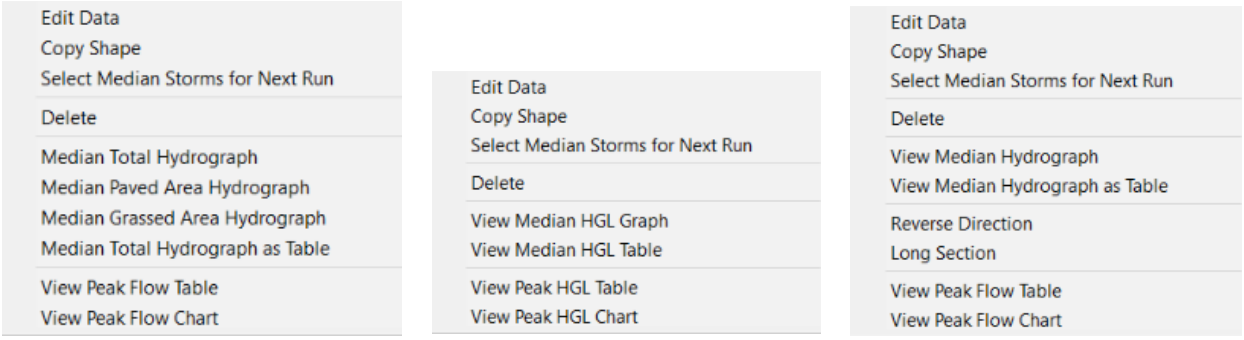


Figure 2.42 The Result of a Minor Storm Analysis following a Design Run

Initially, a run report is displayed, indicating whether there are any problems with the run. After you close this, you will see that the names of components have changed to coloured numbers as follows:

- the **black** numbers are the maximum flowrates from the sub-catchments, in m^3/s,
- the **blue** numbers are the greatest flowrates in each pipe, in m^3/s,
- the **red** numbers are the greatest overflows from pits, in m^3/s, in the standard hydraulics model, or the flowrates at the centre of an overflow path in the premium hydraulic model,
- the **green** numbers are the highest levels reached by the hydraulic grade lines (HGLs) throughout the pipe system, in m elevation, defining the highest water levels during storm ensembles considered. (At sag pits, the highest surface ponding level is also shown.)

Since it calculates conditions at a number of time intervals, DRAINS produces hydrographs or time series of runoff flowrates from the rainfall hyetographs. Time-series plots of HGL levels at pits and nodes are also provided. These are displayed as hydrographs and tables. You can see the available options by right clicking on each object and opening a pop-up menu that lists output options, as shown in Figure 2.43.



Sub-Catchment Pit Pipe

Figure 2.43 Examples of Display Options in Pop-Up Menus

This run can be followed by a major storm run, using 1% AEP storms. The flowrates and HGL elevations are higher than for the minor storms, but results are presenting in the same way, as shown in Figure 2.44.

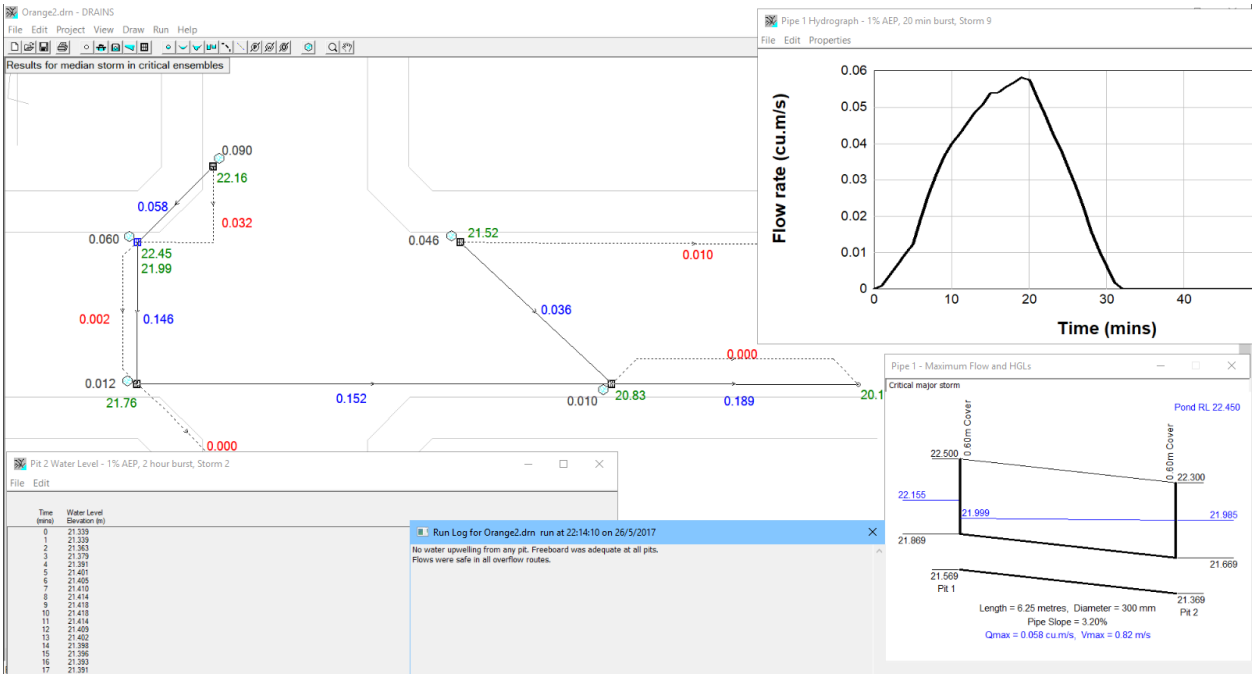


Figure 2.44 Results of a Major Storm Analysis following a Design Run

2.4.5 Reviewing Results

Due to the large number of storms analysed with 2016 rainfall ensembles, it is only possible to display one for each component. This will be the storm giving the most critical result, referred to as the median hydrograph or median HGL graph in the pop-up menus. However, it is also possible to display all the results in a single chart (the last option in the menus shown in Figure 2.43).

The chart for a pipe shown in on Figure 2.45 reveals how DRAINS sorts through the results from different storms. The pink bars are the representative values for each ensemble of 10 storms. They are the sixth highest value in each set. There is one value for the single 5 minute storm, and 10 values for each of the other durations. The red bar is the critical result, being the highest of the pink values.

The means and medians of the values of flowrates and HGL levels are displayed for each duration. These results are available for minor and major storms.

By examining results for the various components in a drainage system, a complex pattern of results can be explored. You can inspect the designed system and check the pipe inverts and sizes determined by DRAINS. There are a number of ways of doing this, using the various menu options. Additional results from analysis runs are shown in Figure 2.46.

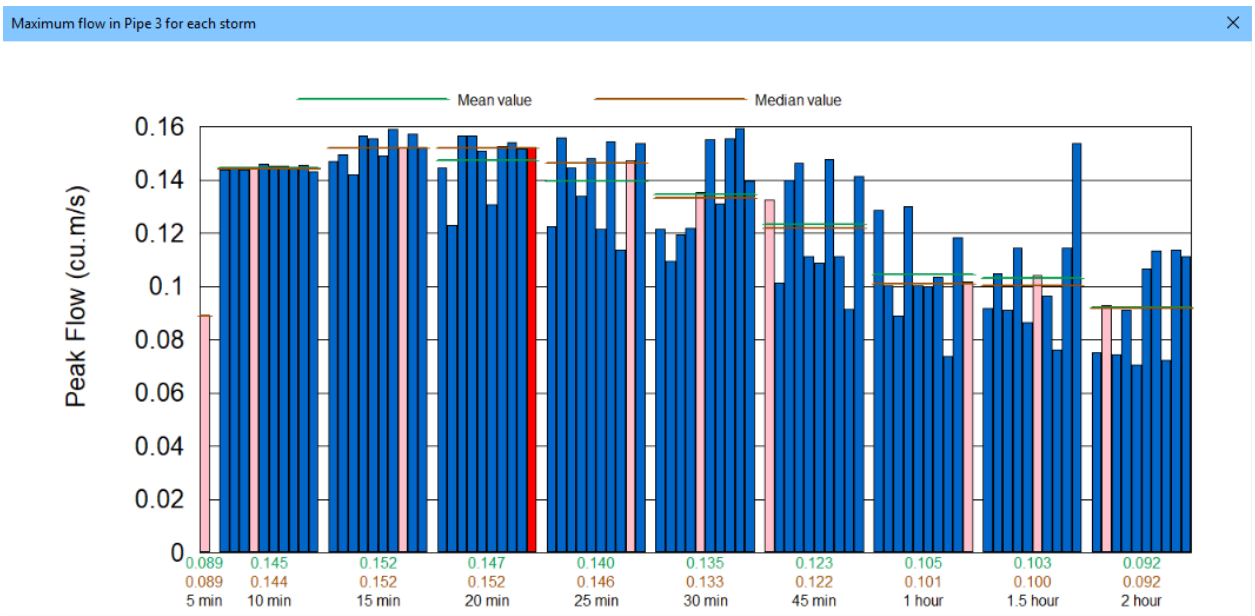


Figure 2.45 Chart of Results for a Pipe

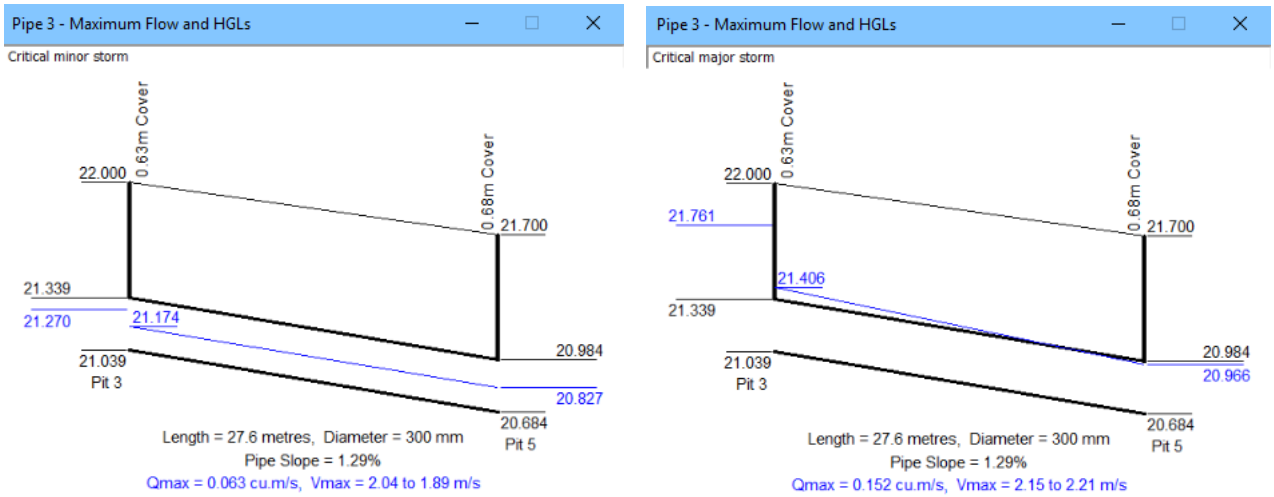
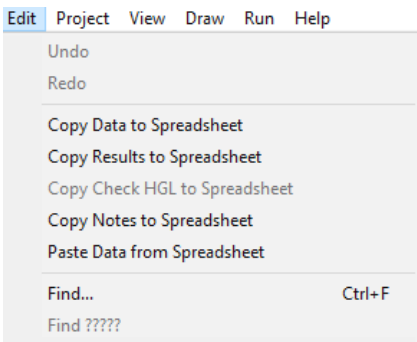


Figure 2.46 Long-Section Display for a Pipe showing 0.2 EY and 1% AEP Results

The suitability of the overflows during minor or major storms can be assessed as shown in Figure 2.47. The system can be enlarged if flow characteristics such as widths exceed acceptable limits, and DRAINS can be re-run.

You can also transfer information to a spreadsheet using options within the **Edit** menu:



The data spreadsheet for the Orange Example that is exported using **Edit → Copy Data to Spreadsheet** is shown in Figure 2.48.

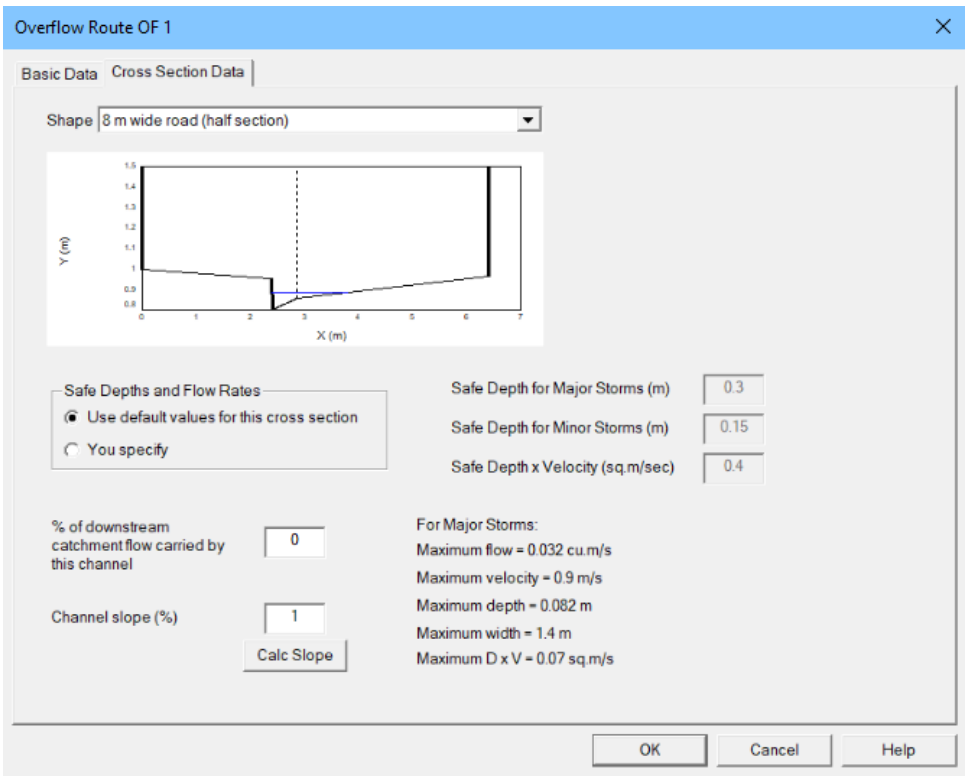


Figure 2.47 Overflow Route Property Sheet, showing Flow Characteristics

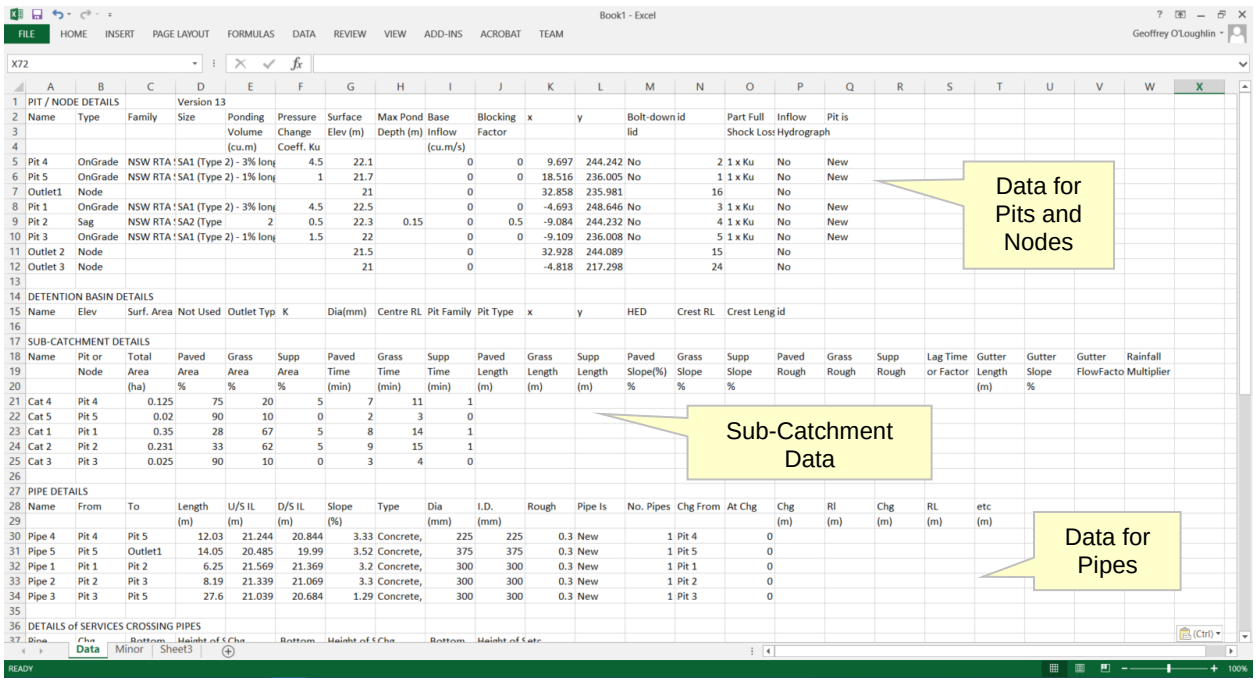


Figure 2.48 Spreadsheet Output for Data

Results of particular runs of DRAINS can also be exported to worksheets using **Edit → Copy Results to Spreadsheet**, as shown in Figure 2.49. These can be, for example, minor and major storm results from design procedures.

Plan and long-section views of pipelines can also be exported, in .dxf drawing format, and information can also be exported in ESRI or MapInfo GIS formats. To export the pipeline in the current example, you can go to **File** → Export → **DXF Long Section…**, and open the window shown in Figure 2.50. You can then enter the names of the pits or nodes at the upper and lower ends of the pipeline to be displayed. This can be done on the keyboard, or by following the instructions for nominating these components by clicking on them.

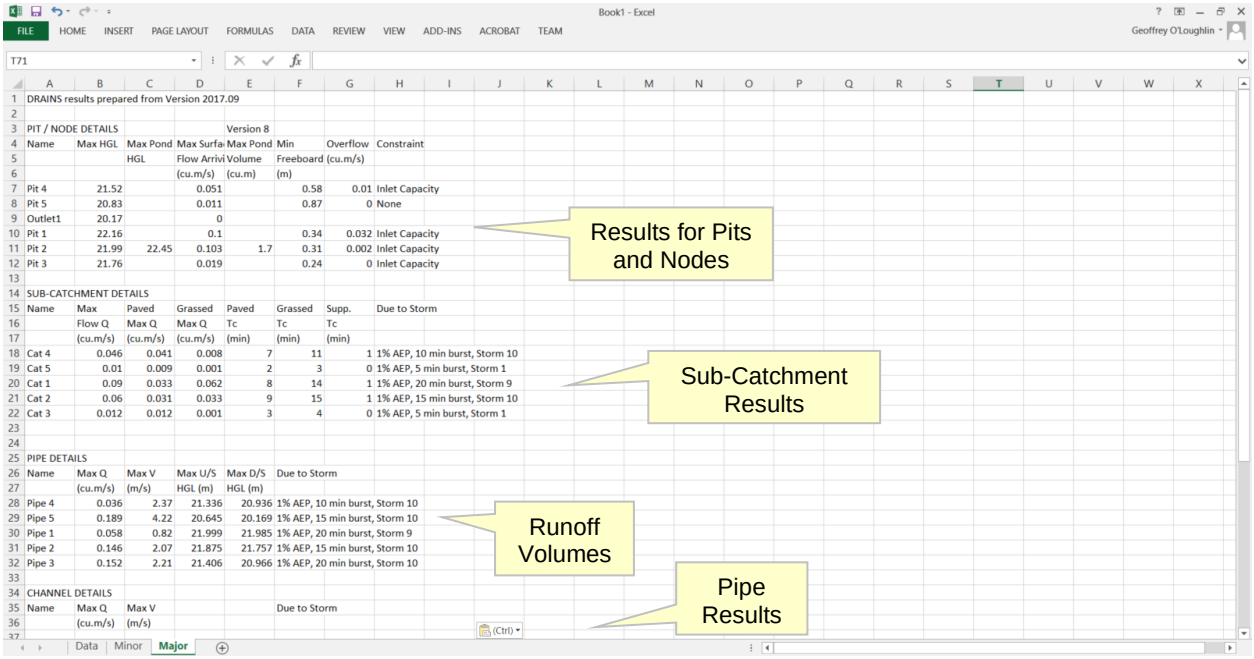


Figure 2.49 Spreadsheet Output for Results

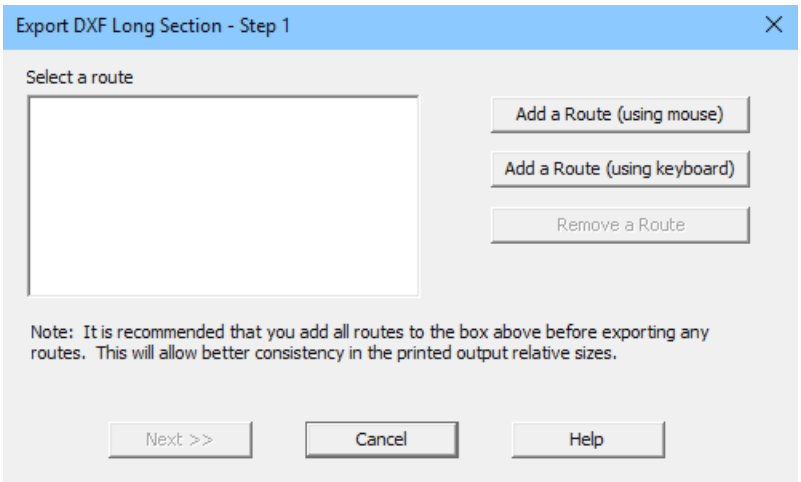


Figure 2.50 Nominating Pipe Routes to Export

If you select the top pit (Pit 1) and the bottom node (Outlet 1), the route will appear in the table, as shown in Figure 2.51. When you click Next, the long section will be displayed, as shown in

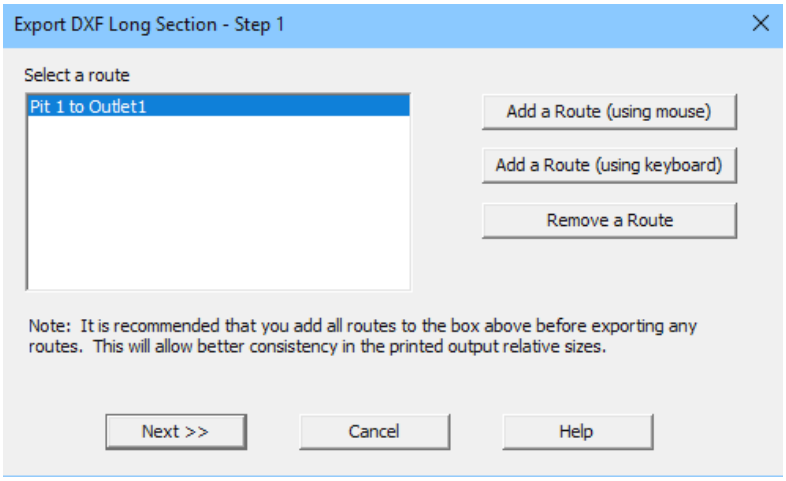


Figure 2.51 Table with Route Inserted

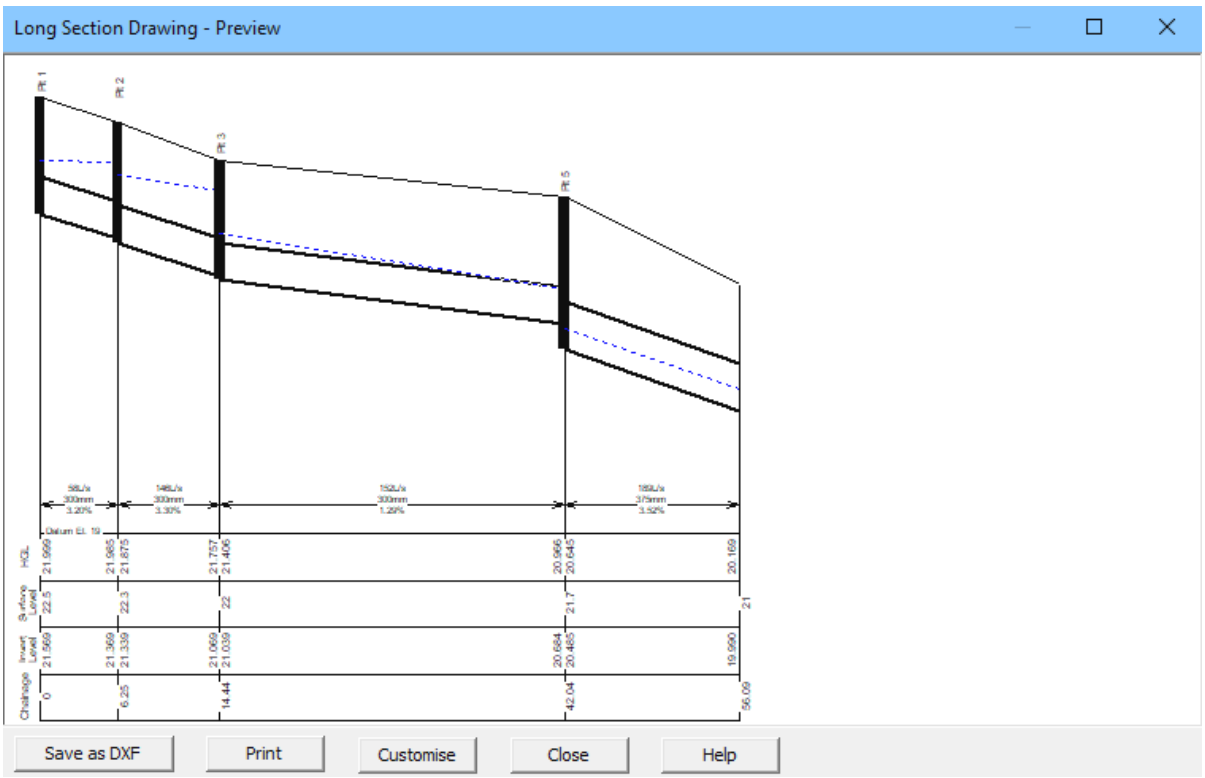


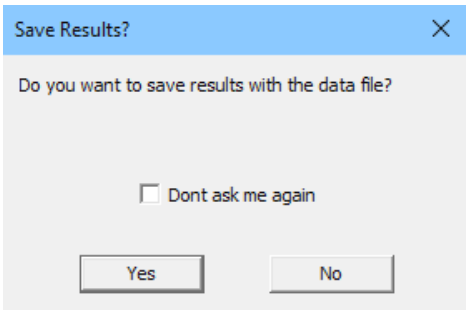
Figure 2.52 Pipe Long-Section Plot

This window can be enlarged if required. You can change the characteristics of the plot by altering settings that can be accessed by clicking on the **Customise** button. Clicking on the **Save as DXF** button opens a window where you can give the .dxf file a name and specify the folder in which it is to be saved. Once saved, you can view the .dxf file in a CAD program.

2.4.6 Saving Data and Results

This last step involves the storage of results. The input data is all stored in the DRAINS data file Orange2.drn, along with the background and the five databases. There is plenty of opportunity to make comments, in the spaces provided in the property sheets for individual components, and in a **Description …** option in the **Project** menu.

When your .drn file that has run is saved, you will have the opportunity to save the results along with the inputs, when this message appears:



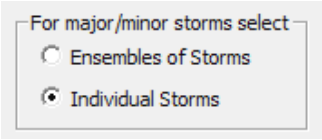
*

The spreadsheet results and .dxf files can also be stored.

2.4.7 Running Individual Storms

Due to the volume of calculations involved with rainfall ensembles (often 100 storms or so), it is necessary to limit the detailed information that is presented. You can view the details of the critical storm for each component (the red storm in the chart giving all results, as shown in Figure 2.45). This chart also shows the values of the flowrate or HGL elevation for all the other storms.

If you want detailed results for a number of storms, you can do this in two ways. The first is it go to **Project → Options…** and select **Individual Storms**.



When you go to Project → Select Major / Minor Storms…, the window shown below appears.

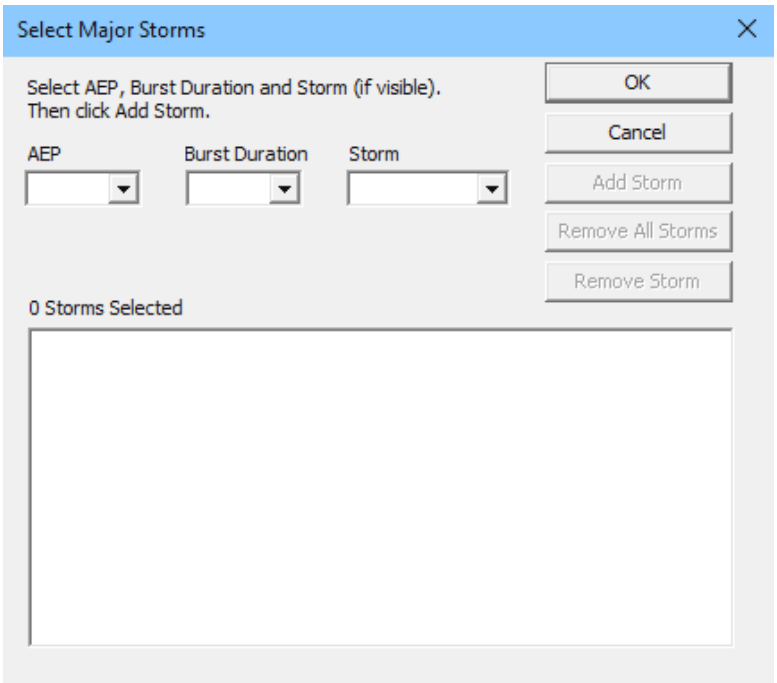


Figure 2.53 Selecting Major Storms Individually

You can select the AEP, burst duration and storm number (1 to 10). In the **Storm** box, you can also select **All 10 storms**, as shown in Figure 2.54. The **Add Storm** button needs to be pressed. Up to 12 storms can be selected using this method, or by making one-by-one selections.

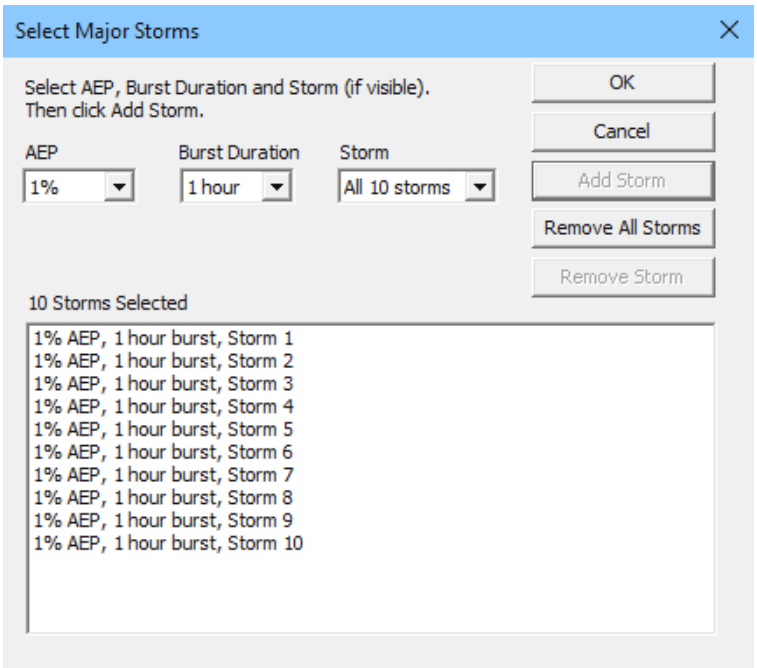


Figure 2.54 Individual Major Storms Selected

When you close this window, you will be asked to enter minor storms in the same way. You will be asked to enter at least one storm – enter any storm if you are not interested in minor storm results. After this window is closed, you can run major storms to get the type of results shown in Figure 2.55. The separate results for each of the 10 storms is displayed.

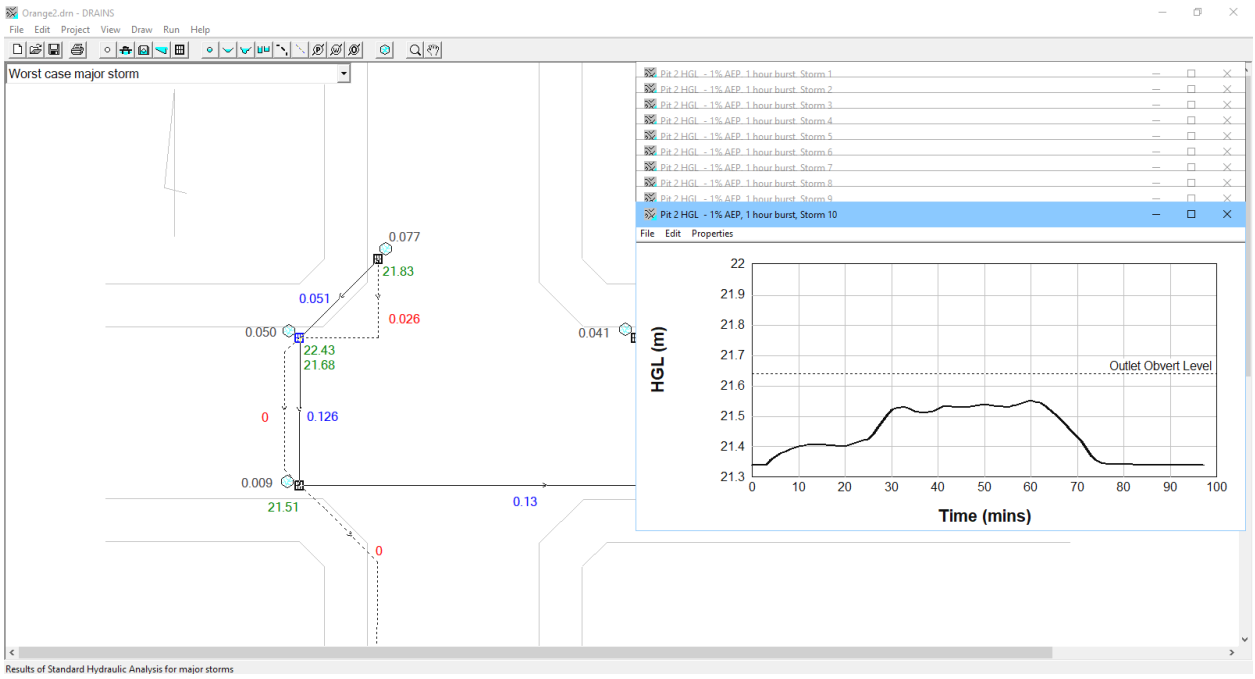


Figure 2.55 Results for Individual Major Storms

This mode of presentation will be familiar to experienced DRAINS users, as it is the way that ARR 1987 results have been displayed in the past.

The other way of selecting individual storms is implemented when viewing results from an analysis with ensembles, as shown below. If you choose **Select Median Storms for Next Run**, these will be set up as the major minor storms to be run individually.

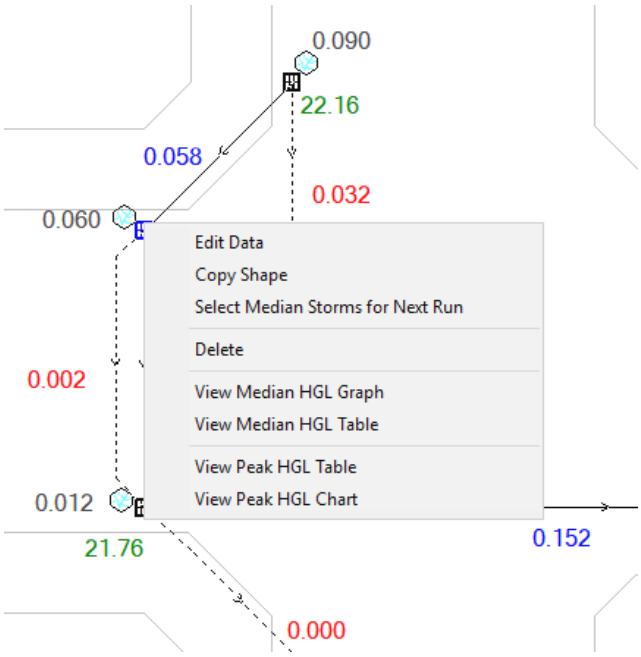
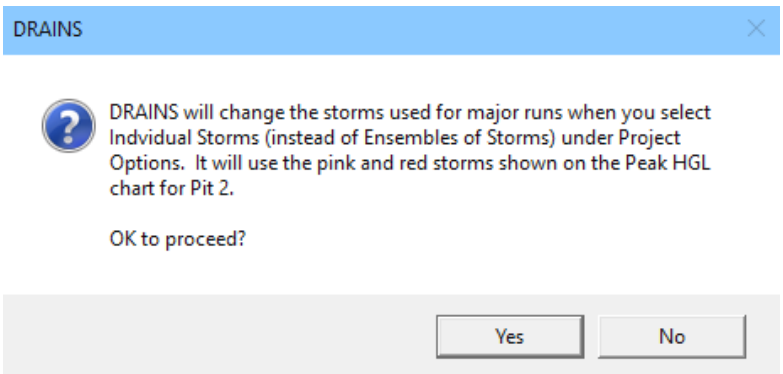
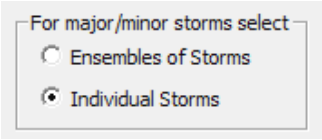


Figure 2.56 Selecting Median Storms as Individual Storms

If you choose this option for a particular component, you will see a message like that shown below.



You will need to click **Yes** and then select **Individual Storms** and **OK** in the **Project** → **Options…** sheet.



You will now be able to make a major run straight away that will produce results like those shown in Figure 2.57. These are the red and pink storms shown in the chart in Figure 2.45.

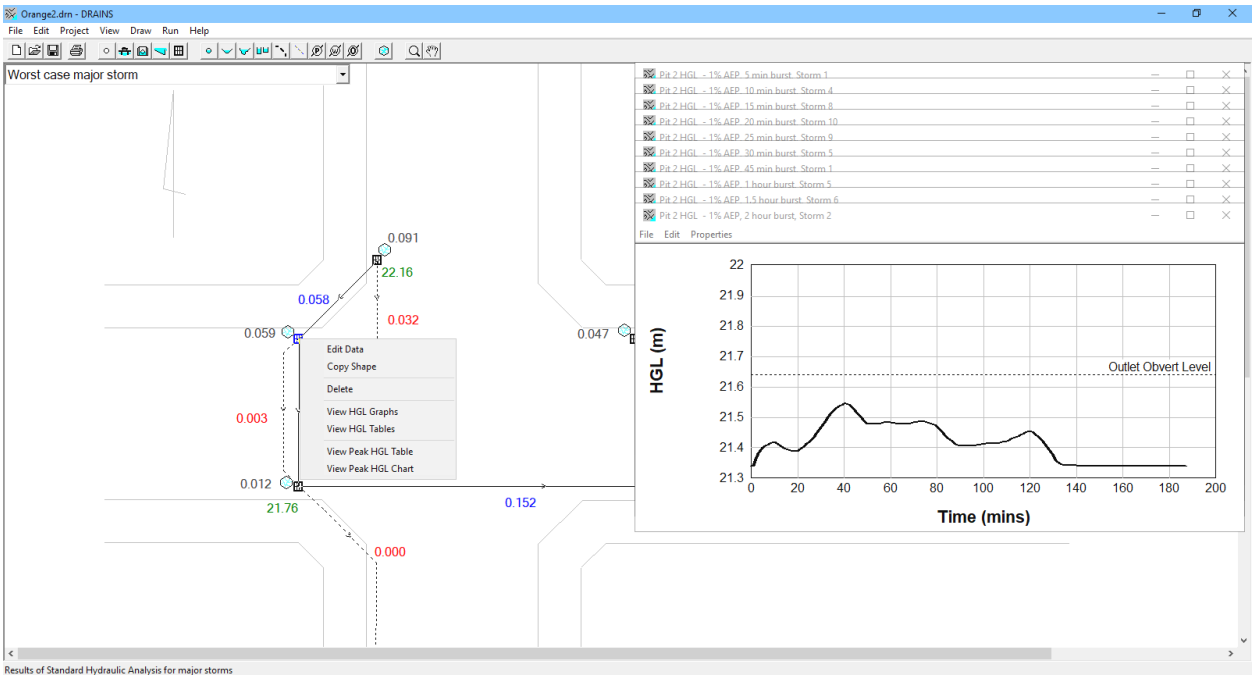


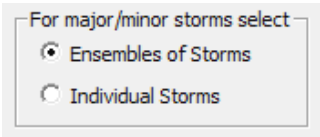
Figure 2.57 Results using Selected Median Storms for Each Duration

(The individual storm results will include some outputs that are not available with ensemble runs, such as detention basin inflow - outflow hydrographs, long sections of overflow route water levels calculated using the premium hydraulic model.)

These procedures make it relatively easy to perform trial and error design calculations, with the following steps.

Step 1 – Set up a model,
Step 2 – Run a Design with ensembles,
Step 3 – Run a minor or major Analysis, whichever you are interested in,
Step 4 – In the pop-up menu for a key component, choose **Select Median Storms for Next Run**,
Step 5 - Open the **Project** → **Options…** sheet and choose Select **Individual Storms**,
Step 6 – Run DRAINS with the individual storms,
Step 7 – Inspect the results for the key component and assess whether they are satisfactory,

Step 8 – If not, alter a component's characteristics, such as increasing a pit's size, and in the **Project** → **Options…** sheet, choose Select **Ensembles of Storms**.



Step 9 – Repeat Steps 3 to 7, and continue this process until the component operates satisfactorily.

This process may seem complicated, but it will become familiar. The complexity is due to the need to work with so many storms in the ensemble system.

2.5 Entering and Running with ARR 1987 Rainfalls

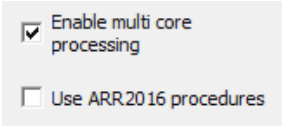
2.5.1 General

This section is included to allow users to run work-in-progress or to check older DRAINS models. The 2016 rainfall data procedure set out in Section 2.4 is preferred for new work.

1987 rainfall patterns can be entered manually, or transferred from a spreadsheet, but a process using I-F-D coordinates downloaded from the Bureau of Meteorology website is more rapid and accurate. Intensities calculated from these coordinates are combined with storm burst temporal patterns that are incorporated into DRAINS. This process is outlined below.

2.5.2 Entering Rainfall Patterns

To apply the old 1987 rainfall patterns, you must first ensure that in the **Project** → **Options** property sheet, the Use ARR2016 procedures box is unticked.



You can then define rainfall patterns through the **Rainfall Data…** option in the **Project** menu, shown in Figure 2.58, in which you can set up a data base of rainfall patterns or hyetographs.

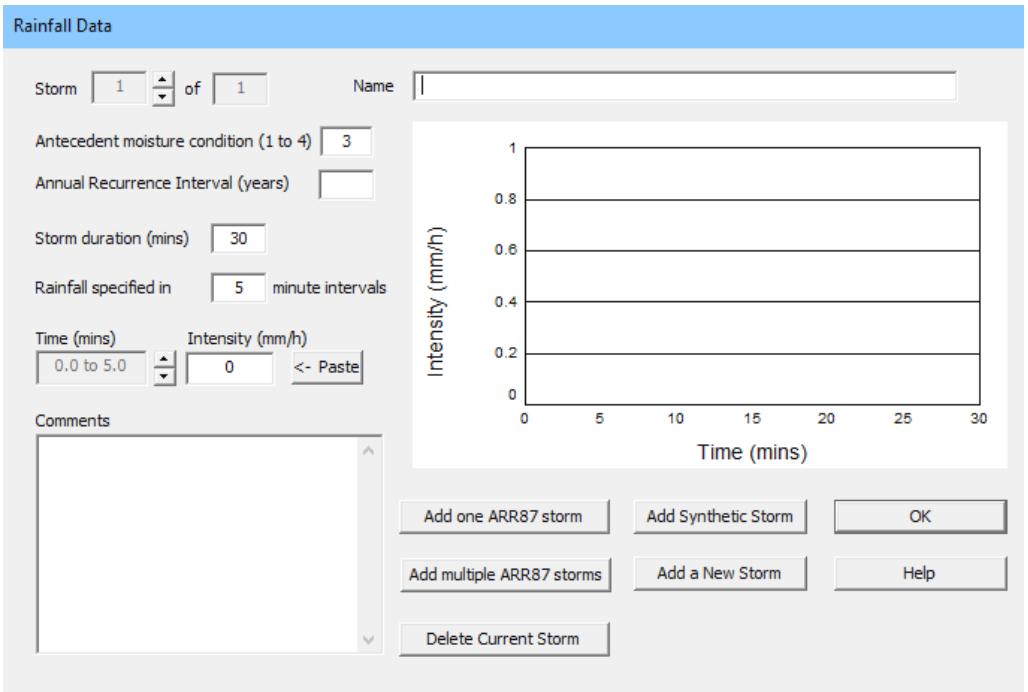


Figure 2.58 Rainfall Data Property Sheet

The best way of doing this is to select **Add multiple ARR87 storms** to open the sheet shown in Figure 2.59, and tick the boxes as shown.

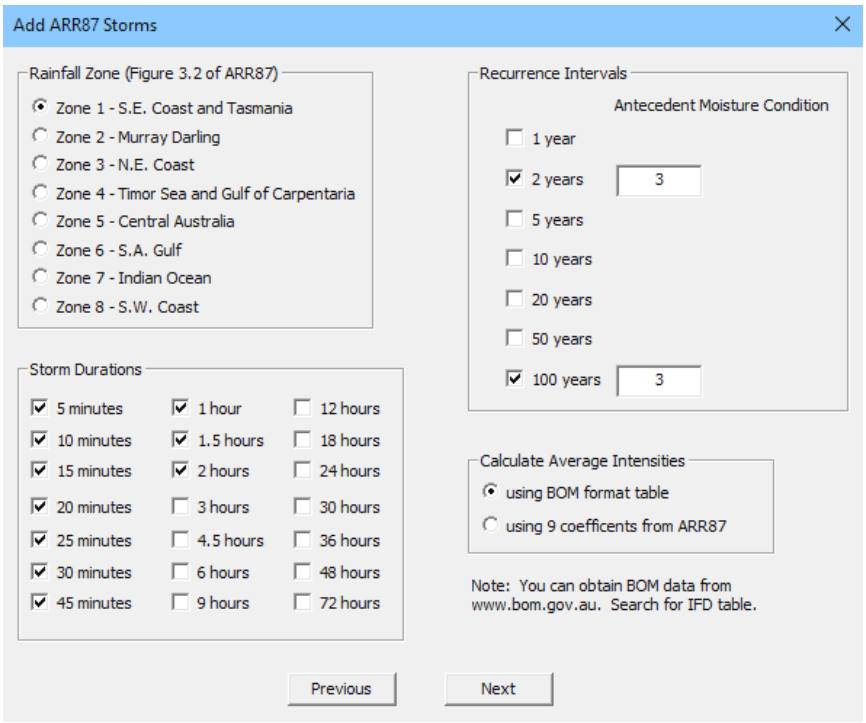


Figure 2.59 Dialog Box for Adding ARR 1987 Storms

You will now need pause operations in DRAINS, and open an internet connection to a website where you can determine the latitude and longitude of the site where you are modelling. This can be done on Google Maps or other sites, but a good location is the ARR Data Hub at data.arr-software.org.

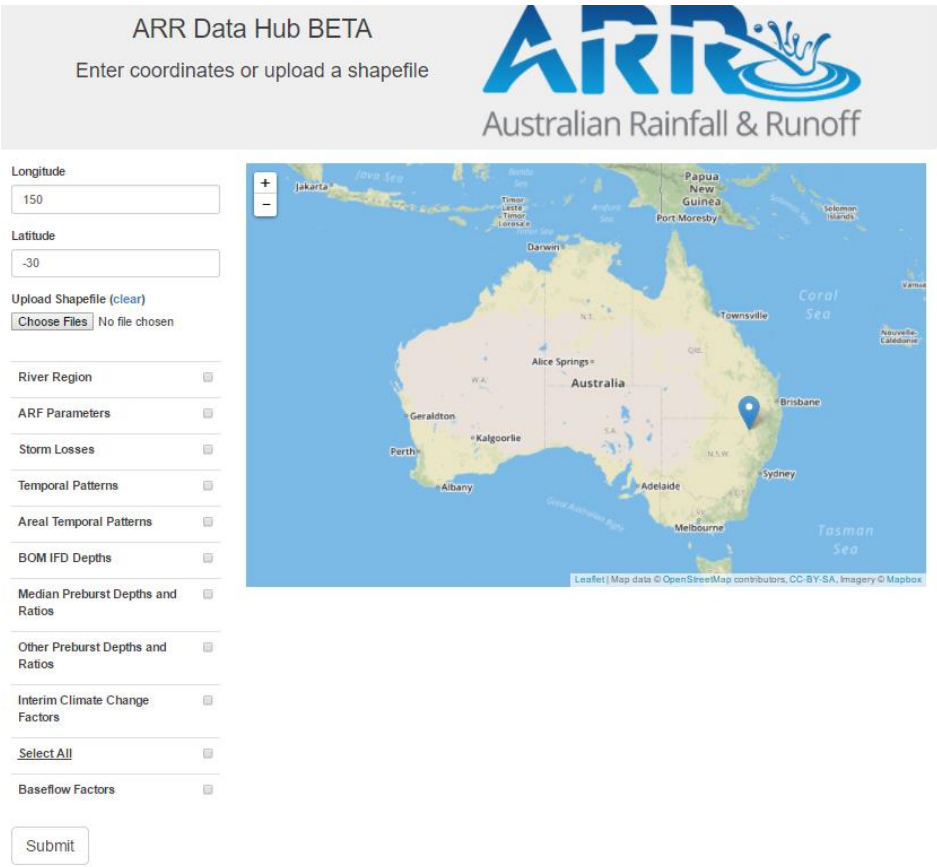


Figure 2.60 ARR Data Hub

Here you can move the blue pointer and pan and zoom to the site you require. The longitude and latitude appear to the left of the window, as shown in Figure 2.61.

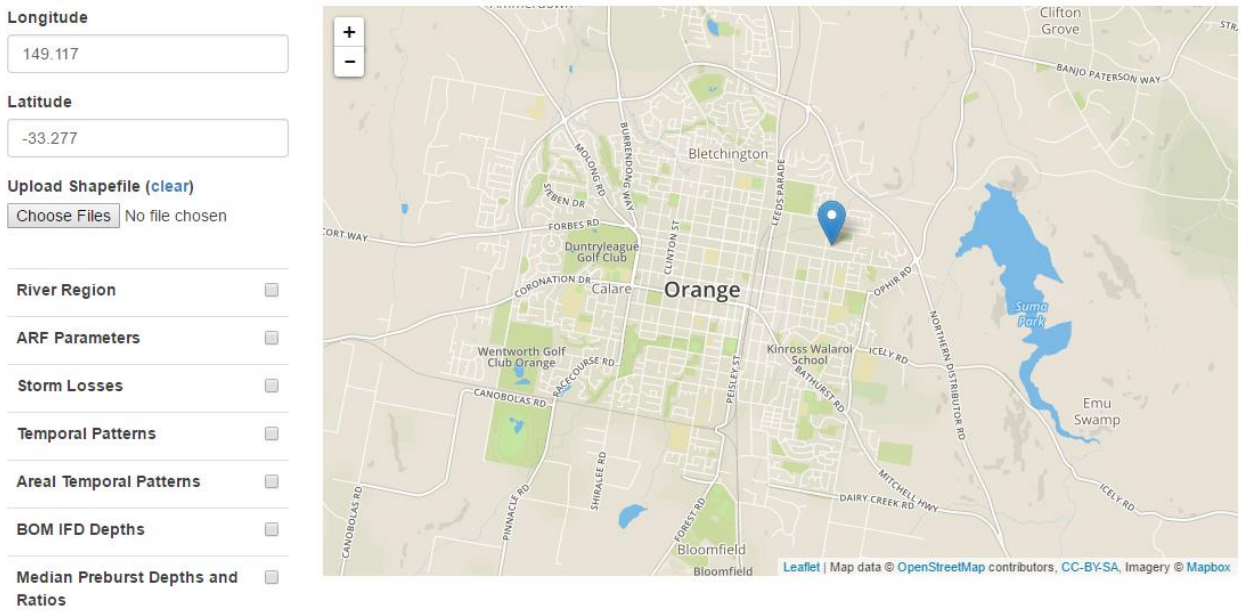


Figure 2.61 Selecting Site and Obtaining Longitude and Latitude

Now you will need to go to the BOM site at www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml, shown below.

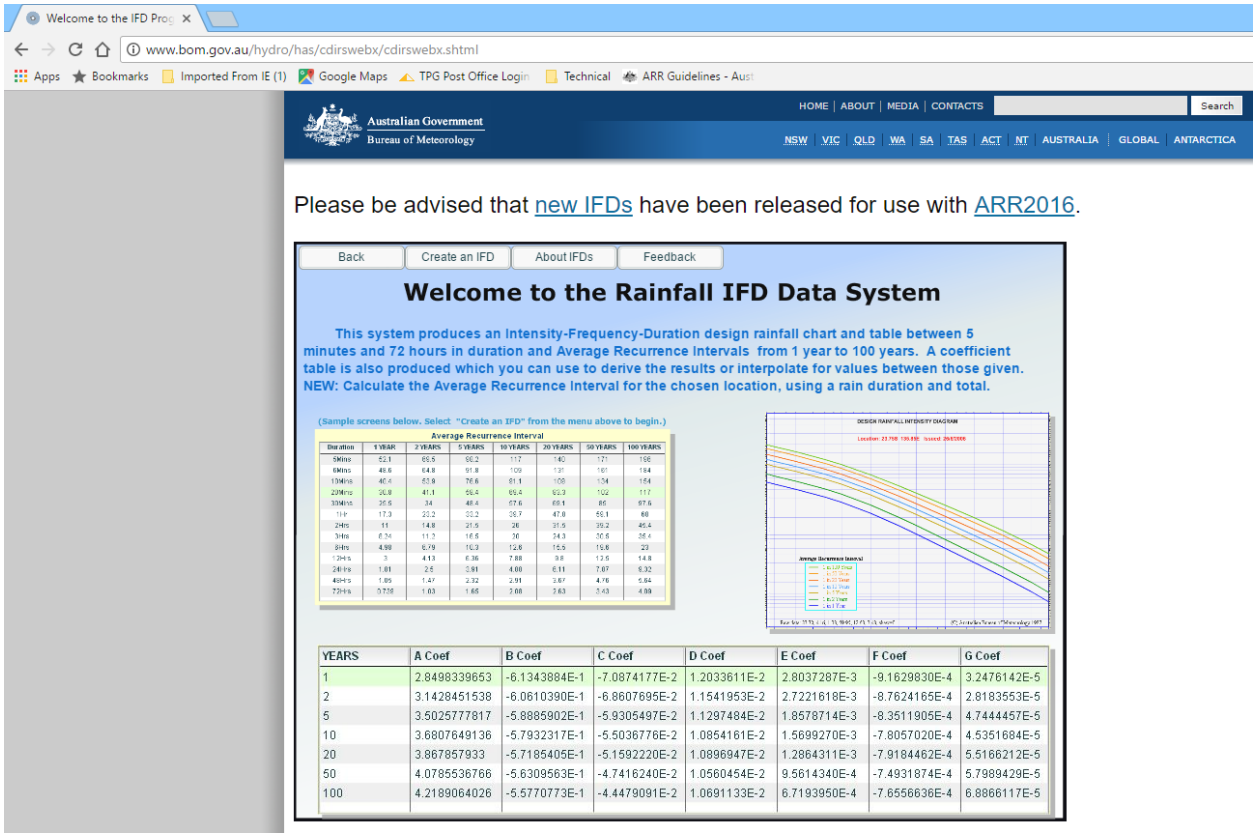


Figure 2.62 BOM 1987 'Flash' Website

You will need to click on **Create an IFD**. This opens a page in which you can enter the latitude and longitude from the ARR Data Hub, as shown below.

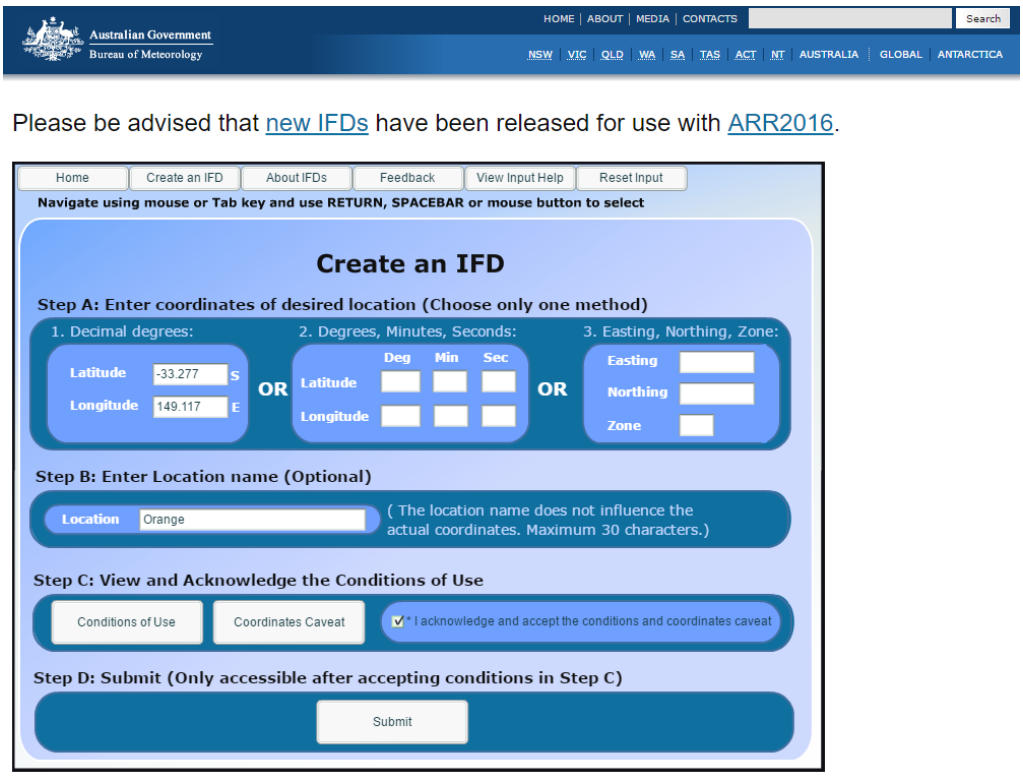


Figure 2.63 Dialog Box for Entering BOM 1987 Data

Then click on the Submit button to produce the page shown in Figure 2.64. Click on Coefficients to open the page shown in **Figure 2.65**. Then click on the **Copy table** button, which transfers the table to the Windows Clipboard.

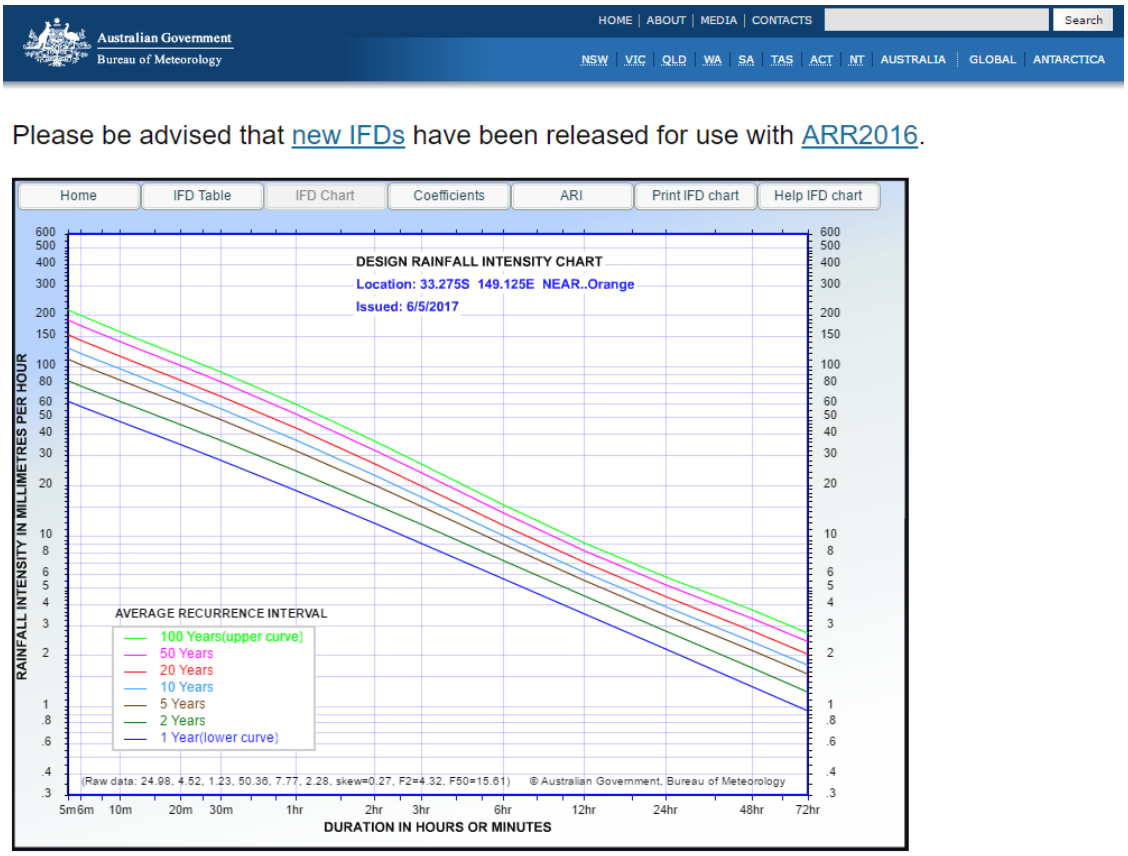
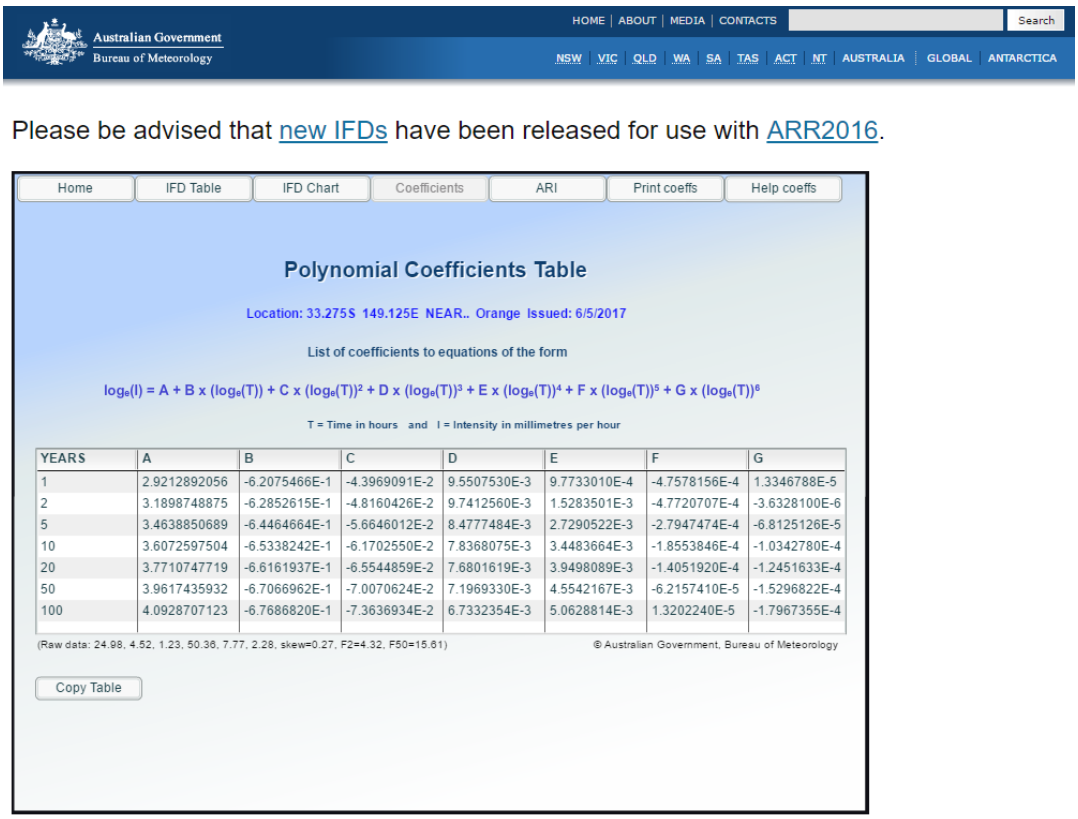


Figure 2.64 I-F-D Chart



YEARS	A	B	C	D	E	F	G
1	2.9212892056	-6.2075466E-1	-4.3969091E-2	9.5507530E-3	9.7733010E-4	-4.7578156E-4	1.3346788E-5
2	3.1898748875	-6.2852615E-1	-4.8160426E-2	9.7412560E-3	1.5283501E-3	-4.7720707E-4	-3.6328100E-6
5	3.4638850689	-6.4464664E-1	-5.6646012E-2	8.4777484E-3	2.7290522E-3	-2.7947474E-4	-6.8125126E-5
10	3.6072597504	-6.5338242E-1	-6.1702550E-2	7.8368075E-3	3.4483664E-3	-1.8553846E-4	-1.0342780E-4
20	3.7710747719	-6.6161937E-1	-6.5544859E-2	7.6801619E-3	3.9498089E-3	-1.4051920E-4	-1.2451633E-4
50	3.9617435932	-6.7066962E-1	-7.0070624E-2	7.1969330E-3	4.5542167E-3	-6.2157410E-5	-1.5296822E-4
100	4.0928707123	-6.7686820E-1	-7.3636934E-2	6.7332354E-3	5.0628814E-3	1.3202240E-5	-1.7967355E-4

Figure 2.65 I-F-D Coefficients

Now you can go back to DRAINS and click the **Next** button in the dialog box shown in **Figure 2.59**, which will open the window shown below:

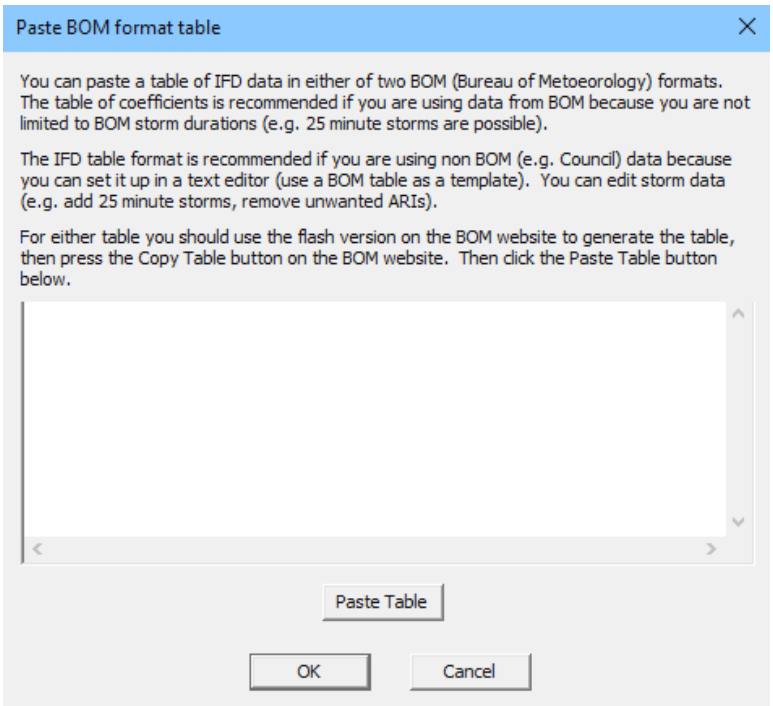


Figure 2.66 Dialog Box for Entering BOM 1987 Data

Click the **Paste Table** button to enter the I-F-D coefficients from the Clipboard, which will appear as shown below:

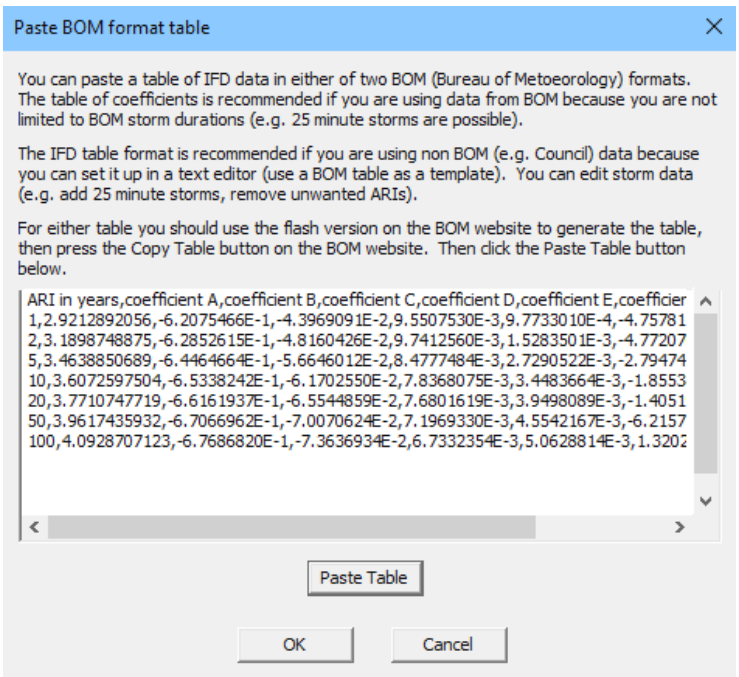


Figure 2.67 Coefficients Displayed

When you press **OK**, the rainfall patterns requested will appear in the Rainfall Data property sheet. (The first of these is a blank one, and can be removed using the **Delete Current Storm** button if you wish.)

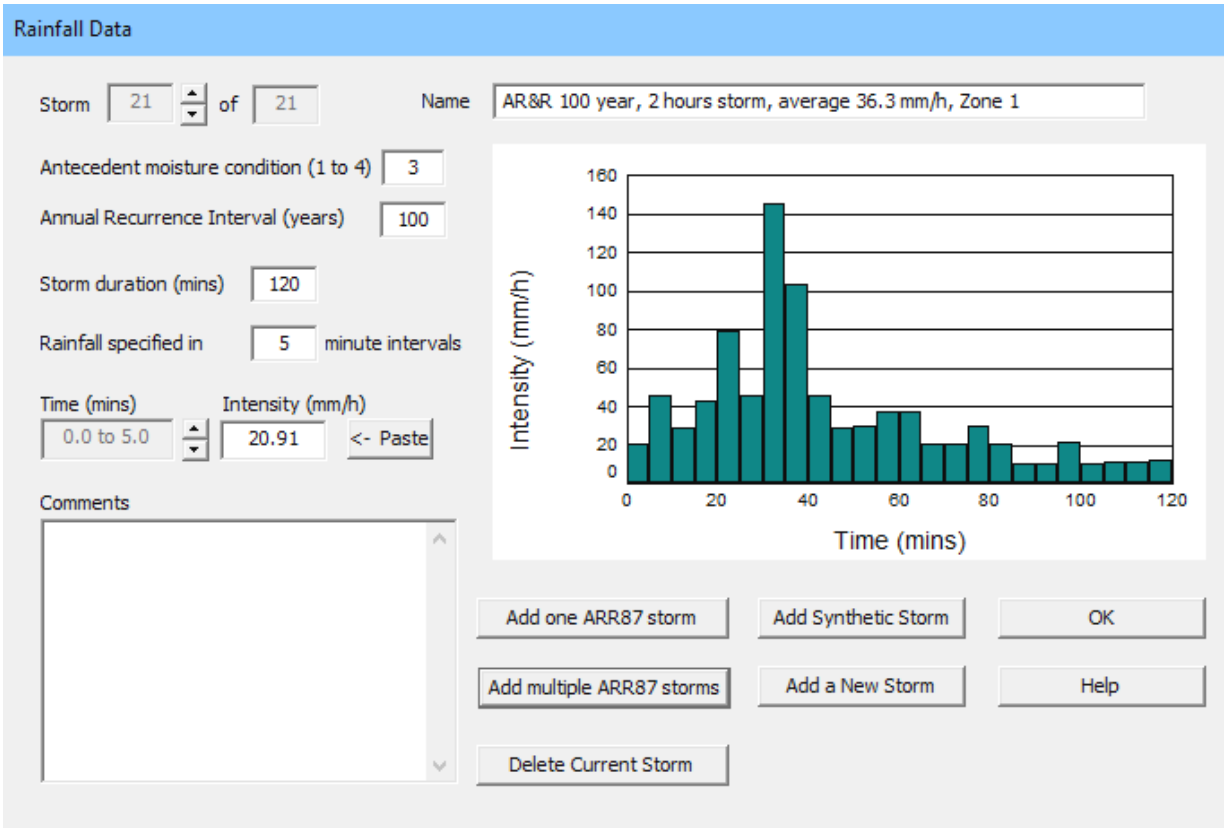


Figure 2.68 Rainfall Patterns for Orange, NSW

Storm patterns or hyetographs can also be defined in DRAINS by clicking the **Add one ARR87 Storm** button, which opens the dialog box shown in Figure 2.69.

Enter the information shown in this figure and press the **OK** button. The pattern will be displayed in the Rainfall Data property sheet, as shown in Figure 2.70. (Note that there are other ways of entering rainfall data, described in Section 5.4.4).

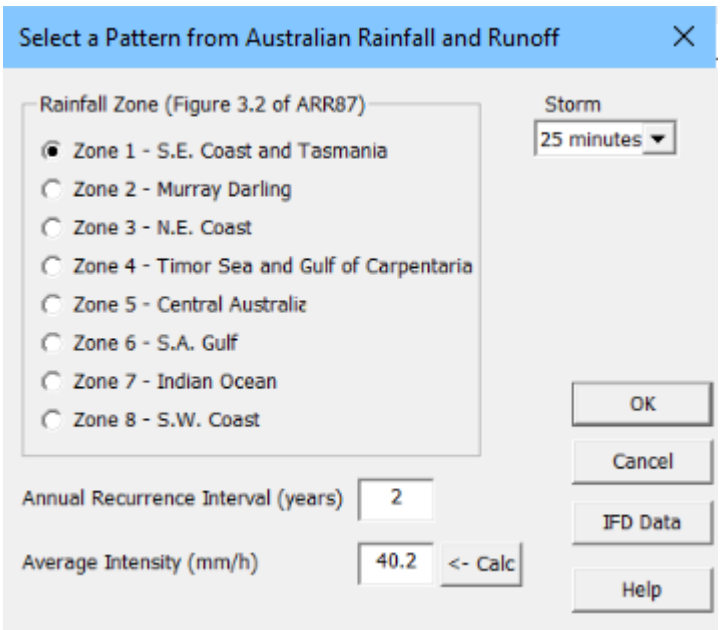


Figure 2.69 ARR87 Rainfall Pattern Dialog Box

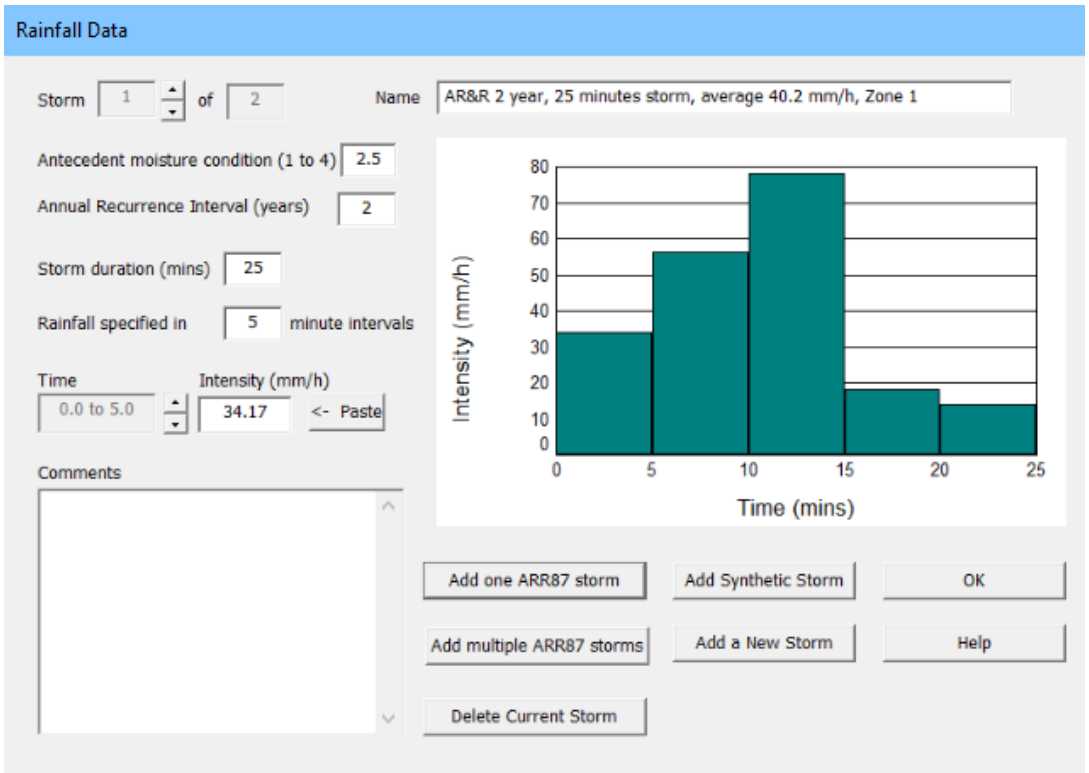


Figure 2.70 Rainfall Patterns for Orange, NSW

Next, change the antecedent moisture condition value in the Rainfall property sheet to 2.5. Set up a second pattern using the same process, this time for an ARI of 100 years and an intensity of 101 mm/h. Then click the **OK** button.

The next step is to select storms from the data base to be used for design and for analysis. This is done using the **Select Minor Storms** option in the **Project** menu, which opens the dialog box shown in Figure 2.71. Click the **Selected storms** button in the top left corner and then click the downwards arrow on the first drop down list box to show the names of the rainfall patterns in the data base. For this example, click on the 2 year ARI, 25 minute pattern to select this storm as the one to be used to design the pipe system.

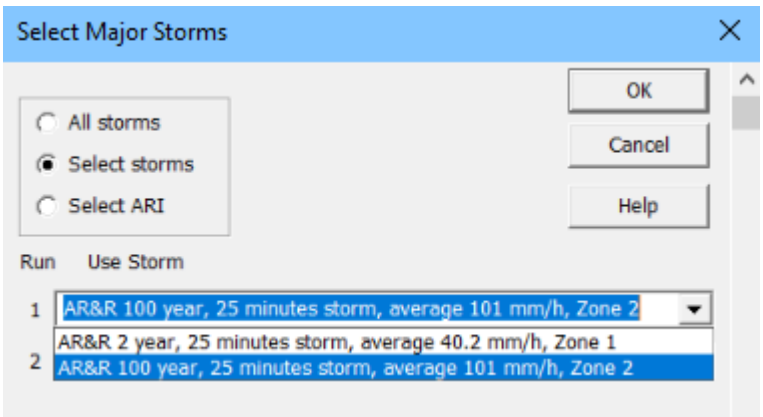


Figure 2.71 Select Minor Storms Dialog Box

Close this dialog box by clicking **OK**, and then follow the same procedure with **Select Major Storms** to select the 100 year ARI, 25 minute storm for major storm runs.

(The design process defines the pipe sizes and depths needed to carry runoff from minor ARI storms satisfactorily, while meeting certain criteria. The system must also 'fail-safe' in runoff from major ARI storms. The system performance can be checked using various Analysis runs.)

Now choose **Options …** in the **Project** menu to open the sheet shown in Figure 2.72. This sets the values of parameters used in design calculations. The only items to be entered in the present example are the blocking factors - enter 0.5 for sag pits and 0.0 for on-grade pits. (Note that the box on the right named **Use ARR2016 procedures** must be unticked to use ARR 1987 data.

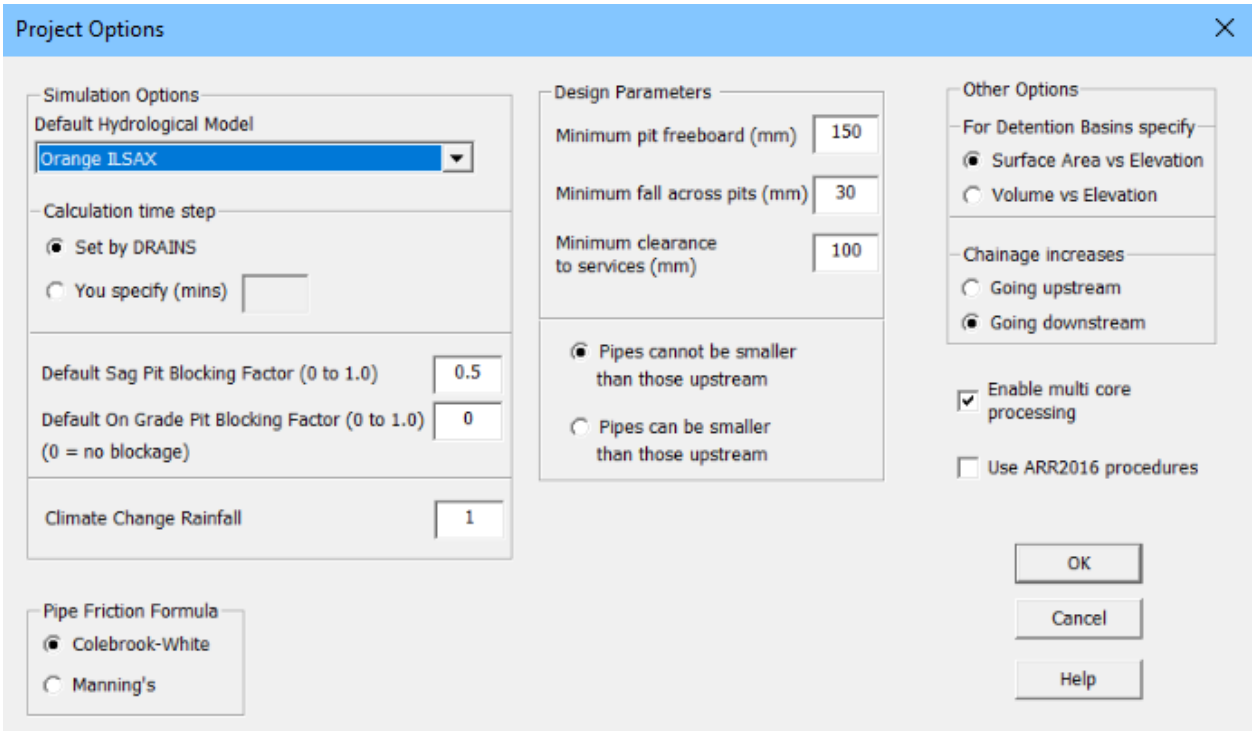


Figure 2.72 The Options Property Sheet

2.5.3 Running the Program

You can now run the program in Design mode from the **Run** menu, shown in Figure 2.73. The pipe design concentrates upon the allowable flow along the overflow route. The method determines this flowrate, taking into account the flows from of the sub-catchment immediately downstream of each pit. It then works backwards to define a set of pit inlets and pipe sizes that will limit overland flows to safe levels in both minor and major storms. Safety requirements are defined in terms of flow depths and velocity-depth products in the Overflow Route Data Base, as shown in Figure 2.19.

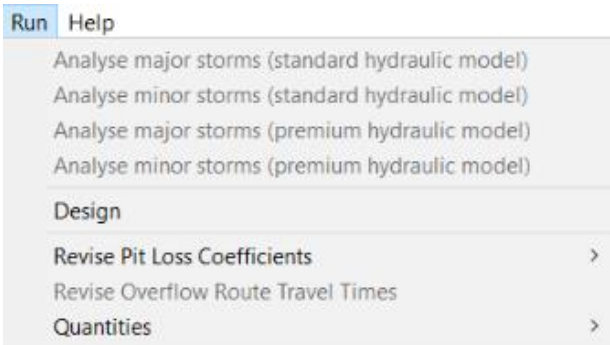


Figure 2.73 Run Options

After a Design run, the message shown **Figure 2.74** appears, advising that the process is complete. If you check pipes and pits, you will find that pit sizes, pipe diameters and pipe invert levels have been defined by the design process. Pipe long-sections can also be viewed, as shown in **Figure 2.75**.

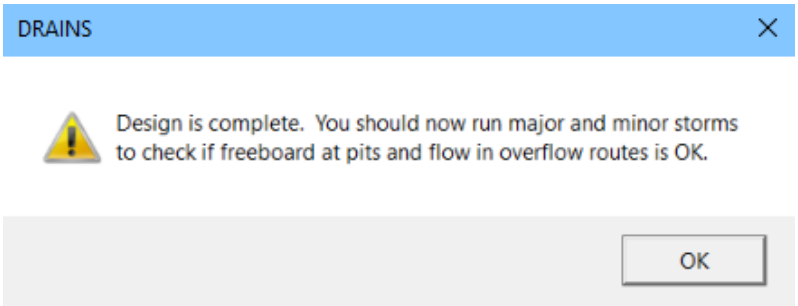


Figure 2.74 Advisory Message

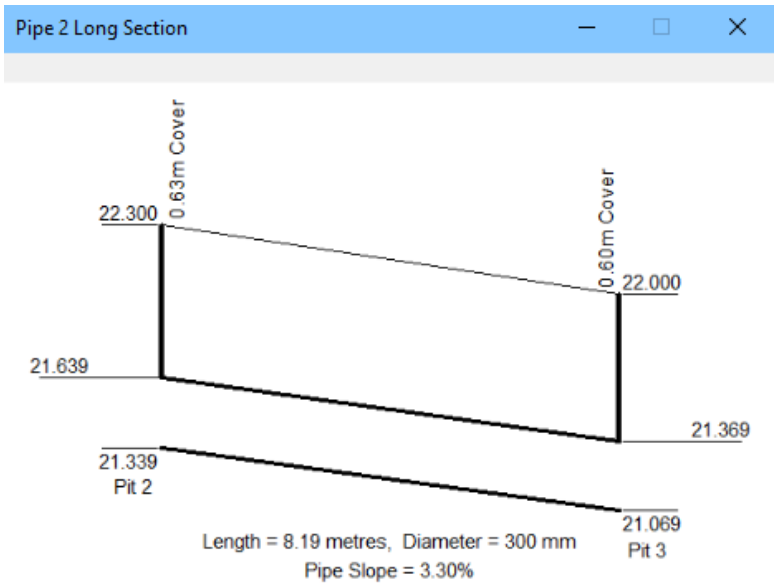
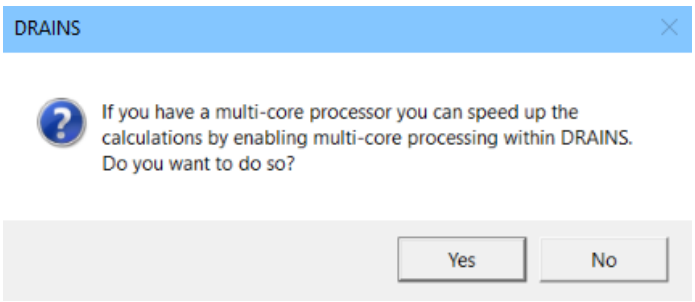


Figure 2.75 A Pipe Long-Section after a Design

You can now run an analysis with minor or major storms to assess the results, by choosing the **Analyse minor storms** and **Analyse major storms** options in the **Run** menu. These run with two types of hydraulic model. The standard hydraulic model is available in all DRAINS model. The optional, premium model requires more detailed information on overflow routes, in order to model them with unsteady flow hydraulics.

When performing an analysis, DRAINS may display the message shown below:



If you agree, DRAINS will display the **Project Options** property sheet (Figure 2.72) in which you can click the box titled **Enable multi core processing** to reduce the processing time. Whatever choice is made, the analysis run proceeds, and a report is displayed after it finishes, as shown in Figure 2.76.

After you close this window you will see that the names of components have changed to coloured numbers as follows:

- the **black** numbers are the maximum flowrates from the sub-catchments, in m^3/s,
- the **blue** numbers are the greatest flowrates in each pipe, in m^3/s,
- the **red** numbers are the greatest overflows from pits, in m^3/s, in the standard hydraulics model, or the flowrates at the centre of an overflow path in the premium hydraulic model (not including any flows from the downstream sub-catchment),
- the **green** numbers are the highest levels reached by the hydraulic grade lines (HGLs) throughout the pipe system, in m elevation, defining the highest water levels during the 2 year ARI, 25 minute storm event considered. (At sag pits, the highest surface ponding level is also shown.)

Since it calculates conditions at a number of time intervals, DRAINS produces hydrographs or time series of runoff flowrates from the rainfall hyetographs. It is possible to view what happens at all times during the storm event, as shown in Figure 2.77.

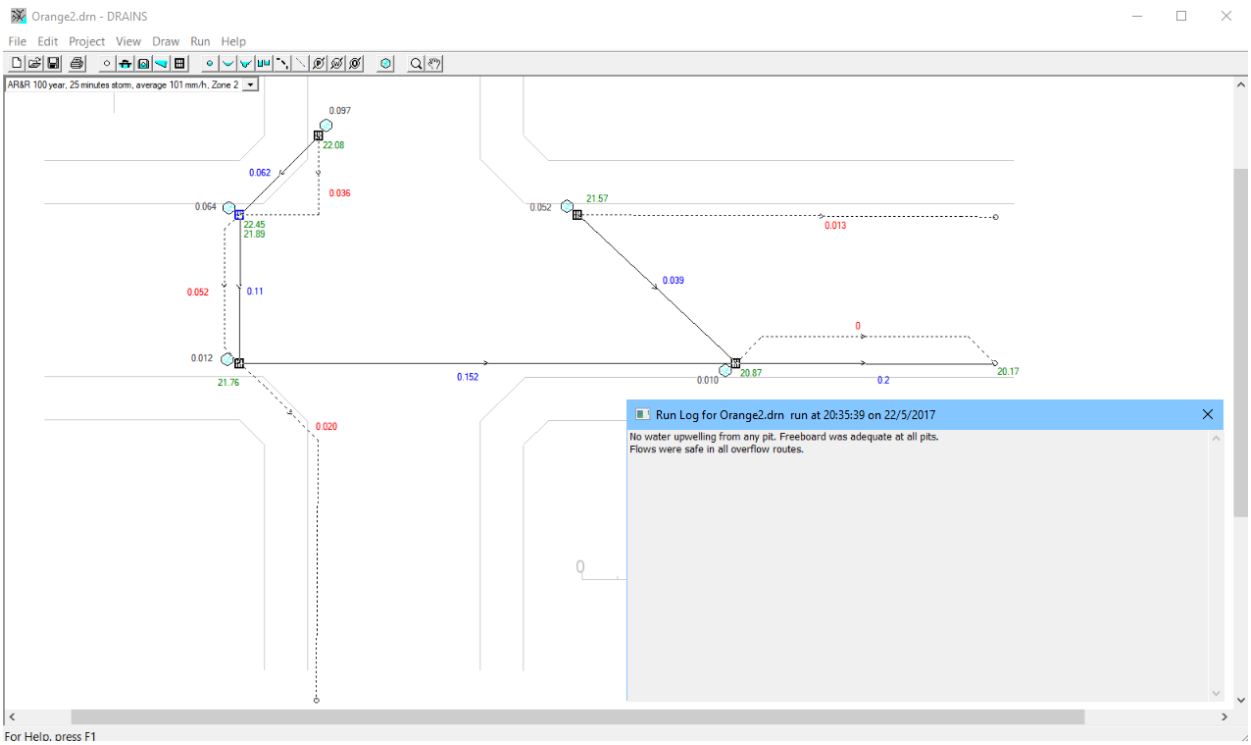


Figure 2.76 The Result of a Design Run and Minor Storm Analysis

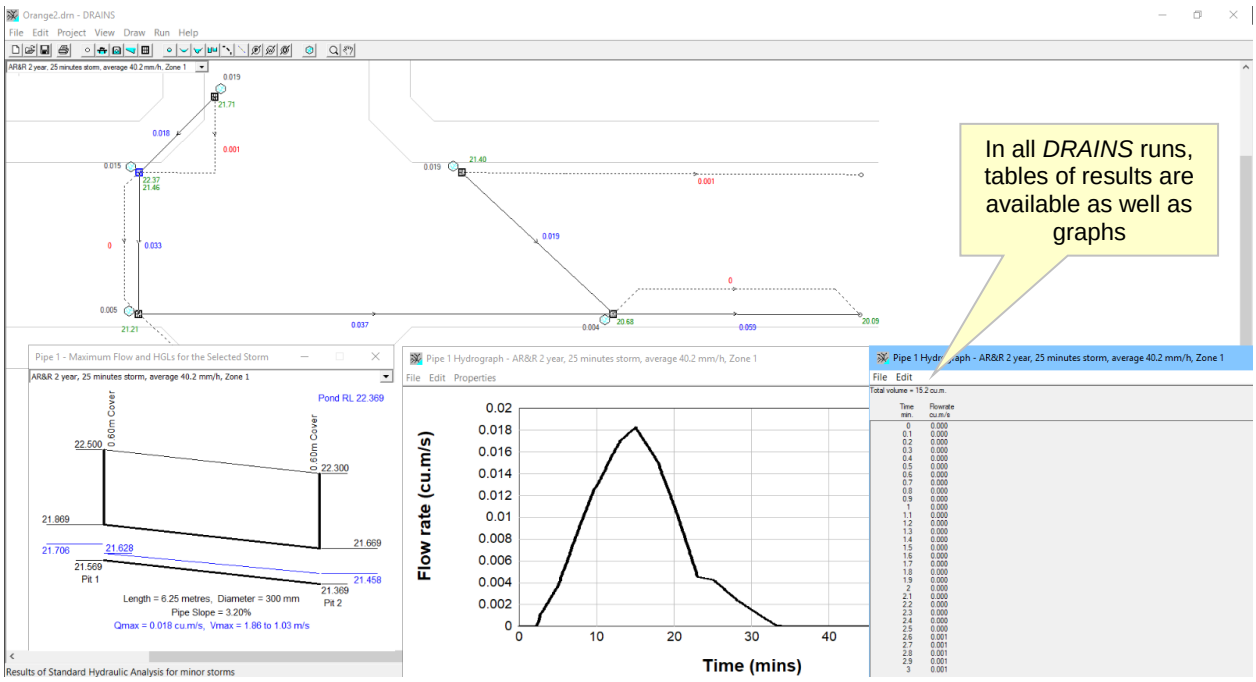


Figure 2.77 Hydrograph and Hydraulic Grade Line Results for a Minor Storm

2.5.4 Reviewing Results

You can now inspect the results and check the pipe inverts and sizes determined by DRAINS. There are a number of ways of doing this, the most comprehensive being the transfer of information to a spreadsheet using options within the **Edit** menu. The data spreadsheet for the Orange Example is shown in Figure 2.78.

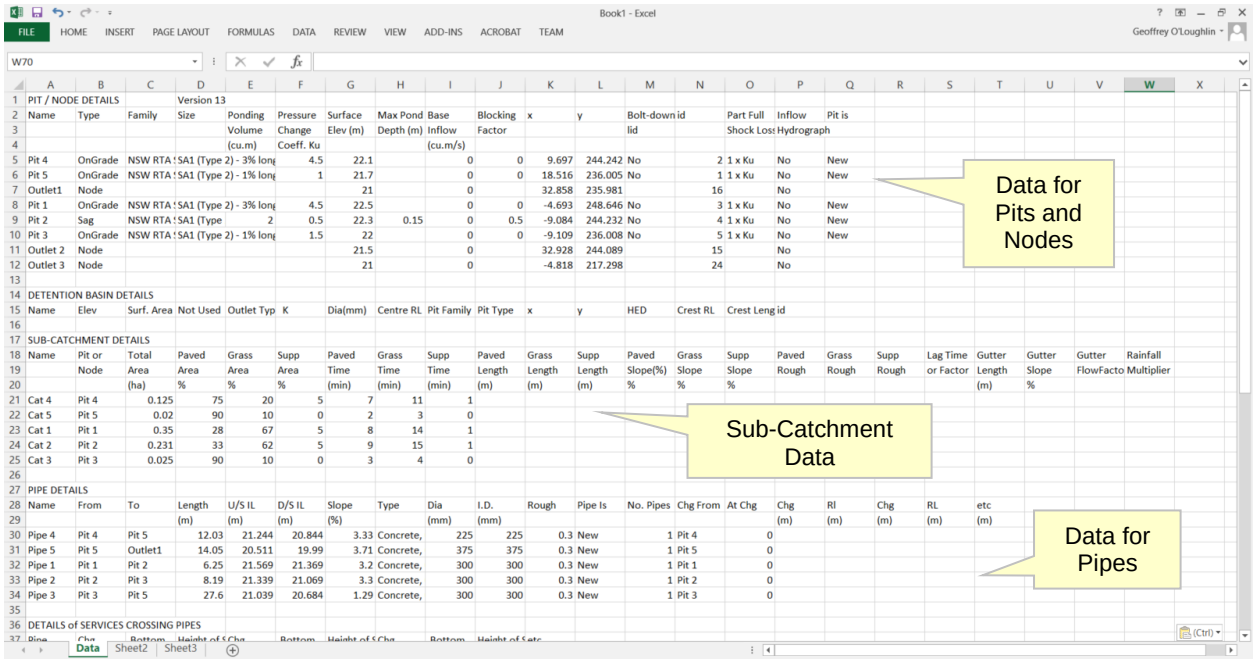


Figure 2.78 Spreadsheet Output for Data

Results of particular runs of DRAINS can also be exported to worksheets using the **Edit** menu, as shown in Figure 2.79. These can be, for example, minor and major storm results from design procedures.

Long-sections of pipes can be displayed and exported in .dxf format using the window opened by **File → Export → DXF Long Section…**, as described at the end of Section 2.4.5.

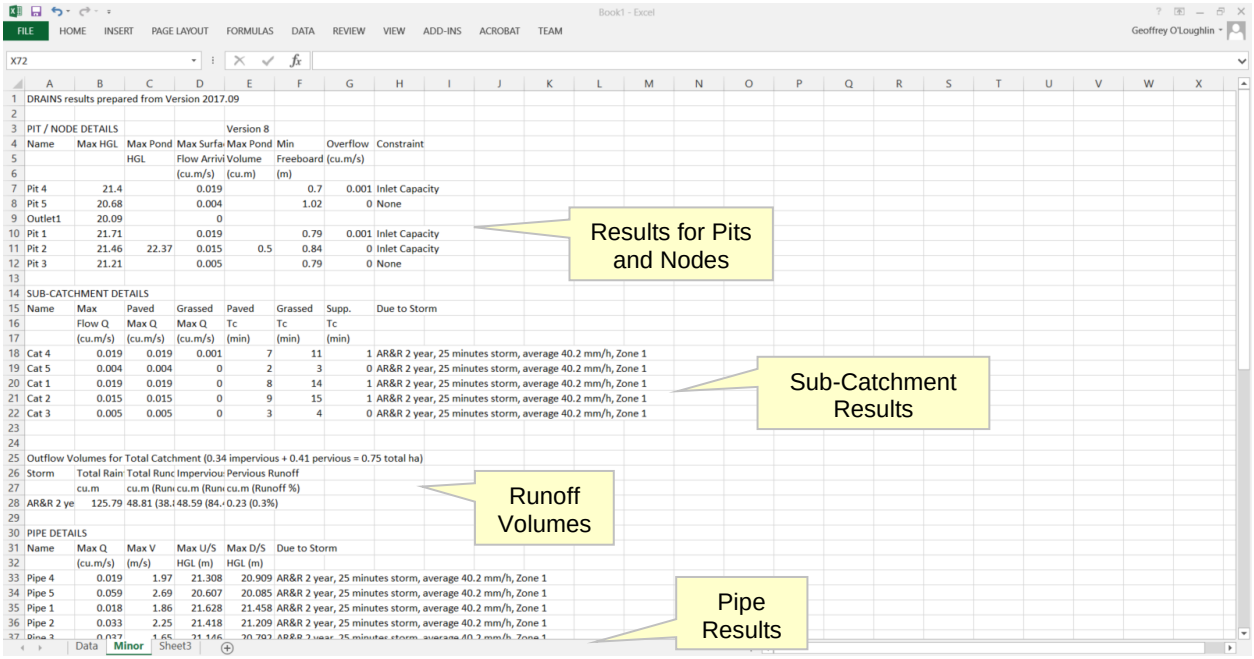


Figure 2.79 Spreadsheet Output for Minor Storm Results

The major/minor system is usually employed in Australian drainage design. Pipes are sized to carry flows of a minor ARI, usually 5 or 10 years, and a check is made to ensure the safe working of the system during a major storm event, with an ARI of 50 or 100 years.

You can now also perform an analysis using the 100 year ARI, 25 minute rainfall pattern. Simply run **Analyse major storms** from the **Run** menu to produce the results shown in Figure 2.80.

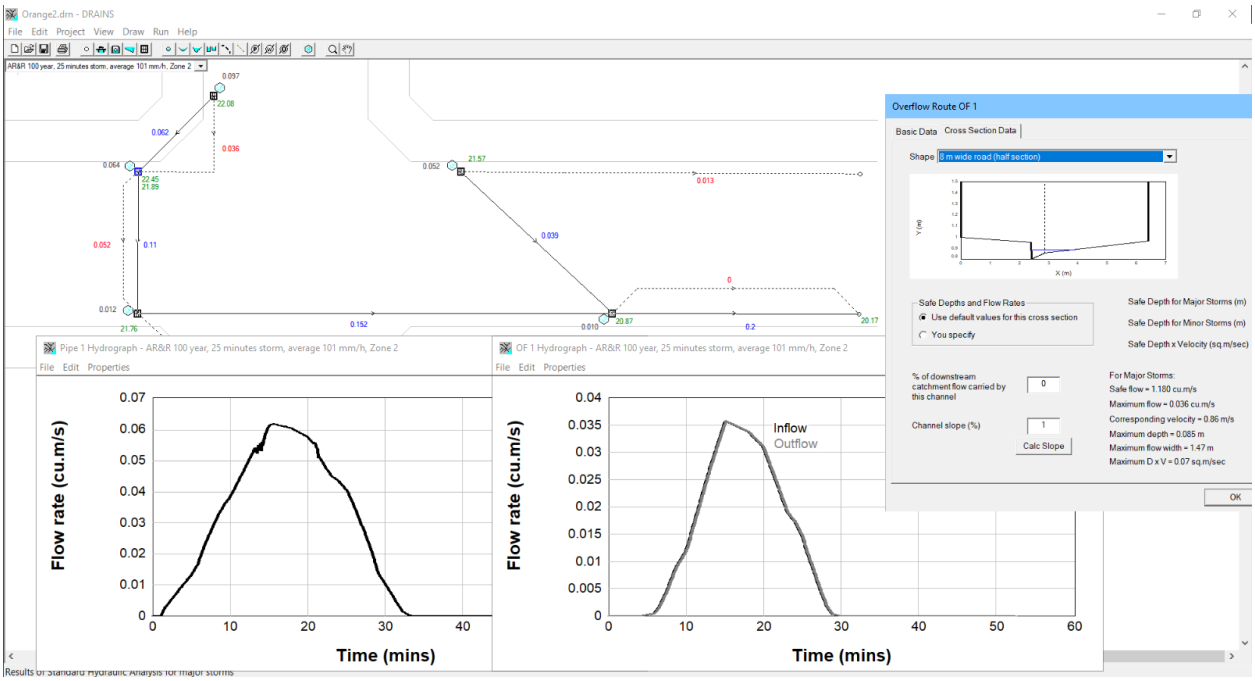


Figure 2.80 Analysis Run Results for a Major Storm

The flowrates are now larger and some overflows occurring. These can be inspected using the Cross Section Data page of the Overflow Route property sheet, as shown in Figure 2.81. With the standard hydraulic model, these characteristics are based on normal depth calculations. (The premium hydraulic model calculations apply a more rigorous and accurate unsteady flow analysis.)

The suitability of the overflows during minor or major storms can be assessed and the system enlarged if flow characteristics such as widths exceed acceptable limits.

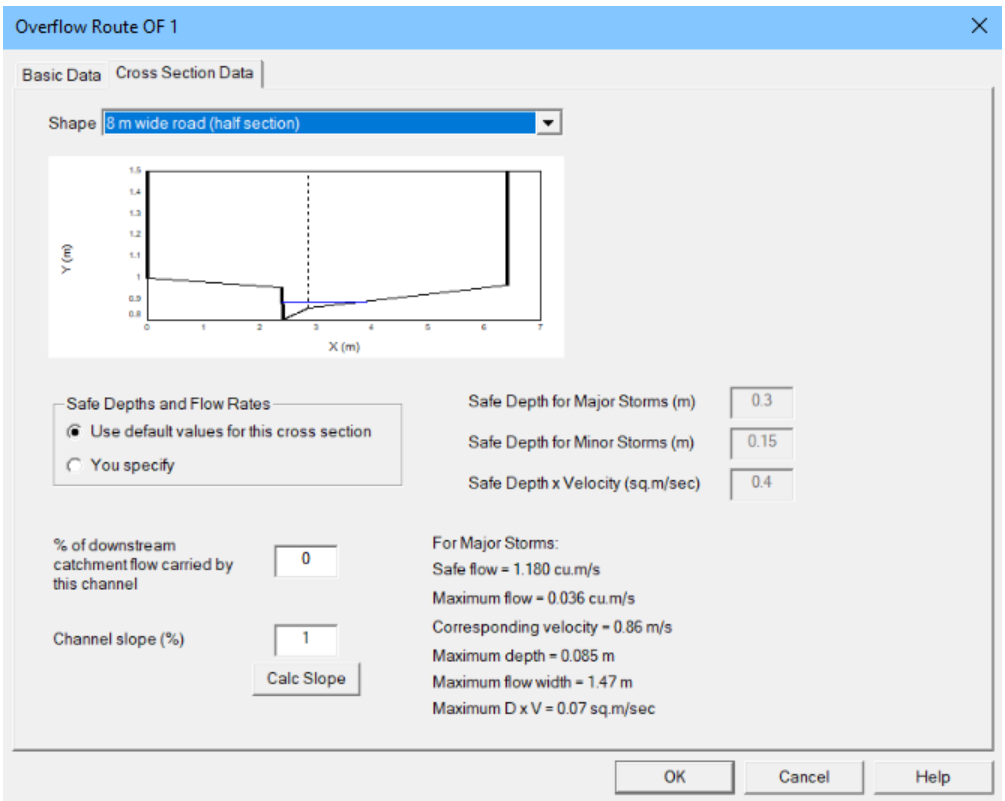
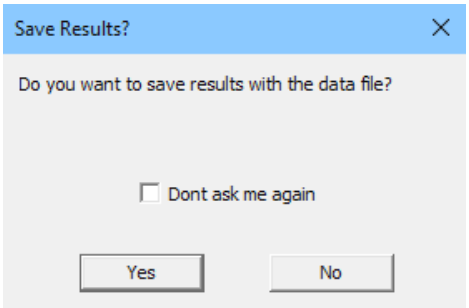


Figure 2.81 Overflow Route Property Sheet, showing Flow Characteristics

2.5.5 Saving Data and Results

This last step involves the storage of results. The input data are all stored in the DRAINS data file Orange2.drn and the numerical results (such as hydrographs and HGL graphs) can also be stored in this file, by responding to the prompt that appears when you save the file.



3. RATIONAL METHOD MODELS

3.1 General

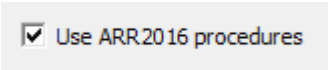
To illustrate rational method procedures, the same Orange system described in the previous chapter is modelled using rational method and extended rational method models in the file named Orange2 – Rational Method.drn. You can run this if your hardware lock is enabled to run the rational method, or if you are using the DEMO version.

Both the rational method and the ERM apply a method based on Chapter 14 of ARR 1987 and the Queensland Urban Drainage Manual (QUDM), whether they are using 2016 or 1987 I-F-D data. This is the only accepted version of the rational method in use in Australia for design of urban drainage systems.

3.2 Rational Method Calculations with 2016 I-F-D Data

3.2.1 Setting Common Specifications

You need to ensure that in the **Project** → **Options** property sheet, the box labelled **Use ARR2016 procedures** is ticked.



A DRAINS model applying the rational method can be created from scratch in the same way as the previous ILSAX model setup, but it is also possible to adapt the ILSAX model to run with rational method procedures, inserting a new rational method model. If you select **Project** → **Hydrological Models…**, the sheet shown in Figure 3.1 appears. You can use the **Add Rational Method Model** option to open the window shown in Figure 3.2.

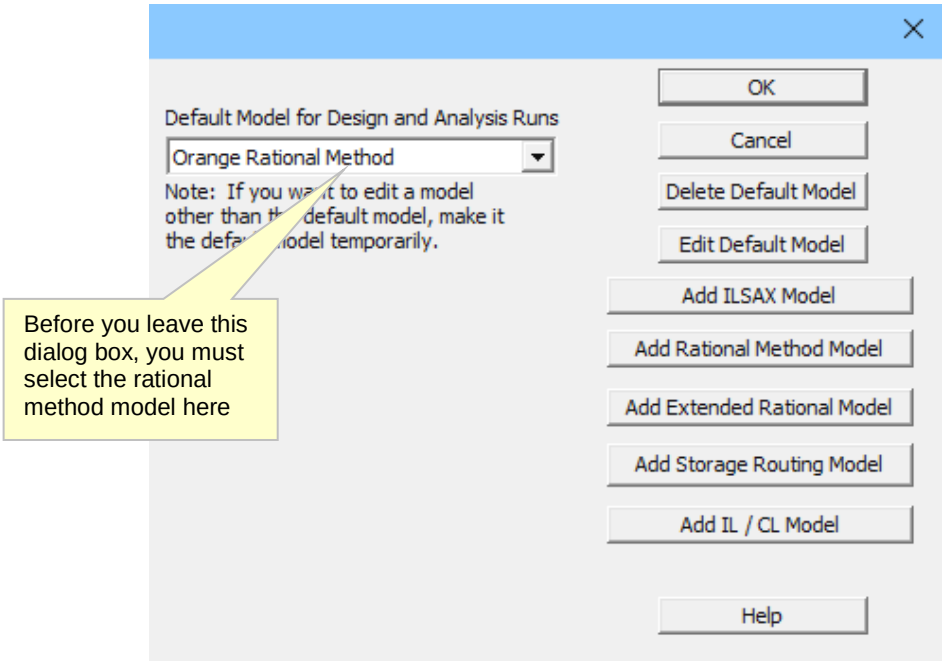


Figure 3.1 Hydrological Model Property Sheet for the Rational Method

There are three choices of type of rational method procedure to be used. The version from *Australian Rainfall and Runoff*, 1987 can be selected, as shown in Figure 3.2. (The other options are discussed in Section 5.3.6(c).)

The 10 year ARI (10% AEP) runoff coefficient C_{10} for the pervious area is set at 0.21, based on a 10% AEP, 1 hour rainfall intensity, ${}^{10\%}I_1$ of 33.2 mm/h entered into Equation 14.12 in *Australian Rainfall and Runoff*, 1987:

$$C_{10} = 0.1 + 0.0133 \times ({}^{10\%}I_1 - 25).$$

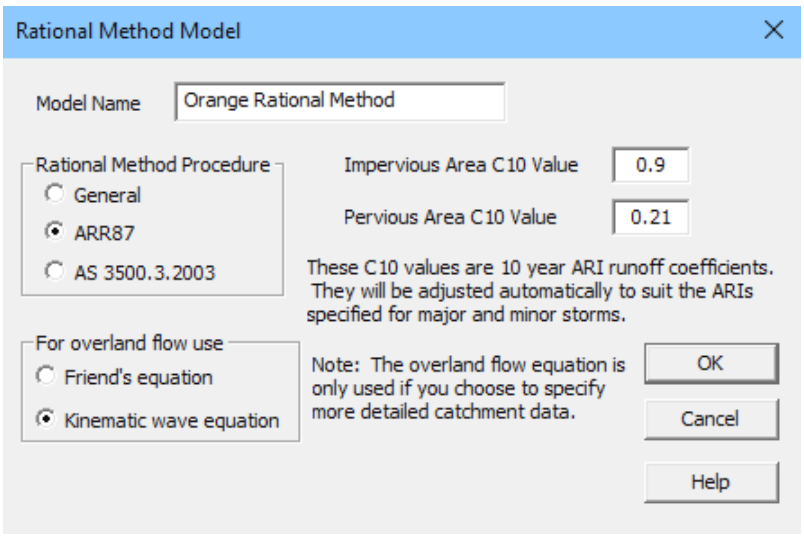


Figure 3.2 Rational Method Model Specification

You should also add options and select a suitable database, as described in Sections 2.2.3 to 2.2.5.

3.2.2 Adding System Components

If you are building a new model, you will also need to add system components, as described in Section 2.3. The only difference between the ILSAX and rational method inputs will be in the sub-catchment property sheets, which will appear as shown in Figure 3.3. The values to be entered are shown in Table 3.1.

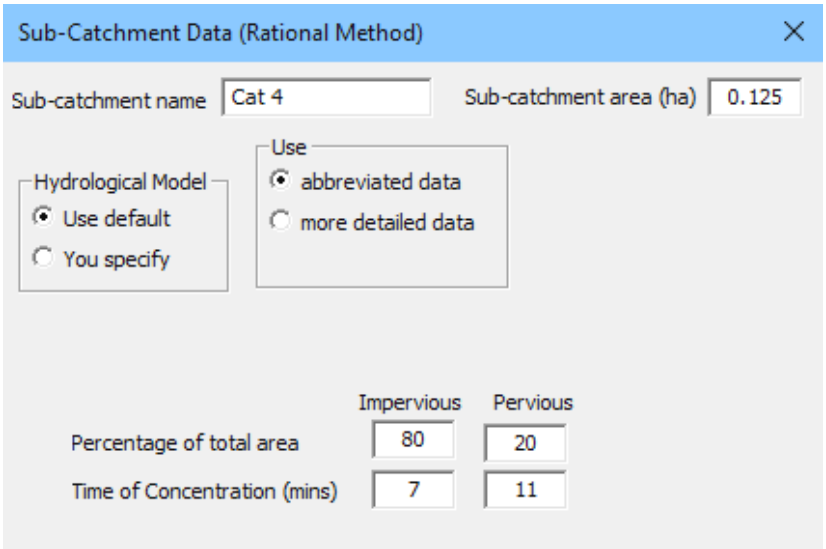


Figure 3.3 Rational Method Sub-Catchment Property Sheet (Upper Part)

Table 3.1 Rational Method Sub-Catchments

Name	Pit or Node	Total Area (ha)	Roofed (%)	Imperv-ious (%)	Pervious (%)	Imperv-ious t_c (mins.)	Pervious t_c (mins.)	Imperv-ious C_{10}	Pervious C_{10}
Cat 1	Pit 1	0.125	0	33	67	8	13	0.9	0.21
Cat 2	Pit 2	0.231	0	38	62	9	15	0.9	0.21
Cat 3	Pit 4	0.025	0	90	10	3	4	0.9	0.21
Cat 5	Pit 5	0.02	0	90	10	2	3	0.9	0.21
Cat 4	Pit 4	0.35	0	80	20	9	15	0.9	0.21

If you are adapting an ILSAX model, the areas and times of concentration will be adjusted automatically. Paved and supplementary area percentages will become impervious area percentages.

3.2.3 Obtaining and Inputting I-F-D Rainfall Data

The selection of a rational method hydrological model acts as a switch that affects other parts of the program. When the **Rainfall Data…** option is selected in the **Project** menu, the property sheet that appears, shown in Figure 3.4. Instead of a number of rainfall patterns, you only need to insert an I-F-D relationship. In the property sheet, you will need to nominate minor and major annual exceedance probabilities (AEPs).

Figure 3.4 2016 Rainfall Data for the Rational Method

To enter data into this, you will first need to obtain .csv (comma-separated variable) files containing I-F-D depths from the Bureau of Meteorology (BOM) website, following the procedure outlined in the latter part of Section 2.4.2. For convenience, this is reproduced below. You will need to find the latitude and longitude of the site using Google Maps, the ARR Data Hub, or a similar source.

You will then need to open the BOM website at www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016, and enter the latitude and longitude, as shown in Figure 3.5. Also enter a name and click the two acknowledgement boxes. Then click on the **Submit** button.

The window that appears in Figure 3.6 contains a table of rainfall depths for various AEPs and durations. Is likely that you will want to add additional durations – 20, 25, 45, 90 and 270 minutes for urban drainage systems, and perhaps 540, 1080, 1800 and 2160 minutes for large catchments. To do this, enter times in the **Non-Standard Durations** boxes to the left of the window, as shown in Figure 3.7.

You can then use the **Download as CSV** icon above the map to download and save a second I-F-D file, which can be named Orange - Very_frequent_table.csv. This will contain the 0.5 EY and 0.2 EY rainfall depths, equivalent to the 2 and 5 year ARI storms.

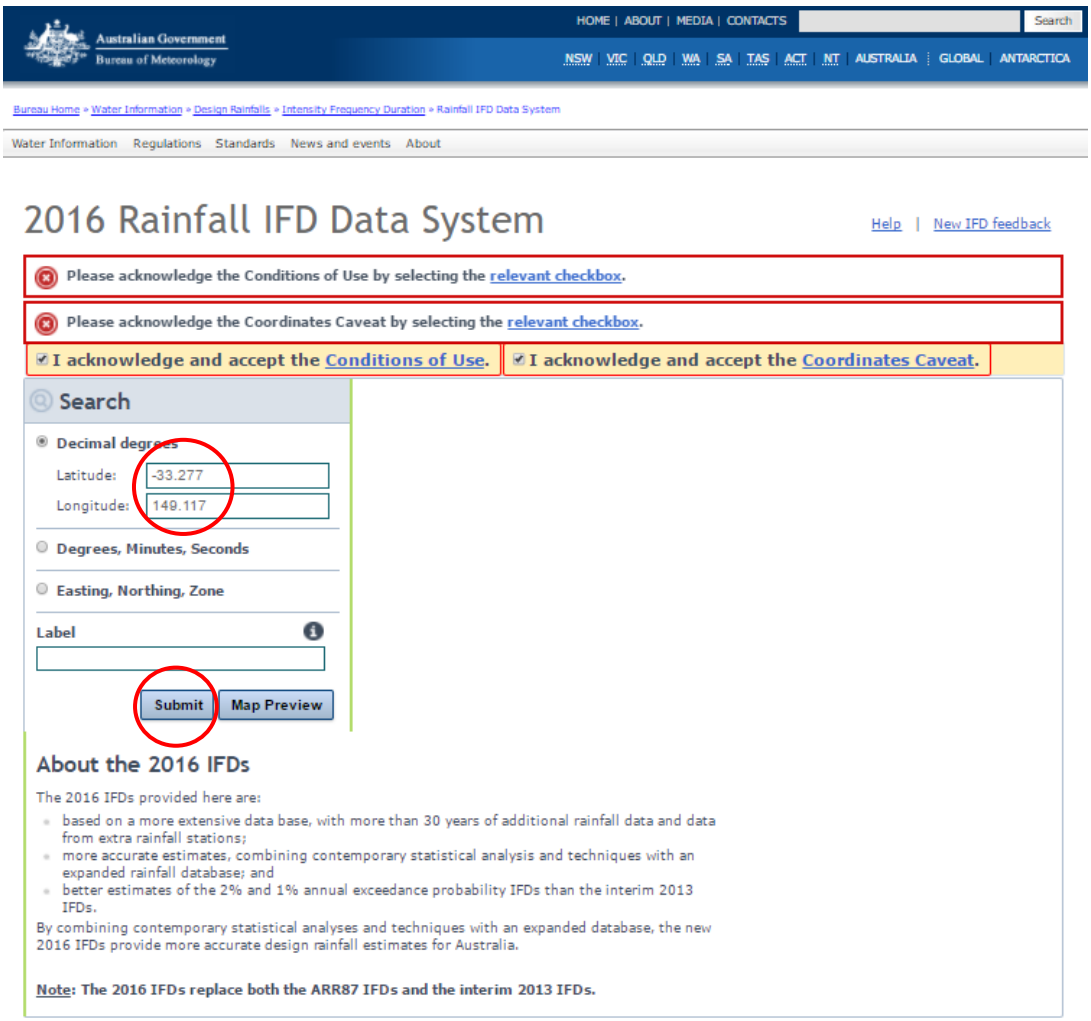


Figure 3.5 BOM 2016 I-F-D Page

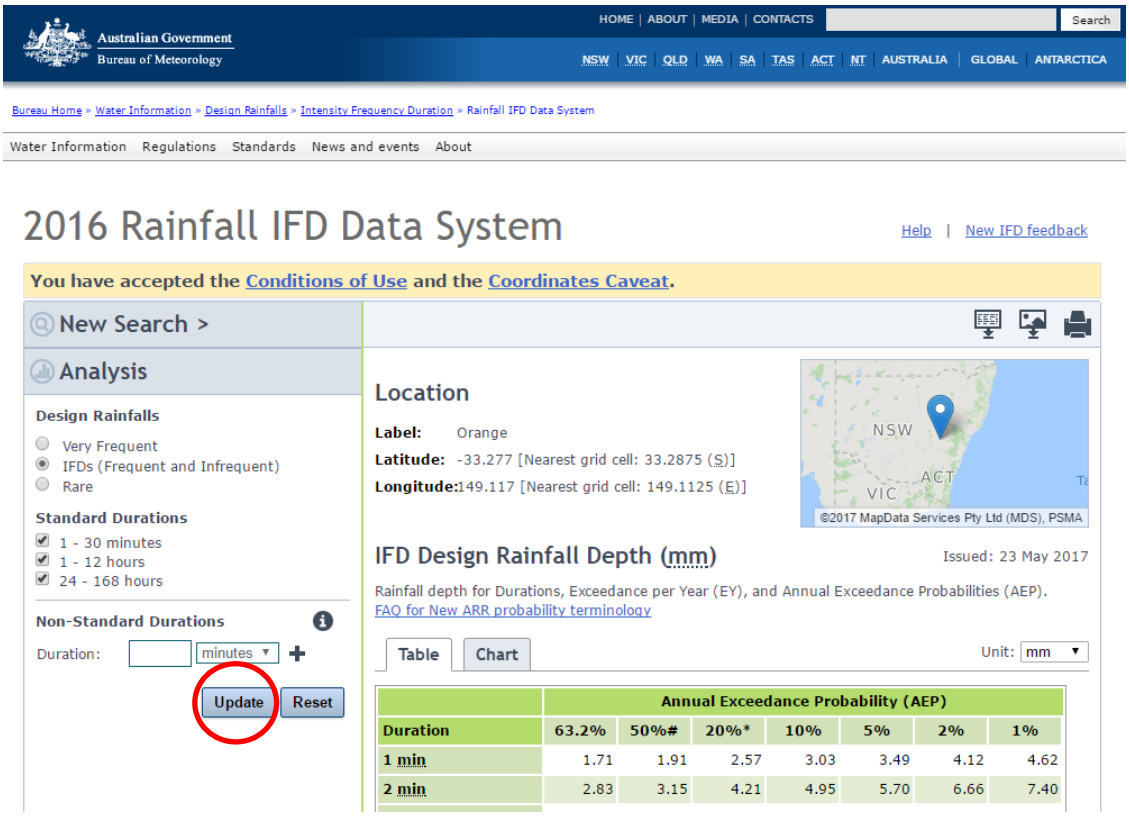


Figure 3.6 BOM 2016 I-F-D Data Page

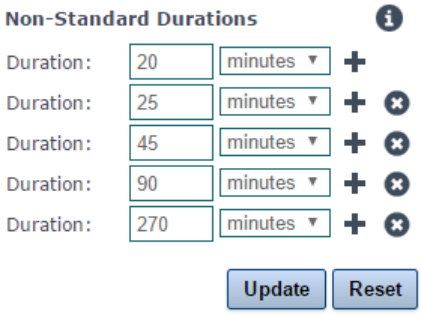
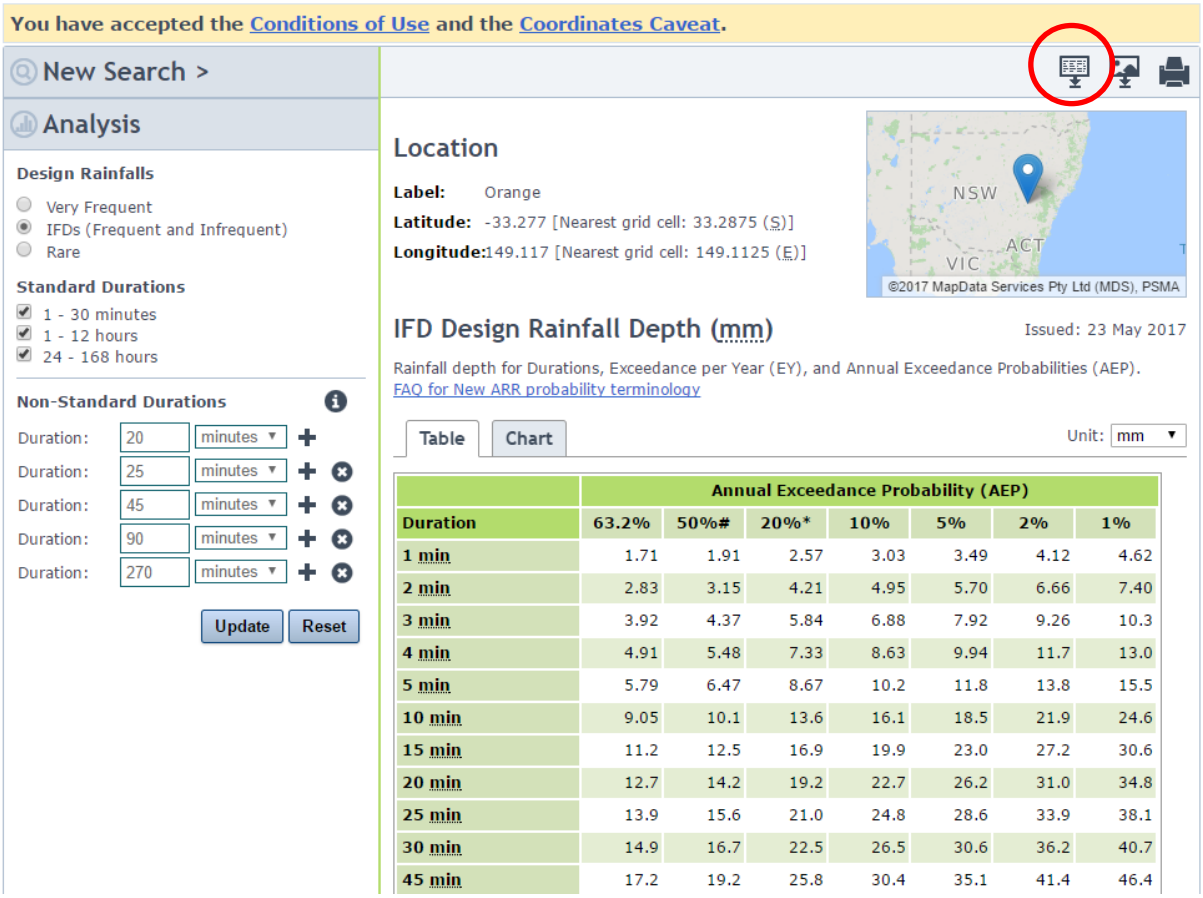


Figure 3.7 Additional Durations

Clicking the Update button will add depths for these durations to the Table, as shown in Figure 3.8.

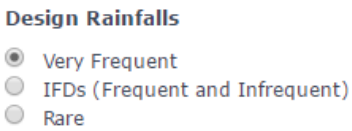


	Annual Exceedance Probability (AEP)						
Duration	63.2%	50%#	20%*	10%	5%	2%	1%
1 min	1.71	1.91	2.57	3.03	3.49	4.12	4.62
2 min	2.83	3.15	4.21	4.95	5.70	6.66	7.40
3 min	3.92	4.37	5.84	6.88	7.92	9.26	10.3
4 min	4.91	5.48	7.33	8.63	9.94	11.7	13.0
5 min	5.79	6.47	8.67	10.2	11.8	13.8	15.5
10 min	9.05	10.1	13.6	16.1	18.5	21.9	24.6
15 min	11.2	12.5	16.9	19.9	23.0	27.2	30.6
20 min	12.7	14.2	19.2	22.7	26.2	31.0	34.8
25 min	13.9	15.6	21.0	24.8	28.6	33.9	38.1
30 min	14.9	16.7	22.5	26.5	30.6	36.2	40.7
45 min	17.2	19.2	25.8	30.4	35.1	41.4	46.4

Figure 3.8 BOM 2016 I-F-D Data Page with Added Durations

Now click on the first symbol above the map, which will open a Save As window (Figure 3.9) that you can use to save a .csv file to your project folder. Add the location name to the filename.

This will give you rainfall depths for the AEPs shown, from 1 exceedance per year (1 EY), equivalent to 63.2% AEP, through to 1% AEP. If you wish to use older frequencies such as 2 year and 5 year average recurrence interval (ARI), you can go to the panel at the top left, and click the box for **Very Frequent**, and the click on **Update**.



The screen will change, and new frequencies will appear, as shown in Figure 3.10.

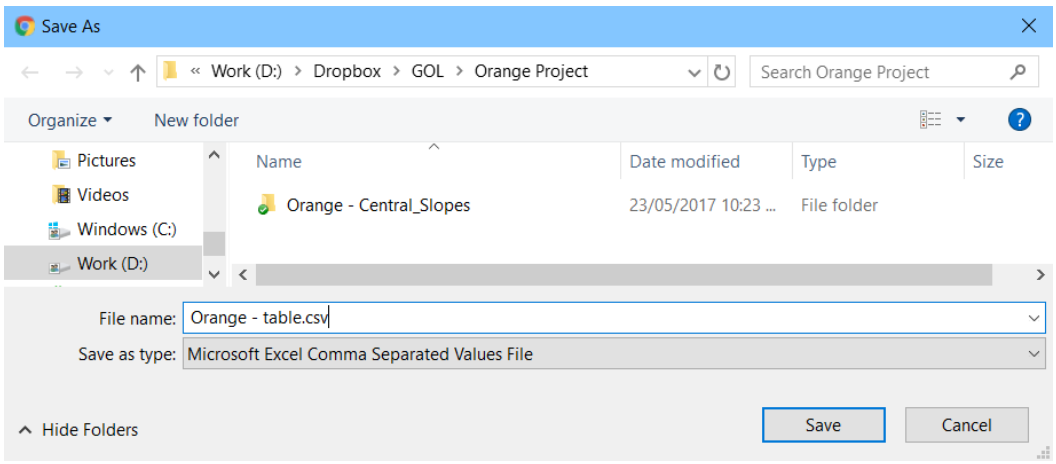


Figure 3.9 Saving BOM 2016 I-F-D Data File

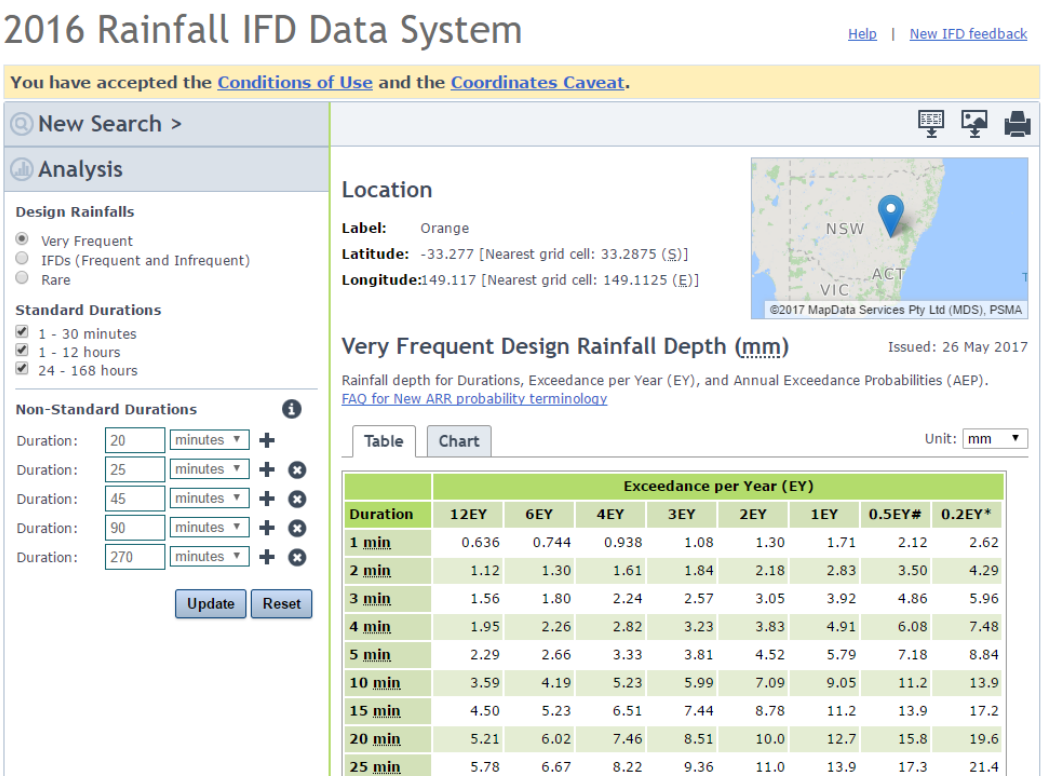


Figure 3.10 BOM 2016 I-F-D Data Page for Very Frequent Rainfalls

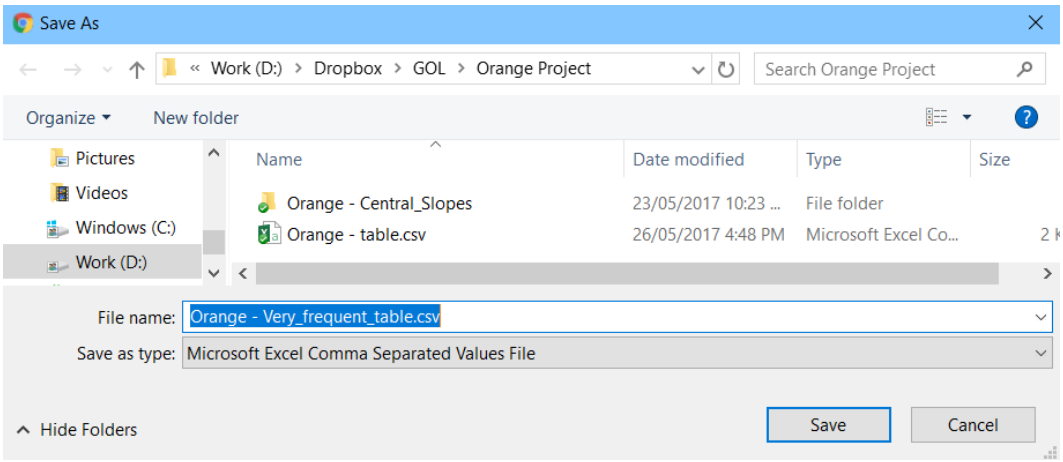


Figure 3.11 Saving Second BOM 2016 I-F-D Data File

After doing this, return to DRAINS and click on the **Import BOM Data** button in Figure 3.4

The window shown in Figure 3.12 will appear, asking you to nominate a .csv file containing the data, here named Orange – table,csv. When this is selected, it should ask you to select a second file, Orange – Very_frequent_table.csv. Once this is entered, the Rational Method Model property sheet should appear as shown in Figure 3.13.

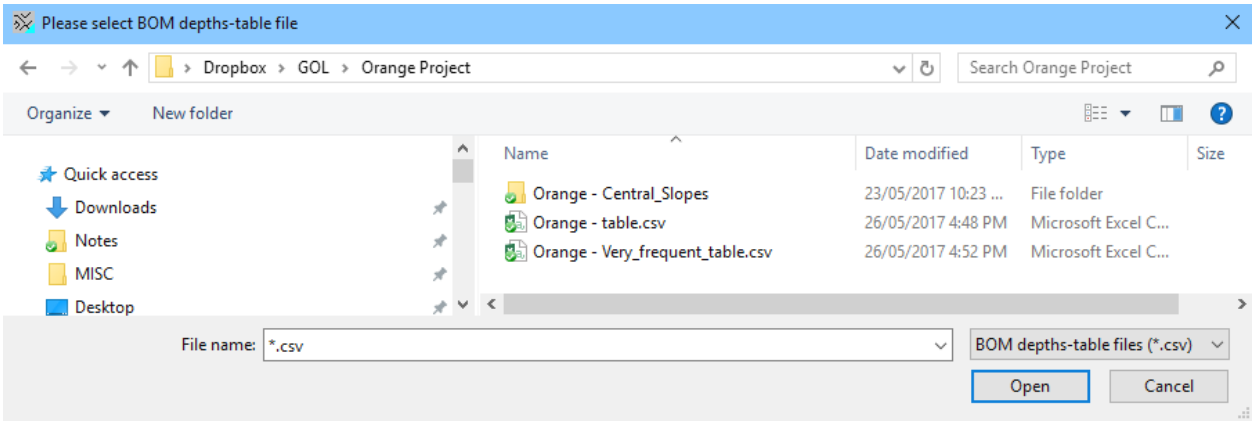


Figure 3.12 Inputting 2016 I-F-D Relationships

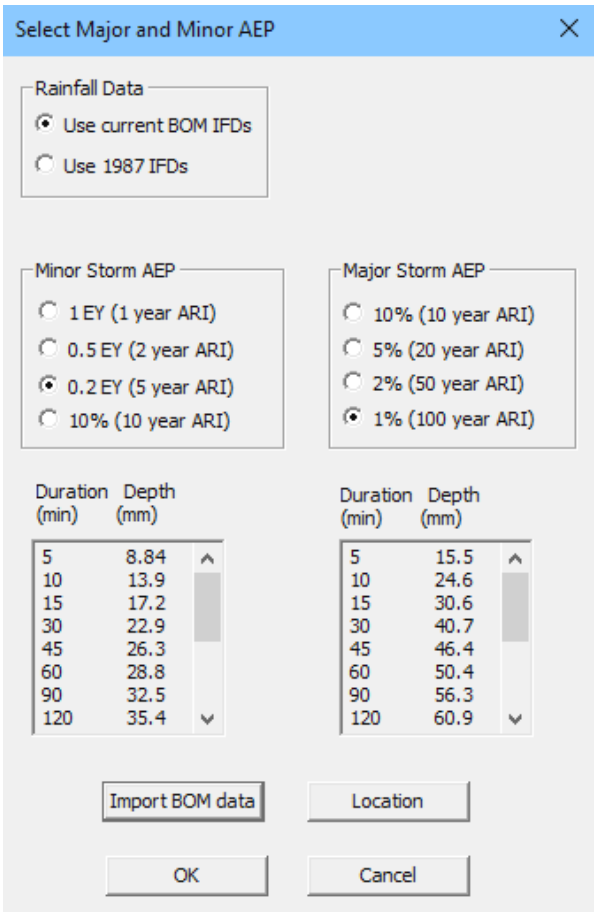


Figure 3.13 Inputted 2016 Rainfall Data for the Rational Method

It was necessary to import two .csv files because a 0.2 EY Minor Storm AEP was specified in Figure 3.4. This is equivalent to a 5 year average recurrence interval (ARI) which is not included in the first I-F-D .csv file provided by the Bureau of Meteorology. If you had clicked 2% or 5% AEP for the minor storm AEP, only one .csv file would have been required.

3.2.4 Running the Model and Examining Results

The major/minor system is usually employed in Australian drainage design. Pipes are sized to carry flows of a minor ARI, usually 5 or 10 years, and a check is made to ensure the safe working of the system during a major storm event, with an ARI of 50 or 100 years.

The pipe design is performed on the basis of the allowable flow along the overflow route. The method determines this flowrate, taking into account the flows from of the sub-catchment immediately downstream of each pit. It then works backwards to define a set of pit inlets and pipe sizes that will limit overland flows to safe levels in both minor and major storms. Safety requirements are defined in terms of flow depths and velocity-depth products in the Overflow Route Data Base, as shown in Figure 2.19.

You can run the program in Design mode from the **Run** menu, shown in Figure 3.14.

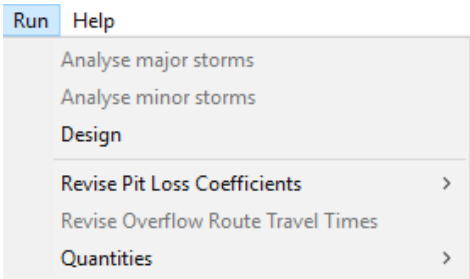
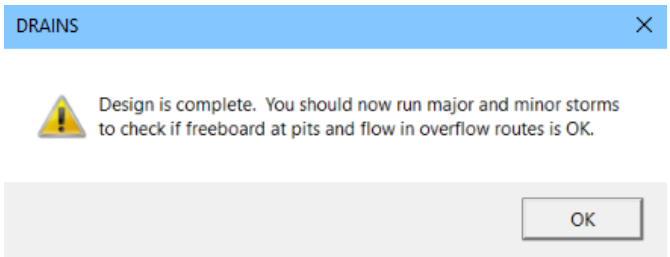


Figure 3.14 Run Options

After a Design run, the message shown below appears, advising that the process is complete and that you should run an analysis with minor or major storms to assess the results.



You can do this by choosing the **Analyse minor storms** and **Analyse major storms** options. The standard hydraulic model is available in all DRAINS model. The optional, premium model requires more detailed information on overflow routes, in order to model them with unsteady flow hydraulics.

When performing an Analysis, DRAINS automatically works with multi-core processing when running with ARR 2016 ensembles. Results of an analysis using minor storm ensembles are shown in Figure 3.15. Only peak flowrates and HGL levels are given. No hydrographs are generated.

After you close this window you will see that the names of components have changed to coloured numbers as follows:

- the **black** numbers are the maximum flowrates from the sub-catchments, in m^3/s,
- the **blue** numbers are the calculated peak flowrates in each pipe, in m^3/s,
- the **red** numbers are the peak overflows from pits, in m^3/s, in the standard hydraulics model, or the flowrates at the centre of an overflow path in the premium hydraulic model (not including any flows from the downstream sub-catchment),
- the **green** numbers are the highest levels reached by the hydraulic grade lines (HGLs) throughout the pipe system, in m elevation, defining the highest water levels during the minor storm event considered. (At sag pits, the highest surface ponding level is also shown.)

More detailed options for reviewing outputs can be accessed by right clicking on each object and opening a pop-up menu that lists output options, as shown in Figure 3.16.

Results from a major system run are shown in Figure 3.17.

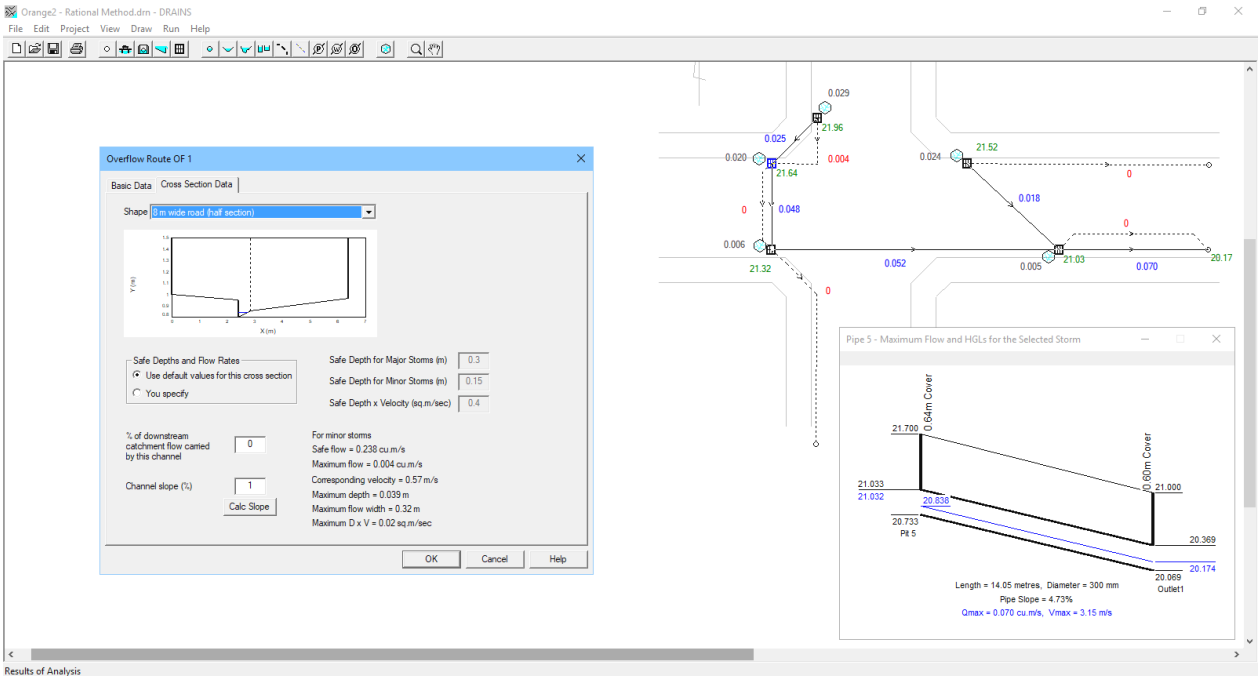
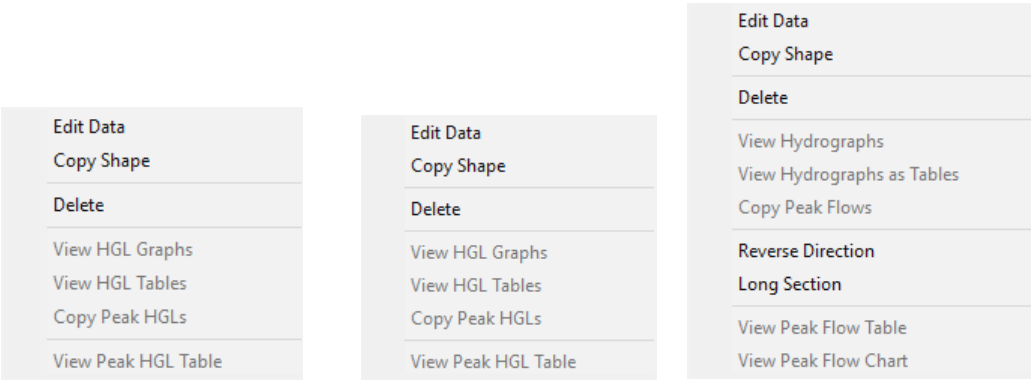


Figure 3.15 Results of a Minor Storm Analysis following a Design Run



Sub-Catchment Pit Pipe

Figure 3.16 Examples of Display Options in Pop-Up Menus

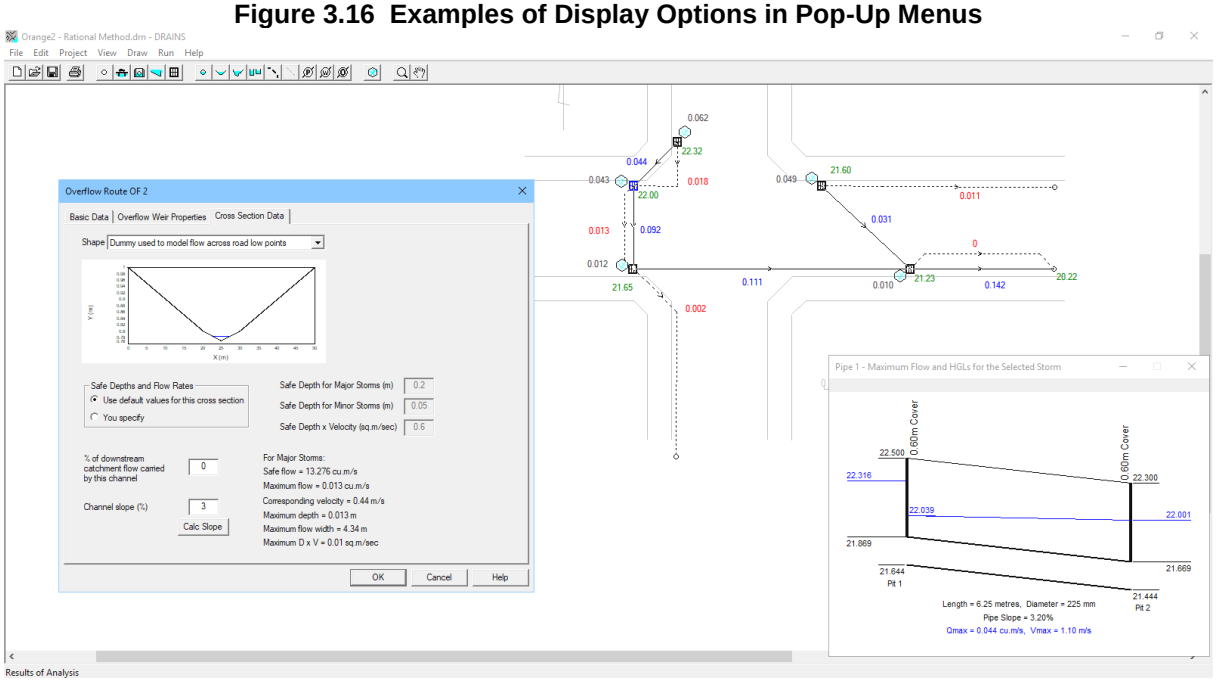


Figure 3.17 Results of a Major Storm Analysis following a Design Run

The suitability of the overflows during minor or major storms can be assessed as shown in Figure 3.18, and the system enlarged if flow characteristics such as widths exceed acceptable limits.

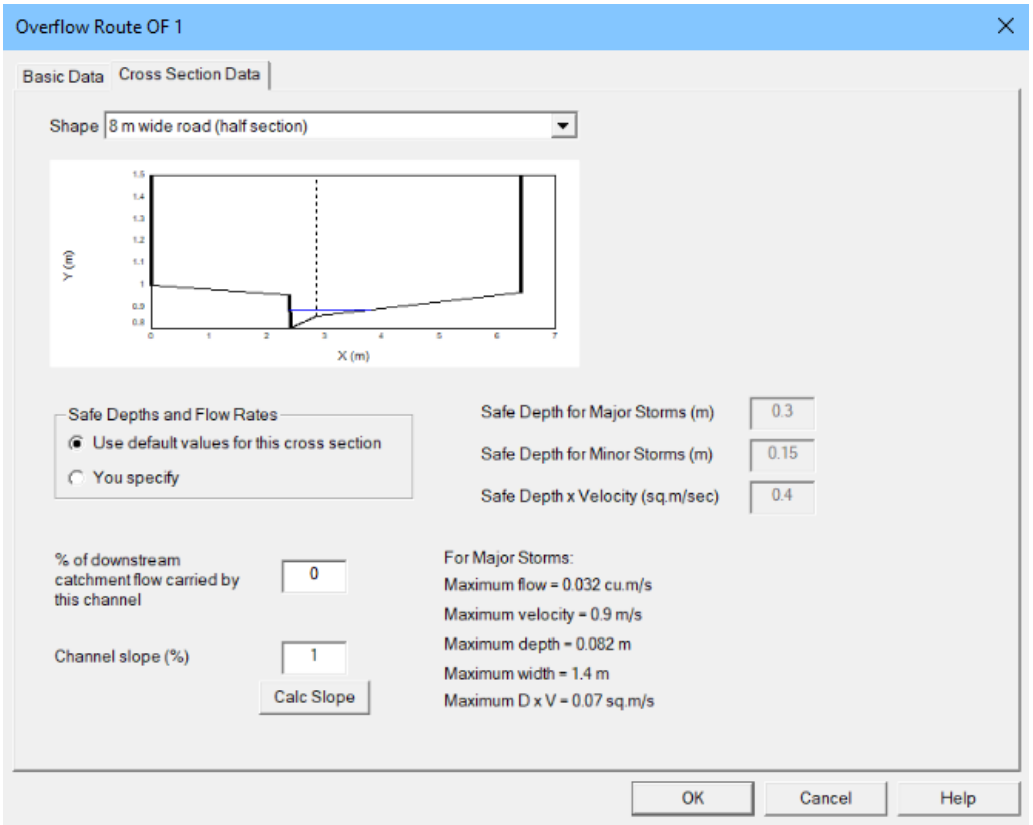


Figure 3.18 Overflow Route Property Sheet, showing Flow Characteristics

3.2.5 Reviewing Results

There is less to review with the rational method than with alternative, hydrograph methods, as no hydrographs are generated. However, peak flowrates and HGL levels can be assessed. You can inspect the designed system and check the pipe inverts and sizes determined by DRAINS.

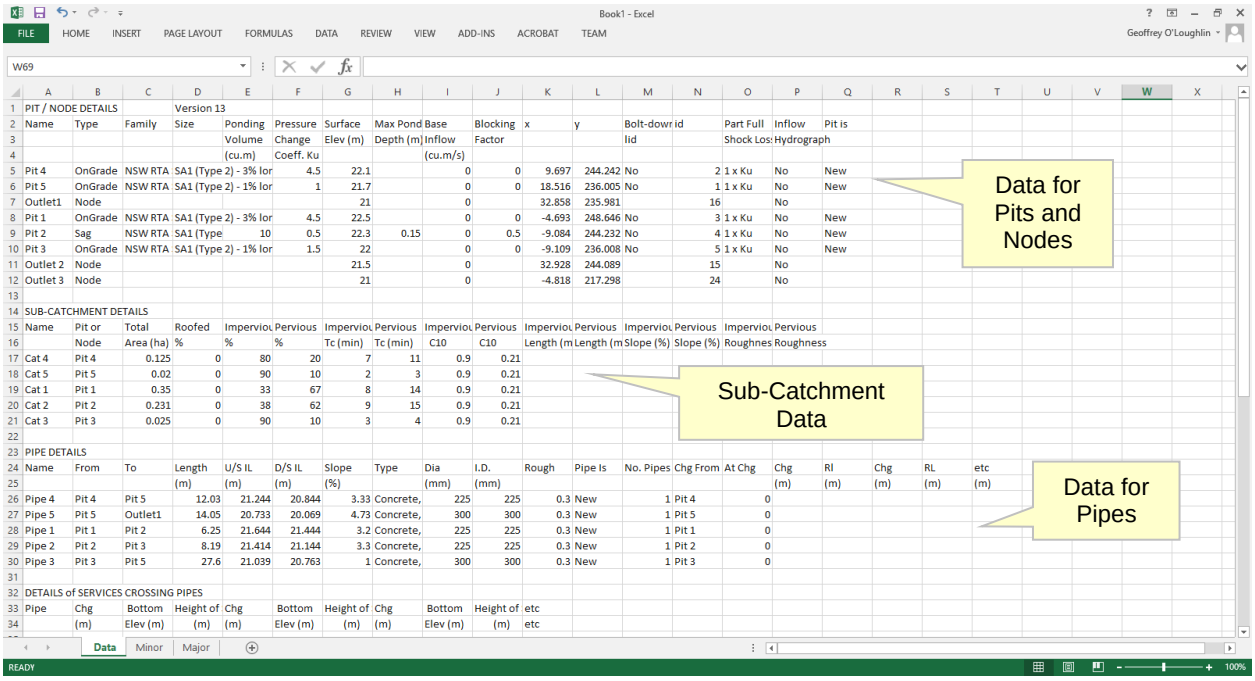
There are a number of ways of doing this, the most comprehensive being the transfer of information to a spreadsheet using options within the **Edit** menu. The data spreadsheet for the Orange2 - Rational Method.drn model is shown in Figure 3.19.

Results of particular runs of DRAINS can also be exported to worksheets using the **Edit** menu, as shown in Figure 3.20. These can be, for example, minor and major storm results from design procedures.

3.2.6 Saving Data and Results

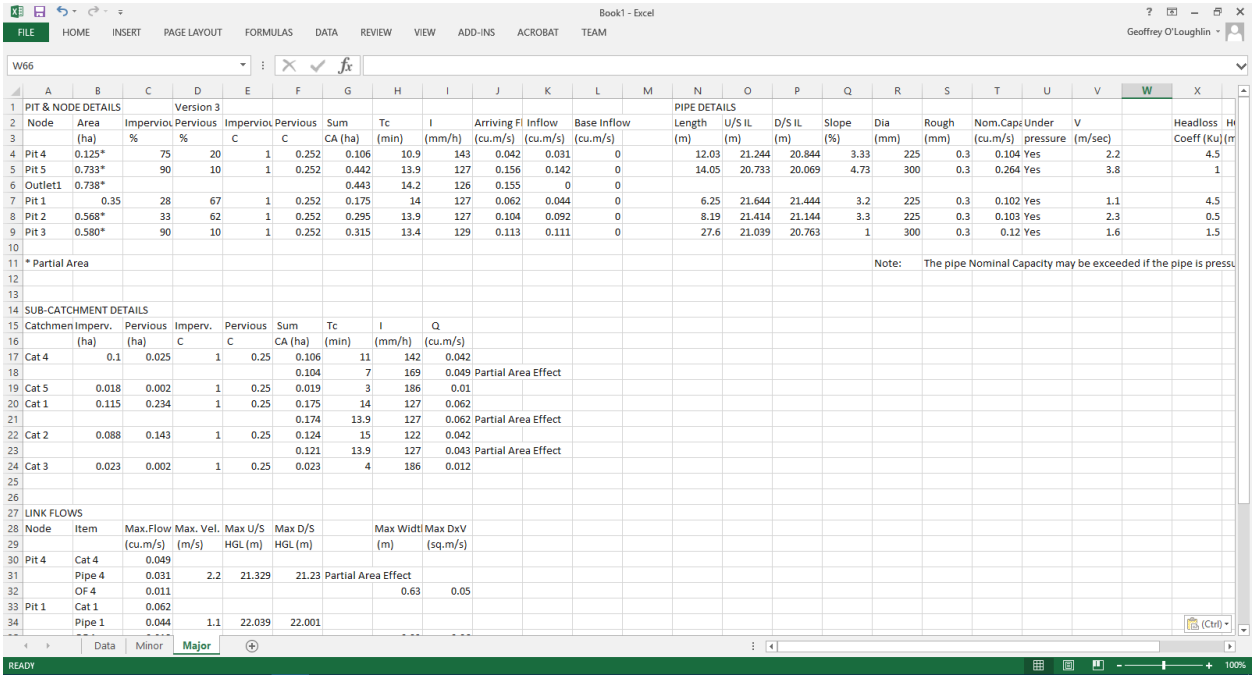
This last step involves the storage of results. The input data is all stored in the DRAINS data file Orange2.drn. There is plenty of opportunity to make comments, in the spaces provided in the property sheets for individual components, and in a **Description …** option in the **Project** menu.

The spreadsheet results can also be stored, and, as is detailed in Chapter 3, it is also possible to transfer the results via a DXF file to drawing programs that can print plans and longitudinal cross-sections of pipe systems.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PIT / NODE DETAILS			Version 13													
2	Name	Type	Family	Size	Ponding	Pressure	Surface	Max Pond	Base	Blocking	x	y	Bolt-down	id	Part Full	Inflow	Pit is
3					Volume	Change	Elev (m)	Depth (m)	Inflow	Factor			lid		Shock Los	Hydrograph	
4					(cu.m)	Coeff. Ku			(cu.m/s)								
5	Pit 4	OnGrade	NSW RTA	SA1 (Type 2) - 3% lor		4.5	22.1		0	0	9.697	244.242	No	2	1 x Ku	No	New
6	Pit 5	OnGrade	NSW RTA	SA1 (Type 2) - 1% lor		1	21.7		0	0	18.516	236.005	No	1	1 x Ku	No	New
7	Outlet1	Node					21		0		32.858	235.981		16		No	
8	Pit 1	OnGrade	NSW RTA	SA1 (Type 2) - 3% lor		4.5	22.5		0	0	-4.693	248.646	No	3	1 x Ku	No	New
9	Pit 2	Sag	NSW RTA	SA1 (Type	10	0.5	22.3	0.15	0	0.5	-9.084	244.232	No	4	1 x Ku	No	New
10	Pit 3	OnGrade	NSW RTA	SA1 (Type 2) - 1% lor		1.5	22		0	0	-9.109	236.008	No	5	1 x Ku	No	New
11	Outlet 2	Node					21.5		0		32.928	244.089		15		No	
12	Outlet 3	Node					21		0		-4.818	217.298		24		No	
13																	
14	SUB-CATCHMENT DETAILS																
15	Name	Pit or	Total	Roofed	Impervio	Pervious	Impervio	Pervious	Impervio	Pervious	Impervio	Pervious	Impervio	Pervious	Impervio	Pervious	
16		Node	Area (ha)	%	%	%	Tc (min)	Tc (min)	C10	C10	Length (m	Length (m	Slope (%)	Slope (%)	Roughnes	Roughness	
17	Cat 4	Pit 4	0.125	0	80	20	7	11	0.9	0.21							
18	Cat 5	Pit 5	0.02	0	90	10	2	3	0.9	0.21							
19	Cat 1	Pit 1	0.35	0	33	67	8	14	0.9	0.21							
20	Cat 2	Pit 2	0.231	0	38	62	9	15	0.9	0.21							
21	Cat 3	Pit 3	0.025	0	90	10	3	4	0.9	0.21							
22																	
23	PIPE DETAILS																
24	Name	From	To	Length	U/S IL	D/S IL	Slope	Type	Dia	I.D.	Rough	Pipe Is	No. Pipes	Chg From	At Chg	Chg	Rl
25				(m)	(m)	(m)	(%)		(mm)	(mm)						(m)	(m)
26	Pipe 4	Pit 4	Pit 5	12.03	21.244	20.844	3.33	Concrete,	225	225	0.3	New	1	Pit 4	0		
27	Pipe 5	Pit 5	Outlet1	14.05	20.733	20.069	4.73	Concrete,	300	300	0.3	New	1	Pit 5	0		
28	Pipe 1	Pit 1	Pit 2	6.25	21.644	21.444	3.2	Concrete,	225	225	0.3	New	1	Pit 1	0		
29	Pipe 2	Pit 2	Pit 3	8.19	21.414	21.144	3.3	Concrete,	225	225	0.3	New	1	Pit 2	0		
30	Pipe 3	Pit 3	Pit 5	27.6	21.039	20.763	1	Concrete,	300	300	0.3	New	1	Pit 3	0		
31																	
32	DETAILS of SERVICES CROSSING PIPES																
33	Pipe	Chg	Bottom	Height of	Chg	Bottom	Height of	Chg	Bottom	Height of	etc						
34		(m)	Elev (m)	(m)	(m)	Elev (m)	(m)	(m)	Elev (m)	(m)	etc						

Figure 3.19 Spreadsheet Output for Data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PIT & NODE DETAILS			Version 3										PIPE DETAILS			
2	Node	Area	Impervio	Pervious	Impervio	Pervious	Sum	Tc	I	Arriving F	Inflow	Base Inflow		Length	U/S IL	D/S IL	Slope
3		(ha)	%	%	C	C	CA (ha)	(min)	(mm/h)	(cu.m/s)	(cu.m/s)	(cu.m/s)		(m)	(m)	(m)	(%)
4	Pit 4	0.125*	75	20	1	0.252	0.106	10.9	143	0.042	0.031	0		12.03	21.244	20.844	3.33
5	Pit 5	0.733*	90	10	1	0.252	0.442	13.9	127	0.156	0.142	0		14.05	20.733	20.069	4.73
6	Outlet1	0.738*					0.443	14.2	126	0.155	0	0					
7	Pit 1	0.35	28	67	1	0.252	0.175	14	127	0.062	0.044	0		6.25	21.644	21.444	3.2
8	Pit 2	0.568*	33	62	1	0.252	0.295	13.9	127	0.104	0.092	0		8.19	21.414	21.144	3.3
9	Pit 3	0.580*	90	10	1	0.252	0.315	13.4	129	0.113	0.111	0		27.6	21.039	20.763	1
10																	
11	* Partial Area																
12																	
13																	
14	SUB-CATCHMENT DETAILS																
15	Catchmen	Imperv.	Pervious	Imperv.	Pervious	Sum	Tc	I	Q								
16		(ha)	(ha)	C	C	CA (ha)	(min)	(mm/h)	(cu.m/s)								
17	Cat 4	0.1	0.025	1	0.25	0.106	11	142	0.042								
18						0.104	7	169	0.049	Partial Area Effect							
19	Cat 5	0.018	0.002	1	0.25	0.019	3	186	0.01								
20	Cat 1	0.115	0.234	1	0.25	0.175	14	127	0.062								
21						0.174	13.9	127	0.062	Partial Area Effect							
22	Cat 2	0.088	0.143	1	0.25	0.124	15	122	0.042								
23						0.121	13.9	127	0.043	Partial Area Effect							
24	Cat 3	0.023	0.002	1	0.25	0.023	4	186	0.012								
25																	
26																	
27	LINK FLOWS																
28	Node	Item	Max.Flow	Max. Vel.	Max U/S	Max D/S		Max Widt	Max DxV								
29			(cu.m/s)	(m/s)	HGL (m)	HGL (m)		(m)	(sq.m/s)								
30	Pit 4	Cat 4	0.049														
31		Pipe 4	0.031	2.2	21.329	21.23	Partial Area Effect										
32		OF 4	0.011					0.63	0.05								
33	Pit 1	Cat 1	0.062														
34		Pipe 1	0.044	1.1	22.039	22.001											

	R	S	T	U	V	W	X
1							
2	Dia	Rough	Nom.Capa	Under	V		Headloss
3	(mm)	(mm)	(cu.m/s)	pressure	(m/sec)		Coeff (Ku)
4	225	0.3	0.104	Yes	2.2		4.5
5	300	0.3	0.264	Yes	3.8		1
6							
7	225	0.3	0.102	Yes	1.1		4.5
8	225	0.3	0.103	Yes	2.3		0.5
9	300	0.3	0.12	Yes	1.6		1.5
10							
11	Note:	The pipe Nominal Capacity may be exceeded if the pipe is pressu					

Figure 3.20 Spreadsheet Output for Major Storm Results

3.3 Rational Method Calculations with 1987 I-F-D Data

3.3.1 Setting Common Specifications

The specification of hydrological model, options, description and pit, pipe and overflow route data bases is carried out in the same way as for the 2016 rainfall data, described in the previous section of this chapter. The differences associated with running with 1987 data are presented in this section. The hydrological model property sheet is shown below.

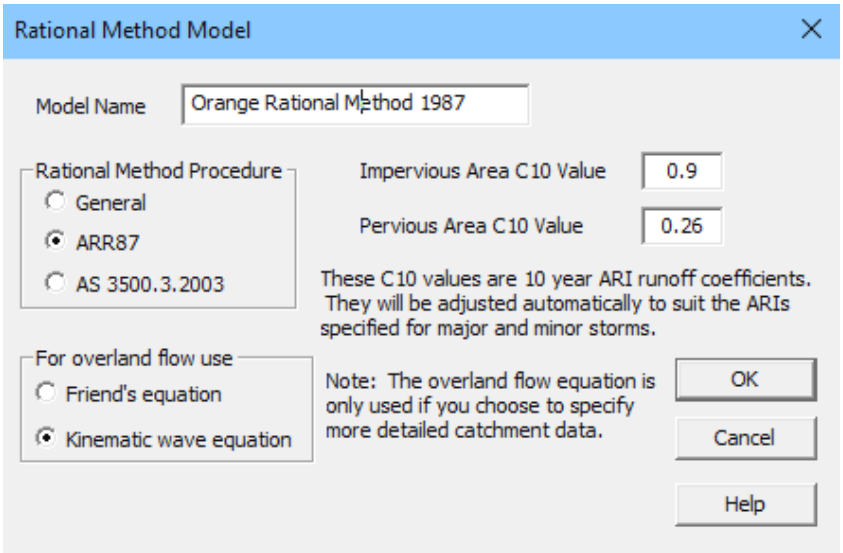


Figure 3.21 Raiional Method Hydrological Model for 1987 Data

At Orange the 10 year ARI (10% AEP) runoff coefficient C_{10} for the pervious area is set at 0.26, based on a 10 year ARI, 1 hour rainfall intensity, ${}^{10}I_1$ of 36.8 mm/h entered into Equation 14.12 in *Australian Rainfall and Runoff*, 1987:

$$C_{10} = 0.1 + 0.0133 \times ({}^{10}I_1 - 25).$$

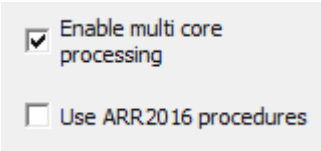
Both the rainfall intensity and the C_{10} value are higher than for the 2016 data. This reflects the rainfall records and analysis techniques that were available in 1987 and 2016. The 2016 I-F-D estimates are based on a considerably larger set of records than the 1987 data, and should be used for all new work. The 1987 procedure is presented here for use on work-in-progress and comparisons of designs based on 1987 and 2016 I-F-D relationships.

3.3.2 Defining System Components

This can be done by the process described in Section 2.3, with the only difference being the entry of data for sub-catchments, which will appear as shown in Figure 3.22. The data that needs to be entered is shown in Table 3.2. The pervious area C_{10} value of 0.25 is larger than that for the 2016 rational method calculations, as the 1987 rainfall intensities are higher, and C_{10} values are linked to these.

3.3.3 Rainfall Inputs

In the **Project** → **Options** property sheet, the **Use ARR2016 procedures** box should be unticked.



In the **Rainfall Data…** option selected from the **Project** menu, you should click the **Use 1987 IFDs** option. The property sheet that appears is shown in Figure 3.23.

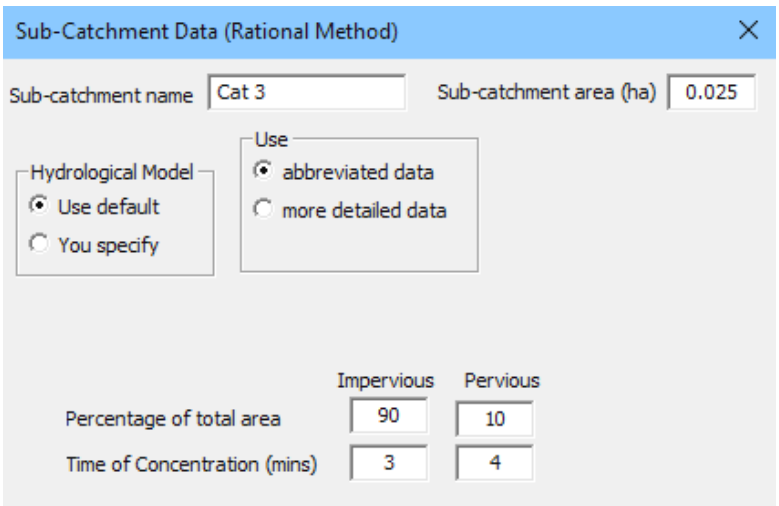


Figure 3.22 Sub-Catchment Data Property Sheet with Rational Method (Top Portion)

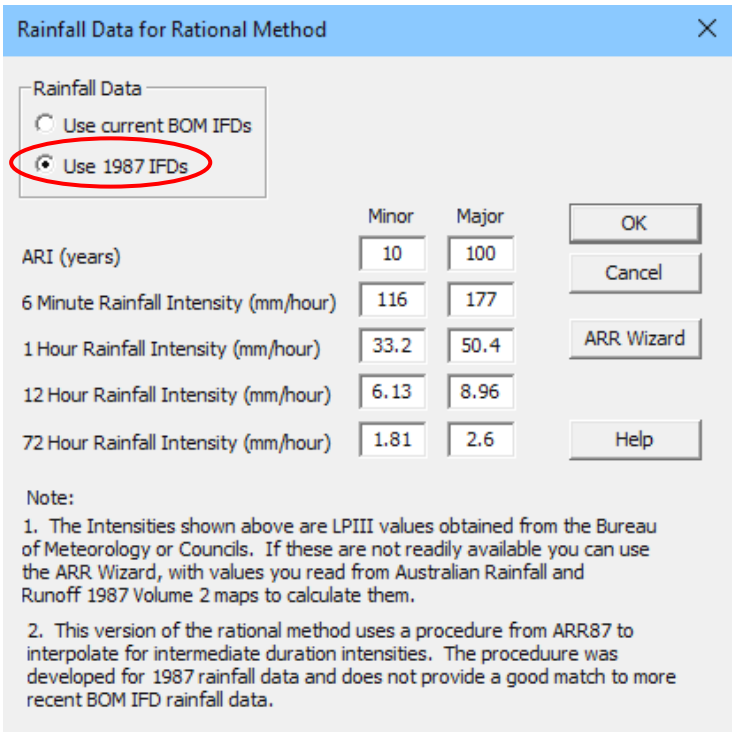


Figure 3.23 The 'Rainfall Data for Rational Method' Property Sheet

Into this sheet you can enter the minor and major ARIs you require and the corresponding design rainfall intensities for durations of 6 minutes, 1 hour, 12 hours and 72 hours. This information is available from the Bureau of Meteorology's website www.bom.gov.au/water/designRainfalls/ifd-arr87/index.shtml.

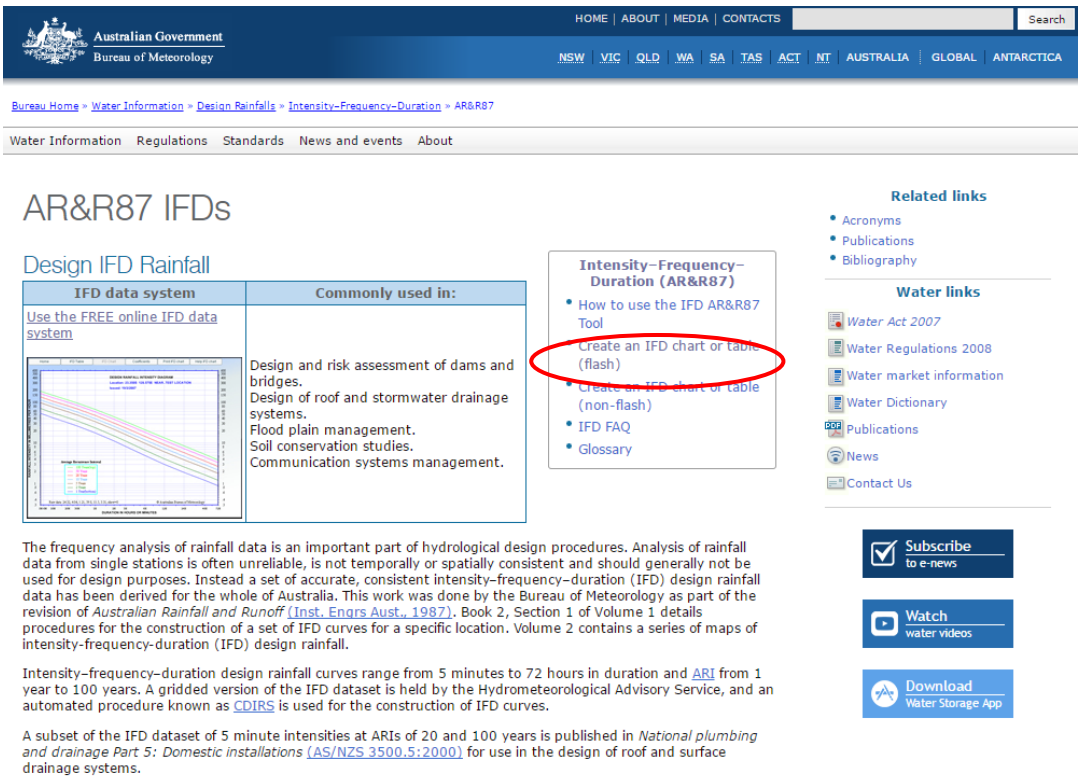


Figure 3.24 BOM 1987 I-F-D Website

To obtain intensities for this site, click on the flash option shown above. In the page that appears (**Figure 3.24**), click on **Create an IFD**.

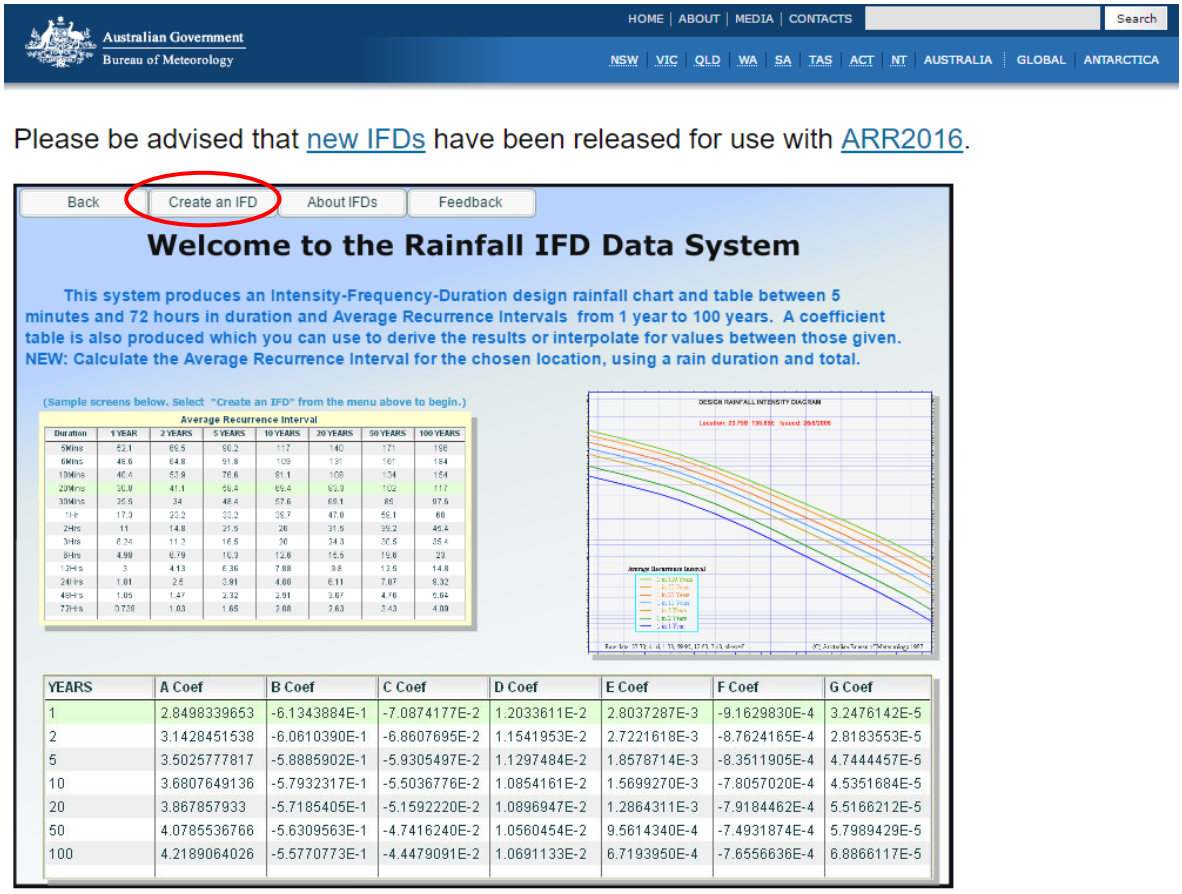


Figure 3.25 Flash 1987 I-F-D Page

In the page that then appears (Figure 3.26), enter the latitude and longitude for the site.

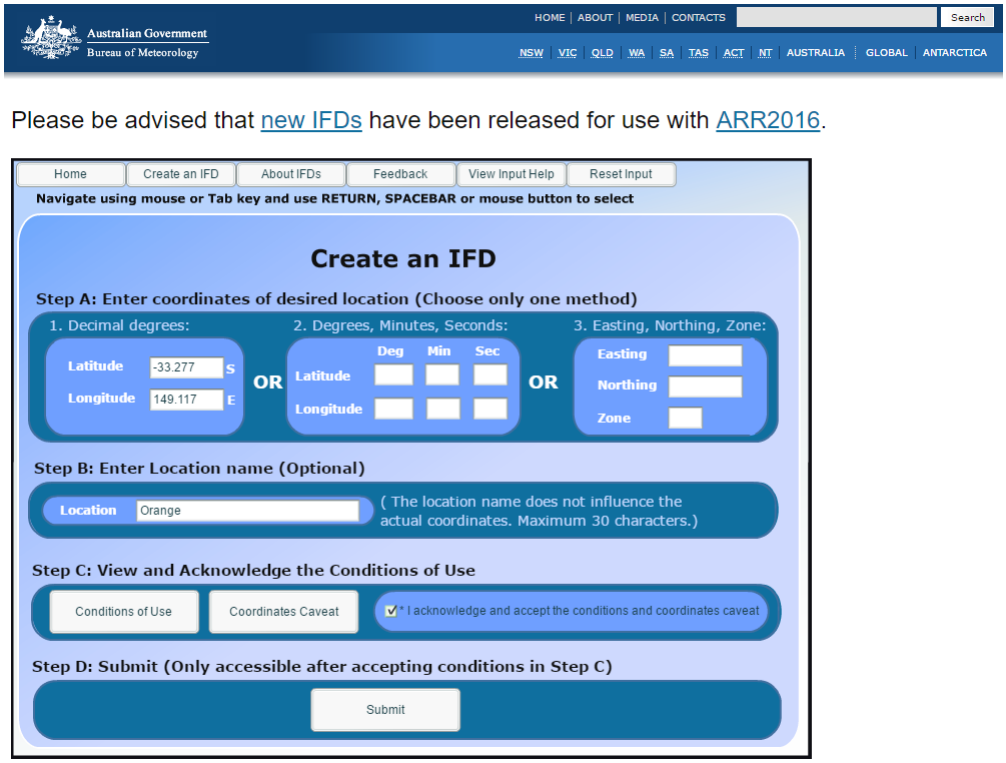


Figure 3.26 1987 I-F-D Page

After clicking the **Submit** button, the following window appears. Click on **IFD Table**.

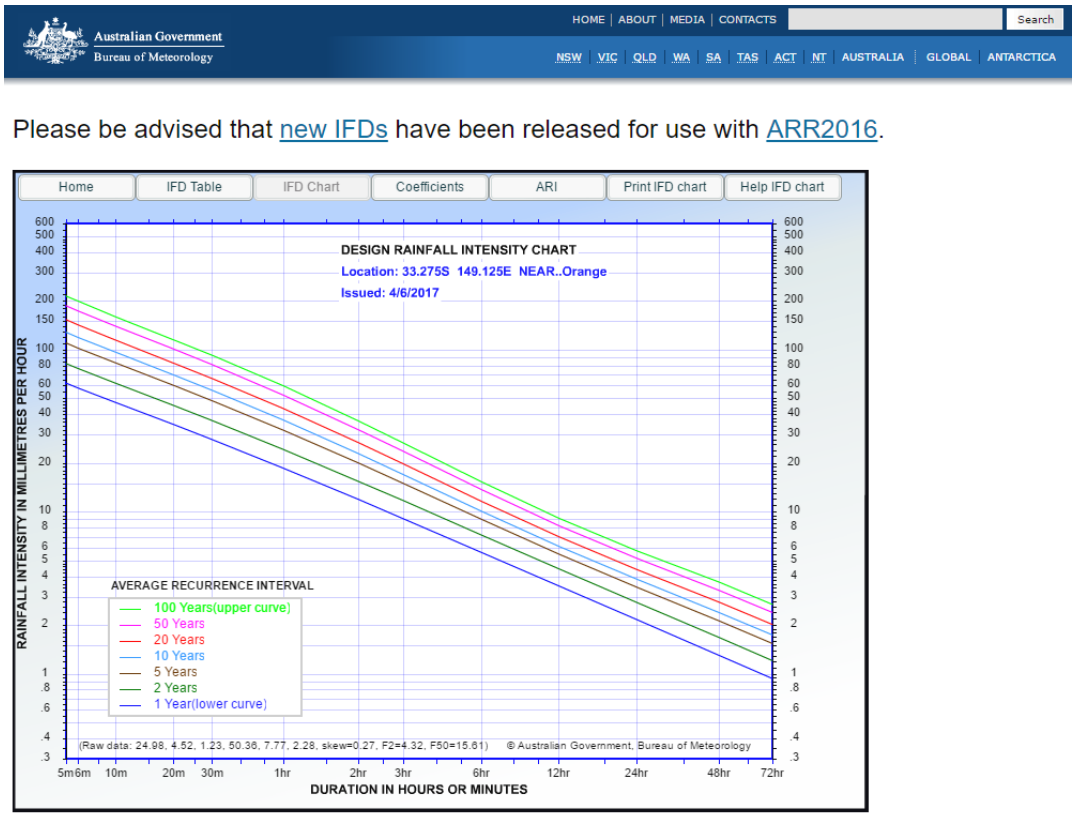
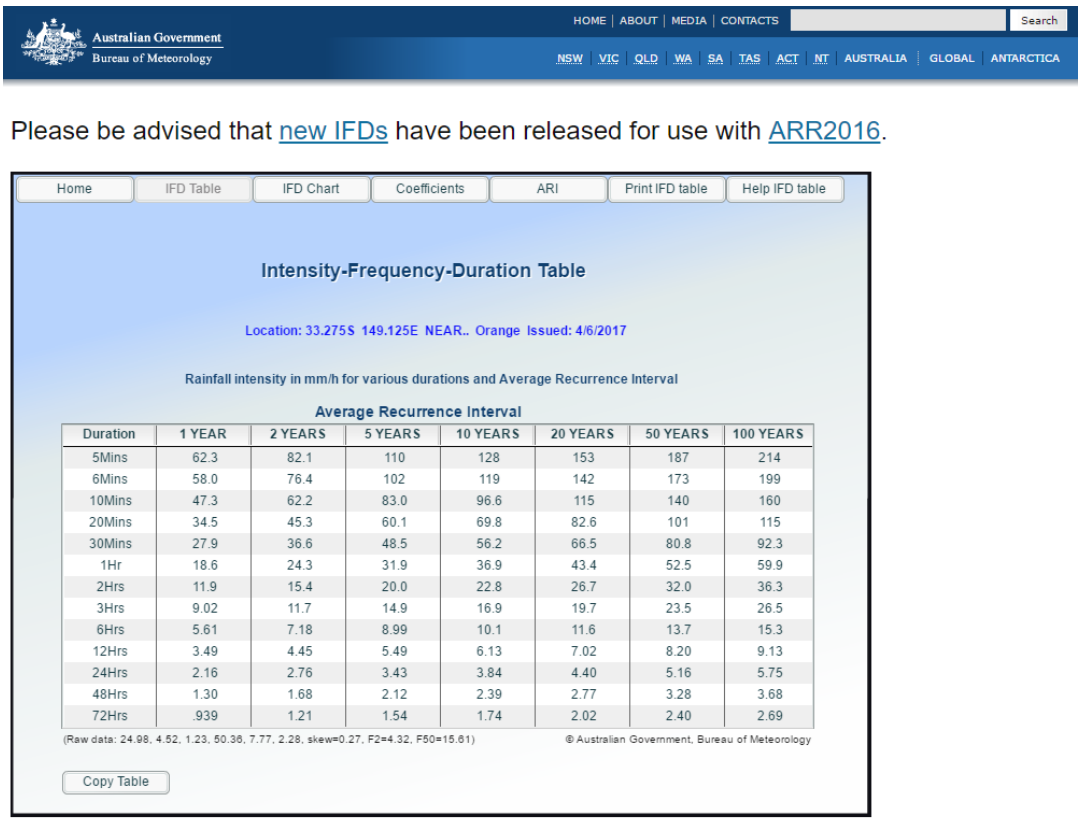


Figure 3.27 1987 I-F-D Plot

You can then manually transfer intensities from this table to the 1987 rainfall property sheet in DRAINS, as shown in Figure 3.23.



Duration	1 YEAR	2 YEARS	5 YEARS	10 YEARS	20 YEARS	50 YEARS	100 YEARS
5Mins	62.3	82.1	110	128	153	187	214
6Mins	58.0	76.4	102	119	142	173	199
10Mins	47.3	62.2	83.0	96.6	115	140	160
20Mins	34.5	45.3	60.1	69.8	82.6	101	115
30Mins	27.9	36.6	48.5	56.2	66.5	80.8	92.3
1Hr	18.6	24.3	31.9	36.9	43.4	52.5	59.9
2Hrs	11.9	15.4	20.0	22.8	26.7	32.0	36.3
3Hrs	9.02	11.7	14.9	16.9	19.7	23.5	26.5
6Hrs	5.61	7.18	8.99	10.1	11.6	13.7	15.3
12Hrs	3.49	4.45	5.49	6.13	7.02	8.20	9.13
24Hrs	2.16	2.76	3.43	3.84	4.40	5.16	5.75
48Hrs	1.30	1.68	2.12	2.39	2.77	3.28	3.68
72Hrs	.939	1.21	1.54	1.74	2.02	2.40	2.69

Figure 3.28 1987 I-F-D Table

3.3.4 Entering System Components

For pits, pipes, overflow routes and most other components, this process is the same as in the other models, as described in Section 2.3. The exception is the sub-catchments, which should include the values shown in Table 3.2. (Note that the C_{10} coefficients differ from the values in Table 3.1, which were based on 2016 I-F-D data.

Table 3.2 1987 Rational Method Sub-Catchments

Name	**Pit or Node**	**Total Area** (ha)	**Roofed** (%)	**Imperv-ious** (%)	**Pervious** (%)	**Imperv-ious t_c** (mins.)	**Pervious t_c** (mins.)	**Imperv-ious C_{10}**	**Pervious C_{10}**
Cat 1	Pit 1	0.125	0	33	67	8	13	0.9	0lues in **Table 3.1**.26
Cat 2	Pit 2	0.231	0	38	62	9	15	0.9	0.26
Cat 3	Pit 4	0.025	0	90	10	3	4	0.9	0.26
Cat 5	Pit 5	0.02	0	90	10	2	3	0.9	0.26
Cat 4	Pit 4	0.35	0	80	20	9	15	0.9	0.26

3.3.5 Running the Model and Inspecting Results

The results of an analysis run using this model are shown in Figure 3.29. This is examined in the same way as with the 2016 data, described in Section 3.8 to 3.10.

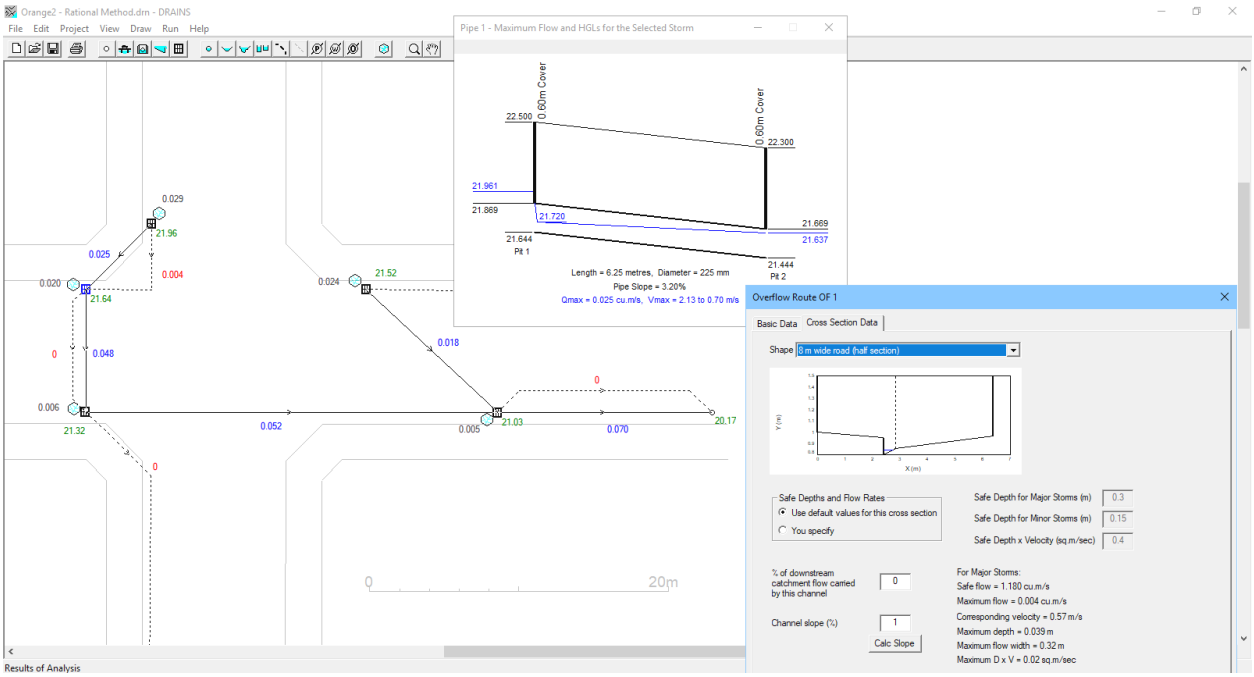


Figure 3.29 Results of Rational Method Design Run

3.4 Extended Rational Method Calculations

3.4.1 General

DRAINS also provides an Extended Rational Method (ERM) model, using many of the assumptions in the *Australian Rainfall and Runoff* version of the rational method. The method is described fully in Section 8.3.5. Like ILSAX, it uses design storm patterns like those employed by the ILSAX hydrological model.

Both 1987 and 2016 rainfall data can be applied. Rather than providing step-by-step instructions for setting up the model, this section refers to material in earlier sections.

3.4.2 Setting Up Common Options

The hydrological model is set up as described in Section 3.2.1 (for 2016 data) or Section 3.3.1 (for 1987 data). The hydrological model property sheet is set up as shown in Figure 3.30, with the 10 year ARI (10% AEP) runoff coefficient C_{10} for the pervious area set at 0.21, which is based on a 10% AEP, 1 hour rainfall intensity, ${}^{10\%}I_1$ of 33.2 mm/h entered into Equation 14.12 in *Australian Rainfall and Runoff*, 1987:

$$C_{10} = 0.1 + 0.0133 \times ({}^{10\%}I_1 - 25).$$

For the 1987 data, the pervious area C_{10} value will be 0.26, based on a higher value of ${}^{10\%}I_1$ drawn from the 1987 I-F-D relationship for Orange.

3.4.3 Drainage System Components

The sub-catchments are the same as those for the rational method, with land-use being divided into impervious and pervious components, as shown in Figure 3.31. The pits, pipes, overflow routes and nodes are set up in the same way as for other models – see Section 2.3 for details.

3.4.4 Adding Rainfall Data and Running DRAINS

This is done in the same way as for the ILSAX model – see Section 2.4 for 2016 rainfall data, and Section 2.5 for 1987 data.

All the functions of the ILSAX model are available with the ERM model. The models are compared in Section 8.3.7.

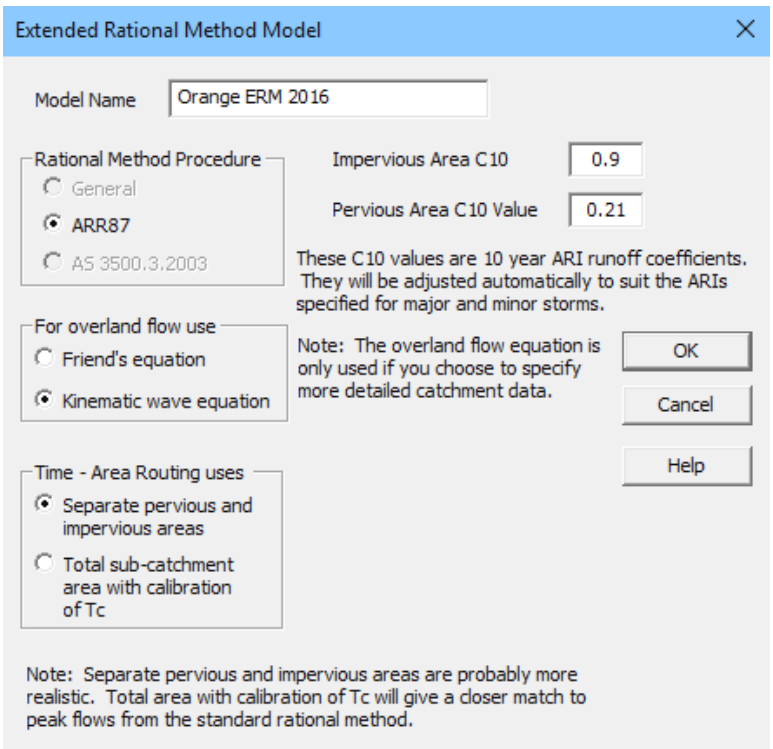


Figure 3.30 Extended Rational Method Hydrology Model

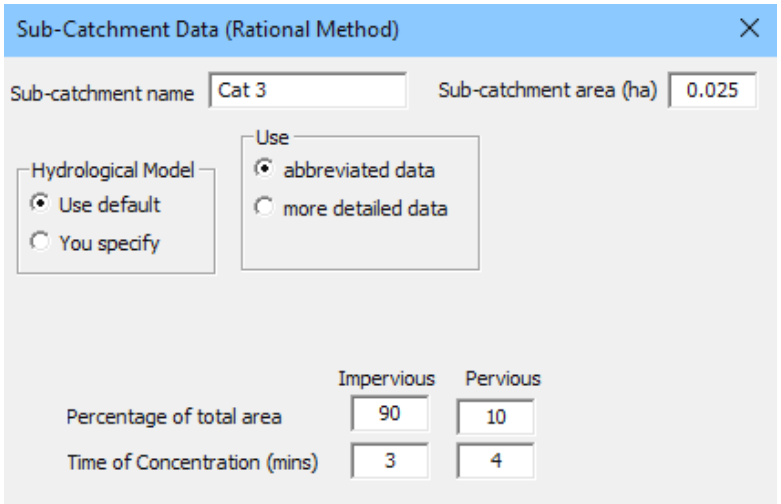


Figure 3.31 Sub-Catchment Data Property Sheet with ERM (Top Portion)

4. OTHER MODELS

4.1 Initial Loss – Continuing Loss Model

4.1.1 General

Australian Rainfall and Runoff 2016 specifies a new urban hydrological model in Chapter 3 of Book 5 of ARR 2016. This divides catchments into three parts – an effective impervious area (EIA), a remaining (impervious and pervious) area and (rarely) a large pervious area like a park. The EIS is about 60% of the total impervious area.

While the EIA has low hydrological losses, the remaining area has initial losses that are about 70% of the rural area initial losses for the site, which are supplied by the ARR Data Hub (data.arr-software.org/). These losses interact with a pre-burst loss depth, also available from the Data Hub. Unfortunately, the pre-burst depths are not available for storm durations less than 1 hour. The ARR Team will eventually supply these, but the IL-CL model must be regarded as provisional until full pre-burst information is available.

Only the 2016 rainfall data can be used with this model. Rather than providing step-by-step instructions for setting up the model, this section refers to material in earlier sections. The processes are very similar to those for the ILSAX and ERM models.

4.1.2 Setting Up Common Options

The hydrological model is set up as shown below:

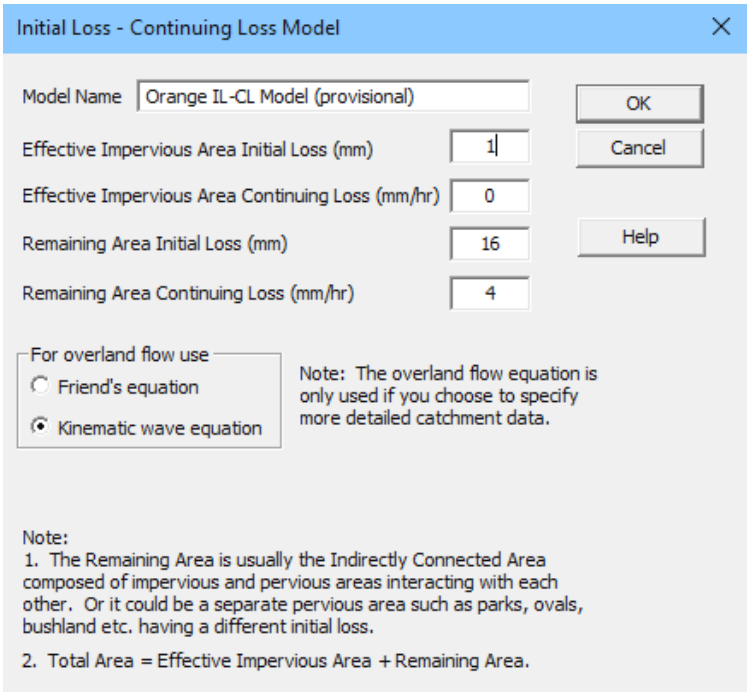


Figure 4.1 IL-CL Hydrology Model

From the ARR Data Hub, the rural initial loss for the Orange site is 23 mm and the continuing loss is 4.7 mm/h. The initial loss is taken as 60% of the 23 mm = 16 mm, and the continuing loss as 4 mm/h, which is the recommended upper limit of remaining area continuing losses.

The other options and data bases are set up in the same way is for ILSAX, as described in Sections 2.2.3 to 2.2.5.

4.1.3 Adding Drainage System Components

Pits, pipes, overflow routes and nodes are set up in the same way as for other models – see Section 2.3 for details. The only different component is sub-catchments, which are set up as shown in Figure 4.2.

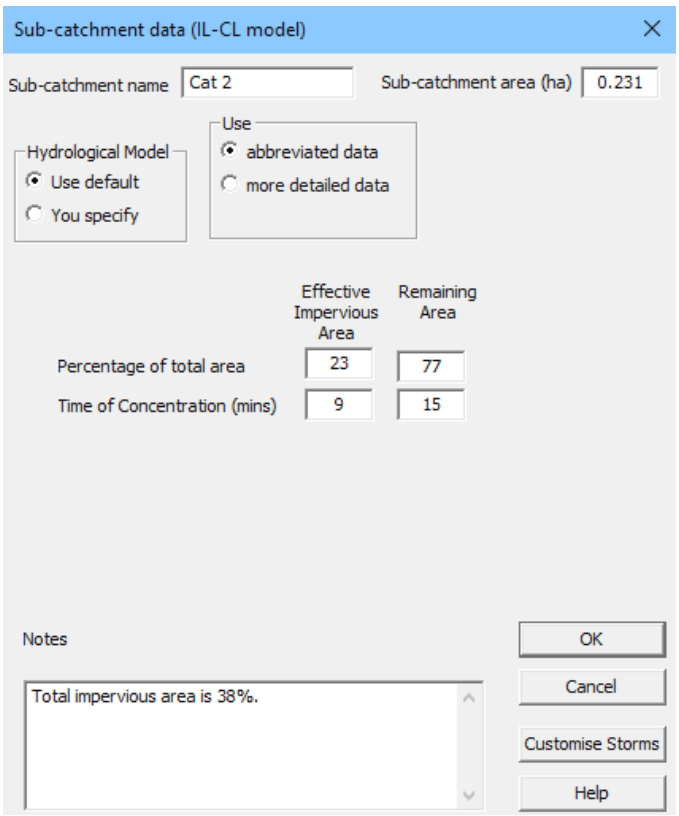


Figure 4.2 Sub-Catchment Data Property Sheet with ERM (Top Portion)

Note that in most sub-catchments, the EIA percentage is set as 60% of the total impervious area, so the model deals with a different type of impervious area to the rational method and ILSAX hydrological models. If an IL-CL model is added to the data base of models in DRAINS, you can easily switch between models and the associated land-use percentages when you change the default hydrological model.

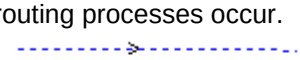
4.1.4 Adding Rainfall Data and Running the Model

This is done in the same way as for the ILSAX model with 2016 rainfall data, as described in Section 2.4.

All the functions of the ILSAX model are available with the IL-CL model. The models are compared in Section 8.3.7.

4.2 Storage Routing Models

Storage routing models can be implemented using many of the same features and processes used with the ILSAX and rational method programs. To illustrate this, consider the RAFTS Model shown in Figure 4.3, modelling a hypothetical creek at Shepparton, Victoria.

This rural catchment has been divided into four sub-areas, and a RAFTS-type model has been superimposed on this. The four sub-catchments shown by the symbol are sites where conversions from rainfall to runoff and routing processes occur. Routing can also occur, if required, in the stream routing reaches, shown as 

Loss information and the routing parameter k_c are entered in the hydrological model property sheet shown in Figure 4.4. Rainfall data is entered in the same way as for ILSAX models. Property sheets for a sub-catchment and a stream routing reach are shown in Figure 4.3 and Figure 4.5.

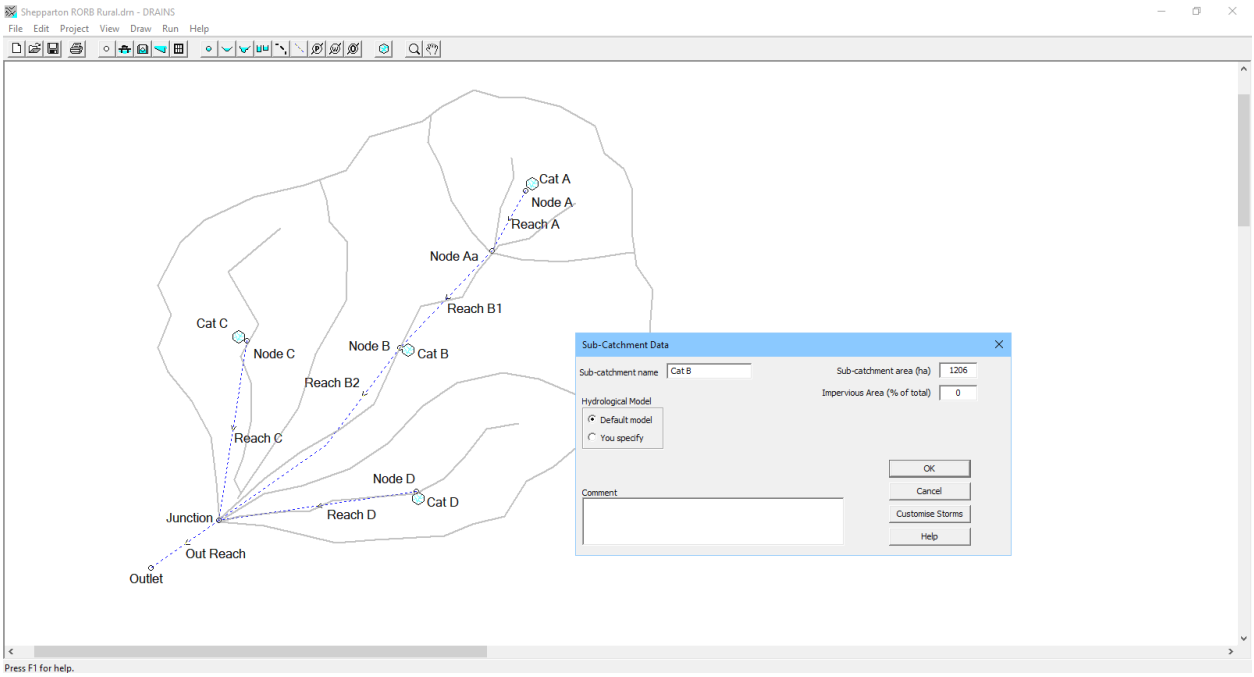


Figure 4.3 Shepparton RORB-Type Model

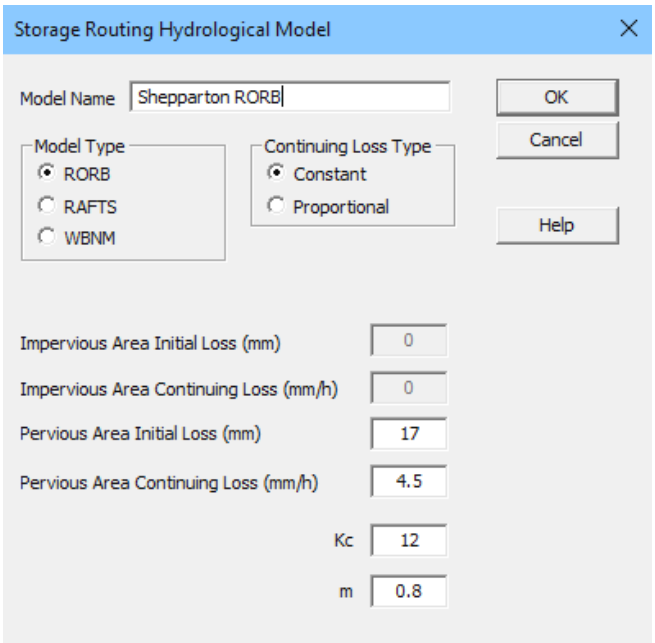


Figure 4.4 RORB Hydrological Model Property Sheet

The stream reach property sheet offers a choice of translation of the hydrograph (movement of flows without changing the hydrograph shape) or an approximate routing procedure based on kinematic wave hydraulic principles.

A name must be entered for nodes, but surface levels are not required, as the routing is not tied to particular elevations or datum levels. Detention basins and completely-defined open channels can be added if desired.

Results from a major storm run involving ensembles of 2016 rainfalls are shown in Figure 4.6. ARR 1987 and other storm patterns can also be run.

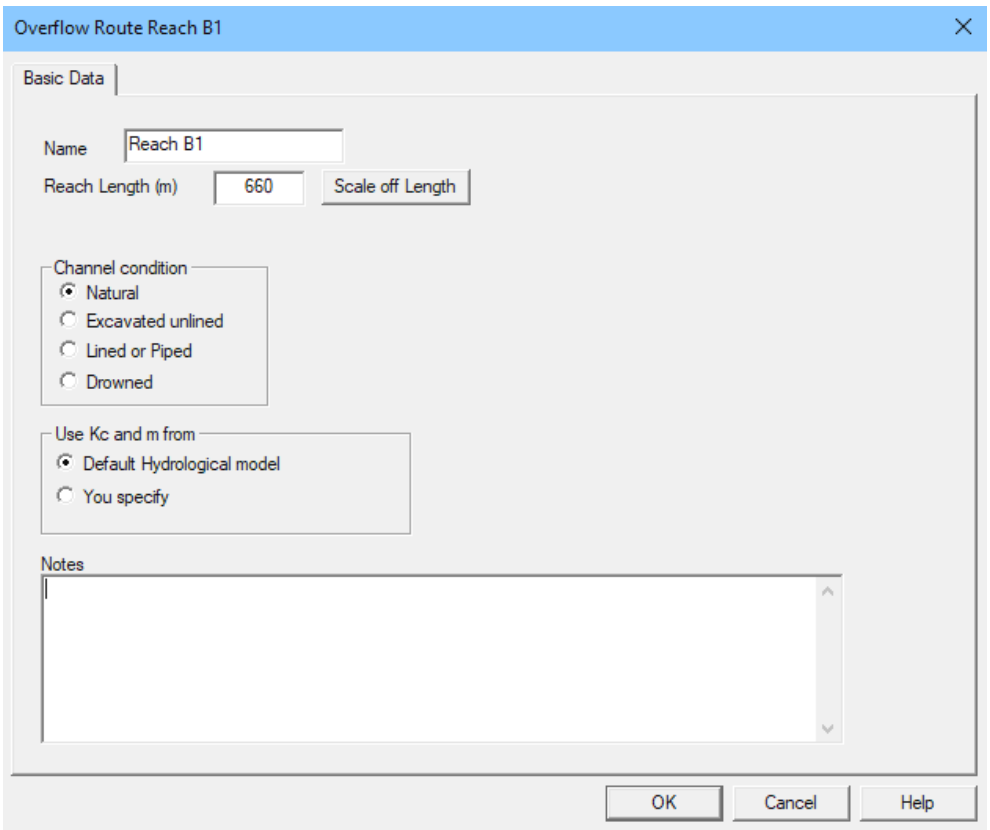


Figure 4.5 RAFTS Stream Routing Reach Property Sheet

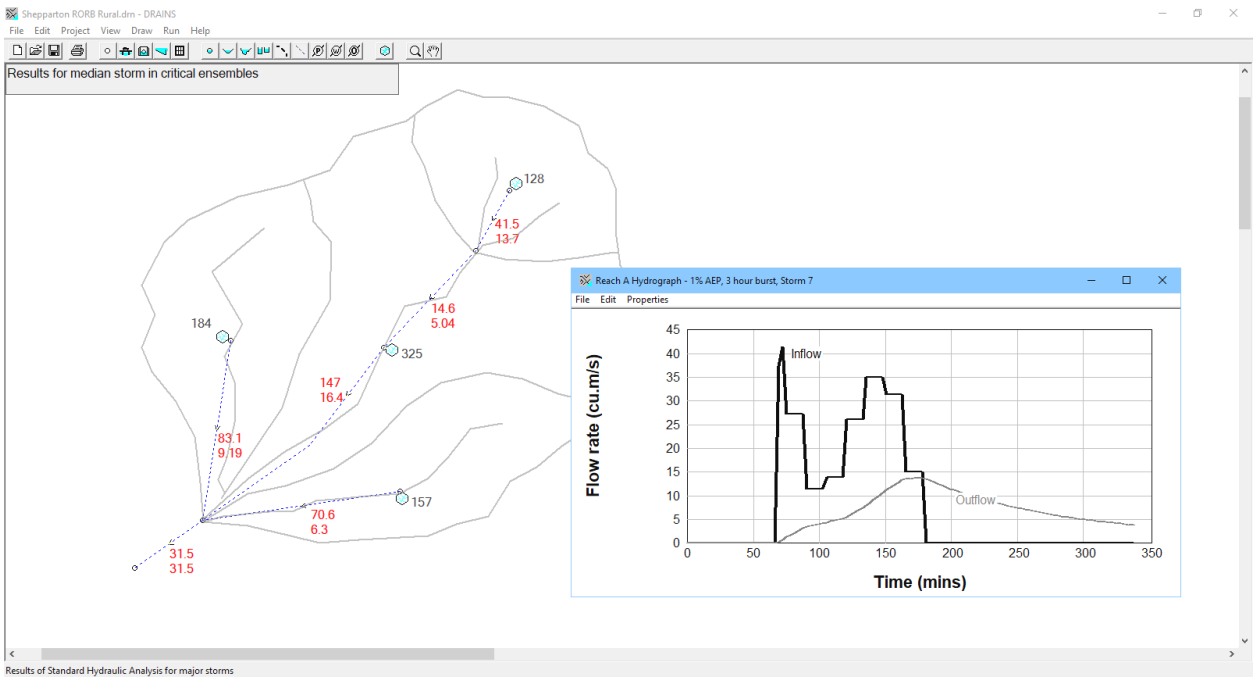


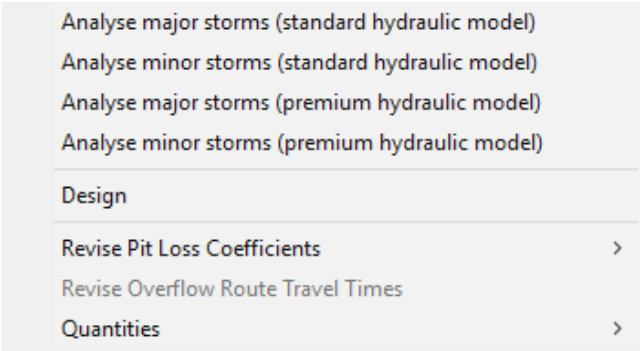
Figure 4.6 Results of Storage Routing Run

The **black** numbers at the sub-catchments represent the peak sub-catchment flows, while the pairs of **red** numbers represent the peak flowrates at the top and bottom ends of a reach. Hydrographs can be examined easily and data can be transferred to a spreadsheet.

4.3 The Premium Hydraulic Model

The unsteady flow model used in the standard hydraulic model makes allowance for the storage effects of flows along pipes and open channels. The premium model extends this to overflow routes, allowing accurate determination of water levels and flow characteristics during large storm events.

Some additional data is required for premium hydraulic model calculations. This is revealed when you attempt to run an existing model such as the Orange2.drn with premium model calculations, using the third or fourth options in the **Run** menu.



For each overflow route, a route length must be specified in addition to the travel time in the Overflow Route property sheet, as shown in Figure 4.7.

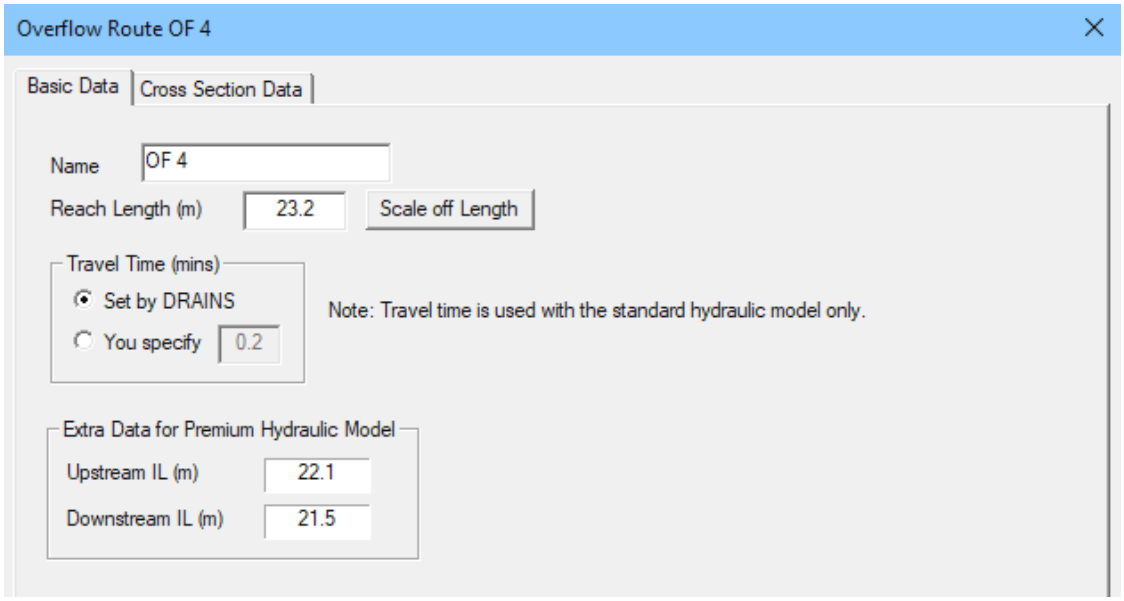


Figure 4.7 Overflow Route Property Sheet for Premium Hydraulic Model Calculations (Top Portion)

Figure 4.7 also shows the entry of required invert levels at the beginning and end of the overflow route. You can enter this yourself, or allow DRAINS to provide values at the start of a run, checking these later. The remaining issue is to specify outlet controls at sag pits. These are usually weirs representing barriers such as road crowns or centrelines. Only one sag pit occurs in the Orange2 - premium.drn model, and the control will be modelled as a parabolic weir, as shown in Figure 4.8.

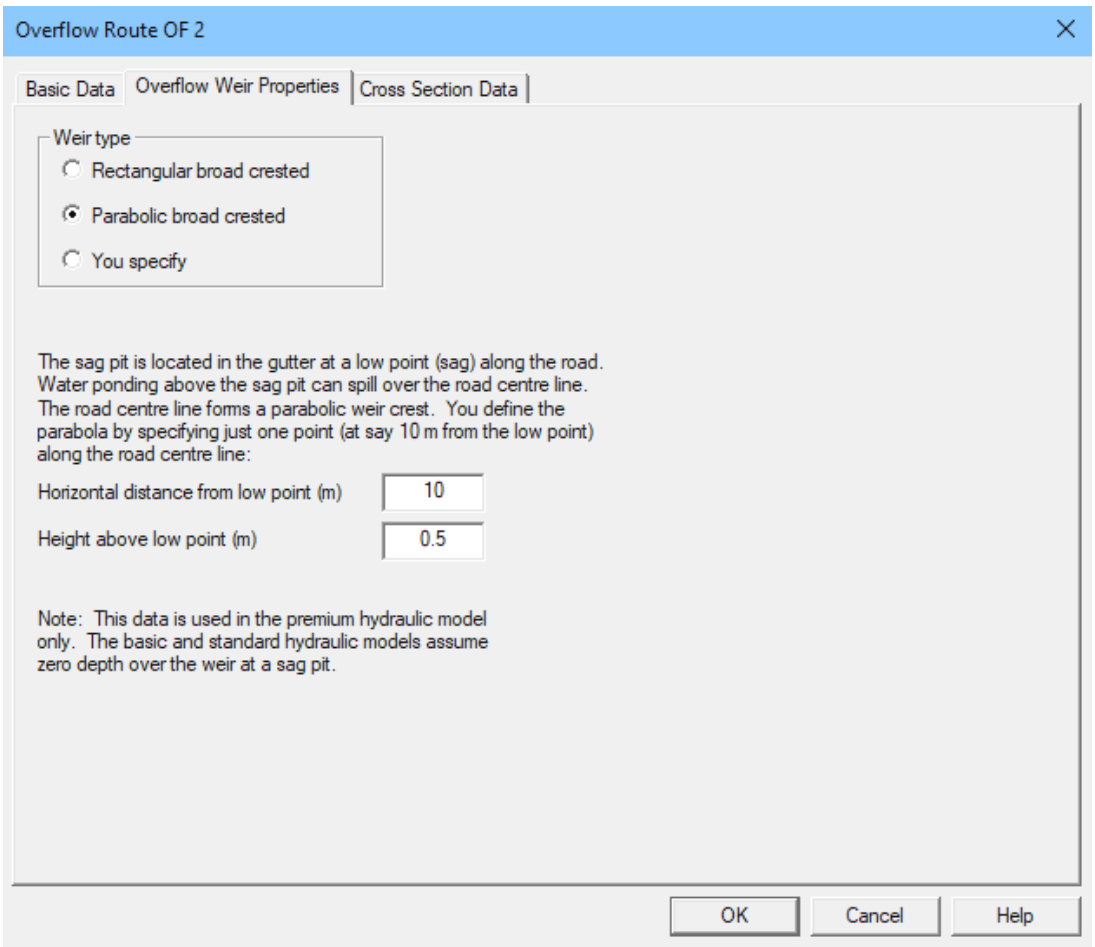


Figure 4.8 Specification of Overflow Weir for a Sag Pit

5. MENUS, TOOLS AND DATA BASES

5.1 Introduction

This chapter presents the options and tools that are used to create and tailor DRAINS models. Drainage systems can be created with the tools on the Toolbar, or can be partially imported using menu options. With optional modules covering rational method, storage routing, GIS transfers, GIS transfers, and premium hydraulic modelling, there are different forms of some menus and property sheets to those described here.

These facilities are explained in the following sections together with the data bases that store information on hydrological models, rainfall patterns and components such as pits. The exposition is detailed and systematic, and is likely to be boring unless you check through each item using the DRAINS demonstration examples, or if you have a hardware lock to run the program fully, the example file Toowoomba Estate.drn, shown in Figure 5.1.

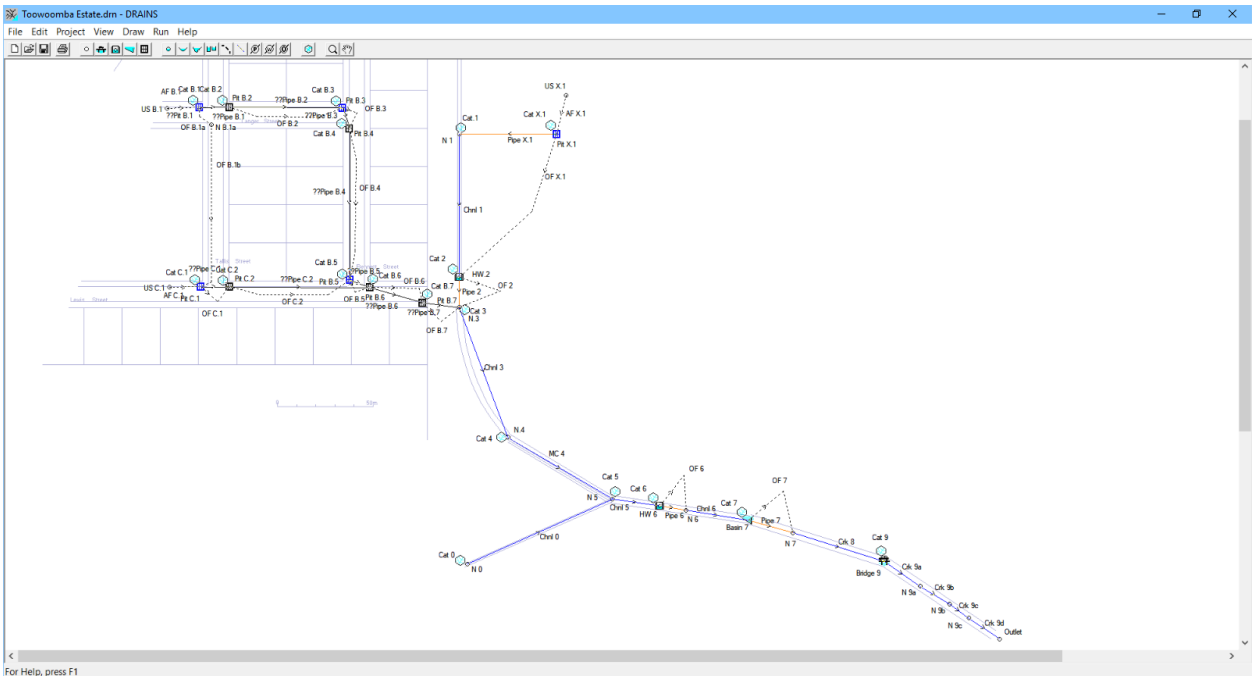


Figure 5.1 Hypothetical Toowoomba Example

5.2 Menus

5.2.1 The Menu Bar

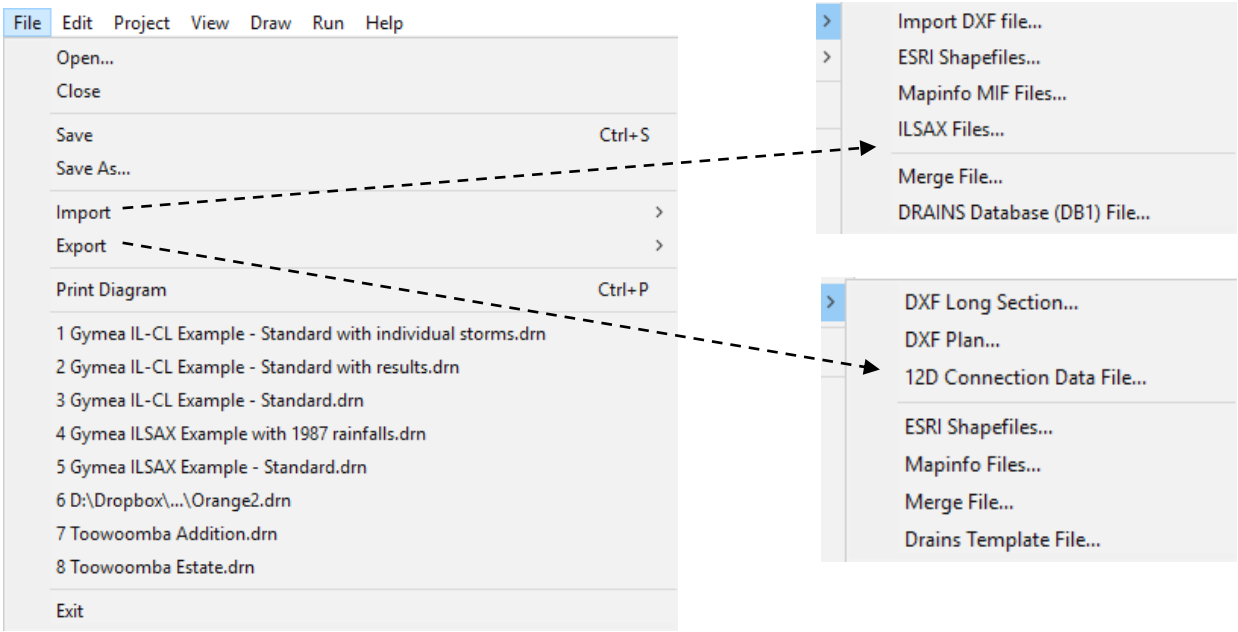
DRAINS employs seven drop-down menus opened from the items in the menu bar:

File Edit Project View Draw Run Help

The broad functions of each menu are described below. You will find material on individual functions in other parts of this manual. Refer to the index for the locations of these.

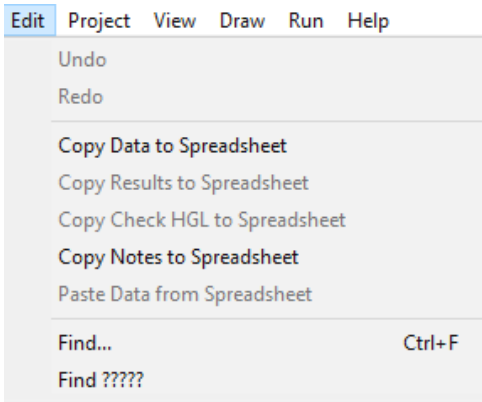
5.2.2 The File Menu

This menu controls most ways of inputting and outputting data. The functions of creating new files, opening and closing stored files, saving and 'saving as' files, and exiting are carried out using standard Windows procedures. Through the additional menus shown below, called through the **Import** ► and **Export** ► options in the **File** menu, information can be taken in and out of DRAINS in various file formats, which are covered in detail in Chapters 3 and 5.



If a DRAINS model already has a background, the first option in the **File → Import ►** option will be **Import DXF background…** instead of **Import DXF file...** in a new model. This enables the background to be changed or updated.

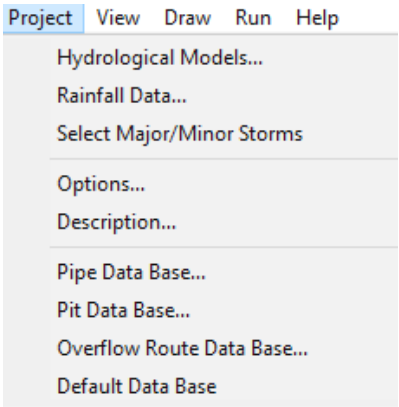
5.2.3 The Edit Menu



This contains functions like Undo and Redo, and Find facilities for locating components in large drainage networks.

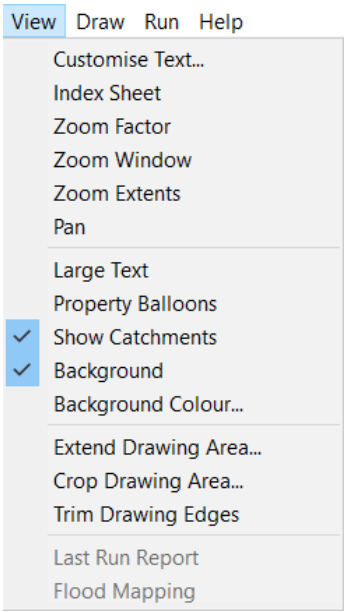
The commands for transferring data and results to and from spreadsheets are also included here.

5.2.4 The Project Menu



This menu accesses information for the particular drainage system being analysed by DRAINS, as well as the pipe, pit and overflow route data bases. It also allows a new data base to be loaded as the standard data base.

5.2.5 The View Menu

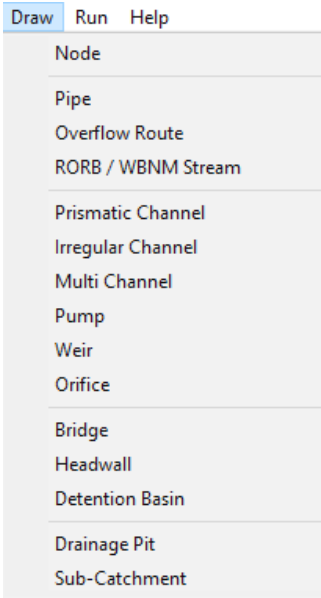


This menu provides options for viewing data and results in different ways.

It controls what is shown in the Main Window. See Section 6.3 for a description of the options.

5.2.6 The Draw Menu

This duplicates the Toolbar choices. Selecting an option has the same effect as clicking on a button in the toolbar.

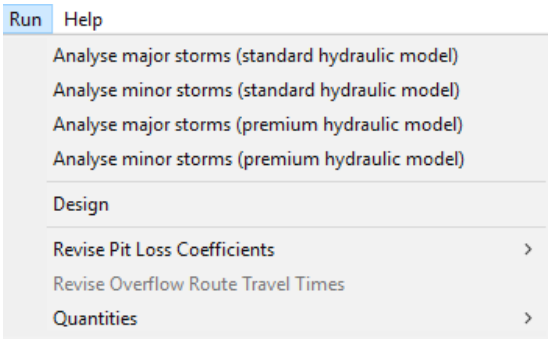


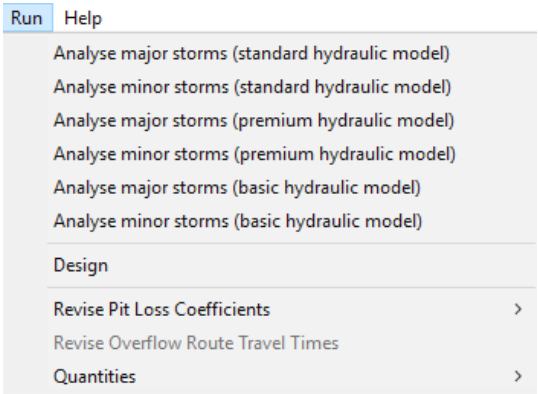
5.2.7 The Run Menu

This includes various options for making runs, and for varying these. Depending on circumstances, this menu can take different forms, the first, shown to the right, being for new models.

For models created prior to December 2010, it is also possible to run with the obsolete basic hydraulic model, which has been replaced by the standard model.

The run menus for rational method models and for storage routing models will be less complicated than those shown.

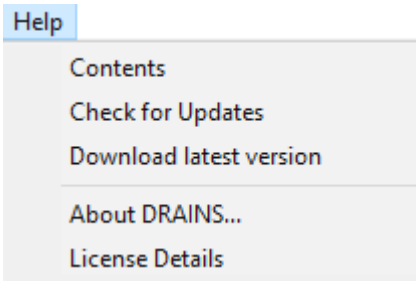




5.2.8 The Help Menu

This contains an access point to the Help system through the **Contents** option, and also identifies the version of DRAINS and allows the capabilities set by the hardware lock to be upgraded using passwords.

Where an item in a menu list is followed by '…' or ' >' it opens another menu, a dialog box or property sheet.



5.3 Tools and Associated Components

5.3.1 General

DRAINS provides 21 buttons in the Toolbar:

The first four buttons are for creating a new file, opening an existing file, saving a file and printing the Main Window, duplicating functions in the **File** menu. The last two buttons are the Zoom Factor function that is also available in the **View** window, and the Pan function. The remaining fifteen buttons can be used to draw components in drainage systems in the Main Window. The first group of five are all nodes or junctions; the next group of nine are links, and the remaining sub-catchment button provides a source of water as runoff derived from rainfalls. If you hold your mouse arrow over each button, a ScreenTip will appear to indicate its function.

Clicking on these buttons changes the cursor from an arrow to a pencil, which is used to place components in the Main Window. Holding down the **Shift** key while entering a component retains the pencil cursor after you have entered a component, allowing you to add another component of the same type. If you become 'stuck', with the cursor still in pencil form when you no longer want to enter a component, simply enter the component and then delete it.

Components should connect properly. The ends of links should be placed near the centre of nodes, and sub-catchments should clearly connect to pits and nodes. Sub-catchments must not be placed over pits, or overflow routes over pipes, as it will be difficult to select particular components later. The layout should be tidy, to enable components to be viewed and accessed easily. Names and positions of components can be shifted to clarify the layout. A background layer imported as a DXF file from a CAD program, as described in Section 6.2.2, or as part of the importation of GIS files (Section 6.2.4), provides a guide for locating pits and other components.

Behind each of the components provided in DRAINS is a computer algorithm (logic + equations + data) that is employed within calculation frameworks. There are often alternative ways to describe the operations of components such as pits or detention basins. When performing analysis work with DRAINS, you should assess the methods and equations used in the program (detailed in Chapter 8) and examine results, to confirm that the program operates as you expect.

You may encounter situations that are not fully described by the standard components, such as a complex system of detention basins. It will then be up to your judgement and modelling skills to use the available tools to describe the situation. This may involve 'tweaking' of the model. An example of this type of manipulation is the use of detention basins to simulate stormwater infiltration systems or pumps, as noted in Section 5.3.8.

The following sections describe the displays and the features of each component, starting with those that you are likely to use most frequently.

5.3.2 Display of Components

Depending on the specifications for pits and pipes, these may appear as different colours. The system used in DRAINS is set out in Figure 5.2.

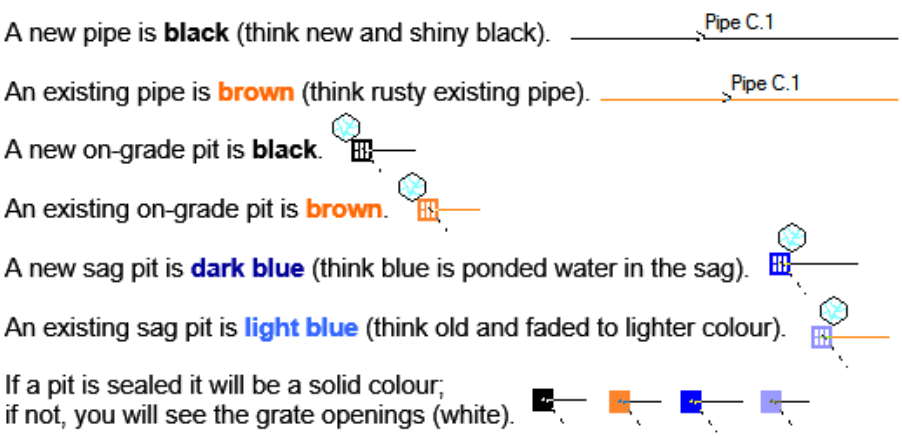


Figure 5.2 Colour-Coding of Pits and Pipes

5.3.3 Pits

(a) General

Pits, like other forms of node, act as entry points for water into the pipe system. They can represent a street gully pit, a manhole, a junction, a flow diversion or other components.

On-grade pits are located on slopes, while sag pits are in hollows or depressions, as shown in Figure 5.3. When stormwater runoff reaches an on-grade pit, at smaller flowrates all flows are collected. As approach flowrates increase, a point is reached where some bypass flow occurs. This will flow away from the pit, perhaps to another pit downstream, with additional flows joining it along the way. To model on-grade pits, a relationship between the approach flow and the flow captured by the pit must be specified. These cannot be established by theory and are usually determined from modelling studies or tests on installed pits, as is discussed further in Section 8.5.

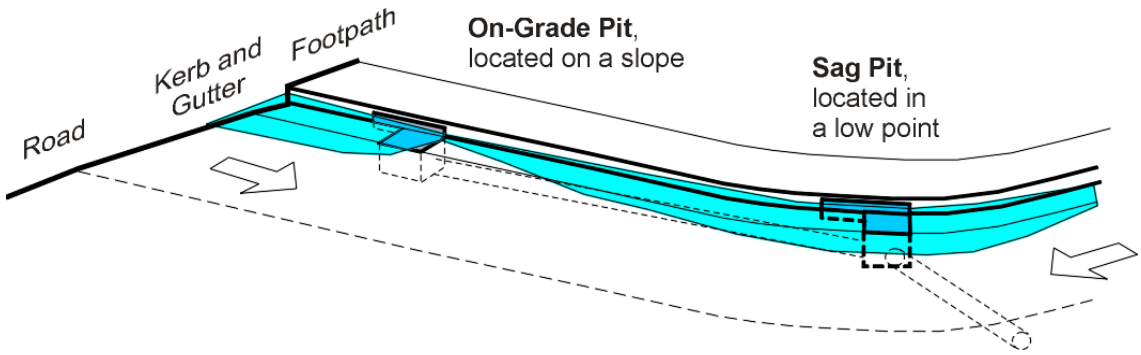


Figure 5.3 On-Grade and Sag Pits

(b) On-Grade Pits

The Drainage Pit property sheet can take two forms, depending on the type of pit selected. The on-grade pit property sheet, shown in Figure 5.4, requires the following inputs:

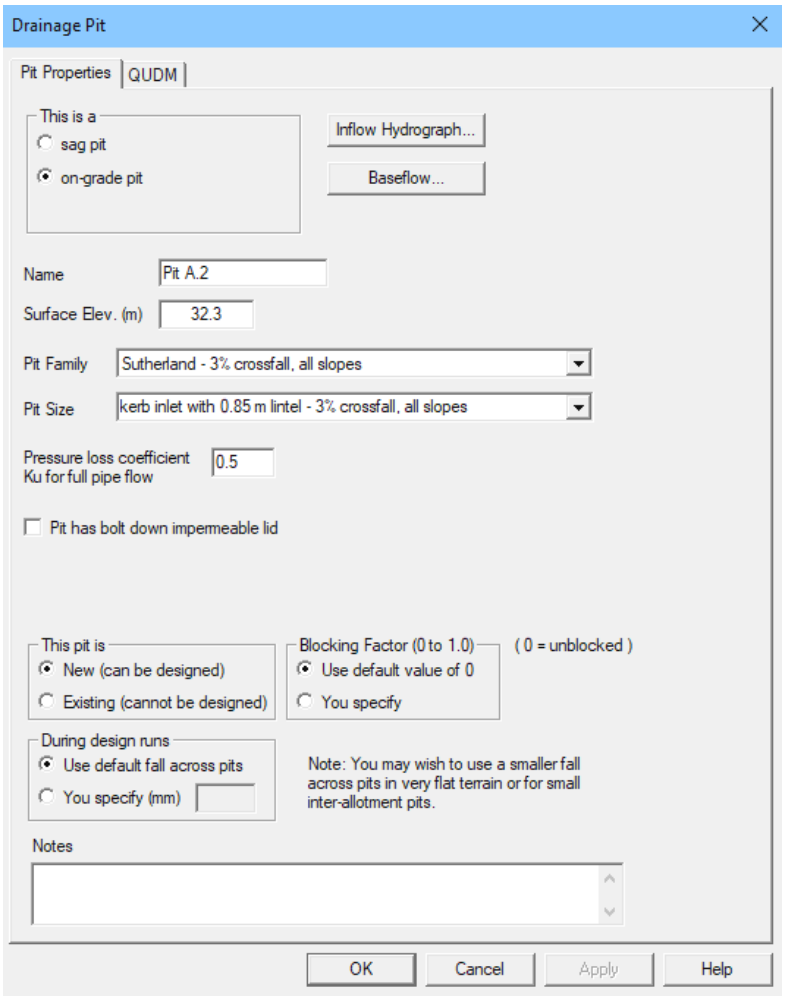


Figure 5.4 Drainage Pit Property Sheet for an On-Grade Pit - First Page

- a pit name of up to 10 characters (including blanks);
- a surface elevation (m) (This can be arbitrary, but it is recommended that you work with a standard datum such as Australian Height Datum (AHD).);

- a pit family and size, defined using drop-down lists linked to inlet capacity information set up in the Pit Data Base, as described in Section 5.4.6. (A pit type must be established in the Pit Data Base for all the pit families used.);
- a dimensionless pit pressure change coefficient for full pipe flow, which defines the change in the hydraulic grade line (HGL) at a pit, due to turbulence and other effects. (Pit pressure changes are explained in Section 8.6.6 and DRAINS offers methods for automatically calculating these. Some typical values are presented in Table 5.1.)

Table 5.1 Approximate Pit Pressure Change Coefficients, k_u

Type of Pit	k_u
Pit at the top of a line	5.0
Pit with a straight through flow, no sidelines, no grate inflow	0.1
Pit with a straight through flow, no sidelines, 50% grate inflow	1.4
Pit with a right angle direction change, no sidelines	1.7
Pit with a straight through flow, one or more sidelines	2.2
Pit with a right angle direction change from two opposed inflow pipes	2.0

On this property sheet there is also a check box with the label 'Pit has bolt-down impermeable lid' that allows pits to be sealed, and the HGL may rise above the surface. A sealed pit cannot accept flows at the surface, and cannot overflow.

In the sheet there is also provision for specifying blocking factors, default values of which can be set in the **Options** property sheet opened from the **Project** menu as shown in Figure 2.72. The inlet capacity calculated from the relationship obtained from the Pit Data Base is multiplied by 1 minus the blocking factor. Thus a factor of 0.2 will reduce the inlet capacity or capture rate by 20%. More restrictive blocking factors are usually applied for sag pits than for on-grade pits. Values of 0.5 for sag pits and 0.2 for on-grade pits are typically used, though the latter in particular is questionable.

On the second page with the tag 'QUDM' shown in Figure 5.5, you can nominate whether the pit is aligned or misaligned and to provide the pit wall width (in mm) at the location of the outlet pipe. (This is only required if you wish to apply the QUDM Chart procedure to define pit pressure change coefficients.)

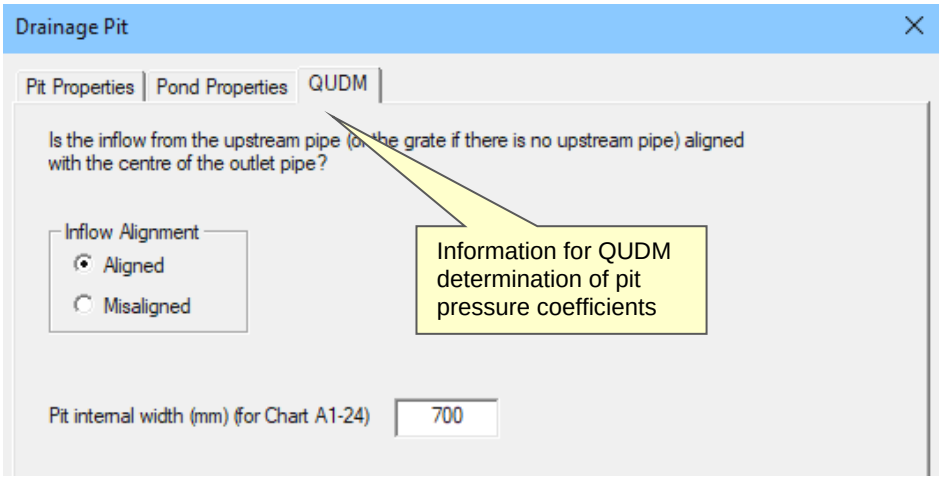


Figure 5.5 Drainage Pit Property Sheet for an On-Grade Pit - Second Page

The original blockage calculation process in DRAINS simply multiplied the inflow capacities for an on-grade pit by a constant blockage factor. The same percentage reduction applied for low and high approach flows. The blocking theory that is now applied results in a lower reduction at low approach flows and an increasing blockage effect with increasing flowrates, up to the specified factor. A further explanation is shown in Figure 5.6. In older DRAINS models the method to be applied could be set in the Options property sheet shown in Figure 2.72.

A pit can be excluded from the design process using the **This pit is** buttons at the bottom left of the property sheet.

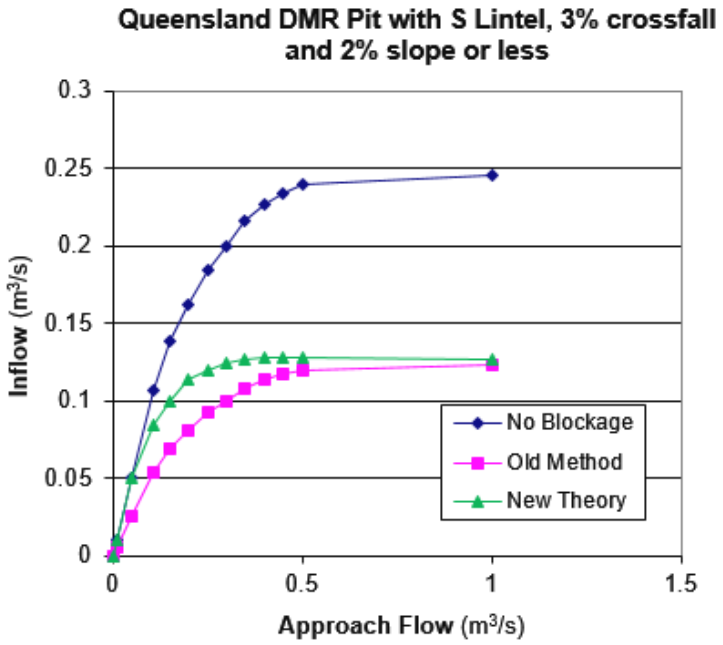


Figure 5.6 Inlet Capacity Relationships allowing for 0.5 (50%) Blocking Factor

(c) Sag Pits

For sag pits, the Drainage Pit property sheet appears as shown in Figure 5.7.

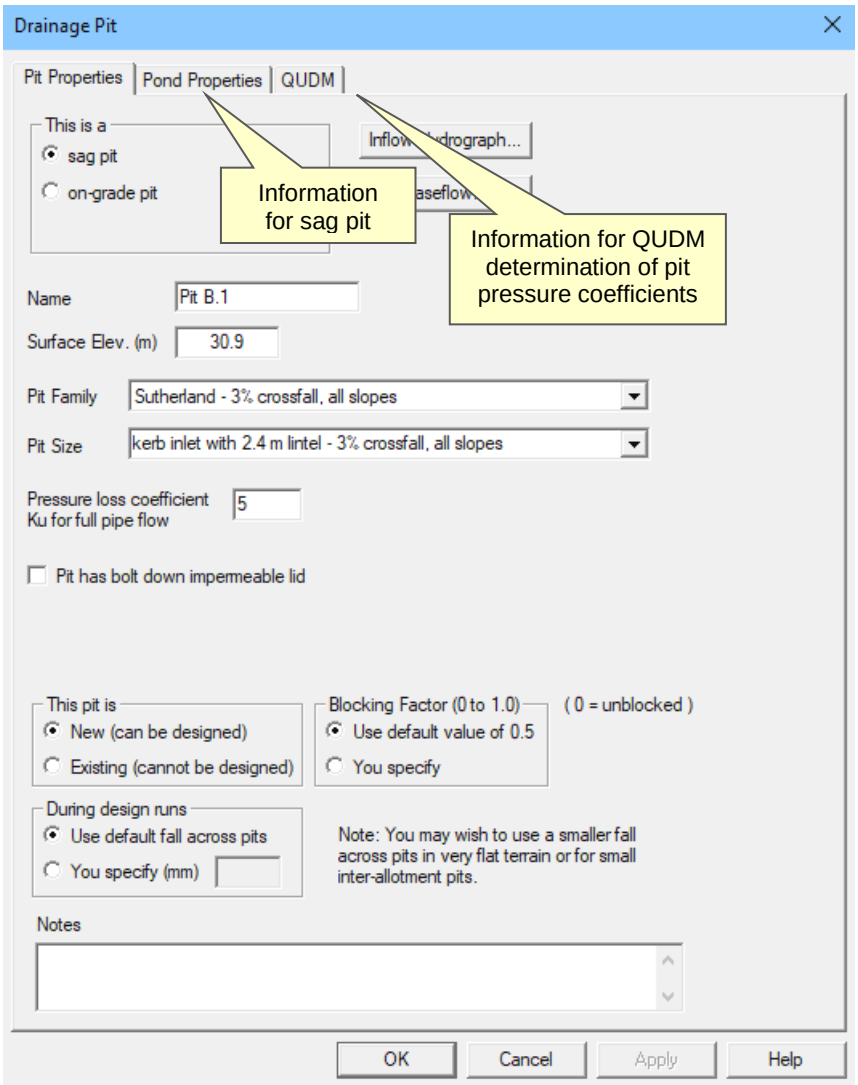


Figure 5.7 Drainage Pit Property Sheet for a Sag Pit – First Part

It is necessary to enter the same information as for an on-grade pit, and additional data required for water that might form a pool over the pit. It is then necessary to specify (i) the maximum ponded depth, (ii) the corresponding volume of ponded water over the pit, and (iii) safe ponding depths for minor and major storm events, based on design considerations.

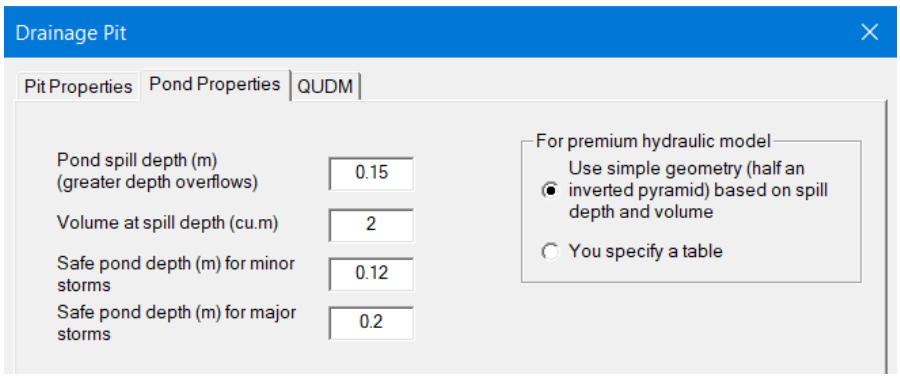


Figure 5.8 Drainage Pit Property Sheet for a Sag Pit – Second Part)

Note that on-grade and sag pits are coloured differently, as part of the colour-coding described in Figure 5.2.

DRAINS will make the ponding area overflow if the water depth exceeds the maximum ponded depth specified in the pit property sheet. Where two sag pits are connected by an overflow route, the overflow level of the upper one (its surface level + ponding depth) should be higher than the overflow level of the lower pit, as shown in Figure 5.9. Otherwise, in basic and standard hydraulic model calculations, DRAINS will have overflows going 'uphill' and will display a warning message, either prior to running a model, or in the report at the end of a run.

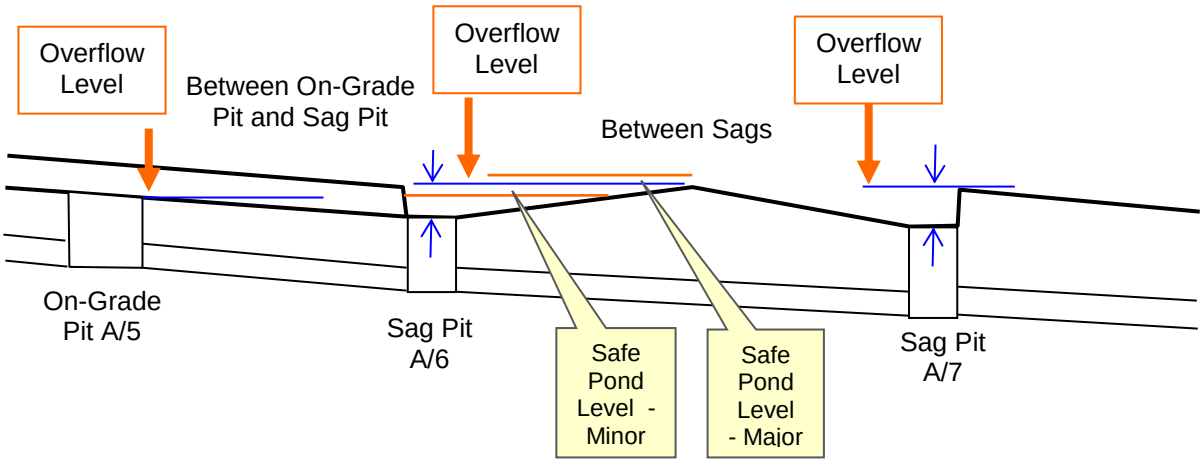


Figure 5.9 Relative Overflow Levels

Appropriate ponding depths can be set by considering the effects of excessive extents of ponding, which may impede traffic, prevent pedestrians from crossing a road, cover footpaths and enter adjoining properties. In major storms, safe ponding depths greater than the pond spill depth may be allowed, permitting flows over road centrelines in major storm events. The choice is up to the designer.

Usually, safe ponding depths are of the order of 0.1 to 0.3 m, and ponding volumes are 1 to 5 m^3. A typical safe depth for minor storms might be 0.12 or 0.15 m. (If these values are set too low, the corresponding sag pit inlet capacities may be impracticably small, so some compromise may be necessary, accepting greater depths.) A typical value for major storms might be 0.2 m, representing a 50 mm depth above a road crest with a 0.15 m spill depth.

The overflow level of a sag pit should be below the surface level of an on-grade pit that overflows to the sag pit, otherwise messages regarding uphill overflows will appear. In reality, on-grade pits may be submerged by ponding over a nearby sag pit, as is the case for the pit to the left in Figure 5.9.

(d) Baseflows and Direct Hydrographs

As well as receiving surface flows, a pit can receive a constant baseflow or a user-provided inflow hydrograph, specified using the buttons at the top of the Drainage Pit property sheet. These can be introduced at the surface or inside the pit. Flows introduced inside the pit are not subject to the pit inlet capacity relationship.

When the **Baseflow…** button is clicked, the property sheet shown in Figure 5.10 appears. Only a single flowrate is entered.

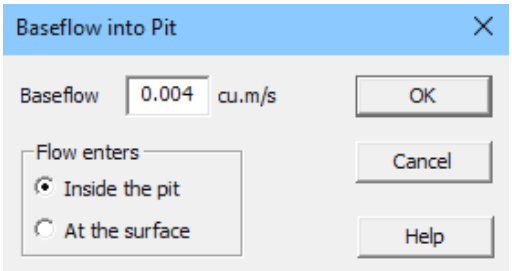


Figure 5.10 Baseflow Property Sheet

When the **Inflow Hydrograph…** button is clicked, the window shown in Figure 5.11 is opened. To specify a hydrograph a set of hydrograph ordinates, or flowrates at particular times, must be entered in the text boxes labelled 'Time (mins)' and 'Flow (cu.m/s)'. The graph assists the entry of data by providing a visual guide. Specific ordinates can be located and altered using the arrows in the spin box associated with the times.

Hydrographs can also be entered from a spreadsheet. You must prepare two columns in a spreadsheet program such as Excel, one containing times at fixed intervals in minutes, starting at zero, and the other containing the values of flowrates in m^3/s. You then select these columns and copy them to the Clipboard. Switching from the spreadsheet program to DRAINS, you can then open the Pit Inflow Hydrograph property sheet and import the data by clicking the **Paste** button.

The presence of baseflows or input hydrographs is not obvious when models are inspected. They can be located by exporting the data to a spreadsheet, as shown in Section 6.5.4, and inspecting the pit and node data. Columns I and P of the spreadsheet output (Figure 2.78) show the values of baseflows and the presence of direct hydrographs.

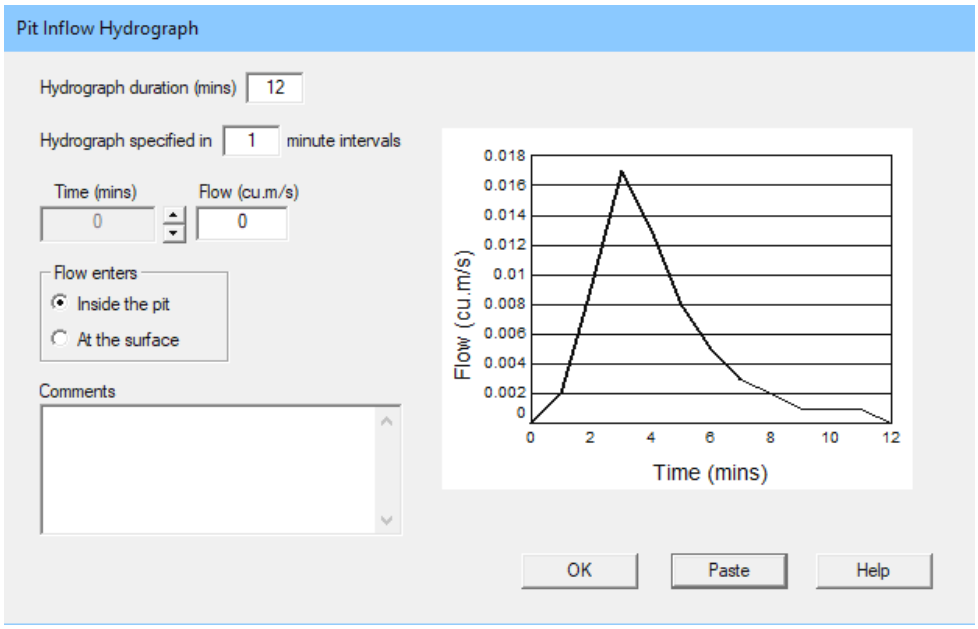


Figure 5.11 User-Provided Inflow Hydrograph for Pits

5.3.4 Simple Nodes

The most basic type of node, called a simple node, can be used for several purposes:

- to represent an outlet,
- to act as a junction linking reaches in an open channel drainage system,
- to provide a junction for stream reaches in a storage routing model,
- to act as a closed, no-loss junction in a pipe system, and
- to provide a joining point for sections of overflow routes.

DRAINS detects whether a node is at an outlet to a system, and if so, it presents the property sheet shown in Figure 5.12. As explained in Chapter 5, for part-full pipe flows DRAINS projects hydraulic grade lines upstream through a drainage system. If a free outfall is specified, the starting point for this upwards projection at each time step is the higher of the pipe's normal and critical depths for the current flowrate. If a tailwater level higher than these depths is specified in the Outlet Node property sheet, this becomes the starting level.

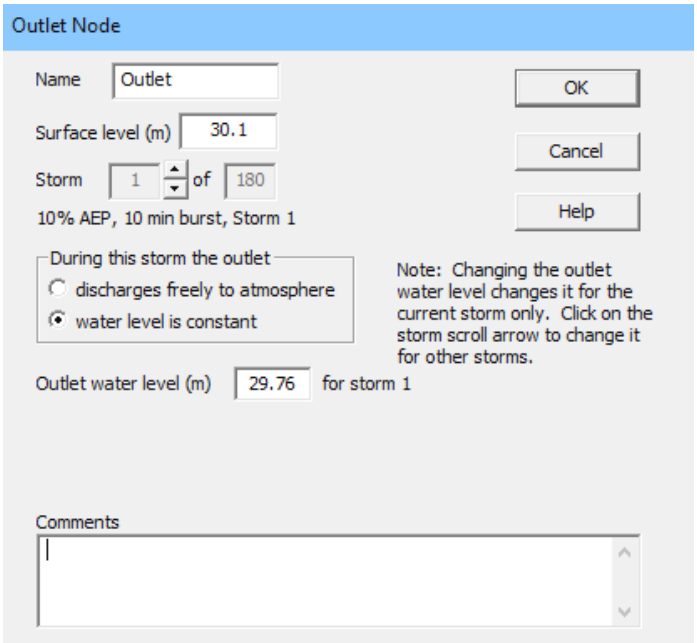


Figure 5.12 Outlet Node Property Sheet

Intermediate nodes connecting overflow routes .have the same property sheet. They can be expected to have free outfalls. Pipes and open channel systems appear as shown in Figure 5.13, with a surface level required. Nodes that link stream routing reaches in a storage routing model have the same property sheet, but no surface level is required, only the node name.

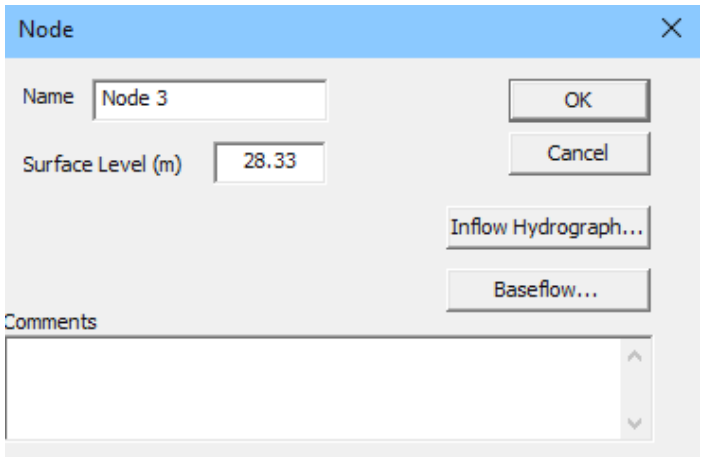


Figure 5.13 Property Sheet for an Intermediate Node

A baseflow or user-provided inflow hydrograph can be entered at each node, by clicking on the corresponding buttons in the node property sheet. This will open property sheets similar to those in Figure 5.10 and Figure 5.11.

5.3.5 Pipes

The Pipe property sheet shown in Figure 5.14 requires, as a minimum, that you enter a name, length and number of parallel pipes (default value 1), and specify a pipe type from the drop-down list box.

This information is sufficient for a Design run, in which DRAINS will specify the pipe diameter and invert levels. The pipe type chosen must be defined beforehand in the Pipe Data Base located under the **Project** menu options. Pipe lengths can be scaled from coordinates if the system is drawn to scale. Rectangular pipes can be used, though not for design, and minimum pipe diameters can be set for design in the manner described in Section 5.4.5.

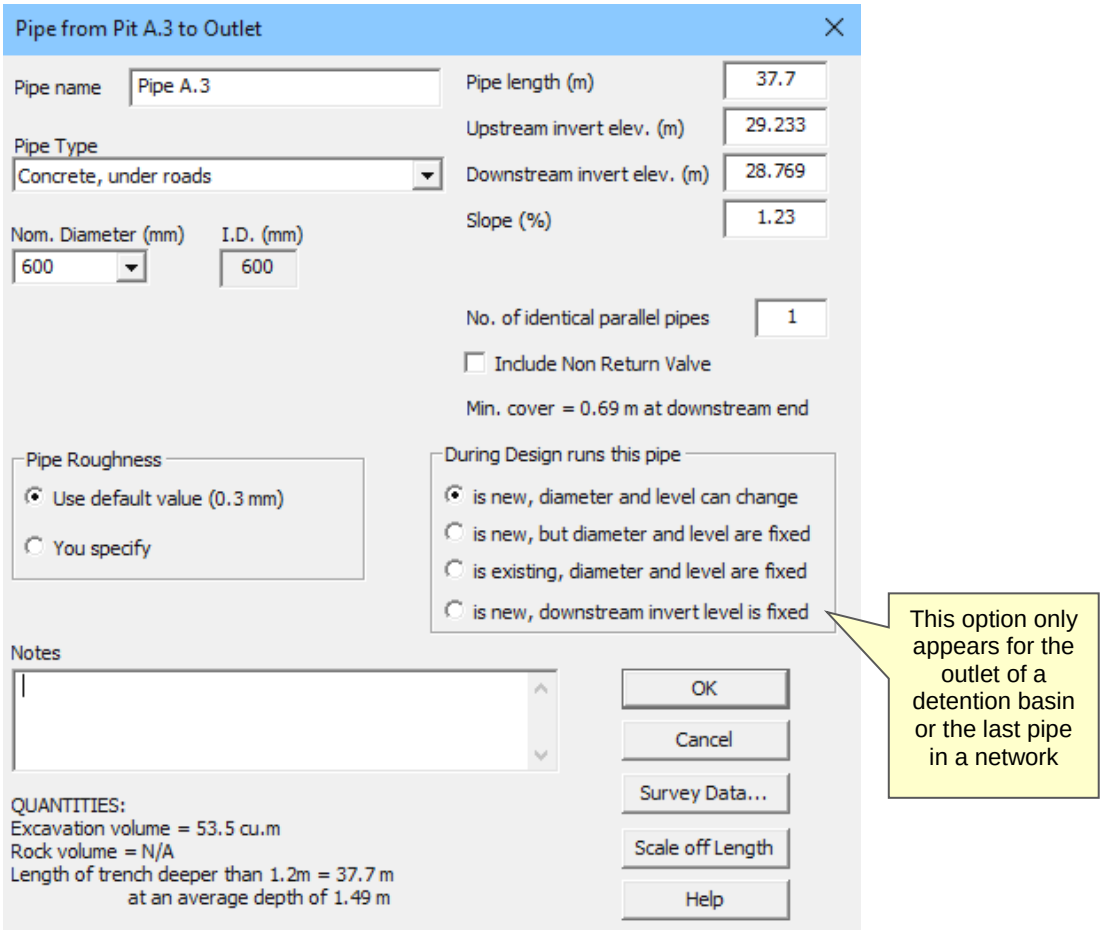


Figure 5.14 Pipe Property Sheet

If the pipe's characteristics are already known, its diameter and invert levels can be specified. If it is not to intended to change these in a Design run, the second or third choices in the 'During Design runs' box should be selected. The fourth choice only applies to the last pipe in a network. It allows the system to be designed to match a specified pipe invert level at the outlet, even if this violates constraints on the minimum allowable pipe cover and minimum slope.

The **Survey Data…** button at the bottom of the sheet opens the property sheet shown in Figure 5.15.

Surface levels can be entered at given chainages along the line of the pipe, so that the design procedure can allow for minimum cover all along the pipe. Intermediate points can be plotted in a long-section drawing, as shown in Figure 5.16.

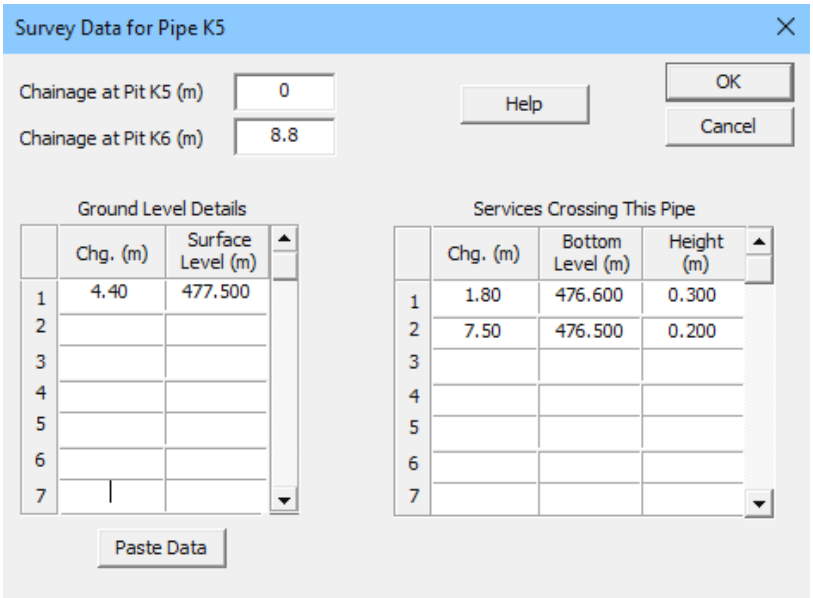


Figure 5.15 Survey Data Property Sheet for Defining Intermediate Levels along a Pipe Line and Positions of Services

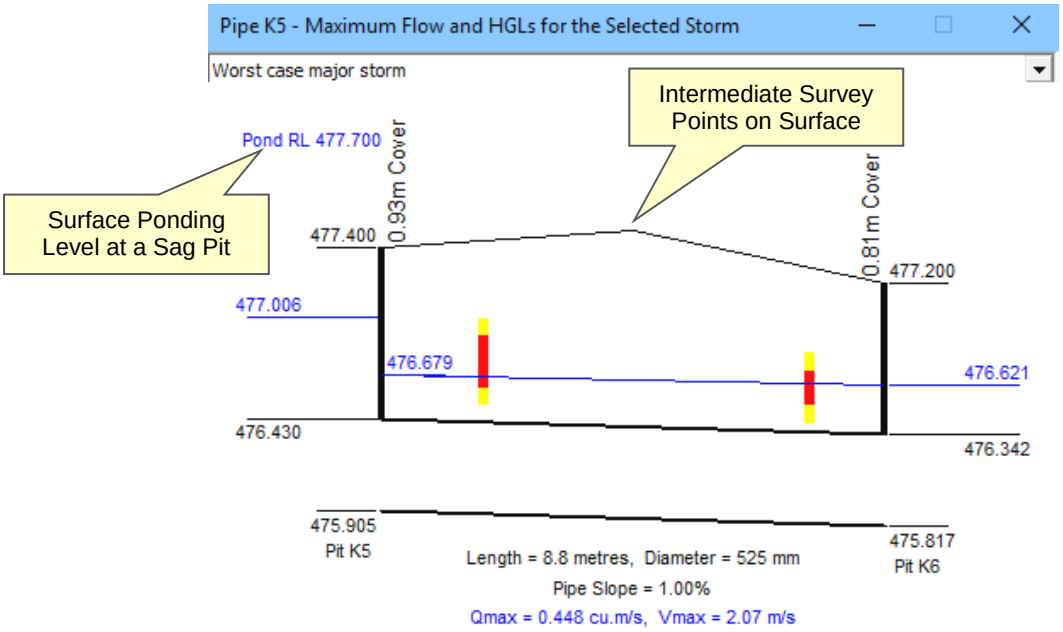
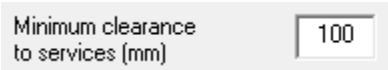


Figure 5.16 Pipe Long Section Display

This property sheet also allows the positions of other services to be defined so that DRAINS can avoid these (allowing for a vertical clearance defined in the **Options**… property sheet in the **Project** menu, as shown below.



In Design runs, DRAINS tries to locate pipes between services, going under them if no other route is possible. If this is unacceptable, the designer can selectively remove services, or make manual adjustments to the pipe cross-section and/or alignment.

The long section display in Figure 5.16 shows how the ground levels and service positions appear after a Design run is carried out, using the **Long Section** option in the pop-up menu for the pipe. The position of the pipe is defined by the intermediate low point in the surface. The pipe fits comfortably under the services, shown in red, and the required clearance, shown in yellow.
In some cases, a non-return device such as a flap gate may be installed in a pipe, preventing flows from moving upstream. This can be modelled by ticking the **Include Non Return Valve** box in the Pipe property sheet.

5.3.6 Sub-Catchments

(a) General

The sub-catchment property sheet will take different forms, depending on the hydrological model that has been specified in **Project** → **Hydrological Models…** The various forms are examined below.

(b) ILSAX Model Sub-Catchments

The form of the property sheet for a sub-catchment depends on the hydrological model defined in the **Hydrological Models…** option in the **Project** menu, as shown in Figure 1.3 and Figure 2.1. If an ILSAX type model is chosen, the sub-catchment can be divided into the paved, grassed and supplementary land-surface types illustrated in Figure 5.17:

- paved area (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system), and
- grassed areas (pervious areas, which can be lawn, bare earth, landscaped areas, bushland, porous pavement or any other pervious surface).

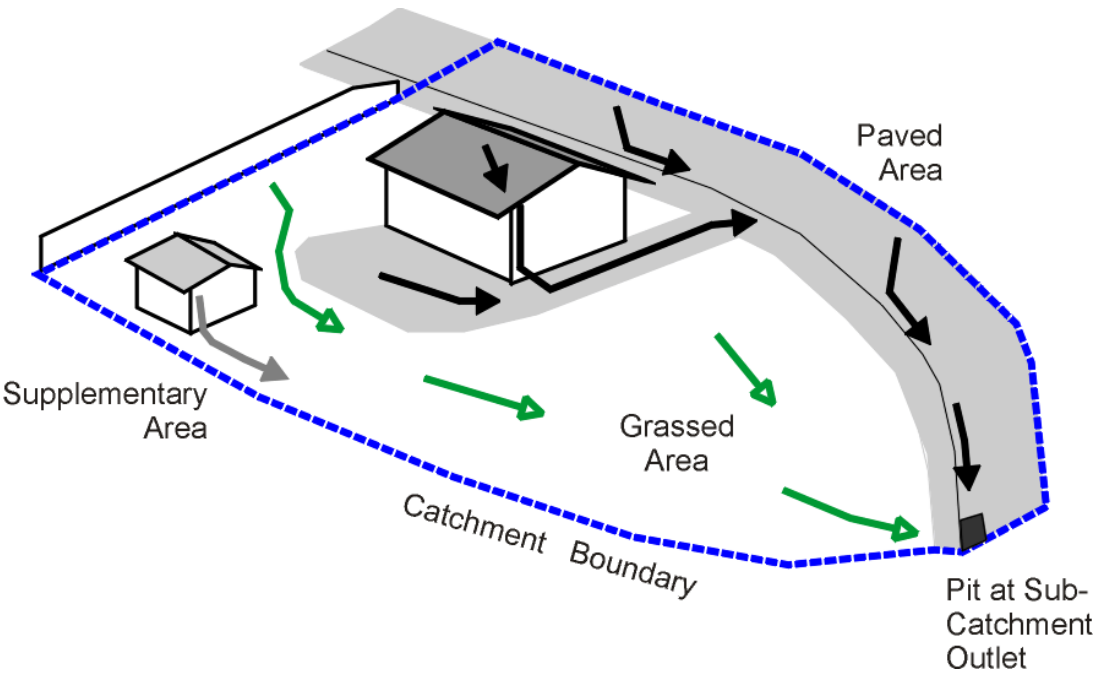


Figure 5.17 ILSAX Catchment Model Land-Use Types

The supplementary area models any impervious surfaces that drain onto pervious or grassed areas, where the runoff might be absorbed into the soil. These could be sheds, swimming pools, parking lots and other impervious areas that do not drain through pipes or over impervious surfaces to the sub-catchment outlet.

In the original specification of these land-uses in the ILLUDAS Model, Terstriep and Stall (1974) defined them using the diagrams in Figure 5.18. These indicate that the supplementary area was used to model systems where downpipes discharged directly onto grassed areas. Thus, this feature can be used to model certain water sensitive urban design (WSUD) options.

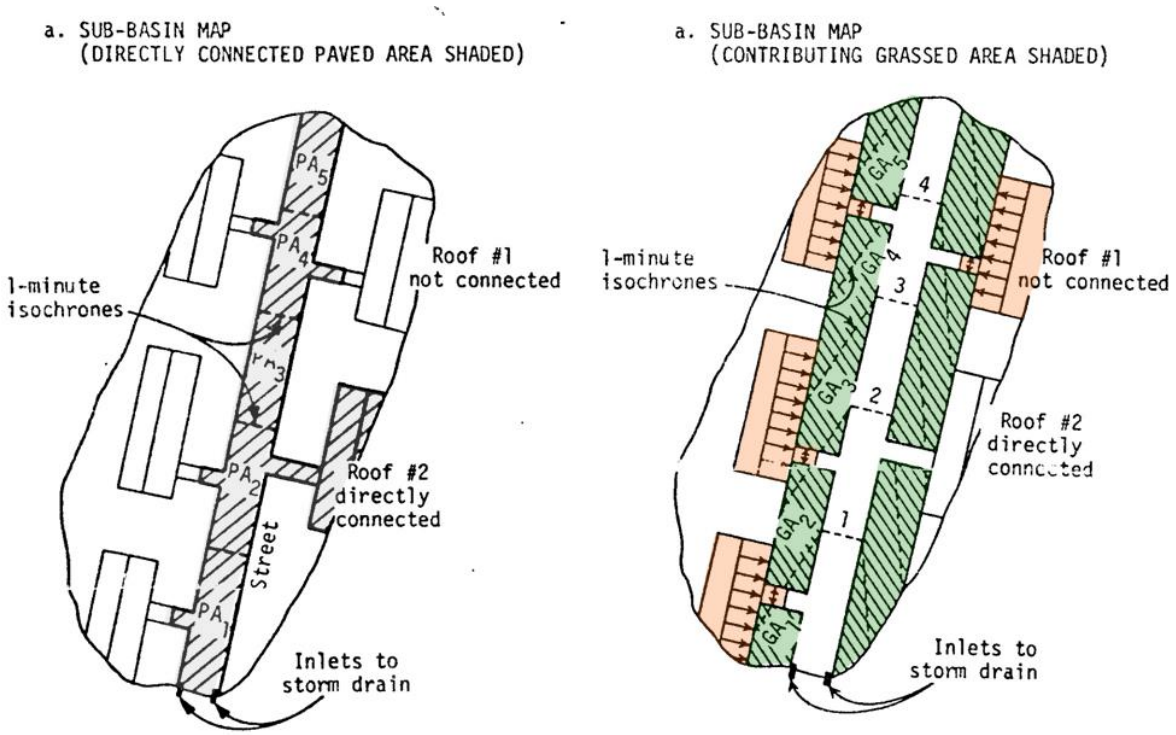


Figure 5.18 Original Definition of Land Use Areas for ILLUDAS Model

The full form of the Sub-Catchment property sheet for the ILSAX Model is shown in Figure 5.19, with the **more detailed data** option chosen in the check boxes labelled **Use**.

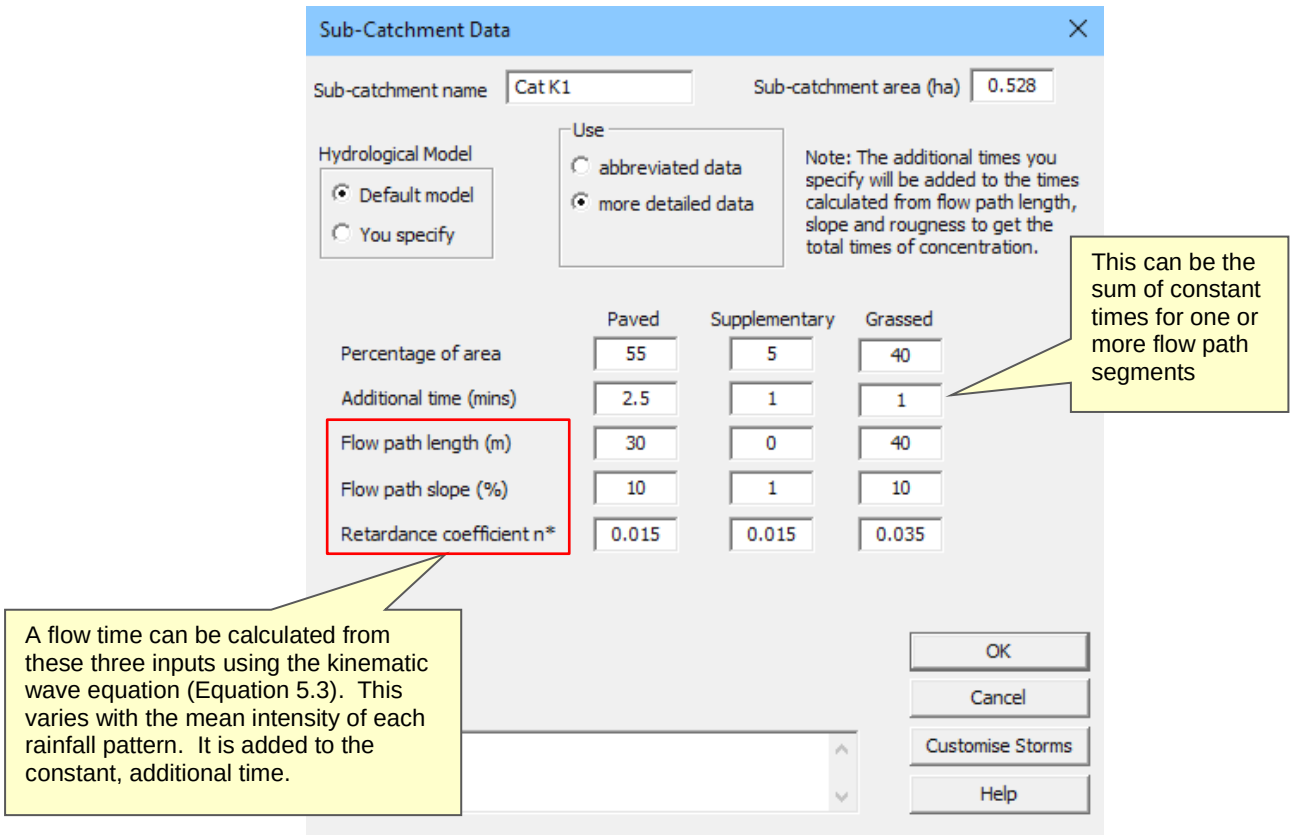


Figure 5.19 Sub-Catchment Data Property Sheet

Figure 2.16 in an earlier chapter displayed the **abbreviated data** option. In both this and the more detailed data option, you must enter the total area in hectares, and the percentages of the three land-use categories that make up the total area. The detailed option in Figure 5.19 requires additional information to establish times of entry using different flow-path components, applying the kinematic wave equation described in Section 8.3.2(d).

For each of the three land-uses, there are two flow components – a constant component and a kinematic wave calculation component. A typical flow path is shown in Figure 5.20, consisting of:

(a) a constant time for the segment from the roof of the furthest building in the sub-catchment to its property boundary (usually 1 minute for a new property drainage system or 2 minutes for an older one with possible blockages),

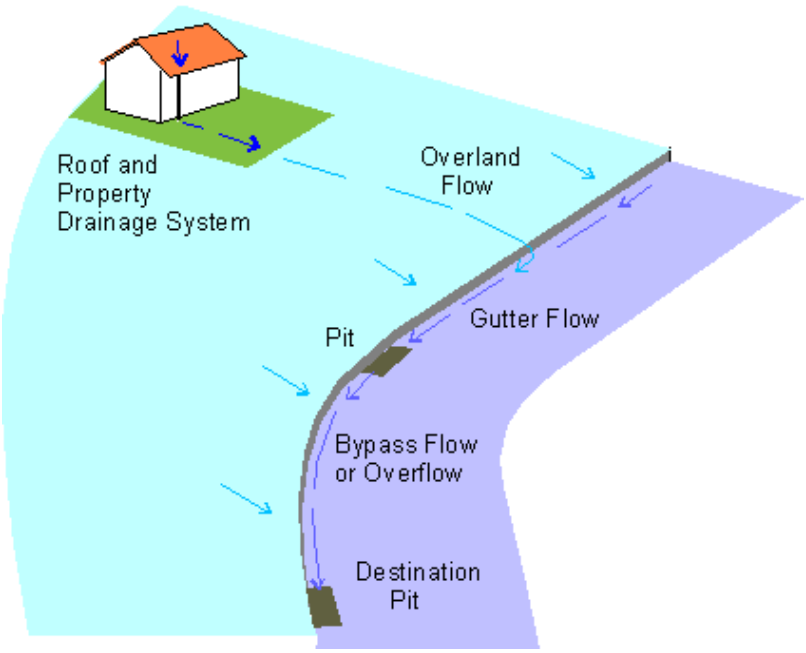


Figure 5.20 Flow Paths to a Pit

(b) a time to be calculated by the kinematic wave equation for the overland flow segment, using the specified length, slope and surface roughness n*, and

(c) a street gutter or channel segment (where a flow time can be calculated from an estimated velocity along the gutter).

Times (a) and (c) can be added to form the constant time in the property sheet.

A lag time can be used to delay the grassed are area runoff hydrograph by a time representing the travel time of runoff over an area of paved area surface between the grassed area and the sub-catchment outlet. This is illustrated in the lower part of Figure 5.21.

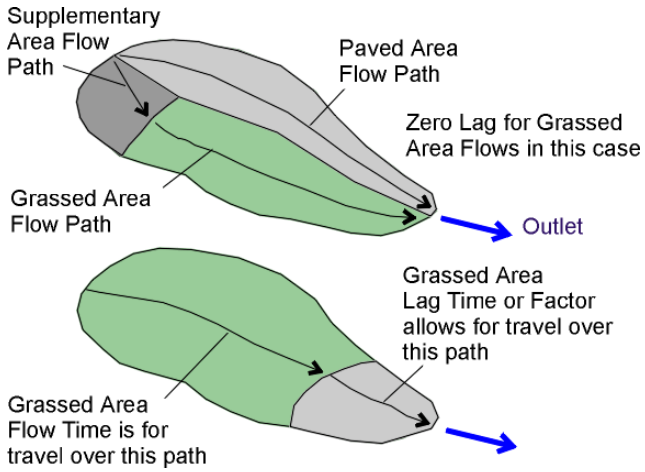


Figure 5.21 Explanation of Lags

It might be used to model a constant flow time along a street gutter or channel. (A lag used to be specified in the sub-catchment property sheet, but this has been discontinued, except in older models where this was specified.) The same effect can be achieved by splitting a sub-catchment into one containing the paved area and another containing the paved and supplementary areas. The latter can be connected to a pit by an overflow route with the required lag time, as shown in Figure 5.22.

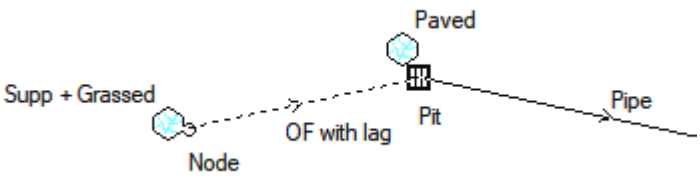


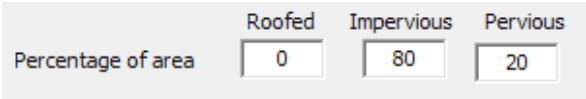
Figure 5.22 Splitting of Sub-Catchment

(c) Rational Method Sub-Catchments

The property sheet for rational method models has a very similar format to the ILSAX model sub-catchment property sheet, the main difference being that sub-catchments are divided into pervious and impervious areas, instead of paved, supplementary and grassed. An example is shown in Figure 5.23.

The setup is the same for both 1987 and 2016 rainfall inputs.

The sheet is similar for the three available types of rational method model (General, Australian Rainfall and Runoff, 1987, and Standards Australia AS/NZS 3500.3:2015). You will need to enter the percentage of roofed areas for the AS/NZS 3500.3 method.



The option of having detailed inputs to calculated times of concentration from the Kinematic Wave or Friends formulae is not available for the AS/NZS 3500.3 method. The General and ARR87 methods can do this, as shown in Figure 5.24.

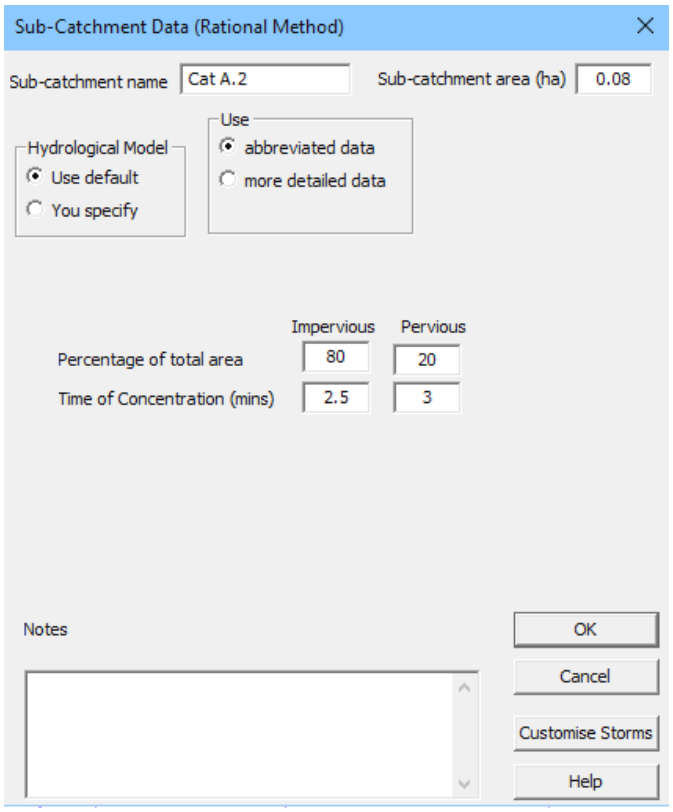


Figure 5.23 Rational Method Sub-Catchment Property Sheet

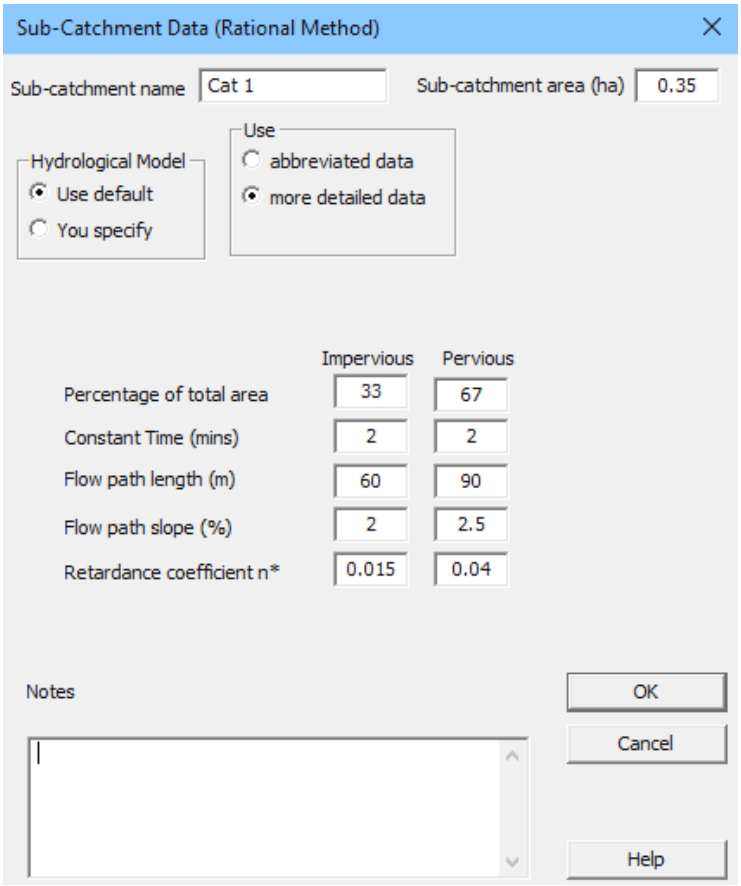


Figure 5.24 Rational Method Sub-Catchment Property Sheet

If a DRAINS model is converted to a rational method model, the paved and supplementary area percentages will be added to form the impervious area percentage. The impervious area constant time will be the paved area constant time and the pervious area constant time will be the grassed area constant time. With the current version of DRAINS, no adjustments are made for supplementary area times or for grassed area lag factors. If allowance is to be made, it will have to be done for each sub-catchment individually.

(d) Extended Rational Method Sub-Catchments

The property sheet used is the same as that for the rational method using the ARR87 procedure, as shown in Figure 5.23 and Figure 5.24. No additional inputs are needed.

(e) IL-CL Models

The ARR 2016 initial loss – continuing loss (IL-CL) model uses the sub-catchment property sheet shown in Figure 5.25.

Text boxes for the effective impervious area (EIA) and remaining catchment parts are arranged as an array with two columns. In the first row, you can enter the percentages of each surface type within the sub-catchment. With the **more detailed data** option, you can enter factors for the kinematic wave equation or Friends formula for times of concentration.

The EIA is not the same as the actual impervious area; in fact, it is about 60% of the total impervious area, according to ARR 2016 (see Section 8.3.6).

(f) Storage Routing Model Sub-Catchments

The three storage routing model described in Section 8.3.7, RORB, RAFTS and WBNM, require different inputs, due to their different structures and parameters.

Figure 5.26 shows a RORB sub-catchment input. Since no routing calculations occur in a RORB sub-catchment in DRAINS, only the sub-catchment area and impervious area percentage are required.

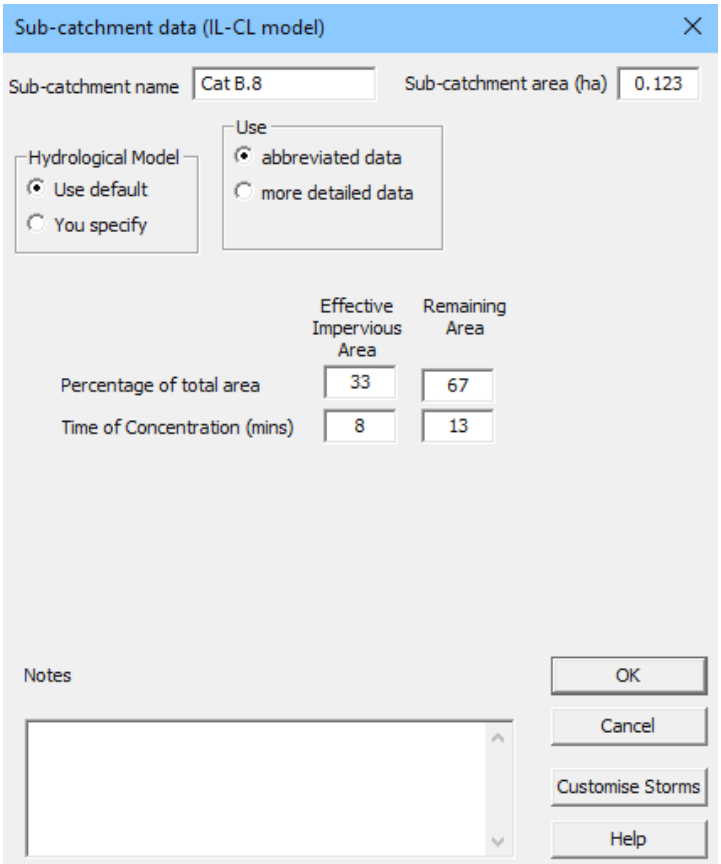


Figure 5.25 IL-CL Sub-Catchment Property Sheet

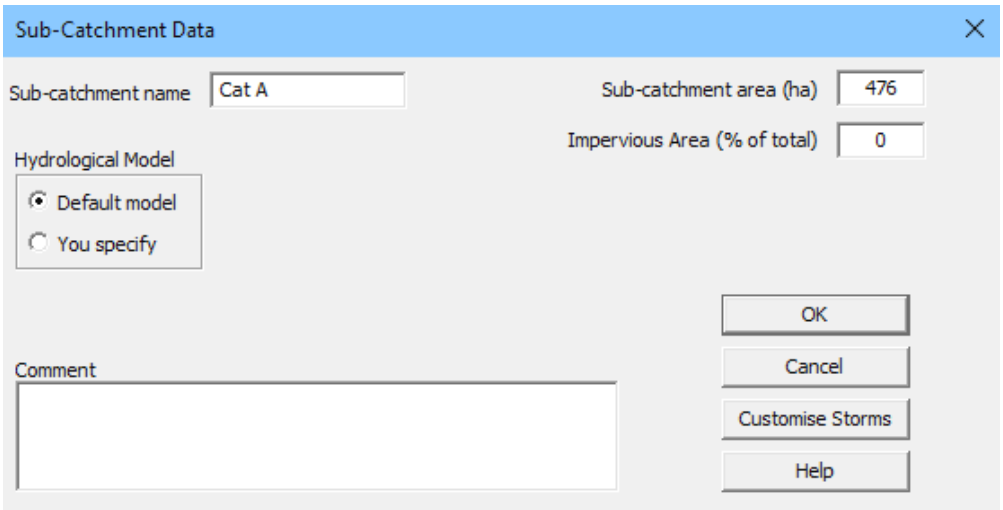


Figure 5.26 RORB Model Sub-Catchment Property Sheet

The sheet for a RAFTS sub-catchment shown in Figure 5.27 requires more information. In addition to catchment area and percentage impervious, a sub-catchment slope and a Manning's n for the pervious portion of the catchment are required to calculate hydrological losses and to define a routing parameter.

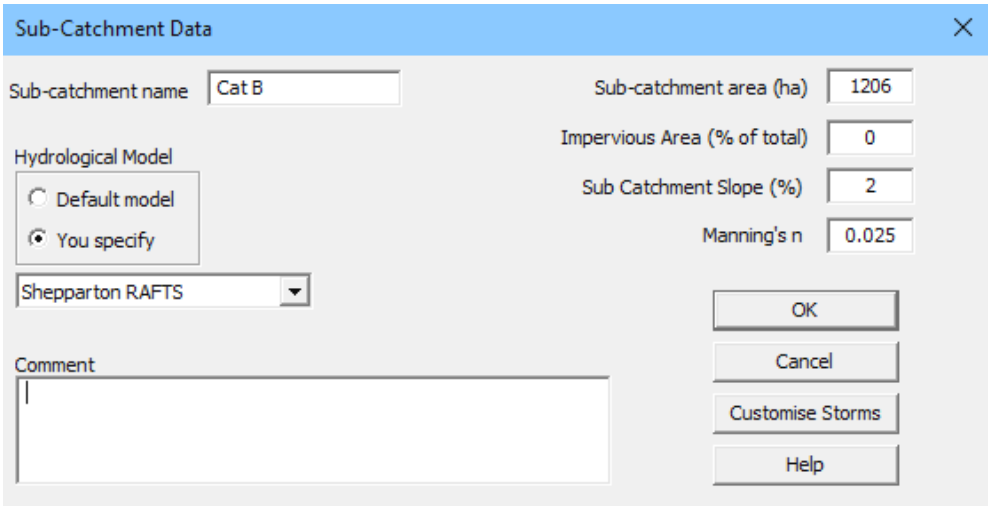


Figure 5.27 RAFTS Model Sub-Catchment Property Sheet

The property sheet for the Watershed Bounded Network Model (WBNM), shown in Figure 5.28, is the same as that for the RORB Model. However, routing does occur in WBNM sub-catchments, using equations based on the sub-catchment area.

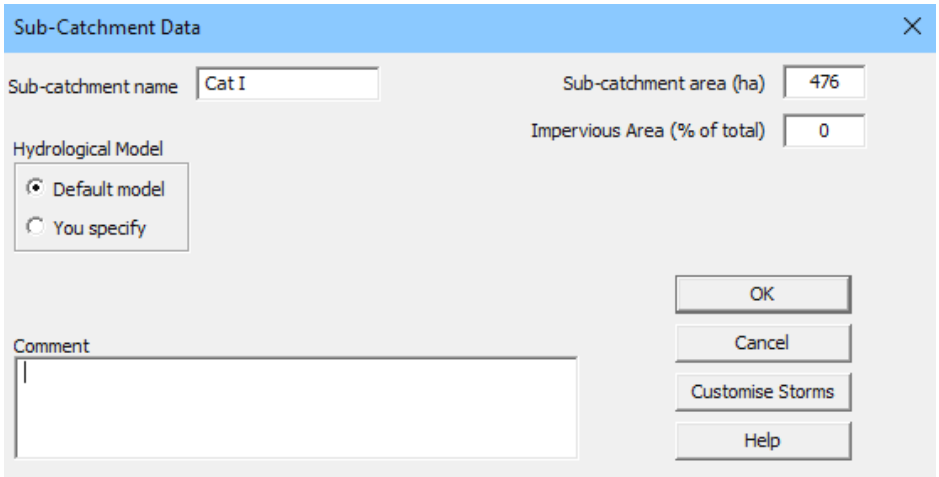


Figure 5.28 WBNM Model Sub-Catchment Property Sheet

(g) Customising Storms

The **Customise Storms** button near the bottom of the ILSAX model Sub-Catchment property sheet allows special features to be chosen, using the property sheet shown in Figure 5.29. These features are useful where you wish to explore the effects of varying the rainfall intensity and timing of storms over the catchment area.

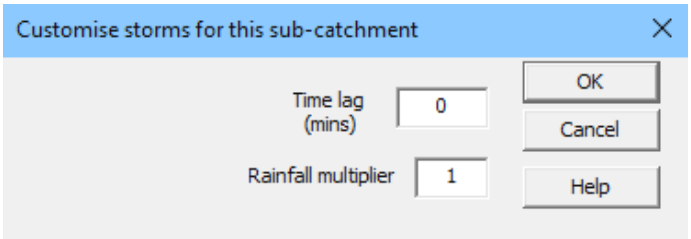


Figure 5.29 Property Sheet for Customising Storms

A time lag can be specified and the storm patterns can be multiplied by a constant rainfall multiplier. These allow for the following situations:

- Areally-varying intensities across a catchment with the same storm pattern can be modelled by setting up a rainfall pattern in the Storm Data Base for each intensity used and selecting appropriate ones for each sub-catchment. A simpler alternative is to set a suitable multiplier for each sub-catchment in the property sheet shown in Figure 5.29.

- A moving storm can be described by specifying different lag times for the start of the storm for each sub-catchment.

In older versions of DRAINS, it was possible to apply separate rainfall patterns at different points in the catchment. This can no longer be done. Such requirements are rarely applied in urban catchments.

5.3.7 Overflow Routes

(a) General

These paths define the routes taken by stormwater flows that bypass on-grade pits and/or overflow from pressurised pipe systems. DRAINS uses this information to calculate flow characteristics along the routes. The property sheet takes different forms depending on the hydraulic model being enabled. Three alternative routing processes may be involved:

i. translation (shifting of a hydrograph by a time lag without changing its shape), employed in the standard and obsolete basic hydraulic calculations,

ii. kinematic wave calculations, employed in stream routing channels with RAFTS storage routing calculations,

iii. full unsteady flow modelling, employed in premium hydraulic model calculations.

Overflow routes between pits or nodes can be divided into a number of overflow route segments, separated by nodes. They can also combine at a node, as shown below:

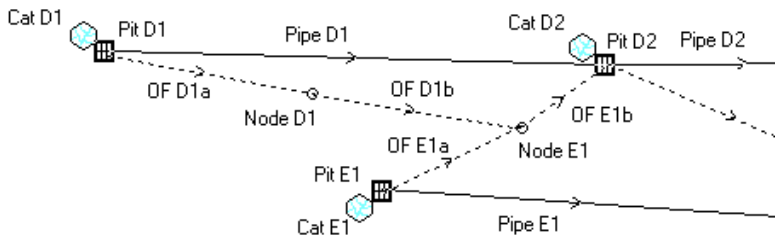


Figure 5.30 Linkages of Overflow Routes through Nodes

A path made of two or more segments can have differing cross-sections, slopes, etc. In premium hydraulic model calculations, DRAINS traces HGLs through these segments at various time steps, allowing for sub-critical and super-critical flows.

(b) Basic and Standard Hydraulic Model Inputs

Clicking on an overflow route opens a two- or three-page property sheet. The first page **Basic Data**, shown in Figure 5.31, can take different forms depending on the DRAINS capabilities that are enabled by the hardware lock being used.

The lower sheet, providing inputs for both that standard and premium hydraulic models, may seem complex. For the basic hydraulic model (now obsolete) and the standard model, all that is required on this page is a name and an estimated time of travel. During calculations, any overflow hydrographs will be delayed by this time of travel. The information on the second, **Cross Section Data** page, which is the same for all hydraulic models, is described in Section (e).

You can also click the **Set by DRAINS** selection under **Travel Time (mins)** and enter the flow path length. DRAINS will work out a suitable time from the geometric information provided. The invert levels are not required in standard hydraulic calculations.

(c) Premium Hydraulic Model Inputs

If premium hydraulic model calculations are enabled, the first page of the property sheet should have the form shown in Figure 5.32. Rather than specifying a travel time, the length of the overflow route and invert levels at each end of the flow path are required. DRAINS uses this with information from the **Cross Section Data** page to route flows along the route.

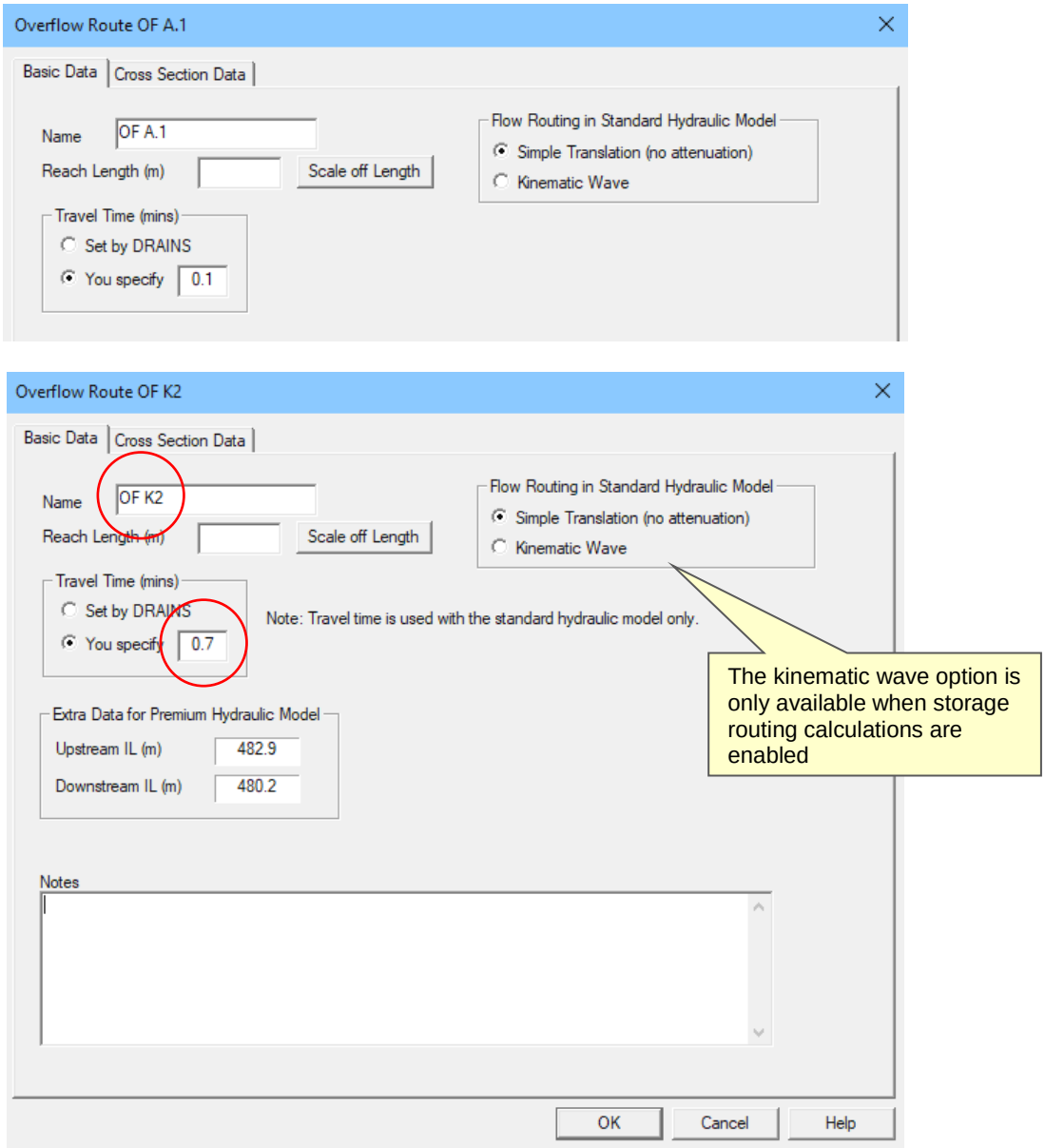


Figure 5.31 First Page of the Overflow Route Property Sheet (Alternative Forms)

If an overflow route leaves a sag pit, you must also specify control weir information in a third, **Overflow Weir Properties** page of the overflow route property sheet, shown in Figure 5.33. This only appears of the premium hydraulic model is enabled.

This is to provide a hydraulic control representing a barrier such as the crown of a road or an entrance to a property. There are three choices on the page:

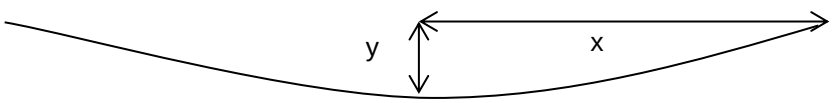
i. a rectangular weir (with a weir coefficient of 2.0),

ii. a parabolic weir representing a vertical road alignment, and

iii. a general depth-discharge relationship that can be set up on a spreadsheet and transferred to DRAINS, and

iv. a 'No weir' option that can be applied when water wells up and flows aver a flat surface.

The rectangular weir requires a weir width (the coefficient is taken to be 1.7); while the parabolic relationship requires a depth at a given distance from the low point (as shown below), while the elevation-discharge relationship is more general.



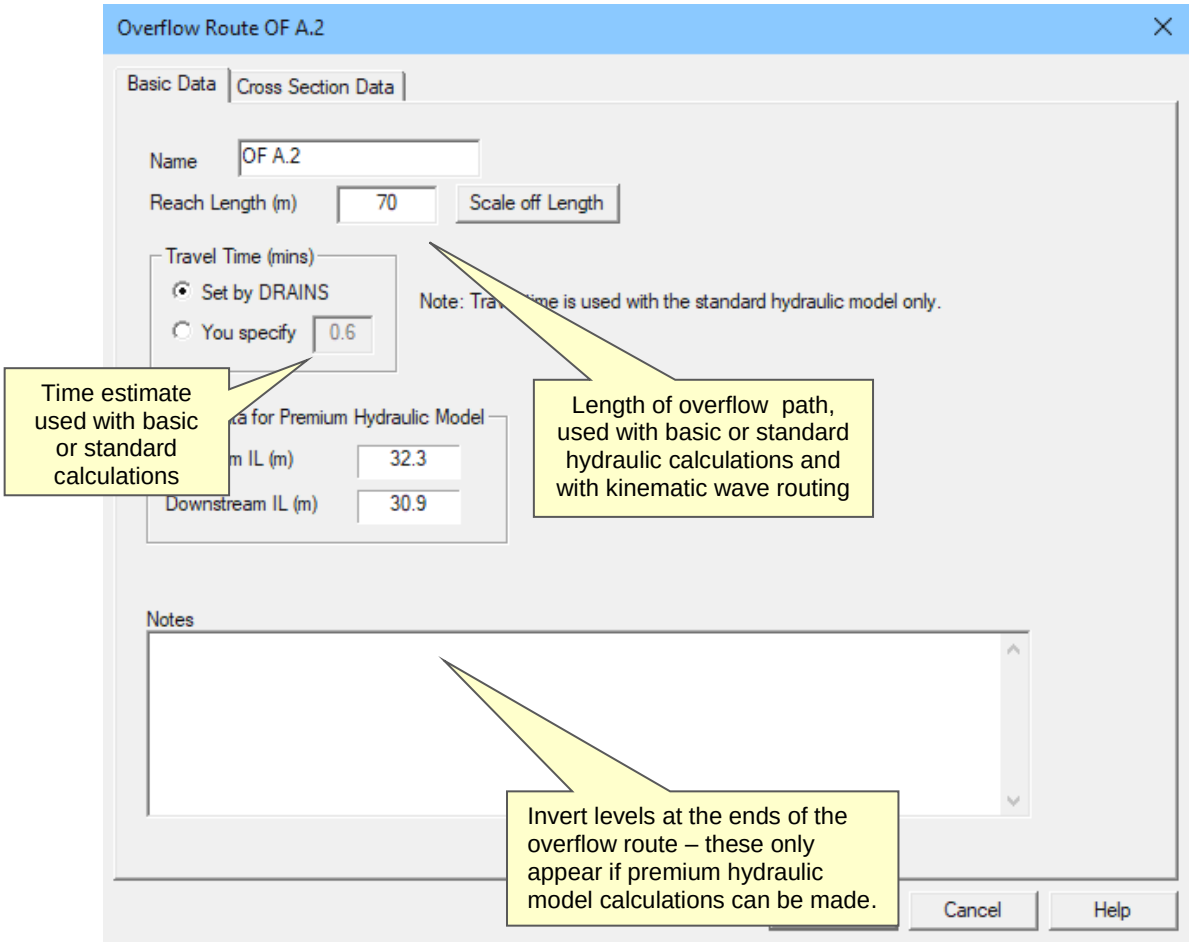


Figure 5.32 First Page of Property Sheet for Premium Hydraulic Model Calculations

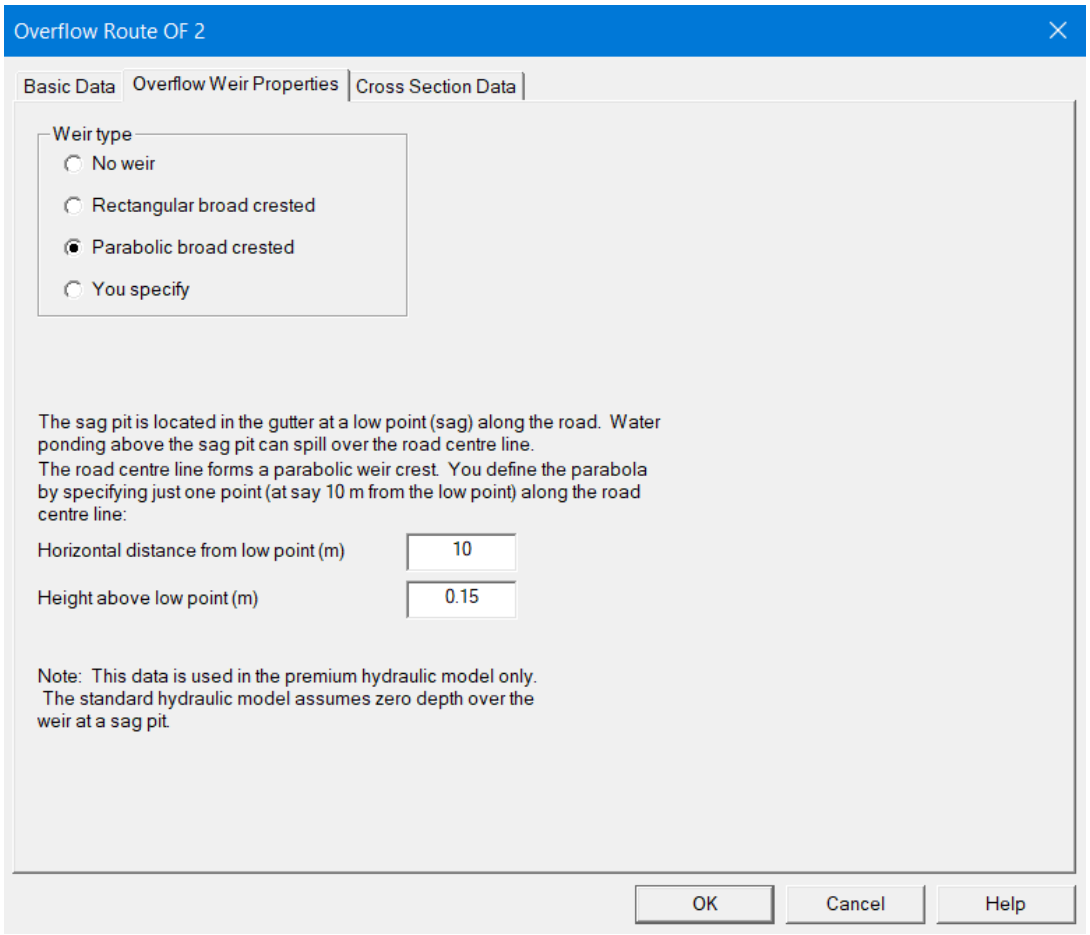


Figure 5.33 Weir Properties Page in Overflow Route Property Sheet

Since the premium hydraulic model must deal with potentially very high flowrates in 100 year ARI and PMP storms, it models situations where there are chains of storages and overflow routes. The storages are likely to be at sag pits, but can also occur at ponding locations that are created in large storms. The overflow routes connect the storages. Both storages and overflow routes can be small or extensive.

A typical situation is shown in Figure 5.34. The overflow route will connect the ponded water on each side of the street. It will begin at the road crown and end at the downstream pit.

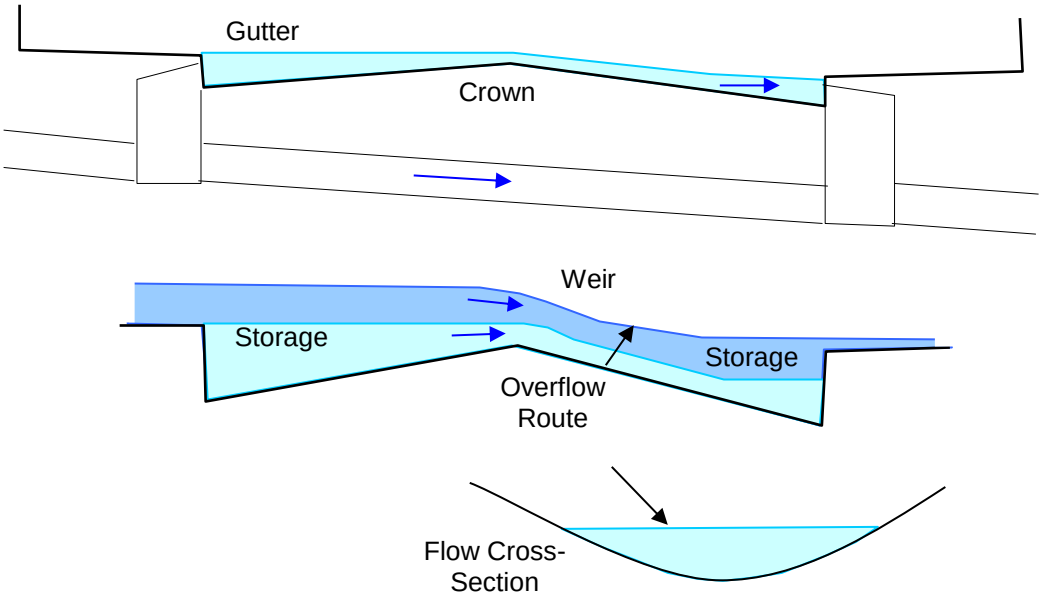


Figure 5.34 Flow Through a Road Low Point

During premium hydraulic model calculations, DRAINS will monitor the ponded levels in sag pits at each time interval. When the defined ponding level, assumed to be the level at which a spill will start to occur, is exceeded, overflow rates and ponding levels will be determined using the weir control specified in the overflow route property sheet (Figure 5.33). DRAINS will also calculate depths of flow in the overflow route and allow for a 'tailwater level' due to ponding downstream, if the overflow route terminates in a sag pit or detention basin. If the water level in the overflow route is greater than the weir crest level, the weir discharge will be reduced using a submerged weir equation, as described in Section 8.6.4.

It is important to establish pipe and overflow route levels and other details correctly. DRAINS provides a large number of checks to detect errors, but final responsibility for the accuracy of the model remains with the user.

(d) Kinematic Wave Routing Inputs

Overflow routes can also be used to model stream linkages in a RAFTS type of storage routing model, with the inputs shown in Figure 5.35. If this feature is enabled your hardware lock you can model urban overland flow paths using the kinematic wave routing procedure. While this has some advantages over the basic calculations for overflow routes from pits, the best procedure is to employ the premium hydraulic model if this is available.

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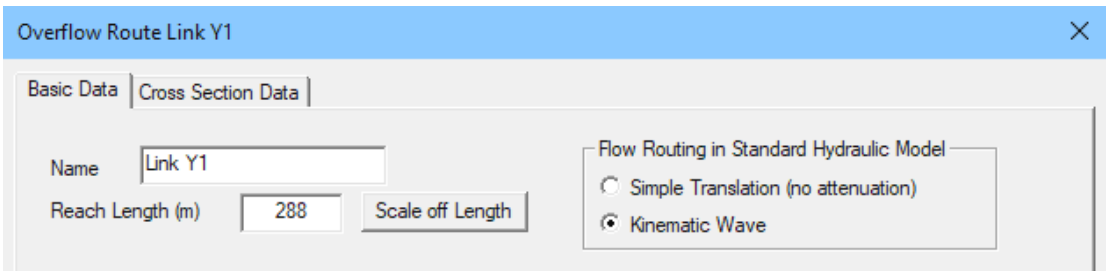


Figure 5.35 First Page of the Overflow Route Property Sheet with Kinematic Wave Routing (Top Portion)

(e) Definition of the Flow Cross Section

On the second page, you should specify an overflow path cross-section from the Data Base set up in the **Project** menu, described in Section 5.4.7. The section may be a roadway, as shown in Figure 5.36, or a trapezoidal, rectangular or other channel shape.

.

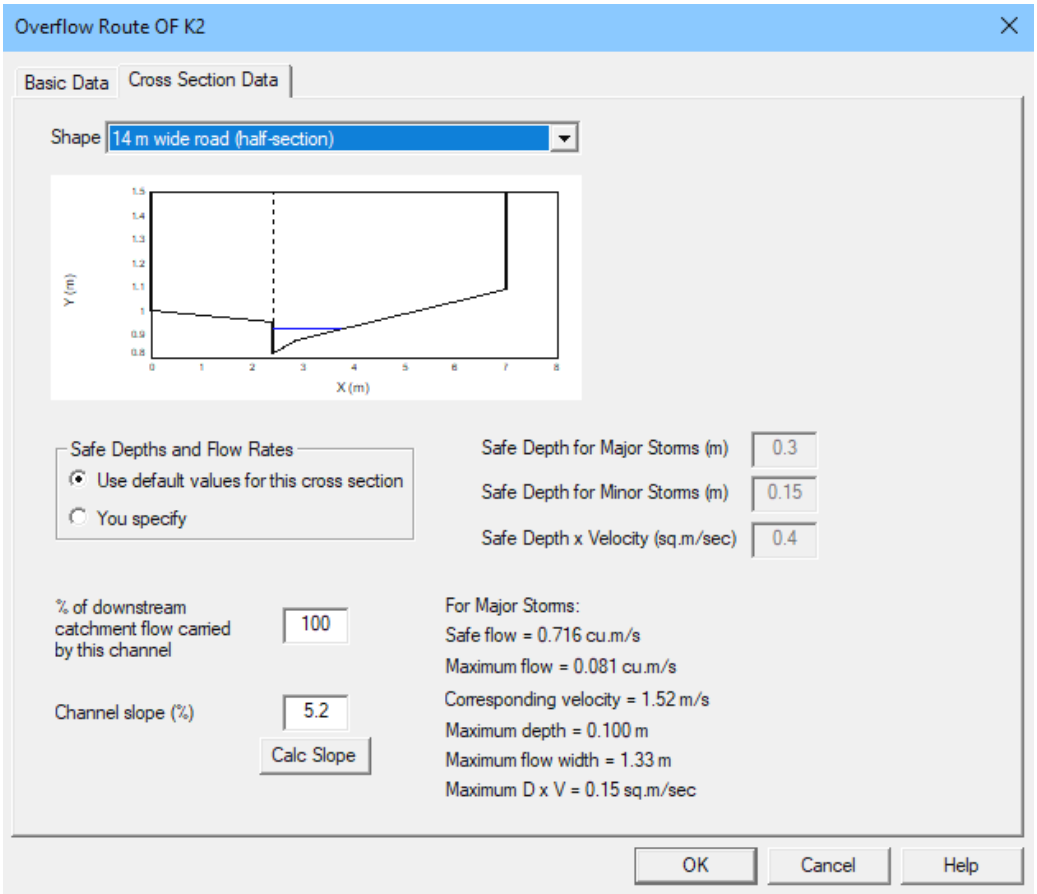


Figure 5.36 Cross-Section Data Entry in Overflow Route Property Sheet

Here it is necessary to select:

i. a flow cross-section shape from the list box,

ii. the percentage of flows in the overflow route estimated to come from the downstream sub-catchment, as explained below, and

iii. a flow path channel slope.

(With the storage routing model option shown in Figure 5.35, DRAINS uses the cross-section in its kinematic wave calculations. In both procedures, it will calculate flow characteristics such as depths and widths, assuming that normal depth occurs at the flow cross-section at the flowrate and slope indicated.)

As overflows from a pit pass through a sub-catchment downstream, it is likely that they will combine with the surface flows on that sub-catchment. When this happens, flowrates will increase along the flow path.

DRAINS defines flow characteristics at a selected critical location, which will usually be at a pit receiving overflows from this overflow route, combined with flows from its local sub-catchment. This location could also be just downstream of the pit from which the overflow occurs. The position is defined by the percentage of the downstream catchment's flow that is carried by the cross-section, which must be entered into the property sheet in Figure 5.36.

Figure 5.37 shows how a downstream sub-catchment may contribute to flows. Here the critical point is the downstream pit, which is in a sag. An estimated 65% of Catchment 2 drains to this point, on the left side of Pit 2.

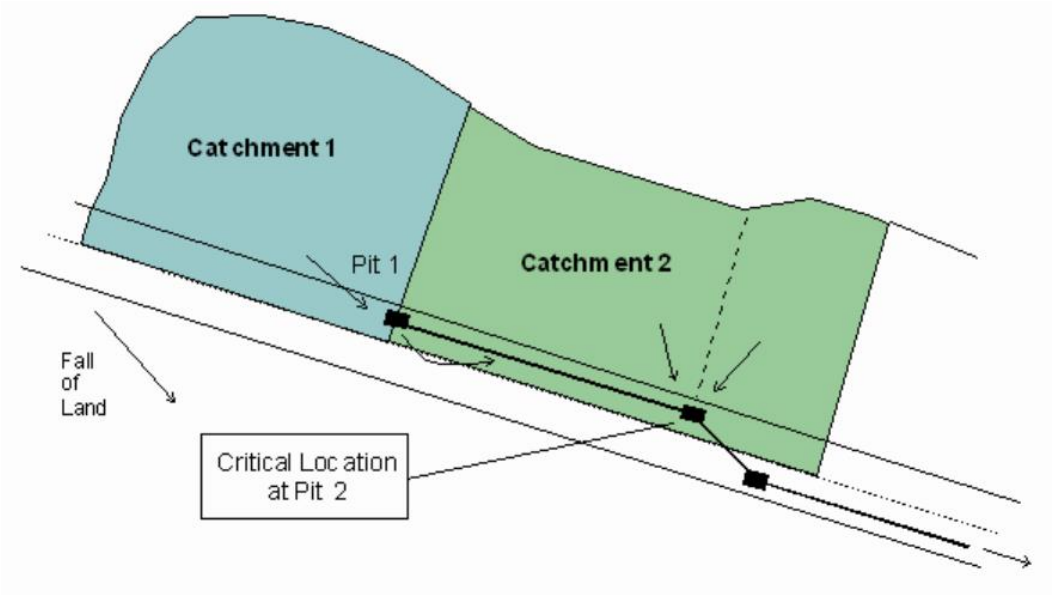
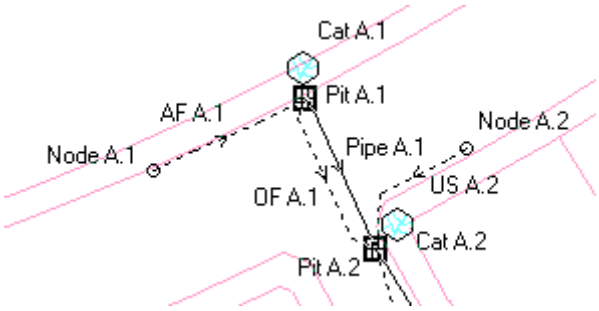


Figure 5.37 Effect of a Lower Sub-Catchment upon Overflows

If the property sheet for the overflow between Pit 1 and Pit 2 specifies a percentage of downstream catchment of 0%, the flowrate displayed in the results will be the overflow from Pit 1. This applies to a point just below Pit 1. If the percentage is set at 65%, the flowrate displayed will be the overflow from Pit 1 plus 65% of the flow from Catchment 2. This sum is calculated from addition of hydrographs, and represents the flow at a point just upstream of Pit 2. By varying the specified percentage between 0% and 65%, we can define surface flows at any point along the flow path.

Using this feature, you can examine the flows approaching pits at the top of a pipeline, as shown below.



Although the overflow routes originate from a node with no connected sub-catchment, a percentage of the flows from sub-catchment Cat A.1 can be specified and the flow characteristics along the flow path determined.

When applying the Design procedure, DRAINS focuses upon the flow at the point defined by the specified percentage of the downstream catchment. This can represent a critical feature such as a child care centre or bus stop that needs to be specially protected. (Note that this feature will only be meaningful on long overflow routes. The flows calculated will not be accurate for short flow paths where the calculated normal depth cannot be established and paths across streets or around corners.)

By changing the value in the box labelled 'Channel slope (%)', the slope can be varied along the entire flow path length to reflect a concave or convex longitudinal profile, as opposed to a constant slope.

Overflow routes can be divided into several segments, linked through simple nodes. These segments can have different properties such as cross-sections and slopes. Two or more overflow routes can be connected to a node, and their flows combined, as shown later 5.3.7.

As described in the next section, the overflow path from a detention basin acts as a high-level outlet to the basin, and requires additional information to an overflow from a pit, this being set out on an additional page of the property sheet.

5.3.8 Detention Basins

DRAINS can incorporate large or small detention and retention basins into drainage networks. To define a basin or storage fully, at least two components are required. The first is the basin, which is defined in the Detention Basin property sheet, an example of which is shown in Figure 5.38. This includes a basin name, options to set an initial water level and infiltration characteristics, an elevation-surface area (or elevation-volume) relationship, and a low level outlet specification.

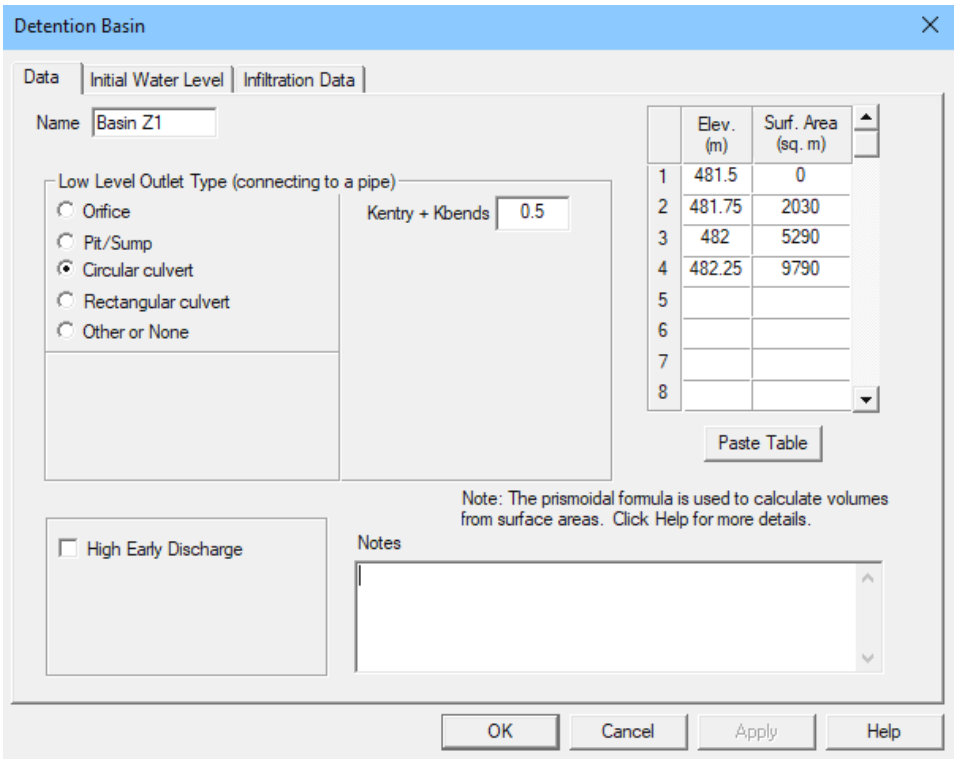


Figure 5.38 Detention Basin Property Sheet

DRAINS applies as a default an elevation-surface area relationship rather than an elevation-storage volume relationship, which will be easier for users, since volumes are calculated from surface areas in most cases. Previously-developed models that specify volumes, shown in Figure 5.39, are still supported in DRAINS, but both types of elevation-based relationship cannot be used in the same model. Elevation-volume relationships can be used in projects by selecting an option in the **Project Options** property sheet opened from the **Project** menu.

When working with elevation-surface area relationships, DRAINS employs an interpolation procedure for calculating volumes corresponding to certain elevations, with a fitted curve rather than the set of straight-line segments. The elevation-surface area relationship must use levels to the same datum as the rest of the drainage network. Relationships can be calculated in a spreadsheet and pasted into DRAINS Using the **Paste Table** button. Numbers must be arranged into two columns, as shown to the right.

700.5	0
701.1	1275
701.4	6170
701.7	17760
701.8	19000
701.9	20000
712	22000

These are then selected and the **Edit** → **Copy** option is used to place the data on the clipboard. Transferring from the spreadsheet program to DRAINS, the data can be entered using the **Paste Table** button.

The Low Level Outlet Type (connecting to a pipe) buttons offer five choices:

(a) an orifice acting as a free outfall of the type commonly used in on-site stormwater detention (OSD) storages in Sydney;

(b) a pit or sump outlet;

(c) a circular conduit (the example shown above);

(d) a rectangular channel, similar to the circular outlet; and

(e) no low-level outlet.

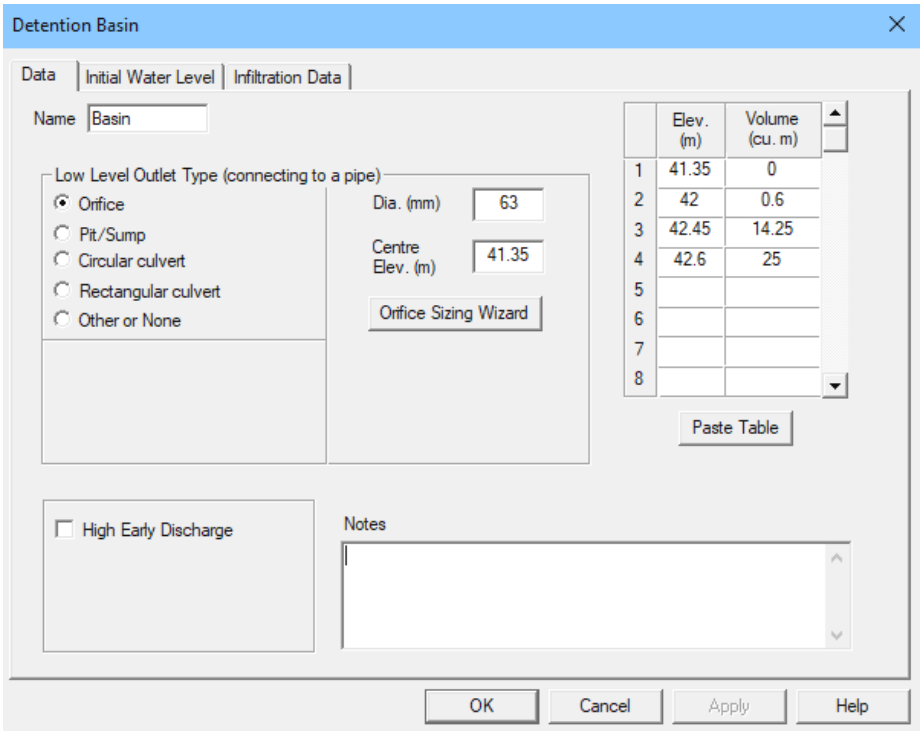
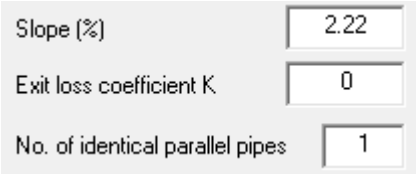


Figure 5.39 Detention Basin Property Sheet with Elevation-Storage Relationship

These are then selected and the **Edit** → **Copy** option is used to place the data on the clipboard. Transferring from the spreadsheet program to DRAINS, the data can be entered using the **Paste Table** button.

For pipes, it is only necessary to specify the entry and bend losses, as shown in Figure 5.38. The rest of the information is included in the property sheet for the outlet pipe. This is the same as the sheet for a pipe located between pits, as shown in Figure 5.14 , except that there is provision for an exit loss different from the loss of 0.0 assumed by DRAINS.



If an orifice outlet is selected, the property sheet takes the form shown in Figure 5.40.

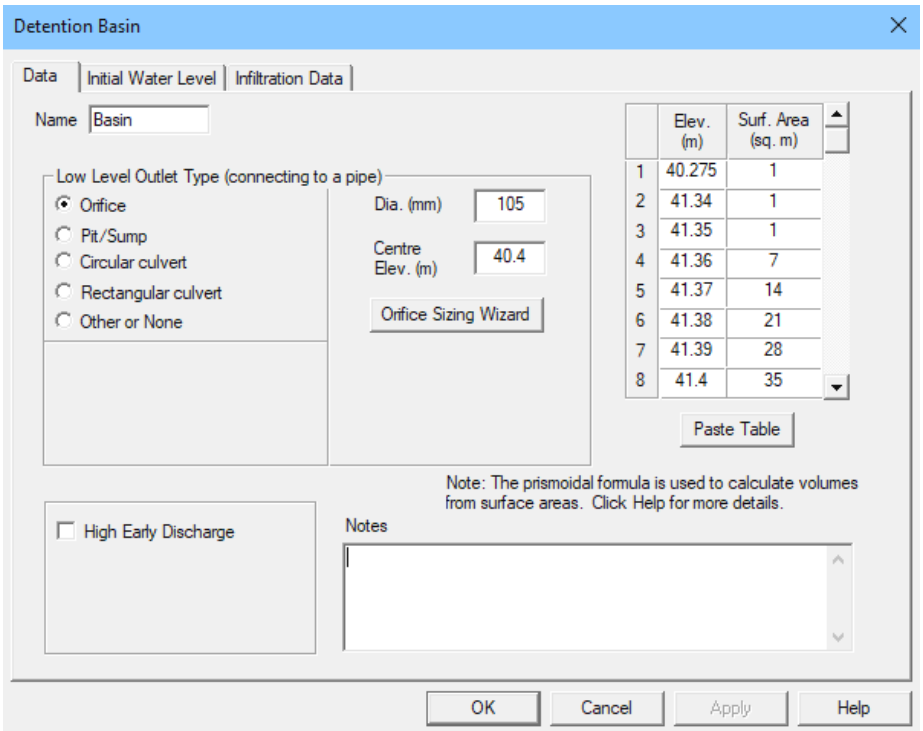


Figure 5.40 Detention Basin Property Sheet with an Orifice Outlet

You must supply a diameter (mm) for a circular orifice, and the elevation of its centre. The check box labelled High Early Discharge allows the modelling of a high early discharge pit, a special type of OSD system. You must provide a crest level and length for an internal weir that is a feature of this kind of storage. Further details of these options are given in Section 8.8.3.

The pit/sump outlet type may apply in detention basins with a pit outlet, and situations where basins are created unintentionally by a barrier such as a road embankment. It assumes a pit pressure change coefficient of 4.0 and does not allow for blockage, which must be incorporated into the elevation-discharge relationship that is specified.

If this outlet type is selected, the outlet changes to that shown in Figure 5.41. A pit family and size is to be selected using the same drop-down list box as in the Drainage Pit property sheet.

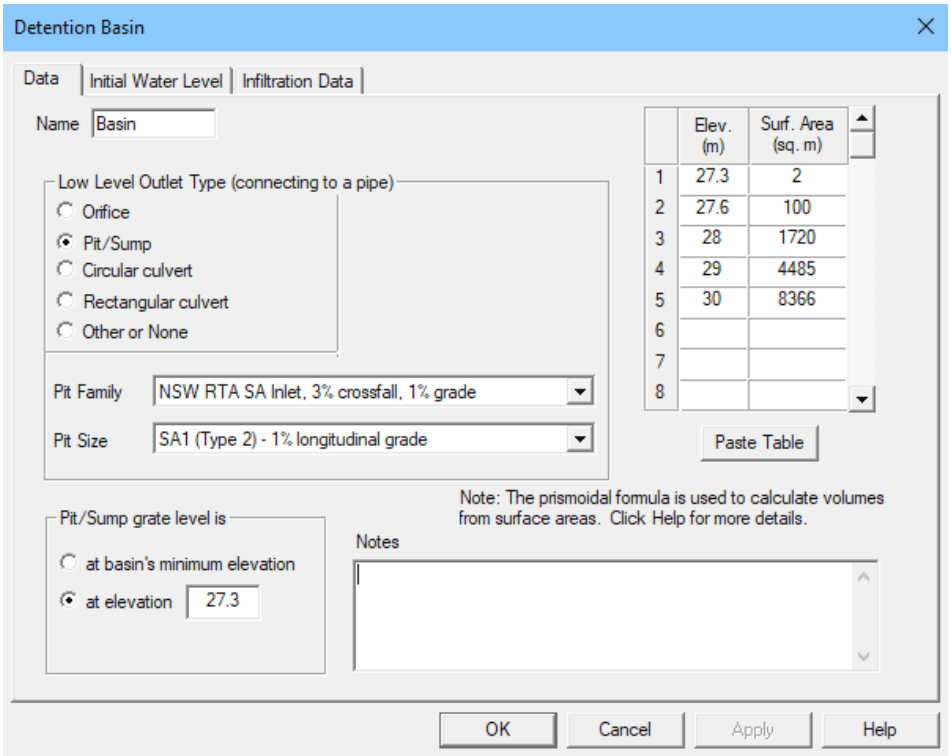


Figure 5.41 Detention Basin Property Sheet for a Pit/Sump Outlet

This type of outlet is prone to instabilities in calculations where there are incoming pipes that are below the surface of the basin, and in the past, it was usually necessary to locate the basin 'off-line', connecting to a sealed pit through a large, artificial pipe with a capacity well in excess of the inlet. An arrangement of this type is shown in Figure 5.42. Surface overflows are directed to the basin, and the main overflow comes out of it.

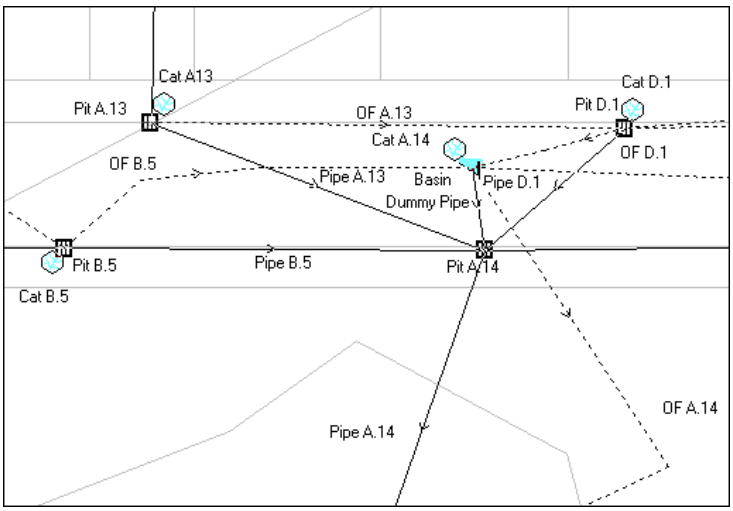


Figure 5.42 Arrangement for a Basin with a Pit/Sump Outlet

The pipe leaving a basin is specified in the same way as a normal pipe. If this is rectangular, it may be necessary to set up a special pipe type and size in the Pipe Data Base, as described in Section 5.4.5.

For some basins in low-lying areas where backflows may occur, a non-return valve may be specified in the Pipe property sheet. Only one low level pipe can exit from a detention basin, with specified invert levels. The required size and invert levels cannot by determined in Design runs, but must be established by trial and error using analysis runs.

Where the 'basin' is a ponding area in a street over a sag pit that acts as an unintended storage, this method can be used with the standard hydraulic model. If the premium hydraulic model is available, this pit should be modelled as a sag pit with a table of elevation-area values describing the storage.

The fifth and last type of outlet is a **'None'** option. If this is selected, water can only leave the basin through a high-level outlet (to be described below), and the outflows will not be affected by downstream hydraulic grade lines or backwater effects. If a height-outflow relationship is specified for a high level outlet, the detention basin modelling will be carried out in the relatively simple way used in ILSAX, rather than having HGLs projected upwards through the basin.

A new development is the provision of an in-built infiltration calculation facility on the second page of the Detention Basin property sheet. This appears as shown in Figure 5.43.

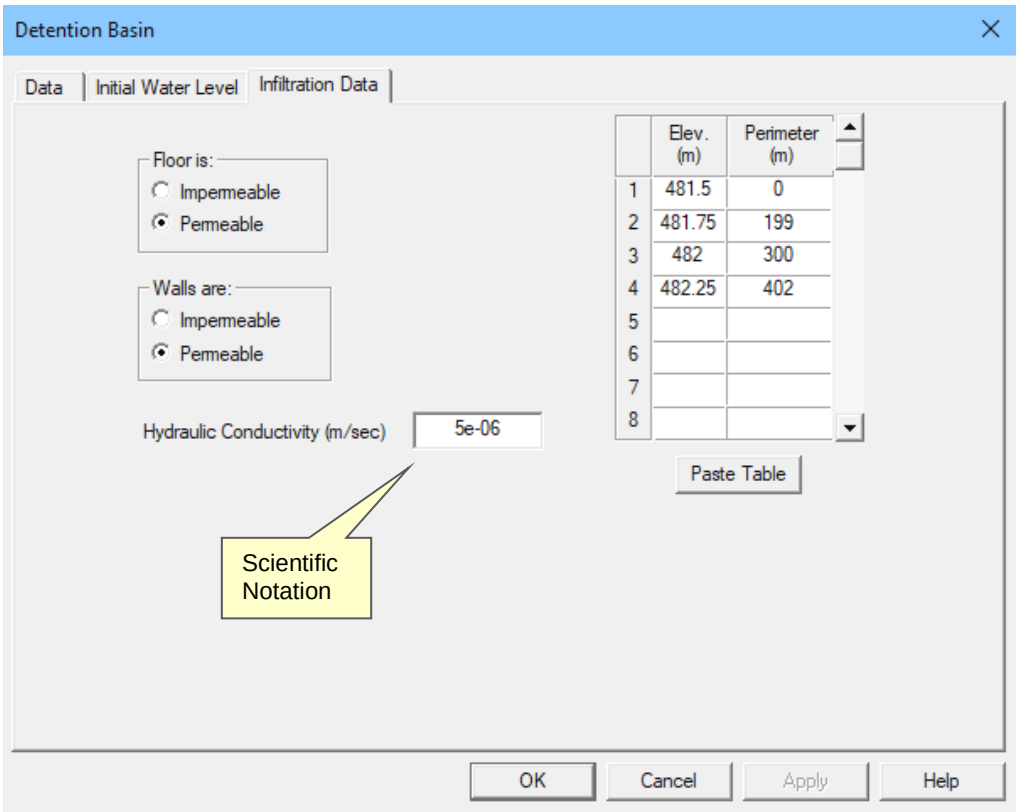
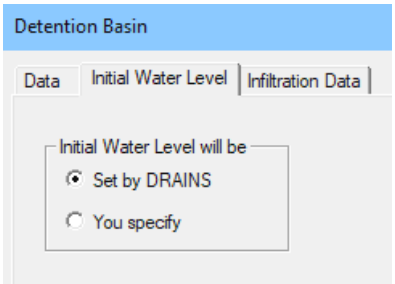


Figure 5.43 Infiltration Data Specification

Allowance is made for a flat floor, as provided in infiltration chambers and trenches, and for walls through which infiltration will occur when the stored water level rises above the floor level. The perimeter of the walls at different elevations can be defined in the table. The hydraulic conductivity depends on the type of strata through while infiltration occurs. Further information is provided in Argue (2004). Conductivities are quite small and in most cases need to be specified in scientific notation. For example, a conductivity of 2×10^{-6} m/s can be specified as '2e-6'. DRAINS specifies these as 2e-006.



The page on the Detention Basin property sheet tagged 'Initial Water Level', shown to the right, can be used to make a basin part-full at the start of a storm. Usually it is assumed that the basin is empty. (Use of this facility may result in some reverse flows at the start of a storm,)

The last component required to define a detention storage is the high level outlet, which is described in the property sheet for the overflow route from a basin. When an overflow route originates in a basin, the property sheet has three pages instead of the two shown in Figure 5.31 and Figure 5.36. Two of these pages are the same as those in those figures. On the third page, labelled 'Weir Data' you have the choice of specifying a weir outlet, as shown in Figure 5.44, or an elevation-discharge (or height-outflow) relationship, as shown in Figure 5.45.

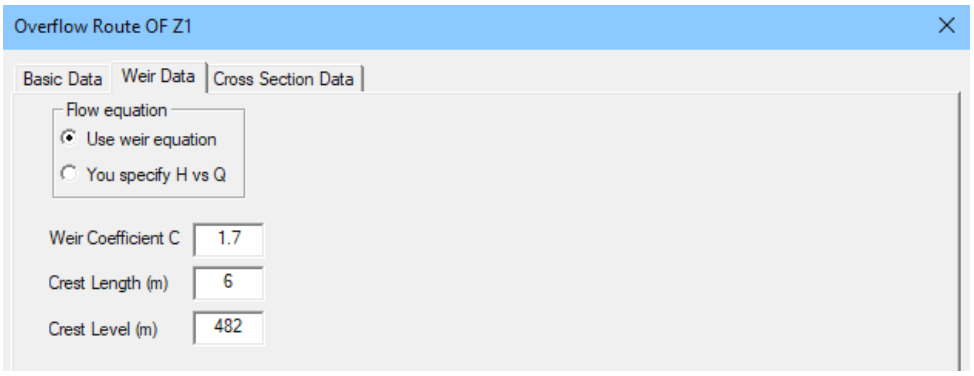


Figure 5.44 Outlet Definition of a Weir (Top Portion of Page)

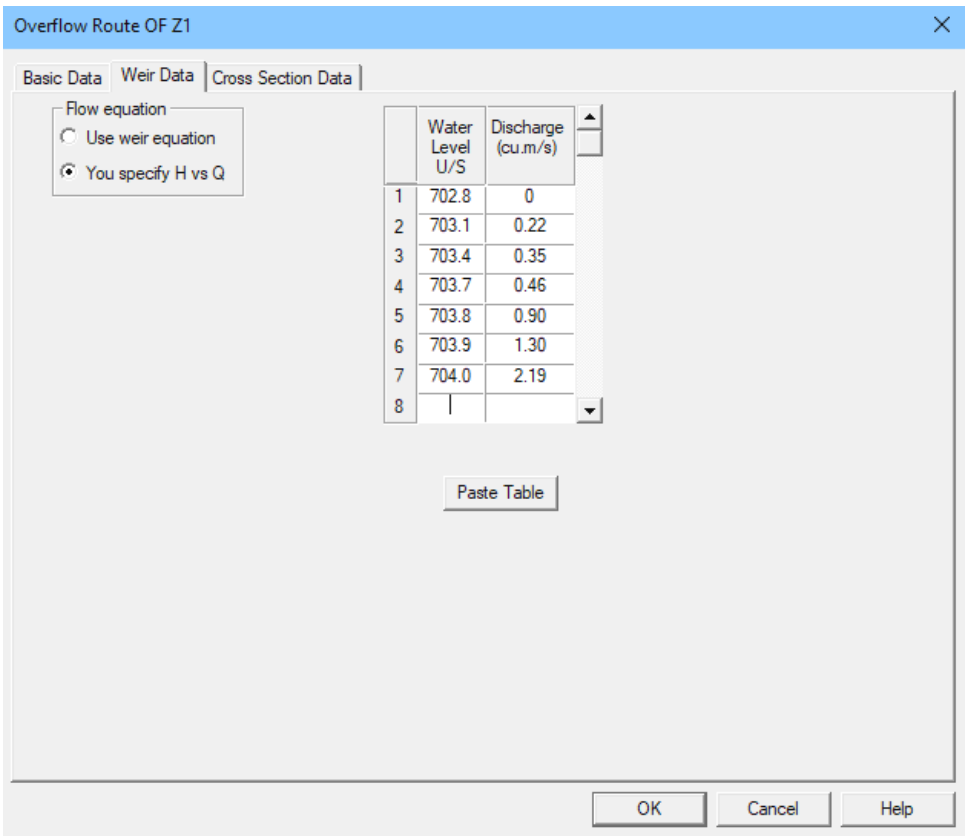


Figure 5.45 Elevation-Discharge Table for a High-Level Outflow (Top Portion)

For a weir, you must provide a weir coefficient, a width (m) (at right angles to the direction of flow) and a crest level (m). Further details are given in Section 8.8. A suitable coefficient for the earth embankments used as high-level outlets for many detention basins is 1.7.

If used alone, the elevation-discharge relationship must be determined using equations relating to both the low and high level outlets. If it is certain that no backwater effect can submerge the outlets, this relationship will be constant. As noted earlier, if '**None**' is specified for the low level outlet in the Detention Basin property sheet and an elevation-discharge relationship is given in the Overflow Route property sheet, a simplified basin routing can be applied.

There can be any number of overflow routes from a basin, representing high level outlets at various levels. Pumped discharges and stormwater infiltration can be modelled using overflow routes with suitable water level - discharge relationships, but it is best to use the specific pumping and infiltration methods provided.

Elevation-discharge relationships can be calculated in a spreadsheet and pasted into the Overflow Route property sheet using the **Paste Table** button in Figure 5.45.

5.3.9 Special Weirs and Orifices

Two new components in DRAINS, the orifice, and the weir, are only available with the premium hydraulic model. These facilitate the modelling of complex detention basins that have multiple orifice or weir outlets that can connect to various outlet points with different tailwater levels. With the standard hydraulic model, it is possible to model a single pipe or orifice-controlled outlet and multiple weirs that are located above tailwater influences. However, it is difficult to model a second pipe or orifice even when this leads to a free outfall. The new components make such modelling easy and accurate under complex tailwater conditions.

Figure 5.46 shows an example that has two orifices and one weir outlets. The orifice and weir links can be bent or kinked to allow several links to go to a common point. This can be done by clicking on the link, so the 'handles' appear at the ends, placing the mouse pointer on the line, holding down the mouse button, and moving the pointer.

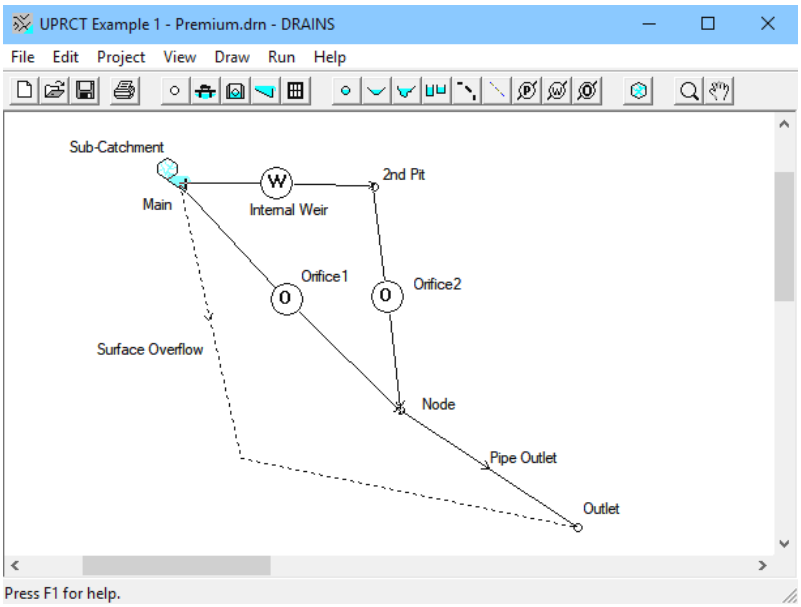


Figure 5.46 Detention Basin with Special Orifice and Weir Outlets

The orifice and weir property sheets are shown in Figure 5.47. The orifice sheet contains a Sizing Wizard that can calculate circular orifice diameters from a number of input parameters. This is shown in Figure 5.48. The orifice coeffient can be varied, but this is usually 0.61 for sharp-edged orifices.

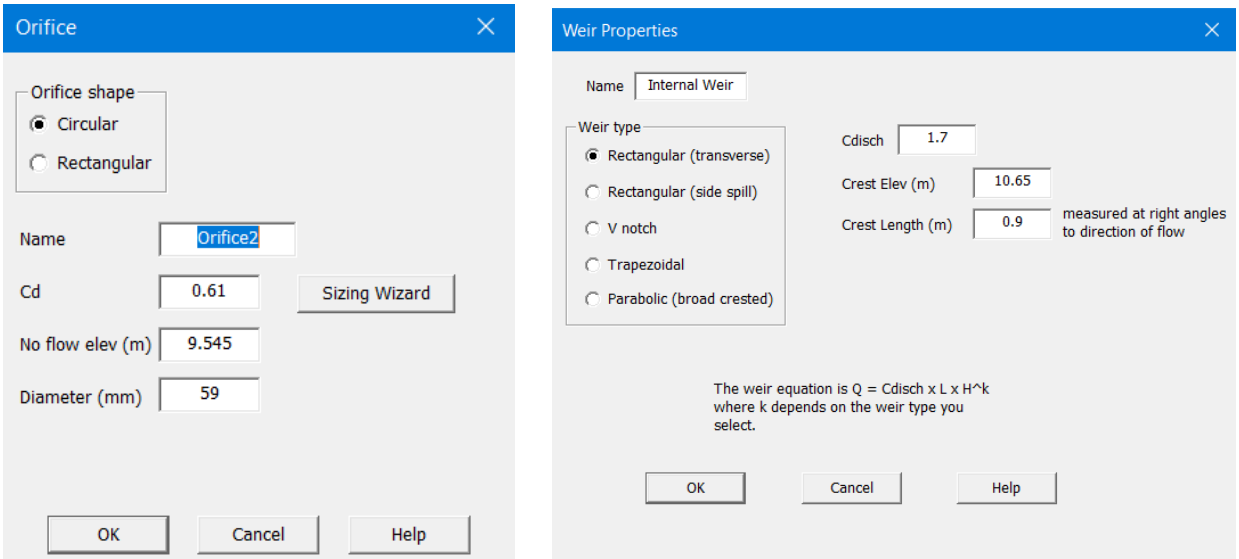


Figure 5.47 Special Orifice and Weir Property Sheets

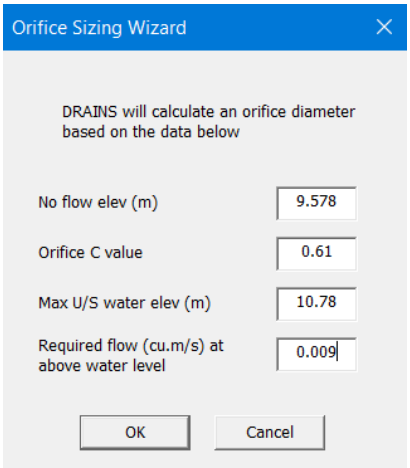


Figure 5.48 Orifice Sizing Wizard

The special weir object in DRAINS can be used as an alternative to an overflow route in situations where there is a parabolic weir, such as flow over a road crest at a low point in a street. For example, if a user has access to the premium hydraulics option in DRAINS, the overflow from a sag pit shown below can be replaced by a parabolic weir, as shown in the following figures.

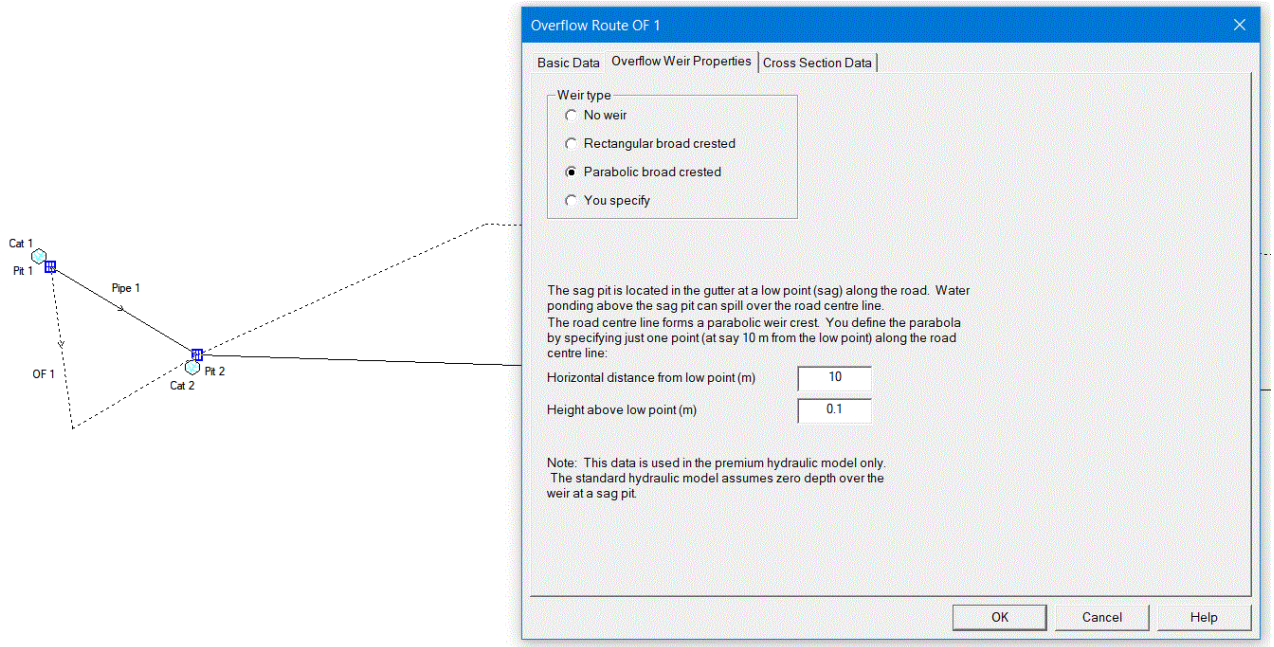


Figure 5.49 Overflow Route with Parabolic Weir

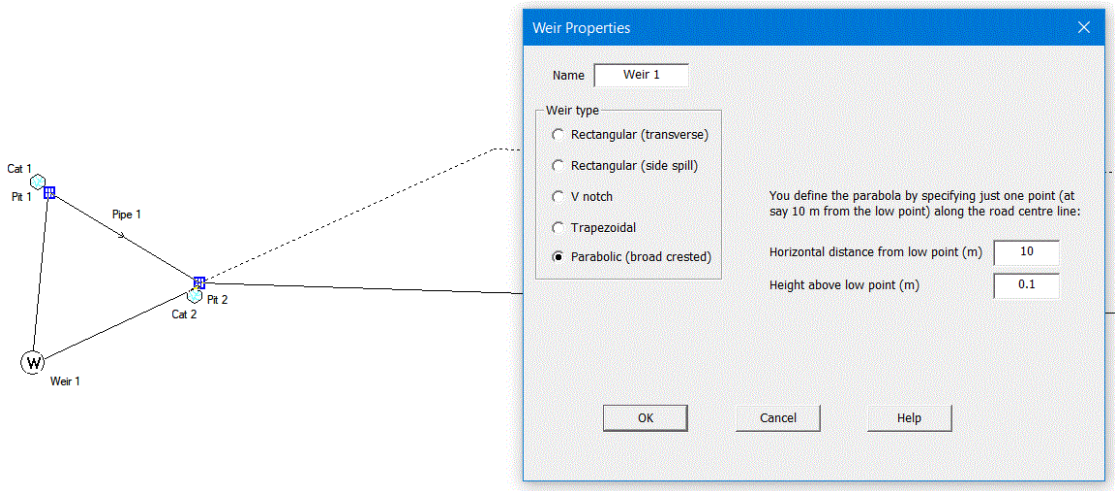


Figure 5.50 A Special Weir Replaces the Overflow Route

The distances required above are:

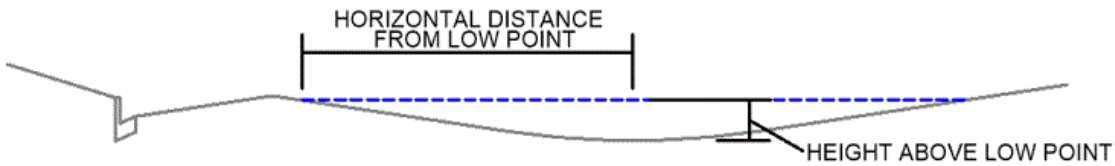


Figure 5.51 Distances Used to Specify a Parabolic Weir

The results will be the same for these arrangements, but the special weir has some advantages:

- It does not include any volumes of overflow routes, avoiding possible double-counting of storage volumes (the volumes specified for the sag pit or detention basin plus the volume inferred from the cross-section and depth in the overflow route). This is exp-lained further in the next section.
- It is not necessary to include a cross-section for the overflow route, which can be confusing when overflows travel a short distance, such as situation where flows cross over the crown of a road.

Using the premium hydraulic calculations, backwater effects due to high water levels downstream can influence the flows across the weir, in a similar way that they influence water levels and flows in overflow routes.

5.3.10 Dummy Overflow Routes

The premium hydraulic calculations in DRAINS treat overflow routes as unsteady flow channels, and allow for the volumes that water can occupy in these. This can sometimes lead to double-councting of the available volumes when overflow routes connect to detention basins or sag pits, and an underestimation of outflow rates. For example, consider this model of a detention basin:

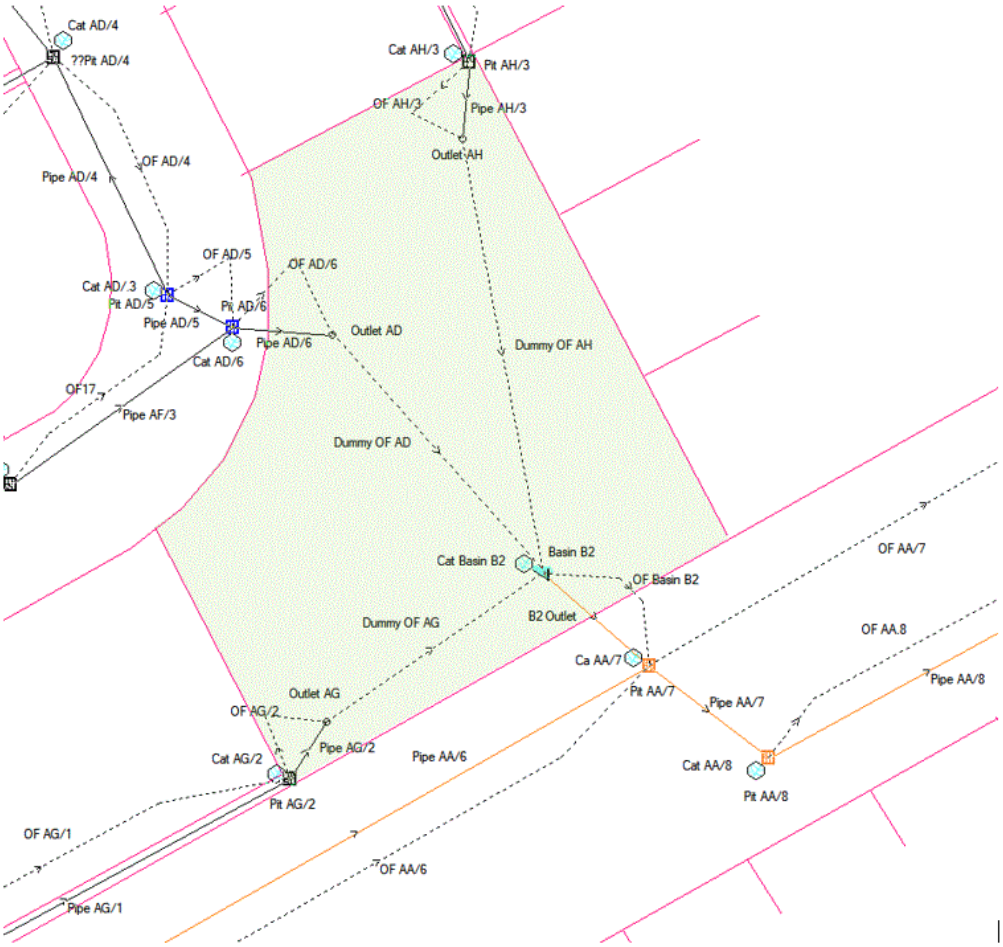
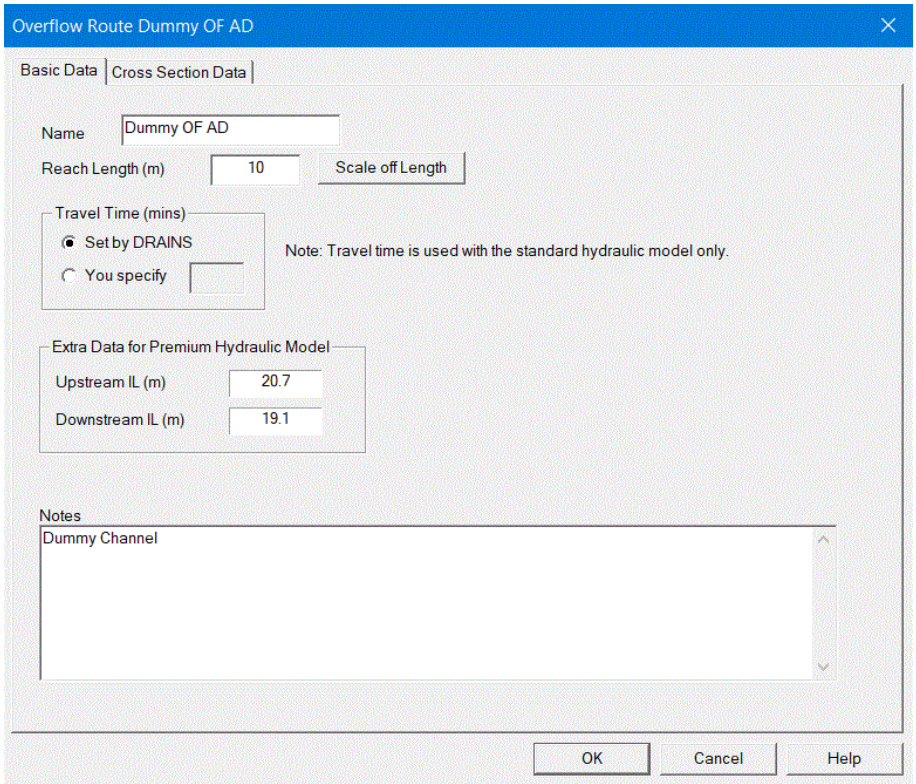


Figure 5.52 Detention Basin and Dummy Overflow Routes

Three drainage lines discharge into the open basin through inlet pipes that are shown to scale. To link these to the basin object, located near the basin's outlet pipe, three dummy overflow routes are shown. These have the following characteristics:



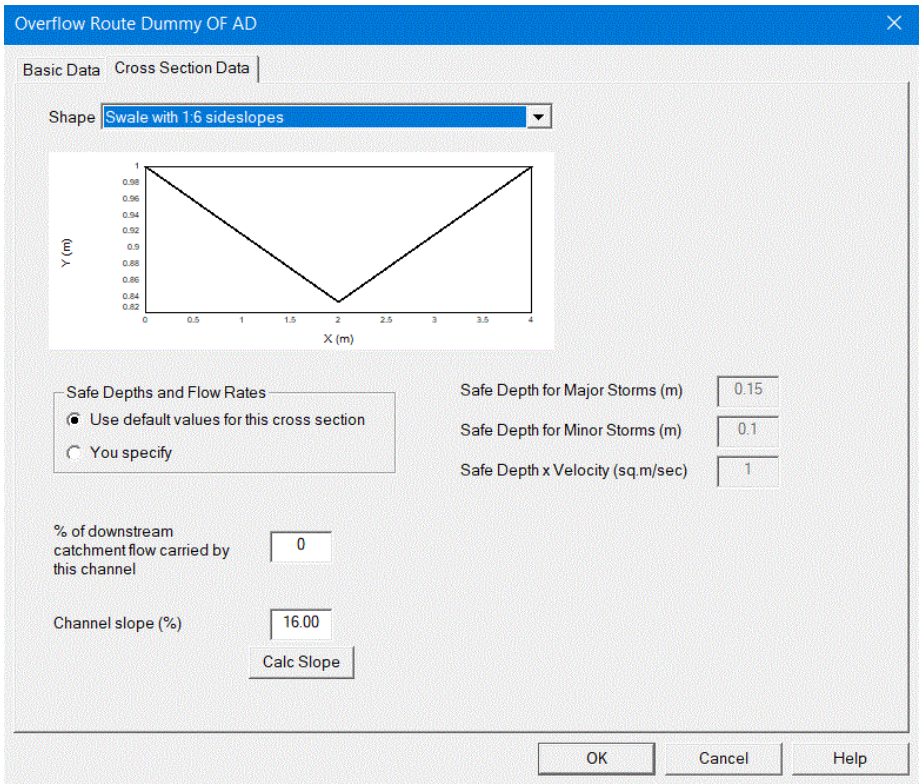


Figure 5.53 Detention Basin and Dummy Overflow Routes

This arrangement is acceptable in standard hydraulic model calculations, where the overflow route is simply used to transfer flows from the inlet pipes to the basin. However, in premium hydraulic model calculations, the channel is assumed to occupy volume that is already defined in the elevation-volume relationship for the basin, resulting in a double counting of storage.

This problem might be minimised by making the dummy overflow routes shorter than the nominal lengths of 10 m specified, but this can cause instabilities in calculations. A better solution is to eliminate the dummy overflows altogether, as shown below, at the expense of displaying the inlet pipes with an incorrect end position.

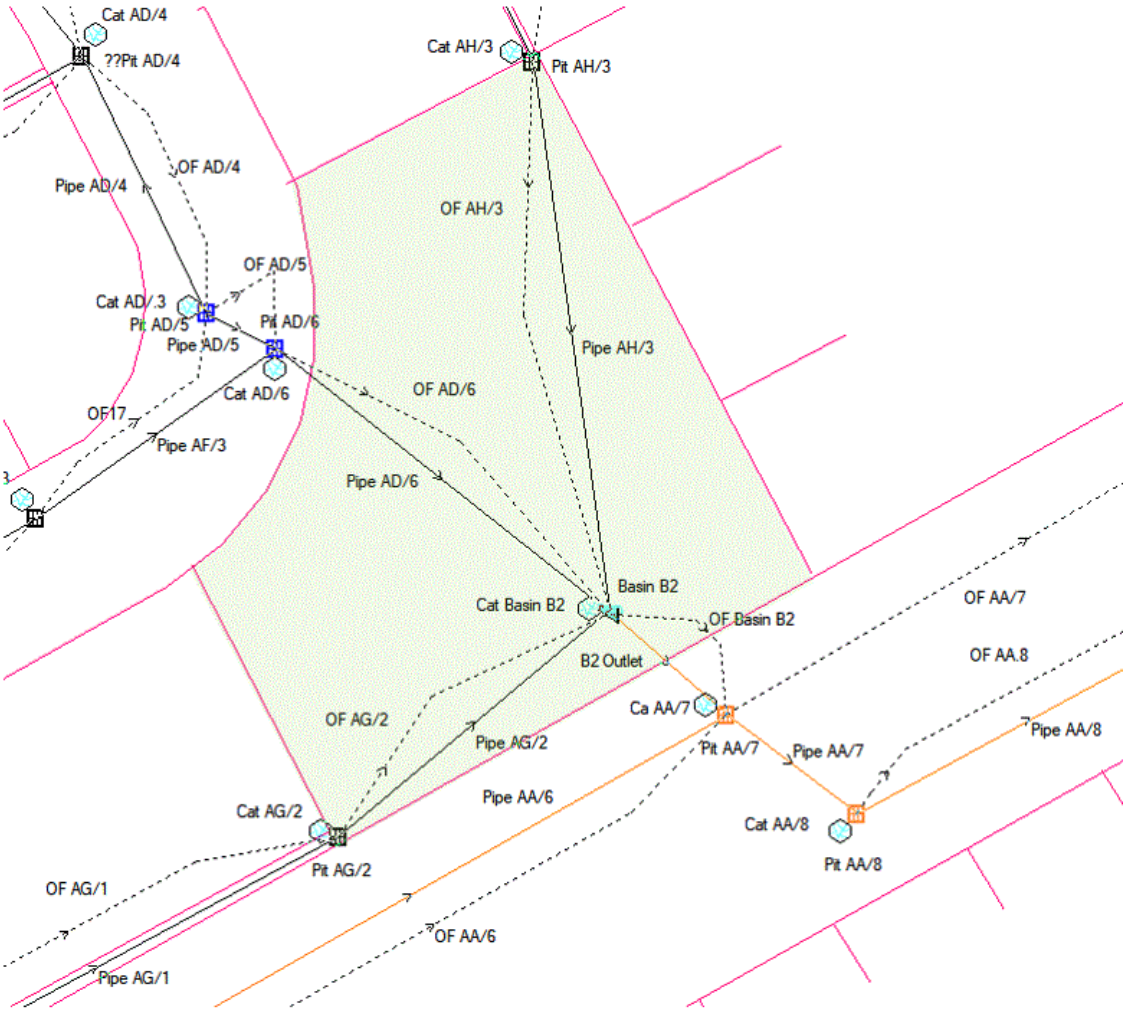


Figure 5.54 Detention Basin and Dummy Overflow Routes

Minor problems can also occur in premium calculations when overflows in streets interact with sag pit storages into which they flow. The link between two sag pits can be replaced by a special weir (described in the previous section), which does not include a volume.

5.3.11 Pumps

As described in the previous section, pumps can be modelled with an overflow route coming out of a detention basin. Howe However, this can cause problems when applying the premium hydraulic model, and a specific pumping link has been provided.

When the tool is selected a pump link can be drawn. This must come out of a detention basin and can be directed to a pit, a simple node or another detention basin. The associated property sheet, shown in Figure 5.55, requires a level at which the pump switches on and off (relative to the water level in the basin out of which it comes), and a table of water elevation vs. flowrate.

The pump starts operating when the storage water level rises above 222.0 m. The pump rate increases from 160 to 300 L/s as the water level rises to 223.5 m, reflecting the characteristic head versus discharge relationship for the pump and the friction and shock losses through the delivery pipe. A worksheet in the DRAINS *Utility Spreadsheet* (Section 6.2.3) can assist in developing an appropriate pumping relationship, which can be imported into the Pump property sheet using the **Paste Table** button.

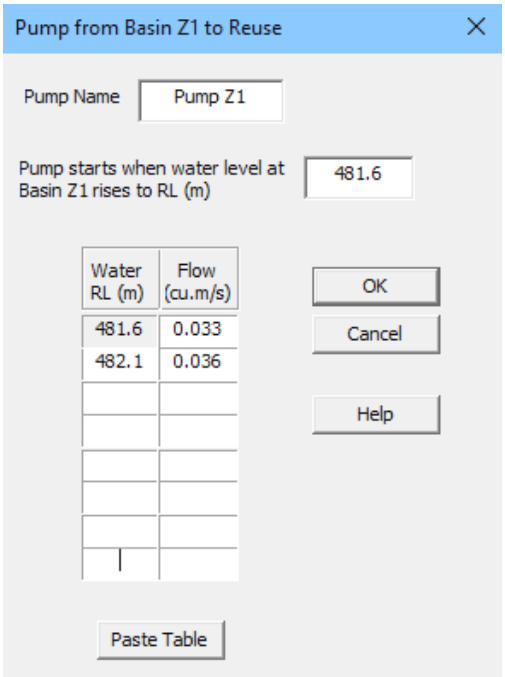


Figure 5.55 Specification of a Pump from a Detention Basin

Pump links can be bent of kinked, like those for special orifices and weirs. Pumps on and off switches can only be set at the same level. Siphons that commence operating when water rises to a certain level can be partially modelled as pumps.

5.3.12 Prismatic Open Channels

The Prismatic Open Channel property sheet, shown in Figure 5.56, enables easy entry of the parameters needed to define trapezoidal. Rectangular or triangular channels of uniform cross-section and slope. (Rectangular channels have zero side-slope factors, and triangular channels have a zero base width.)

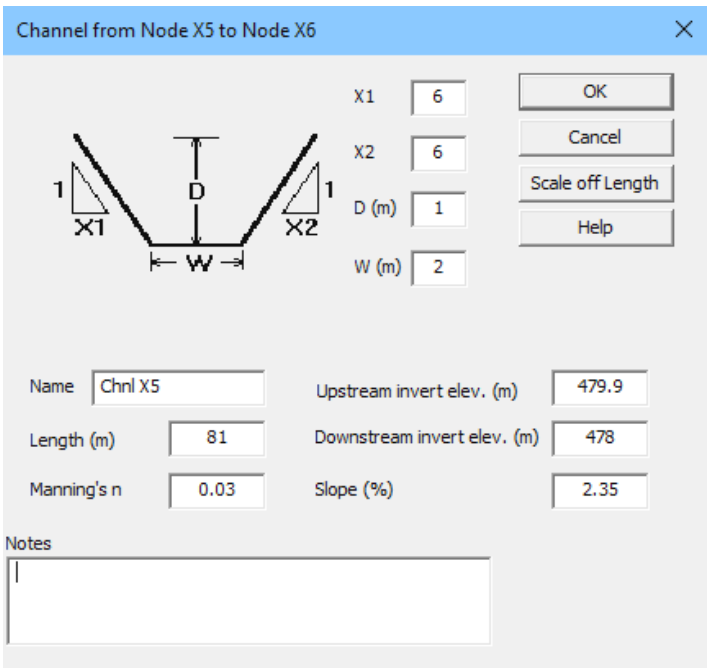


Figure 5.56 Prismatic Open Channel Property Sheet

If calculations determine that the channel depth exceeds that specified in this property sheet, the sides of the channel will be extrapolated upwards, and a warning message will be provided. DRAINS does not allow for overflows from channels. In the majority of cases, where overflows will follow the same route as the main stream channel, they can be accommodated by defining a channel cross-section large enough to carry them. If necessary, the channel should be defined as an irregular open channel, as explained in the following section, to include overbank flow areas.

Where an overflow from a channel will cause a breakout that follows a different path to the main stream, special ways of modelling the separation of flows are required (such as a detention basin that acts as a flow-splitter or diverter.)

5.3.13 Irregular Open Channels

(a) General

This component, with the property sheet in Figure 5.57, allows you to set up stream reaches to model a stream or channel with varying cross-sections and slopes.

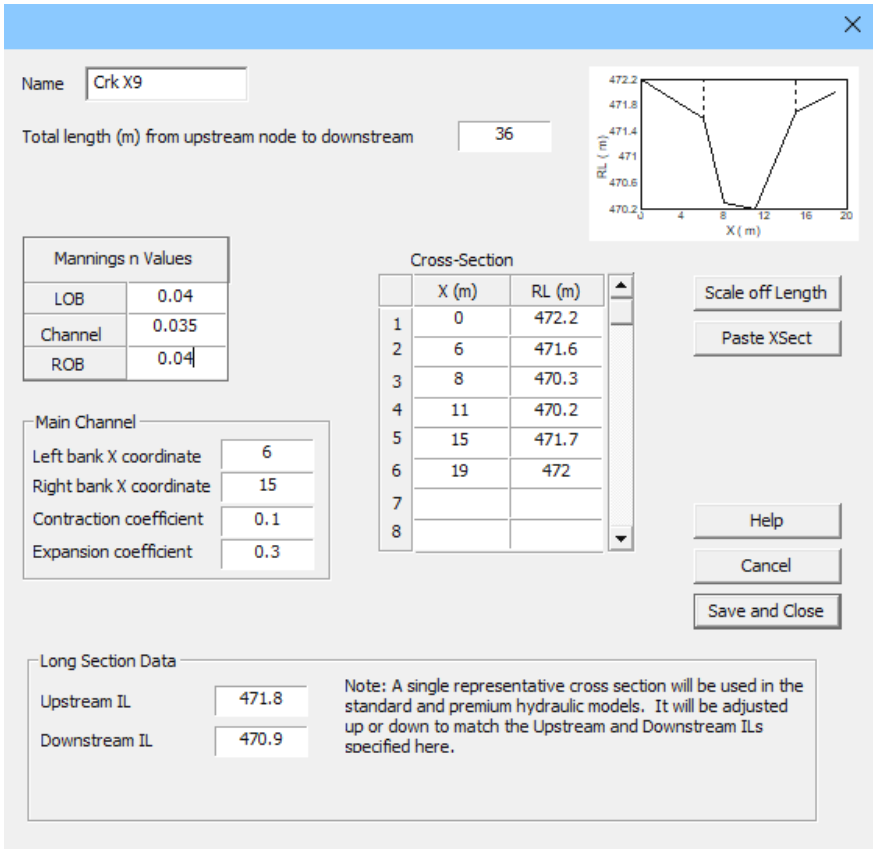


Figure 5.57 The Irregular Channel Property Sheet

It can also be used to model closed and open conduits with cross-sections other than circular, rectangular or trapezoidal.

The information required differs between the obsolete basic hydraulic models calculations and the unsteady flow calculations used in the standard and premium hydraulic models.

(b) Basic Hydraulic Model Calculations

It is necessary to define channel reaches over which flowrates are the same, and to define for each reach at least two cross-sections, at the upstream and downstream ends of the reach. At each cross-section, you must enter:

- the channel name, total length and chainages or lengths of reaches along a stream; a set of X-Y coordinates (m) that define the cross-section, with the X datum being at an arbitrary point on the left bank of a channel, and the Y datum being Australian Height Datum (AHD) or some other standard datum (as shown in Figure 5.58).
- distances from the upstream node (m) and Manning's roughnesses for the left overbank, main channel and right overbank areas;
- coordinate locations of the left and right banks (m), and expansion and contraction coefficients (dimensionless).

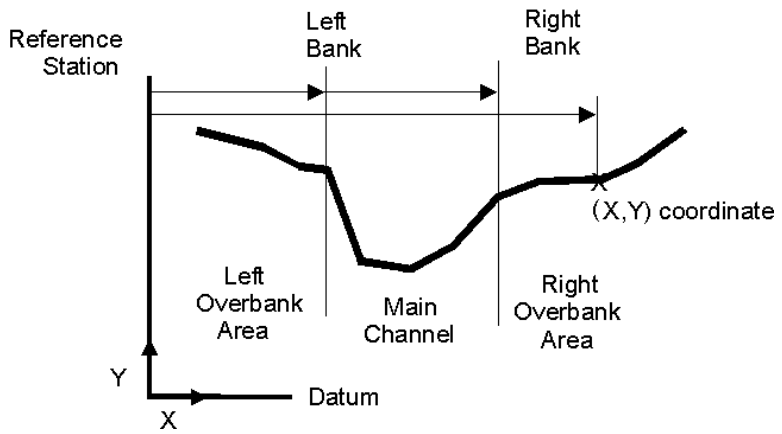


Figure 5.58 Coordinate System for Irregular Channel Cross-Section (looking downstream)

Various features assist the entry of cross-sections. Sections can be copied and pasted. The top section of a reach must be the same as the bottom section of the reach above it. If reaches are entered in a downwards direction, DRAINS automatically enters data from the previous reach. Sections can be viewed and checked using the **View Cross Sections** and **View maximum water level profile** options in the pop-up menu for an irregular channel component, as shown in Figure 5.59.

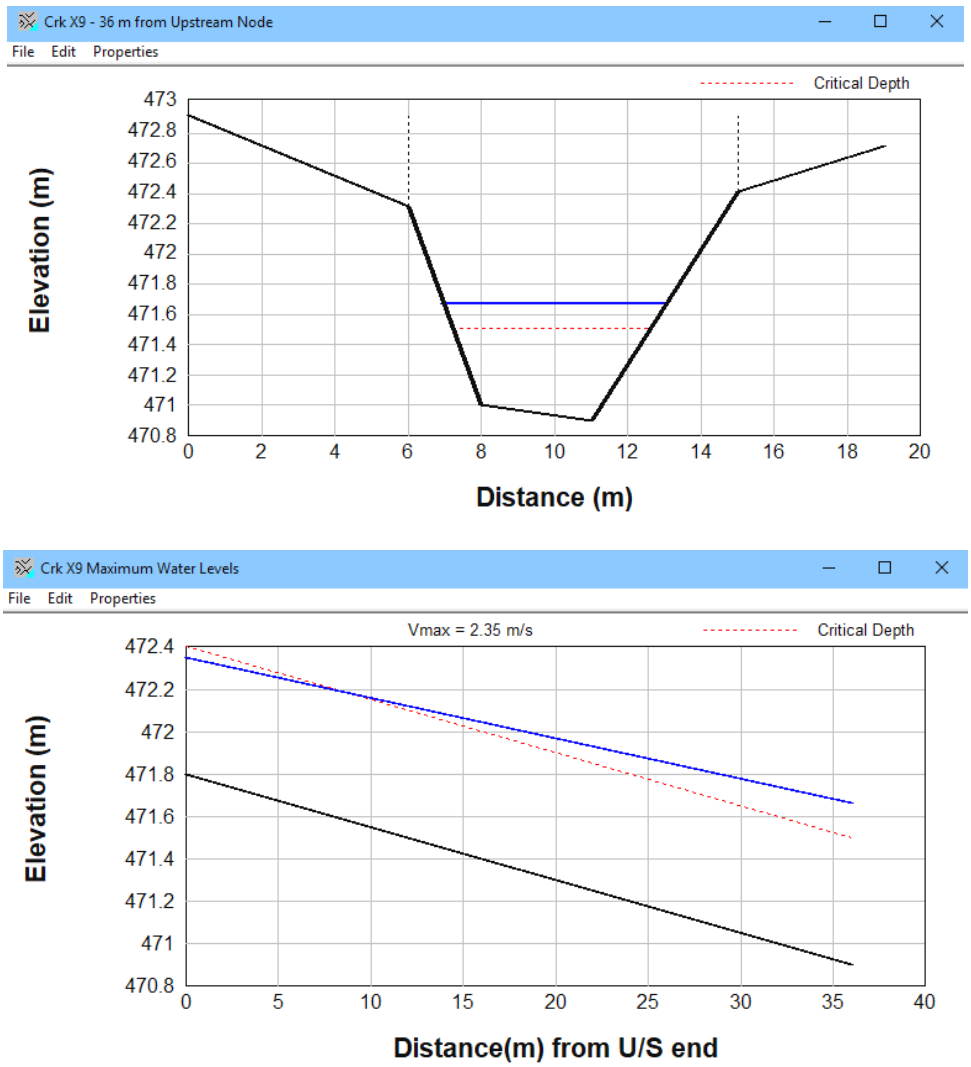


Figure 5.59 Irregular Channel Cross-Sections and Longitudinal Profiles

(a) Standard and Premium Hydraulic Model Calculations

The same inputs as those shown in Figure 5.57 are required, with the additional information specified at the bottom of the property sheet. The additional inputs are the invert levels at the upstream and

downstream ends of the reach, and the number of the cross section to be considered as representative of the channel reach.

The two hydraulic calculation options use entirely different procedures. The basic method uses methods akin to the steady flow modelling carried out by the well-known HEC-RAS program (Hydrologic Engineering Center, US Army Corps of Engineers, 1997), in which cross-sections are required at each end of an irregular channel.

Like HEC-RAS, DRAINS allows cross-sections, roughnesses and bed slopes to vary along a channel, though it is not possible to change the flowrate along a channel. This can be done by specifying two or more irregular channels in series.

The unsteady calculations assume that each open channel has a constant cross-section and slope. This will suit lined channels well, but for natural channels, it may be necessary to define several sections of channel to allow for changes of cross-section.

5.3.14Multi-Channels

The prismatic and irregular channel types do not adequately cover the situation where two or more channels with different characteristics connect the same two points. This is handled in the basic hydraulic calculations by multi-channels that use the property sheet shown in Figure 5.60 to call up the boxes for prismatic or irregular channels, or a box for circular channels.

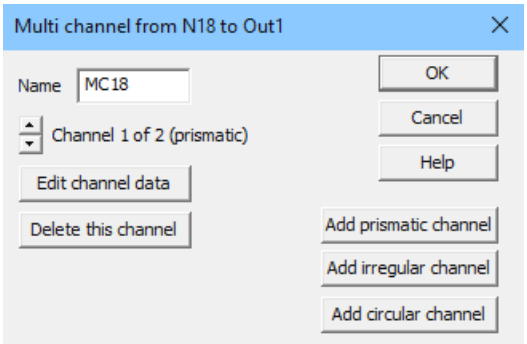


Figure 5.60 Multi-Channel Property Sheet

The data required is similar to that for other open channels. Conduit lengths, roughnesses, slopes and even starting and ending levels can vary. DRAINS distributes flows between the different conduits. At present, DRAINS does not report on the separate flowrates.

Situations requiring multi-channels occur where inadequate open drainage systems are amplified by building a parallel channel or pipe, and where grassed floodway channels have a piped underdrain.

5.3.15Stream Routing Reaches

This link type, shown as , is used with the RORB and WBNM storage routing models to connect nodes and sub-catchments as described in Section 8.3.7, and to perform non-linear routing. Its exact function differs between the two models as they have differing structures. (The RAFTS storage routing model describes stream reaches using the same overflow routes that were used for pipe systems, described in Section 5.3.7.)

If a RORB storage routing model is selected, the property sheet for its stream routing reaches appears as shown in Figure 5.61. A reach name and length must be specified, and a Channel condition selected. If a channel condition of 'excavated unlined' or 'lined or piped' are selected, it is also necessary to provide the reach slope.

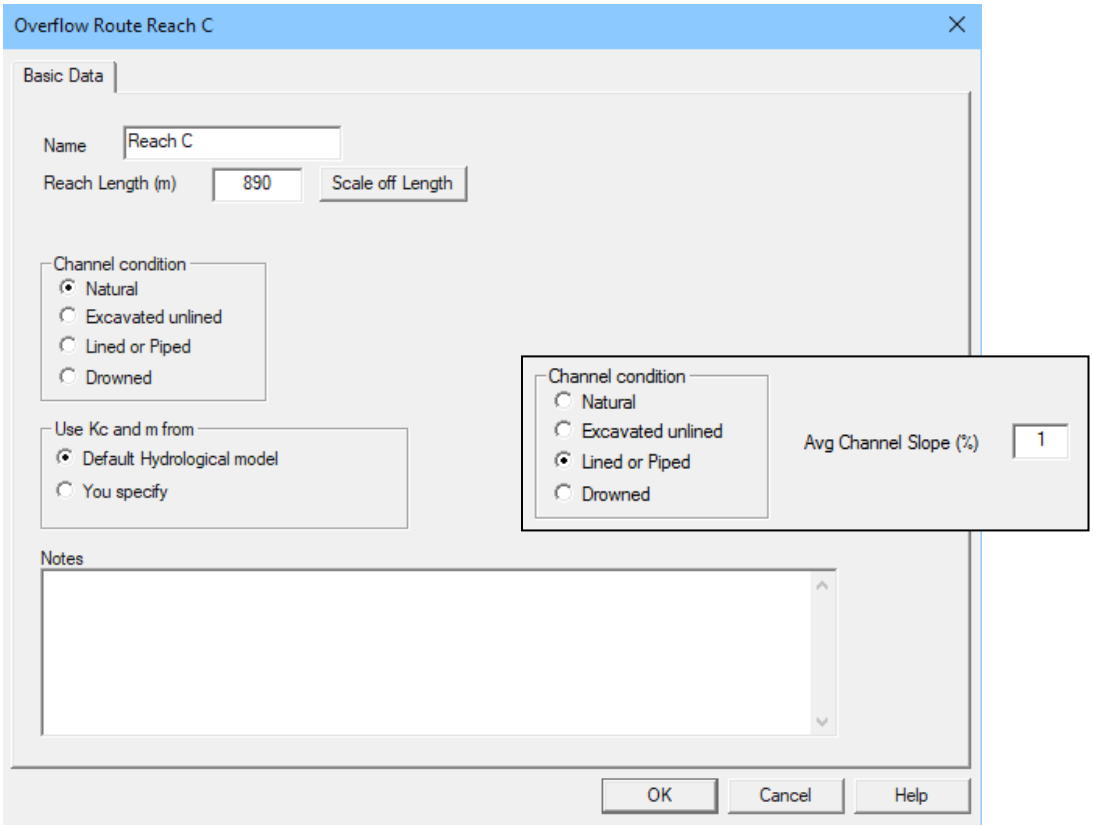


Figure 5.61 RORB Stream Routing Reach Property Sheet

The RAFTS stream channel property sheet, shown in Figure 5.62, is identical to that for an overflow route from a pit. A name is required, and if **Simple translation (no attenuation)** is chosen in the box labelled **Flow Routing Method**, a travel time through the reach must be entered. With a RAFTS model, this can be zero if a conservative result is required.

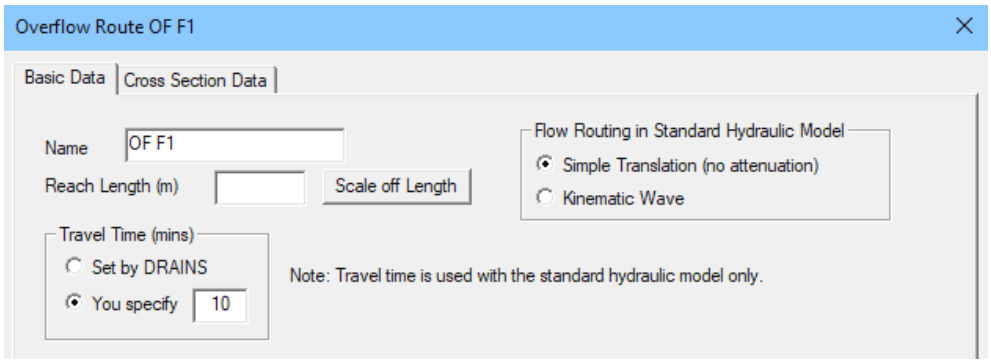


Figure 5.62 First Form of the RAFTS Stream Routing Reach Property Sheet (Top Part)

If the second option in the **Flow Routing Method** box is chosen, the property sheet changes to the form shown in Figure 5.63. It is now necessary to provide a reach length and, using the second page of the property sheet shown in Figure 5.64, a cross-section is to be selected from the Overflow Route Data Base. This section is meant to be representative of the whole stream reach and to be used in a kinematic wave routing procedure derived from Chapter 9 of *Open Channel Hydraulics* by F.M Henderson (1966).

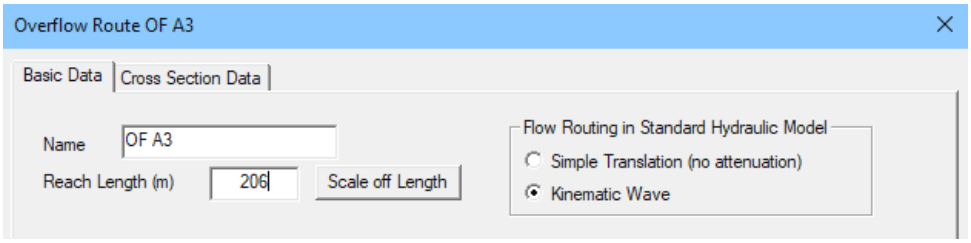


Figure 5.63 Second Form of the RAFTS Stream Routing Reach Property Sheet (Top Part)

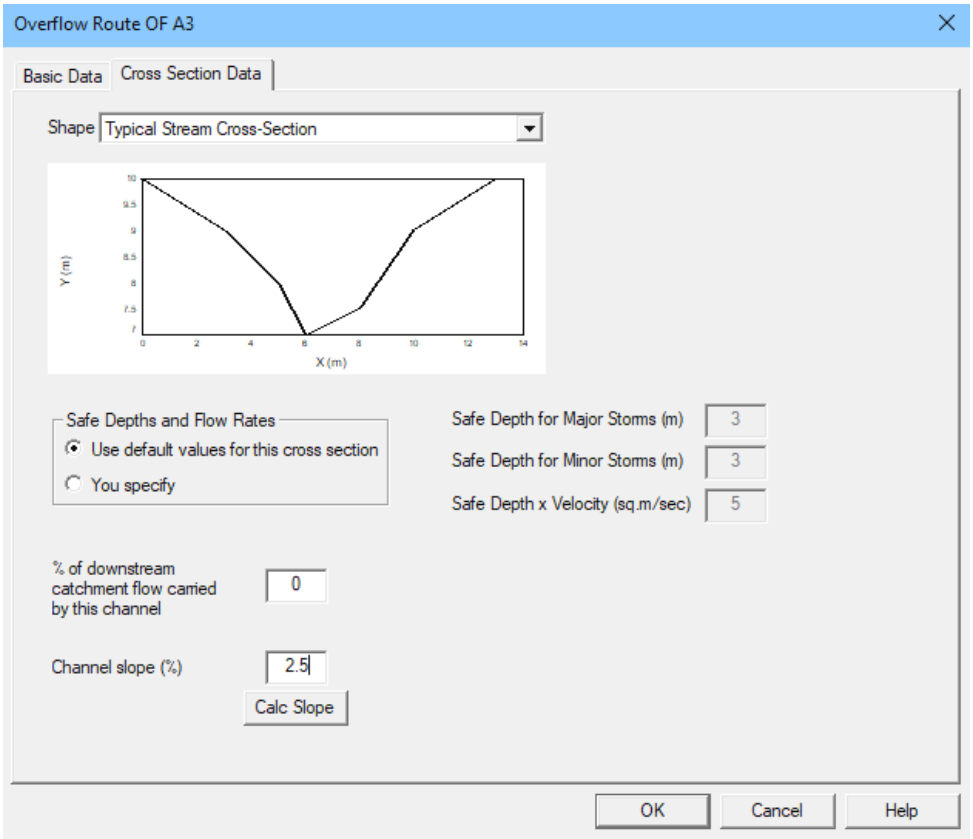


Figure 5.64 Second Page of the RAFTS Stream Routing Reach Property Sheet

When run, the kinematic wave option will produce two hydrographs, at the top and bottom ends of the reach, with a small reduction in peak flows. (As noted in Section 5.3.7, this specification can also be applied to conventional overflow routes in piped urban drainage systems, but the premium hydraulic model calculations are preferable.)

The WBNM stream routing reach property sheet shown in Figure 5.65 requires only a name and a stream lag factor. When this factor is not zero, routing occurs along the reach using parameters based on the area of the sub-catchment at the node at the end of the reach.

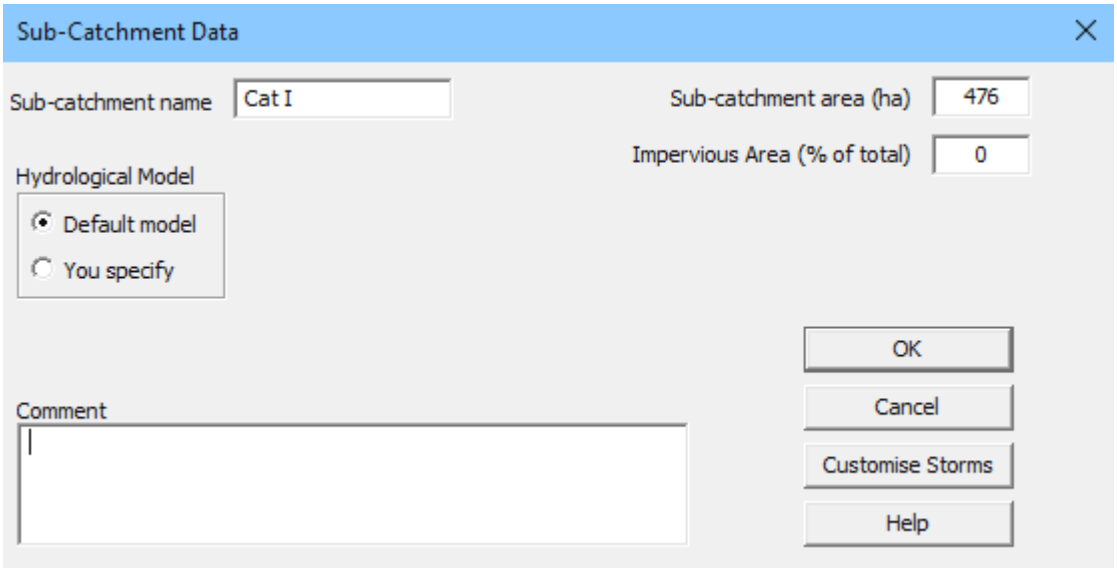


Figure 5.65 WBNM Stream Routing Reach Property Sheet

5.3.16 Headwalls

The headwall allows open channels to flow directly into a pipe system, and overflows to be directed to the pipe outlet or other locations. It is not to be used as the outlet of a pipe, which is modelled as a node. The Headwall property sheet is shown in Figure 5.66

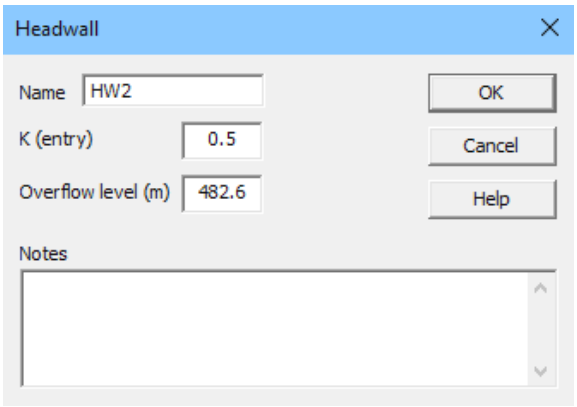


Figure 5.66 Headwall Property Sheet

For water levels below the overflow level entered on this sheet, the pipe flow is governed by the culvert equations described in Section 8.9.1. Once the overflow level is reached, the inflow to the pipe is assumed to be that corresponding to the nominated overflow level, while the headwater level (the water level upstream) is assumed to be governed by relationships in the property sheet for the overflow route provided (Figure 5.44 and Figure 5.45). Assuming the overflow rate to be the upstream flowrate minus the pipe capacity, DRAINS calculates a flow depth based on the weir or elevation-discharge relationship, and adds this to the overflow level to obtain the headwater level.

With the standard hydraulic model, this process sets a headwater level that is slightly conservative, as the depth of the overflow path flow is not considered in determining the flow through the pipe. This avoids considerable iterative calculations caused by the splitting of the flows and the uncertainty of the effects of changing flowrates on the calculations for downstream pipes. A more accurate procedure is applied in the premium hydraulic model, allowing for backwater from the water levels in the overflow route.

The headwall can be used to model culverts, as described in the next section.

5.3.17 Culverts

Initially, culverts were modelled in DRAINS using the Culvert component the concentrated all the functions of culverts into a single object. This has now been replaced by the combination of a headwall with a pipe and overflow route, as shown in
Figure **5.67**, and the old culvert object has been removed from the DRAINS Toolbar. This is similar to the arrangement used for detention basins.

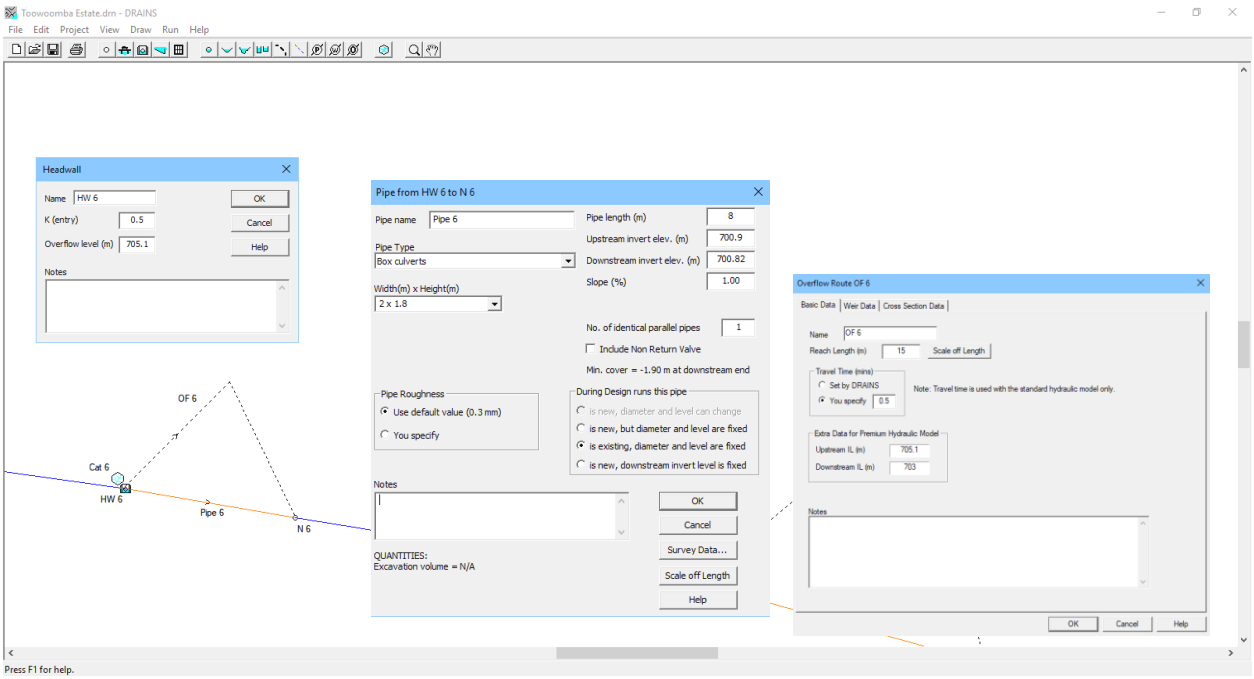


Figure 5.67 Culvert Constructed from Headwalls and Other Components

The inputs for these components are described in other parts of this chapter, while the inputs for the discontinued culvert object will be described in the Help System. If the obsolete culvert object has been used in an older DRAINS model, it will re-appear when this model is opened with the current version of DRAINS.

5.3.18 Bridges

The property sheet for Bridges is shown in Figure 5.68. Because of the differences in shapes, abutment and pier arrangements and approach conditions, bridges are more complex that culverts. In DRAINS, calculations are performed using a relatively-simple method provided in the AUSTROADS (1994) manual, which is based on the US Federal Highway Administration report by Bradley (1970). More complex bridge modelling procedures are available in HEC-RAS, MIKE-11 and other open channel hydraulics programs. DRAINS results should be checked using these programs if the accurate determination of levels is critical.

You will need to refer to the original references to understand the inputs required fully. It is necessary to specify:

- the name of the bridge, and the levels of the deck (m) and the soffit (underside of deck) (m);
- the weir coefficient for overflows over the bridge deck, typically 1.7;
- pier width, locations of piers (as noted in Figure 5.69), and pier type;
- the abutment type and the X-Y coordinates at the bridge section (m), left overbank, main channel and right overbank Manning's roughnesses, and the X locations of the left and right banks that divide the zones of different roughness (m).

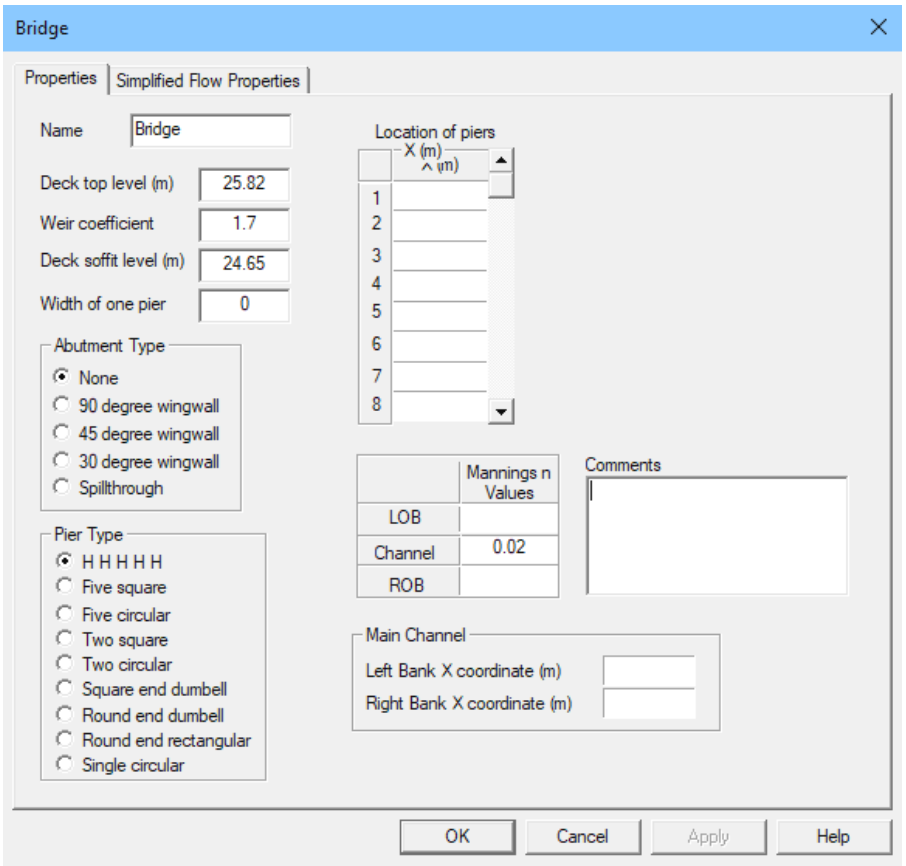


Figure 5.68 Bridge Property Sheet

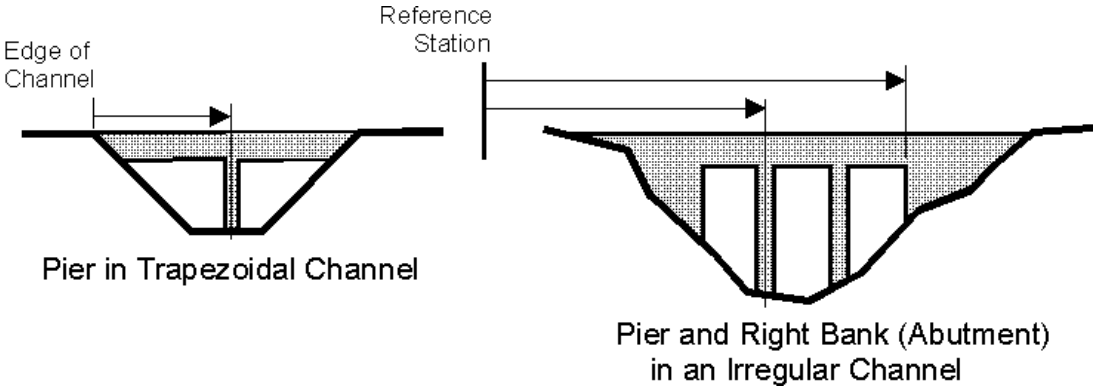


Figure 5.69 Pier and Abutment Locations

With the standard and premium hydraulic models, the data shown in Figure 5.70 must be entered in the second page of the property sheet. This provides instructions on choosing the values to be entered.

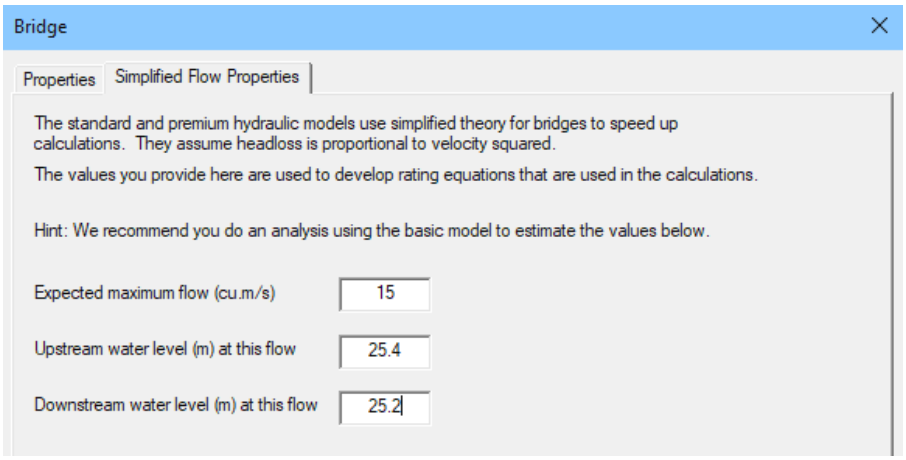


Figure 5.70 Second Page of Bridge Property Sheet (Top Part)

This information might be obtained by running the DRAINS model without a bridge to estimate the maximum flowrate, and inserting the bridge later. The upstream and downstream water levels can be estimated from the level without the bridge, making the upstream level higher and the downstream level lower. The differences might also be determined from relationships from texts or manuals.

5.3.19 Combining Components

Some arrangements of the components described in the preceding sections cannot be modelled because they are not logical, or they create computational difficulties.

Table **5.2** describes the possible connections between nodes and links noting those that cannot be made. The footnotes provide suggestions as to how you can get around some of these limitations. Experienced modellers can use dummy components to model complex situations.

Table 5.2 Allowable Connections between DRAINS Nodes and Links

	Link into Node from Upstream (U/S) or Downstream (D/S)			
	Pipe	Prismatic or Irregular Channel	Multi-channel	Overflow Route
Simple Node	U/S - yes[1] D/S - yes[1]	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes[2] D/S - maybe[3]
Detention Basin	U/S - yes D/S - yes[4]	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - yes[5]
Headwall	U/S - no D/S - yes[4]	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - yes
Culvert object (discontinued)	U/S - no[6] D/S - no[6]	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes D/S - no[7]
Bridge[8]	U/S - no[6] D/S - no[6]	U/S - yes D/S - yes	U/S - yes D/S – no[7]	U/S - yes D/S - no[7]
Pit	U/S - yes D/S - yes	U/S - no D/S – no[8]	U/S - no D/S – no[8]	U/S - yes D/S - yes

Notes:

1 - If a node has pipes both upstream and downstream, it acts as a closed junction, and can be pressurised, with the HGL rising above the surface. Generally, however, it is better to connect pipes through sealed or unsealed pits, where a head loss can be specified.

2 - You need to be aware that nodes will accept all flows coming to them, and check whether this is realistic. Where there are likely to be overflows, a pit should be substituted if the node is in a pipe system, and a detention basin if the node is in an open channel system.

3 - In the standard hydraulic model, overflows are permitted from a node, but not if there is also a pipe or channel leaving that node. For an open channel where overflows will run along the banks, the height of the channel cross-section needs to be raised so that the overbank areas are included. Where channel overflows are to be directed out of a channel, a detention basin can be placed at the point where overflows might occur, with an elevation-storage relationship based on the storage within the upstream channel. The surface areas or storages allocated to this basin should not be too small, otherwise instabilities can occur. High-level outlets with weir data or a height-discharge table can be used to specify the overflows. The premium hydraulic model allows a channel and overflow route to come out of the same node, so that dividing or bifurcating channels can be modelled.

4 - Overflow links from a detention basin or headwall require more information than a normal overflow link, to define high level outlets. It is possible to have several high-level outlets from a basin.

5 - Culverts and bridges must have open channels or routing reaches upstream and downstream. Where a road is located at a point where stormwater emerges from a pipe, or goes from on open channel into a pipe, it is probably inappropriate to model this situation as a bridge or culvert. If cross-sections change under a road in these circumstances, the transitions can be modelled by pipe or open channel sections linked to nodes.

6 - The discontinued culvert component, , may be encountered in older DRAINS models. It has been replaced by a combination of headwall, pipe, overflow route and node, which provides more information and flexibility (see Section 5.3.17). Information on the discontinued component is given in the DRAINS Help System.

7 - Bridges have more restrictions than culverts in DRAINS. You cannot have two upstream channels meeting at a bridge, as they can at a culvert. You can insert a section of combined channel upstream of the bridge. A multi-channel cannot be placed downstream of a bridge - a short section of single channel can be interposed, however.

8 - You cannot have an open channel coming out of a pit. However, a short section of pipe and a simple node might be used to link the pit and a channel.

In a DRAINS Main Window, it is possible to have several, separate drainage systems. These may be completely independent, or may be connected by overflow links. When DRAINS runs, it applies the same rainfall and loss data to all systems, unless local options are selected in the **Hydrological Model** and **Customise Storms** options in the Sub-Catchment property sheet described in Section 5.3.6. This feature allows systems to be analysed together, to provide 'before' and 'after' comparisons.

The example file Sydney OSD.drn provides such a comparison for an on-site stormwater detention system. As shown in Figure 5.71, the pre-developed catchment is set out on the lower left, and the developed drainage system around a house and backyard occupies most of the window. These two systems are run together using the same project specifications, allowing a direct comparison of results.

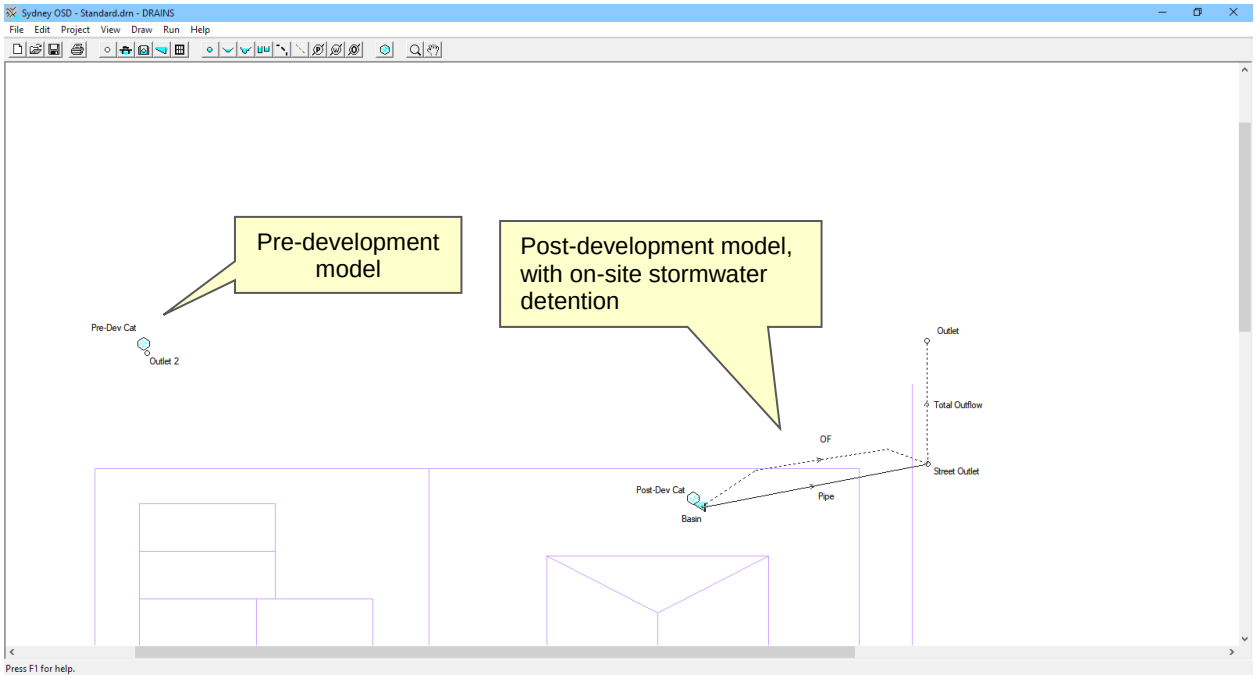


Figure 5.71 Two Drainage Systems Set Up in DRAINS **for Comparison**

5.4 Data Bases

5.4.1 General

By storing data about inputs and common components in five data bases that are easily accessible from drop-down list boxes, DRAINS makes it easy to select and alter hydrological models, rainfall patterns, pipe types, pit types and overflow route cross-sections. By referring to standardised types, the amount of data that has to be entered into files is greatly reduced.

The role of data bases is particularly important in the DRAINS pipe design procedure. Pipes and pits are both organised into types or families of different sizes from which the program can select.

Data bases can be set up, element by element, using the editing procedures described in the following sections. Hydrological model and rainfall pattern data bases can be stored in template files, and retrieved, as described in the next section. Pipe, pit and overflow route data bases can be imported directly into DRAINS using the **Default Data Base** option in the **Project** menu (for a new project) and the **Import** > → **DRAINS Database (DB1) File…** in the **File** menu (for existing DRAINS files).

5.4.2 Standardised Data Bases

When you start DRAINS it loads the standardised data base file, Drains.db1, located on the C:\ProgramData\Drains folder. This contains information on pipe, pit and overflow route components that are likely to be used in your model..

If you work in only one geographical area, always with the same hydrological model and set of storms, this file need not change. In this case, when you first use DRAINS you should set up the storms and hydrological model for your area, set up the pipe, pit and overflow route data bases, then save the file as a template or base that can be used whenever you begin a new project in the area. This file should not contain pipes or other components. If you work in different locations, you will need to set up a different template file for each geographical area.

Another way to set up a file with required data bases is to open a DRAINS file with the data bases that are required, and then close this. The drainage system disappears, hydrological model and data bases remain. The data for pits, pipes and overflow routes can be changed using the **Project → Default Data Base** option, and editing the entries. You can then copy this file as a template file and start a new job with a different filename.

5.4.3 Hydrological Models

The set ups for ILSAX, the rational method, ERM, the IL-CL model and storage routing hydrological models are described in Chapter 2. More detailed descriptions of these models are given in Section 8.3. DRAINS is structured to deal with two categories of hydrological model:

- ILSAX, ERM, IL-CL and storage routing models that produce hydrographs, developing a time series of flowrates, and
- rational method models that produce only peak flows,

and to apply different forms of rainfall data (hyetograph patterns and intensity-frequency-duration (I-F-D relationships) with these model types.

It is possible to develop a number of different ILSAX models, say for different soils, and to include these in a model. The storage routing models can be mixed with ILSAX models, although it is only possible to have one type of storage routing model. You cannot mix RORB and WBNM models, for example. However, it would be possible to create a DRAINS model that used three kinds of ILSAX model and two kinds of RORB model. The extended rational method can be mixed with storage routing models. Three different kinds of rational method model can be applied, as shown in Figure 5.72, and you can inter-mix these.

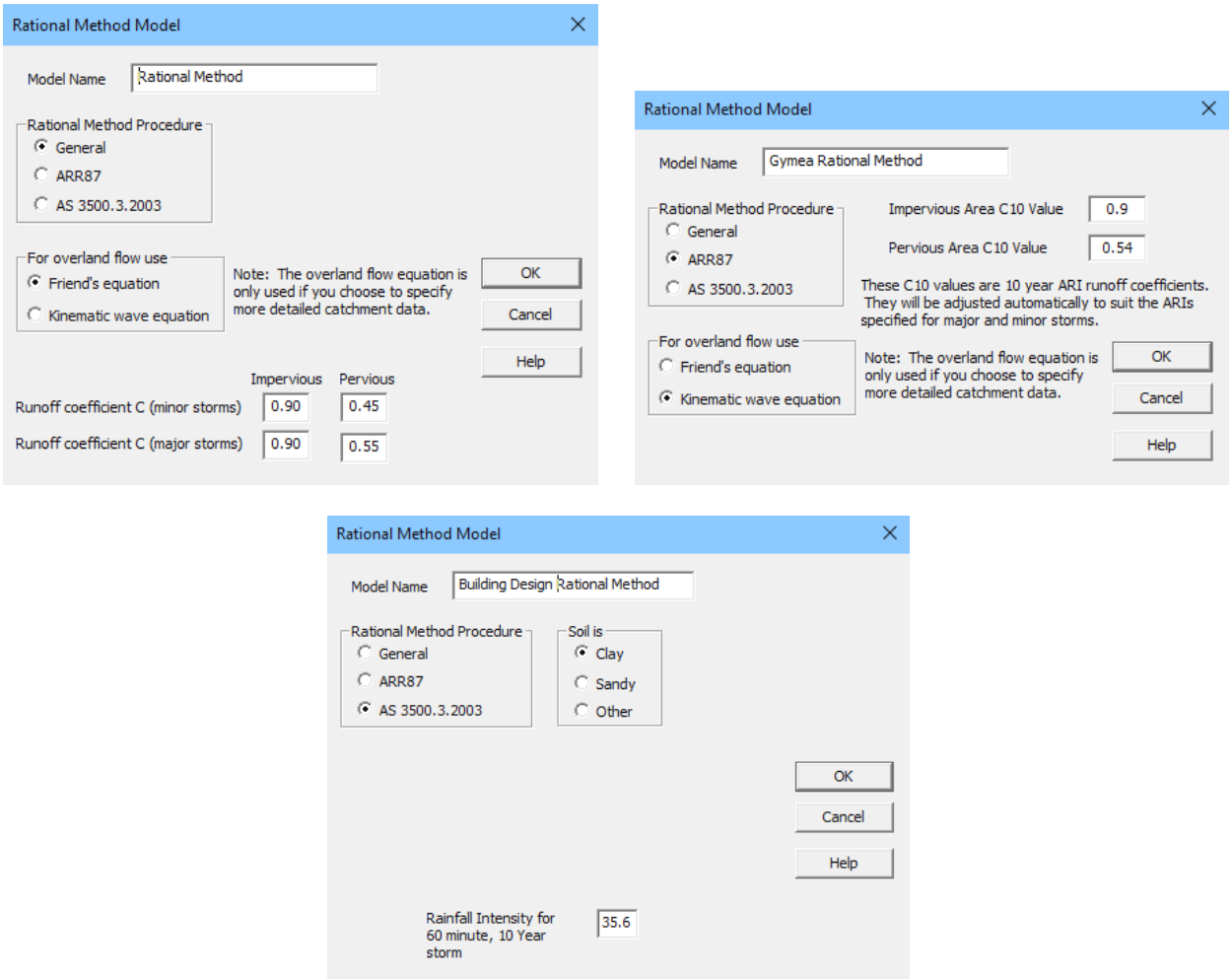


Figure 5.72 Rational Method Selection Property Sheets

Many models of different types can be stored in the Hydrological Model data base. The hydrological model that is selected in the Hydrological Specifications dialog box acts as a default model that applies to all sub-catchments. However, in many cases a local model can be selected in the property sheet for a particular sub-catchment, as shown in Figure 5.73.

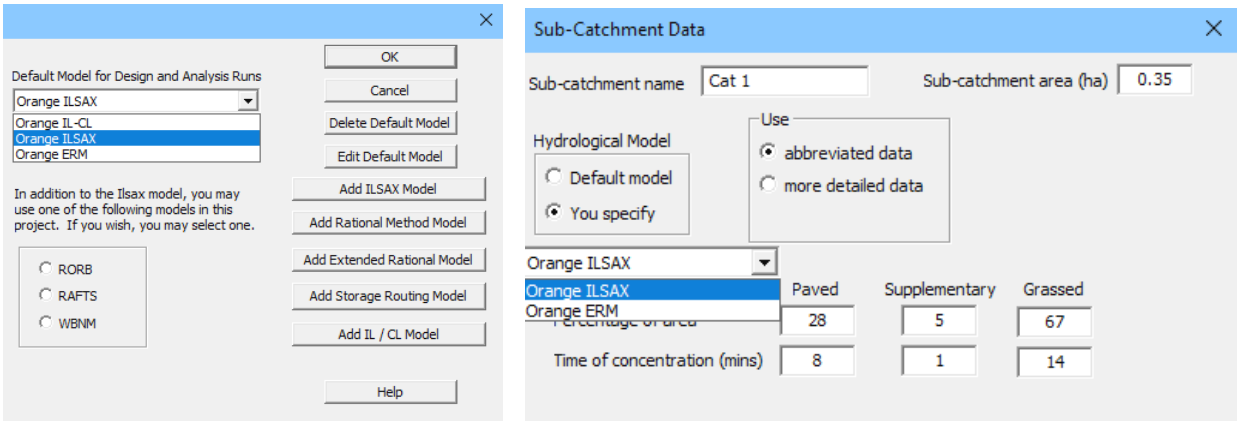


Figure 5.73 Selection of a Default and a Local Hydrological Model

5.4.4 Rainfall Data Bases

(a) New 2016 Procedures

The input procedures for the data base of rainfall burse patterns (in ensembles of 10 patterns) are available from the Bureau of Meteorology website (www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016) and the ARR Data Hub (data.arr-software.org/).

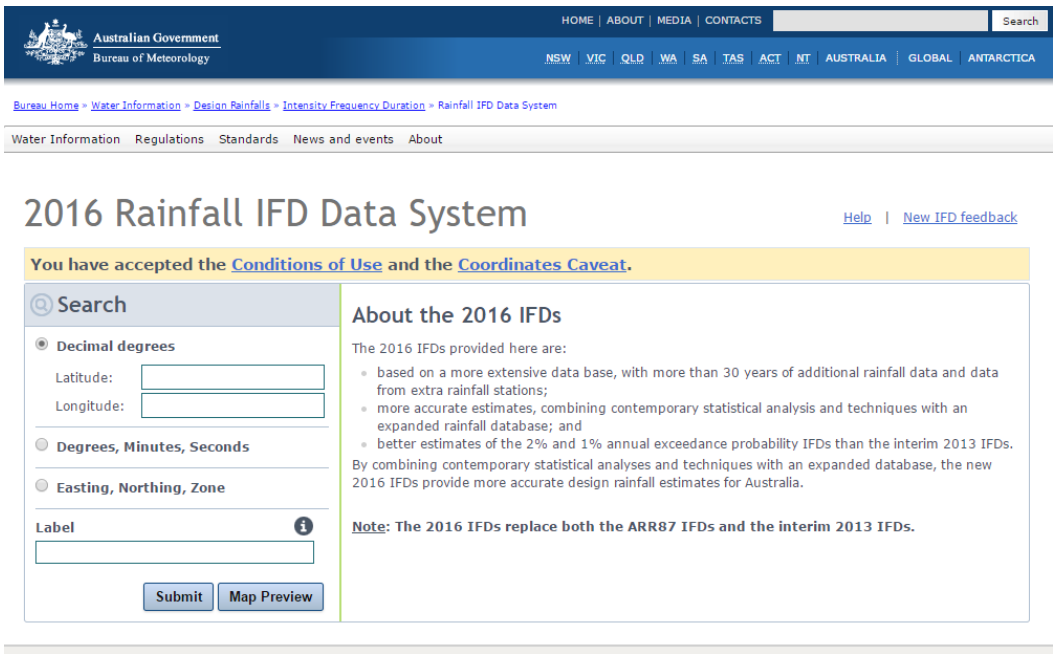


Figure 5.74 Bureau of Meteorology I-F=D Website

The entry procedures for hydrograph models (ILSAX, ERM, IL-CL and storage routing models have been set out in Section 2.4 and those for the rational method in Section 3.2.3.

(b) Entering Single and Multiple ARR87 Patterns for ILSAX and ERM

The setting up of 1987 rainfall patterns in the Rainfall Patterns dialog box is demonstrated in Section 2.5.2. Please refer to this.

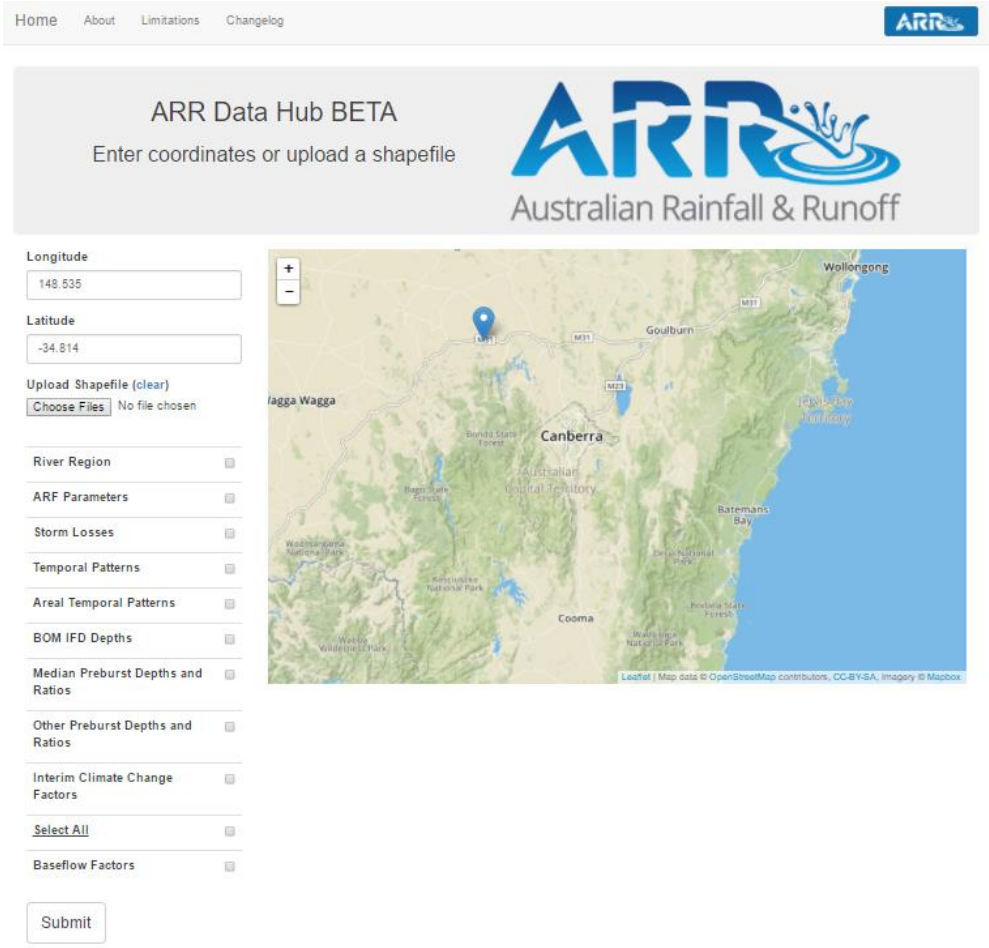


Figure 5.75 ARR Data Hub Website

(c) Entering Synthetic Storms for the Extended Rational Method

As an alternative to working with ARR 1987 rainfalls, the ERM can be applied using synthetic patterns derived from the local intensity-frequency-duration (I-F-D) relationships. These will give the same peak rainfall values as the rational method because they are derived directly from the I-F-D data. They can be added to the rainfall pattern data base by pressing the **Add Synthetic Storm** button in the Rainfall Data property sheet and completing the dialog box shown in Figure 5.76 to produce the pattern shown in Figure 5.77.

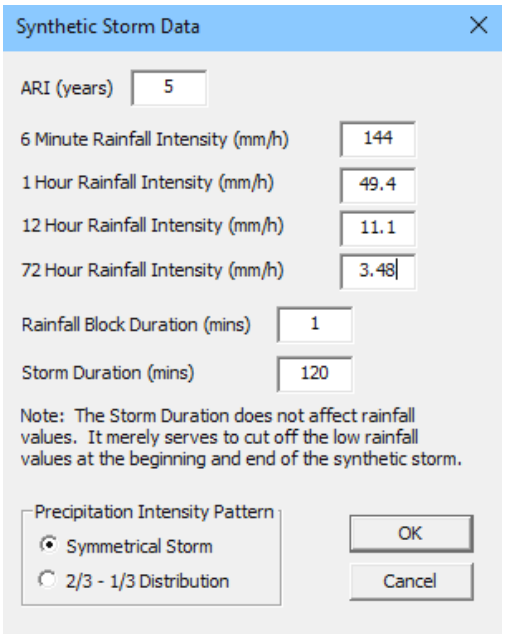


Figure 5.76 Dialog Box for Setting Up Synthetic Storms

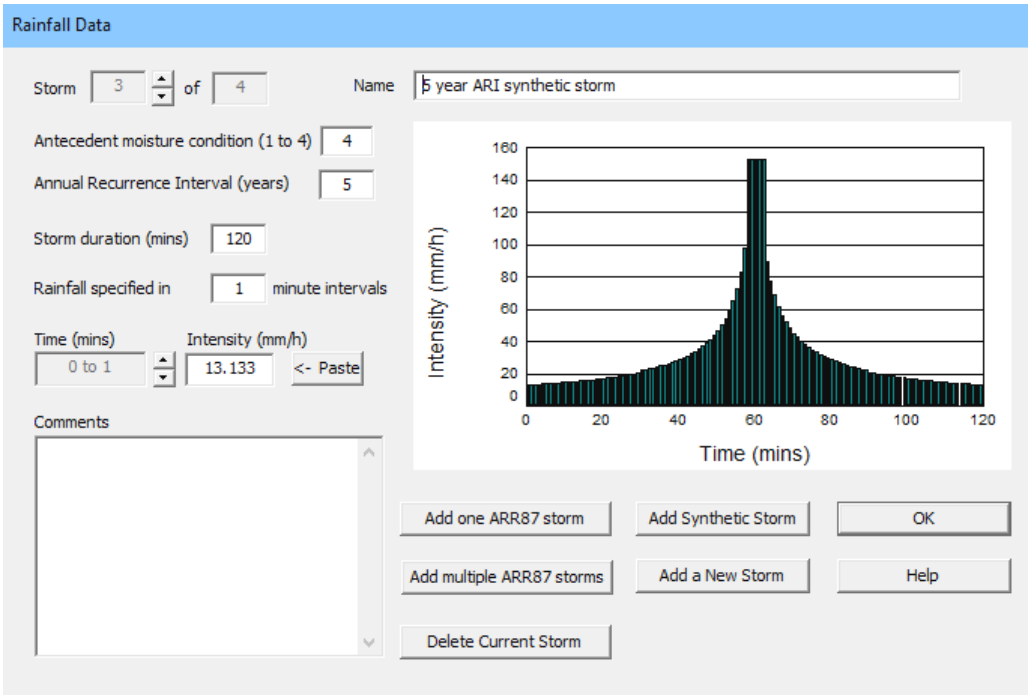


Figure 5.77 Synthetic Rainfall Pattern

The four intensities must be obtained from the local I-F-D data. A block duration of 1 minute is recommended to allow exact matching of 5, 6, 7, 8, etc. minute intensities in the I-F-D data. The volume of the hydrograph will increase for longer storm durations. The storm duration selected should be considerably longer than the time of concentration of the catchment.

The **2/3 - 1/3** option pushes the peak of the rainfall pattern to the right so that its peak occurs at two-thirds of the specified storm duration. Further information on this can be obtained in the San Diego County Hydrological Manual available on the internet. This is claimed to be more conservative for detention basin design.

Synthetic storm patterns consist of a number of nested storms, with the average intensity for any duration equalling the intensity specified by the I-F-D relationship for that duration. Originally known as the Chicago storm patterns, these relationships have been used in the United States for some time and are also applied in the UK and Hong Kong.

Note that this method cannot be applied with 2016 I-F-D data.

(d) Adding Storms by Hand or by Spreadsheet Transfer

It is also possible to set up non-ARR patterns by clicking the **Add a New Storm** button in the Rainfall Data property sheet to open the box shown in Figure 5.78.

Single storms can be entered into the property sheet by clicking on the **Add a New Storm** button. You can then specify the storm duration and time units for rectangular rainfall blocks, and enter rainfall intensities directly into the property sheet in the box labelled 'Intensity (mm/h)' to the left of the window.

If you are using the ILSAX hydrological model, it is also necessary to add an antecedent moisture condition (AMC) as defined in Section 8.3.2(e). The average recurrence interval (ARI) or annual exceedance probability (AEP) must also be entered. If you are entering a special pattern, such as a real storm, you can enter the nearest standard frequency for this pattern. If probable maximum precipitation storms are to be entered, a value of 999 might be used.

Another way of entering patterns is to set them up in a spreadsheet in two columns, as shown in Figure 5.79, one with times in minutes and the other with the corresponding rainfall intensities in mm/h. These can then by copied to the Windows Clipboard and then pasted into the Rainfall Data Property Sheet using the **<- Paste** button, as shown in Figure 5.80. This is an effective way of entering patterns for probable maximum precipitation and extreme flood modelling.

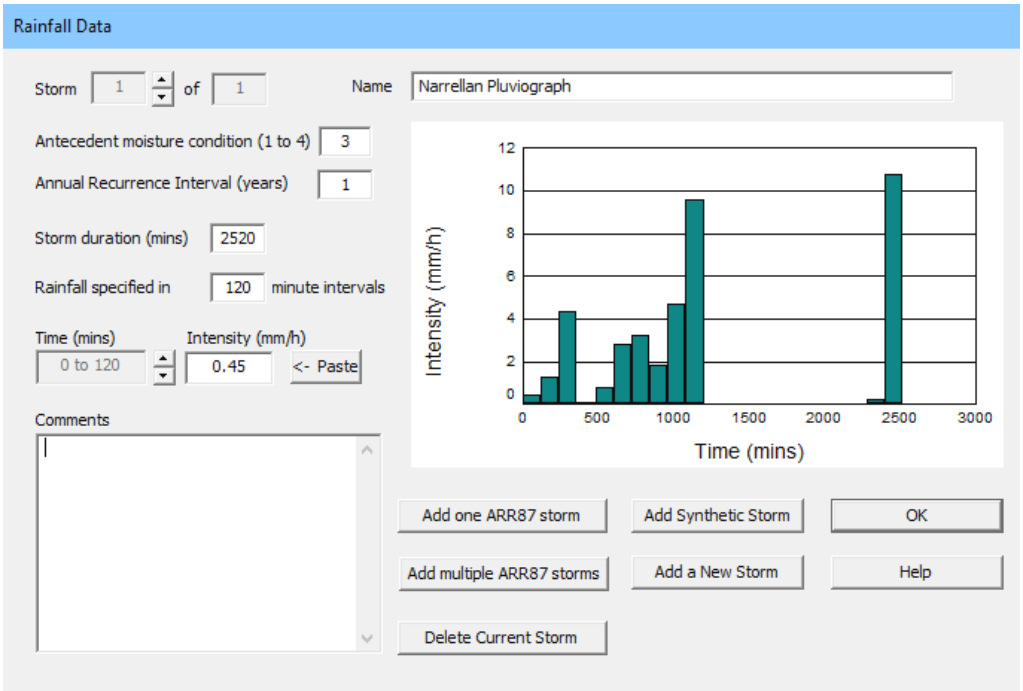


Figure 5.78 Manual Data Entry of a Rainfall Hyetograph

0	5.6
5	14.9
10	21.3
15	55.6
20	34
25	2.3
30	0
35	0.5
40	22.9
45	67.7
50	90.4
55	36.4
60	34.2
65	10
70	3

Figure 5.79 Spreadsheet Data Entry

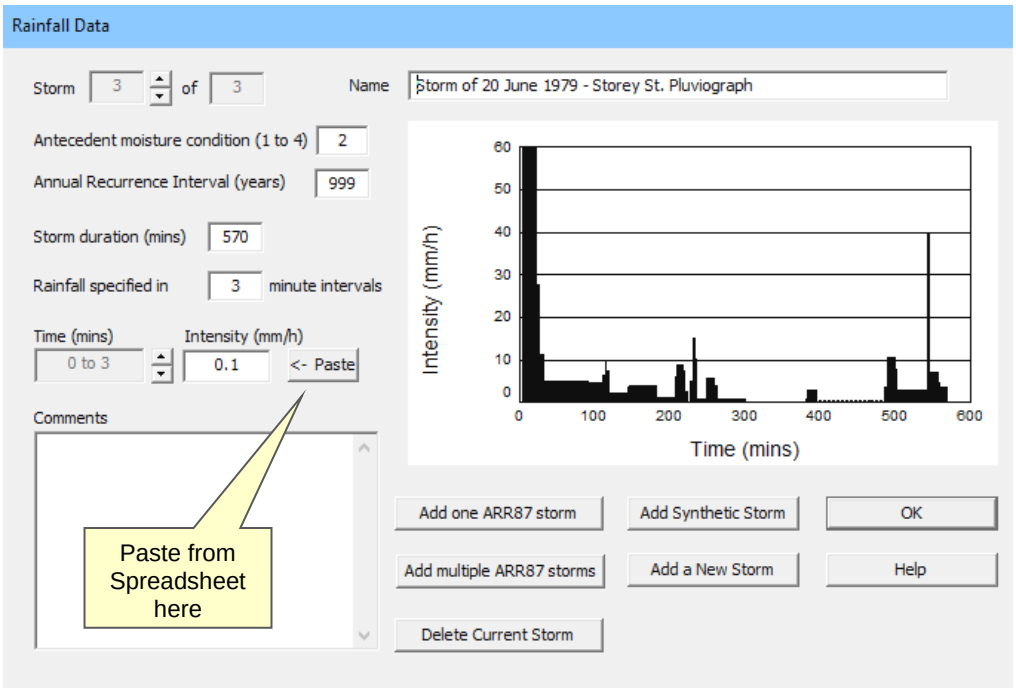


Figure 5.80 Observed Actual Rainfall Pattern

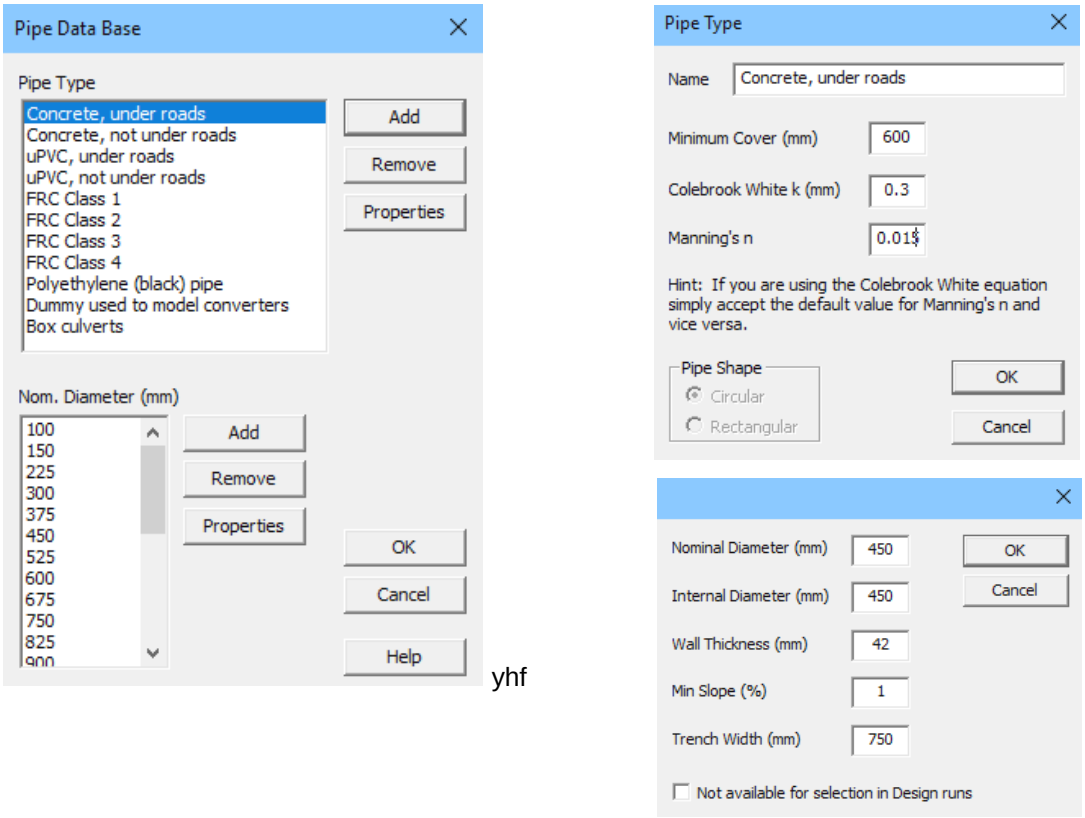
At times DRAINS may not calculate hydrographs for as long a period as you may require. The calculation period can be easily extended by increasing the given storm duration in Figure 5.78. This automatically assumes that the extra rainfall ordinates are zero, and extends the calculation period.

Whatever data are entered into the rainfall database, they must be nominated as major or minor storms using the options shown in Figure 2.71, in order to run with the available options (as set out in Section 6.4).

5.4.5 Pipe Data Base

The Pipe Data Base property sheet shown in Figure 5.81 is opened by selecting the **Pipe Data Base …** option in the **Project** menu. This operates in two stages. The first is to define a pipe type, and to specify its name, whether it is circular or rectangular, its roughness (according to the pipe friction formula set in the **Options** property sheet called from the **Project** menu), and its minimum cover (m). The second stage is to provide data for specific pipe sizes in the property sheet shown to the right in Figure 5.81. For circular pipes, the nominal diameter, internal diameter (I.D.) and wall thickness must be supplied in mm. For rectangular pipes, the width (m), height (m) and wall thickness (mm) must be supplied.

The check box labelled '**Not available for selection in design runs**' allows you to omit pipe sizes that are considered too small or are unavailable. If you wish to vary cover depths with pipe sizes, or to have different classes of pipes (with different wall thicknesses), specific pipes classes should be entered as pipe types.



yhf

Figure 5.81 Main Pipe Data Base and Pipe Type Property Sheets

Once the data base is established, pipe types and sizes are readily accessed from the Pipe Data property sheet. The data base can be edited, and factors such as cover depths can be altered. When such changes are made, the title should also be changed to note that the default set of pipe data has been altered. Additional pipe types can be added using **Import** > **DRAINS Database (DB1) File…** in the **File** menu, which requests the name of a .db1 file to be added. These are located in the C:\Program Files\Drains\Program or C:\Program Files (x86)\Drains\Program folders. When a file is nominated, DRAINS opens the dialog box shown in Figure 5.82. You can then select the particular data you wish to transfer.

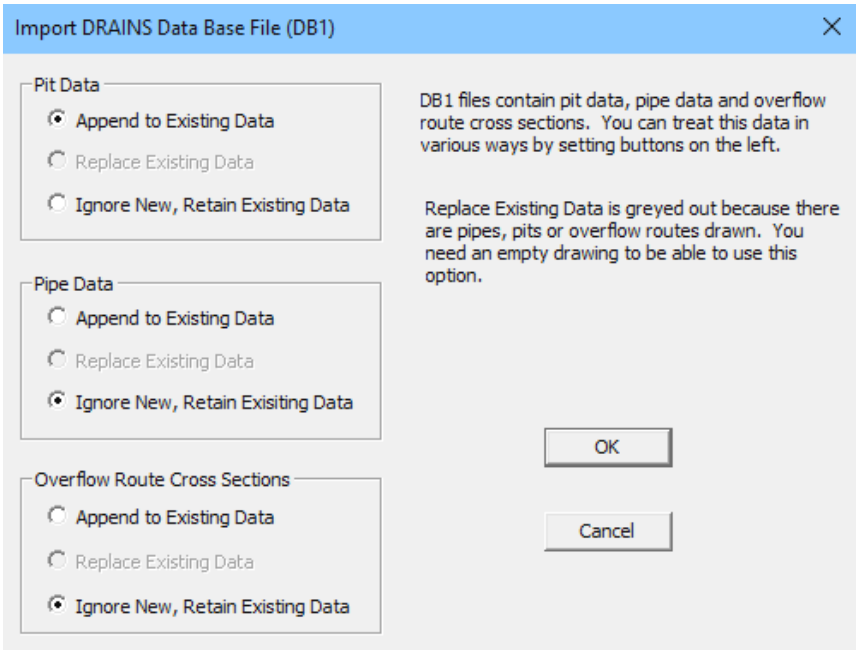


Figure 5.82 Dialog Box for Importation of Additional Pipe, Pit and Overflow Data

Note that deletion of pipe types and sizes is not possible if pipes are present in the Main Window. It can be done on a template file that does not contain any drainage system components.

When a DRAINS file is opened and closed, its pipe, pit, overflow profile data bases remain in DRAINS, and some may be inherited by the new system. Template files can also supply suitable data bases.

5.4.6 Pit Data Base

The Pit Data Base is accessed through the **Pit Data Base**… option in the **Project** menu. As shown in Figure 5.84, pits are organised into types or families of different sizes, in a similar way to pipes. The pit type is described in the Pit Type property sheet, also shown in Figure 5.84.

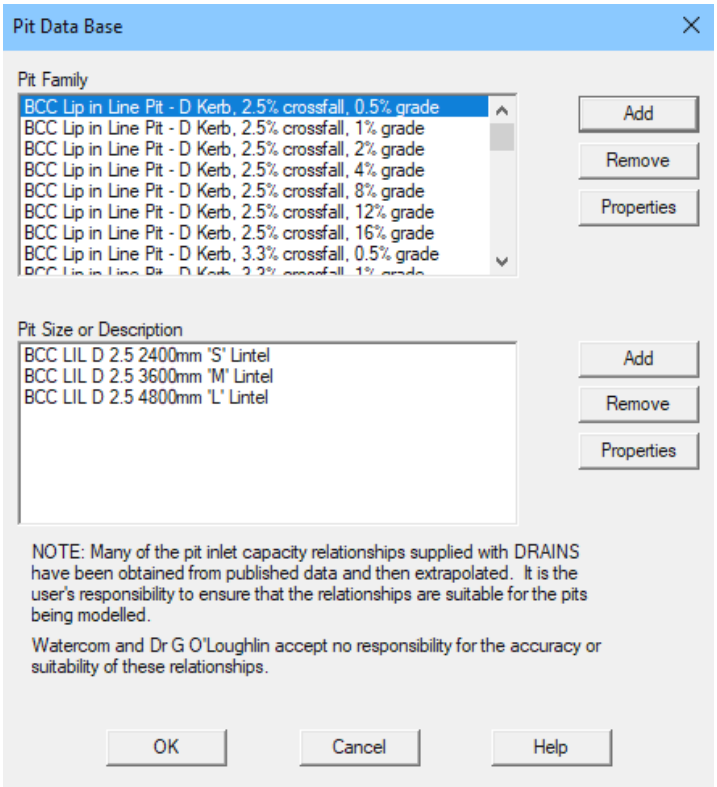


Figure 5.83 Main Pit Data Base Property Sheet

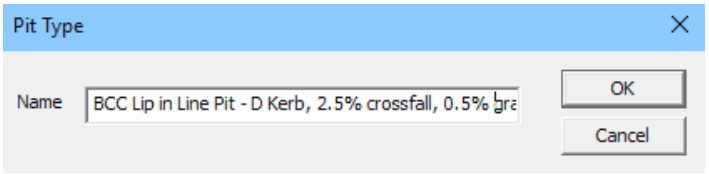


Figure 5.84 Pit Type Property Sheet

Data for each individual pit is entered in the triple property sheet shown in Figure 5.85. The relationships are entered directly, as tables. This provides flexible relationships, particularly at the top end of the curves. It is possible to set an upper limit on inlet capacities if required.

As part of the DRAINS design method, sets of relationships for pits in various regions have been provided in .db1 data files contained in the C:/Program Files/Drains/Program or C:/Program Files (x86)/Drains/Program folder, under names such as NSW Pits June 2008.db1. Relationships for NSW, Queensland, Victoria, the Australian Capital Territory, South Australia and Western Australia are now available. Instead of a single data base, these are made up of sets of relationships that can be combined as required, using the **Import** > **DRAINS Database (DB1) File…** option in the **File** menu.

Additional pit types can be entered into the data base via the dialog box shown in **Figure 5.82** This process can be assisted by the **Paste Data** and **Copy Data** buttons in the On-Grade Data and Sag Data windows shown in Figure 5.85. The first function can bring in data from two columns of a spreadsheet, in the same way as for rainfall patterns (Section 5.4.4). The **Copy Data** function can transfer data to a spreadsheet, or directly to another DRAINS pit data base. A pit data base can be selected for a new project using the **Default Data Base** option in the **Project** menu, in the dialog box shown in Figure 5.86.

In DRAINS, inlet capacity relationships are available for many Australian pit types, as indicated in Table 8.18 to Table 8.24,

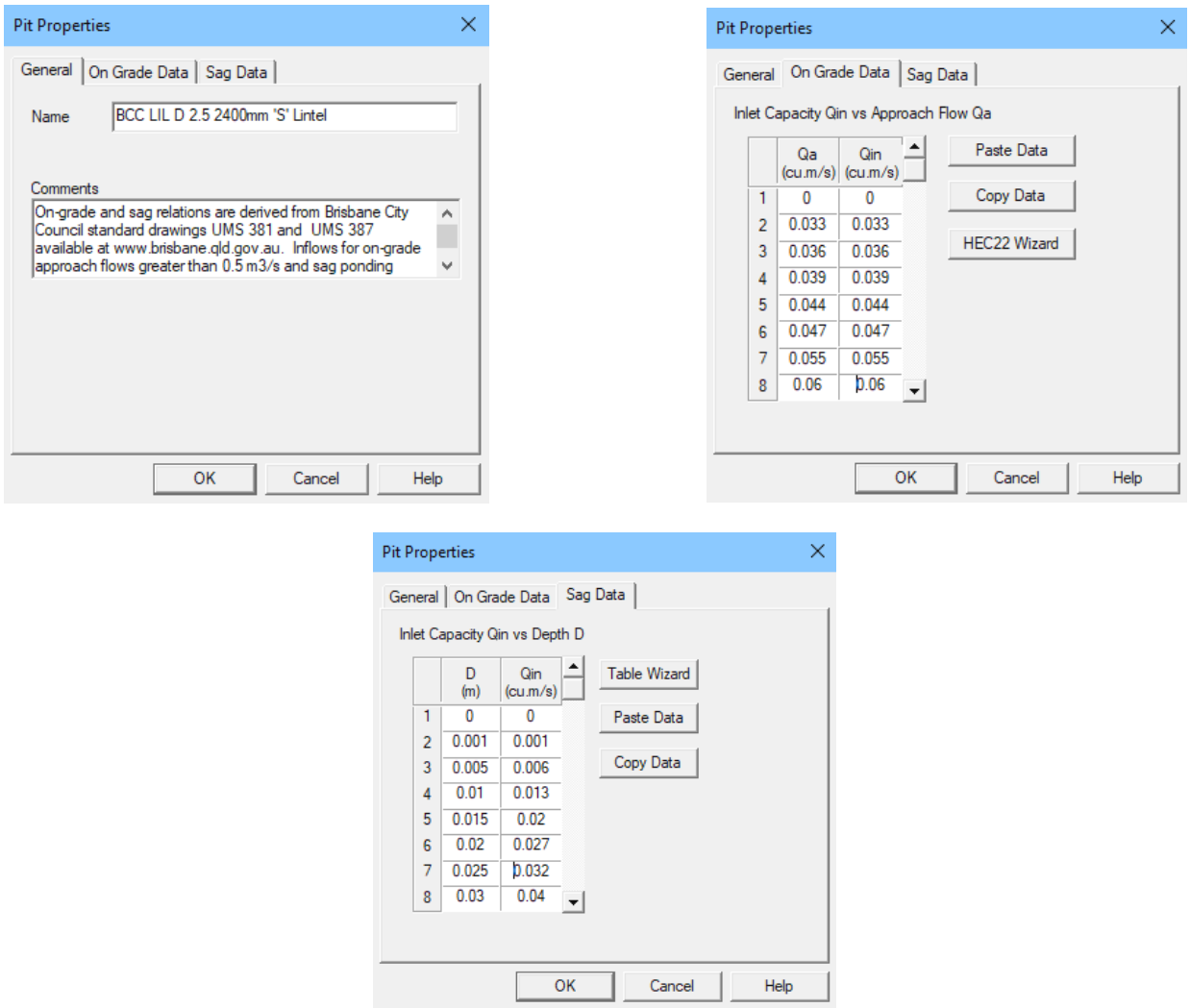


Figure 5.85 Inlet Capacity Data for an Individual Pit

These may be periodically updated. To update a DRAINS model it will be necessary to import the data in the revised .db1 file using the **Import ► DRAINS Database (DB1) File…** option in the **File** menu, and then change the name of the old relationship to show that it is obsolete. The pit types nominated for particular pits can then be changed one by one, or altered by exporting the system data to a spreadsheet, as described in Section 6.5.4, altering pit type and size names in the columns, and then exporting the altered spreadsheet back to the DRAINS model.

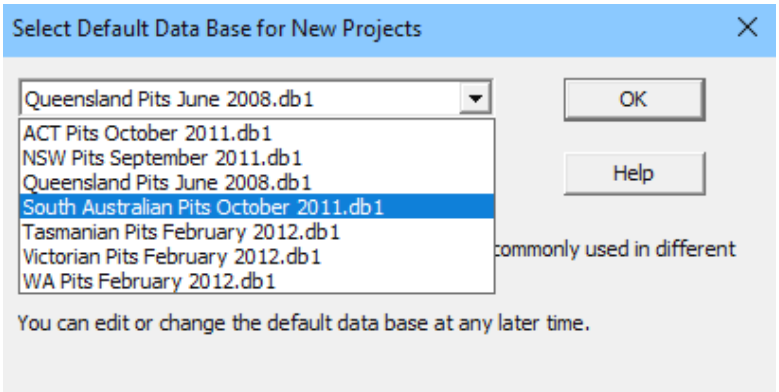
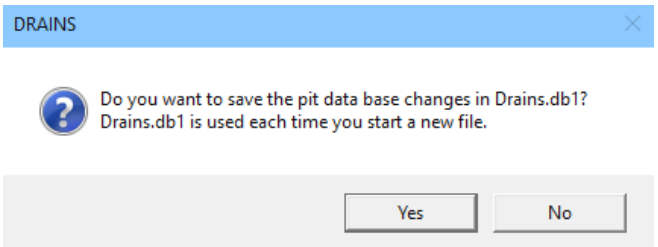


Figure 5.86 Dialog Box for Selecting a Default Data Base

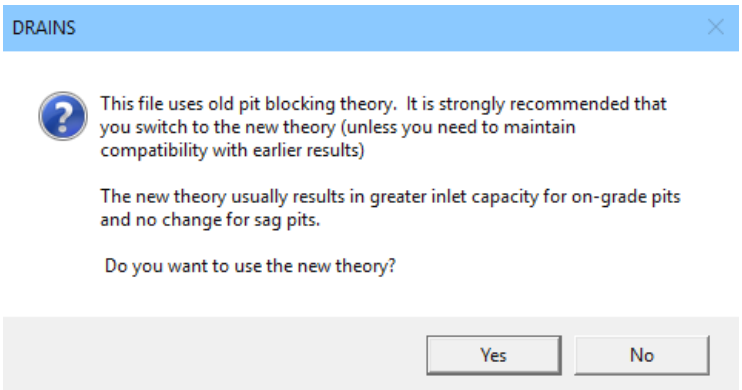
However, there are many types of pit for which no relationships are available. Using the HEC22 procedures in the wizards for on-grade and sag pits implemented by the buttons shown in Figure 5.85, inlet capacity relationships can be estimated for these. A 'generic' pit spreadsheet that calculates capacities using methods from the US Federal Highway Administration HEC-22 manual (US FHWA, 2001) can also be applied. More explanation is provided in Section 8.5.3.

If a Pit Data Base is opened, and a change is made to the data for one of the pits, the following message appears when this is closed by clicking on the **OK** button: Clicking the **Yes** button sets up the file's pit data base as the selected one.



Various regional pit types are available as .db1 files in the C:/Program Files/Drains/Program folder. If ACT Pits June 2008.db1 or Queensland Pits June 2008.db1 is copied as Drains.db1 into the folder C:/ProgramData/Drains, the ACT or Queensland pit types will be installed. DRAINS uses separate folders in C:/Program Files, C:/Program Files (x86) and C:/ProgramData following Microsoft rules for handling files for applications.

DRAINS still accepts old files that use the ILSAX equations described in Section 8.5.1 for pit inlet capacities. However, if you attempt to run the Design method, the following message will appear. It would then be possible to import a new Pit Data Base and to alter each pit's type to conform to this.



5.4.7 Overflow Route Data Base

The property sheet opened from the **Overflow Route Data Base…** in the **Project** menu is shown in Figure 5.87. Using X-Y coordinates, a cross section can be defined for a roadway, footpath or other route that may operate as a path for overflows.

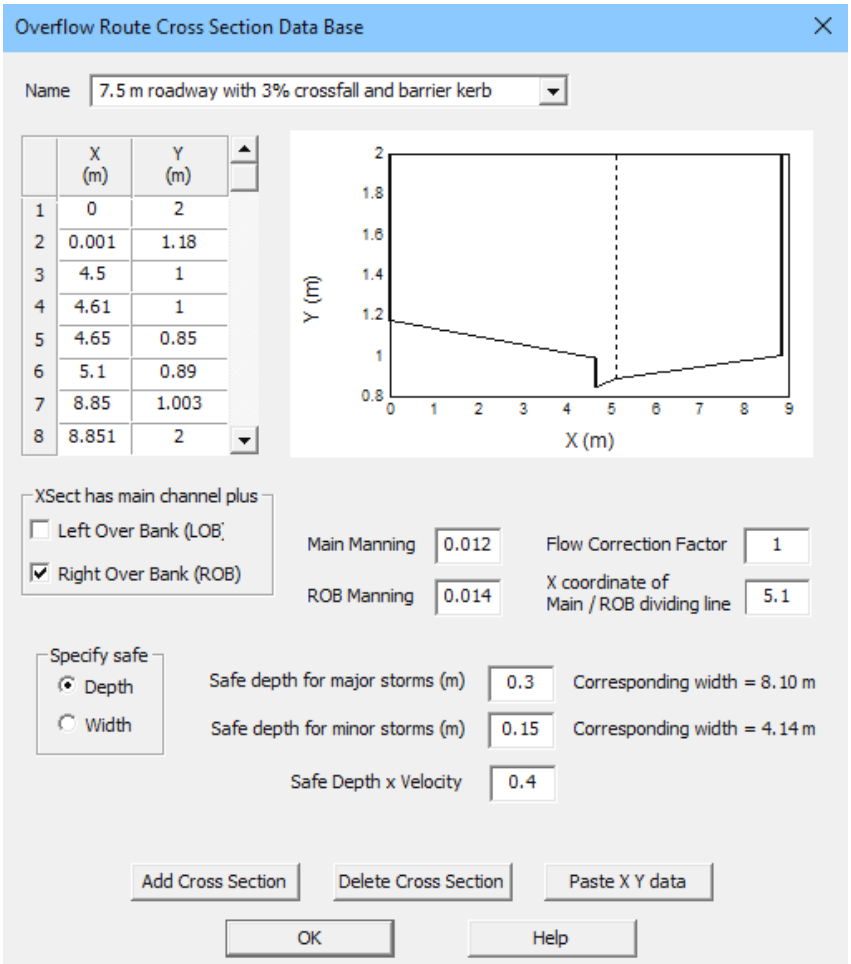


Figure 5.87 Overflow Route Cross Section Data Base Property Sheet

At present, the section may be divided into two zones with different Manning's n roughnesses, by specifying these, and the X value of the dividing line. As X-Y values are entered, the picture shows the section being produced.

In the boxes at the bottom, you can specify safe depths for minor and major storms and a safe depth-velocity product. These are applied at selected cross-sections in the Design method. DRAINS works backwards to ensure that overflows from pits are kept to levels that will meet these safety criteria. It does this by providing pits and pipes with the appropriate capacities to do this, following procedures within the *Queensland Urban Drainage Manual* (Neville Jones & Associates et al., 1992).

6. OPTIONS WITHIN DRAINS

6.1 Introduction

Most of the functions or processes within DRAINS are presented here, referring to the example files that accompany this manual. They are arranged into:

- Input Options,
- Display Options,
- Run Options,
- Output Options, and
- Help Options.

6.2 Input Options

6.2.1 General

The example file in Chapter 1 was established using the screen tools provided on the Toolbar, and their associated property sheets. Other options are available that allow a substantial part of the information required to be inputted by other means. These are mainly implemented through the **File** menu shown in Figure 6.1, and the two additional menus that are opened using the **Import ► and Export ►** options. (Note that not all options may appear when the hydrological model in DRAINS is set to be a rational method model.)

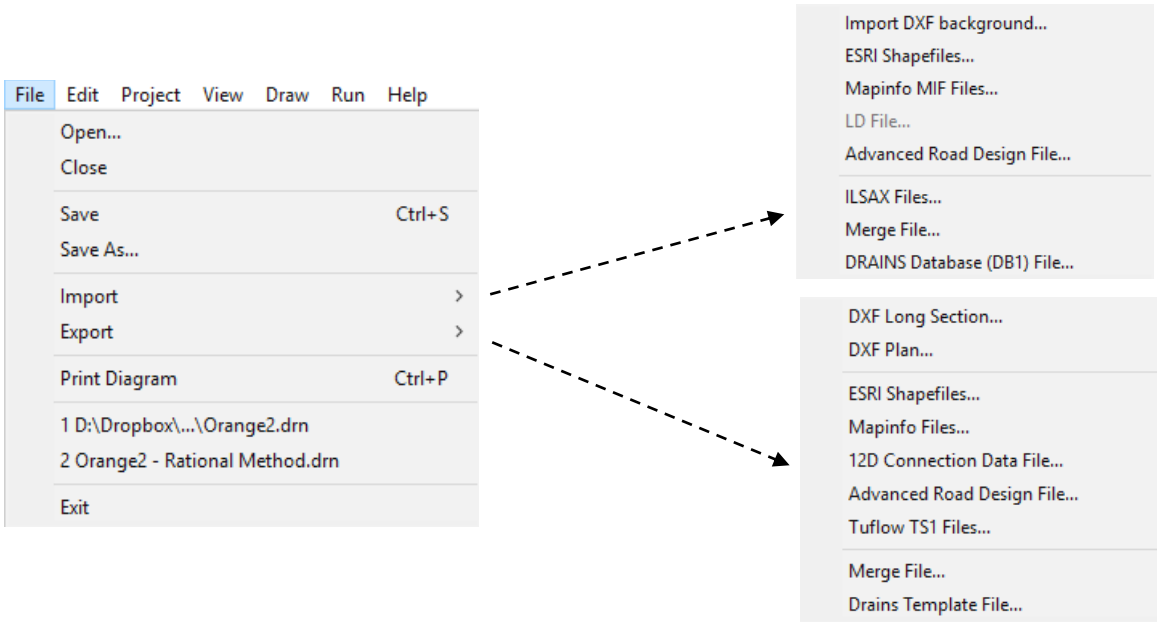


Figure 6.1 The File Menu and Sub-Menus showing Import and Export Options

In design work, it is likely that considerable data will be available from CAD files created by surveyors and used by designers to set out street layouts, cadastral (land boundary) data and positions of services. Some of this data can be taken directly into DRAINS by importing CAD files in DXF format. This includes a background showing streets, lot boundaries and other information. Other data obtainable from CAD drawing files, such as sub-catchment areas, will have to be entered into property sheets, or via a spreadsheet.

For investigation of established drainage systems, data is likely to be available in a number of forms: paper plans, CAD drawings, spreadsheet tables, data bases from GIS systems and aerial photographs. DRAINS can accept ESRI (ArcView, ArcInfo, and ArcMap) files and MapInfo files. A background can be imported as a DXF file, and spreadsheets can be assembled into a form accepted by DRAINS.

6.2.2 Importing DXF Files

(a) New Systems

Where a drainage system has been drawn in a drawing package or digital terrain model, it can be imported into DRAINS in DXF format. This is one of the oldest drawing formats, which can be created in almost all technical graphics packages. Newer formats such as DWG, the widely-used AutoCAD binary format, can be converted to DXF format before transfer to DRAINS.

The external software package must include three layers:

- one for pits, with the location of each pit marked by a circle,
- one for pipes, with pipes shown as lines, and
- a background, which may show street boundaries, cadastral information and contours.

Other layers can also be present, but will not be used. Lines, poly-lines and arcs on the background layer will be imported into DRAINS as a bitmap.

Figure 6.2 shows a drawing created in AutoCAD LT, representing a drainage system assumed to be at Brisbane.

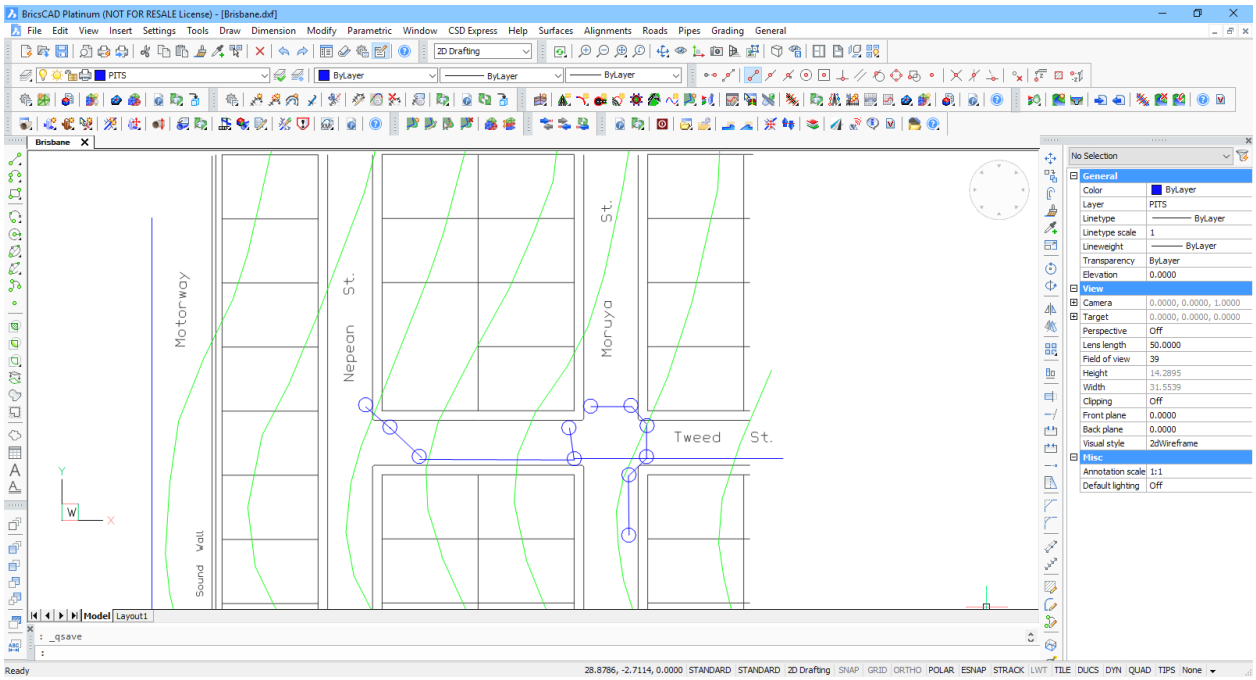


Figure 6.2 Drawing of Drainage Network

Information that is in this file can be imported by opening DRAINS and selecting Import a **DXF File…** from the **File** menu. You will be requested to nominate a file with a .dxf suffix. You will then see a dialog box that asks you to nominate the names of the layers on which pipes, pits and background are located, as shown in Figure 6.3. This is saved as a file Brisbane.dxf.

Using the drop-down list box, you can select the appropriate layers. Pits and pipes can be placed on the same layer if you wish. Once layers are selected, a number of information windows appear. The first one shown in Figure 6.4 allows pipe lengths to be automatically scaled off the DXF drawing, according to the length allocated to the first pipe for which full data is entered.

The DRAINS Main Window then appears with the drainage system and background shown as in Figure 6.5. This can be enlarged if necessary, using the Zoom tool. The colour of the background and its intensity can be changed using **the Background Colour…** option in the **View** menu. If the background has a much greater extent than the pipes in the model, DRAINS will reduce the field of view. This can be extended again using the **View** → **Extend Drawing Area…** option. Dummy pipes and pits can also be inserted to provide a large background, as shown to the left of Figure 6.5.

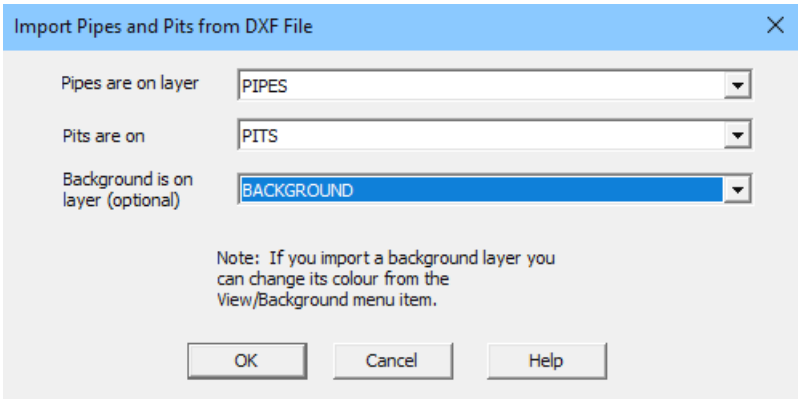


Figure 6.3 Layer Selection Dialog Box

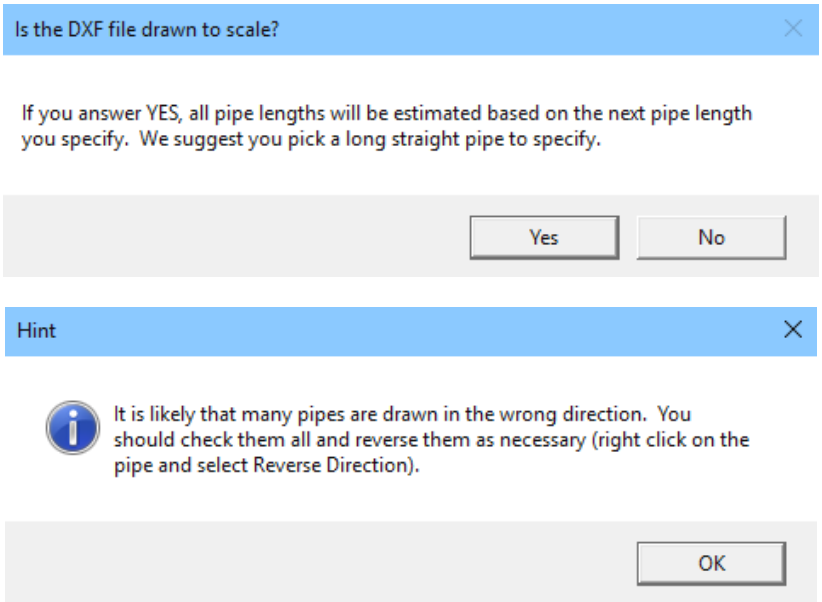


Figure 6.4 Messages in DXF Import Procedure

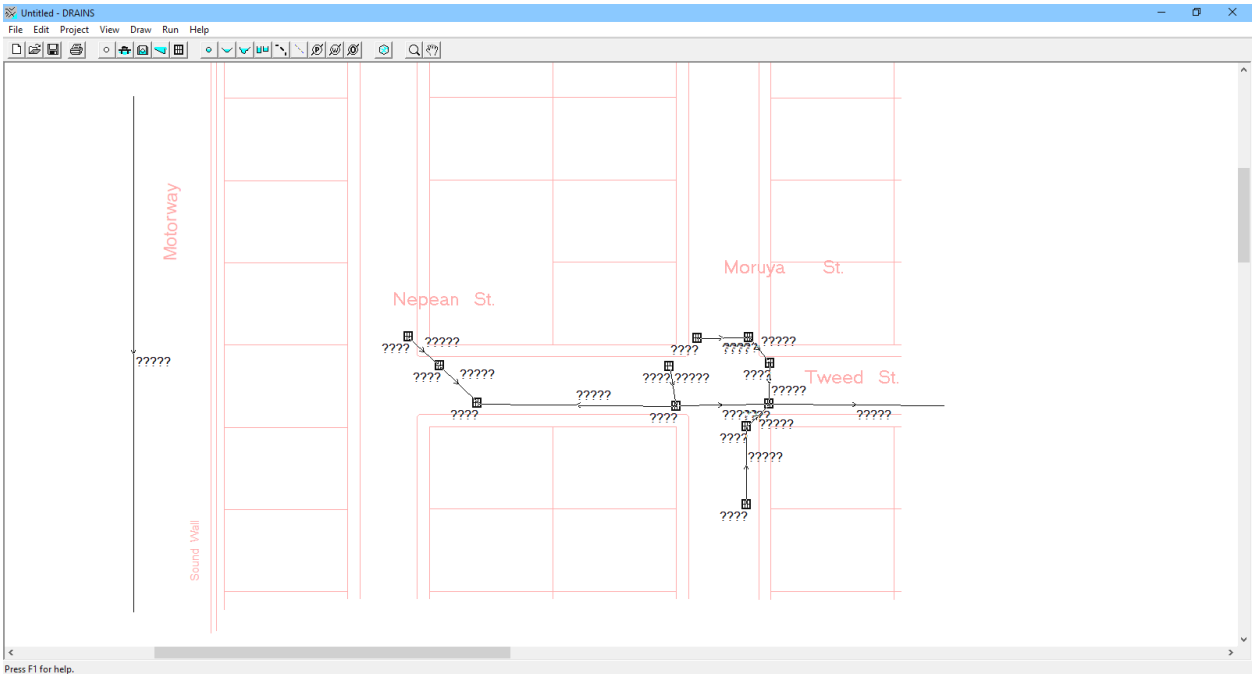
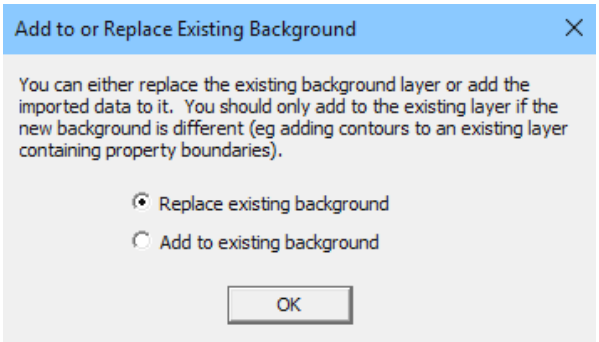


Figure 6.5 Imported DXF File Information

You must now enter information for pits and pipes, and draw in sub-catchments, overflow routes and outfall nodes, as shown in the example in Chapter 1. Directions of pipes will have to be changed if the pipes in the CAD drawing are drawn from 'the bottom up'.

Lettering for features such as street names can be brought into DRAINS from a CAD file if it is in an acceptable format. Text in the Standard style on a single line (created using Draw → Text > → Single Line Text) can be transferred.



The long dummy pipe to the left in Figure 6.5 can be used to define the lengths of the other pipes when these are scaled. A length for this should be defined first, and it can be retained if nodes are placed at its ends.

(b) Replacement of Backgrounds

It is possible to import a new background or to exchange the current background with another. Using the **File → Import → Import DXF background…** option brings up a dialog box from which a DXF file can be opened. When a file is selected, the window shown to the right appears.

Note that if you replace a background, it does not open the dialog box shown in Figure 6.3 and will not transfer pits and pipes. All layers in the replacement CAD file will be shown. For example, if the Brisbane background is read in again, the contours and pipes will appear in the background. You must be careful that the replacement file only contains the layers that you want. This will probably involve the creation of an additional CAD file containing only those layers that you want to display.

If you have a DRAINS model without a background, you will be able to insert a background provided that it has a similar extent (in x-y coordinates) to the coverage of the x-y coordinates of the pits and nodes used in the model, which are displayed in the spreadsheet data output. Backgrounds can be inserted into models that include saved results.

6.2.3 Spreadsheet Imports

Information about a drainage system can also be imported from a spreadsheet file. Since this file will usually be created by outputting information from a DRAINS file, both the spreadsheet output and input processes are described later, in Section 6.5.4 of this chapter. Some sets of information can be pasted into DRAINS property sheets for rainfall patterns, hydrographs, pits, detention basins, headwalls and culverts as columns from a spreadsheet.

A DRAINS *Utility Spreadsheet* and a *Generic Pit Inlet Capacity Sheet* are available to DRAINS Users, with the former being on the www.watercom.com site. Information from these can be pasted into DRAINS as shown in Figure 6.6.

6.2.4 GIS File Imports

(a) Importing ESRI (ArcView) Files

This process enables you to import data into DRAINS from one to six sets of ESRI or ArcView files, plus an optional background from a DXF file. The procedure is the reverse of the exporting process for ESRI files described in Section 6.5.5(a).

If you wish to model an existing drainage system in DRAINS, importing data from available ArcView records, you must edit these into the format required by DRAINS, described in Section 8.10.3(b). You can also scrutinise this format by exporting a small drainage system and examining the resulting DBASE tables. The six sets of files contain data for nodes (pits and outlets), pipes, overflow routes, sub-catchments, survey levels along pipe routes and the positions of other services along a pipe routes. Each set includes three files with SHP, SHX and DBF suffixes.

30 Minute Pattern		
Time	Intensities	Percentages
(minutes)	(mm/h)	(%)
0	552	20
5	662	24
10	552	20
15	497	18
20	331	12
25	166	6
30		

45 Minute Pattern		
Time	Intensities	Percentages
(minutes)	(mm/h)	(%)
0	418	12
5	592	17
10	522	15
15	487	14
20	452	13
25	383	11
30	313	9
35	209	6
40	104	3
45		

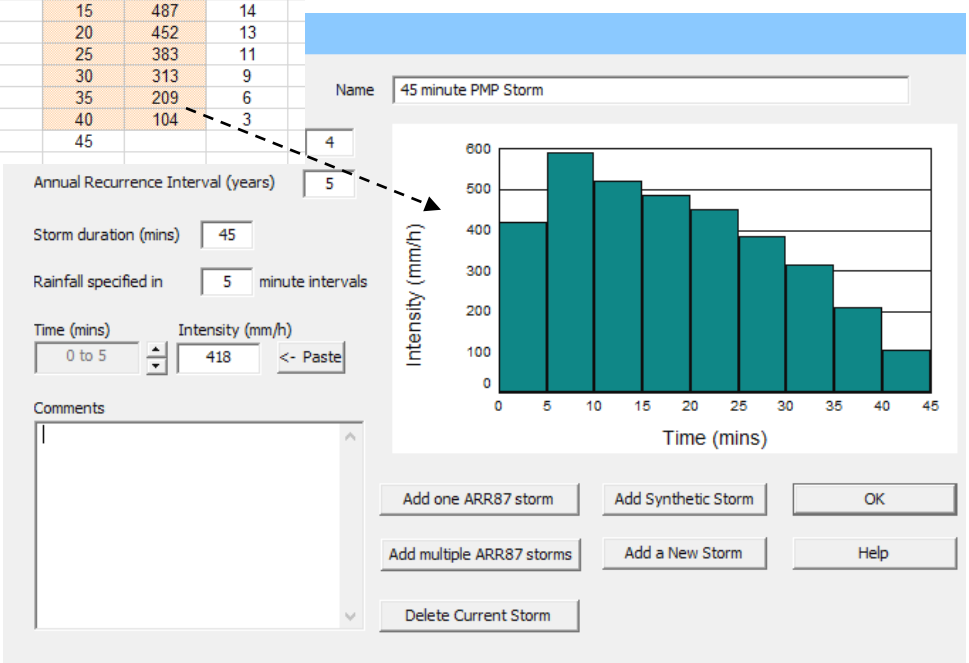


Figure 6.6 Transfer of a PMP Rainfall Pattern from a Utility Spreadsheet to DRAINS **Rainfall Data**

The transfer must include the files for nodes, but the rest are optional. In a first transfer, it is unlikely that all the information required by DRAINS will be available in the GIS. Information that is already in the GIS should be included in the files to be transferred. You can then choose whether to add additional data in these files, or to use dummy values and enter the required values later, in DRAINS.

The example shown in Figure 6.7 illustrates the process. The data for nodes (including pits and outlets) and pipes, each contained in a 'theme', needs to be entered in the data base tables shown in Figure 6.8, which can be created by editing in ArcMap or other GIS programs. A DXF file containing a background for the DRAINS model can be created from GIS layers.

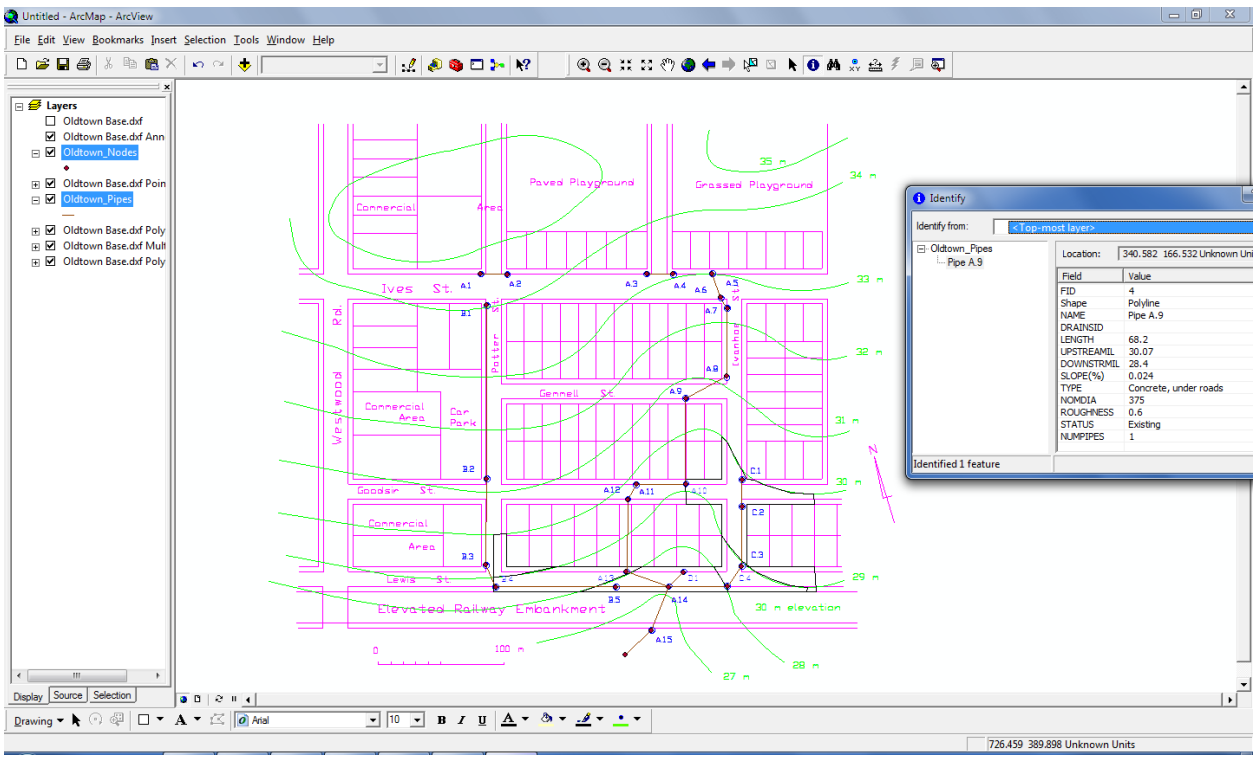


Figure 6.7 The 'Oldtown' Example in ArcMap

Attributes of Oldtown_Nodes

FID	Shape	NAME	DRAINSID	TYPE	FAMILY	SIZE	PONDINGVOL	KU	SURFACEEL	PONDDEPTH	BASEFLOW	BLOCKFACTR	BOLTDNLID
0	Point	Pit A.1		OnGrad	N/A	N/A	0	1.5	35.6	0	0	0	N/A
1	Point	Pit A.2		OnGrad	N/A	N/A	0	1.5	35.5	0	0	0	N/A
2	Point	Pit B.1		OnGrad	N/A	N/A	0	1.5	34	0	0	0	N/A
3	Point	Pit A.3		OnGrad	N/A	N/A	0	1.5	33.1	0	0	0	N/A
4	Point	Pit A.4		OnGrad	N/A	N/A	0	1.5	33	0	0	0	N/A
5	Point	Pit A.5		OnGrad	N/A	N/A	0	1.5	32.8	0	0	0	N/A
6	Point	Pit A.6		OnGrad	N/A	N/A	0	1.5	32.6	0	0	0	N/A
7	Point	Pit A.7		OnGrad	N/A	N/A	0	1.5	32.2	0	0	0	N/A
8	Point	Pit A.8		OnGrad	N/A	N/A	0	1.5	31.1	0	0	0	N/A
9	Point	Pit A.9		OnGrad	N/A	N/A	0	1.5	30.9	0	0	0	N/A
10	Point	Pit A.10		OnGrad	N/A	N/A	0	1.5	29.3	0	0	0	N/A
11	Point	Pit A.15		OnGrad	N/A	N/A	0	1.5	26.5	0	0	0	N/A
12	Point	Pit A.14		OnGrad	N/A	N/A	0	1.5	27.3	0	0	0	N/A
13	Point	Pit D.1		OnGrad	N/A	N/A	0	1.5	27.6	0	0	0	N/A
14	Point	Pit C.4		OnGrad	N/A	N/A	0	1.5	28	0	0	0	N/A
15	Point	Pit C.3		OnGrad	N/A	N/A	0	1.5	29.1	0	0	0	N/A
16	Point	Pit C.2		OnGrad	N/A	N/A	0	1.5	29.7	0	0	0	N/A
17	Point	Pit C.1		OnGrad	N/A	N/A	0	1.5	29.9	0	0	0	N/A
18	Point	Pit A.11		OnGrad	N/A	N/A	0	1.5	29.2	0	0	0	N/A
19	Point	Pit A.12		OnGrad	N/A	N/A	0	1.5	29.1	0	0	0	N/A
20	Point	Pit A.13		OnGrad	N/A	N/A	0	1.5	28	0	0	0	N/A
21	Point	Pit B.5		OnGrad	N/A	N/A	0	1.5	27.9	0	0	0	N/A
22	Point	Pit B.4		OnGrad	N/A	N/A	0	1.5	28.7	0	0	0	N/A

Record: 1 Show: All Selected Records (0 out of 26 Selected) Options

Attributes of Oldtown_Pipes

FID	Shape	NAME	DRAINSID	LENGTH	UPSTREAMIL	DOWNSTRMIL	SLOPE(%)	TYPE	NOMDIA	ROUGHNESS	STATUS	NUMPIPES
0	Polyline	Pipe A.5		21.9	32.05	31.78	0.012	Concrete, under roads	300	0.6	Existing	1
1	Polyline	Pipe A.6		8.7	31.78	31.38	0.046	Concrete, under roads	375	0.6	Existing	1
2	Polyline	Pipe A.7		54.8	31.38	30.27	0.02	Concrete, under roads	375	0.6	Existing	1
3	Polyline	Pipe A.8		37.8	30.27	30.07	0.005	Concrete, under roads	375	0.6	Existing	1
4	Polyline	Pipe A.9		68.2	30.07	28.4	0.024	Concrete, under roads	375	0.6	Existing	1
5	Polyline	Pipe A.10		38.6	28.4	28.3	0.003	Concrete, under roads	450	0.6	Existing	1
6	Polyline	Pipe A.11		14	28.3	28.2	0.007	Concrete, under roads	450	0.6	Existing	1
7	Polyline	Pipe A.12		57.9	28.2	26.95	0.022	Concrete, under roads	450	0.6	Existing	1
8	Polyline	Pipe A.13		35.5	26.95	25.75	0.034	Concrete, under roads	600	0.6	Existing	1
9	Polyline	Pipe C.1		21.5	29.15	28.95	0.009	Concrete, under roads	300	0.6	Existing	1
10	Polyline	Pipe C.2		47.3	28.95	28.35	0.013	Concrete, under roads	300	0.6	Existing	1
11	Polyline	Pipe C.3		21.1	28.35	27.25	0.052	Concrete, under roads	300	0.6	Existing	1
12	Polyline	Pipe C.4		46.4	27.25	26.5	0.016	Concrete, under roads	300	0.6	Existing	1
13	Polyline	Pipe D.1		17.4	26.85	25.75	0.063	Concrete, under roads	300	0.6	Existing	1
14	Polyline	Pipe B.5		41.7	27.07	26.25	0.02	Concrete, under roads	375	0.6	Existing	1
15	Polyline	Pipe B.4		96.2	27.87	27.07	0.008	Concrete, under roads	375	0.6	Existing	1
16	Polyline	Pipe B.3		18.7	28.45	27.87	0.031	Concrete, under roads	300	0.6	Existing	1
17	Polyline	Pipe B.2		68.9	30.35	28.45	0.028	Concrete, under roads	300	0.6	Existing	1
18	Polyline	Pipe B.1		138.3	33.25	30.35	0.021	Concrete, under roads	300	0.6	Existing	1
19	Polyline	Pipe A.1		20.6	34.85	34.75	0.005	Concrete, under roads	300	0.6	Existing	1
20	Polyline	Pipe A.3		21.6	32.35	32.25	0.005	Concrete, under roads	300	0.6	Existing	1

Record: 1 Show: All Selected Records (0 out of 23 Selected) Options

Figure 6.8 ArcView Tables of Characteristics of Nodes and Pipes, ready for Import into DRAINS

To make the transfer, you must place all files to be transferred into the same Windows folder, set up a DRAINS model with the ILSAX hydrological model and pit and pipe data bases that you require, and then use the **File** → **Import** → **ESRI Shapefiles…** option, which will display the message in Figure 6.9.

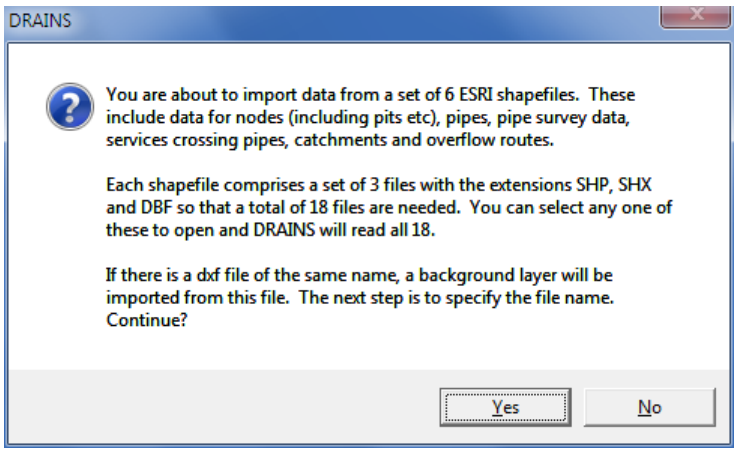


Figure 6.9 Shapefile Transfer Message

After entering 'Yes', you must select one of the ESRI files to be transferred, as shown in Figure 6.10 The transfer will then take place, and the pits and pipes will come into view, as shown in Figure 6.11.

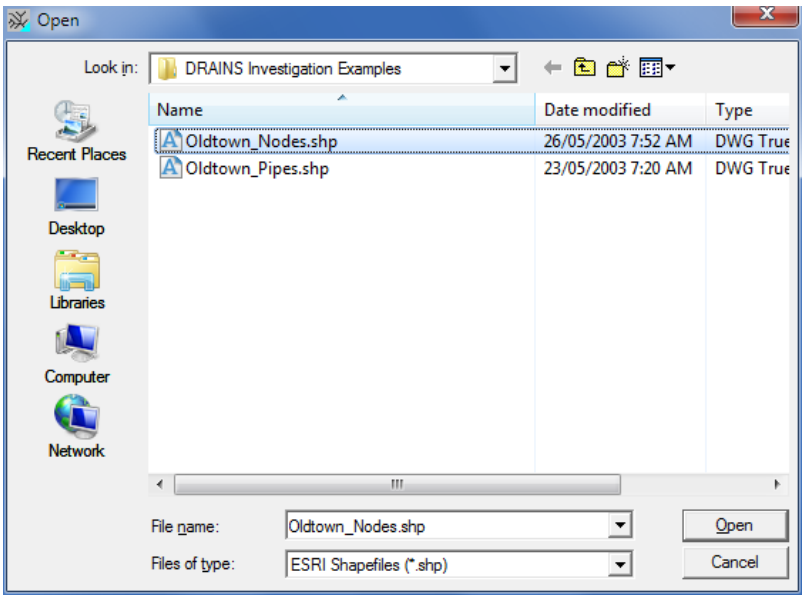


Figure 6.10 Choosing a Shapefile

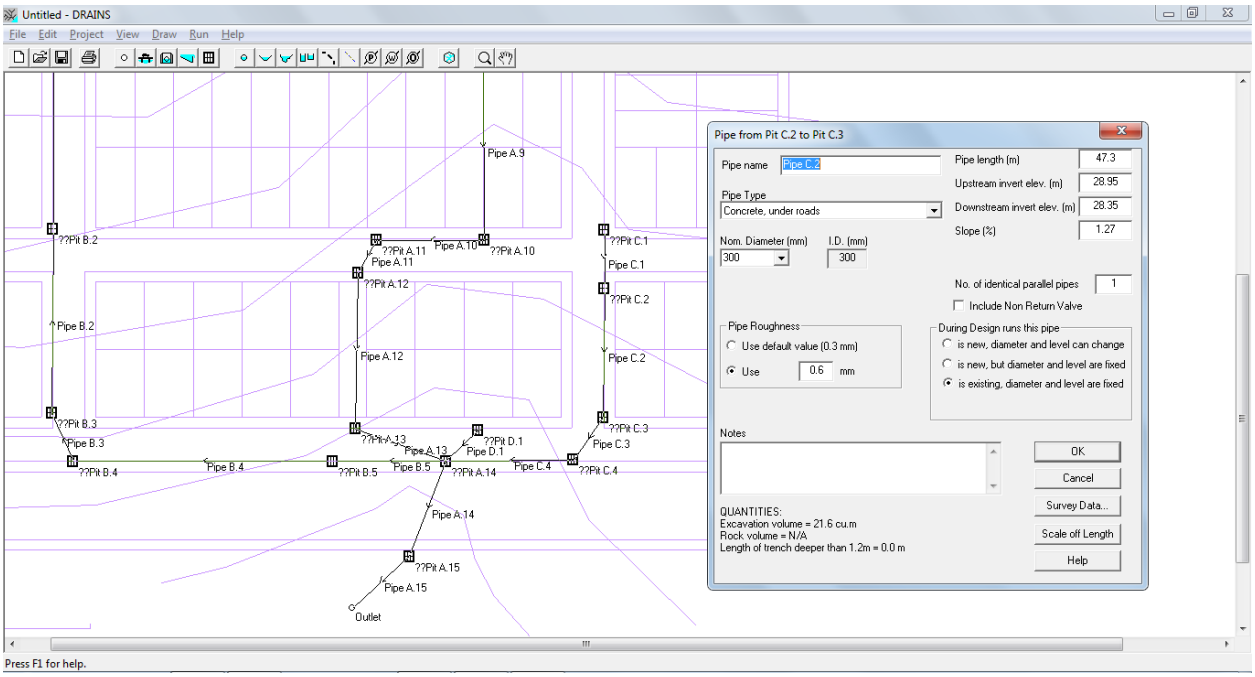


Figure 6.11 Transferred Data

(b) Importing MapInfo Files

This process enables you to import data into DRAINS from one to six sets of MapInfo files, plus an optional background from a DXF file. The procedure is the reverse of the exporting process for MapInfo files described in Section 6.5.5(b), and is similar to the ESRI transfer process described in the previous section of this chapter. The six sets of files cover nodes (pits and outlets), pipes, overflow routes, sub-catchments, location of ground levels along the pipe routes, and the location of other services along these routes.

To transfer MapInfo data to DRAINS, you need to edit the available MapInfo data into pairs of MID and MIF files in the format required by DRAINS, specified in Section 8.10.3(c). This is the same as the format generated in the export process that creates MapInfo files from DRAINS data, which you can see by exporting a small system and examining the resulting tables.

All the required information that is already in the GIS should be included in the files to be transferred. It is then a matter of choice as to whether you add additional data in these files, or enter dummy values, and enter the missing data later in DRAINS.

The following example illustrates the process, paralleling the ESRI file import example. Figure 6.12 shows the Oldtown System in MapInfo, with the data for one pipe being displayed. This can be set up in MapInfo or in a text editor. The corresponding node data is similar.

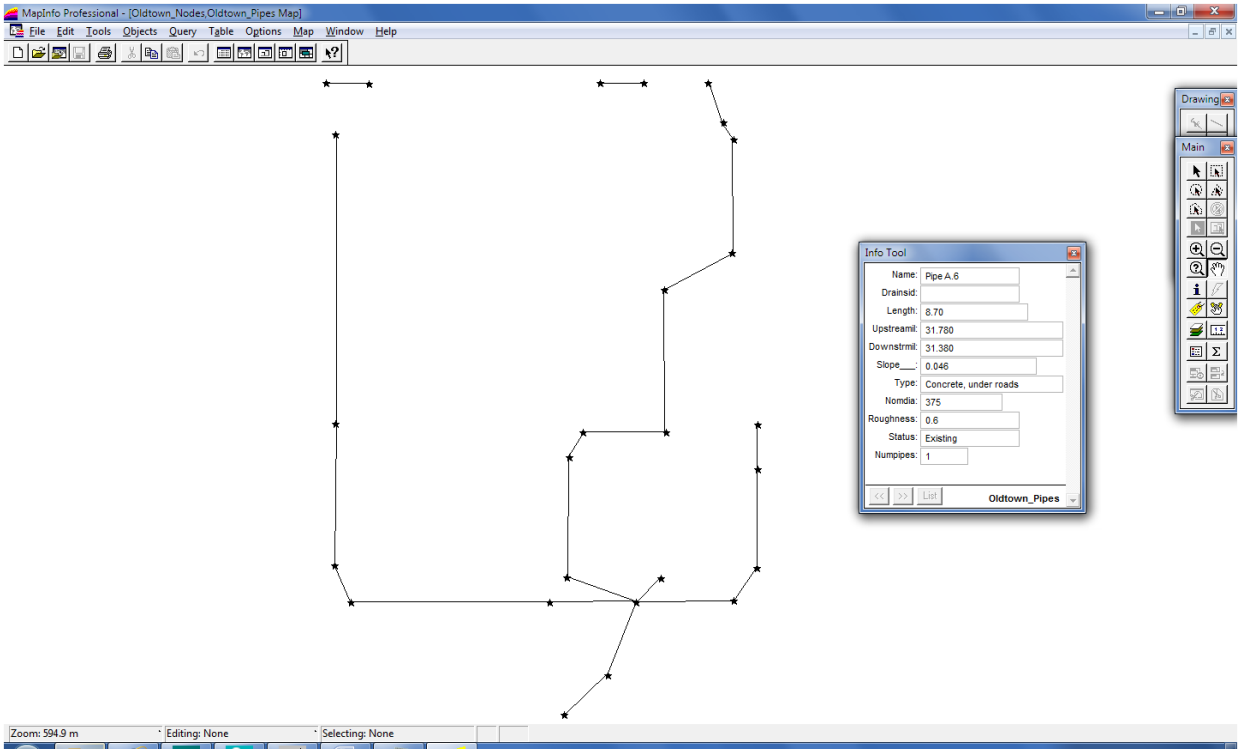
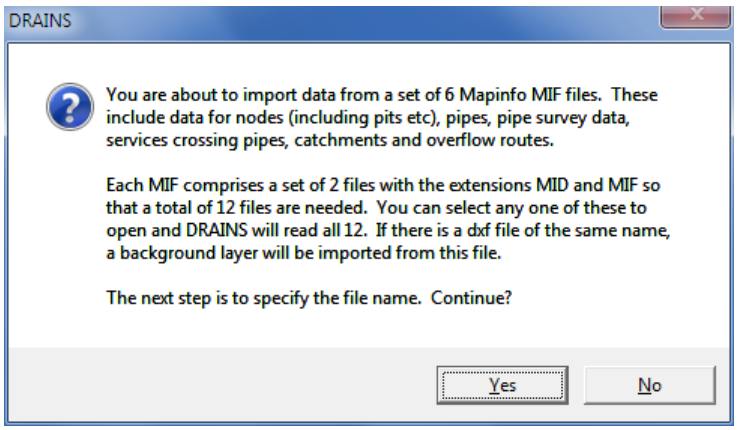


Figure 6.12 The 'Oldtown' Example in MapInfo

From the MapInfo layers, a DXF file containing a background for the DRAINS model can be created. This will appear in the same form as Figure 6.10.

To make a transfer, you will need to place all the files to be transferred into the same Windows folder, set up a DRAINS model with the ILSAX hydrological model and pit and pipe data bases that you require, and then use the **File** → **Import** → **MapInfo MIF files…** option, which will display the following message:



After you enter 'Yes', you must select one of the MapInfo MIF files to be transferred, as shown in Figure 6.13. The transfer will then take place, and the pits and pipes will come into view, in the same form as Figure 6.11.

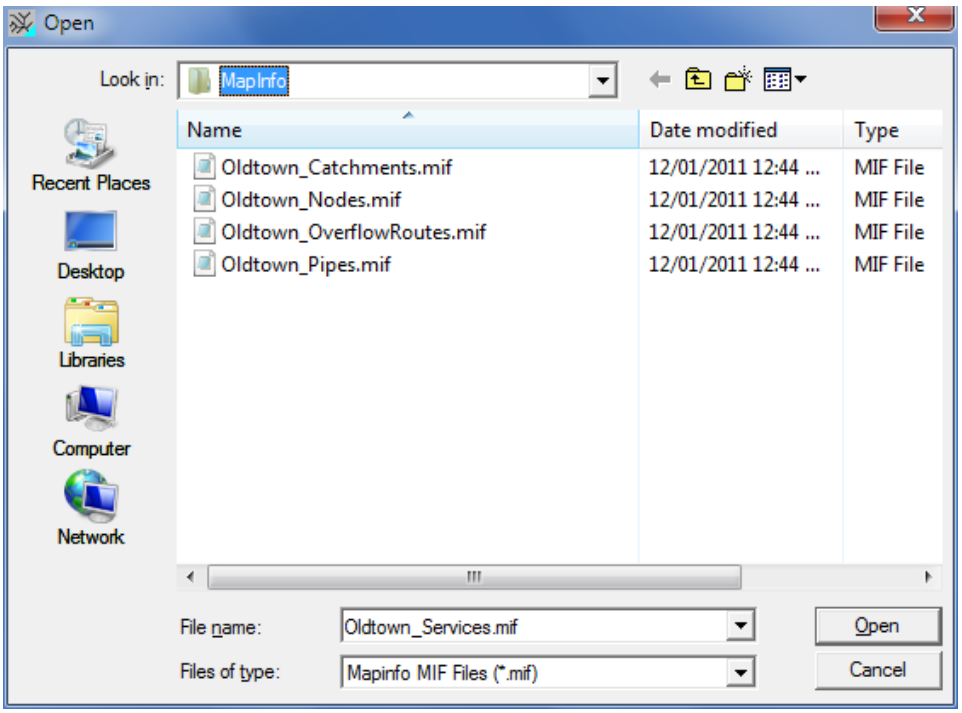
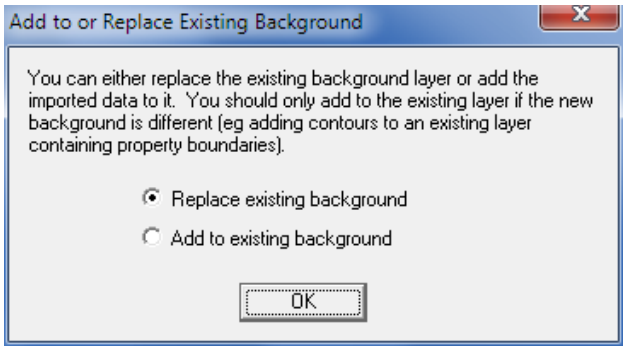


Figure 6.13 Choosing a MIF File

As with the ESRI transfers, with this setup it is possible to import a new or additional background. Using the **File** → **Import** → **Import DXF background…** option brings up a dialog box from which a DXF file can be opened. When a file is selected, the following window appears. When a choice is made, the background is replaced.



6.2.5 ILSAX File Imports

DRAINS is partly based on the ILSAX program that was used widely in Australia since 1986. Many Government organisations developed ILSAX files describing their drainage systems that could be converted to DRAINS files using the **Import ILSAX Files …** option in the **File** menu. However, there have been changes to DRAINS that mean that now it is hardly worthwhile to make transfers by these means. These changes include the use of a different type of pit inlet capacity relationship and the omission of the ILLUDAS type pit that was employed in the transfer (refer to the DRAINS Help system).

It is therefore recommended that this feature not be used, and that models be created by other means. However, the transfer facility is still available, and instructions are available in the DRAINS Help system under the topic 'Importing ILSAX files'.

6.2.6 Merging Files

There is an option in the **File** menu to merge DRAINS files together. Since this first involves an output process, it is described in Section 0.

6.2.7 Transferring to and from CAD Programs

Drafting programs such as AutoCAD, Microstation and Bricscad can be used for creating the network geometry. In the drawing, all pipes must be on a layer and all pits on a separate layer. Pipes must be drawn as lines and pits as circles. (If the drawing uses other symbols for pits, a separate layer should be created, with a circle over each pit.) The file should be saved in DXF format. At the time of import to DRAINS you will be asked to nominate the respective layers, as described in Section 6.2.2 using the **File** → **Import** > → **Import DXF file…** command.

6.2.8 Transferring to and from the 12d Model

Data for setting up DRAINS models can be imported directly from the 12d digital terrain modelling program, as DXF files, using the procedure command in the previous section. After design and analysis have been carried out in DRAINS, using the ILSAX or ERM hydrological models, but not rational method models, the resulting system information can be returned to 12d for further analysis and plotting. An important requirement is to ensure consistency in pit and pipe names used.

In DRAINS, the **File** → **Export** > → **12D Connection Data File…** command can be used to export completed designs back to 12d.

For further information, contact 12d at www.12d.com.au.

6.2.9 Transferring to and from Civil Site Design

The Civil Site Design application is used inside CAD programs such as AutoCAD, Civil 3D and BricsCAD. It was previously called Advanced Road Design. It has purpose-built tools for creating drainage network geometry and assigning the catchment/overflow route/surface profile geometry information required by DRAINS. Civil Site Design was developed by Peter Bloomfield and Civil Survey Solutions (www.civilsitedesign.com.au, www.civilsurveysolutions.com.au).

This transfer procedure works when DRAINS has ILSAX or ERM specified, but not for the rational method. In DRAINS, the **File** → **Import** > → **Civil Site Design File…** command is ised to import models set up in Civil Site Design to DRAINS. The **File** → **Export** > → **Civil Site Design File…** command is used to export completed designs back to Civil Site Design. In some older models, → **Advanced Road Design File…** may appear as the command for importing or exporting.

For further details, view the Youtube video produced by Civil Survey Solutions at
www.youtube.com/watch?v=cA1h26wMF9k&feature=youtu.be,
or contact Civil Survey Solutions at 1300 254 004 or tech@civilsurveysolutions.com.au.

6.2.10 Transferring from CatchmentSIM

CatchmentSIM, developed by Chris Ryan (2005), is a program that manipulates topographic data to define catchments and to determine catchment characteristics. Starting with data in a 3-dimensional vector format such as MID/MIF or TIN files, CatchmentSIM converts these to a raster grid, from which catchments and sub-catchments can be defined. For urban catchments, barriers to flow along fences and road crowns can be specified, and the sub-catchments derived reflect these.

This information can be used to develop DRAINS models. For further information, contact Catchment Simulation Solutions at www.csse.com.au.

6.2.11 Setting Up New Pipe, Pit and Overflow Route Data Bases

New data bases can be established using the **Default Data Base** Option in the **Project** menu. This opens the dialog box shown in Figure 6.14, from which a base can be selected from the .db1 files stored in the C:/Program Files/Drains/Program folder. This is followed by a warning indicating that the default .db1 file, Drains.db1, will be overwritten.

Note that due to a programming issue in the DRAINS code, it is not possible to delete pipe and pit types from their data bases in a model containing pit or pipe components, though their characteristics can be edited and changed.

An additional feature, implemented through the **Import > → DRAINS Database (DB1) File…** option in the **File** menu can be used to add extra pipe, pit and overflow route types to a data base, as described in Section 5.4.5.

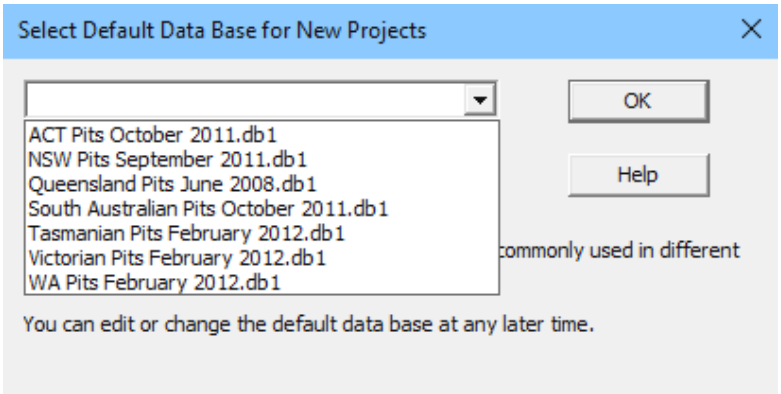


Figure 6.14 Default Data Base Dialog Box

6.3 Display Options

6.3.1 Introduction

DRAINS provides several options for viewing data on screen in addition to usual Windows facilities such as scrolling bars. The options available before calculations are performed are demonstrated in this section using the Toowoomba Estate.drn example that is ready to run in Design mode, which will define the pipe diameters and invert levels.

6.3.2 Screen Presentation Options

You can vary the way that a drainage system is presented on screen using options that are mainly included in the **View** menu (
FFigure 6.15).

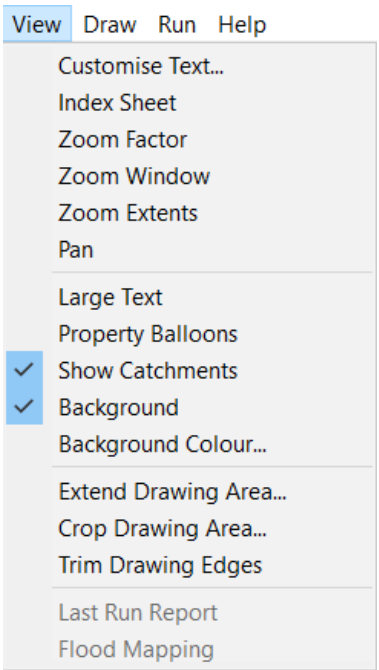
(a) Customise Text

The **Customise Text …** option at the top of the **View** menu produces the dialog box shown in Figure 6.16. By selecting options here, you can change the information provided, as indicated in Figure 6.17. Many choices are only available after a Design or Analysis run. The custom display numbers are coloured purple to distinguish them from names of components (black) and numerical outputs (black, green, blue and red).

This dialog box can also be opened by right-clicking on the name of any component, though not the component itself.

(b) Index Sheet

Selecting **Index Sheet** from the DRAINS **View** menu produces the view of the system shown in Figure 6.18. The rectangle represents the screen size. Placing this 'mask' in a certain position and clicking sets the screen to that position, as shown in Figure 6.19.



F
Figure 6.15 View Menu

(c) Zoom

There are three zoom options for enlarging or reducing the image in the Main Window. The **Zoom Factor**, which is also available through a button on the Toolbar, changes the cursor to a magnifying glass, which you should place over the area to which you wish to zoom. Clicking on this opens the

dialog box shown in Figure 6.20, in which you can nominate the magnification. If you accept the default value of 1.5, an enlarged presentation is obtained. Entering a factor less than 1 reduces the size of the system, but the size of lettering remains the same. If required, it can be enlarged using the **Large Text** option in the menu.

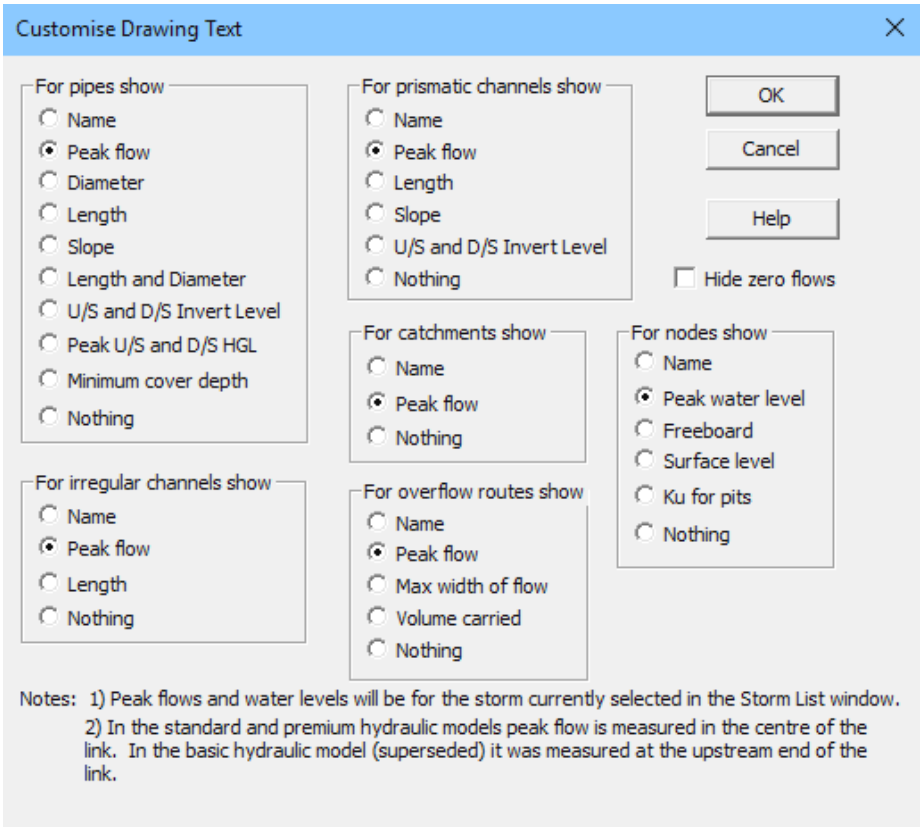


Figure 6.16 Dialog Box for Customising or Changing the Text Displayed

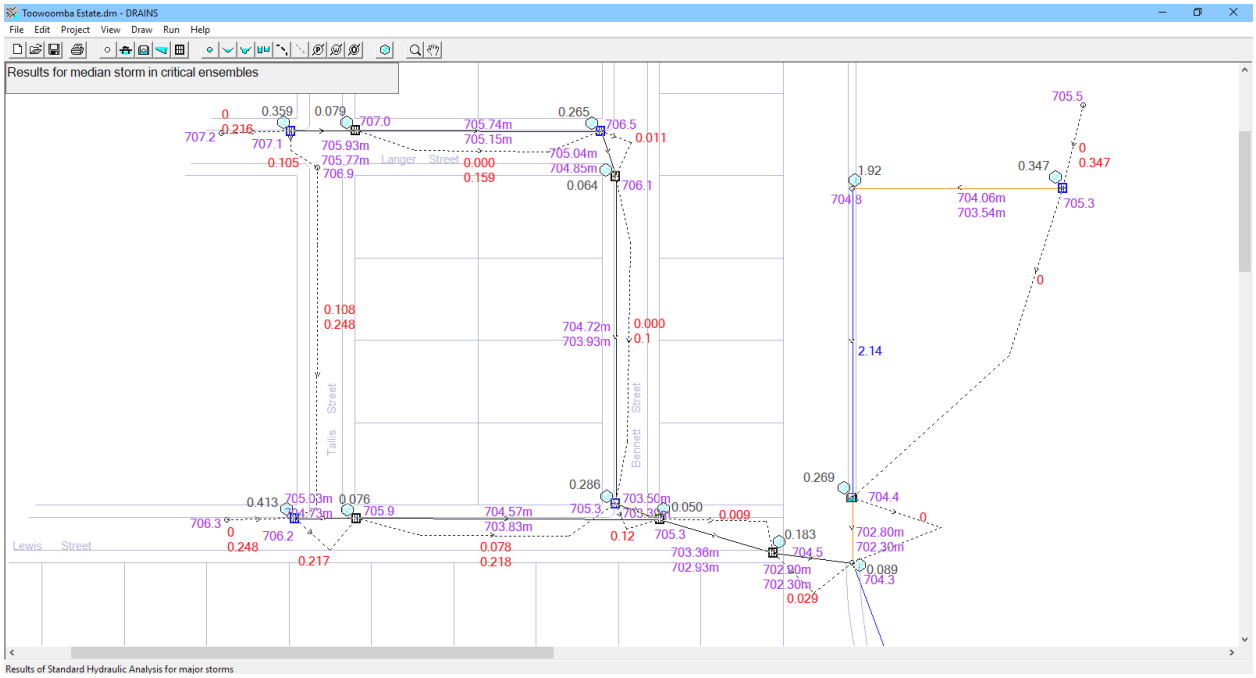


Figure 6.17 Drainage System with Surface Levels (coloured purple) replacing Pit Names and Upstream and Downstream Invert Levels replacing Pipe Names

The wheel on a mouse can also be used to zoom in and out of DRAINS models. To pan, you can press the **Pan** button on the Toolbar , or the sliding bars on the margins. In large drainage systems, you can use the Index Sheet facility described in the previous section.

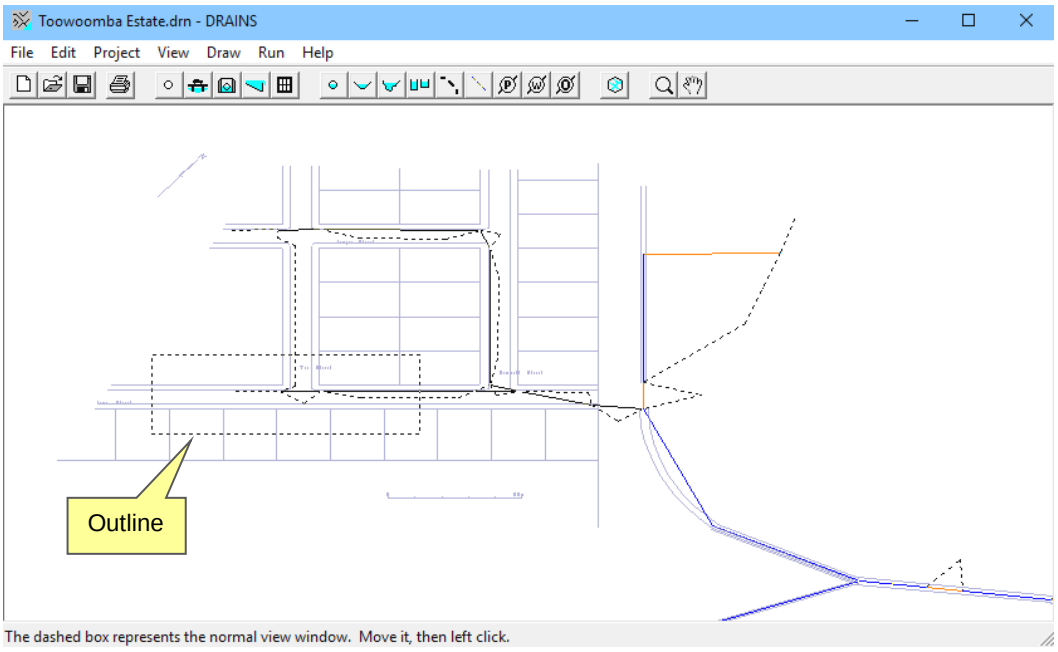


Figure 6.18 Index Sheet View

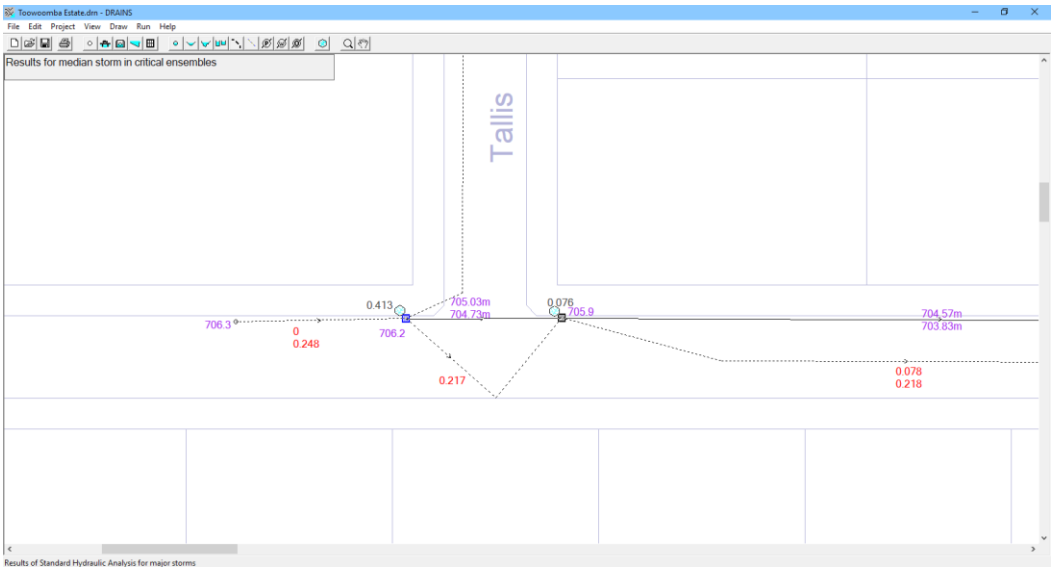


Figure 6.19 Toowoomba Pipe System selected using the Index Sheet

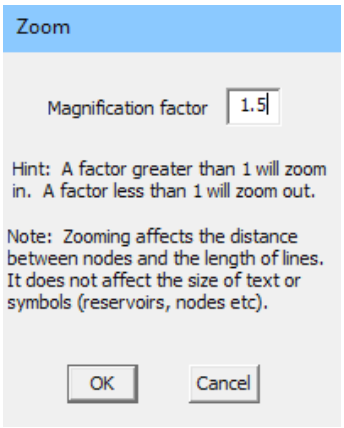


Figure 6.20 Zoom Window

The **Zoom Window** option in the **View** menu changes the cursor to crosshairs that can be used to define the rectangular area that is to be enlarged. When the mouse button is released, the enlarged area fills

the Main Window. The **Zoom Extents** option zooms out, but not to the full extent of the model. It can provide the desired extent when applied a number of times.

(a) Large Text

The size of text can be changed with this option.

(b) Property Balloons

These can be switched on and off by clicking on **Property Balloons** in the **View** menu.

(c) Description Option

Note that the Main Window area includes a title block in the lower right corner. Text can be inserted into this block using the **Description…** option in the **Project** menu, which opens the property sheet shown in Figure 6.21. Comments and lines for the title block can be entered. If no block is required, the three TITLE BLOCK lines can be made blank.

(d) Removing Items from View

Facilities like the Status Bar at the bottom of the Main Window and components such as sub-catchments can be removed from the window if desired, using the options in the central part of the **View** menu.

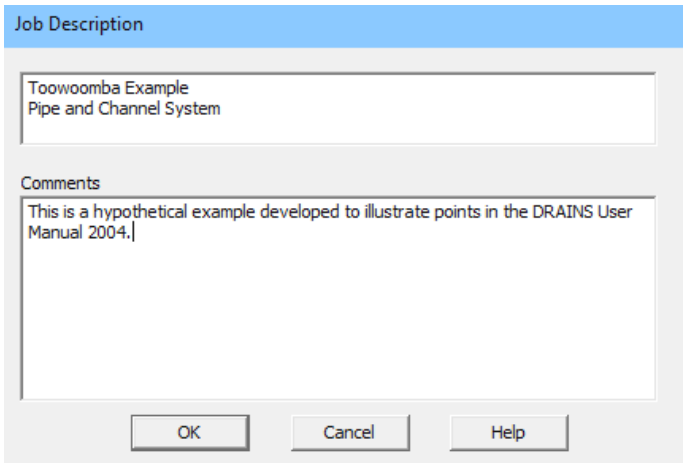


Figure 6.21 The Description Property Sheet

(e) Changes to the Main Window Coverage

The Drawing Area can be extended at the four corners, cropped (reduced selectively) or trimmed all round, using options in the **View** menu – **Extend Drawing Area ...**, **Crop Drawing Area ...**, and **Trim Drawing Edges**.

(f) Last Run Report

The report presented afer a run can be re-displayed using this option.

(g) Flood Mapping

This feature is activated after a premium hydraulic model run It allows you to display or hide flood mapping extents along overflow routes.

(h) Pop-Up Menu Displays

The pop-up menus opened by right-clicking on an object are the main means of presenting results of calculations on-screen. They also provide some information prior to calculations. Two displays from the Toowoomba example are shown in Figure 6.22.

6.4 Run Options

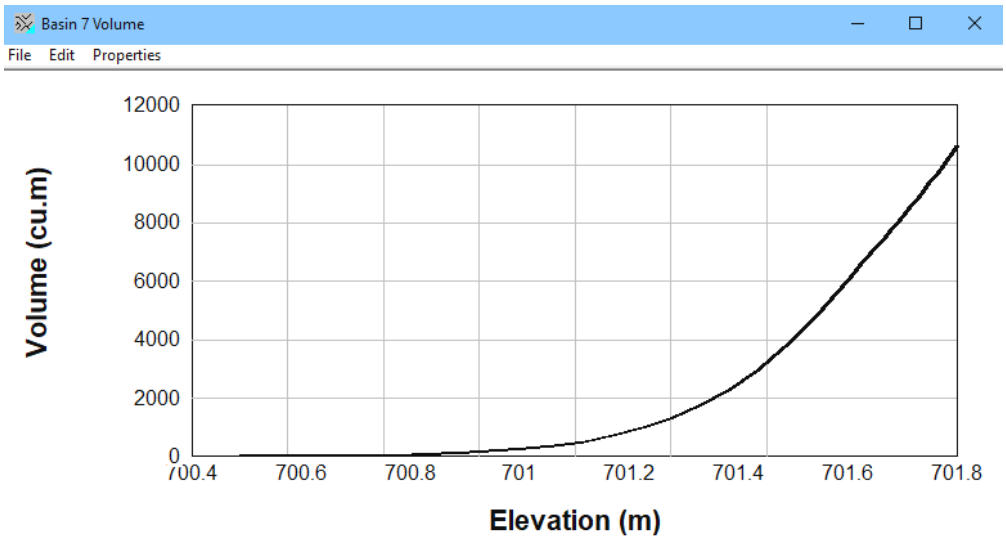
6.4.1 Design and Analysis Runs

In the **Run** menu shown in
Figure **6.23** there are at least three run options:

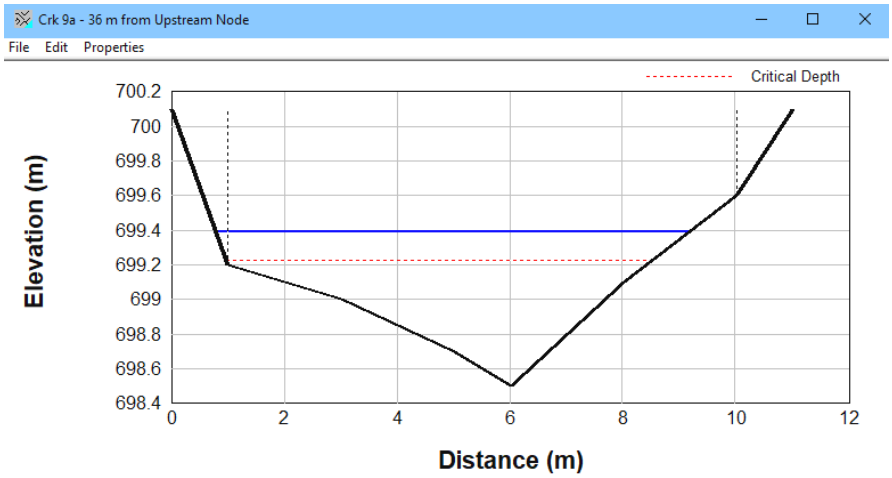
(a) the **Analyse major storms (standard hydraulic model),**

(b) the **Analyse minor storms (standard hydraulic model)**,

(c) the **Design** option.

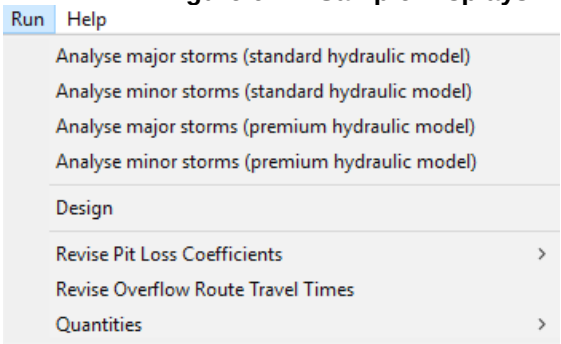


Detention Basin Elevation-Storage Relationship Display



Irregular Channel Cross-Section Display

Figure 6.22 Sample Displays from the Pop-Up Menus for Components



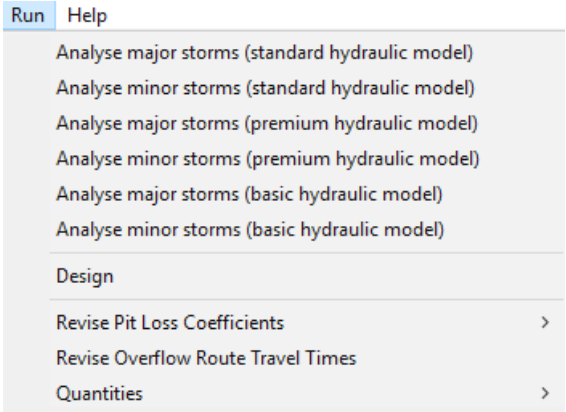


Figure 6.23 Run Menus for New DRAINS Models and for Older Models

If the premium hydraulic model is enabled by the hardware lock being used, there are two more options:

(a) the **Analyse major storms (premium hydraulic model),**

(b) the **Analyse minor storms (premium hydraulic model),**

and, if the model was created prior to the end of 2010, these additional options may appear:

(c) the **Analyse major storms (basic hydraulic model),**

(d) the **Analyse minor storms (basic hydraulic model).**

There is also the **Design** option that sets pipe sizes and invert levels, and options for revising pit pressure change factors and outputting pipe quantities.

The alternative hydraulic models are described in Sections 7.2.7 and 0. The standard model that replaces the obsolete basic model applies unsteady flow calculations to pipes and open channels, but not to overflow routes. The premium model applies the unsteady calculations to all three types of conduits. The models can be run with either the set of minor or the set of major storms established in the rainfall inputs using **Select Storms > Minor storms** or **Select Storms > Major storms** options in the **Project** menu (see Section 5.4.4).

When any of the above options are chosen, DRAINS launches into a run. There may be warnings and a request to use parallel processing. Once these are noted are acted upon, the run begins. Rational method calculations are quick because only peak flows are generated and there are no unsteady flow calculations. The simulation runs used with the other, hydrograph-producing models will take longer to run, and will produce much more comprehensive results.

Analysis runs treat all pipes as fixed, and do not alter the given pipe diameters and invert levels. Complex situations, such as pits with the invert of the outgoing pipe being higher than those of the incoming pipes, can usually be modelled.

For pipes that have the specification shown in Figure 6.24, the **Design** option selects pit sizes from the specified pit family for each pit, and defines the pipe diameters and invert levels for circular pipes. (Design cannot be performed with rectangular pipes.) If you have already specified invert levels, these will most probably be changed in a design. (In calculations, the second option in Figure 6.24 is treated exactly the same as the third, except that when DRAINS calculates quantities of soil volumes for excavation, volumes for pipes defined under Option 2 are included in the table of quantities along with those defined under Option 1; volumes for Option 3 pipes are not.)

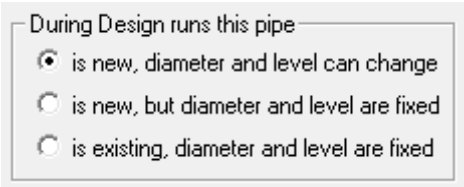


Figure 6.24 Specification of Pipe Types

DRAINS does not specifically try to design around existing pipes with fixed invert levels, so situations will be encountered where it is not possible to do this while obeying the restrictions set in the **Options** property sheet opened from the **Project** menu. In these cases, the invert levels at the downstream end of designed pipes may be specified as being lower than the existing pipe to which they connect.

The design method applied, based on the *Queensland Urban Drainage Manual*, varies both pits and pipes to obtain an optimal result. It is possible to set the pit size and the pipe diameter and invert levels as fixed, using options in the Pit and Pipe property sheets.
Both procedures allow for intermediate levels along a pipeline route between pits. These are considered when pipe invert levels are determined, allowing for minimum cover depths.

6.4.2 Run Logs

Following a run, DRAINS presents a log reporting on the results, as shown in Figure 6.25, indicating problems and possible causes. The first example shows a trouble-free run and the second one that has complex results.

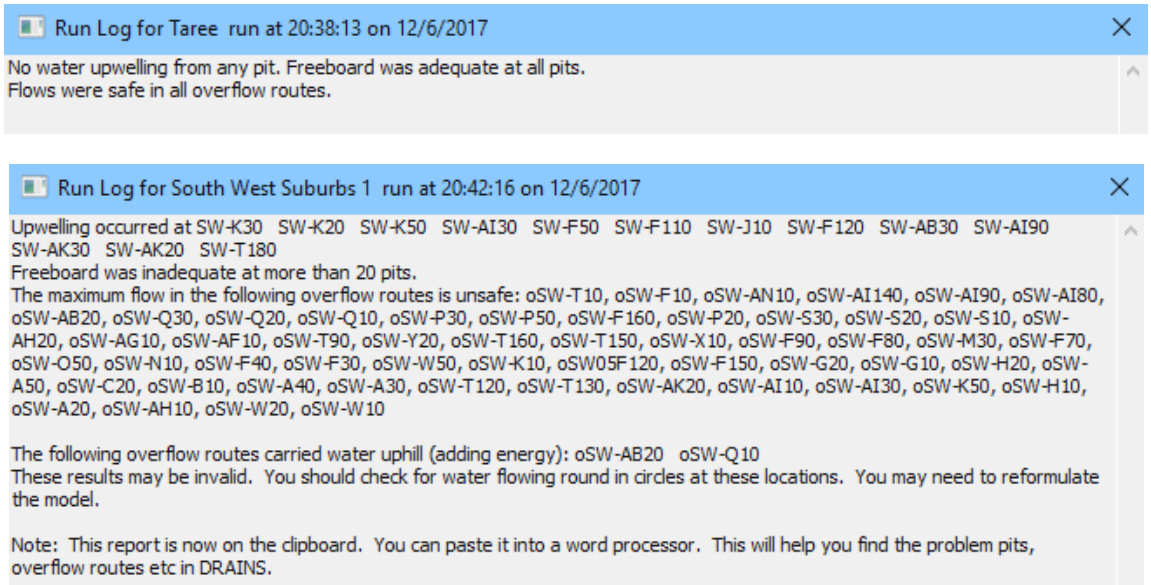


Figure 6.25 Examples of Messages Reporting Results from Design and Analysis Runs

The report must be closed (by clicking on the X at the top right of the window), but it can be recalled using the **Last Run Report** option in the **View** menu. The information in the log is also reproduced in the spreadsheet output for results.

6.4.3 Warning and Error Messages

DRAINS performs a number of checks as data is entered. One is to ensure that all the required data is provides. In some instances DRAINS requires values to be within certain ranges of expected values, in others it queries values that appear to be unusual. Warnings like those shown in Figure 6.26 also appear when a run is initiated, and after a run. It is important to heed these, and to try to eliminate the causes.

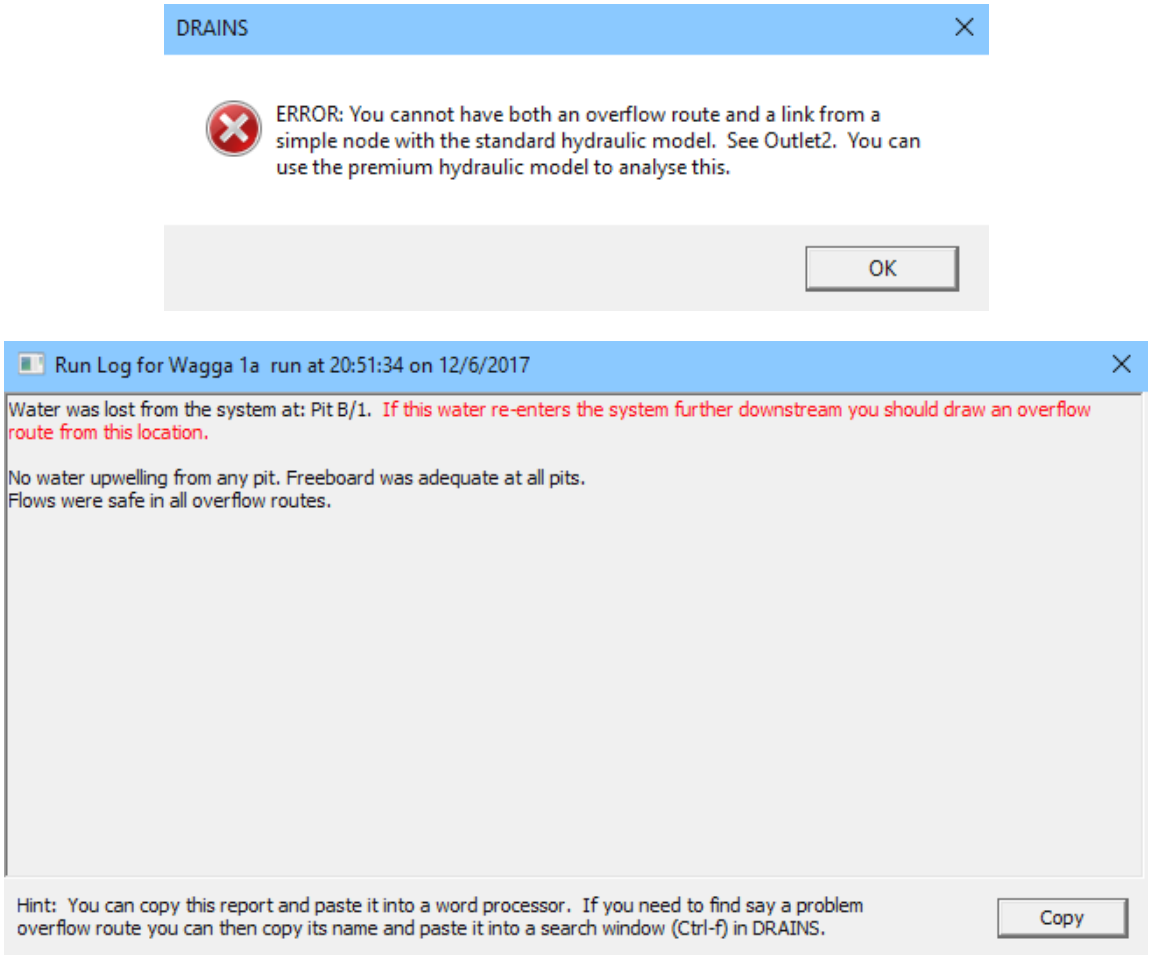


Figure 6.26 Warning Messages (see also Figure 6.25)

If a serious computational problem occurs, and DRAINS cannot resolve this, an error message may appear, and the program will shut down after this is closed. Sometimes such messages will request that you contact Watercom Pty Ltd to resolve the problem.

6.4.4 Options for Modifying Pit Pressure Change Factors

The **Revise Pit Loss Coefficients** option alters the pit pressure change coefficients using an algorithm based on an approximate relationship developed by Mills or a method based on the *Queensland Urban Drainage Manual*, QUDM (see Section 8.6.6(c)). Before using these procedures, you must run DRAINS to obtain a set of flows and HGLs, as shown in Figure 6.27.

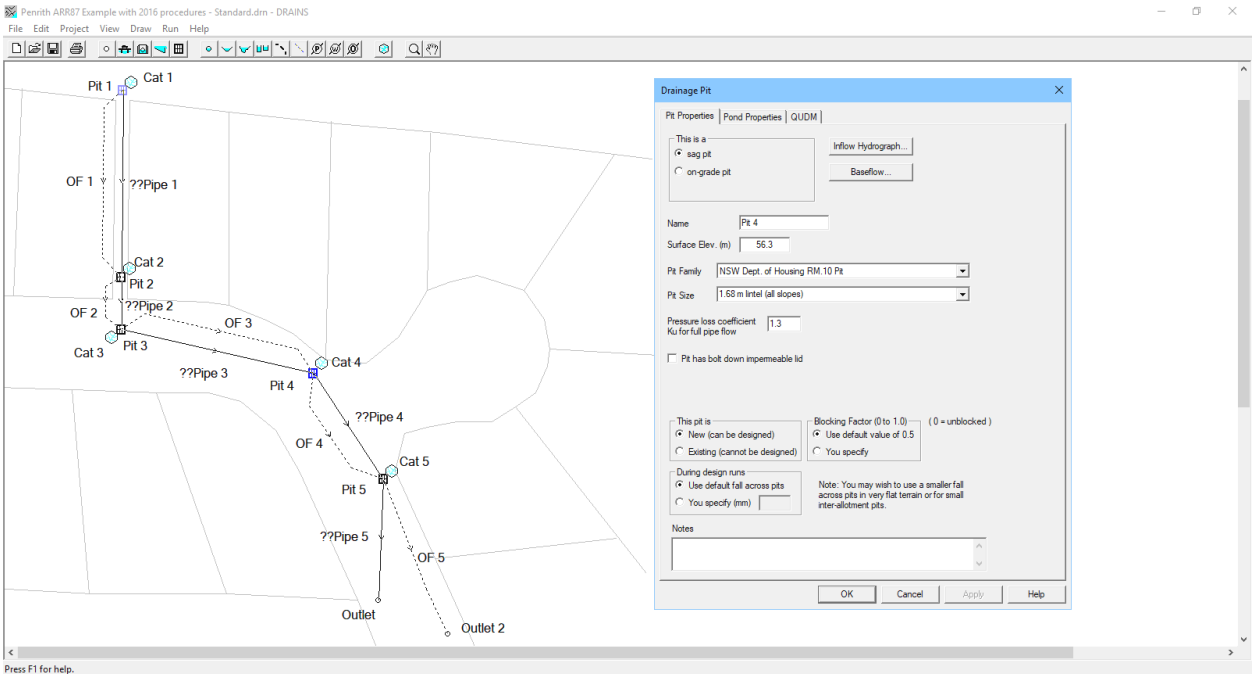


Figure 6.27 Sample System with Initial Pressure Change Coefficients

For example, you might set up a system as shown below, guessing K_u factors, or setting all factors to the default value of 1.5. You would than run the models and select the method you wish to apply, in this case the QUDM Chart procedure, as shown in Figure 6.28.

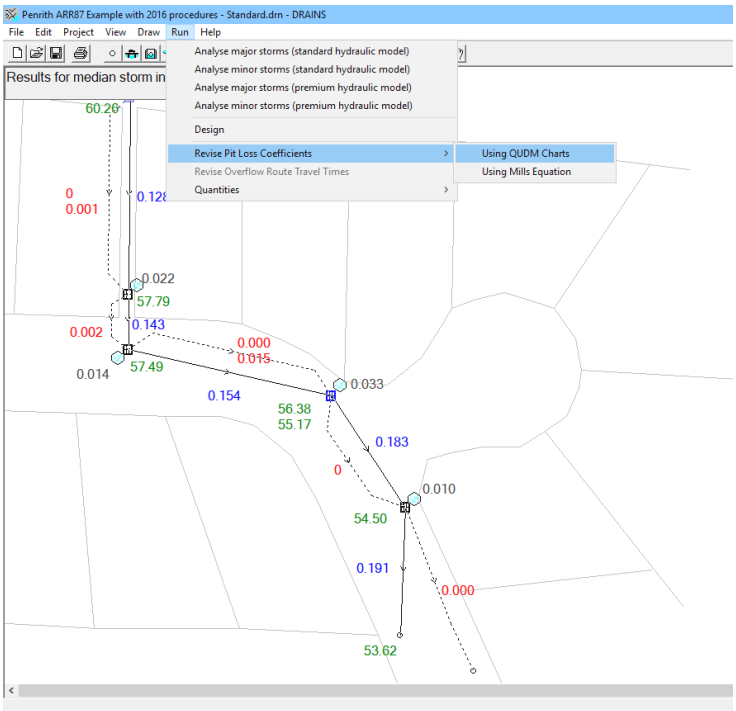
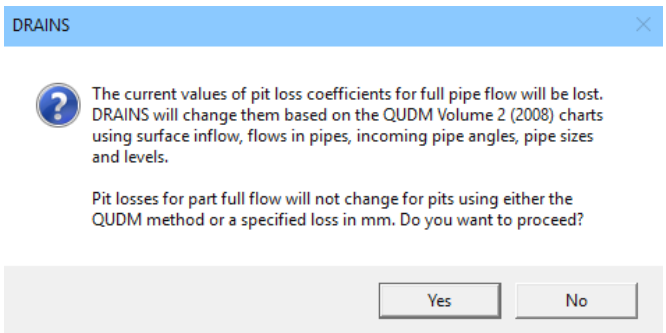
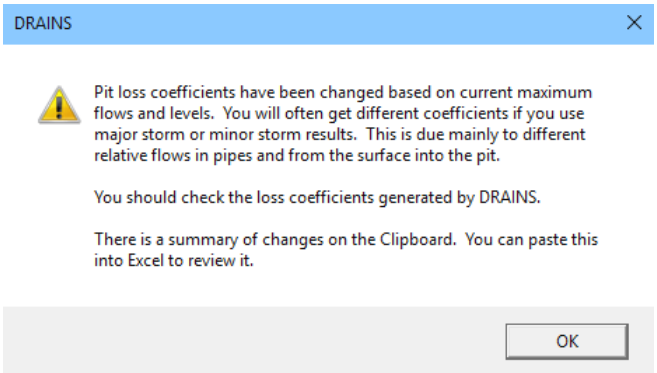


Figure 6.28 Applying the QUDM Charts Procedure

The following messages will appear.





A table of changes can be pasted from the Clipboard to a spreadsheet and displayed:

	A	B	C	D	E	F	G	H
1	Pit	Initial K	Revised K	Chart	Ratios			
2	Pit 5	0.83	0.83	A1-9	Du/Do=1.00, Qg/Qo=0.05, S/Do=1.0			
3	Pit 4	1.28	1.28	A1-9	Du/Do=1.00, Qg/Qo=0.19, S/Do=1.1			
4	Pit 3	1.87	1.87	A1-14	Du/Do=1.00, Qg/Qo=0.12, S/Do=1.1			
5	Pit 2	0.72	0.72	A1-5	Du/Do=1.00, Qg/Qo=0.13, S/Do=1.0			
6	Pit 1	5.93	5.93	A1-4	H/Do=0.0, Vo2/(2gDo)=0.02			
7								

The Chart referred to in Column D is the one selected from those in the Queensland Urban Drainage Manual, and the Ratios are those used to enter the chart to determine the k_u or K values. Further details are given in Section 8.6.6(c).

The model will contain the revised coefficients. The process of running the model and adjusting the coefficients should be repeated once or twice more to allow the procedure to converge to a fixed set of k_u values. Since values depend on flowrates and HGL levels, this process must be run separately for minor and major flows in pipe system design, generating different sets of coefficients.

The procedure for the Mills equation is similar, but simpler. Strictly speaking, both procedures need to be applied iteratively, since changing k_u values will alter flowrates and HGLs, which in turn influence the selection of the k_u values. Two iterations might be usually required when using Mills Method while three or four iterations may be required using the QUDM procedure. As indicated in the second message displayed for the QUDM procedure, the changes made are presented in a spreadsheet placed on the Clipboard, and this can be used to check that convergence has occurred. k_u values created by this method can be manually overwritten.

6.4.5 Quantities

The **Quantities** option in the **Run** menu displays or prints out a table of quantities for the pipes in the current system, as shown in Figure 6.30. This complements the information printed for each completely-defined pipe at the bottom of its property sheet, as shown in Figure 6.29.

DRAINS calculates excavation volumes from pipe lengths and invert levels, assuming the trench widths given in **Table 6.1**, with 200 mm and the diameter being added for each additional parallel pipe. The bedding depth is assumed to be 50 mm below the outside of the pipe wall.

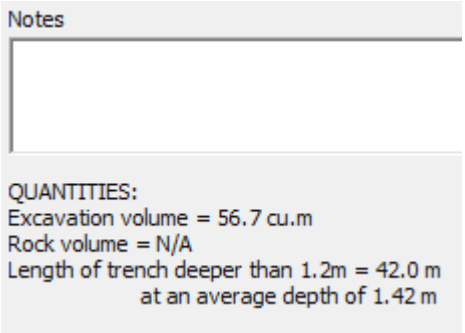
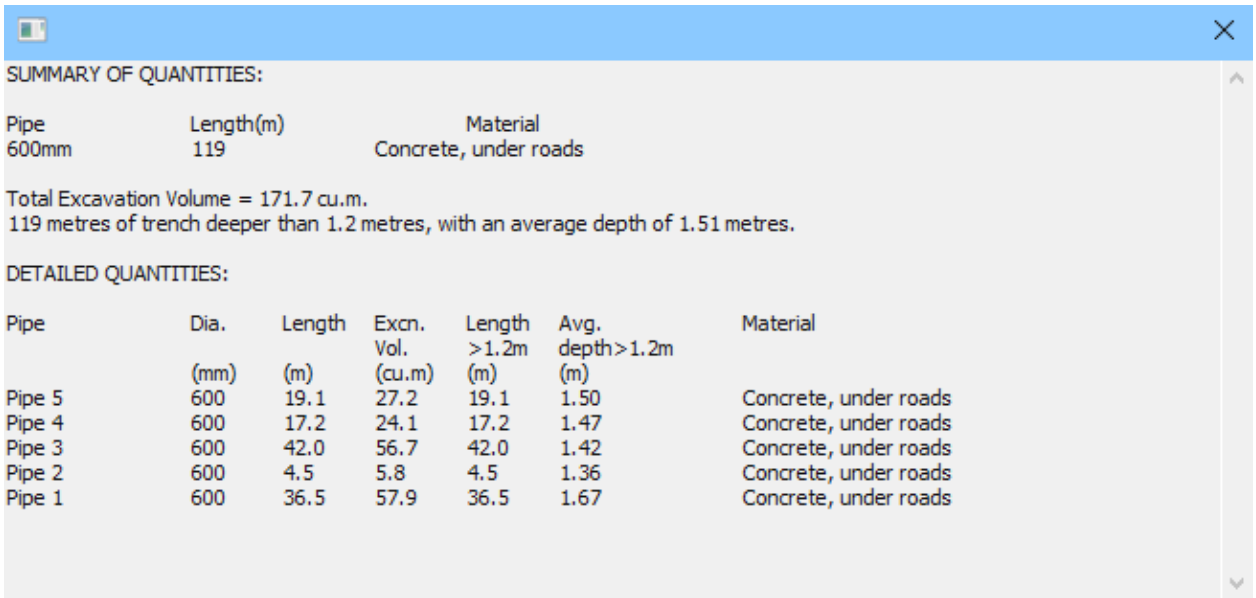


Figure 6.29 Quantities Information in Pipe Property Sheet



SUMMARY OF QUANTITIES:

Pipe	Length(m)	Material
600mm	119	Concrete, under roads

Total Excavation Volume = 171.7 cu.m.
119 metres of trench deeper than 1.2 metres, with an average depth of 1.51 metres.

DETAILED QUANTITIES:

Pipe	Dia. (mm)	Length (m)	Excn. Vol. (cu.m)	Length >1.2m (m)	Avg. depth>1.2m (m)	Material
Pipe 5	600	19.1	27.2	19.1	1.50	Concrete, under roads
Pipe 4	600	17.2	24.1	17.2	1.47	Concrete, under roads
Pipe 3	600	42.0	56.7	42.0	1.42	Concrete, under roads
Pipe 2	600	4.5	5.8	4.5	1.36	Concrete, under roads
Pipe 1	600	36.5	57.9	36.5	1.67	Concrete, under roads

Figure 6.30 The Summary of Quantities

Table 6.1 Default Trench Width Table

Nominal Diameter (mm)	**Trench Width** (mm)
300 mm or less	550 mm
301 - 375 mm	650 mm
376 - 450 mm	750 mm
451 - 525 mm	850 mm
526 - 600 mm	950 mm
601 - 675 mm	1050 mm
676 - 750 mm	1150 mm
751 - 900 mm	1400 mm
902 - 1000 mm	1550 mm
1001 - 1200 mm	1800 mm
1201 mm or greater	Diameter + 750 mm

6.5 Output Options

6.5.1 Transfers of Displays and Screen Print-Outs

Section 6.3.2 described the various screen displays that are provided by DRAINS prior to run calculations. Additional displays become available once a run is made. These include hydrographs, HGL level plots, tables of flowrates and HGLs. Data and results can be printed from many of the display windows using the **File** and **Edit** options in their windows, such as the hydrograph display in Figure 6.31.

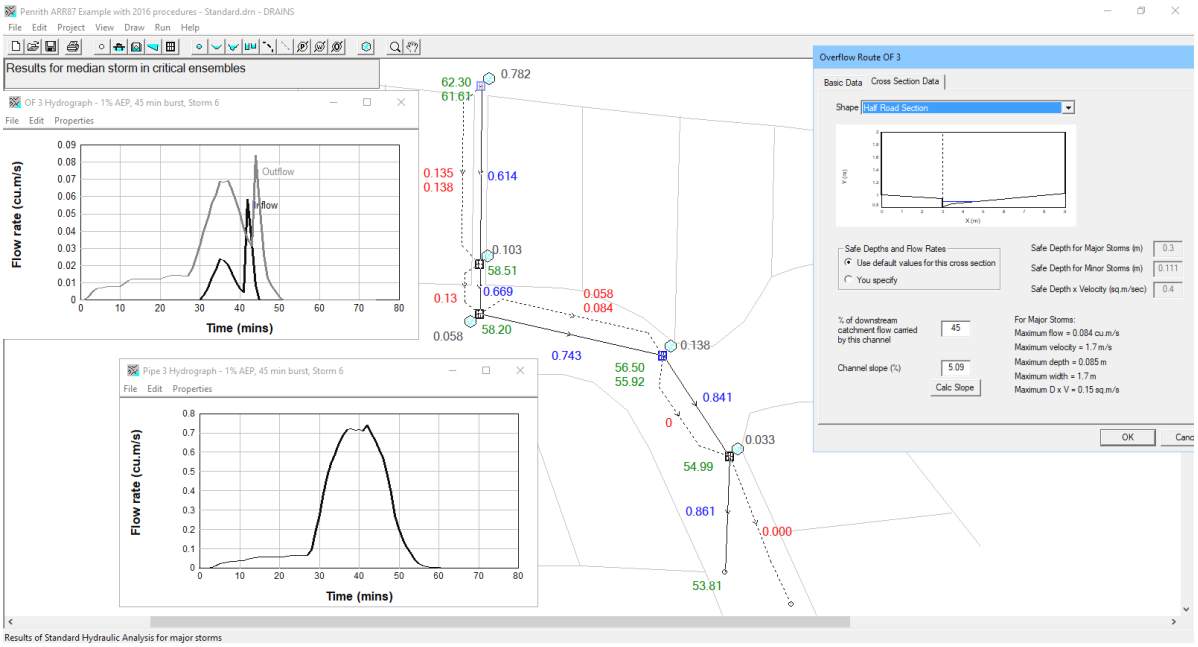


Figure 6.31 DRAINS Results showing Main Window, Hydrograph and HGL Plot Windows

These can also be copied to reports and calculation files. You can also use the screen capture techniques available in all Windows applications, such as the **Print Screen** key and **Alt** + **Print Screen** keys, or specialist screen capture programs to produce outputs such as Figure 6.31.

6.5.2 DRAINS Print Diagram Option

DRAINS has a facility for printing out the system displayed on a screen, either completely, or as the view shown on the screen. This is implemented in the **Print Diagram** option in the **File** menu, using the dialog box shown in

Figure 6.32. Font sizes can be altered. The **OK** button starts the printout, while the **Setup...** button opens a Printer Setup dialog box.

In the past, this facility has not worked with some printers, due to problems with printer drivers. Trying the options now available should produce a satisfactory image. Another way around printing problems is to print to a **pdf** file, if you have Adobe Acrobat or another program capable of doing this, and then to print from the **pdf** file.

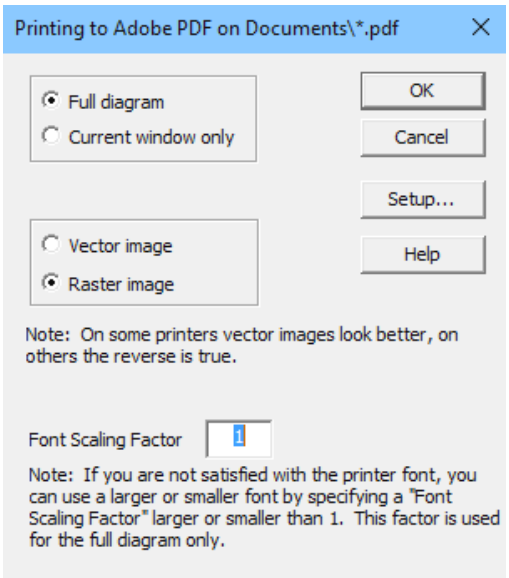


Figure 6.32 Print Diagram Dialog Box

6.5.3 DXF Exports

The process of importing data in DXF format was presented in Section 6.2.2. There are two types of output via DXF file format, one of the most common formats used for drawings. With the Toowoomba Estate.drn file, you can export a plan view to scale using the **Export DXF File…** option in the **File** menu. This opens a **Save As** dialog box, and after a file name and location are specified, opens the DXF File dialog box shown in Figure 6.33.

The resulting file can be opened in a drawing program, appearing as shown in Figure 6.34. The background and pipes are supplied on different CAD layers.

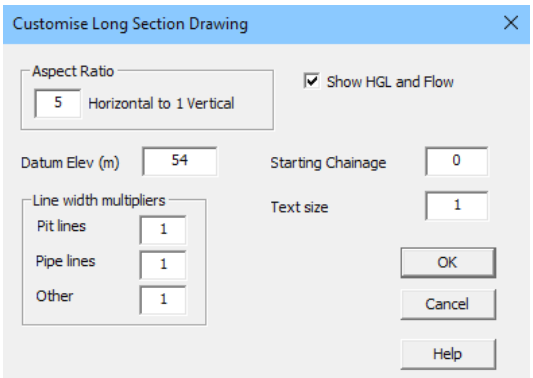


Figure 6.33 DXF File Details Dialog Box

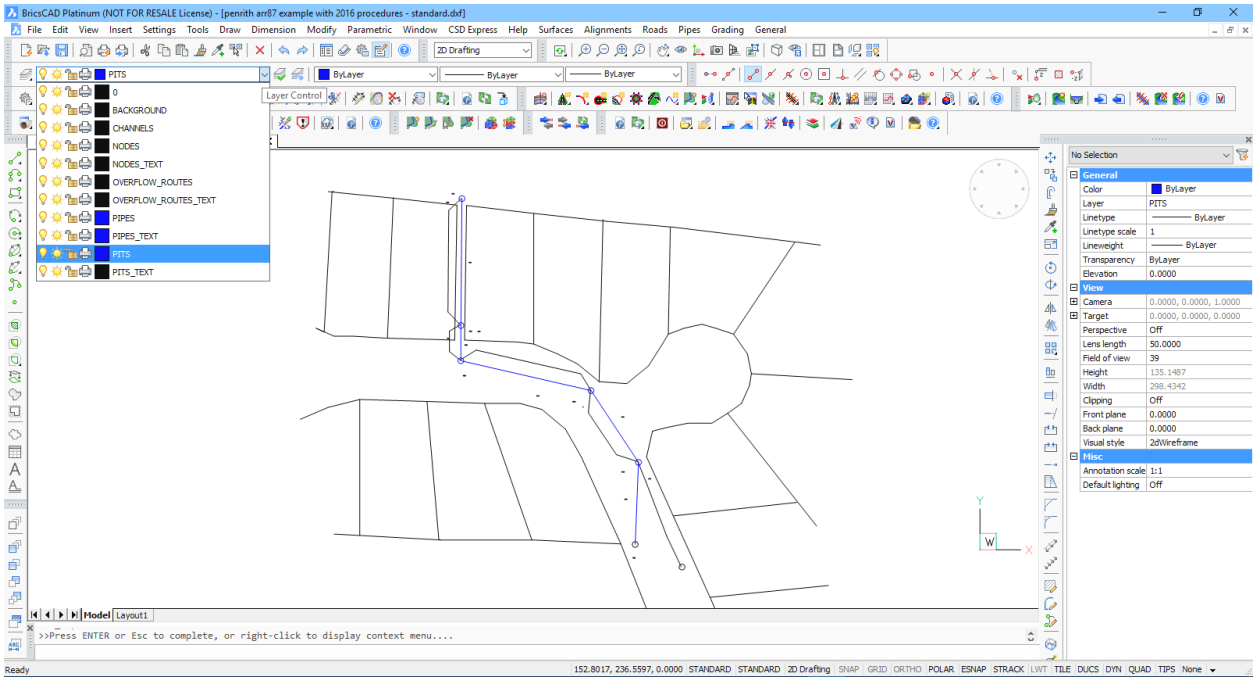


Figure 6.34 Drawing Transferred Out of DRAINS **in DXF Format**

A longitudinal section can be exported by nominating a path between neighbouring pits, and then specifying drawing characteristics. The option **Export > DXF Long Section…** in the **File** menu opens the dialog boxes shown in Figure 6.35.

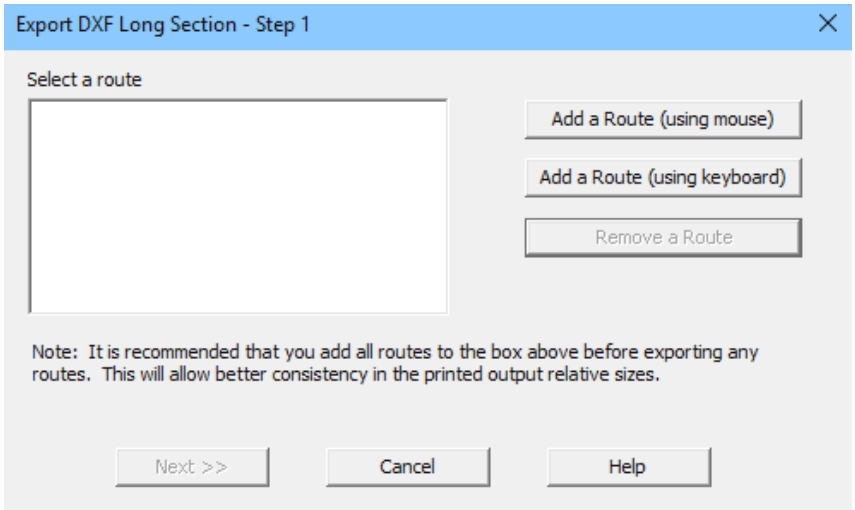


Figure 6.35 Dialog Boxes for setting Paths for Plotting Long Sections

The easiest way to add a long-section is to choose the first option **Add a Route (using mouse)**. The smaller box is used to define a continuous pipe route. You need to specify the starting and ending node names exactly, allowing for blanks and the case of words.

Once a route is selected and the Next button is clicked, a preview like that shown in Figure 6.36 appears. This is in a window that can be enlarged by clicking on the **Maximize** button (circled) at the top right of the window.

The **Customise** button opens the dialog box shown in Figure 6.37, which can be used to set drawing features. Changes are reflected in the preview.

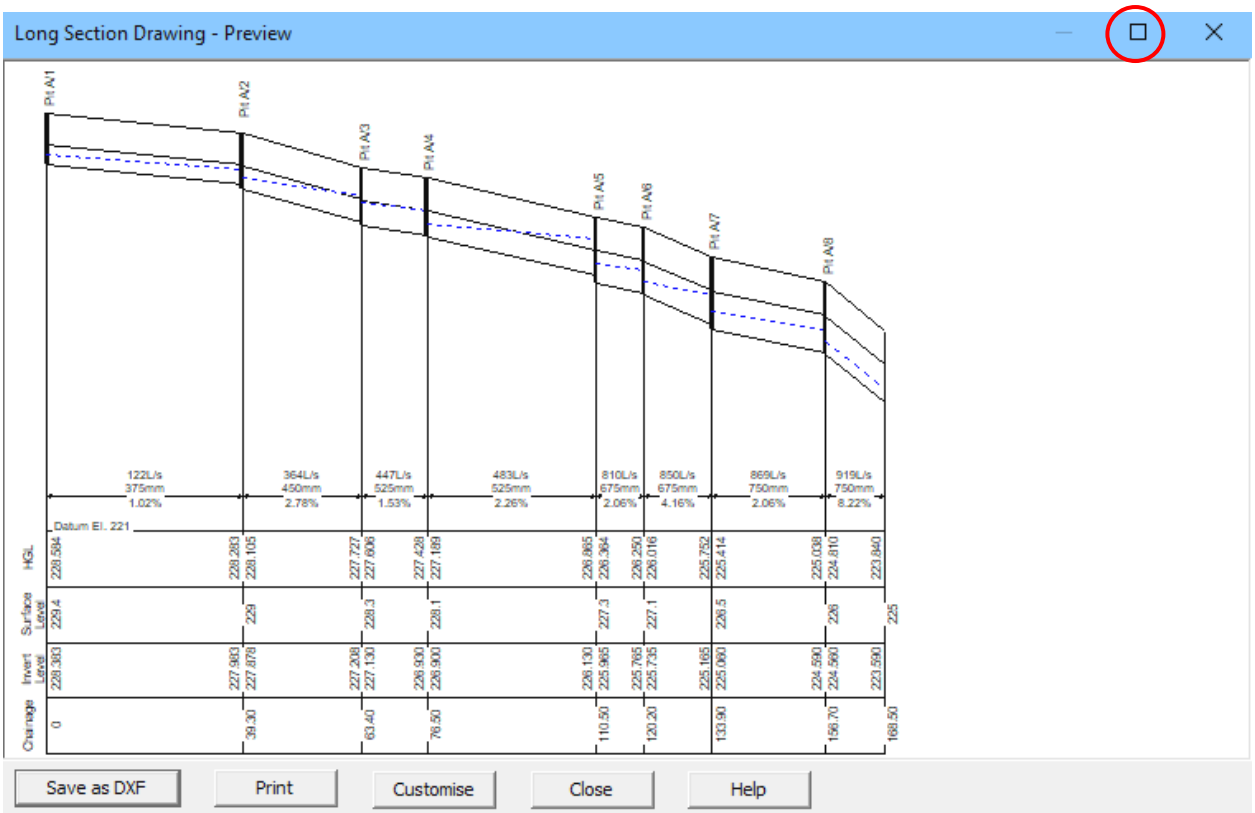


Figure 6.36 Preview of Long Section Plot

Once a satisfactory layout is achieved, clicking the **Save as DXF** button opens a window in which the file name and location can be specified. This creates the DXF file, which can then be viewed and manipulated in a CAD program, as shown in Figure 6.38 and printed from this.

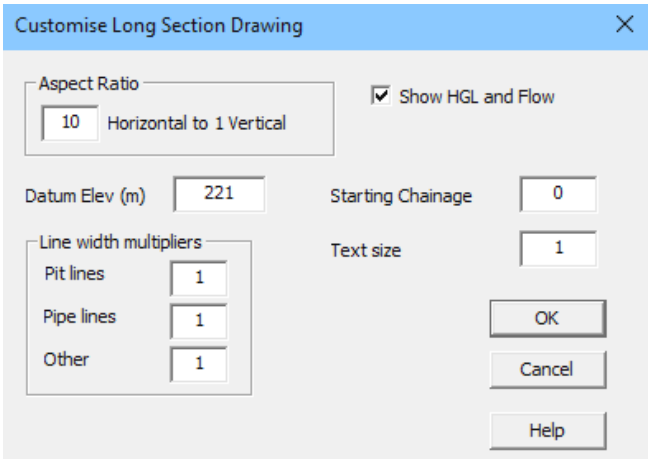


Figure 6.37 Dialog Box for Customising a Long Section

6.5.4 Spreadsheet Outputs (and Inputs)

The spreadsheet option provides a convenient way to view and store data and results, as well as a medium for transferring information between DRAINS and other programs. It effectively supersedes the text file output described in the previous section, although this is retained for the convenience of users.

To exchange information with a spreadsheet program, say Excel, both programs must be opened. Information is exchanged via the Windows Clipboard by selecting the copy and paste options in the **Edit** menu. After selecting **Copy Data to Spreadsheet** in DRAINS, as shown in Figure 6.39, transfer to Excel and select **Paste** from its **Edit** menu.

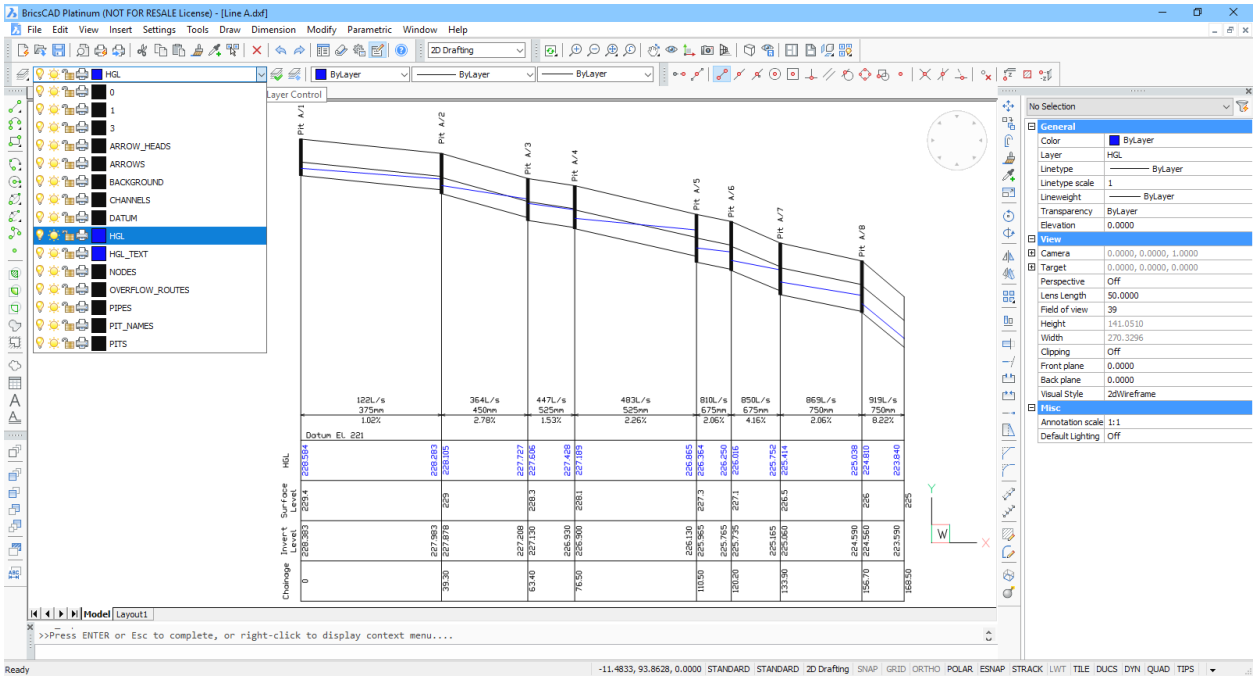


Figure 6.38 The Exported Longitudinal Section, with Hydraulic Grade Line

The information shown in Figure 6.40 appears. Almost all the information entered for components is presented, organised by type of component - PIPE/NODE, SUB-CATCHMENT, etc. This worksheet can be given a name such as 'Data' by double-clicking on the tag at the bottom of the sheet and writing in the name in the space that is highlighted. X-Y coordinates are given for pits and nodes, referring to their positions in the Main Window. If a base drawing is imported from a CAD or GIS file the coordinate system will be consistent with this.

The results from a Design can then be transferred using the **Copy Results to Spreadsheet** option from the **Edit** menu. This can be pasted into a second worksheet with the tag 'Design' or 'Minor', as shown in Figure 6.41.

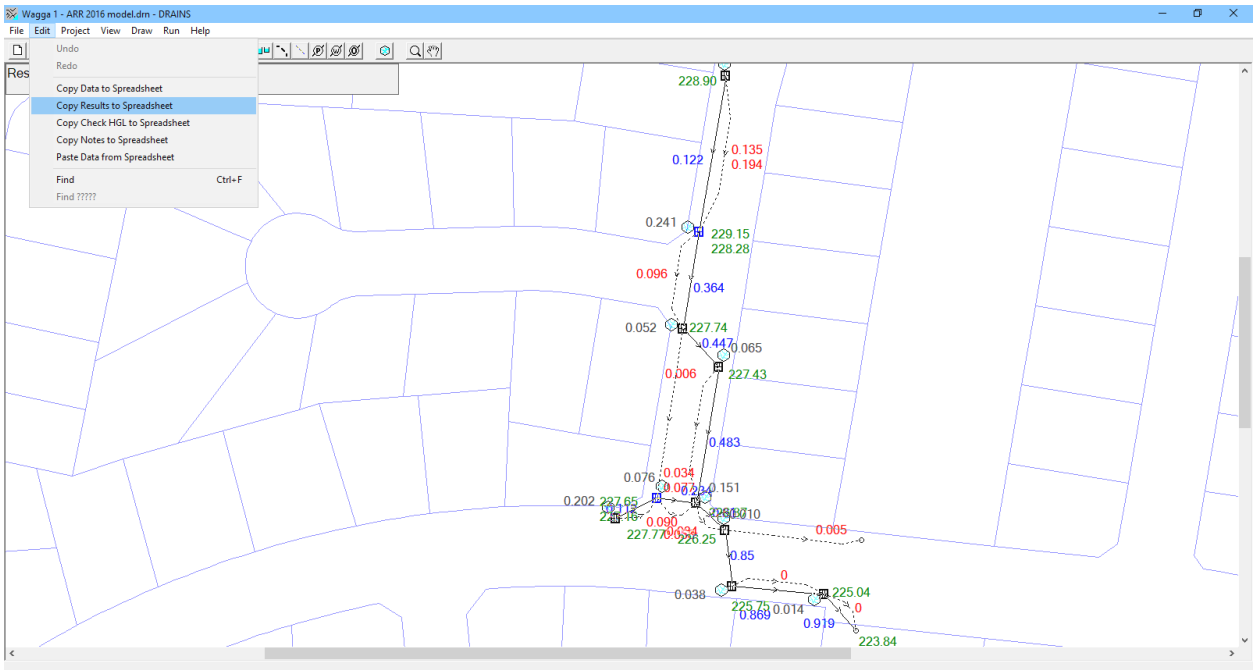
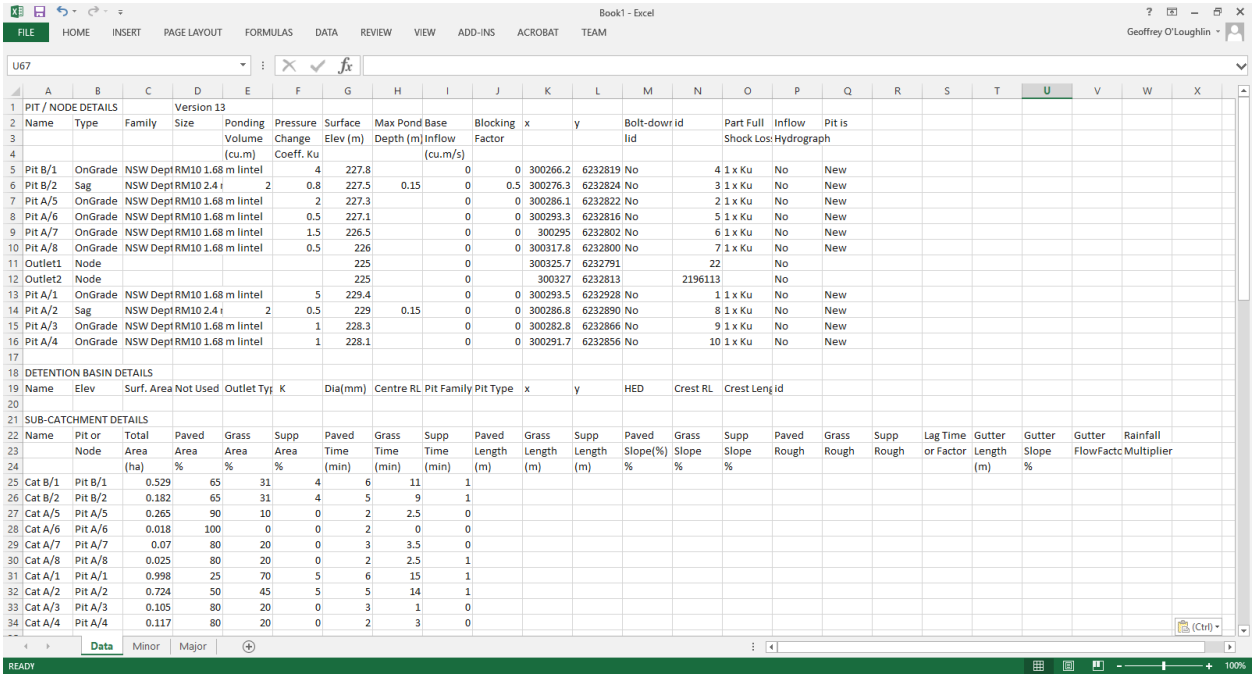


Figure 6.39 Copying Spreadsheet Data to the Clipboard after an Analysis Run



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PIT / NODE DETAILS			Version 13													
2	Name	Type	Family	Size	Ponding	Pressure	Surface	Max Pond	Base	Blocking	x	y	Bolt-down	id	Part Full	Inflow	Pit is
3					Volume	Change	Elev (m)	Depth (m)	Inflow	Factor			lid		Shock Los	Hydrograph	
4					(cu.m)	Coeff. Ku			(cu.m/s)								
5	Pit B/1	OnGrade	NSW Dept	RM10 1.68 m	lintel	4	227.8		0	0	300266.2	6232819	No	4	1 x Ku	No	New
6	Pit B/2	Sag	NSW Dept	RM10 2.4	2	0.8	227.5	0.15	0	0.5	300276.3	6232824	No	3	1 x Ku	No	New
7	Pit A/5	OnGrade	NSW Dept	RM10 1.68 m	lintel	2	227.3		0	0	300286.1	6232822	No	2	1 x Ku	No	New
8	Pit A/6	OnGrade	NSW Dept	RM10 1.68 m	lintel	0.5	227.1		0	0	300293.3	6232816	No	5	1 x Ku	No	New
9	Pit A/7	OnGrade	NSW Dept	RM10 1.68 m	lintel	1.5	226.5		0	0	300295	6232802	No	6	1 x Ku	No	New
10	Pit A/8	OnGrade	NSW Dept	RM10 1.68 m	lintel	0.5	226		0	0	300317.8	6232800	No	7	1 x Ku	No	New
11	Outlet1	Node					225		0		300325.7	6232791		22		No	
12	Outlet2	Node					225		0		300327	6232813		2196113		No	
13	Pit A/1	OnGrade	NSW Dept	RM10 1.68 m	lintel	5	229.4		0	0	300293.5	6232928	No	1	1 x Ku	No	New
14	Pit A/2	Sag	NSW Dept	RM10 2.4	2	0.5	229	0.15	0	0	300286.8	6232890	No	8	1 x Ku	No	New
15	Pit A/3	OnGrade	NSW Dept	RM10 1.68 m	lintel	1	228.3		0	0	300282.8	6232866	No	9	1 x Ku	No	New
16	Pit A/4	OnGrade	NSW Dept	RM10 1.68 m	lintel	1	228.1		0	0	300291.7	6232856	No	10	1 x Ku	No	New
17																	
18	DETENTION BASIN DETAILS																
19	Name	Elev	Surf. Area	Not Used	Outlet Typ	K	Dia(mm)	Centre RL	Pit Family	Pit Type	x	y	HED	Crest RL	Crest Leng	id	
20																	
21	SUB-CATCHMENT DETAILS																
22	Name	Pit or	Total	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass
23		Node	Area	Area	Area	Area	Time	Time	Time	Length	Length	Length	Slope(%)	Slope	Slope	Rough	Rough
24			(ha)	%	%	%	(min)	(min)	(min)	(m)	(m)	(m)	%	%	%		
25	Cat B/1	Pit B/1	0.529	65	31	4	6	11	1								
26	Cat B/2	Pit B/2	0.182	65	31	4	5	9	1								
27	Cat A/5	Pit A/5	0.265	90	10	0	2	2.5	0								
28	Cat A/6	Pit A/6	0.018	100	0	0	2	0	0								
29	Cat A/7	Pit A/7	0.07	80	20	0	3	3.5	0								
30	Cat A/8	Pit A/8	0.025	80	20	0	2	2.5	1								
31	Cat A/1	Pit A/1	0.998	25	70	5	6	15	1								
32	Cat A/2	Pit A/2	0.724	50	45	5	5	14	1								
33	Cat A/3	Pit A/3	0.105	80	20	0	3	1	0								
34	Cat A/4	Pit A/4	0.117	80	20	0	2	3	0								

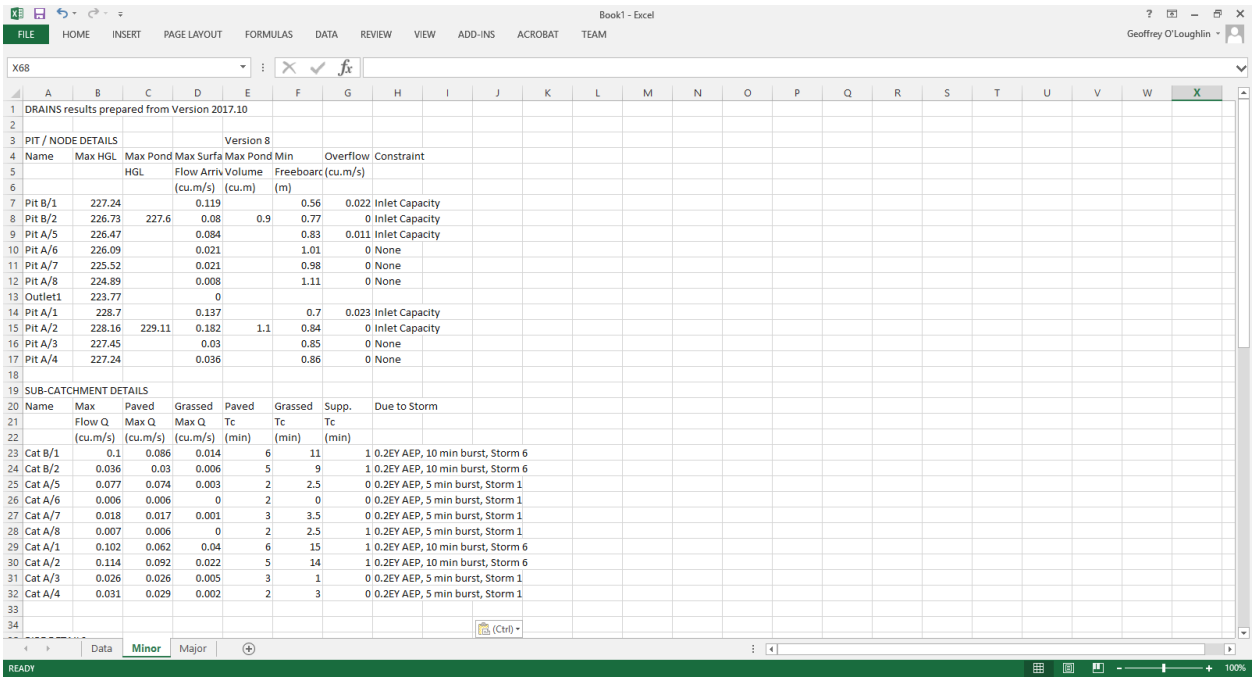
	R	S	T	U	V	W	X
23	Rough	Lag Time or Factor	Gutter Length (m)	Gutter Slope %	Gutter FlowFactc	Rainfall Multiplier	

Figure 6.40 Transferred Data

As with the data, results are organised by the type of component, in the same order. Calculated flowrates, times, velocities and other information are presented. Where multiple rainfall patterns are specified, the information presented is for the worst-case result - the greatest flowrate, highest HGL level, etc. among the results for the various storms.

The particular storm that causes this worst condition is noted in the last column for each component. (DRAINS does not transfer the specific results for each individual storm. If you wish to do this, you should use the **Select Storms** option in the **Project** menu to run DRAINS with single storms and transfer the results one at a time.) The velocities shown correspond to the peak flowrates and may be part-full or full pipe velocities, depending on the conditions when the maximum flowrate occurred.

When a Design run is followed up by a major storm Analysis run, the results can also be transferred, being pasted in a 'Major' worksheet. These spreadsheets can be saved and used to document a design or analysis. They can also be transferred from the spreadsheet program to a word processor for inclusion in a report.



	A	B	C	D	E	F	G	H
1	DRAINS results prepared from Version 2017.10							
2								
3	PIT / NODE DETAILS				Version 8			
4	Name	Max HGL	Max Pond	Max Surfa	Max Pond	Min	Overflow	Constraint
5			HGL	Flow Arriv	Volume	Freeboarc	(cu.m/s)	
6				(cu.m/s)	(cu.m)	(m)		
7	Pit B/1	227.24		0.119		0.56	0.022	Inlet Capacity
8	Pit B/2	226.73	227.6	0.08	0.9	0.77	0	Inlet Capacity
9	Pit A/5	226.47		0.084		0.83	0.011	Inlet Capacity
10	Pit A/6	226.09		0.021		1.01	0	None
11	Pit A/7	225.52		0.021		0.98	0	None
12	Pit A/8	224.89		0.008		1.11	0	None
13	Outlet1	223.77		0				
14	Pit A/1	228.7		0.137		0.7	0.023	Inlet Capacity
15	Pit A/2	228.16	229.11	0.182	1.1	0.84	0	Inlet Capacity
16	Pit A/3	227.45		0.03		0.85	0	None
17	Pit A/4	227.24		0.036		0.86	0	None
18								
19	SUB-CATCHMENT DETAILS							
20	Name	Max	Paved	Grassed	Paved	Grassed	Supp.	Due to Storm
21		Flow Q	Max Q	Max Q	Tc	Tc	Tc	
22		(cu.m/s)	(cu.m/s)	(cu.m/s)	(min)	(min)	(min)	
23	Cat B/1	0.1	0.086	0.014	6	11	1	0.2EY AEP, 10 min burst, Storm 6
24	Cat B/2	0.036	0.03	0.006	5	9	1	0.2EY AEP, 10 min burst, Storm 6
25	Cat A/5	0.077	0.074	0.003	2	2.5	0	0.2EY AEP, 5 min burst, Storm 1
26	Cat A/6	0.006	0.006	0	2	0	0	0.2EY AEP, 5 min burst, Storm 1
27	Cat A/7	0.018	0.017	0.001	3	3.5	0	0.2EY AEP, 5 min burst, Storm 1
28	Cat A/8	0.007	0.006	0	2	2.5	1	0.2EY AEP, 5 min burst, Storm 1
29	Cat A/1	0.102	0.062	0.04	6	15	1	0.2EY AEP, 10 min burst, Storm 6
30	Cat A/2	0.114	0.092	0.022	5	14	1	0.2EY AEP, 10 min burst, Storm 6
31	Cat A/3	0.026	0.026	0.005	3	1	0	0.2EY AEP, 5 min burst, Storm 1
32	Cat A/4	0.031	0.029	0.002	2	3	0	0.2EY AEP, 5 min burst, Storm 1

Figure 6.41 Transferred Design Results

In the past, a continuity check of inflow and outflow hydrograph volumes at each node has been included in the outputs. This has been suspended due to the volume of ensemble calculations, but may be re-instated in future.

In connection with rational method calculations, DRAINS has the option **Edit → Copy Check HGL to Spreadsheet** that presents results of a simplified analysis of the drainage system, using assumptions similar to those in the manual analysis procedures set out in Chapter 14 of *Australian Rainfall and Runoff*, 1987 and Chapter 5 of the *Queensland Urban Drainage Manual*. These results are not available for other hydrological models such as the ILSAX and extended rational method models.

For the rational method example shown in Figure 6.42, we can determine pit pressure change coefficients using the method from the outlined in Section 6.4.4 and run this model for minor and major storms.

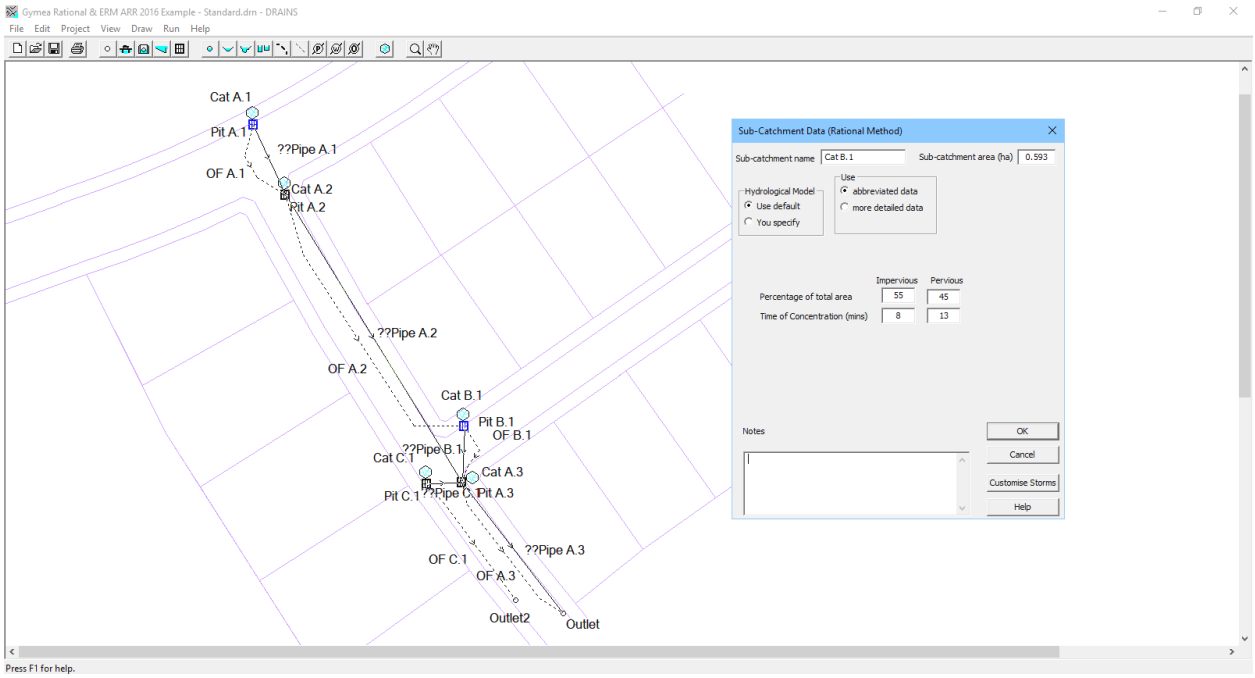


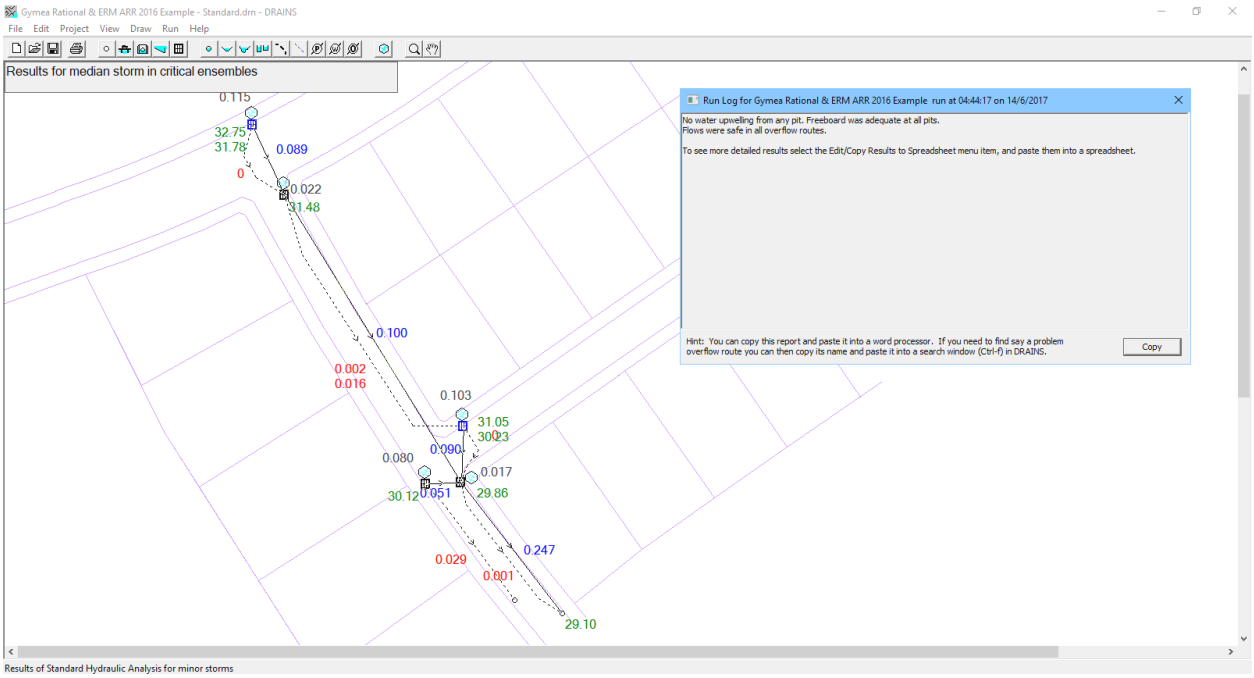
Figure 6.42 Rational Method Example

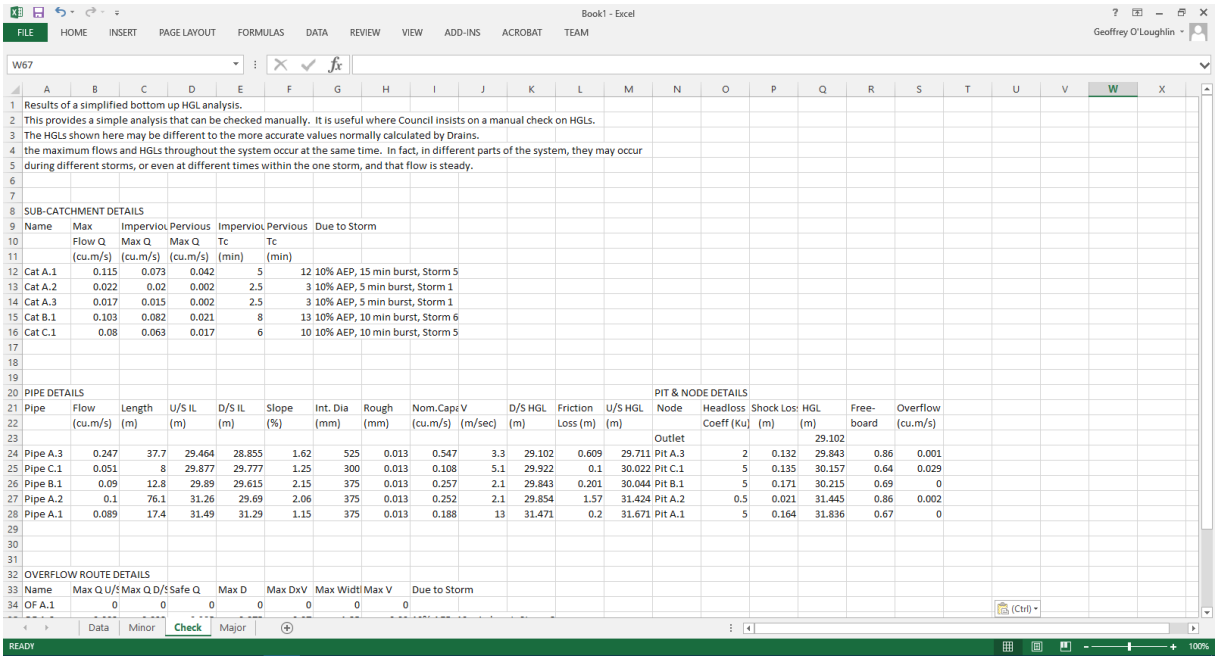
We can then transfer the results of the simplified analysis to Excel in the form shown in Figure 6.43. Overflow routes from nodes have been provided at the tops of lines. By specifying percentages of downstream sub-catchments contributing, it is possible to define the hydraulic characteristics of approach flows in the spreadsheet output (see Columns L to O of the Excel worksheet in Figure 6.43.

his feature has been provided to assist persons documenting or checking designs. It is more conservative than the DRAINS calculation procedures, and will specify higher HGLs that might sometimes exceed the freeboard limits at pits. It should therefore be considered as a guide or 'sanity check' rather than as a true representation of the peak HGL levels. Among the reasons for conservatism are that peak flowrates in all pipes are assumed to occur simultaneously.

If you are running with ARR 1987 data, you will be able to convert the DRAINS Check HGL outputs to forms set out in QUDM and manuals from Brisbane City Council and Pine Rivers Shire Council, using a 'DRAINS Rational Method Output Converter' spreadsheet available from www.watercom.com.au. This is not useable with 2016 I-F-D data, but the 'Drains Output Converter' spreadsheet can be used.

Data for pipes, pits, nodes and sub-catchments can be transferred back into DRAINS using the **Paste Data from Spreadsheet** option in the **Edit** menu. You must first make the required changes and then copy the entire spreadsheet to the Clipboard using the **Copy** option in the spreadsheet. (A quick way of selecting an entire Excel spreadsheet is to click the cell top-left cell between the '1' and 'A' cells.) The changes can then be pasted into DRAINS using the **Paste Data from Spreadsheet** option in the **Edit** menu. Because the transfers are made via the Clipboard, it is not necessary to have any direct connection between the spreadsheet file and the DRAINS file.





Results of a simplified bottom up HGL analysis.
This provides a simple analysis that can be checked manually. It is useful where Council insists on a manual check on HGLs.
The HGLs shown here may be different to the more accurate values normally calculated by Drains.
the maximum flows and HGLs throughout the system occur at the same time. In fact, in different parts of the system, they may occur
during different storms, or even at different times within the one storm, and that flow is steady.

SUB-CATCHMENT DETAILS

Name	Max Flow Q (cu.m/s)	Impervious Max Q (cu.m/s)	Pervious Max Q (cu.m/s)	Impervious Tc (min)	Pervious Tc (min)	Due to Storm
Cat A.1	0.115	0.073	0.042	5	12	10% AEP, 15 min burst, Storm 5
Cat A.2	0.022	0.02	0.002	2.5	3	10% AEP, 5 min burst, Storm 1
Cat A.3	0.017	0.015	0.002	2.5	3	10% AEP, 5 min burst, Storm 1
Cat B.1	0.103	0.082	0.021	8	13	10% AEP, 10 min burst, Storm 6
Cat C.1	0.08	0.063	0.017	6	10	10% AEP, 10 min burst, Storm 5

PIPE DETAILS

Pipe	Flow (cu.m/s)	Length (m)	U/S IL (m)	D/S IL (m)	Slope (%)	Int. Dia (mm)	Rough (mm)	Nom.Cap (cu.m/s)	V (m/sec)	D/S HGL (m)	Friction Loss (m)	U/S HGL (m)
Pipe A.3	0.247	37.7	29.464	28.855	1.62	525	0.013	0.547	3.3	29.102	0.609	29.711
Pipe C.1	0.051	8	29.877	29.777	1.25	300	0.013	0.108	5.1	29.922	0.1	30.022
Pipe B.1	0.09	12.8	29.89	29.615	2.15	375	0.013	0.257	2.1	29.843	0.201	30.044
Pipe A.2	0.1	76.1	31.26	29.69	2.06	375	0.013	0.252	2.1	29.854	1.57	31.424
Pipe A.1	0.089	17.4	31.49	31.29	1.15	375	0.013	0.188	13	31.471	0.2	31.671

PIT & NODE DETAILS

Node	Headloss Coeff (Ku)	Shock Loss (m)	HGL (m)	Free-board	Overflow (cu.m/s)
Outlet			29.102		
Pit A.3	2	0.132	29.843	0.86	0.001
Pit C.1	5	0.135	30.157	0.64	0.029
Pit B.1	5	0.171	30.215	0.69	0
Pit A.2	0.5	0.021	31.445	0.86	0.002
Pit A.1	5	0.164	31.836	0.67	0

OVERFLOW ROUTE DETAILS

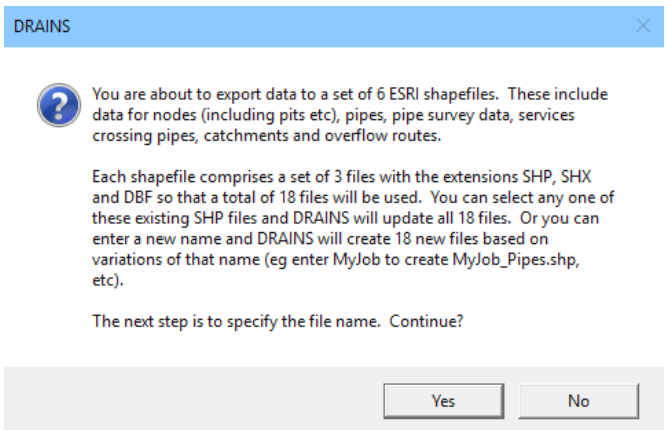
Name	Max Q U/S	Max Q D/S	Safe Q	Max D	Max DxV	Max Width	Max V	Due to Storm
OF A.1	0	0	0	0	0	0	0	

Figure 6.43 Transferred Check HGL Results

6.5.5 GIS File Exports

(a) Exporting ESRI (ArcView, ArcInfo, ArcMap) Files

It is first necessary to establish a system that is capable of being run, such as the example shown in Figure 6.44. Selecting the **ESRI Shapefiles**… option from the **File** → **Export** menu presents the message shown to the right.



If you continue, you will then need to nominate a filename for shapefiles in the dialog box shown in Figure 6.45. You can see from the existing files in this example how six ESRI SHP files are established. Another 12 SHX and DBF files will also be produced.

After a name is entered, the process is complete if there are no results. If results are available, the dialog box shown in Figure 6.46 appears. A suitable name should be added describing the results; here they are for a 2 year average recurrence interval storm. The limited size is due to restrictions on the size of column headings in the database files used in ArcMap. After this is entered, the process is finished.

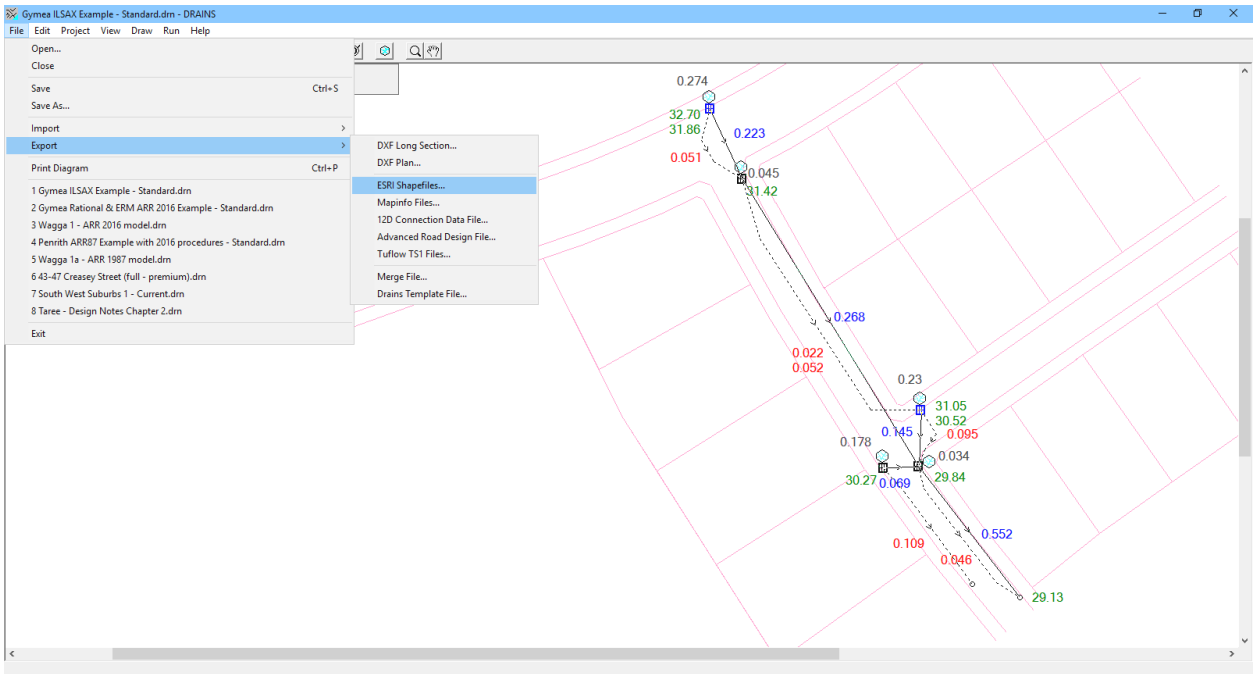


Figure 6.44 System to be Exported to GIS

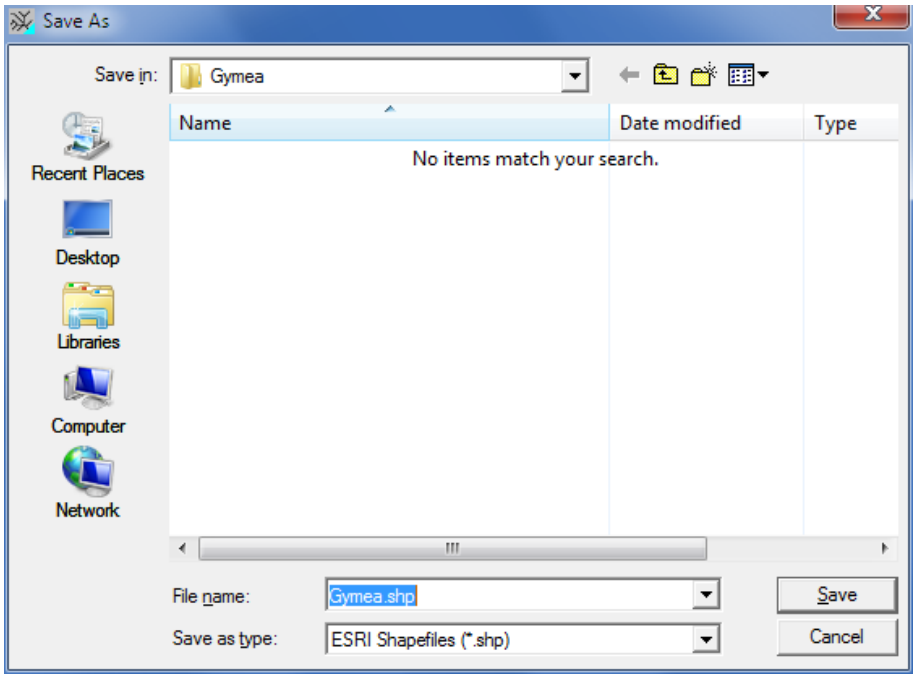


Figure 6.45 Nomination of Shapefile Name

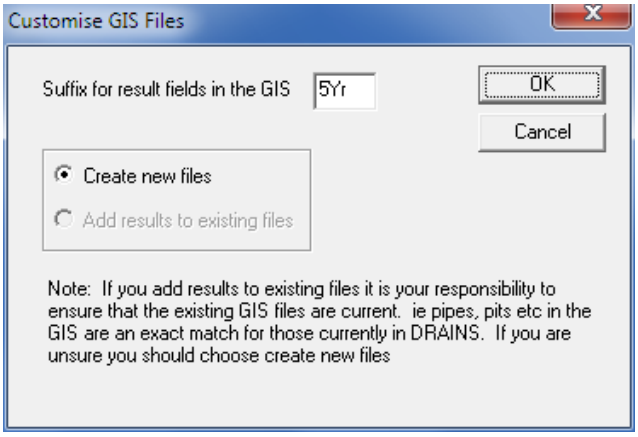


Figure 6.46 Naming of Set of Results

If a background is present in the DRAINS model, this will be transferred with the ESRI files. The transferred files can now be viewed in ArcMap as shown in Figure 6.47.

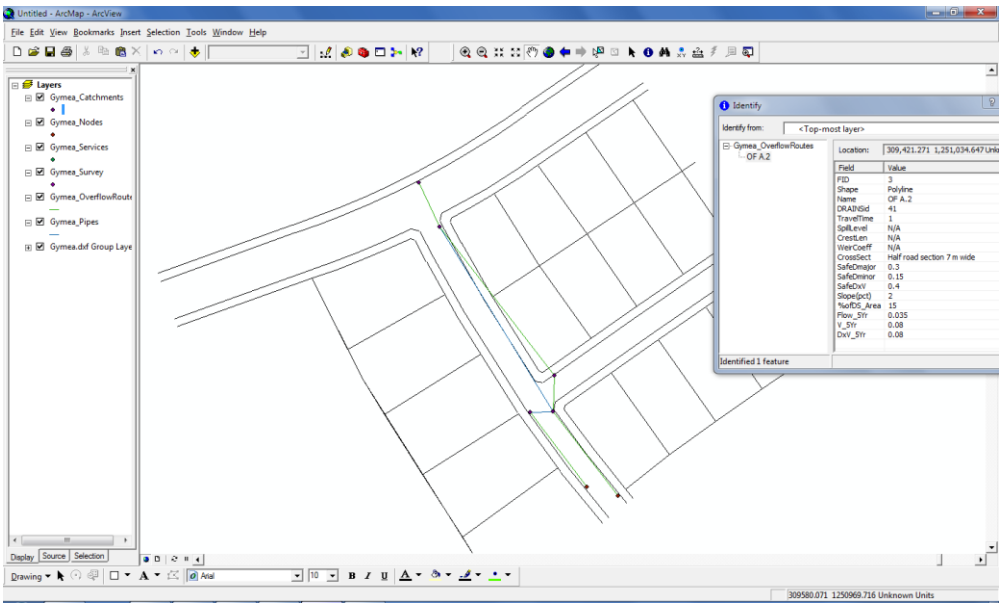


Figure 6.47 Display of Results in ArcMap

A database table is associated with each theme, as shown in Figure 6.48. Note that most values are specified as strings of characters, and must be converted to numerical values using procedures within ESRI programs if these are required to provide thematic displays where colours, line thicknesses or other attributes indicate properties.

Attributes of Gymea_Nodes

FID	Shape	Name	DRAINSid	Type	Family	Size	PondingVol	Ku	SurfaceEl	PondDepth	BaseFlow	BlockFactr	BoltDnLid	HGL_5Yr
0	Point	Outlet2	19	Node	N/A	N/A	N/A	N/A	30	N/A	0	N/A	N/A	
1	Point	Outlet	17	Node	N/A	N/A	N/A	N/A	30.1	N/A	0	N/A	N/A	29.01
2	Point	Pit C.1	6	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	5	30.8	N/A	0	0	No	30.26
3	Point	Pit B.1	4	Sag	Sutherland - 3% crossfall, all slopes	kerb inlet with 3.0 m lintel - 3% crossfall, all slopes	20	5	30.9	0.2	0	0.5	No	30.34
4	Point	Pit A.3	3	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	2	30.7	N/A	0	0	No	29.73
5	Point	Pit A.2	2	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	0.5	32.3	N/A	0	0	No	31.43
6	Point	Pit A.1	1	Sag	Sutherland - 3% crossfall, all slopes	kerb inlet with 1.8 m lintel - 3% crossfall, all slopes	30	5	32.5	0.3	0	0.5	No	32.10

Record: 1 Show: All Selected Records (0 out of 7 Selected) Options

Figure 6.48 Table of Pit Data

Note that this includes results with the '2Yr' added to headings as a suffix. If another run is made and the process is repeated with one of the existing shapefiles nominated in the Save As dialog box, additional results will be appended, as shown in Figure 6.49 and Figure 6.50, where 100 year ARI results are added to the 5 year ARI results.

If data from a GIS data base can be assembled into this same format, less the results, the **File ► Import** option ESRI **Shapefiles…** can be used to import data into DRAINS.

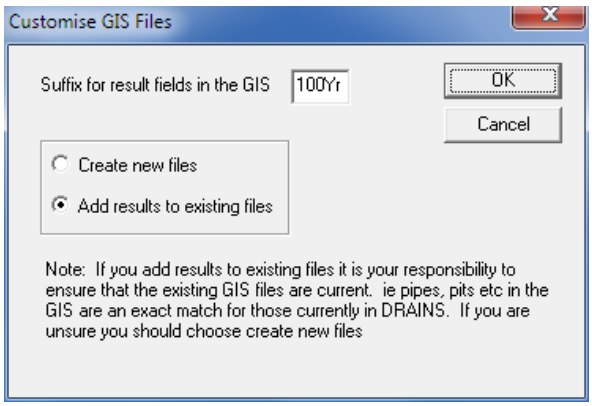
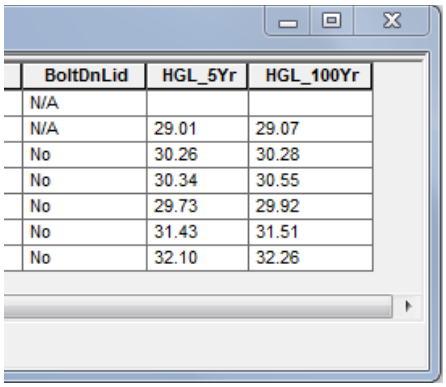


Figure 6.49 Naming of Second Set of Results



BoltDnLid	HGL_5Yr	HGL_100Yr
N/A		
N/A	29.01	29.07
No	30.26	30.28
No	30.34	30.55
No	29.73	29.92
No	31.43	31.51
No	32.10	32.26

Figure 6.50 Expanded Table of Pipe Data

(b) Exporting MapInfo Files

It is first necessary to establish a system that is capable of being run in DRAINS, such as the demonstration example shown in Figure 6.44. Selecting the **MapInfo files…** option from the **File** → **Expor**t menu presents the message in Figure 6.51. If you continue, you will then need to nominate a filename for MID/MIF files in the dialog box shown in Figure 6.52.

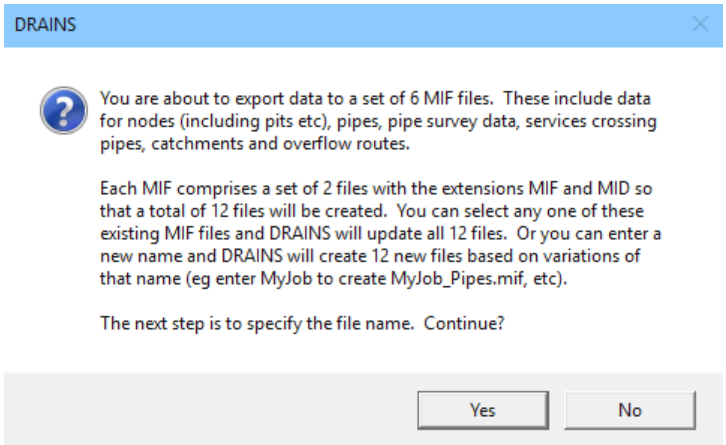


Figure 6.51 Message in MapInfo File Export Procedure

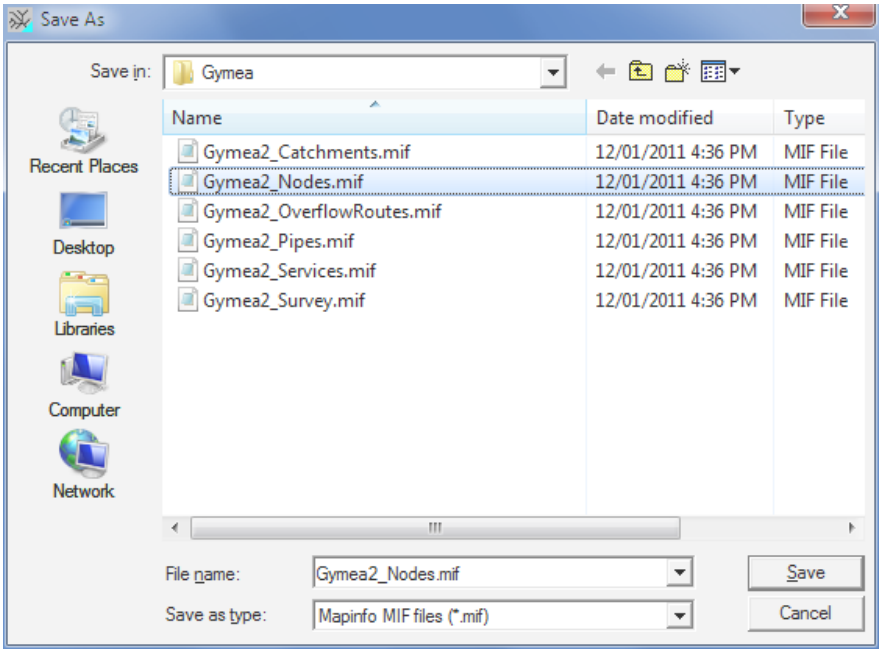


Figure 6.52 Nomination of MID/MIF File Name

You can see from the existing files in this example how six MapInfo MIF files are established. Another six MID files are also produced. After a name is entered, it will be necessary to nominate the projection to be used if the data has not been brought in from MapInfo files. This can be done in the dialog box shown in Figure 6.53 that appears. This has a similar format to the equivalent window in MapInfo.

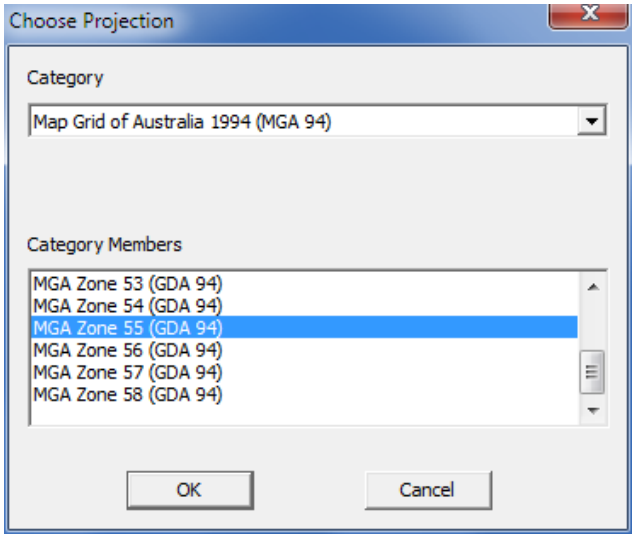


Figure 6.53 Nomination of Projection

The process is then complete if there are no results. If results are available, a dialog box similar to that shown in Figure 6.46 appears. A suitable name should be added describing the results; such as '10Yr' for a 10 year average recurrence interval storm.

A background in the DRAINS model will be transferred with the MapInfo files. If there are any problems with the projections, these can be overcome by editing the ASCII MIF file, inserting a line giving the appropriate projection. The transferred files can now be viewed in MapInfo, as shown in Figure 6.54.

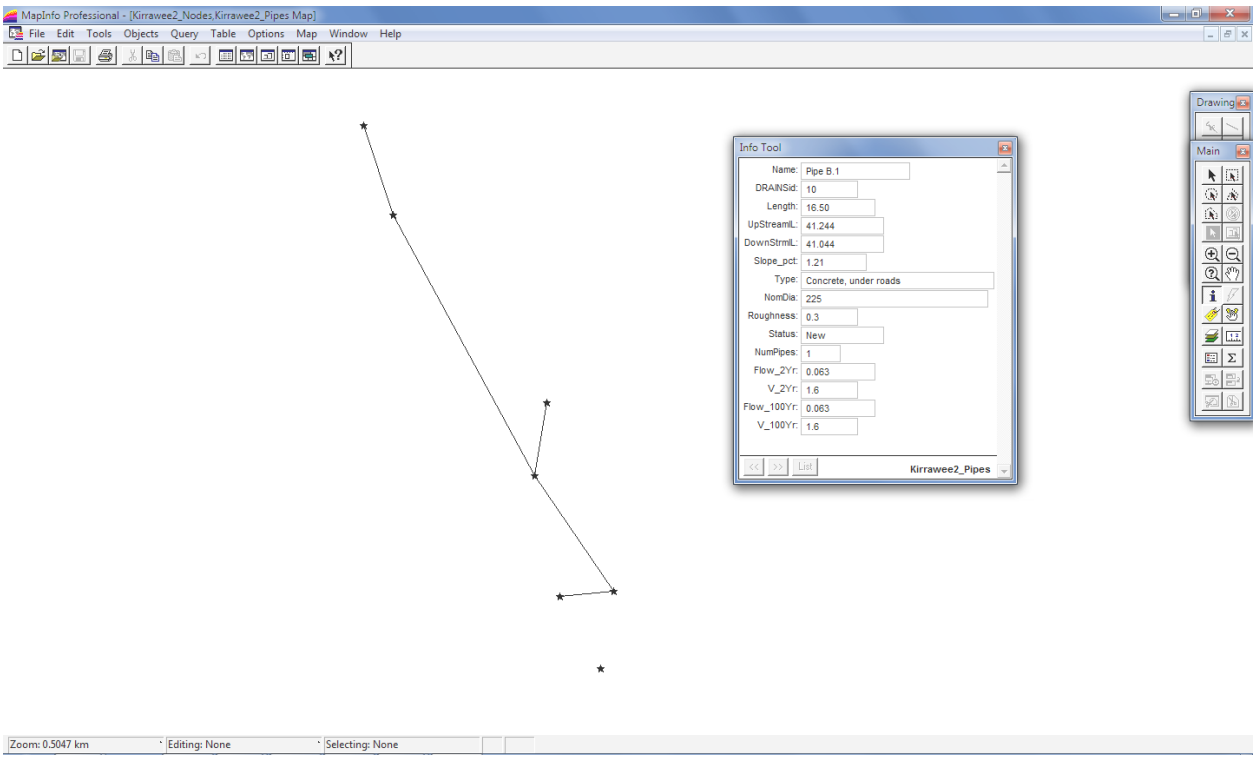
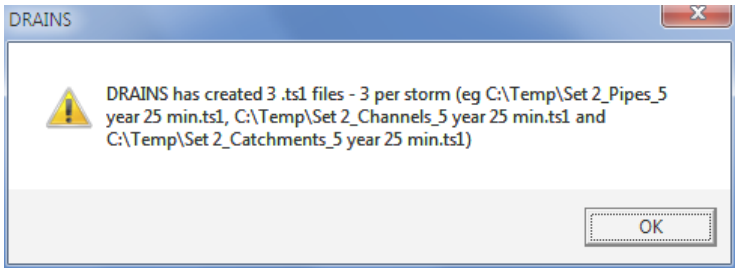


Figure 6.54 Display of Data transferred to MapInfo

'2Yr' and '100Yr' are added to headings as a suffix. If another run is made and the process is repeated with one of the existing shapefiles nominated in the **Save As** dialog box, additional results will be appended.

6.5.6 Hydrograph Outputs in TUFLOW Format

Using the **File** → **Export** → **Tuflow TS1 Files…** option, you can export hydrographs in a format used by the 2-dimensional TUFLOW hydraulics program (BMT WBM, 2010). Hydrographs are produced for sub-catchments, pipes and overflow routes for all storm runs made prior to exporting. This format can be read by spreadsheets and editors, and can be used by other programs than TUFLOW. When a transfer is made, the message to the right appears:



6.5.7 Outputs to Linked Applications

As part of the dedicated links from Civil Survey Design (formerly Advanced Road Design) and 12d to DRAINS, results are transferred back to these applications via database files and the spreadsheet outputs, as described in Sections 6.2.7 to 6.2.10.

6.5.8 Merge Outputs (and Inputs)

The merge options allow you to add DRAINS systems together. It is first necessary to export a system as a merge file, before importing it into another system. The two systems are linked the pits at each end of a common pipe, which is the lowest pipe in the system to be added. The procedure is as follows:

(a) Edit the files so that both include two adjacent pits with the same names. Make sure that you have zoomed in to the model so that there is an observable distance between pits. (If the model is at a low magnification, so that individual pipes cannot be seen, there may be round-off errors in the process that DRAINS applies when creating a merge file. This may lead to sub-catchments and other components being connected wrongly.)

(b) In the file to be added, use the **Export a Merge File**... option in the **File** menu to create and name a .mrg merge file.

(c) Then close the file to be added, and open the file with the receiving system. Using the **Import a Merge File…** option in the **File** menu, read in the .mrg merge file created in Step (b).

(d) The merged system will appear. The orientation of pipes will be that of the receiving system. You can then tidy this up, save the combined file and make runs as required.

This process is demonstrated by opening the file shown as Toowoomba Addition.drn in Figure 6.55 and creating a merge file named Toowoomba Addition.mrg with **the Export a Merge File** option in the **File** menu.

This can then be imported into Toowoomba Estate.drn, displayed in Figure 6.20, using the **Import a Merge File** option in the **File** menu. The joined system is shown in Figure 6.56.

It is possible to join models together when these do not have common pits, by drawing top dummy pits. The process is as follows:

(a) On the first model, draw two dummy pits 100 m or 200 m apart. Give them distinctive names. Pit details should be filled in, but the exact information entered is not important.

(b) Export the model data to a spreadsheet using the procedures in Section 6.5.4.

(c) Open the second DRAINS model and export the data from this to another worksheet in the spread sheet. Among the PIT/NODE outputs insert two additional rows.

(d) Return to the worksheet created from the first DRAINS model and copy the two rows describing the dummy pits. Paste these into the two blank rows in the worksheet for the second model. Then copy the whole worksheet to the clipboard.

(e) Return to the second DRAINS model and use the **Edit** → **Paste Data from Spreadsheet** option to bring the two dummy pits into this model.

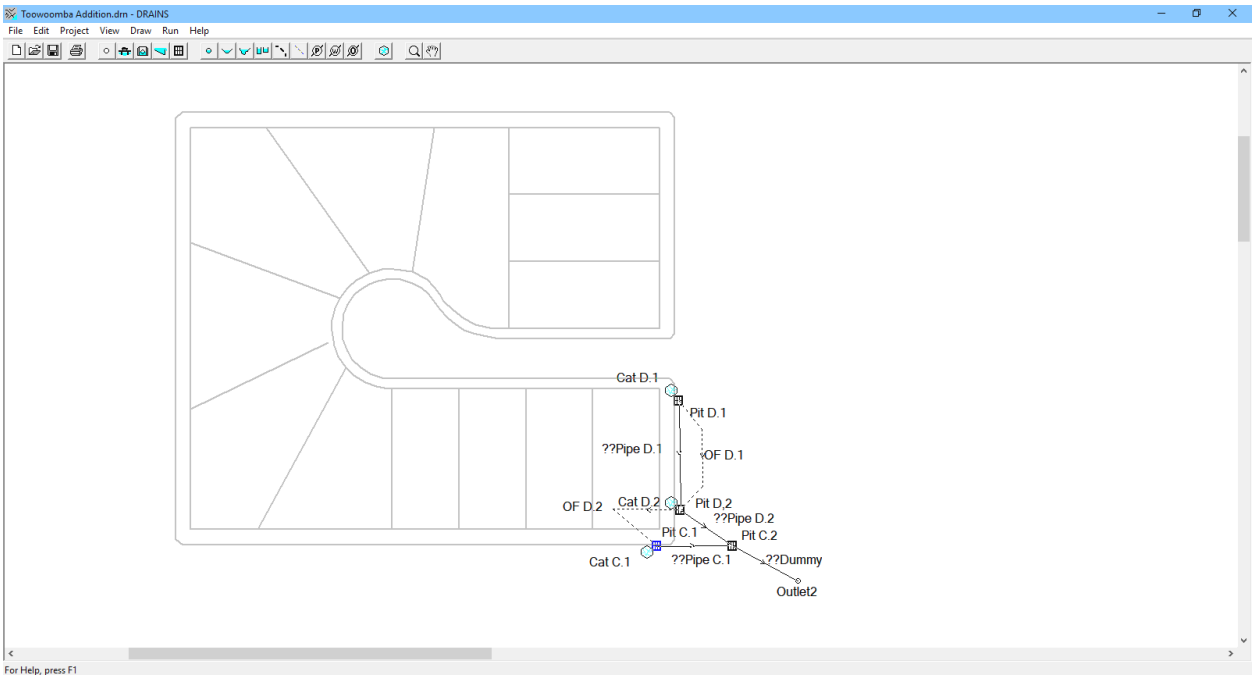


Figure 6.55 The File that is to be Added using the Merge Options

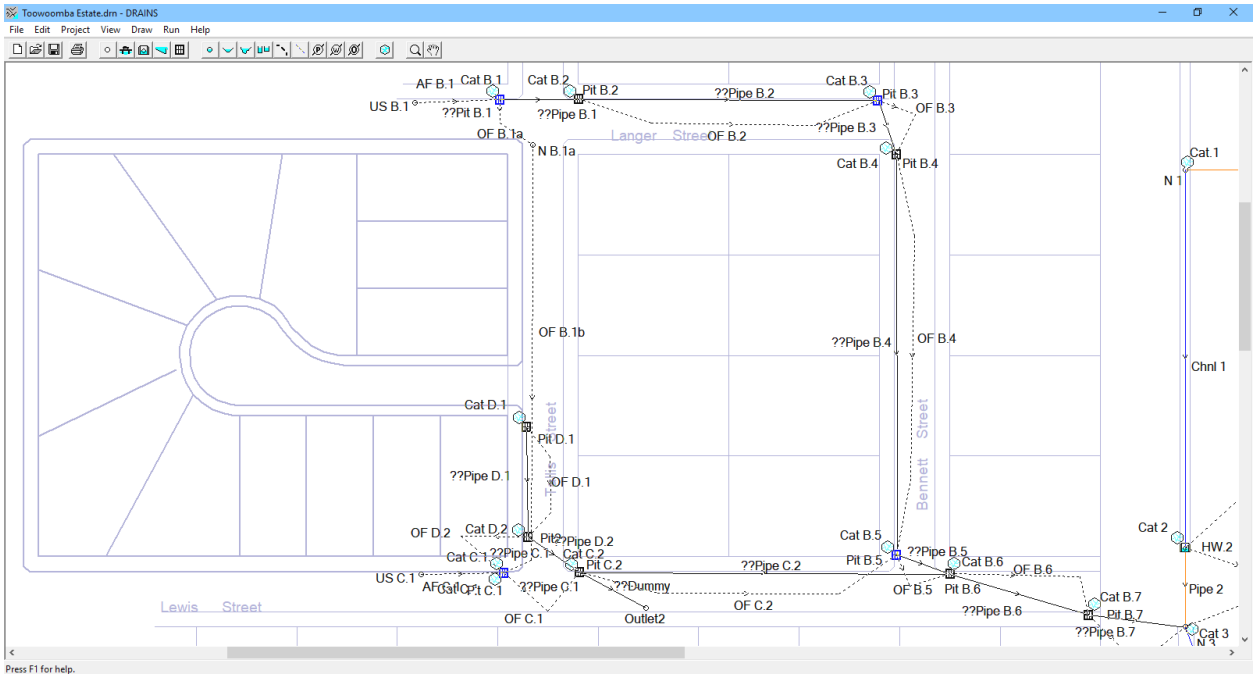


Figure 6.56 The Combined File

Both models should than have two common pits and can then be joined using the merge procedure described earlier in this section. If necessary, the background can be replaced using the procedures described in Section 6.2.2(b). A problem may occur if there is a conflict in the 'id' numbers that are used by DRAINS for internal purposes, and which appear in the spreadsheet output. Contact Watercom Pty Ltd if this occurs.

6.5.9 Template File Exports

To assist in the preparation of files that can be used as the basis of other models, DRAINS has a function implemented by selecting **File** → **Export** → **Drains template file…**. This opens the following window:

After selecting a file type and clicking the Next button, a window appears allowing the file name and path to be nominated, and it can then be saved.

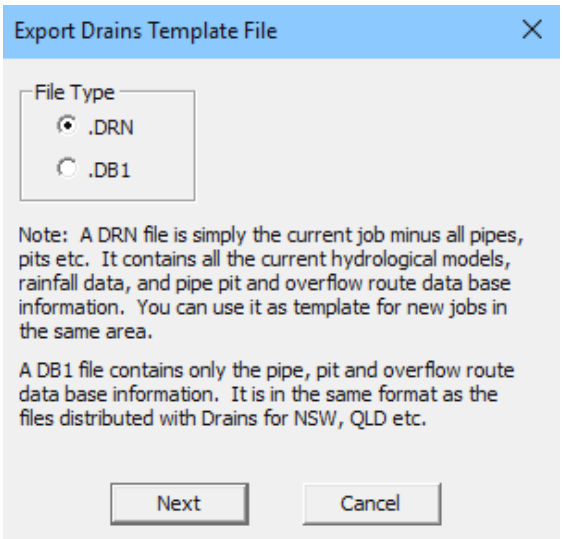


Figure 6.57 Dialog Box for Exporting Template Files

6.6 Flood Mapping

The premium hydraulic model now includes a flood mapping capability for overflow routes. Following a run of the premium hydraulic model you can now turn flood mapping on or off from the View menu.

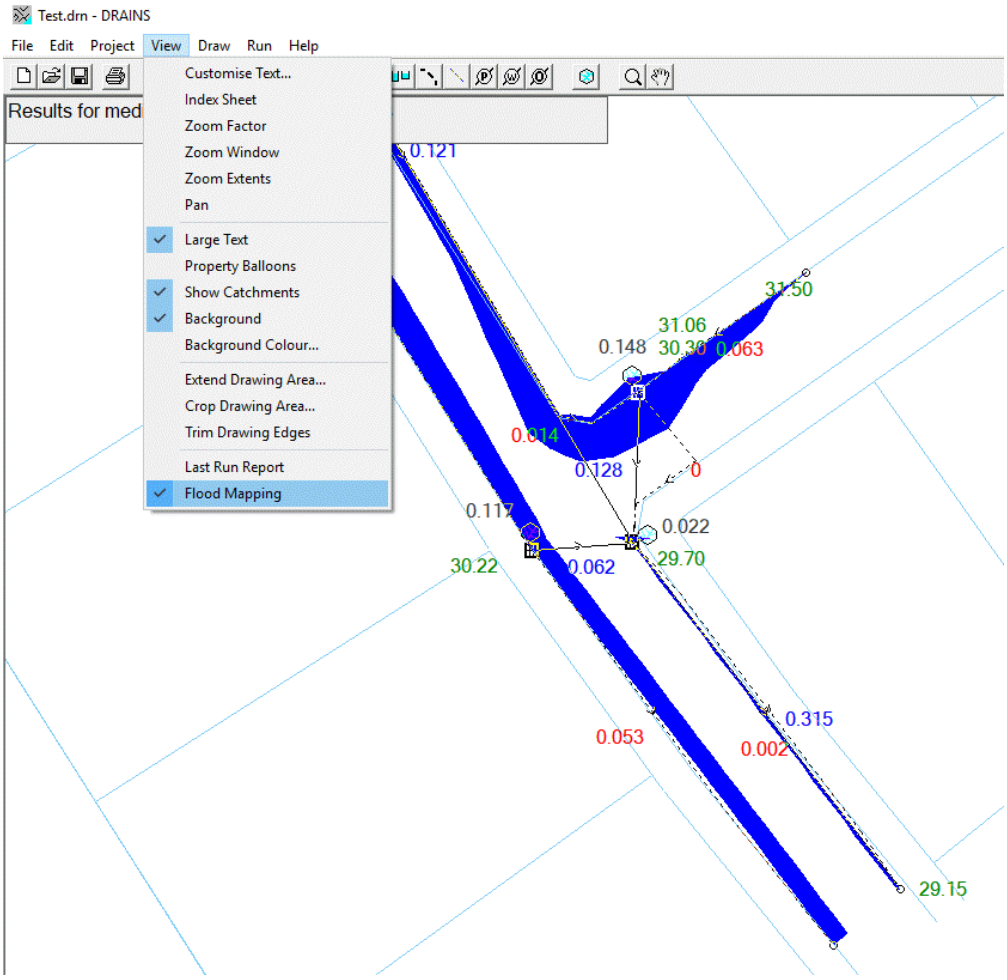


Figure 6.58 Example showing Flood Mapping along Overflow Routes

The mapping relies on DRAINS knowing the location of invert levels at points along an overflow route. It is common practice to draw overflow routes schematically (e.g. to visually separate them from a pipe directly below them). In that case, the flood mapping would also be distorted if DRAINS assumed the on-screen location defined the invert level of the overflow route. To prevent this distortion, you have the option to specify whether the on-screen location is correct or whether DRAINS should assume a straight line from end to end of the overflow route. Right click on an overflow route and tick or untick the item **Treat as straight line for flood mapping**.

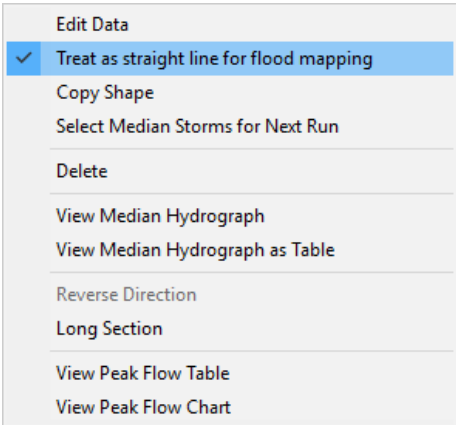


Figure 6.59 Choosing 'straight line' Option in an Overflow Route Menu

An overflow route cross section is often not symmetrical (e.g. a half road section - the road pavement to the right of the kerb and gutter is different to the footpath to the left). So the extent of flooding to the right of the invert level is often different to that to the left. Often the same cross section is used for the gutters on each side of the road. This has not mattered in the past, but it does matter now when DRAINS plots the extents of flooding. As Figure 6.60 shows, there are extra radio buttons in the overflow route property sheet (under the Cross Section Data tab) where you can specify whether the cross-section represents the view looking upstream or downstream.

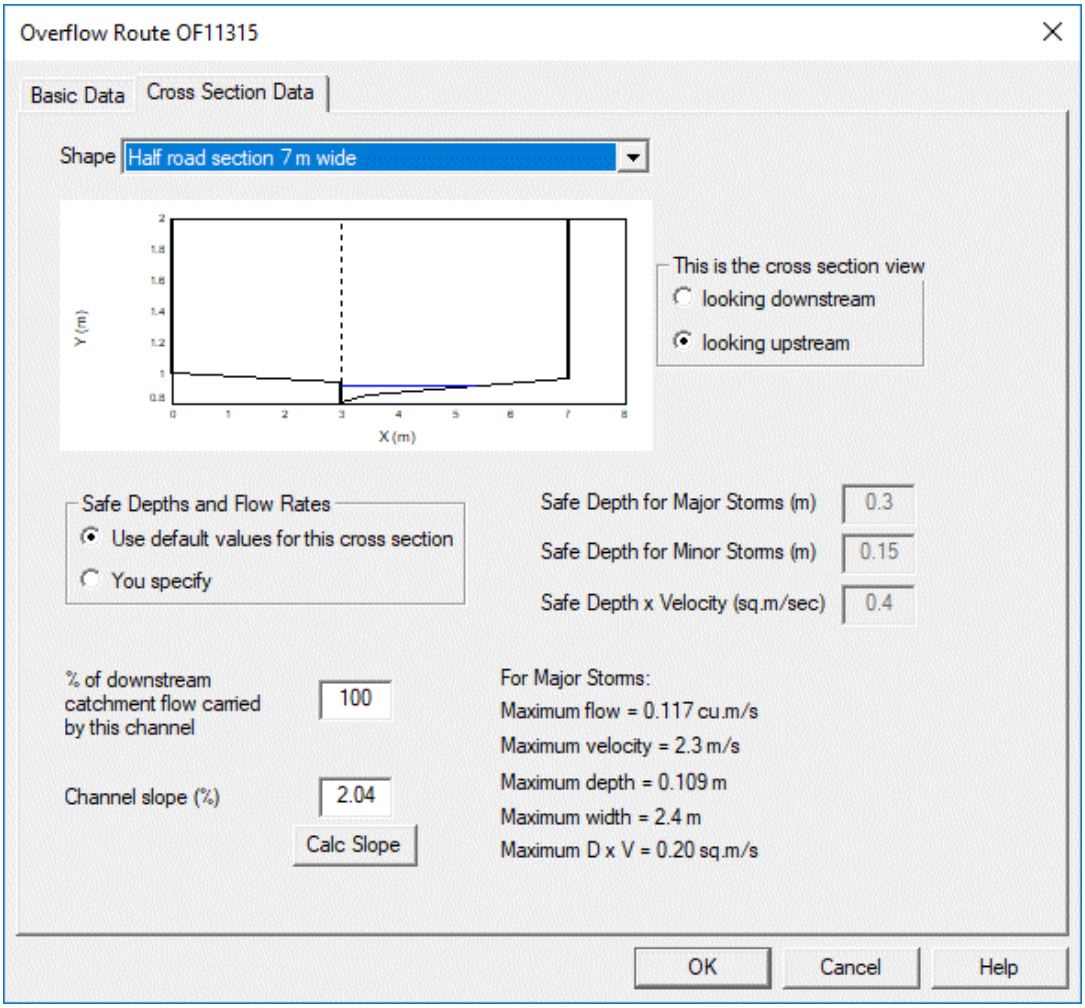


Figure 6.60 Overflow Route property Sheet

The accuracy of the flood mapping relies on the accuracy of the cross section data. Some older models may need revision if the cross sections are not accurate (e.g using a 7 m wide road section when it should be a 5 m wide road section may show the flows crossing the centerline of the road). Adding additional incremental points while drawing an overflow route may also improve the visual representation of the flood mapping, particularly around a kerb return. You may find you need to draw extra overflow routes in a model.

For example if you have only one overflow route into a sag pit, and the outgoing overflow route is at ninety degrees to the incoming one, you may find that part of the pit surface flooding is missing. As shown in Figure 6.61, an extra incoming overflow route from another direction (in line with the other incoming overflow route) provides DRAINS with the extra information it needs to plot the flood mapping.

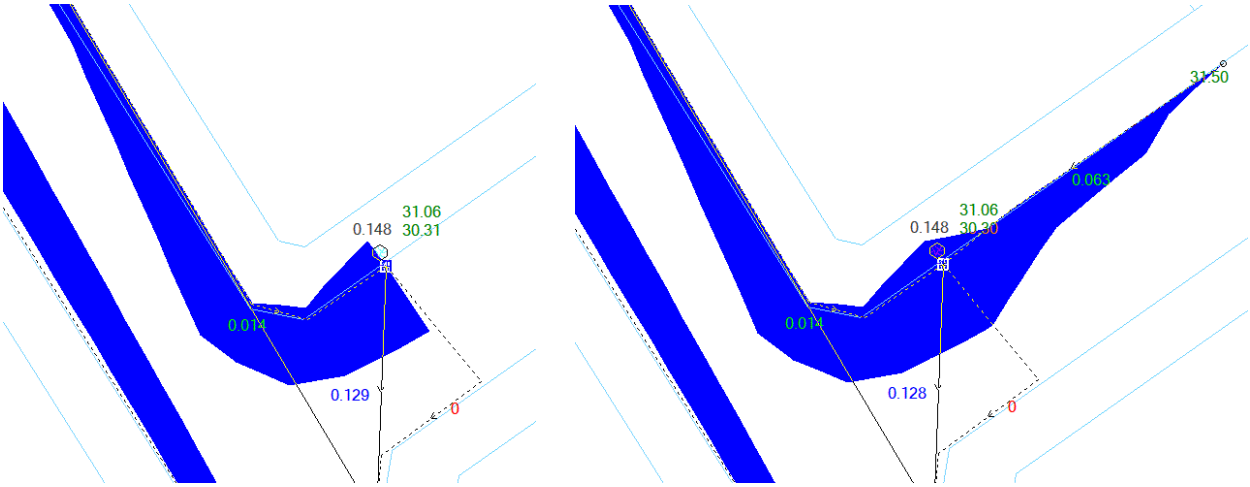


Figure 6.61 Addition of an Overflow Route from the Eastern Side of a Sag Pit

6.7 Help Options

The Help system in DRAINS can be called in three ways: (a) by choosing **Contents** in the **Help** menu, (b) by pressing the F1 key, or (c) by pressing a **Help** button in a property sheet or dialog box to deliver context-sensitive Help.

It is implemented as a HTML Help system in a three-pane window with an index as well as topics, as shown in Figure 6.62. The panes can be re-sized as required.

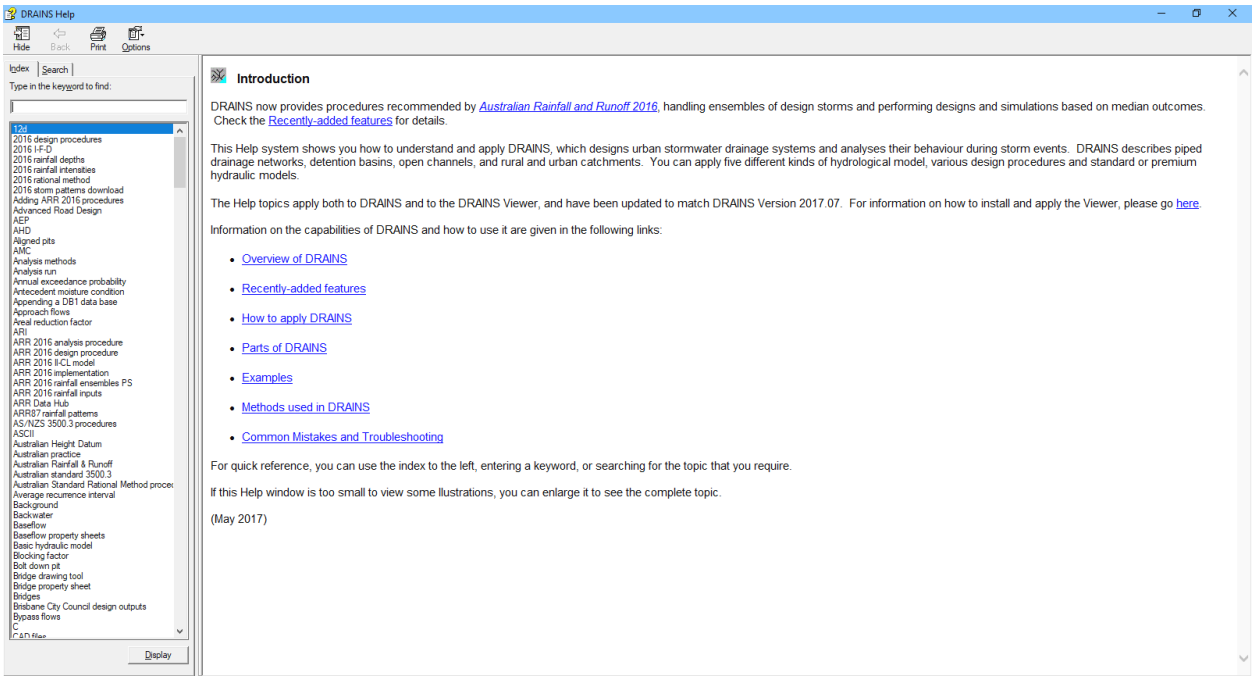


Figure 6.62 A Typical HTML Help Message

Within particular Help topics, the underlined links open additional topics. The index can also be used to find specific topics.

With well over 200 topics, the DRAINS Help system provides a comprehensive guide to the program, and a glossary of urban stormwater drainage terms and concepts. It complements the material in this manual, and provides timely advice on enhancements to DRAINS.

7. OPERATIONS

7.1 Introduction

This chapter outlines how DRAINS works and how to perform design and analysis tasks. The detailed procedures within the program cannot be explained in simple terms, so only a general description is provided here. Likewise, DRAINS can be put to many uses, and it is not possible to cover all of these. The DRAINS training workshops provide information of this type though examples and exercises.

7.2 DRAINS Workings

7.2.1 Units

DRAINS uses metric units throughout. Where possible, it follows SI conventions for these, but in many displays and outputs it is not possible to show superscripts. Thus, 'cu.m' and 'cu.m/s' are frequently used in place of 'm^3' and 'm^3/s'.

7.2.2 Programming

DRAINS is written in C++ and works on PCs with Microsoft Windows operating systems from Windows 95 to Windows 7. The calculation procedures from the PIPES program are used to model pressurised flow situations. It inputs and outputs data in binary, spreadsheet CSV, DXF, ESRI shapefile, MapInfo MID/MIF and data base formats.

DRAINS is structured so that different hydrological and hydraulic models can be run via the same interface, with many functions being shared, such as the display of hydrographs. There are choices of:

- Hydrological models - ILSAX, storage routing and extended rational method (producing hydrographs) and rational method (producing peak flowrates);
- Hydraulic calculations – standard or premium hydraulic model calculations, and perhaps for older models, the obsolete basic model calculations; and
- Procedures – design of pipe systems or analysis of pipe, open channel and detention systems.

The free DRAINS Viewer operates in the same way as DRAINS, but is limited to inspecting data and results saved in a .drn file. It can also export spreadsheet and CAD outputs.

7.2.3 Data Storage and Files

To run, DRAINS requires run specifications, rainfall data and a pipe or channel system. This data is stored temporarily in the computer's memory and, more permanently, in a binary data file with a .drn suffix, such as the sample files that have been described in this manual. After a data file has been saved, you can re-open it in DRAINS and modify the data. Since it is saved in binary format, it cannot be viewed or changed using a text editor. The binary file formats change as DRAINS is updated, but will always be back-compatible. That is, the current version of DRAINS will open and operate with files created in previous versions. You will probably not be able to open files created with a later version of DRAINS than the one you are using - it is not forward-compatible.

Each DRAINS .drn file is effectively a data base describing a drainage system and its components, together with reference data bases for pipes, pits and overflow routes, and possible the results of a run. Most of the data on the drainage system can be readily accessed in ASCII or text form, using the spreadsheet output option described in Section 6.5.4. Data on rainfall patterns, hydrological models and run specifications are not transferred to spreadsheets.

As well as the sets of pipe, pit and overflow route types and associated information contained in the .drn file, a set called **`Drains`**.db1 is contained in the C:/Program Data/Drains folder. This is set that is applied when DRAINS is first .opened. The regional sets of pipe, pit and overflow route data for New South Wales, Queensland and other states are stored as .db1 files in the C:/Program Files/Drains/Program or C:/Program Files/Drains/Program folders, along with the Drains.exe file. These sets can be installed using the **Default Data Base** option in the **Project** menu, which copies these to Drains.db1. (It is important that users determine what they require before starting a project, as it may be awkward to change the available options later.)

7.2.4 Processes

As shown in Figure 7.1, you can operate DRAINS through a number of processes, such as:

(a) Data entry and file storage,

(b) Performing calculations,

(c) Inspection and possible storage of results,

(d) Changing or correcting data, and re-running calculations,

(e) Transferring data and results to files and other programs.

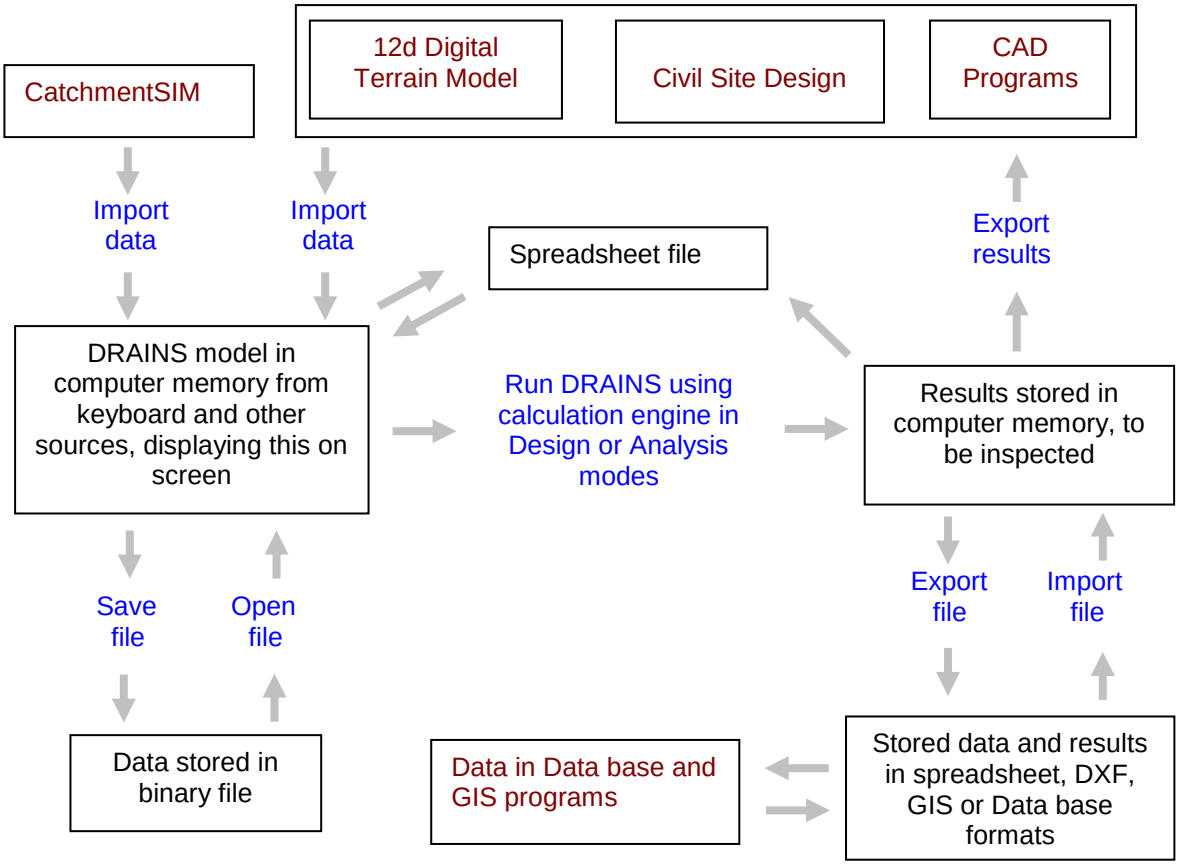


Figure 7.1 Typical Processes in DRAINS

Performing calculations in Action (b) is a batch process. Once started it continues without intervention by the user, unless it is aborted by pressing the **Esc** key. On the other hand, Actions (a), (c) and (d) are event-driven. They can be carried out in many different ways, depending on your preferences. The programming style follows Microsoft Windows conventions, so that it will be familiar to most users.

The main calculation procedures in DRAINS are:

- hydrological calculations, which produce the flowrates to be transported through the drainage system,
- the hydraulic design procedure for pipes, which determines pipe diameters and invert levels allowing for minor and major storms, and,
- hydraulic analysis calculations for pipes and channels, which define flow characteristics such as discharge rate, velocity and depth, and determine whether systems can convey flows without overflowing.

Applications using hydrological storage routing models may only apply the first of these procedures.

7.2.5 Initial Processes

The various run options are described in Section 6.4. Before these become available in the **Run** menu, DRAINS performs checks to confirm that:

- a hydrological model and rainfall patterns have been specified,
- the components of a system are joined correctly,
- the drainage system components have been fully specified.

The run options in the menu are greyed out if these conditions are not met.

Once a run begins, DRAINS sorts through the various components to define linkages throughout the system and the order in which calculations should occur. Using the coordinates of the objects, it identifies connections between pits or nodes and links, such as pipes or channels where the positions of the ends of a link are within the symbol of a node in the Main Window. The connections between pits and sub-catchments are established where the symbols overlap. The pits or nodes at the extremities of drainage systems are identified as those having no incoming links. DRAINS also checks inputs for any inconsistencies that have escaped the checks in property sheets during data entry.

7.2.6 Hydrological Calculations

With the ILSAX model, hydrological calculations involve the computation of the hydrographs from the paved and grassed surfaces of each sub-catchment using the Horton loss model and the time-area routing methods described in Section 8.3.2(b). They are carried out in the same way for both Design and Analysis runs. With the extended rational method and the storage routing models, hydrographs are calculated by different procedures. The rational method procedure only calculates peak flowrates.

In calculated hydrographs, flowrates are defined at times that are multiples of the calculation time step that is (a) defined in the **Options** property sheet called from the **Project** menu, or (b) automatically defined by DRAINS using various criteria, including the requirement that unpressurised flows should take at least one time step to travel through any pipe in the system.

DRAINS results change when it is run with different time steps. Most of the time, users should accept the time step defined by the program. This is determined so that it will take at least one time step for water to travel through each conduit. The minimum time step is 0.005 minutes or 0.3 seconds, and the maximum for pipe calculations is 1 minute. Sensitivity tests can be carried out to determine a suitable time step. If two time steps provide essentially the same results, the longer one can be used. Generally, smaller time steps will give more accurate and stable results, but this may not always be the case.

The hydrographs in all links begin at the same time, the start of the storm rainfall pattern. Any baseflows and user-provided inflow hydrographs introduced at pits or nodes begin at this starting time. User-provided hydrographs can be specified at any time step, and flowrates will be converted to the calculation time step by linear interpolation.

Where flow values are zero, due to:

- losses absorbing the initial rainfalls,
- a lag time or factor being specified for a grassed area hydrograph in the ILSAX model (see Section 5.3.6(b)), or
- a delay used to model a moving storm (also see Section 5.3.6(g)),

zero flows will be placed at the start of the hydrograph so that it begins at the rainfall pattern's starting time. This common starting time simplifies the combination of hydrographs at junctions.

With the rational method model, peak flows are calculated and stored with the data for each component. Hydrographs produced by other models for sub-catchments, pipes, channels, overflow links and detention basins can be viewed as graphs or tables using the pop-up menus for individual components, and can be transferred to the Clipboard, as shown in Figure 5.3. They also can be printed out in the **Print Data and Results…** option in the **File** menu. Calculated hydrographs and HGL levels are stored temporarily as part of each sub-catchment 'object', and can be retained in the saved .drn file.

The procedures for the storage routing models emulating the RORB, RAFTS and WBNM models, are simpler than those from ILSAX. Results are presented in the same way as ILSAX hydrograph outputs in Figure 7.2.

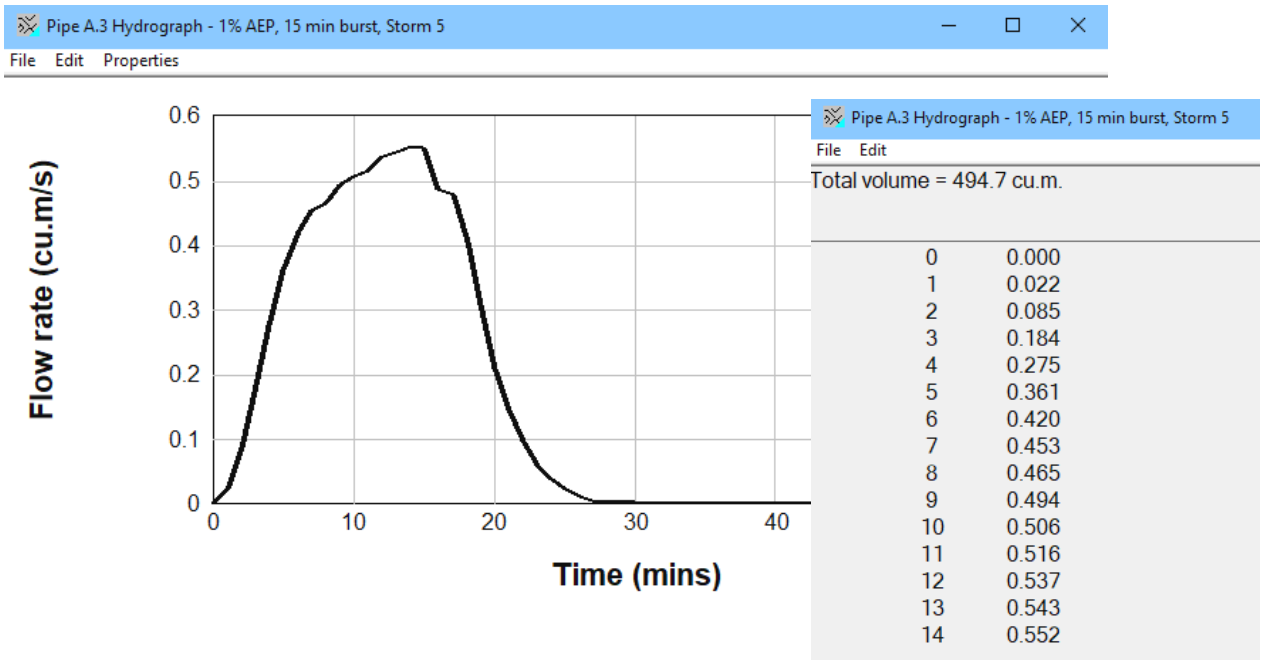


Figure 7.2 DRAINS **Hydrograph Outputs for an ILSAX Sub-Catchment**

7.2.7 Hydraulic Calculations

(a) General

Once hydraulic calculations begin, DRAINS determines the inflow into the pipe and channel system at each time step. At each node, the following flows are combined: flows off areas on the local sub-catchment, any overflows from upstream pits or detention basins that are directed to this destination, any baseflows or flows from user-provided inflow hydrographs applied at the surface for a pit or simple node.

This surface flow is assumed to enter the system without restriction at a simple node, detention basin, culvert or bridge. For an on-grade or sag pit, the pit capacity relationship defined in the Pit property sheet is applied to estimate the inflow rate, as described in Section 0.

For Design calculations, a pipe system will be sized to carry all flows that enter the system. The only overflows will be the bypasses caused by restrictions on inlet capacities. In Analysis, there may be upwelling of flows from the pit due to the capacity of the downstream pipe system being insufficient to carry the assumed flows. As shown in Figure 7.3, these are added to any bypass flows to define the total overflow from the pit.

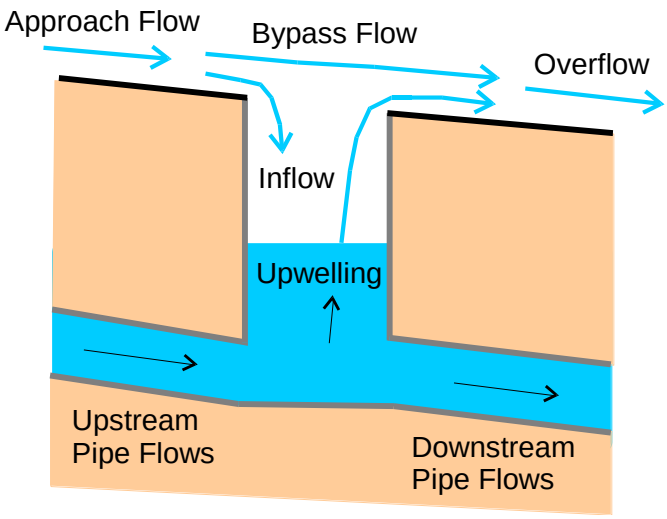


Figure 7.3 Pit Inflows and Outflows

No overflows can occur at simple nodes or from ILLUDAS type pits (now obsolete). Situations where overflows or breakouts occur from channels might be modelled by adding a detention basin at the overflow location, as noted in Table 5.2.

The calculated inflow rates at each time step can then be used as boundary conditions for the main set of calculations through a pipe or open channel system. These provide information on HGLs and water surfaces at nodes, and flowrates through the various links within a system.

With the rational method, only peak flow conditions are considered, but for hydrograph models, conditions are calculated at each time step.

(b) Basic Hydraulic Calculations

In the basic calculations that are now obsolete, drainage systems are analysed by making downwards and upwards passes through the pipe or channel network at each time step, going from each pit or node to the next one downstream or upstream. The first pass moves downwards from the top of each line in the system, establishing the surface flows arriving at each node by adding flows from the local catchment, overflows from upstream and user-provided flows. Using the pit inlet capacity relationship, bypass flows are determined. The flow entering the pit is then added to any flows through upstream pipes and possible user-provided inflow hydrographs to define provisional pipe flows.

When the calculations reach the system outlet or outlets, DRAINS makes the upwards pass, starting from the tailwater level at the outlet. Allowing for pipe friction and pressure changes at pits, it defines the position of the HGLs at pits and nodes, and if necessary, modifies the flowrates in the pipes and the corresponding overflows. For part-full pipe flow, this process is carried out by projecting HGLs upwards and allowing for pressure changes at pits. If a pipe flows full, a pressurised flow calculation procedure is used to define HGLs at pits and flowrates in pipes. Whenever it encounters a junction, DRAINS projects HGLs up both branches from the pit water level. If the calculated water level in a drop pit is determined to be below the invert level of an incoming pipe, the tailwater is set at the critical depth in this pipe, and upwards HGL projections are continued.

This model provides information on water levels at pits and nodes and flowrates through pipes. When there is subcritical open channel flow, the standard step method employing the Colebrook-White or Manning's equation is used to compute backwater curves in pipes and channels. Where pipe flow is supercritical, the water surface is assumed to follow the normal depth. (In open channels, the basic model conservatively assumes surfaces to be no lower than the critical depth.)

The basic calculations define HGLs at nodes and inside pipes for subcritical part-full flows, but they only presents the results at nodes. They define flowrates in links such as pipes or channels, and provides continuity checks in the spreadsheet output summing the inflows and outflows at each node. The flowrates presented for pipes are those calculated at their upper ends, so that the flows displayed in DRAINS outputs at a particular time will probably differ from the flowrates emerging from the pipe at that time. If a pipe is unpressurised, these outflows will be the same as the flows that entered a conduit a certain number of time steps previously (depending on the pipe length and flow velocity). If it is pressurised, there is no time delay. DRAINS manages the transfers between part-full and full-pipe flow so that there are only small continuity errors.

(c) Unsteady Hydraulic Calculations

The unsteady flow calculations carried out with the standard and premium hydraulic models are quite different, using the equations of mass and momentum conservation (Section 8.6.4) to set up a matrix specifying the equations to be solved over a space-time grid. The space or x dimension represents the conditions at various points in a system, with conditions being calculated at multiple points in longer conduits. The time or t dimension relates to the time steps used. While results are reported at fixed times, calculations can be carried out at smaller time intervals. The main quantities being calculated are water elevations H and flowrates Q. The main calculation involves the solution of the matrix equations to determine H and Q values at all locations at each time step during the simulation. As well as the core calculation procedures, this involves the determination of states at many boundaries in the system (such as pits where water enters, and outflow locations).

Water or HGL levels are presented at pits and nodes and also appear on some plots of pipe, overflow route and open channel long-sections. The flowrates displayed apply at the centre of the link.

The DRAINS hydraulic calculation procedures permit two outlet pipes to be specified for each pit, and can model looped or branching pipe systems, where there is a bifurcation with two pipes coming out of a pit.

The premium hydraulic model permits two or more overflow routes from sag and on-grade pits, so the invert levels of overflow routes from a pit can be at different levels. This allows modelling of situations that cannot be adequately modelled using the basic or standard models (e.g. overflow from an on-grade pit down a gutter and across the road crown).

(d) Pit Modelling

As flows pass through pits, a pit pressure change relationship is applied, using the k_u factor shown in Figure 7.4, which is specified by the user in the pit's property sheet.

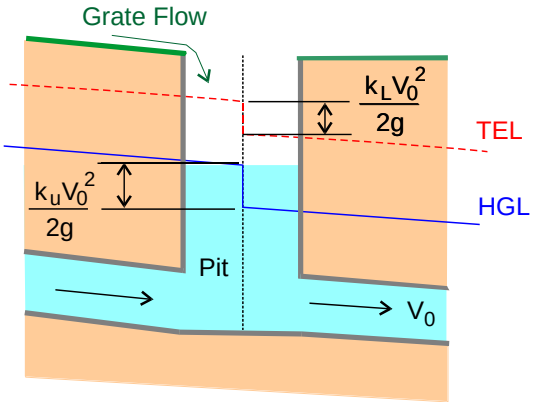


Figure 7.4 Pit Pressure Change Relationships

The change from part-full to full pipe flow often results in a large increase in the pit pressure change. This raises the HGL level and causes a rise of HGL that moves upwards through the system. A jump in pressure at a pit may actually be due to filling of another pit somewhere downstream. A similar drop in HGL and pressure may occur when a full-flowing pipe changes to part-full flow.

While pit pressure changes have been studied for full-pipe flows, there is little information available about pit pressure changes and energy losses in pits with part-full flow. Currently, DRAINS assumes that k_u coefficients are constant , and the same for both full- and part-full flows. This is likely to be conservative, overestimating changes for part-full flows. It also provides more stable results.

If a sag or on-grade pit is defined as being sealed using the check box labelled 'Pit has bolt down lid' in the Pit property sheet, the HGL can rise above the surface without any upwelling occurring. DRAINS calculates upwelling flows using hydraulic analyses. With the basic hydraulic model, no outlet restrictions are placed on upwelling flows unless the pit has a bolt-down lid. With the standard and premium hydraulic models, a hydraulic loss is assumed to occur when water upwells. This is based on the sag pit depth-inflow relationship for the pit type and size being used.

(e) Tailwater Levels

At system outlets, DRAINS sets a tailwater level, depending on the entries in the Outlet property sheet. If a free outfall is specified, it determines the higher of the normal and critical depths for the current flowrate. If a higher tailwater level is specified in the property sheet for the particular storm being analysed, this level becomes the starting point for an upwards projection in the obsolete basic hydraulic model and a boundary condition in the current unsteady models.

Where a drop pit is so deep that the pit water surface is below the invert of the upstream pipe, the starting level for upstream HGL projections will be set in the same way as for a free outlet. It will be the higher of the normal and critical depths in the upstream pipe. In effect, the calculations start again at this pit.

(f) Surface Overflows

Overflows follow the defined overland flow path to a destination, with flows being lagged by the specified time delay, which must be at least one calculation time step.

Although a slope and cross-section must be specified for flow paths, the standard hydraulic method calculations allow a flow to go from one pit or node to another at a higher surface level, despite warnings that are displayed by DRAINS. The premium model is stricter, and all overflow paths must have downwards slopes. In this model, overflow routes are modelled in the same way as open channels, and backwater effects can apply.

(g) Detention Basins

The calculations for detention basins in DRAINS can be complex because the elevation-discharge relationship will change if the downstream tailwater level submerges the outlet. This can happen at many time steps during a DRAINS run, so that the relationship changes. By contrast, ILSAX and most other models for trunk drainage systems assume that the relationship is fixed. Thus, DRAINS can model interconnected basins.

Flows through culverts and bridges are modelled using the same equations as outflows from detention basins, since they obstruct flows and can have low level outlets (the channel under the roadway) and high level outlets (overflows over the road). They do not have any associated storage. Where this may be significant, the situation can be modelled as a detention basin. DRAINS returns similar information in the Main Window for detention basins, culverts and bridges - the upstream and downstream water levels.

7.2.8 Calibration

This process of fitting a hydrological computer model to observed or recorded information is done by varying the model parameters. Some calibrations made using DRAINS and similar models are presented in Sections 8.3.3 and 8.3.5. In DRAINS, the main factors that can be varied are:

- the soil type, depression storages, and AMC,
- the proportions of paved, supplementary and grassed areas,
- the times of entry for paved, supplementary and grassed areas.

All of these relate to physical quantities that are easily understandable, so that values that are estimated, as is usually the case, will not be greatly wide of the mark.

Where rainfall and runoff data for storms is available, the hydrological modelling in DRAINS can be improved by calibration, though not to a large extent (O'Loughlin, Haig, Attwater and Clare, 1991). Times of entry and travel through a drainage system can be defined more accurately. Less accurate calibrations can also be carried out based on ponded volumes. If rainfall is available for a storm, DRAINS can estimate the stored volume at a location where depths have been observed. The volume from DRAINS can be compared with that corresponding to the maximum depth observed.

Calibration of drainage system hydraulics is usually performed by altering the roughnesses of conduits to match observed water levels. Observations may often be available for open channels, but are unlikely to be available for closed pipe systems, unless a special gauging programme is undertaken. If such information is available, it can be used to verify the DRAINS model, though it is likely to be difficult to refine the model because of the many pipe links that may be involved.

7.2.9 Interpretation of Results

Most DRAINS hydrographs and HGL plots are simple 'rise and fall' patterns, reflecting the simple design rainfall patterns that are commonly used. However, in complex or badly-implemented pipe systems, complex patterns such as the hydrograph shown in Figure 7.5 can occur.

A DRAINS plot may show frequent rises and falls at some times, giving rise to 'black ink'. The plot also shows a flow peak that has caved in, or reversed itself. This can occur when the HGL at the pit upstream of a pipe overflows, while the HGL at the pit at the downstream end is still below the ground surface. As flowrates increase, or tailwater levels rise higher, the HGL level in the downstream pit rises, flattening the HGL for the pipe and reducing the flowrate through it. This produces the 'hollowed out' effect.

The hydrograph in Figure 7.5 also displays negative flows, indicating that there has been a flow reversal. Flows can reverse in any DRAINS model if the HGL slope is negative, but this occurs rarely. In this case, a high HGL downstream causes flows to run backwards.

These can also be sudden 'spikes' and instabilities that occur at very low flows, due to waves that are numerically generated. Users should interpret plots with strange patterns to understand what is going on. Often this requires inspection of two or more flow and HGL plots together.

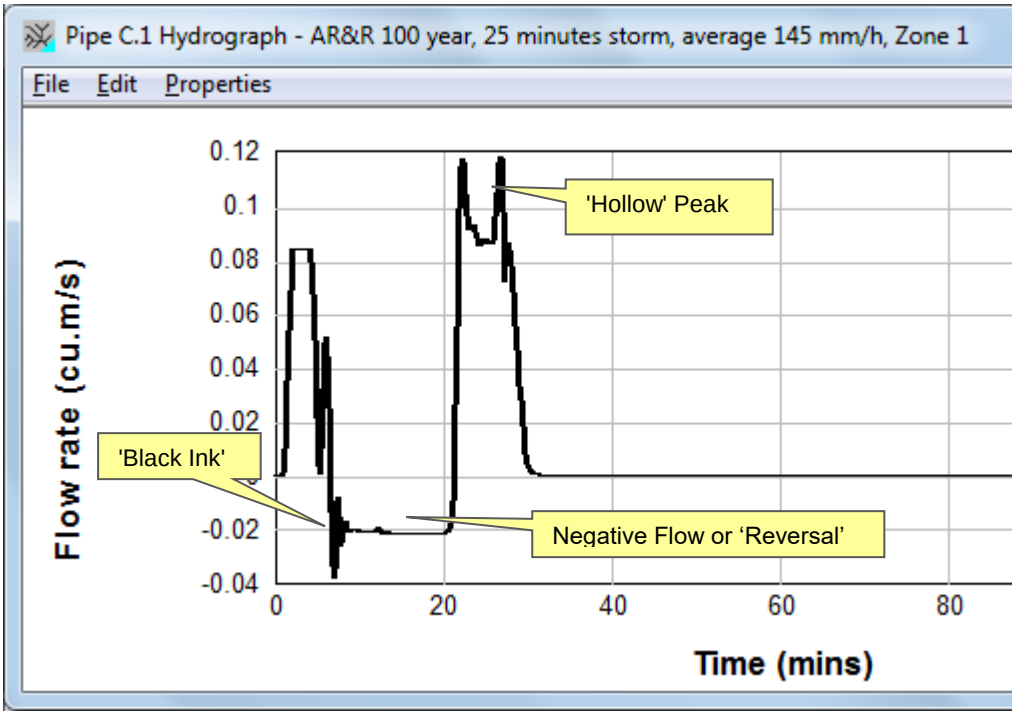


Figure 7.5 Complex Flow Hydrograph Old Format)

Due to the large volume of calculations needed with ARR 2016 rainfall ensembles, DRAINS now presents flows at 1 minute intervals, so that the detail of instabilities is not as apparent as it was in earlier versions. It might look something like **Figure 7.6**.

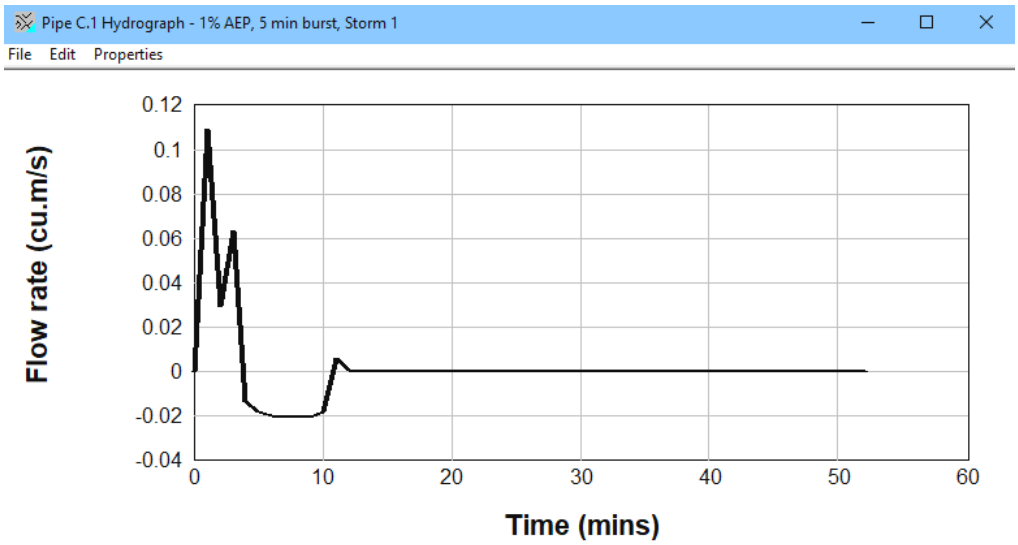


Figure 7.6 Complex Flow Hydrograph (New Format)

7.2.10 Design Procedures

The pipe design process in DRAINS makes a pass down the various branches of a drainage network from pits at the tops of lines to the main outlet. At each pit, it determines the maximum pipe outflow, allowing for inlet flows, flows in upstream pipes, and any baseflows or user-provided direct hydrograph flows. It then determines suitable pipe sizes and invert levels, taking account of:

- the roughness and the allowable cover depth associated with the chosen pipe type,
- the values set of minimum pipe slope, pit freeboard and fall in the **Options** property sheet opened from the **Project** menu,
- a restriction preventing pipes decreasing in diameter as the calculations move downstream,
- likely pit pressure changes at pits in full or part-full pipe flows, and
- the hydraulic capacities of pipes with various diameters and slopes.

In 2014, an enhanced design procedure has been introduced. Following a design by the original procedure, a review is carried out that reduces pipe sizes where possible. It provides a message saying how many pipes were able to be downsized. Pipes reduced by more than one size increment will only be counted as one pipe downsize.

It may still be possible to improve on a DRAINS design by manually downsizing pipes, although there is much less scope to do this than with the original design procedure. If you try to do this, some things to keep in mind are:

- You should not make any pipe smaller than the biggest pipe upstream (i.e. if you have a run of say, 1200 mm pipes, you could try to downsize the one furthest upstream. If you can't downsize this, you will not be able to downsize any pipes in the run.
- For major storms, you should use the same freeboard criterion as set in **Project** → **Options**. If you want to relax this criterion for major storms, you should also relax it in **Project** → **Options** prior to a design run in DRAINS.

The selection of invert levels is mainly based on allowable cover depths and slope restrictions. The aim is to keep the pipe as shallow as possible, and pipe sizes are increased where necessary to achieve this. (In cases where pipes need to be set deep enough to pass under other services, such as water supply pipes, increased cover depths can be defined in the **Project** → **Options** property sheet, effectively specifying a minimum pipe depth.)

Allowance is made for cover depths at intermediate levels along a pipeline, as defined in the Survey Data property sheet called from a Pipe property sheet (see Section 5.3.5). A result is shown graphically in Figure 7.7. This output also shows a pit with a significant drop, which might be a consequence of aiming to keep the pipe system as shallow as possible. If you wish to grade the upstream pipe down to the pit, it will be necessary to adjust the invert levels and run the model in Analysis mode, or make the pipe inverts fixed.

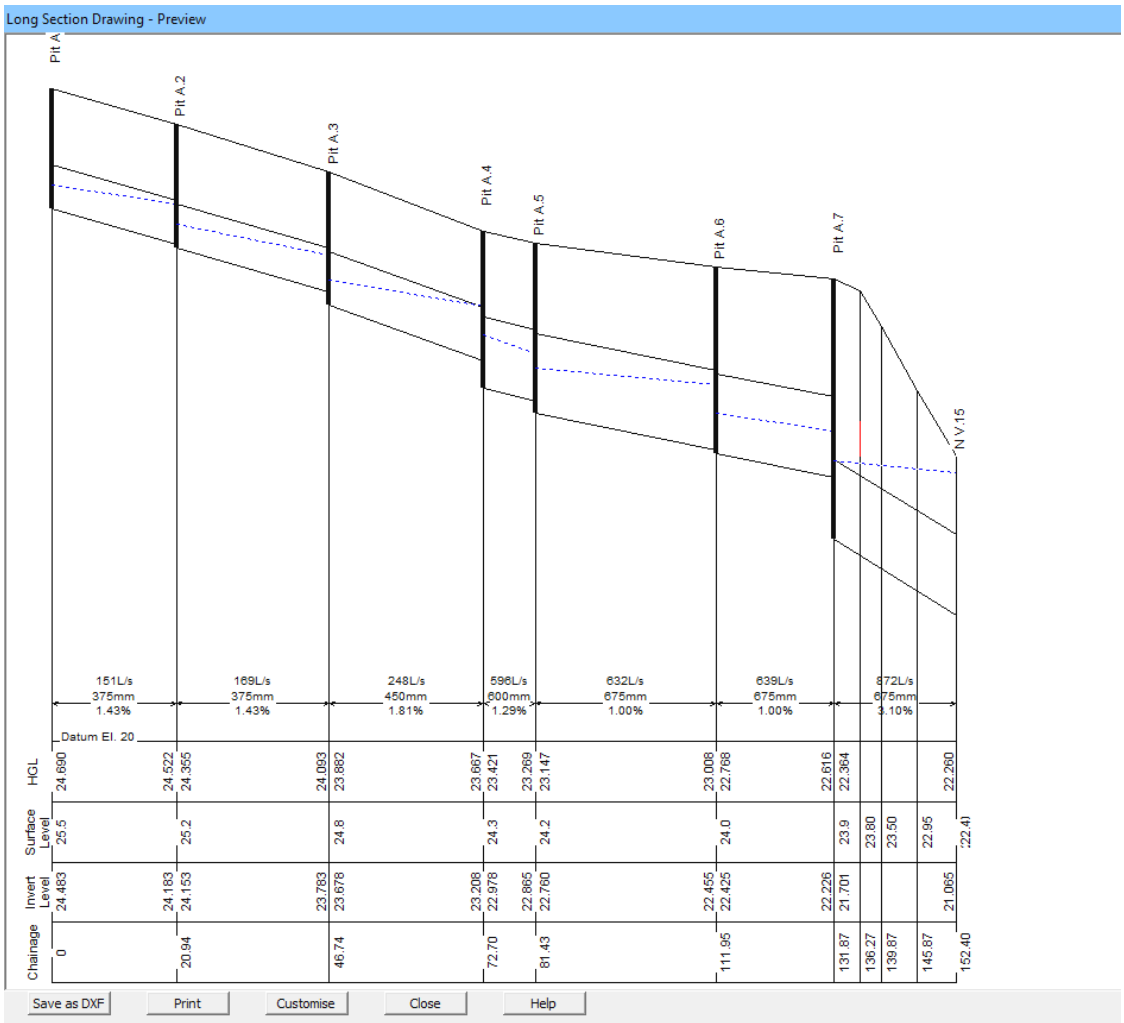


Figure 7.7 Display showing a Drop Pit and Intermediate Levels

DRAINS can automatically design to avoid fixed services, where possible, using service location information entered in the Survey Data property sheet and a minimum design clearance to services set in the **Options** property sheet called from the **Project** menu. One such service is shown in Figure 7.7 and also in Figure 7.8.

If a Design run is made with the positions of some of the pipes fixed, the results must be carefully checked, especially if these are located in the middle of lines. In some complex Design cases, pipes entering pits might be lower than a fixed pipe flowing out. The fallback in this case is to run in Analysis mode with pits and pipes made 'existing', and to vary pipe sizes and invert levels individually to achieve a satisfactory design.

Where multiple storm patterns are specified, the program repeats the downwards pass for each storm and selects the pipe diameters and invert levels that convey the most critical flows.

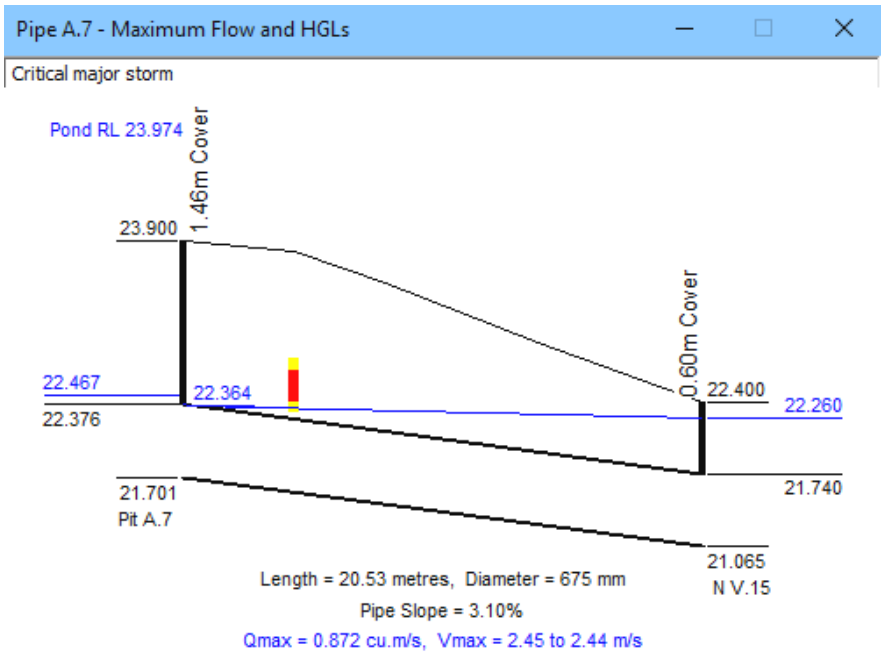


Figure 7.8 Long Section Display (from Pop-Up Menu for a Pipe

The design procedure also determines the sizes of inlet pits, using a method that was first presented in the *Queensland Urban Drainage Manual* (Neville Jones & Associates et al., 1992). The method focuses upon the flows along overflow routes. It sets appropriate safety levels for these, in terms of tolerable flow depths in the minor and major storms and a maximum velocity x depth product. A point along each flow path must be nominated, by specifying a cross-section from the Overflow Route data base as shown in Figure 7.9, a percentage of downstream catchment contributing to the flow, and a longitudinal slope. The basis for selecting the percentage of the downstream sub-catchment is explained in Section 5.3.7.

Having established safe flows for each flow path, the method then determines the pit and pipe sizes needed to restrict the surface overflows to the safe limits, considering both minor and major flows.

This process requires that pit types be classified into families and sizes, in a similar way to the classification of pipe types and diameters. With the user having defined the pit and pipe types required, DRAINS searches through the available sizes to determine the required ones at each overflow location. It also selects pipe sizes so that at a major storm level, such as the 100 year ARI storm event, HGL levels at pits are still below the ground surface. This ensures that the drainage system does not completely fill with water, and the pipe flows will be maintained even when stormwater ponds over pits.

In some cases, DRAINS cannot arrive at a solution that meets the safety requirements, most obviously when the flow from a sub-catchment is much larger than the capacity of any of the pits that can be selected. DRAINS returns the notice in Figure 7.10, advising that the pipe system must be changed or that different pits are required.

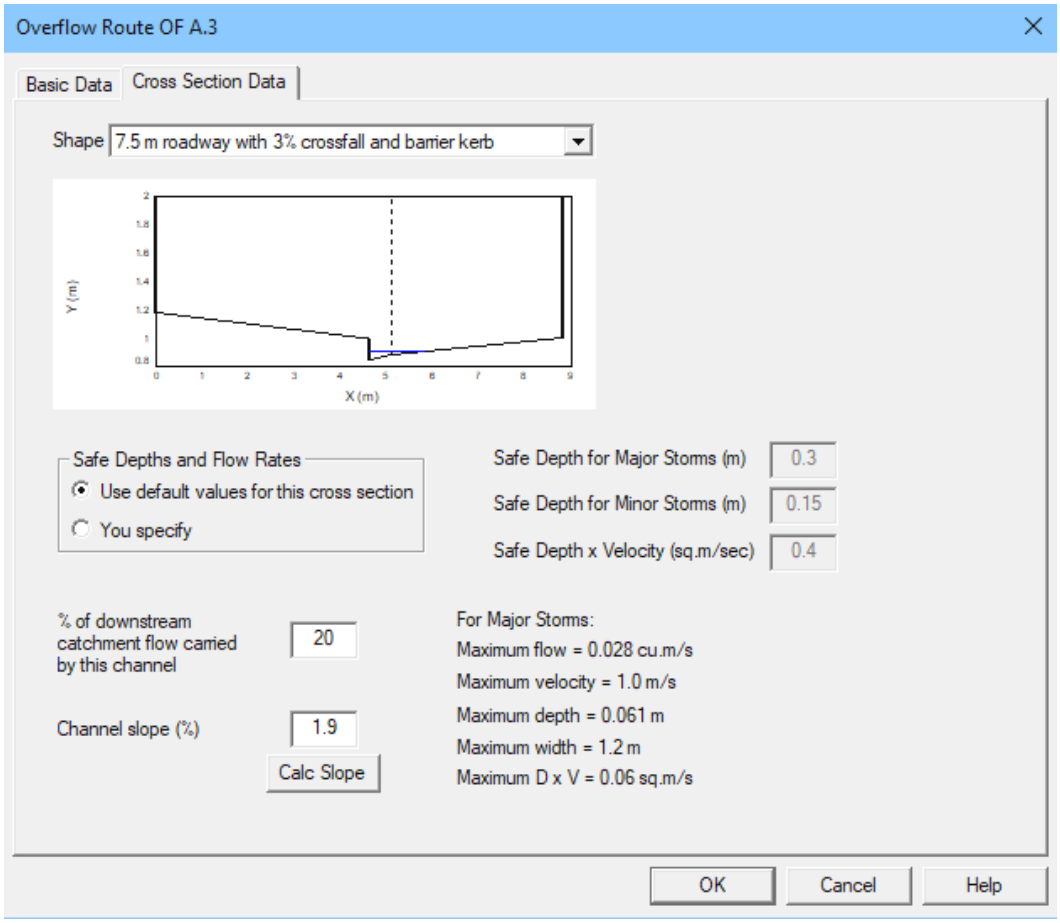


Figure 7.9 The Overflow Route Property Sheet (Standard Hydraulics Run Result)

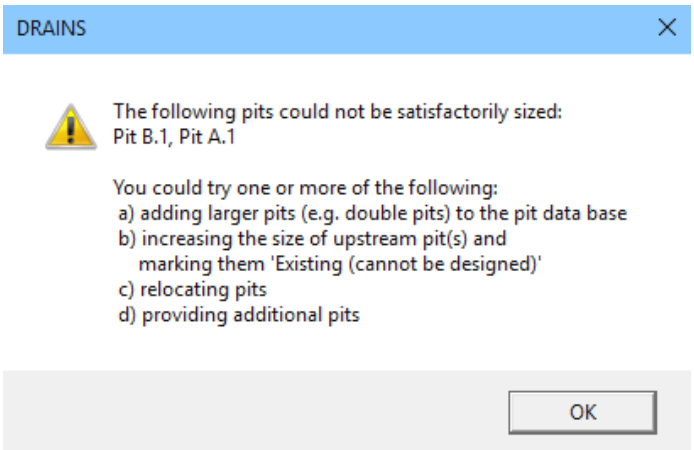


Figure 7.10 Warning of Failure to Define a Feasible Design

The results can be checked by Analysis runs to ensure that the design conditions are met. By taking full advantage of allowable surface flow capacities, the sizes and costs of pipe systems can be minimised.

7.3 Applying DRAINS

7.3.1 Integration

A key feature of DRAINS is integration. This occurs internally, with the data inputs, hydrology, hydraulics and presentation of results operating in the same package, and the ability to model different parts and scales of stormwater systems together. It also occurs externally, with the linkages to other programs shown in Figure 7.11.

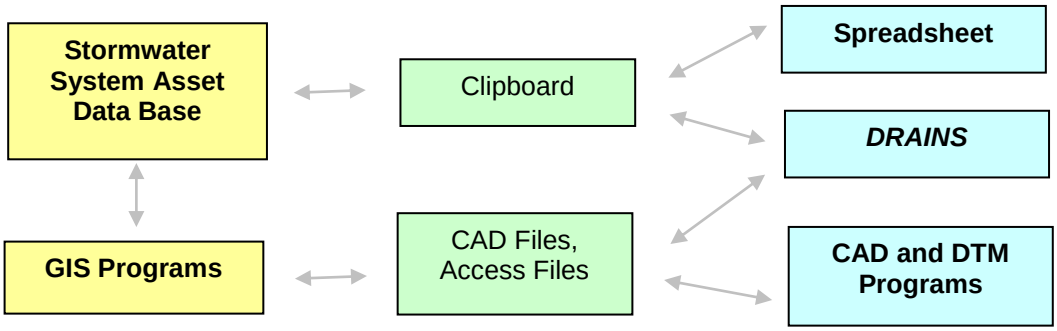


Figure 7.11 Integrated Linkages between DRAINS and Other Programs.

The general operation of DRAINS have been illustrated in Chapter 1. This section provides guidance on applications to specific types of stormwater drainage system.

7.3.2 Designing Subdivision Piped Drainage Systems

Design runs are mainly made for new systems on greenfields sites where the developer and designer have considerable scope to alter the system. The available information will be:

- a survey of the area showing contours to a standard datum such as AHD and a mapping grid such as MGA94, available on paper and electronically as a CAD file in a format such as DXF or DWG.
- the planned layout for roads, either on plans, or as a partly- or fully-completed road design model;
- cadastral (property boundary) data, available on plans and as drawing layers over which the contour drawing can be overlaid;
- the technical requirements of the consent authority for the project;
- local design rainfall data and other local information.

There is usually some give and take in design, so that the road and allotment layout can be altered to suit drainage requirements. However, the initial layout made by an experienced subdivision and road designer should anticipate potential conflicts.

The products or 'deliverables' of the design will be a drainage layer in the drawings with all drains and channels detailed, together with design calculations. Plans, specifications, tables of quantities and estimated costs can be derived from these.

The main aims in designing pipe networks with DRAINS are to develop a file that describes the proposed system, and to produce the deliverables - plans and documentation. The single `.drn` file can be run for both Design and checking by Analysis, and can quickly be re-run, with data and results being transferred to a spreadsheet or report. It forms the basis for the design variations and checks that may be required.

For a small system, data can be entered from the keyboard into property sheets, as described in Chapter 1. For larger systems, it is likely that information will be transferred from a CAD file, as described in Section 6.2.2, or from DTMs such as 12d and Advanced Road Design. Imported data can be augmented with data entered directly into the property sheets for components. The information for a component is retained when it is copied and pasted using the **Copy Shape** option in the pop-up menu for a component and the associated **Paste Shape** option. It is often easier to copy and paste an existing component and to modify its data, rather than to enter all data each time an object is created.

For large systems, the spreadsheet outputs and inputs described in Section 6.5.4 can provide an efficient means of entering repetitive data. Components can be entered with nominal values and can then be

edited in the Data spreadsheet, before transferring the information back to DRAINS. The process is shown diagrammatically in Figure 7.12.

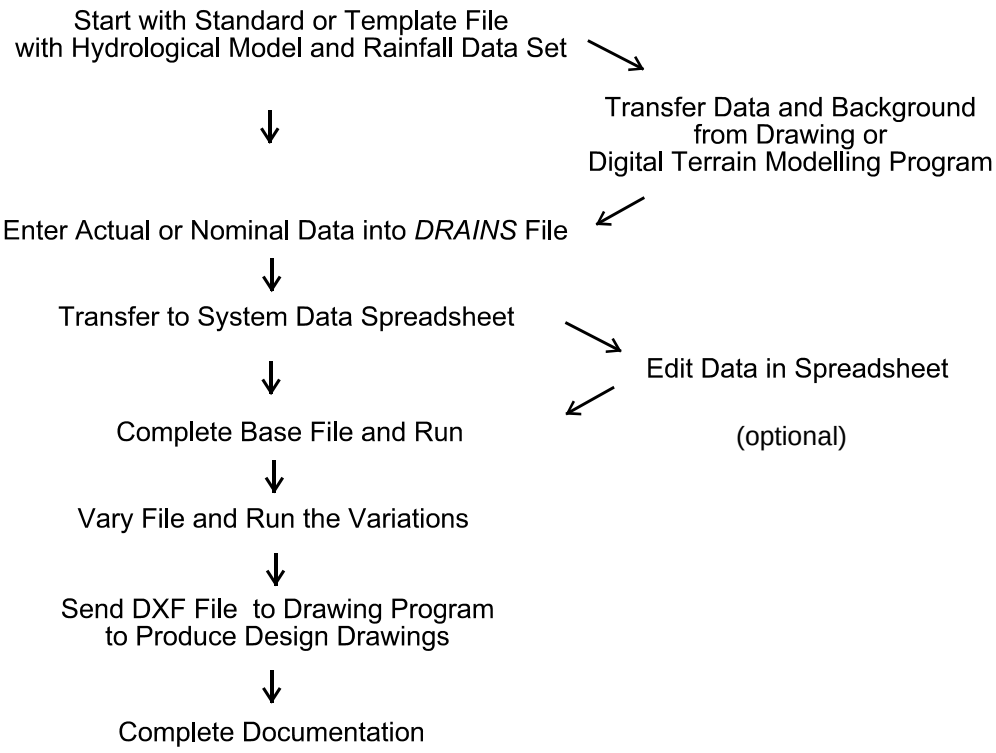


Figure 7.12 The Design Process

Using CAD and DTM programs, catchment areas can be defined as polygons and the areas directly measured. The lengths of flow paths, and in some models, their slopes, can also be determined. In some models, the automatic definition of impervious and pervious areas will be possible where suitable overlays are available.

For convenience in design, the parts of the system can be separated into small sub-systems. For example, where several branched pipe systems in steep terrain flow to a common open channel, the pipe systems can be analysed independently, as long as there are no backwater effects. In flat terrain with backwater influences the system must be designed as a whole. Individual systems can be joined using the merging procedures described in Section 0.

DRAINS produces information on pipe sizes, invert levels and locations that can be transferred to drawing programs to produce detailed plans and longitudinal sections. The spreadsheet tables act as documentation that can be printed or supplied in electronic form to a consent authority, together with the DRAINS data files. Diagrams of the network can be printed, say as a PDF file using the **File → Print Diagram** option.

Models and results can be checked by persons inside or outside the designer's organisation using the DRAINS Viewer, which is free. A reviewer can open all property sheets in a model and export data summaries in spreadsheet format. If a DRAINS file contains stored results, these can also be viewed and exported to spreadsheets. CAD outputs and system diagrams can also be exported, but other types of output are not available. It is not possible to edit or run files in the Viewer. Since reviewers have direct access to models, it should not be necessary to provide elaborate printed sets of results to reviewers. However, some converter spreadsheets have been developed to transfer results from ILSAX and rational method models to tables similar to those in *Australian Rainfall and Runoff* and the *Queensland Urban Drainage Manual*. These are available as downloads from www.watercom.com.au (see the last item on the downloads page).

Since DRAINS runs rapidly and its results are quite apparent, it is easy for consent authorities such as municipal councils to run files and inspect the results, or else to view these using the DRAINS Viewer. As discussed in Section 7.3.4, files prepared by consultants can be retained and incorporated into the authority's DRAINS model of its overall drainage system.

The results provided by an appropriate ILSAX hydrological model are likely to be superior to those obtained using the rational method, since allowance can be made for multiple storms and detention storages, and major system modelling is more accurate. The extended rational method gets overcomes most of these difficulties, as it produces hydrographs using a rational method loss model.

The pipe system design method employed in DRAINS is dependent on having good information on pit inlet capacity relationships. The best data is available from Queensland where overflows are larger than in southern states, and more attention has been given to controlling them. If good quality pit capacity data is unavailable, the Design method cannot be realistically employed.

The design method can be applied with the rational method and extended rational method as well as the ILSAX hydrological model. The design calculations for sizing pipes and determining invert levels are carried out using simplified assumptions, and need to be followed by one or more analysis runs.

DRAINS allows hydrological models to be swapped easily, so that it is not difficult to convert rational method models to ones using ILSAX hydrology. Only the hydrological model and rainfall data need to be changed, and the impervious areas for each sub-catchment to be split into paved and supplementary areas. The reverse change, from an ILSAX Model to the rational method, can be done even more easily. This might be done to compare the results given by the models, or to check an older design using rational method hydrology.

7.3.3 Designing Infill Developments with On-Site Stormwater Detention Systems

Design work for re-developments, and developments located within established urban areas, is more complex that greenfields design. There are many more constraints, such as:

- the presence of existing infrastructure such as water pipes and electricity cables,
- the need to connect into an existing drainage system, which may create problems due to low availability of head and limited downstream capacity,
- the presence of multiple land-owners,
- difficulties of construction due to limited space and conflicts with traffic and other activities in the area.

It is unlikely that designs of pipe systems can be carried out automatically, as in a new subdivision. Analysis capabilities are required when exploring solutions. Users will probably have to vary some features by hand to develop a trial and error solution. Fortunately, DRAINS can be easily edited and re-runs can be carried out rapidly.

While DRAINS allows users to mix pipes that have fixed inverts with pipes with positions that can be varied, it may not be able to develop with a suitable design in some cases. When dealing with a complex situation, a suitable strategy would be to see whether DRAINS can come up with a satisfactory design first, and then make modifications by hand to cope with problems such as conflicting services and the inability of a pipe system to match the inverts of the downstream pipe to which it must connect, while carrying the required design flows.

DRAINS can 'design around' existing services or utilities, and can allow for surface levels all the way along a pipe if suitable survey data is provided in the Pipe property sheet. However, the solution provided may set pipe inverts too deep, so that it will be necessary to make adjustments by hand. It may be necessary to use stronger pipe classes (with greater wall thicknesses), multiple pipes or box-section conduits to reduce the cover requirements. In complex cases, relocation of existing stormwater pipes or other services may be the best solution.

Because re-developments usually involve an increase in the density of development and the percentage of impervious area, several drainage authorities have imposed on-site stormwater detention (OSD) requirements. These have become an important and often complicated issue for designers. The Upper Parramatta River Catchment Trust has been the most influential developer of OSD design procedures in New South Wales, introducing requirements such as a permissible site discharge (PSD) in L/s/ha of catchment, and site storage requirement (SSR) in m^3/ha.

DRAINS models detention basins by simulation, presenting several relationships, such as storage vs. time, upstream and downstream water levels vs. time, and inflow and outflow hydrographs. It can also handle multiple outlets, infiltration into soils and pumped systems. The high early discharge (HED) system can also be modelled. Details are given in Section 5.3.8.

The detention basin routing has to be explored by trial and error, but the ability to edit the data quickly and re-run the model makes this a fast process.

7.3.4 Analysing Established Drainage Systems

Established systems may need to be examined for deficiencies at particular locations, such as problem areas, where complaints of flooding have been made by householders, or on an area-wide basis, taking in all drainage system components. This latter type of investigation may be prompted by asset management or liability concerns, rather than by particular experiences of flooding.

The processes in creating DRAINS files for Analysis are almost the same as for Design. However, all pits and pipes should be defined as 'existing'. Invert levels of all conduits must be defined.

The sources of the information required include:

- scaled plans showing road and cadastral layouts and contours,
- information on additions and remedial works for the drainage system,
- information on detention storage systems on sites or on public land,
- files detailing reports and complaints stemming from storm events and drainage system defects,
- any previous analysis studies relating to the area being considered,
- information on past storm events.

Since an existing system has to be modelled in some detail, it will be necessary to draw information from GIS and data base sources. If these are unavailable or inadequate, it will be necessary to carry out topographic surveys to determine the exact positions and levels of system components, including:

- surface levels of pits,
- invert levels of pipes, including if possible, those in sealed pits and junctions,
- lengths of pipes,
- floor levels of houses and businesses, and driveway levels where flows may enter properties and yard levels where ponding may occur.

Techniques such as GPS measurements and LiDAR aerial laser scanning, supplemented by conventional surveying, can be used to obtain large amounts of levels efficiently.

Inspections are needed to define many aspects of drainage systems, such as low points on roadways and likely overflow paths. It is likely that the same areas may have to be inspected two or three times during modelling to define drainage components and paths exactly. Information can also be sought from residents about their experiences of flooding during these visits. Closed circuit television (CCTV) investigations can provide detailed information on pipes and defects such as erosion, cracks and faulty joints.

If resources are available, the drainage system may be gauged to record storms rainfalls and corresponding drainage system flows that can be used to calibrate models. Rainfalls are usually recorded by tipping-bucket rain gauges and pipe and channel flows by magnetic or laser-Doppler flow meters. Gauging for a period of at least 3 months will probably be necessary. When the model is run with recorded data, the times of flow can be varied by altering values in the spreadsheet output and re-inserting these into DRAINS. The DRAINS model can be calibrated or 'tuned' so that the times of the calculated hydrograph peaks match those of the recorded ones. A similar process can be carried out by varying the Hydrological Model parameters and percentages of land use, to make the calculated flow peaks or volumes match the recorded ones. This is more difficult because pervious areas may only contribute flows in larger storms, and the gauging period may be too short or dry to record significant runoff-producing storms.

From the available mapping and the survey data, DXF or DWG drawings can be prepared, and a suitable file prepared with the three layers containing pits (as circles), pipes and a background. DXF files then can be imported into DRAINS to provide the initial file for the data entry and modelling processes.

As in Design, it will be necessary to develop a set of guidelines on matters such as:

- the definition and modelling of flow paths,

- the factors used in pit inlet capacity relationships for the various kinds of pits encountered in the drainage system,
- pit blockage factors,
- existing pipe roughnesses and shapes, and
- the modelling of ponding of stormwater in streets and backyards.

In modelling existing systems, a difficult issue will be the definition of the flow paths taken by flows from paved and grassed surfaces, as shown in Figure 7.13. These will be greatly influenced by the size and arrangement of allotments and the buildings on them, and especially by the style of fencing along allotment boundaries.

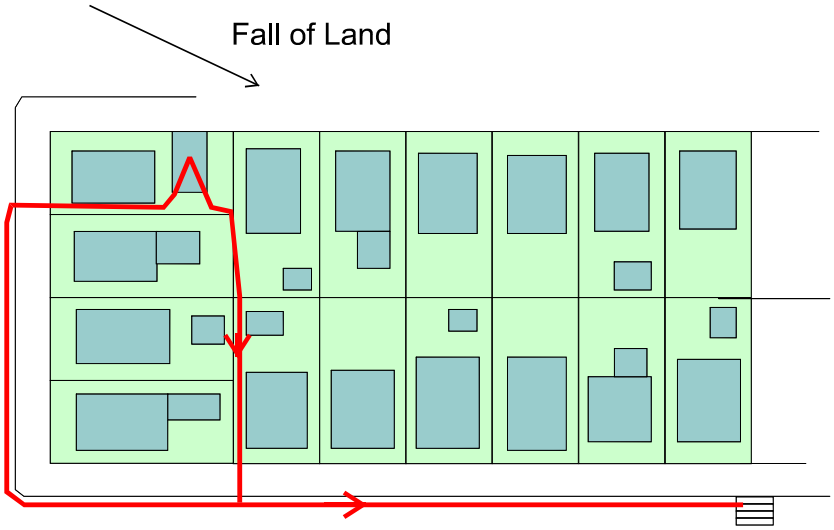


Figure 7.13 Flow Paths to a Pit

If there was no fencing, or if flows could easily pass under fences, the flows would follow the land contours and the definition of paths and overland flow lengths, slopes and roughnesses would be relatively easy. Once flows have to pass through fences, or be directed along them, the situation becomes quite complex, with some storage effects probably coming into play. Even in a detailed analysis with abundant scope for survey data collection, it would be prohibitively expensive and complex to model each property's drainage system and to include possible storages. Some judgements about overall or average effects must therefore be made. Calibration with gauged data would be particularly useful for refining these judgements.

Another difficult issue will be the ponding of stormwater on streets and in backyards. This occurs where development has occurred in the natural floodway areas, and various barriers to flow have been erected, including road crowns, road embankments, walls and fences. It is fairly easy to see where stormwater will run into properties. Usually those on the downstream side of a road at a low point will be affected, as shown in Figure 7.14.

Storages on streets might be modelled as detention basins with a height-storage relationship and a low-level outlet to the pipe system. Their high level outlet or outlets can be modelled as one or more weirs, usually located a driveways into properties.

Storages within allotments can be very complicated, with flows being blocked by gates and fences, so that several instances of ponding may occur on the one property. Some situations can be modelled readily, such as flow under a fence represented as a sluice gate, or flow over a low wall as a weir flow. However, in many Australian situations, the barrier may be a metal Colorbond fence extending to the ground. Such fences can probably hold back stormwater to a depth of 1 m or more. When failure occurs, there may be catastrophic effects from the resulting rush of water and debris. Modelling such events is difficult. Our knowledge of how they are initiated is poor, and DRAINS does not model 'dambreaks' of this type.

Existing systems that have been augmented can have two pipes with different characteristics running more or less parallel. These might be modelled as multi-channels if there are no significant inflows along one of these that will change the distribution of flows. If this is the case, they can still be modelled as two outlet pipes from a pit. DRAINS can model these using its full-pipe and open channel network calculation procedures.

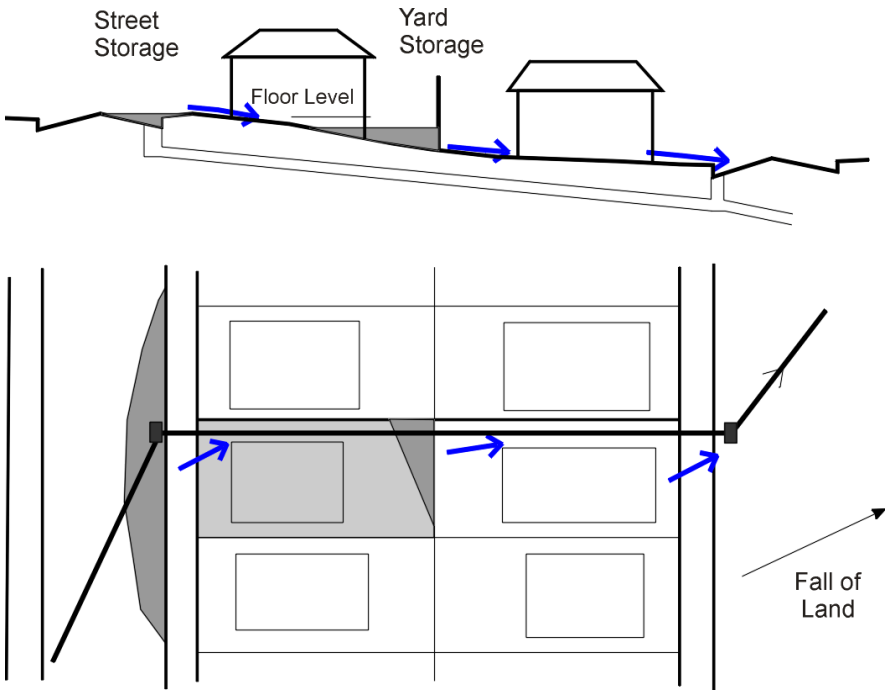


Figure 7.14 Ponding Storages on Streets and in Allotments

The spreadsheet documentation provided by DRAINS is very useful for recording results, which can be separated into worksheets and suitably tagged.

When analysing very large systems (say 500 pipes and over) computation times can be quite long with multiple storms. It is therefore necessary to plan the analysis work, starting with storm events likely produce the highest flowrates. Once the system has been refined, final runs can be made with a wider range of rainfall patterns of different average recurrence intervals and durations.
Once a working model has been established, the likely flowrates, heights of storages, flooding impacts and resulting damages can be assessed. Flooding trouble spots can be identified, and remedial works can be considered. The initial DRAINS model can then be varied to produce a number of models for assessing different remedies. In some cases, the remedies will interact with each other, some reinforcing the beneficial effects of other remedies, others diminishing these. This makes the consideration of options quite complex.

The rational method analysis procedure should not be used to simulate the behaviour of existing systems, since the various flow peaks calculated can occur at different times, and the flowrates obtained from combining peak flows are approximate. This procedure should only be used to check newly-designed systems. The extended rational method can be used as a valid analysis procedure, but the ILSAX hydrology is a more accurate and proved hydrological procedure.

Analyses should be carried out using the unsteady standard and premium hydraulic model calculations. These are superior to the basic hydraulic model in the following respects:

- They are more soundly based on theory, including all the terms of the St. Venant equations of mass and momentum conservation (see Section 8.6.4), so that they can model sub- and supercritical flows in pipes, channels, and with the premium hydraulic model, overflow routes
- They are more stable, and will give more accurate results for pipe and open channel flows.
- The premium model permits modelling of overflows and other configurations that are not possible in the basic model. (For example, it is possible to model two or more outflows from a sag or on-grade pit, or a node. Situations such as flows spilling from a street gutter or channel into a driveway or across a road centreline can be modelled in this way.)
- The premium model can model situations where on-grade pits are submerged by water ponding over adjacent sag pits, with the on-grade pit operating as a sag pit while it is submerged.
- The premium model provides greater allowance for storage in surface flow systems, such as ponded water over sag pits and surface flows between these, leading to generally lower flowrates.

With the availability of multi core processing, running times for the standard and premium models are faster than those for calculations with the older basic model. The basic model should only be used for checking older models, using the methods that applied when such models were developed.

7.3.5 Asset Management

Once developed and used to prepare construction plans and specifications, DRAINS models should be retained by the authority that maintains the system. Besides being a record of the system, with its own readily-accessible database, the DRAINS model is a working model of the system, which can be altered to reflect any changes. It can form part of the authority's asset management system, especially when it is integrated with drainage system data base and a geographic information system (GIS).

When the drainage system is constructed, it is likely that some details will have been changed during construction. The model should be updated to reflect the work-as-executed information. It will then require further modification as, whenever:

- additional drainage systems are connected,
- rezonings and re-developments create more impervious areas and increase runoff volumes and rates,
- possible flow diversions occur within the catchment, and between it and other catchments,
- compensatory detention storages are provided,
- additional information and experience about the drainage system accumulates,
- design rainfalls are revised, and climatic change effects occur,
- the system deteriorates and defects due to damage and ageing of assets become apparent,
- remedial works are constructed, and
- design standards change.

DRAINS can be easily updated to reflect all these changes. Periodic reviews can be made using the DRAINS model, which becomes a permanent feature of the drainage authority's asset management system.

Many municipalities and stormwater authorities do not have full information on their systems. Nevertheless, they can start with this incomplete data, setting up data bases and models with the available information, and then refining these. Experience during storm events special surveys to determine pit and pipe invert levels, CCTV inspections, preparation of lists of trouble spots and asset registers will provide added information, so the records can be gradually expanded and the modelling improved. As shown in Figure 7.15, DRAINS provides transfers to GIS programs in the form of ArcView shapefiles and MapInfo MID/MIF files. The connection of DRAINS to the GISs of drainage authorities allows the results of DRAINS analyses to be included in the GIS. These can include flowrates and hydraulic grade line levels for average recurrence intervals of 1, 2, 5, 10, 20, 50 and 100 years, plus probable maximum precipitation (PMP) storms - see Bureau of Meteorology (2003). These results can be mapped and displayed in many ways, using colour-coded symbols and lines. The GIS can also act as a means of querying the underlying database, so that flows or HGL levels at particular locations can be checked on-screen.

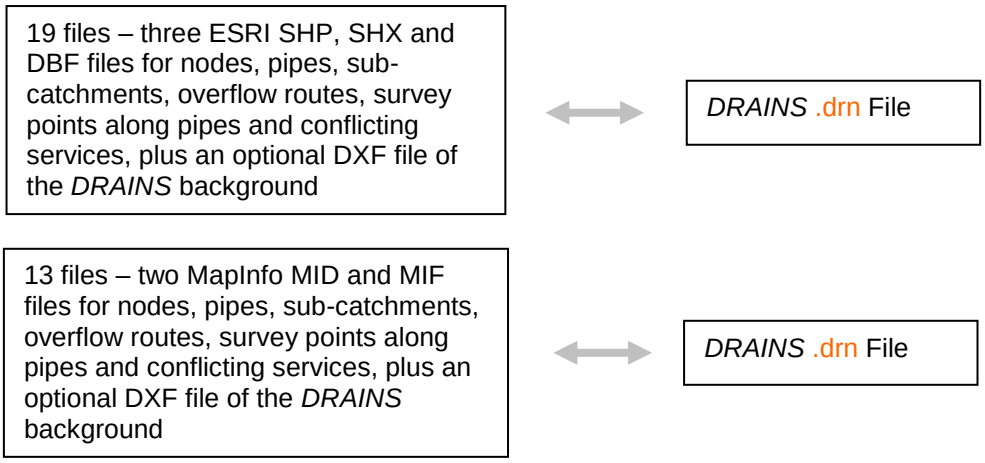


Figure 7.15 Transfers of Data Between DRAINS **and GIS Programs**

DRAINS does not export overflow routes as polylines, but as lines connecting the first and last points of the overflow route polyline. To display complex routes such as those passing through properties, it is recommended that these be represented by two or more segments joined at nodes.

Ultimately, drainage system managers can develop systems where revised DRAINS models can be created from information on previous DRAINS models in their GIS. As new developments and re-developments occur, it will be possible to include these. Results from various models can be retained in the GIS system. The combination of DRAINS with GIS allows managers to maintain and ongoing record of their drainage systems that included records of performance and flooding risk.

7.3.6 Performing Flood Studies with Storage Routing Models

The catchment must be defined on a contour map and sub-catchments defined using the stream pattern and the internal ridge lines as shown in Figure 7.16. The CatchmentSIM software (Ryan, 2005) can do this if suitable topographic information is available. Sub-catchment areas, channel reach lengths and other characteristics are then measured. The number of sub-areas should reflect the detail of the information required and the important features of the catchment, such as reservoirs and changes in the type of channel.

Streamflows and other data suitable for calibration of the model are then assembled. Ideally, there should be at least three recorded flood events. Loss parameters and initial values of the parameters (k_c in RORB, BX in RAFTS and C in WBNM) are established.

The program is then run and the outflows are compared with the calibration data, or rural catchment flood estimates developed by methods in Chapter 5 of *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987). The parameters are then adjusted and the final calibration flowrates determined. If more than one storm event is available for calibration, it may require different parameters to obtain exact matches to recorded peak flows. A compromise set of parameters must then be selected.

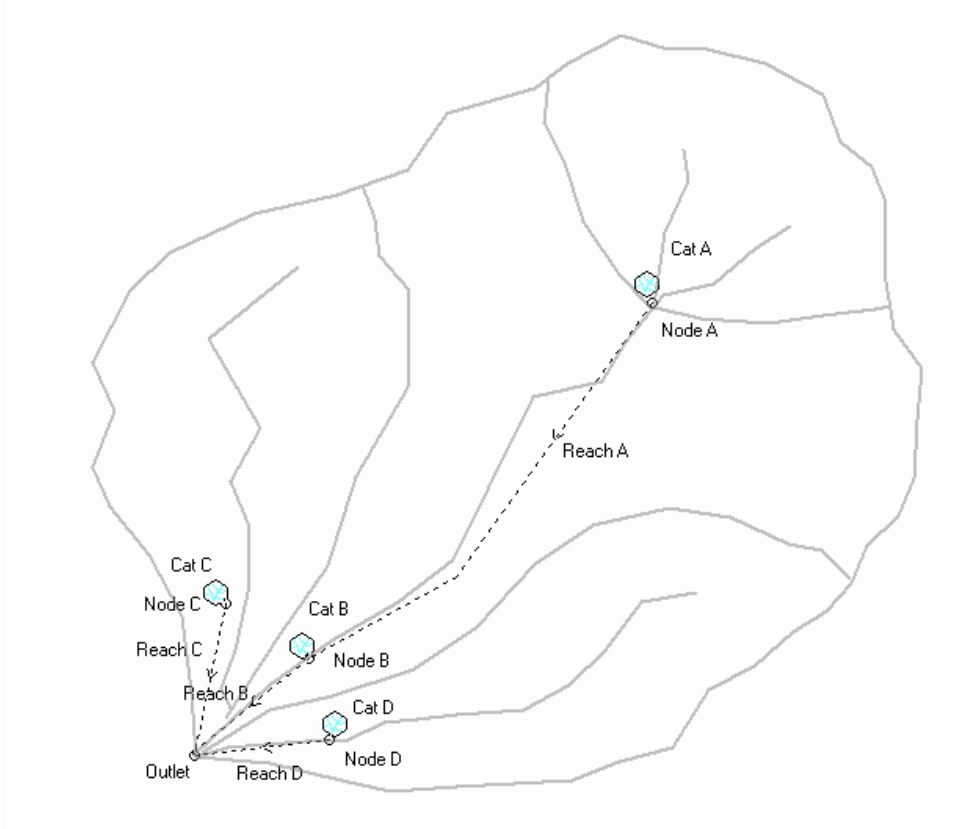


Figure 7.16 Layout of a RAFTS Storage Routing Model

With the parameters established, the model can be used to estimate the flows from large floods such as a 100 year ARI flood. The effects of detention basins and stream break-outs or diversions can be assessed.

If you wish to combine the storage routing model results with the open channel hydraulic calculations available in DRAINS and/or an ILSAX model, this can be done to obtain more detailed results. The open

channel and ILSAX models can be set up in the usual way. This integration of models should be useful in situations where there is interaction between a large watershed and a smaller urban catchment.

7.3.7 Methods and Parameters Applied in DRAINS

Usually, designers must follow guidelines established by drainage consent authorities, such as local councils or state road authorities, supplemented by authoritative guides such as *Australian Rainfall and Runoff*, the *Queensland Urban Drainage Manual* or *AS/NZS 3500.3*. Nevertheless, there will be many situations that are not covered completely in these sources. It is the responsibility of the designer to choose how these situations are to be modelled and what parameters are to be applied.

DRAINS is a flexible tool that can be used with many different procedures and parameters, and it is inappropriate for this manual to recommend specific methods or values, or to specify how DRAINS should be applied in specific situations. There is a discussion of alternative hydrological models in Appendix A.

7.3.8 Choice of Model

DRAINS offers a choice of hydrological and hydraulic models. Some are available to all purchasers, while others can be purchased as optional add-ons. The choice of hydrological model will depend on the task to be undertaken with the model, and by the likelihood of acceptance of the model by approval authorities or assessors. Comparisons of alternative models are presented in the guidance on the DRAINS Viewer that is included in Appendix A.

All hydrological models except the rational model produce hydrographs, which are necessary for modelling detention storages and complex networks. The ILSAX and storage routing models (RORB, RAFTS and WBNM) are backed by testing programs in which their performance has been tested against gauged rainfall and runoff data. The rational method models have not been extensively tested, but have been the most commonly-used models in many applications. Some authorities consider them to be acceptable benchmarks. The extended rational model included in DRAINS is an extension of the rational method.

The storage routing models are the accepted methods of modelling broad-scale urban catchments and can cope with the hydrological effects of urbanisation. The various models produce different flow estimates due to (a) use of different rainfall data, notable I-F-D statistical relationships and Australian *Rainfall and Runoff* patterns, (b) models being derived for different purposes, scales of operation (pipe system sub-catchments compared to larger broad-area sub-catchments), and calibration to different data sets, and (c) modelling choices by users. (Some models allow users much more scope than others.)

For routine applications such as OSD calculations, designers probably should choose models accepted by approval authorities, while for more complex or critical applications, the more scientifically-proven and calibrated models will be the ones that can best model situations and be most easily justified.

The basic hydraulic model that was used from the first release of DRAINS has been replaced by the standard and premium hydraulic models, which are based on different principles and are more rigorous and stable. Because both of these models allow for volumetric effects in stored and flowing runoff, they calculate lower flowrates than the old basic hydraulic model, with the premium model usually giving the lowest flowrates and HGL levels.

8. TECHNICAL REFERENCE

8.1 Introduction

This chapter sets out the background and the technical basis for the procedures used in DRAINS. Some features, such as the ILSAX hydrological model, were inherited from other programs while others were developed specially for DRAINS.

8.2 Predecessors

DRAINS is the result of a chain of development that originated with the U.K. Transport and Road Research Laboratory (TRRL) Method in the early 1960s:

TRRL Method (UK, 1962)
⇓
ILLUDAS (US, 1974)
⇓
ILLUDAS-SA (South Africa, 1981)
⇓
ILSAX (Australia, 1986)
⇓
PIPES++ ⇒ DRAINS (Australia, 1998)

Figure 8.1 The Initial Development Path of DRAINS

The TRRL method was developed by Watkins (1962) following extensive studies in which storm rainfalls and runoff were recorded for several years on twelve catchments. Flow estimates from the rational method and other hydrological models were compared with the recorded data. A design procedure using the time-area method (Ross, 1921) applied to impervious areas was developed from this research (UK Transport and Road Research Laboratory, 1976). A simple procedure was applied to route flows through pipe systems. This was released as a FORTRAN program in 1963, replacing the rational method.

The Illinois Urban Drainage Area Simulator, ILLUDAS, was developed and extensively tested by Terstriep and Stall (1974), who adapted the TRRL Method to cope with pervious area runoff and added other features. Tests involving gauged data from 21 catchments were made. Although ILLUDAS was popular among researchers, it has not been widely used by designers in North America. For most design tasks, ILLUDAS and SWMM (Stormwater Management Model) have been overshadowed by U.S. Soil Conservation Service programs TR20 and TR55 and other, relatively-simple methods.

After testing ILLUDAS on two South African gauged catchments, Watson (1981) produced a version named ILLUDAS-SA, with many additional features. This was the basis for the ILSAX program. In Australia, ILLUDAS-SA and various development versions of ILSAX were applied to data from gauged urban catchments in Sydney and Melbourne by Cartwright (1983), Mein and O'Loughlin (1985), Vale, Attwater and O'Loughlin (1986), and others. The first practical application was in a large-scale drainage study of Keswick and Brownhill Creeks in suburban Adelaide in 1982-83.

ILSAX was developed by Geoffrey O'Loughlin between 1982 and 1986, with the aim of producing a better hydrological method for stormwater drainage design. This development occurred alongside the preparation of the chapter on urban stormwater drainage in *Australian Rainfall and Runoff*, 1987. ILLUDAS-SA was adapted to model overflows from pits, so that it could model major storm flows in the major/minor design system recommended in *Australian Rainfall and Runoff*. ILSAX started to be used widely in 1986, when it was released in a public domain version for IBM PCs. Its flexibility, low cost and robustness made it acceptable, despite its limited hydraulic calculation method. Early testing with gauged catchment data showed that the hydrological model was at least as accurate as alternative urban hydrology models. In the 1990s, it was commonly used for analysis of on-site stormwater detention systems. It has now been superseded by DRAINS and is no longer supported.

PIPES and PIPES++ are hydraulic network analysis programs developed by Bob Stack in the 1990s for design and analysis of piped water supply systems. They model full pipe flows using steady flow equations, and their graphical user interface became the basis for the interface in DRAINS.

8.2.1 DRAINS

DRAINS grew out of attempts by Geoffrey O'Loughlin to provide a successor program to ILSAX. A joint venture with Bob Stack of Watercom Pty Ltd yielded a program that combines an effective user interface from Watercom's PIPES programs with the ILSAX model and a much-improved pipe and channel hydraulics system. Development took place from 1994 to 1997, and has continued to the present time, with important developments being shown in Table 8.1.

Table 8.1 Significant Developments in the Capabilities of DRAINS

Date	Development
1993-1997	Development of DRAINS from ILSAX and PIPES with HGL projection procedures for pipes and open channels
January 1998	Commercial release of DRAINS
Early 1998	Addition of pressurised models to allow for sealed pits
1999	Addition of spreadsheet input-output; Introduction of rational method procedures.
2001	Introduction of the Advanced Design Method (with new pipe, pit and overflow route data bases)
2002	Introduction of storage routing models emulating procedures in the RORB, RAFTS and WBNM programs
Early 2003	Allowance for looped pipe systems
Mid 2003	Introduction of transfers to and from GIS programs
Late 2004	Addition of the extended rational method
Mid 2005	Addition of HEC22 procedures for calculating pit inlet capacities
March 2006	Introduction of fully dynamic (unsteady) calculations for pipes, open channels and overflow routes
2007	Use of DRAINS Utility Spreadsheet to prepare input data externally.
February 2008	Introduction of Queensland Urban Drainage Manual (QUDM) procedures for automatically determining pit pressure change coefficients.
March 2009	Release of the free DRAINS Viewer
December 2010	Replacement of the basic hydraulic model by the standard and premium models. Parallel processing introduced to greatly reduce run times.
2012	Multiple rainfall pattern entry, New orifice and weir components
2012-14	Enhancements to unsteady flow calculations, improving speed and stability.
2014	Enhanced pipe system design procedure.
August 2015	Color-coding of components.
January 2017	Introduction of ARR 2016 procedures – I-F-D data, temporal pattern ensembles and median design procedures; 64-bit calculations.
June 2018	Introduction of flow path flood mapping.

The rational method, the extended rational method and storage routing models have been added to the original ILSAX hydrological model. The basic hydraulic model, which underwent considerable development between 1989 and 2010, has now been replaced by unsteady flow models.

8.3 Hydrology

8.3.1 General

Simulation models such DRAINS require a model to transform rainfall patterns to runoff hydrographs in the part of the hydrological cycle shown in Figure 8.2.

Urban stormwater drainage design can be carried out by three categories of models:

(a) simple models that produce a peak flow estimate only (such as the rational method),

(b) hydrograph-producing models (such as the time-area model in ILSAX) applied to storm events, and

(c) more complex models, capable of continuous simulation of hydrographs (such as the Stormwater Management Model, SWMM).

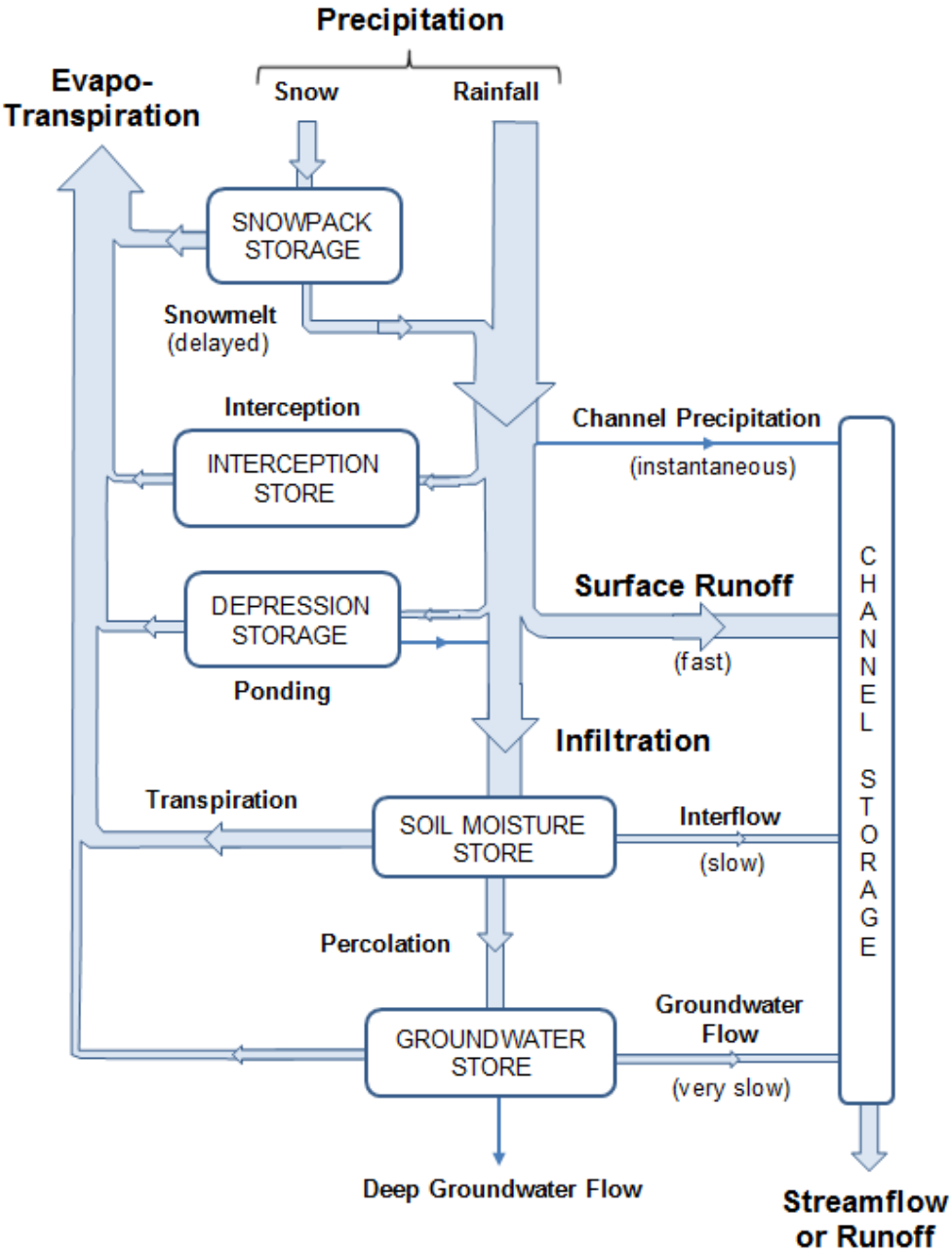


Figure 8.2 The Rainfall-Runoff Process

Models can be split into loss models and routing models, as shown in Figure 8.3. Loss models represent hydrological processes such as interception, depression storage, evaporation and infiltration, which prevent water from running off catchments immediately. The most common types are: (a) initial loss – continuing loss models, and (b) infiltration models using procedures such as Horton's equation.

Routing models allow for the distribution of rainfall across a catchment surface, with some rainfall inputs being closer to the outlet than others, and so spreading out the pattern of flow or hydrograph at the outlet. They also account for storage effects on the catchment. The main types are (a) time-area routing, (b) unit hydrographs, (c) routing through artificial storages, (d) kinematic wave routing, and (e) unsteady flow hydraulic modelling across catchment surfaces.

The ILSAX hydrological model in DRAINS is a medium-level rainfall-runoff model that combines a Horton loss model with time-area routing. The rational method only calculates peak flowrates. The ERM applies a loss model based on the rational method with time-area routing. These models are adaptable to many situations, but do not perform continuous simulation. The storage routing models that emulate the RORB, RAFTS and WBNM models commonly used in Australia are also 'event models', designed to produce hydrographs for flood estimation, but not capable of modelling long periods of runoff under wet and dry conditions.

8.3.2 The ILSAX Hydrological Model

(a) General Description

This model relates to an urban or semi-urban catchment, subdivided into sub-catchments linked to a drainage system of pipe and channel sections as shown in Figure 8.4. Sub-catchments are divided into three surface types - paved, supplementary and grassed. Runoff hydrographs generated from inputted rainfall patterns are used to model system behaviour and to perform design tasks. The model works to a fixed time scale, beginning at the start of a storm, performing calculations at specified time steps.

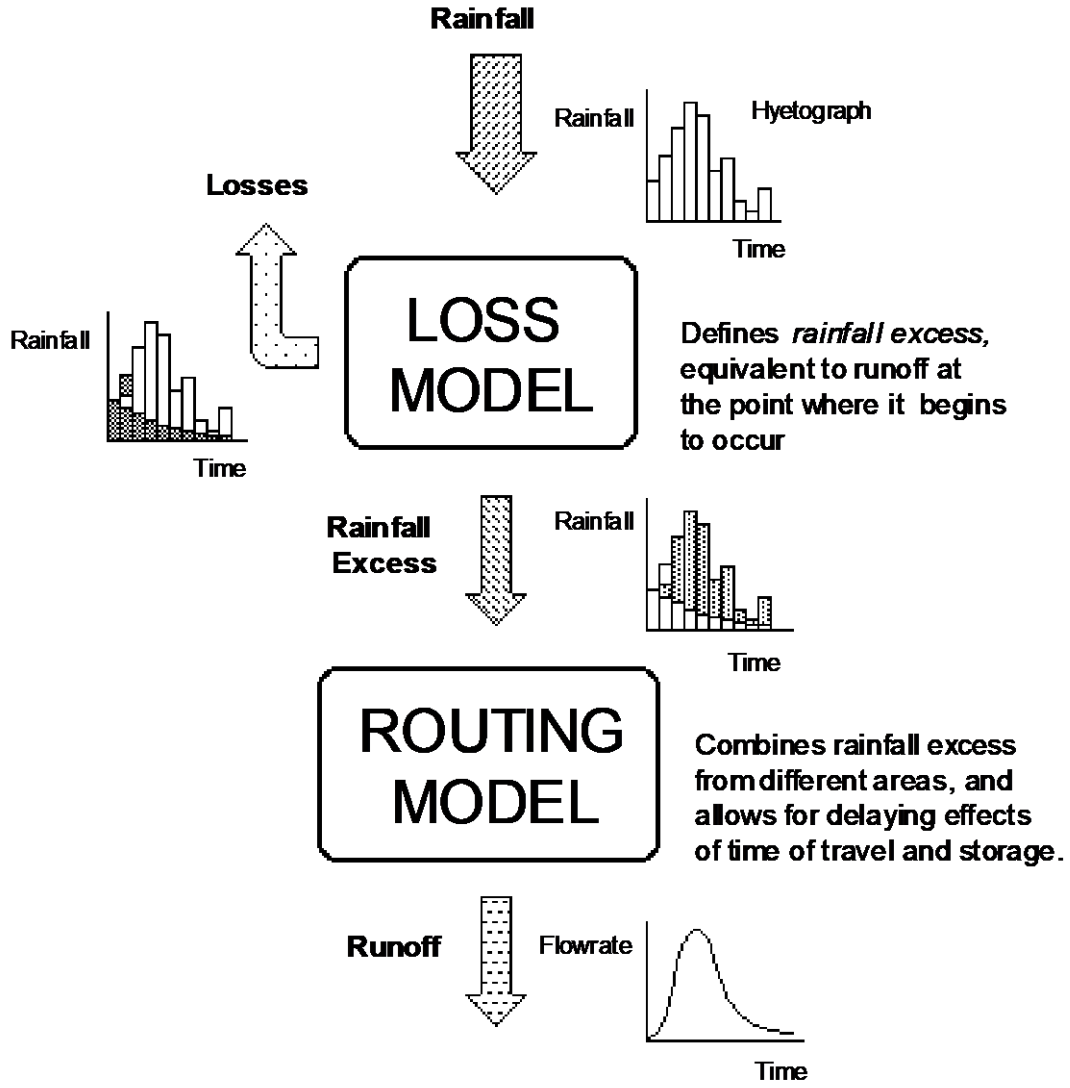


Figure 8.3 Loss and Routing Models

Since this is an event model, conditions at the start of each storm event must be established by defining a value of the antecedent moisture condition, AMC, for the soil underlying the pervious portions of the catchment. The loss model subtracts depression storages from all surfaces and calculates additional losses for grassed or pervious areas using Horton's infiltration model. The soil type and AMC parameters are easily understandable and can be related to identifiable soils and rainfall depths preceding a storm. Results are quite sensitive to the AMC and users must consider the effects of their choices using sensitivity studies. Despite this, few problems with employing this model have been reported.

The model relies on times of travel as the main parameters used in routing. These can be determined to an acceptable level of accuracy for urban catchments, but are very variable for rural catchments. Thus, while the ILSAX model can be applied to pervious sub-catchments of a drainage system, it is not strictly applicable to rural catchments. This reflects the lack of suitable studies to calibrate the model in rural conditions, rather than any defect in the model itself.

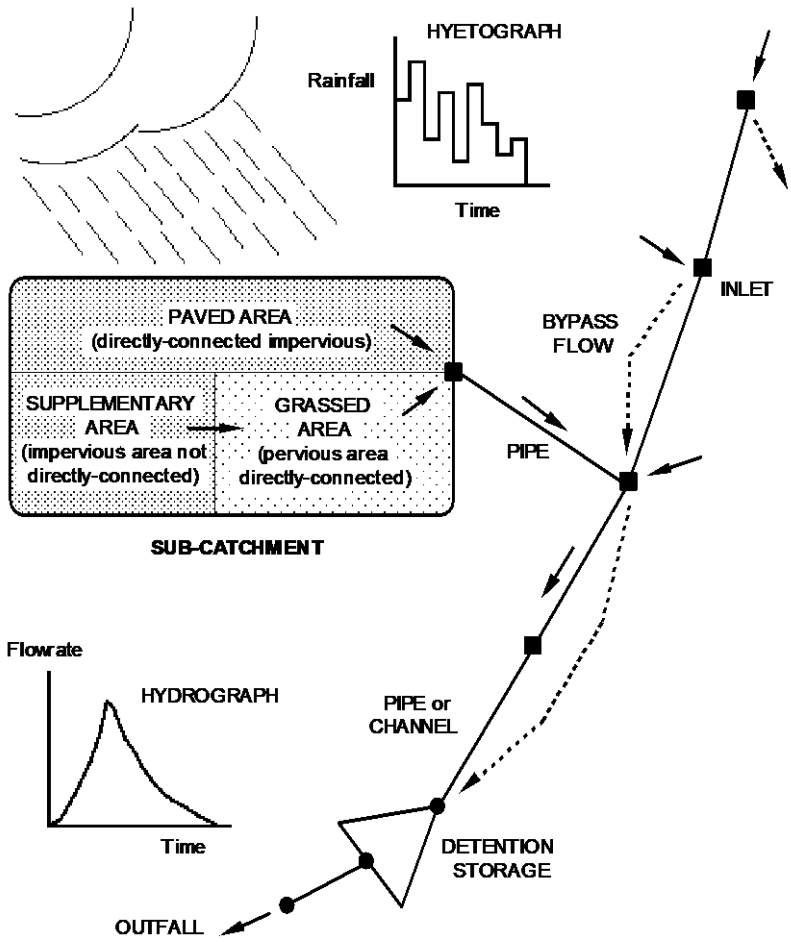


Figure 8.4 The Layout of the ILSAX Model

(b) Time-Area Routing

The basis of the ILSAX model's hydrograph generation is the time-area method, illustrated in Figure 8.5, which 'convolves' the rainfall hyetograph with a time-area diagram, in a similar manner to unit hydrograph calculations. A time of entry (or time of concentration) must be determined for a drained area using methods discussed later in Section (d).

Assume that the rainfall hyetograph has had losses removed and so represents rainfall excess, and that the hyetograph is divided into time steps of Δt. The time-area diagram, a plot of the catchment area contributing after a given number of time steps is divided in the same intervals. This diagram can be visualised by drawing isochrones, or lines of equal time of travel to the catchment outlet. For times greater than the time of concentration, the contributing area equals the total area of the catchment.

When a storm commences on a catchment that has a time of entry of $5\Delta t$, the initial flow Q_0 is zero. After one time step Δt, only sub-area A1 contributes to the flow at the outlet. Any runoff from other sub-areas is still in transit to the outlet. Thus the flowrate at the end of the first time step can be approximated by $Q_1 = c.A_1 . I_1$, where c represents the conversion factor from mm/h to m^3/s units, and I1 is the average rainfall intensity during the first time step.

At the end of the second time step, there are two contributions to the outlet flow, Q_2, due to the second block of rainfall falling on the sub-area nearest to the outlet, $c. A_1 .I_2$, and to runoff from the first rainfall block on the second sub-area, $c. A_2 . I_1$. At the end of the third time step, there are three contributions, $Q_3 = c. (A_1 . I_3 + A_2 . I_2 + A_3 . I_1)$, and so the process continues, as shown in Figure 8.5. The hydrograph builds up to a peak and then recedes once rainfall stops and the catchment drains.

In practice, losses can be subtracted from the rainfalls and flows before or after these time-area calculations are made. The latter choice is recommended for grassed or paved areas, as this allows infiltration to occur from flows moving across a sub-catchment after rainfall has stopped. In this case, the hydrograph of Q values represents a 'supply rate', from which losses must be subtracted later.

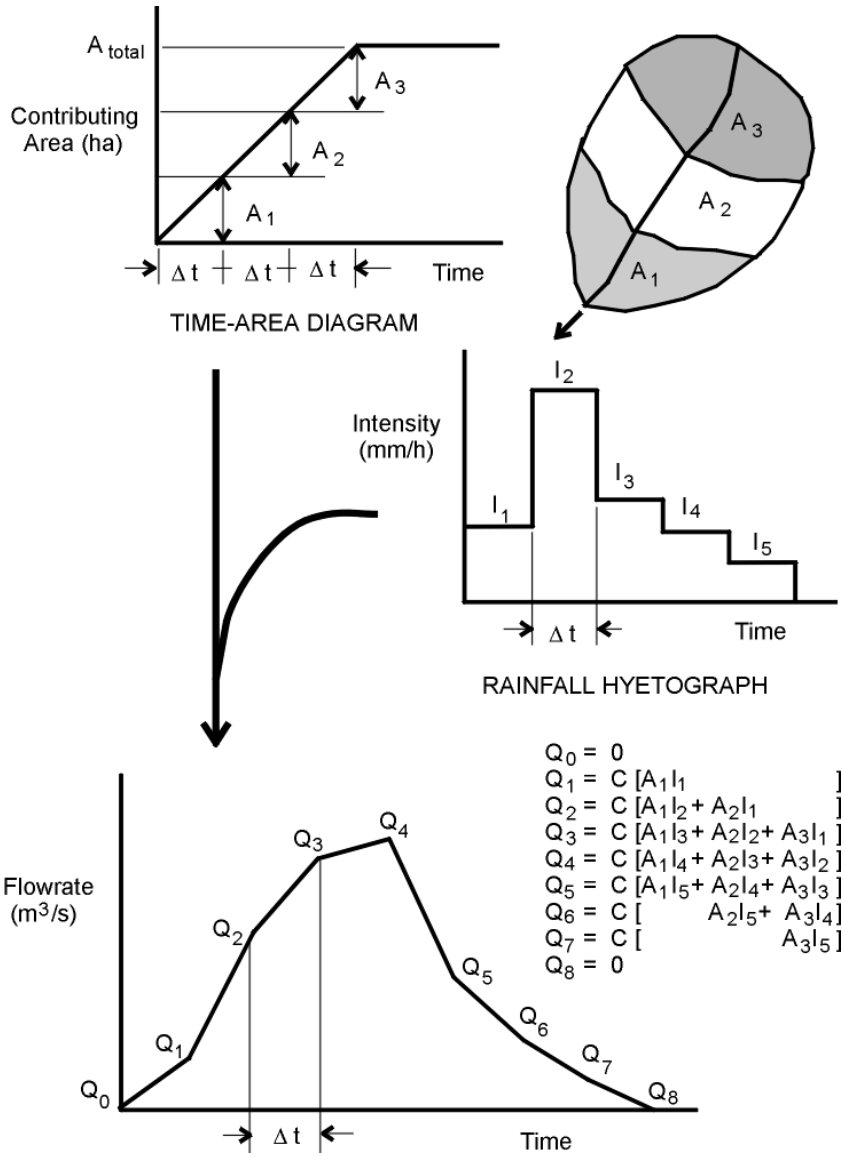


Figure 8.5 Time-Area Calculations

In DRAINS, as in ILSAX, it is assumed that all time-area diagrams are straight-lines. It is conceivable that they could be concave or convex, depending on catchment shape on other factors, however, investigations conducted in the U.K. with the TRRL Method concluded that this degree of accuracy was not necessary.

(c) Catchment Surface Types

The sub-catchments draining to each entry point on the pipe and channel system can be obtained from maps, aerial photographs and GIS information, as well as field inspections. The likely effects of fences along property boundaries and other barriers must be assessed.

In the ILSAX model used in DRAINS, each sub-catchment must be divided into the sub-areas shown in Figure 8.6, with the following surface and drainage characteristics:

- paved areas, impervious areas directly connected to the pipe system, including road surfaces, driveways, roofs connected to street gutters, etc.,
- supplementary areas, impervious areas not directly connected to the pipe system, but draining onto pervious surfaces which connect to this system (These may include tennis courts surrounded by lawns, house roofs draining onto pervious ground, etc. distributed evenly next to the grassed area.), and
- grassed areas, pervious areas directly connected to the pipe system, including bare ground and porous pavements as well as lawns.

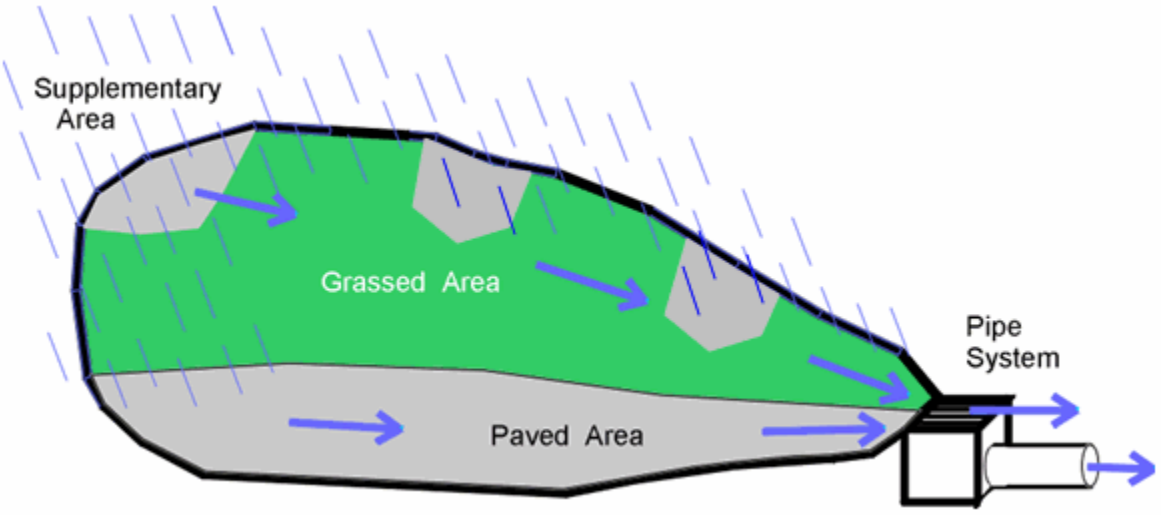


Figure 8.6 ILSAX Model Surface Types

In DRAINS, the total sub-catchment area and the percentages of paved, supplementary and grassed areas must be specified for each sub-catchment. If there is some part of a sub-catchment that does not drain to the drainage system, for example, a hollow or depression in volcanic areas, it should be excluded from the model.

Generally, fully-developed medium density residential catchments will have areas impervious between 30 and 70%. Dayaratne (2000) has obtained the following relationships from modelling of storms on 16 gauged residential catchments in four Victorian municipalities:

Directly connected impervious area (or paved area) percentage,

$$\text{DCIA (\%)} = -0.85\ \text{hhd}^2 + 23.38\ \text{hhd} - 101.19 \quad (r^2 = 0.90) \qquad \text{… (Equation 8.1)}$$

Supplementary area percentage,

$$\text{SA (\%)} = -0.04\ \text{hhd}^2 + 1.13\ \text{hhd} - 3.79 \quad (r^2 = 0.91) \qquad \text{… (Equation 8.2)}$$

where hhd is the number of houses/ha.

These equations produce the numbers shown in **Table 8.2**.

Table 8.2 Estimates Paved and Supplementary Area Percentages

Housing Density, hhd (houses/ha)	**Paved Area**, DCIA (%)	**Supplementary Area** (%)
6	8.5	1.5
7	21	2.2
8	31	2.78
9	40	3.1
10	48	3.5
11	53	3.8
12	57	4.0
13	59	4.1
14	60	4.2

As noted in connection with Figure 5.18, supplementary areas may be used to model systems where roofwater is discharged onto grassed areas.

(d) Overland Flows and Times of Entry

Times of entry must be specified for the paved and grassed areas (and also for the supplementary area in DRAINS). These are effectively the same as the times of concentration or times of travel used in the rational method. They set the base lengths of the time-area diagrams used to create hydrographs.

The DRAINS property sheet for a sub-catchment is shown in Figure 8.7. Information on surface types is arranged in three columns. The length of these varies according to the level of detail selected in the **Use** box. For many applications, fixed times can be entered.

However, it is also possible to calculate a time by the steady-state 'kinematic wave' equation for overland flows (Ragan and Duru, 1972):

$$t_{overland} = 6.94 \cdot \frac{(L \cdot n^*)^{0.6}}{I^{0.4} \cdot S^{0.3}} \qquad \text{...(Equation 8.3)}$$

where time $t_{overland}$ is in minutes, flow path length L is in m, rainfall intensity I is in mm/h and slope S is in m/m.

The surface roughness n* is similar to the coefficient n in Manning's Formula for open channel flows, but is of a different magnitude. It typically takes the values set out in Table 8.3. Values for lawns and grassed surfaces show considerable variation, depending on the depth of flow relative to the height of grass blades. Values from 0.05 to 1.0 have been obtained by various researchers, as described by Engman (1986).

In DRAINS, intensity I is taken as the mean intensity of the rainfall pattern supplied. This should be satisfactory for design rainfall bursts such as those supplied in *Australian Rainfall and Runoff*, 1987, but may be erroneous for some more variable or patchy patterns that occur naturally.

For paved areas, it is also possible to calculate a gutter flow time using (a) an equation for flows in street gutters or channels (U.S. Federal Highway Administration, 1984) , (b) Manning's equation, or (c) more simply, by dividing a flow path length by a speed to obtain a time.

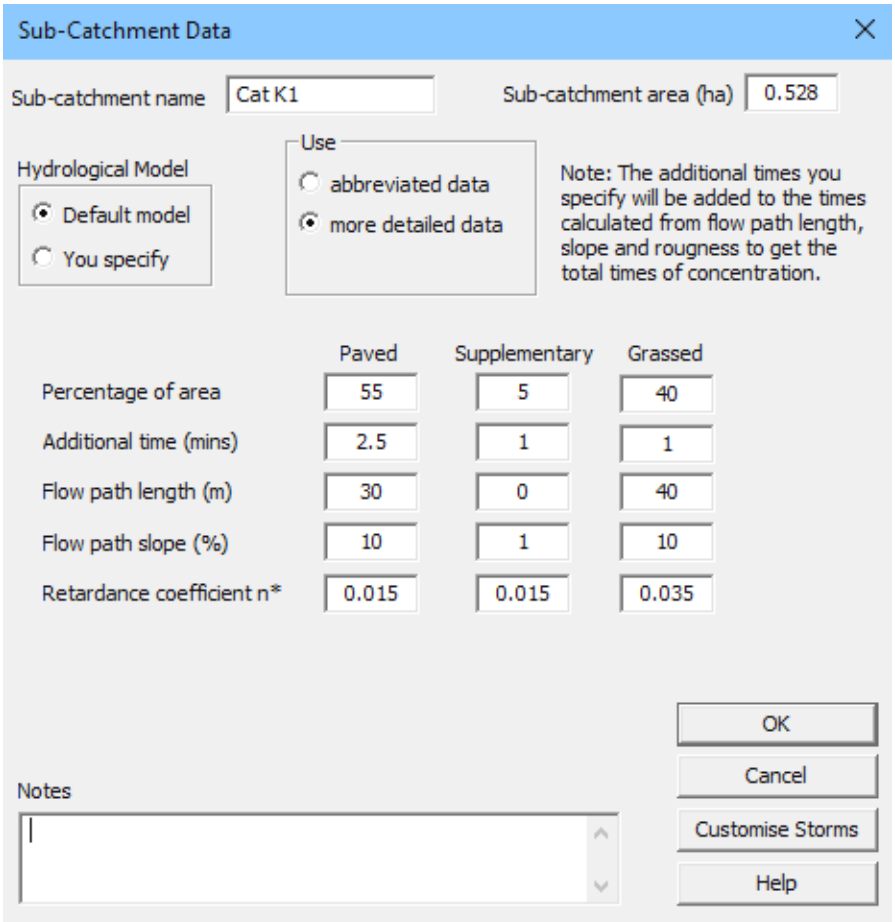


Figure 8.7 Sub-Catchment Property Sheet with Text Boxes for Entry of Data

Table 8.3 Surface Roughness Factors

Surface Type	Roughness Coefficient n
Concrete or Asphalt	0.010 - 0.013
Bare Sand	0.010 - 0.016
Gravelled Surface	0.012 - 0.030
Bare Clay-Loam Soil (eroded)	0.012 - 0.033
Sparse Vegetation	0.053 - 0.130
Short Grass Prairie (Veldt or Scrub)	0.100 - 0.200
Lawns	0.170 - 0.480

[Source: Woolhiser (1975)]

In DRAINS, a kinematic wave flow time can be added to a constant time, as follows:

Total time = Constant time, which can represent property drainage time plus gutter flow time
+ Overland flow time calculated from length, slope and roughness … (Equation 8.4)

Users can specify the times associated with paved, supplementary and grassed areas as (a) a constant time, (b) a constant time, now called an 'additional' time, plus a kinematic wave calculation, or (c) a kinematic wave time only, by specifying the additional time as zero. Up to 2005, there was a third term that modelled street gutter flow times using equations based on road cross-sections. This has been omitted in the current version of DRAINS but may appear in older models. It is described in the DRAINS Help system.

The property drainage time is that required for all water to contribute to flow at the boundary outlet. There is conflicting evidence on property drainage times (Stephens and Kuczera, 1999, Goyen and O'Loughlin, 1999, Dayaratne, 2000), with some pointing to short times, 1 or 2 minutes, and some to longer times, 5 to 10 minutes). 1 to 2 minutes is recommended as being reasonably conservative.
In DRAINS, a lag time for grassed area flows can be applied where flows from such areas pass over paved surfaces before reaching a pit, as described in Section 5.3.6(b).

The *Queensland Urban Drainage Manual*, QUDM (2008) recommends a simplified procedure for setting inlet times, using the values in Table 8.4. Should the calculated t_c be less than 5 minutes, this minimum value is customarily adopted as the t_c.

Table 8.4 Recommended Standard Inlet Times in Queensland Urban Drainage Manual

Location	**Inlet Time** (minutes)
Road surfaces and paved areas	5
Urban and residential areas where:	
- average land slope is greater than 15%	5
- average land slope is between 10% and 15%	8
- average land slope is between 6% and 10%	10
- average land slope is between 3% and 6%	13
- average land slope is up to 3%	15

(e) ILSAX Loss Models

Losses from paved and supplementary areas are calculated simply in the ILSAX model. Depression storages are considered as initial losses subtracted from rainfall hyetographs prior to time-area calculations. The general range of depression storages is from 0 to 2 mm for impervious surfaces and 2 to 10 mm for pervious surfaces. Commonly-used values for paved, supplementary and grassed areas are 1, 1 and 5 mm, respectively. Dayaratne (2000) recommends values of 0 to 1 mm for impervious areas.

The procedures for grassed areas are more complex. They are based on the general equation developed by Horton in the 1930s:

$$f = f_c + (f_0 - f_c) \cdot e^{-kt} \qquad \text{… (Equation 8.5)}$$

where f is infiltration capacity (mm/h),
f_0 and f_c are initial and final rates on the curve (constants, mm/h),
k is a shape factor, here taken as 2 h^{-1},
and t is the time from the start of rainfall (minutes).

This describes the curves shown in Figure 8.8. These only apply when there is sufficient rainfall to satisfy completely the infiltration capacities, and accumulated infiltration is increasing at its full rate.

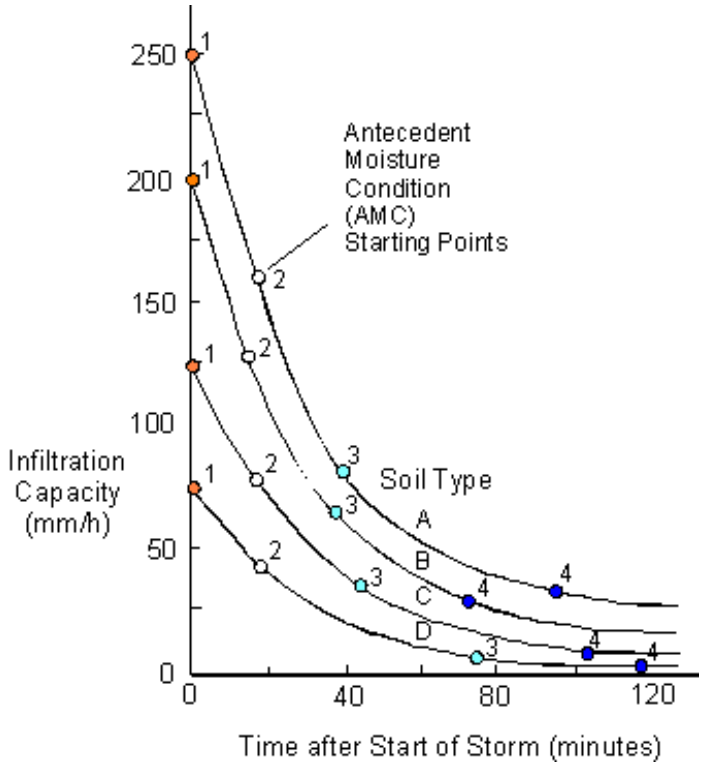


Figure 8.8 Horton Infiltration Curves

The curves represent soil types which follow the classification used by Terstriep and Stall (1974), based on the system developed by the U.S. Department of Agriculture, and described in references such as Chow (1964) and U.S. Natural Resources Conservation Service (2007). These are used in North American procedures such as Technical Release 55 of the U.S. Soil Conservation Service (1975). The four main soil classifications, designated A, B, C and D (corresponding to 1, 2, 3 and 4 in the ILSAX type model), are described as:

1 (or A) - low runoff potential, high infiltration rates (consists of sand and gravel);

2 (or B) - moderate infiltration rates and moderately well-drained;

3 (or C) - slow infiltration rates (may have layers that impede downward movement of water);

4 (or D) - high runoff potential, very slow infiltration rates (consists of clays with a permanent high water table and a high swelling potential).

These soil types are used in conjunction with antecedent moisture conditions (AMCs) that define the points on the infiltration curves at which calculations commence. This is specified, not by an initial infiltration rate in mm/h, but by an antecedent depth of moisture, corresponding to the area under the curve to the left of the starting point. On each curve in the above figure, four starting points (numbered 1, 2, 3 and 4) are shown, representing possible AMCs.

AMCs can be estimated from Table 8.5. Both soil types and AMCs can be interpolated between the levels of 1, 2, 3 and 4.

Users also can also provide their own values. One method to do this is to analyse daily rainfall records and on a spreadsheet calculate the rainfalls for the 5 days preceding each day. Daily rainfalls can then be ranked and the antecedent rainfalls for the highest 100 rainfalls, say, can be analysed, as shown in Figure 8.9 which gives results for Observatory Hill rainfall records in Sydney. From the mean or median antecedent rainfalls and classification numbers, a most-likely value of AMC can be selected.

Table 8.5 Antecedent Moisture Conditions

Number	Description	Total rainfall in 5 days preceding the storm (mm)
1	Completely dry	0
2	Rather dry	0 to 12.5
3	Rather wet	12.5 to 25
4	Saturated	Over 25

For the curve and AMC selected, the model calculates an infiltration loss in each time step. This is subtracted from the rainfall inputs to the pervious area.

Values of parameters involved with various combinations of soil types and AMCs are set out in Table 8.6.

Table 8.6 Infiltration Model Parameters

Factor	Soil Type			
	A (or 1)	B (or 2)	C (or 3)	D (or 4)
Initial Rate, f_0 (mm/h)	250	200	125	75
Final Rate, f_c (mm/h)	25	13	6	3
Shape Factor, k (h^{-1})	2	2	2	2
Antecedent Rainfall Depths (mm) for AMCs:				
1	0	0	0	0
2	50	38	25	18
3	100	75	50	38
4	150	100	75	50
Initial Infiltration Rates (mm/h) for AMCs:				
1	250	200	125	75
2	162.3	130.1	78.0	40.9
3	83.6	66.3	33.7	7.4
4	33.1	30.7	6.6	3.0

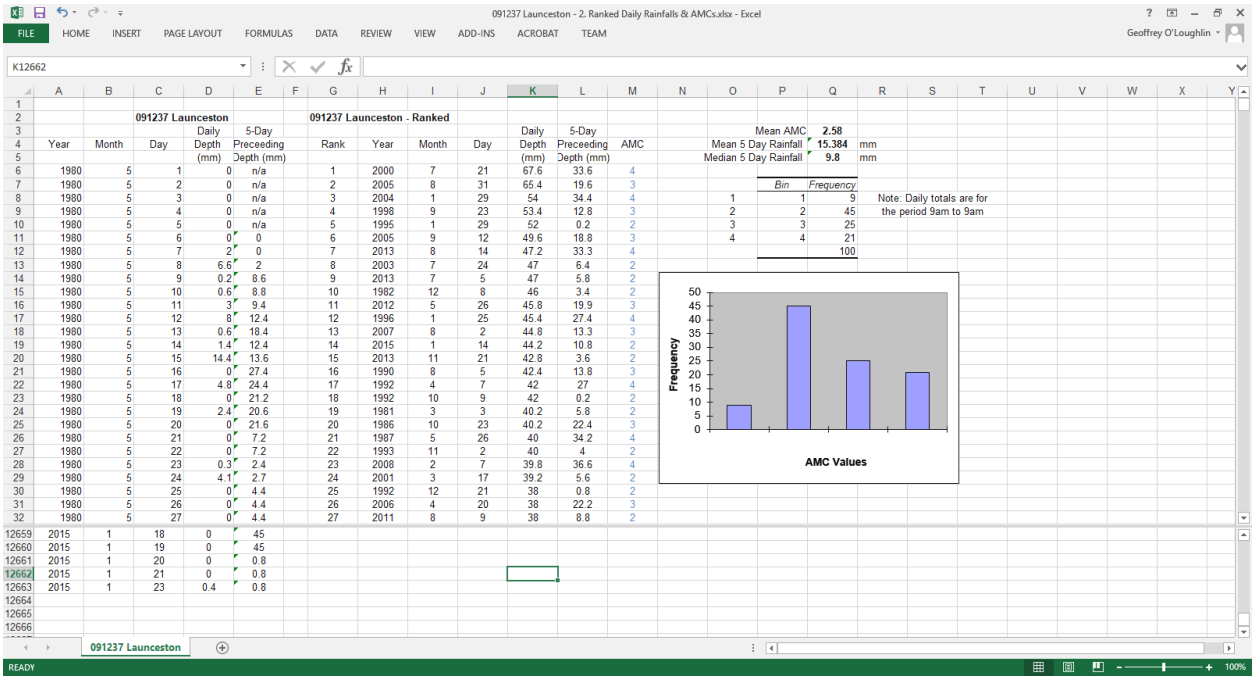


Figure 8.9 Procedure for Determining AMCs for Design Purposes from Daily Rainfalls

This classification involving soil type and AMC has been found to give good fits to recorded storm hydrographs from gauged catchments in Australia, and the soil types have been accepted by ILSAX and DRAINS users. Siriwardena, Cheung and Perera (2003) compared the infiltration rates in Table 6.4 with those measured with infiltrometers at eight urban gauged catchments in Victoria. They found that the f_0 and f_c values measured were generally higher than those for the same soil classification in Table 8.6. They obtained f_0 values of 28 to 503 mm/h compared to 13 mm/h for a Type B soil, and f_c values of 4 to 135 mm/h, compared to values of 31 to 200 mm/h. They also obtained a shape factor, k, of 0.85 h^{-1} compared to 2 h^{-1} in the table.

Siriwardena, Cheung and Perera did not explore the implications of changing these parameters in modelling hydrographs from the test catchments. It is not possible to assess the effects of this at present, but Victorian users of DRAINS and similar programs should take the above results into consideration when setting parameters. DRAINS s allows user-provided parameter values to be specified in the hydrological model inputs.

In ILLUDAS-SA and ILSAX, the following form of Horton's equation was used to determine the infiltration rate from the accumulated depth of infiltration. This allows for variable rainfall intensities that might be less than the infiltration capacities at some times.

$$f = f + f_c \cdot \left(1 - \frac{f}{f_c + (f_0 - f_c).e^{(f_0 - kF - f)/f_c}}\right) \qquad \text{... (Equation 8.6)}$$

where f is the current infiltration capacity (mm/h), and
F is accumulated depth of infiltration (mm).

The infiltration rate calculated from this is subtracted from the hyetograph or supply rate, and should any water remain, depression storage is subtracted. Once the depression storage has been fully satisfied, any excess over infiltration is assumed to be runoff. The accumulated infiltration depth is increased by the amount assumed to be infiltrated. For porous soils and light rainfalls, it is quite possible that there will be zero runoff from pervious surfaces.

Malcolm Watson, the developer of ILLUDAS-SA, suggested that an alternative method could be used which would not involve iterative calculations, and this was incorporated into ILSAX. This procedure, described by Watson (1981b), involved the division of the infiltration curve equation into diminishing and constant components $(f_0 - f_c) \cdot e^{-kt}$ and f_c. Watson used this concept in the following analysis:
The actual depth of infiltration, ΔF, over time step Δt is the lesser of $I \cdot \Delta t$, where I is rainfall intensity, and

$$F_{cap} = (1 - e^{-k\Delta t}) \cdot \left(\frac{(f_0 - f_c)}{k} - F_d\right) + f_c \cdot \Delta t \qquad \text{… (Equation 8.7)}$$

where F_d is the accumulated diminishing infiltration, determined at each time step by

$$F_d = F_d - \frac{\Delta F}{\Delta F_{cap}} \cdot (\Delta F_{cap} - fc. \Delta t) \qquad \text{… (Equation 8.8)}$$

which apportions actual infiltration depths between diminishing and constant components, as shown in Figure 8.10.

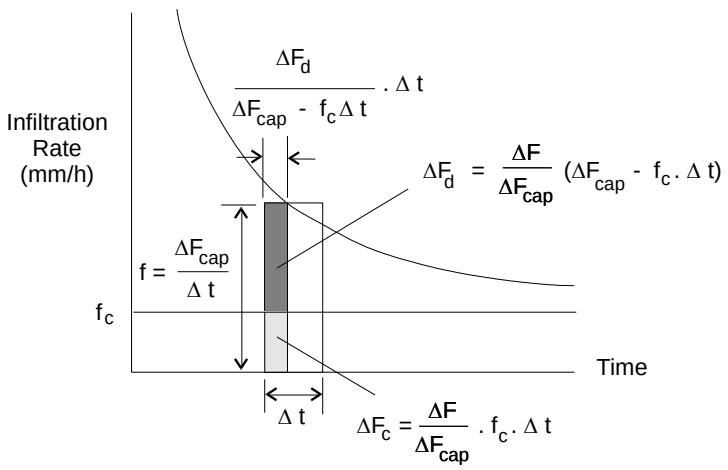


Figure 8.10 Infiltration Capacity Calculation Procedure

(f) Combination of Hydrographs

The time-area method is applied separately to the paved, supplementary and grassed area portions of the catchment. DRAINS allows for a supplementary area depression storage and time of travel. (These must both be set to zero if you wish to exactly reproduce ILSAX hydrographs.)

The process for paved and supplementary areas is shown in Figure 8.11. Hyetograph values are scaled (by area/360) to convert intensities to flowrates in m^3/s.

The more complex process for grassed area runoff is shown in Figure 8.12. This diagram is actually an oversimplification. Some details not shown are that:

- the process is actually a step-by-step one, mixing loss and routing calculations for a number of strips across a sub-catchment, and allowing for water running from one strip to another;
- supplementary area runoff is added to the grassed area flows; and
- depression storage is actually calculated after the infiltration is calculated.

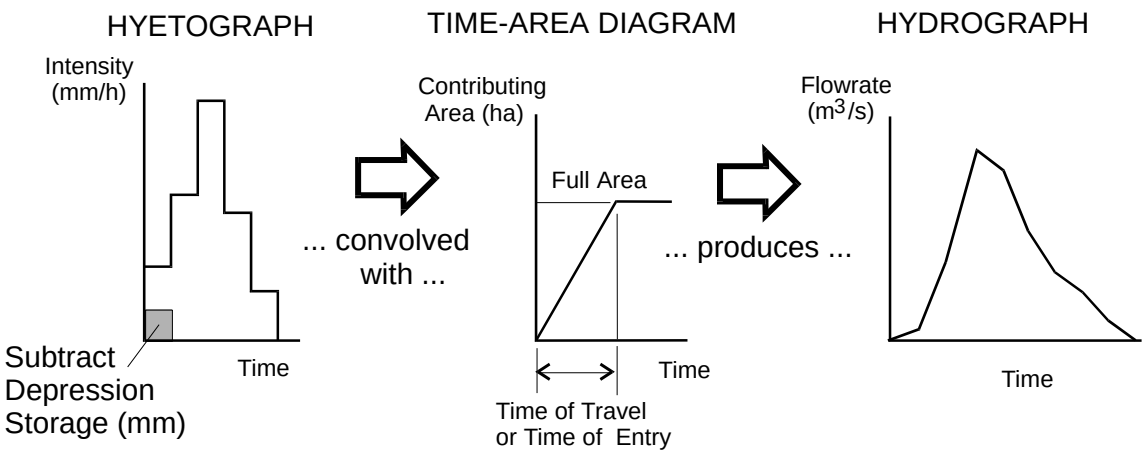


Figure 8.11 Calculation of Hydrographs from Paved and Supplementary Areas

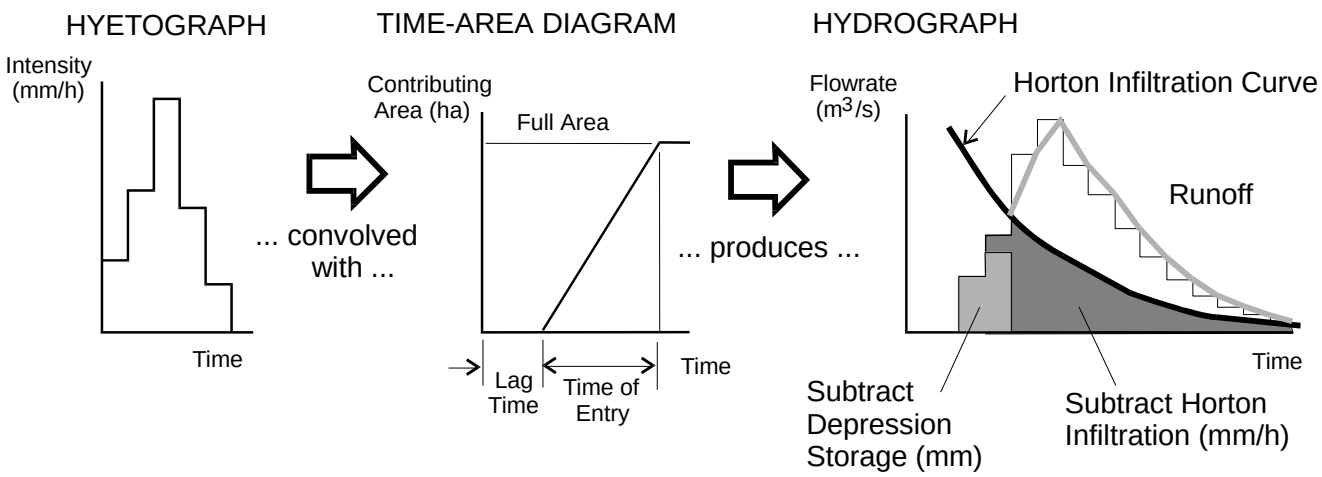


Figure 8.12 Calculation of Hydrographs from Grassed Areas

As explained earlier, grassed area hydrographs can be delayed to allow for any time lag occurring when grassed area flows travels over paved surfaces to the pipe system.

All hydrographs in the program are linked to the same time base and are synchronised, and combination of input hydrographs is a straightforward addition process. As shown in Figure 8.13, the supplementary area hydrograph is incorporated in the grassed area hydrograph. This is added to the paved area hydrograph and possible user-provided hydrographs or baseflow, to obtain the total runoff hydrograph coming off the local sub-catchment. Overflows from upstream pits, if present, are then added to this to obtain the total approach flow to a pit, simple node or detention basin.

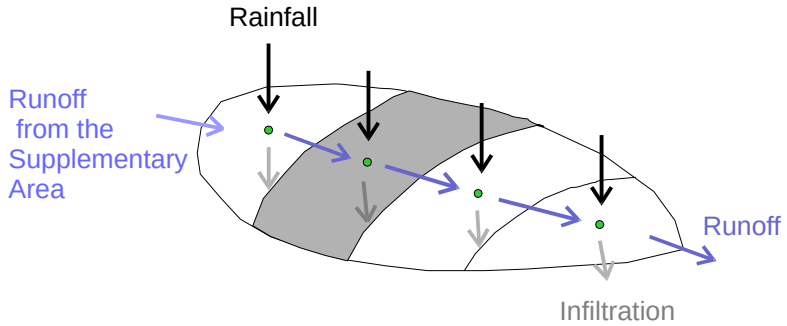


Figure 8.13 Flows between Strips in Time-Area Calculations

At pits, an entry capacity relationship applies, and bypass flows and overflows from the pipe system can occur. With the elaborate hydraulic routing calculations that are applied in DRAINS, it is not possible to explain these processes in detail, but generally, various inflow hydrographs are added at each time step, and combined with calculated flows through the upstream pipe system.

8.3.3 Testing and Verification of DRAINS

Testing during development has shown that the ILSAX hydrological model has been reproduced exactly in DRAINS, with the additional feature of more detailed calculations of supplementary area flows operating satisfactorily. In comparisons with data from gauged urban catchments, ILSAX has been shown to provide results that are at least as good as other urban hydrology programs such as SWMM (see Vale, Attwater and O'Loughlin, 1986; O'Loughlin et al, 1991; and Diamante, 1997, 2000). Table 8.7 and Table 8.8 show comparative results between recorded data, SWMM, ILLUDAS-SA (a predecessor of ILSAX) and ILSAX, showing that the ILSAX Hydrological Model provides a reasonable reproduction of storm flow characteristics.

Table 8.7 ILLUDAS-SA and Observed Results (Mein and O'Loughlin, 1985)

Catchment Name	Storm Date	Total Rain (mm)	Peak Flowrate (m^3/s)		Volume (m^3)	
			ILLUDAS	Observed	ILLUDAS	Observed
Vine Street Sunshine Melbourne	6-11-71	89	1.2	1.1	0.54	0.69
	5-2-73	88	2.8	2.3	0.64	0.69
	15-5-74	81	1.2	1.7	0.49	0.74
	11-10-75	14	1.6	1.6	0.37	0.51
	31-10-75	28	1.4	1.4	0.53	0.60
	29-12-75	29	2.4	1.6	0.29	0.22
	2-11-76	39	2.5	1.6	0.31	0.26
	13-11-76	18	2.5	1.6	0.26	0.27
	7-4-77	113	2.4	2.2	0.54	0.46
	7-8-78	43	0.9	1.4	0.33	0.60
Powells Creek, Strathfield Sydney	18-2-81	25	6.6	4.1	0.34	0.21
	2-3-81	32	14.8	12.0	0.37	0.27
	21-10-81	53	17.7	12.5	0.76	0.60
	14-12-81	38	6.0	5.3	0.37	0.37
	18-1-82	6	2.3	2.7	0.22	0.32
	24-3-82	45	22.4	16.0	0.68	0.38
Berowra Sydney	9-11-80	31	0.6	0.7	0.18	0.18
	29-12-80	38	1.1	1.2	0.18	0.11
	7-1-81	22	0.5	0.3	0.18	0.19
	24-1-81	14	0.3	0.3	0.17	0.18
	7-11-81	10	1.5	0.7	0.17	0.15
	15-11-81	8	0.9	0.8	0.16	0.21
	21-11-81	47	0.7	0.7	0.21	0.25
	19-12-81	16	1.1	0.8	0.19	0.07
	30-9-82	18	0.2	0.1	0.18	0.02

Table 8.8 SWMM and ILSAX Results for Bunnerong Catchment, Maroubra, Sydney
(Vale, Attwater and O'Loughlin, 1986)

Storm Date	AMC	Total Rain (mm)	Peak Flowrate (m^3/s)			Runoff Volume (m^3)		
			SWMM	ILSAX	Obser-ved	SWMM	ILSAX	Obser-ved-
1-3-77	4	40.5	1.68	1.44	1.02	20.3	17.2	8.78
5-3-77	4	12.3	0.96	1.19	0.55	5.49	4.87	1.98
3-3-78	1	34.8	3.21	2.91	1.64	17.8	14.6	6.59
18-3-78	2	60.2	3.14	3.08	1.56	30.0	25.2	11.9
18/19-3-78	4	14.4	1.39	1.75	0.90	6.58	5.93	3.23
19/20-6-79	2	49.6	2.41	2.20	1.37	23.9	20.7	8.03
20/21-6-79	4	20.5	1.30	1.46	0.57	9.52	8.36	2.61
17-3-83	4	36.0	4.46	4.66	2.11	22.1	27. 0	5.25
5-11-84	2	169.1	4.69	4.58	1.81	94.3	95.0	25.4
6-11-84	4	4.47	0.26	0.40	0.31	1.21	1.50	0.75
6/7-11-84	4	17.0	0.56	0.60	0.36	6.80	6.89	3.06
8/9-11-84	4	89.3	3.33	4.21	1.70	54.6	58.6	14.3

Table 8.9 and Figure 8.14 present comparisons between ILSAX, DRAINS and observed data for 25 storms recorded at the University of Technology, Sydney gauging station at Hewitt, Penrith. This and other comparisons with data recorded at Penrith (Pereira, 1998; Tran, 1998) have shown that ILSAX and DRAINS produce similar hydrographs at catchment outlets, except in large storms where backwater effects influence the pipe system hydraulics.

Table 8.9 Comparisons between ILSAX and DRAINS **Calculated Flows and Observed Flows at the Hewitt Gauging Station, Penrith, Sydney**
(O'Loughlin, Stack and Wilkinson, 1998; Shek and Lao, 1998; Chan, 1998)

Storm Date	AMC	Peak Flowrate (m^3/s)			Runoff Volume (m^3)		
		ILSAX	DRAINS	Obs.	ILSAX	DRAINS	Obs.
23-1-92	1	3.28	3.06	3.97	5452	4540	7944
23-2-92	1	0.92	0.94	0.92	2251	2162	1973
21-12-92	2	1.26	1.30	1.26	3368	2920	4257
13-11-93	1	0.42	0.42	0.42	1822	1791	2787
18-11-93	3	0.34	0.38	0.34	1115	1096	1140
1-2-94	1	0.72	0.76	0.65	827	1547	593
12-2-94a	2	0.56	0.52	0.54	1192	1160	1042
12-2-94b	3.6	0.36	0.35	0.37	3034	3018	3158
15-2-94	3	6.49	6.51	3.87	18071	14885	11683
7-3-94	1	0.62	0.63	0.47	1064	1046	858
9-3-94	3.7	0.39	0.40	0.36	2277	2206	2366
29-3-94	3	0.48	0.47	0.39	607	586	405
29-3-94	2	0.46	0.46	0.32	1426	1377	1080
30-3-94a	3.6	1.64	0.99	1.62	1335	1310	1263
30-3-94b	3.7	0.95	1.45	0.95	2705	2280	2003
20-11-94	3	1.90	1.70	2.69	1314	1163	1735
25-12-94	1	0.23	0.24	0.22	3009	2937	2744
1-1-95	1	2.08	1.83	2.55	2663	2118	2486
14-4-95	1	0.24	0.25	0.16	968	923	565
15-4-95	2	0.20	0.20	0.15	809	813	604
2-5-95	1	0.15	0.16	0.12	822	815	654
5-5-95	3	0.27	0.30	0.41	4275	4238	4957
13-5-95	2	2.06	1.95	2.49	4053	3655	5446
16-5-95	4	0.33	0.36	0.88	5460	5504	11358
25-5-95	2	0.63	0.63	0.67	778	824	886

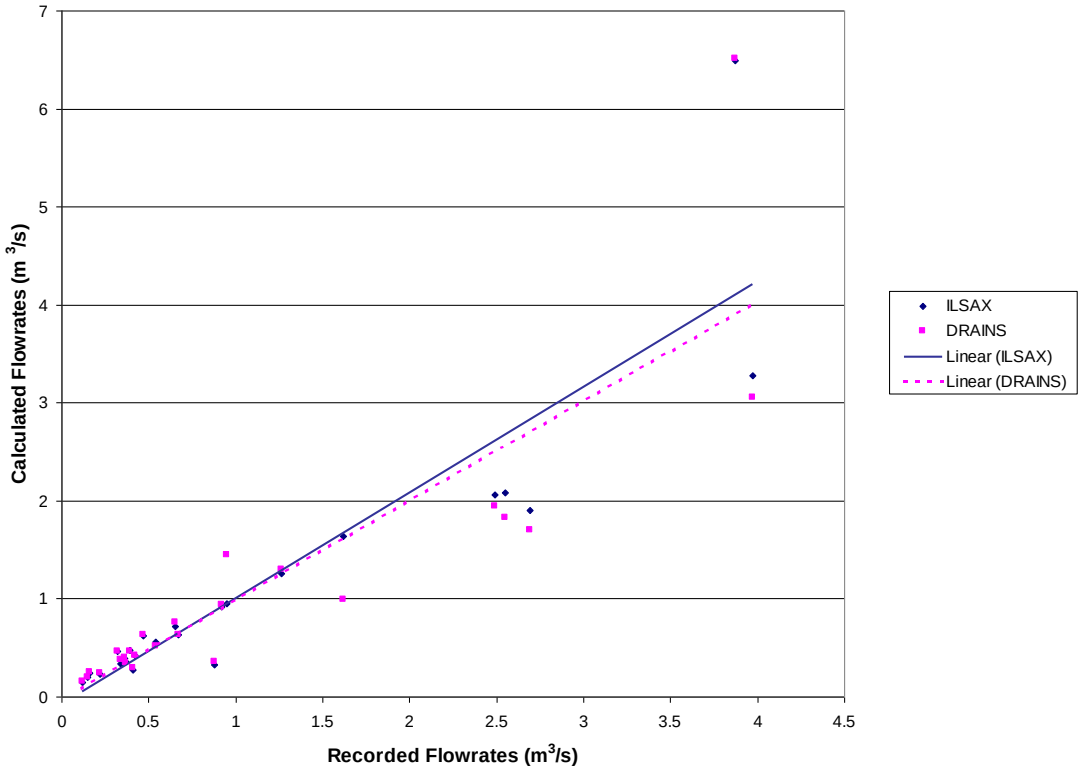


Figure 8.14 Hewitt Results

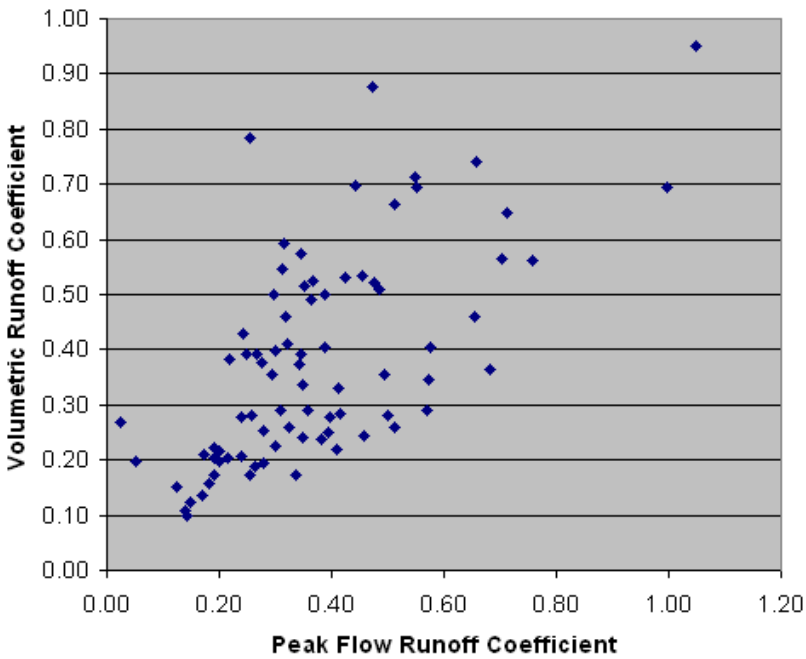


Figure 8.15 Jamison Park Volumetric vs. Peak Flow Runoff Coefficients

8.3.4 Rational Method Procedures

DRAINS offers three options for the rational method, which can be mixed together in a single system. If your version of DRAINS is enabled to run the rational method, it is chosen by selecting a rational method model as a default in the Hydrological Model Specifications dialog box opened from the **Project** menu.

The first option available in the Rational Method Model property sheet that is called from the Hydrological Model Specifications box is a general rational method procedure. It is necessary to specify four runoff coefficients - an impervious and a pervious area coefficient for design, and another set of these for analysis.

For a particular sub-catchment, the rational method is applied as follows:

$$Q = (C_{imp} \cdot A_{imp} + C_{perv} \cdot A_{perv}) \cdot I \qquad \text{… (Equation 8.9)}$$

where Q is the design flowrate in m^3/s,
C_{imp} and C_{perv} are impervious and pervious area runoff coefficients
A_{imp} and A_{perv} are the impervious and pervious areas (ha), and
I is the rainfall intensity (mm/h) corresponding to the appropriate time of concentration.

DRAINS performs a search between 5 minutes and the (usually longer) times specified for the impervious and pervious areas, to find the time that provides the greatest value of Q = C.I.A, overcoming the partial-area problem whereby the lower part of a catchment produce a higher estimate of a flowrate than the total catchment.

Rational method times of concentration are specified in exactly the same way as ILSAX model times of entry in the property sheet for sub-catchments, as described in Section 8.3.2(d).

The first, general method is a 'plain' implementation that has no special fixed features, and can be applied outside Australia, or within Australia if the user wants to depart from the *Australian Rainfall and Runoff*, 1987 method. The second method, from *Australian Rainfall and Runoff* (institution of Engineers, Australia, 1987), is fully explained in that publication. C_{10} values must be entered for impervious and pervious areas. These are 10 year average recurrence interval (ARI) runoff coefficients that are adjusted for other ARIs by multiplying the C_{10} values by the frequency factors shown in Table 8.10. The value for the impervious area is always 0.9.

Table 8.10 Rational Method Frequency Factors

ARI (years)	**Frequency Factor**
1	0.80
2	0.85
5	0.95
10	1.00
20	1.05
50	1.15
100	1.20

The pervious area runoff coefficient is calculated from the formula:

$$C_{10} = 0.1 + 0.0133\,({}^{10}I_1 - 25) \qquad \text{…(Equation 8.10)}$$

with upper and lower values of 0.1 and 0.7. ${}^{10}I_1$ is the 10 year ARI, 1 hour rainfall intensity, used as an index of the rainfall climate.

The third method is taken from the Australian / New Zealand Standard AS/NZS 3500.3. This gives different procedures for Australia and New Zealand, and only the Australian procedure is implemented in DRAINS at present. In the Rational Method Model property sheet, this option requires that only the 10 year ARI, 1 hour rainfall intensity ${}^{10}I_1$ be entered. This is used to determine the pervious area C value using the above equation. This runoff coefficient is adjusted upwards by 0.1 for clay soils and downwards by 0.1 for sandy soils. The frequency factors from Table 8.10 are applied with a factor of 1.25 being used for ARIs greater than 100 years. The runoff coefficient for roofs is assumed to be 1.0 and that for impervious surfaces at ground level to be 0.9.

Only a property site itself is considered in these calculations. The rational method formula is expanded to allow for the three surface types:

$$Q = I (C_r A_r + C_i A_i + C_p A_p) / 3600 \qquad \text{… (Equation 8.11)}$$

where A_r, A_i and A_p are the areas of roofs, impervious areas and pervious areas in the sub-catchment being considered. In calculations, the time of concentration is fixed, at 5 minutes.

All methods require intensity-frequency-duration (I-F-D) data that is entered in the Rational Method Rainfall Data property sheet opened from the **Rainfall Data…** option in the **Project** menu.

8.3.5 The Extended Rational Method

A number of methods have been developed for extending the rational method to produce hydrographs, usually by assuming a triangular or trapezoidal shape. In the US, a Modified Rational Method (Poertner, 1981) has been applied in many locations. This produces hydrographs corresponding to uniform rainfall blocks of various durations, which can be used to model detention basins in the same way that can be done using *Australian Rainfall and Runoff* design rainfall patterns.

DRAINS presents a variation on this method named the Extended Rational Method (ERM), which is available if the rational method is enabled in the hardware lock used. It was introduced to meet the needs of users who wish to develop hydrographs that are consistent with Rational Method flowrates derived using the methods from *Australian Rainfall and Runoff*, 1987 and the *Queensland Urban Drainage Manual*, 1992. While the ILSAX hydrological model in DRAINS should produce superior results to the rational method due to the testing and verification described in Section 8.3.3 and previous parts of this chapter, it cannot provide similar peak flowrates to the rational method across a range of ARIs and storm durations.

The ERM employs the same time-area routing procedure as the ILSAX model rather than assuming hydrograph shapes. The loss model is different, applying a continuing loss to all blocks of rainfall. When the ERM was first released, it assumed a constant continuing loss but inconsistencies were found when it was applied with storms of various durations. The ERM assumes a continuing loss proportional to rainfall intensities.

The ERM requires the same input data as the ARR87 rational method (Figure 3.2) but runs with rainfall patterns or hyetographs, rather than intensities from an I-F-D relationship. When applied with the design storm patterns from *Australian Rainfall and Runoff*, 1987 Chapter 3 the peak flows obtained from a set of design storms will differ from those given by the ARR87 rational method. The synthetic storm option in the Rainfall Data property sheet (Figure 5.77) has been provided to produce rainfall patterns that incorporate many blocks of rainfall of different average durations that are consistent with the I-F-D duration curves of the design rainfalls. Using these patterns with the ERM, rather than the

The volumetric runoff coefficient (the ratio of volume of runoff to volume of rainfall) obtained from a pervious area with the ERM will be the same as the C_{10} coefficient supplied, adjusted by a frequency factor. The validity of this has been checked using data collected at the Jamison Park Gauging Station in Western Sydney, as shown in Figure 8.15.

Results from 80 storms shown in indicate that this is reasonable for this locality. (Peak flow coefficients were derived assuming a time of entry of 20 minutes.)

8.3.6 The Initial Loss-Continuing Loss Model

This urban loss model is recommended in Chapter 3 of Book 5 of ARR 2016. The model and its parameters based on research by Phillips et al. (2014) are set out in Section 3.5.3 of ARR 2016, where it is favoured over the ILSAX (Horton) and rational method models.

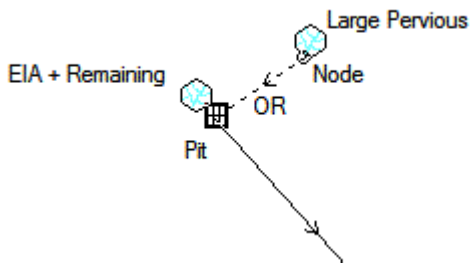
It is based on the concept of an effective impervious area (EIA). The research indicates that runoff from urban areas is less than the runoff calculated by urban hydrological models using the total impervious area (TIA) or directly-connected impervious area (DCIA). According to Table 5.3.2 of ARR 2016, the EIA is approximately 60% of the TIA and 70% of the DCIA.

The recommended model identifies the three parts of a catchment described in Table 8.11.

Table 8.11 IL-CL Model Details

Part of Sub-Catchment	Loss Parameters
Effective impervious Area (EIA) including part of the directly connected impervious area (DCIA) + possibly some of the indirectly connected impervious area (ICIA). According to Table 5.3.2 of ARR 2016, the EIA is approximately 60% of the total impervious area (TIA) and 70% of the DCIA.	1-2 mm initial loss (IL), zero constant continuing loss (CL) (Section 3.5.3.2.1 of ARR 2016)
Indirectly Connected Areas, made up of indirectly connected impervious and pervious areas that interact with impervious areas)	IL is 60% to 80% of the rural IL for the location (Section 3.5.3.2.1) with some qualifications, CL is 1 - 4 mm/h, with typical values of 2.5 mm/h for South Eastern Australia. For some state or territory capitals, losses could be determined from Figures 5.3.21 and 5.3.22. (The ARR Data Hub cautions against using rural loss estimates in urban areas, but this conflicts with Section 3.5.3.2.1.)
Urban Pervious Areas (large, self-contained areas such as parks or bushland)	IL and CL are the same as for a rural area at the same location (Section 3.5.3.2.3).

The last part is rarely encountered, so that most sub-catchments can be considered to consist of an EIA and a remaining area. If you wish to add a large pervious area to a catchment, you can do this by linking a sub-catchment for this area to a node, and using an overflow route to link this to the same pit or node as the sub-catchment containing the EIA and remaining areas. This arrangement is shown below:



The suggested loss parameters and other information in ARR 2016 allow a wide range of interpretations, and users will need more guidance, or may adopt conservative assumptions. The application of losses to bursts and complete storms is confusing, and clear guidance is needed. When defining details for sub-catchments, the EIA might be assumed to be 60% of the TIA for a sub-catchment consisting mainly of house lots, but the ratio should be higher for sub-catchments consisting of roadways and footpaths. Designers of roads and small-scale systems such as on-site detention storages may be reluctant to assume that a large proportion of the impervious area on a property is not part of the EIA.

With the assumptions outlined above, the model is likely to underestimate flowrates because, a pre-burst depth should usually be subtracted from the assumed initial loss (See Section 5.9.9 in Chapter 5 of Book 2 of ARR 2016). The ARR Data Hub specifies pre-burst depths for storms of 60 minute duration or greater. We understand that depths will be available for durations below 60 minutes in future. However, the most critical durations for urban drainage systems are likely to be the shorter ones for which no pre-burst information is available. Until this matter is resolved, the IL-CL model should be used with caution. The correct design flowrates will be somewhere between those obtained with the losses outlined in the above table and the results with zero initial losses.

In DRAINS, the parameters for the IL-CL model are entered in its property sheet:shown in Figure 5.25 Sensitivity tests can be undertaken in DRAINS to assess different modelling assumptions, and to compare results from the IL-CL hydrological model with those from ILSAX, the rational method or other calculations

8.3.7 Comparison of Hydrological Methods for Piped Drainage Systems

(a) Comparision of Older Models

This section provides comparative information on three of the models provided by DRAINS for use with piped drainage systems. An example based on the Gymea model is shown in **Figure 8.16** and the sub-

catchment characteristics relevant to the ILSAX and rational method models are shown in Table 8.12. The focus is on the runoff produced by the sub-catchments and flows in pipes are not considered in this assessment. An additional sub-catchment has been added at the outlet to model a sub-catchment that is mainly pervious.

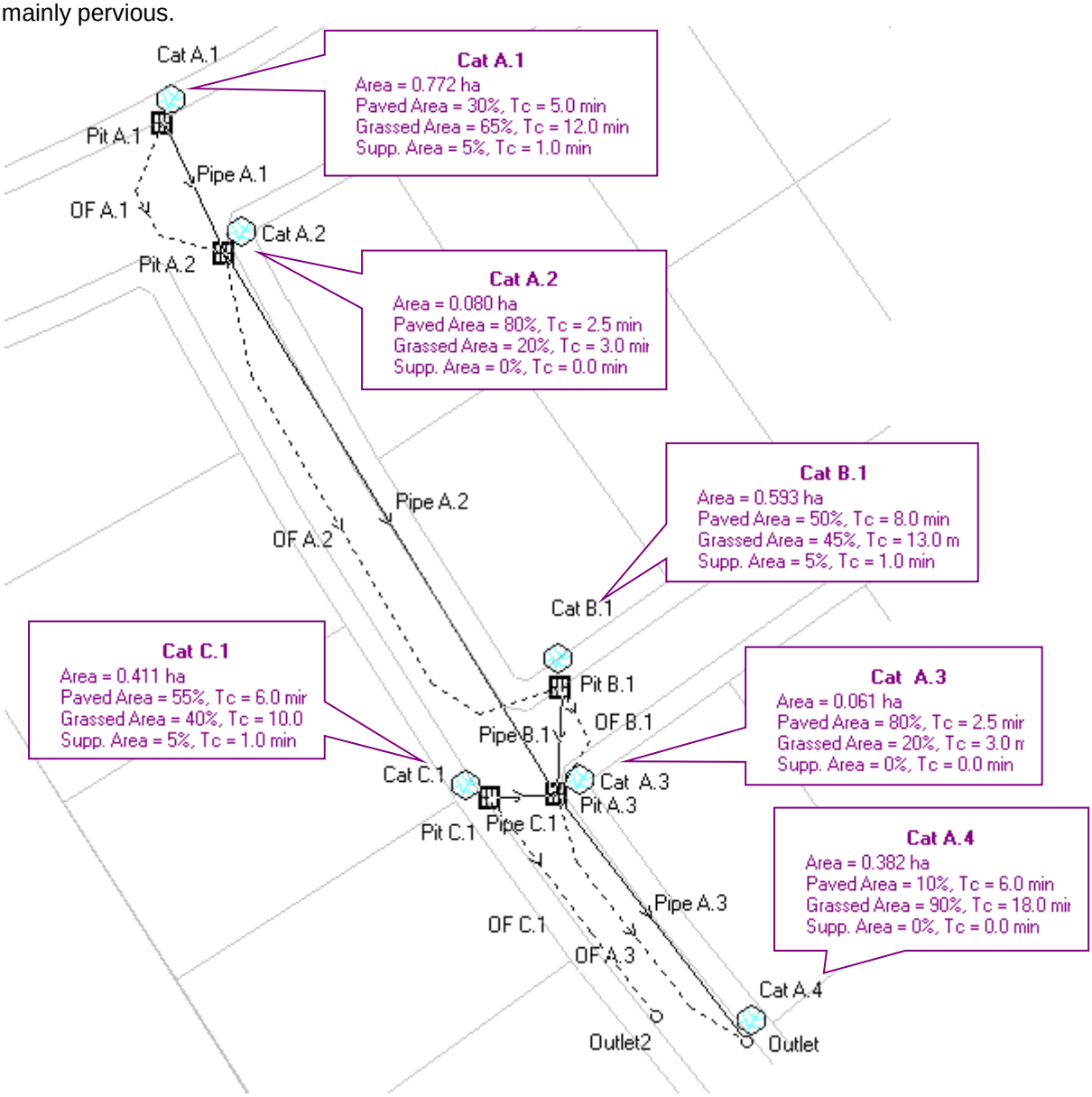


Figure 8.16 Gymea Model used for Comparisons

Table 8.13 sets out the results of a series of runs made with the modified Gymea ILSAX model and ARR 1987 rainfalls. . Four ILSAX models apply a typical Soil Type of 3 and AMC values of 1, 2, 3 and 4. The rational method uses a 10 year ARI pervious area runoff coefficient of C_{10} = 0.51, based on a 10 year ARI, 1 hour intensity of 56 mm/h to develop 5 and 100 year ARI coefficients of C_5 = 0.48 and C_{100} = 0.61. The extended rational method (ERM) uses the same coefficients, but is applied in three ways, with ARR87 and synthetic storms being used, and impervious and pervious runoff being calculated separately or on a total basis. Times of concentration are consistent for all models.

Peak flowrates for 5 and 100 year ARI are shown for each sub-catchment. Those from the ILSAX models and the ERM with ARR87 storms are the highest values out of twelve storm patterns with durations from 5 minutes to 4.5 hours.

Relative results vary with the proportions of impervious and pervious areas, but the rational method and ERM generally specify lower flowrates than the ILSAX models, especially where an AMC or 3 or 4 is used, which will be the usual situation at Gymea.

The reasons for the rational method providing lower flowrates than ILSAX are:

- ILSAX uses ARR87 patterns such as that shown in Figure 2.68, which contain higher peak intensities than the rational method, which assumes that rainfall occurs as a rectangular block.
- The ILSAX hydrological model gives different runoff volumes to the rational method and applies different routing procedures. It only applies a depression storage loss of 1 mm for impervious areas while the rational method and ERM apply C_5 = 0.86 and C_{100} = 1.0.

Table 8.12 Characteristics of Comparative Gymea Model Sub-Catchments

Sub-Catchment	Area (ha)	Hydrological Model					
		ILSAX		Rational Method and ERM			
		Paved, Supplementary & Grassed %	Paved, Supplementary & Grassed t_c (minutes)	Impervious & Pervious %	Impervious & Pervious. t_c (minutes)	Imperv. C_{10}	Perv. C_{10}
Cat A.1	0.772	30, 5, 65	5, 1, 12	35, 65	5, 12	0.9	0.51
Cat A.2	0.08	80, 0, 20	2.5, 0, 3	80, 20	2.5, 3	0.9	0.51
Cat A.3	0.061	80, 0, 20	2.5, 0, 3	80, 20	2.5, 3	0.9	0.51
Cat A.4	0.382	10, 0, 90	6, 0, 18	10, 90	6, 18	0.9	0.51
Cat B.1	0.593	50, 5, 45	8, 1, 13	55, 45	8, 13	0.9	0.51
Cat C.1	0.411	55, 5, 40	6, 1, 10	60, 40	6, 10	0.9	0.51

Table 8.13 Comparison of Flowrates and Volumes Generated by Gymea, New South Wales Pipe System Models

Sub-Catchment	Hydrological Model							
	ILSAX with Soil Type of 3 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	~~Separate areas, Synthetic~~	Total areas, Synthetic
0.2 EY (5 Year ARI) Flowrates (m^3/s)								
Cat A.1	**0.081**	**0.094**	**0.148**	**0.180**	**0.145**	**0.098**	~~0.169~~	**0.117**
Cat A.2	**0.025**	**0.025**	**0.028**	**0.030**	**0.027**	**0.019**	~~0.027~~	**0.024**
Cat A.3	**0.019**	**0.019**	**0.021**	**0.023**	**0.020**	**0.015**	~~0.020~~	**0.018**
Cat A.4	**0.012**	**0.022**	**0.052**	**0.070**	**0.051**	**0.029**	~~0.053~~	**0.034**
Cat B.1	**0.091**	**0.104**	**0.125**	**0.139**	**0.091**	**0.091**	~~0.138~~	**0.109**
Cat C.1	**0.073**	**0.080**	**0.098**	**0.108**	**0.072**	**0.072**	~~0.110~~	**0.089**
1% AEP (100 Year ARI) Flowrates (m^3/s)								
Cat A.1	**0.178**	**0.225**	**0.268**	**0.300**	**0.226**	**0.161**	~~0.337~~	**0.229**
Cat A.2	**0.044**	**0.047**	**0.049**	**0.050**	**0.045**	**0.032**	~~0.052~~	**0.045**
Cat A.3	**0.033**	**0.036**	**0.037**	**0.038**	**0.034**	**0.024**	~~0.039~~	**0.035**
Cat A.4	**0.052**	**0.073**	**0.106**	**0.127**	**0.072**	**0.113**	~~0.109~~	**0.069**
Cat B.1	**0.181**	**0.204**	**0.225**	**0.239**	**0.197**	**0.148**	~~0.272~~	**0.212**
Cat C.1	**0.141**	**0.159**	**0.176**	**0.187**	**0.167**	**0.117**	~~0.215~~	**0.173**
0.2 EY Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	**38**	**38**	**49**	**69**	n/a	**50**		
25 minute	**39**	**45**	**68**	**85**		**50**		
4.5 hour	**40**	**56**	**66**	**77**		**49**		
Synthetic							~~65~~	n/a
1% AEP Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	**43**	**52**	**70**	**83**	n/a	78		

25 minute	**52**	**65**	**82**	**82**		78		
4.5 hour	**62**	**73**	**81**	**84**		78		
Synthetic							~~78~~	n/a

* The ERM does not run with the total area assumption and ARR87 storms

The three alternative ERM combinations demonstrate how this model produces different peak flows depending on the assumptions and rainfall inputs applied. The last of the three variations provides peak flowrates that are the same as the rational method estimates.

Table 8.13 also displays the volumes of hydrographs generated for selected storm patterns. These are expressed as a percentage of the total rainfall in these patterns. The ILSAX models show a spread of volumes depending on AMCs and storm durations, while the ERM results show consistent volumes of 65% for 5 year ARI and 78% for 100 year ARI. These percentages are the weighted average C values obtained from the impervious and pervious coefficients. The ERM assumes that the volumetric coefficient (ratio of total runoff to total rainfall) is the same as the runoff coefficient used to define peak flowrates.

A designer at Gymea using a (Soil Type, AMC) combination of (3, 3) or (3, 4) would generally generate greater volumes than from the ERM. If the results were applied to a detention basin design, a larger storage would be required when the ILSAX mode is used. Similar variations in ILSAX model results to those caused by AMC occur when Soil Types are changed, although the extent of variations is not as great.

To check whether these results apply in other parts of Australia, the analysis has been applied using rainfall and parameter values applying at a location with higher rainfalls, the suburb of Manly in Brisbane, and a site with lower rainfall – Port Adelaide, South Australia. Results from models adapted from the Gymea model are shown in Table 8.14 and Table 8.15.

At Manly, the 10 year ARI, 1 hour rainfall intensity of 68 mm/h leads to pervious area runoff coefficients of C_{10} = 0.67, C_5 = 0.64 and C_{100} = 0.80. An AMC of 3 is used for comparisons. The impervious area coefficients are the same as at Gymea, and the comparative results are similar to those at Gymea, with the ILSAX models giving higher peak flows and volumes.

At Port Adelaide, the 10 year ARI, 1 hour rainfall intensity of 24.5 mm/h defines pervious area runoff coefficients of C_{10} = 0.10, C_5 = 0.095 and C_{100} = 0.12. The Soil Type is assumed to be 2, reflecting sandy soils, and combined with the lower rainfall intensities, runoff can be assumed to be much lower than at Gymea and Manly. The ILSAX estimates in Table 8.15 are generally below the rational method peaks and volumes. Even if the AMC is set at 3, the rational method estimates are still slightly higher, although the differences in flows and volumes are small.

These comparisons are provided as information for designers and reviewers. It is beyond the scope of this Guide to argue the merits of the individual models.

(b) Comparisions with the IL-CL Model

We plan to extend these comparisons to include that ARR 2016 IL-CL model. However, we are awaiting the provision of additional loss data from the ARR Team.

8.4 Storage Routing Models

Traditionally, storage routing or 'runoff routing' models such as RORB, RAFTS and WBNM have been used for flood studies for larger rural catchments and somewhat smaller semi-urban catchments. These models were introduced in the 1970s as computer models became more widely-used than previously, and methods for modelling urban areas became more important.

Previous models, notably synthetic unit hydrograph procedures, provided a flow estimate at the outlet to a catchment. By dividing the catchment into sub-areas, the storage routing models provided flood estimates at several points throughout the stream system. They also allowed hydrological losses to be varied across the catchment area, reflecting various soil types. Since these models are essentially networks of storages, detention basins and reservoirs can be easily incorporated.

RORB, RAFTS and WBNM belong to a class of models termed runoff routing models, which also includes models based on unit hydrograph and kinematic wave calculations. Runoff routing models can 'route' a

hydrograph from one geographical location to another, allowing for changes such as translation and attenuation of the hydrograph, as shown in Figure 8.17.

Table 8.14 Comparison of Flowrates and Volumes Generated by
Manly, Queensland Pipe System Models

Sub-Catchment	Hydrological Model							
	ILSAX with Soil Type of 3 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	Separate areas, Synthetic	Total areas, Synthetic
5 Year ARI Flowrates (m^3/s)								
Cat A.1	0.179	0.231	0.292	0.329	0.209	0.254	0.237	0.209
Cat A.2	0.038	0.040	0.041	0.042	0.034	0.034	0.034	0.034
Cat A.3	0.029	0.030	0.031	0.032	0.026	0.026	0.026	0.026
Cat A.4	0.038	0.064	0.098	0.120	0.08	0.085	0.081	0.08
Cat B.1	0.170	0.197	0.226	0.245	0.171	0.199	0.185	0.171
Cat C.1	0.139	0.160	0.184	0.193	0.136	0.153	0.146	0.136
100 Year ARI Flowrates (m^3/s)								
Cat A.1	0.367	0.429	0.483	0.512	0.416	0.465	0.466	0.416
Cat A.2	0.063	0.065	0.067	0.068	0.066	0.066	0.066	0.066
Cat A.3	0.048	0.050	0.051	0.052	0.05	0.050	0.050	0.050
Cat A.4	0.111	0.149	0.181	0.196	0.163	0.167	0.165	0.163
Cat B.1	0.305	0.336	0.366	0.385	0.332	0.361	0.362	0.330
Cat C.1	0.247	0.267	0.281	0.290	0.262	0.274	0.283	0.261
5 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	38	44	61	75	n/a	73		
25 minute	46	60	76	87		73		
4.5 hour	50	63	75	82		73		
Synthetic							73	73
100 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	50	62	75	84	n/a	89		
25 minute	63	74	85	92		89		
4.5 hour	71	78	85	89		89		
Synthetic							89	89

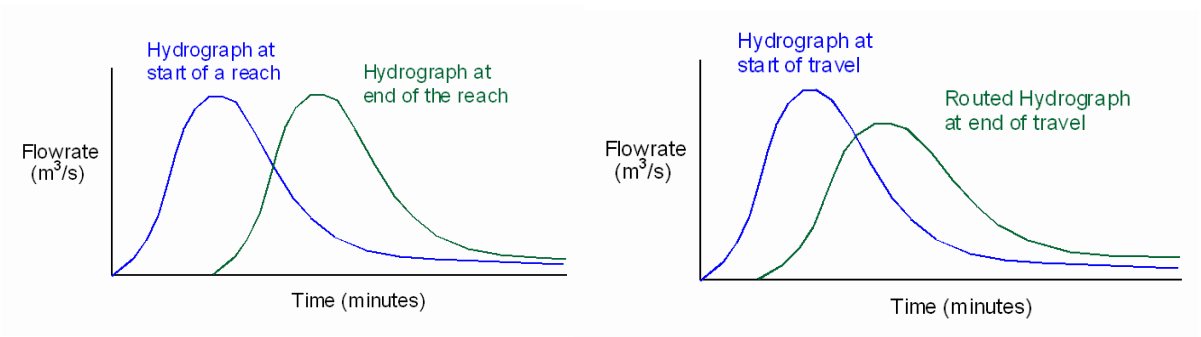


Figure 8.17 Translation and Attenuation Effects on Hydrographs

Table 8.15 Comparison of Flowrates and Volumes Generated by Port Adelaide Pipe System Models

Sub-Catchment	Hydrological Model							
	ILSAX with Soil Type of 2 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	Separate areas, Synthetic	Total areas, Synthetic
5 Year ARI Flowrates (m^3/s)								
Cat A.1	0.046	0.046	0.046	0.056	0.054	0.054	0.056	0.054
Cat A.2	0.014	0.014	0.014	0.014	0.012	0.012	0.012	0.012
Cat A.3	0.011	0.011	0.011	0.011	0.009	0.009	0.009	0.009
Cat A.4	0.007	0.007	0.009	0.009	0.009	0.01	0.01	0.009
Cat B.1	0.051	0.051	0.051	0.058	0.052	0.052	0.053	0.052
Cat C.1	0.042	0.042	0.042	0.047	0.044	0.041	0.045	0.044
100 Year ARI Flowrates (m^3/s)								
Cat A.1	0.112	0.122	0.122	0.208	0.152	0.153	0.159	0.152
Cat A.2	0.033	0.033	0.033	0.040	0.034	0.034	0.034	0.034
Cat A.3	0.025	0.026	0.026	0.031	0.026	0.026	0.026	0.026
Cat A.4	0.015	0.017	0.017	0.087	0.025	0.025	0.029	0.025
Cat B.1	0.112	0.114	0.114	0.169	0.145	0.133	0.147	0.145
Cat C.1	0.092	0.097	0.097	0.134	0.123	0.111	0.125	0.123
5 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	33	33	33	33	n/a	42		
25 minute	37	37	37	40		42		
4.5 hour	38	38	38	38		42		
Synthetic							42	42
100 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	37	37	37	61	n/a	50		
25 minute	38	38	38	71		50		
4.5 hour	39	39	39	56		50		
Synthetic							50	50

The basic non-linear model used in Australian storage routing models was developed by Eric Laurenson. RORB, a practical computer application of this model, was produced by Eric Laurenson, Russell Mein and Tom McMahon at Monash University, Melbourne in the mid-1970s. At the same time, the RSWM (Regional Stormwater Model) was developed by Allan Goyen of Willing & Partners and Tony Aitken of SMEC. These models were immediately popular, as they filled a need for modelling mixed rural and urban catchments, allowing for soil and rainfall variability, and providing flow estimates at points throughout the catchment. In 1979, they were followed by the WBNM (Watershed Bounded Network Model) of Michael Boyd, David Pilgrim and Ian Cordery.

Initially, these models were run on mainframe and mini computers. RAFTS (Runoff Analysis and Flow Training Simulation), an enhanced version of RSWM, was released in 1983 and sold commercially by Willing & Partners (later WP Software and XP-Software). This includes continuous modelling processes as well as the storage routing model discussed here. A version for PCs was released in 1987. A PC version of RORB was released in 1988.

WBNM was revised in 1987 and a new version was produced by Michael Boyd, Ted and Rudy VanDrie in 1994, which modelled urban catchments. WBNM2000, introduced in 1999, used a different structure to earlier models and added many features.

Storage routing calculations are carried out over a series of time steps, with the information obtained from solving equations at one time step being used as an input to the next step. Each of the models available in DRAINS has been developed on different principles. RORB performs calculations based on the equation:

$$S = k_c \,.\, k_r \,.\, Q^m = k_c \,.\, (l_i / l_c) \,.\, Q^m \qquad \text{… (Equation 8.12)}$$

where S is storage (m^3),
k_c and m are parameters, with m being in the range 0.65 to 0.85,
k_r is a routing factor for a particular sub-catchment, being the ratio of the stream length running through that sub-catchment, l_i, and the average flow distance from sub-catchments to the catchment outlet, l_c, calculated by dividing the sum of catchment areas multiplied by their distances from the outlet by the total catchment area, $\Sigma(A_r.d_r) / A$, and
Q is flowrate (m^3/s).

k_c acts as a calibration parameter, enabling the model's results to be varied and fitted to recorded hydrographs. A k_c of 0.0 will perform no routing, so that values of rainfall excess and flows from upstream storages will pass through a sub-catchment unchanged. A k_c that is very large will delay flows considerably, so that flowrates will be very low. By adjusting k_c, the peak of a calculated hydrograph can be varied over the range from the peak rate of rainfall excess to zero. Decreasing k_c increases flowrates.

Allowance is made for different channel conditions by multiplying the routing factors by the values in Table 8.16, in which S_c is the reach slope (%).

Table 8.16 Reach Adjustment Factors in RORB Model

Reach Type	Multiplier
Natural	1.0
Excavated and unlined	$1/(3S_c^{0.25})$
Lined or piped	$1/(9S_c^{0.5})$
Drowned (by a reservoir)	0.0

The routing through a sub-catchment in a RORB model will depend on the length of the stream channel through the sub-catchment and the average distance to the outlet, l_c. When combining a RORB model with an ILSAX model, the lengths of channels and pipes in the ILSAX model will be used to calculate lc. If a k_c value from a stand-alone RORB model is used in this case, it will result in an incorrect routing calculation. It will be necessary to use a different k_c that can be derived or by dividing the k_c derived for a stand-alone model by l_c for the new model multiplied by l_c for the original RORB model. Since DRAINS does not reveal the lengths to outlets, it will be easiest to determine a new k_c by trial and error, matching the peak flowrates defined by the original model.

For sub-catchment routing, RAFTS uses the equation:

$$S = BX \,.\, IBFL \,.\, PERN \,.\, 0.285\, A^{0.52} .\, (1+U)^{-1.97} .\, S_c^{-0.50} .\, Q^{0.715} \qquad \text{… (Equation 8.13)}$$

where BX is a calibration factor similar to RORB's k_c,
IBFL is a factor for modelling overbank flow,
PERN is a factor that adjusts the catchment routing factor to allow for catchment roughness,
A is the sub-catchment area (km^2),
U is the fraction of the catchment that is urbanized, and
S_c is the main drainage slope of the sub-catchment.

For routing along stream reaches, RAFTS applies a translation over a nominated time, or performs Muskingum-Cunge routing based on the stream cross-section and roughness.

For sub-catchments, WBNM uses the routing equation:

$$S = 60 \,.\, LP .\, A^{0.57} .\, Q^{0.77} \qquad \text{… (Equation 8.14)}$$

where LP is a lag parameter and A is catchment area (ha).

Values of the WBNM lag parameter are typically between 1.3 and 1.8. This can be used to calibrate the model in a similar way to the RORB parameter, k_c. WBNM2003 also allows for translation and Muskingum routing in stream reaches.

For stream reaches, a similar equation is used:

$$S = 0.6.\ 60\ .LP.A^{0.57}.Q^{0.77} \qquad \text{… (Equation 8.15)}$$

with the 0.6 allowing for the routing effects in the reach, the length of which is related to the area of the catchment through which it runs, A. A stream lag factor can be applied to allow for different types of channel. Indicative values are shown in Table 8.17.

Table 8.17 Stream Lag Factors used in WBNM

Reach Type	Stream Lag Factor
Natural channel	1.0
Gravel bed with rip-rap	0.67
Excavated earth	0.5
Concrete lined	0.33
Drowned (by a reservoir)	0.0
No lag, artificial link	0.0

Modelling facilities based on RORB, RAFTS and WBNM have been included in DRAINS. The three models have different structures, as shown in Figure 8.18: RORB has a well-defined structure, with nodes located close to sub-catchment centroids. Routing is only carried out in the stream reaches. There is modelling of losses at nodes but no routing.

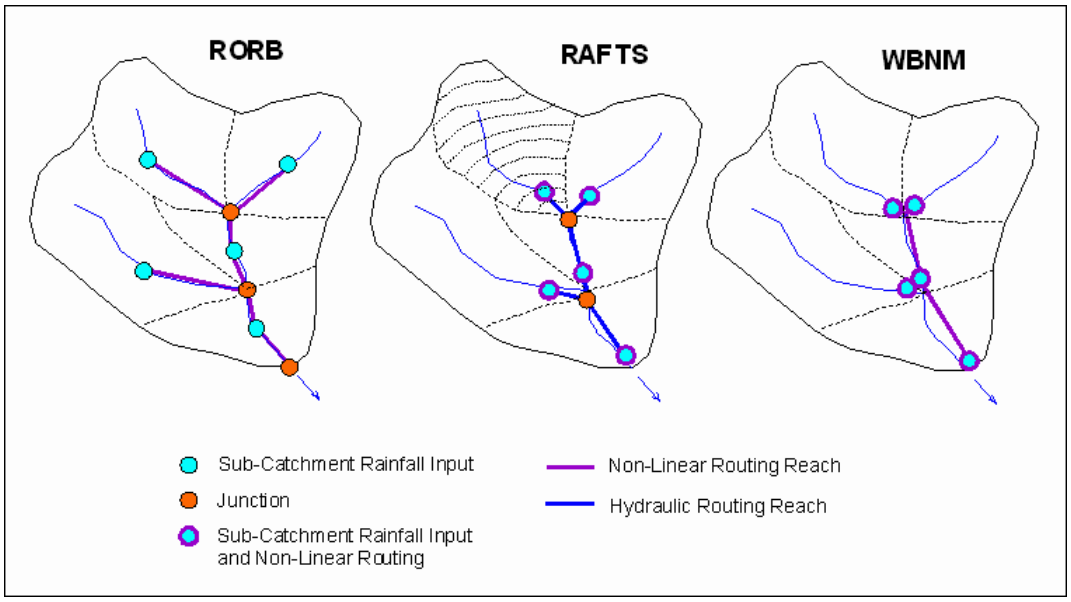


Figure 8.18 Structure of Three Storage Routing Models

By contrast, RAFTS can carry out routing at nodes representing sub-catchments, and also in stream reaches, where flows can be translated or routed using the Muskingum-Cunge method, based on the reach cross-section and roughness. The routing within sub-catchments differs from RORB and WBNM in that flows are commonly routed through 10 successive non-linear storages, as indicated in one of the sub-catchments in Figure 8.18.

In WBNM, routing occurs at the sub-catchment nodes and in stream reaches that convey runoff from upstream sub-catchments through the local sub-catchment. Like RAFTS, it is flexible, and can be set out in different configurations.

To fit these different structures into the DRAINS framework, it has been necessary to apply different property sheets and relationships between model sub-catchments and stream routing reaches. These are described in Chapter 2. For stream channels, routing can also be undertaken by methods such as the Muskingum Method, lag and route methods, Muskingum-Cunge routing and hydraulic routing using

methods such as kinematic wave calculations. DRAINS employs the latter in RAFTS-style stream routing reaches, following a method given in Chapter 9 of *Open Channel Hydraulics* by F.M. Henderson (1966).

The three storage routing models in DRAINS were made available in DRAINS to model rural or largely-rural catchments. The time-area procedure used by ILSAX has not been calibrated to rural catchment data, while the other three have been extensively tested and used in rural environments, and are supported in *Australian Rainfall and Runoff*, 1987.

The emulations of the models will give similar answers to the original RORB, RAFTS and WBNM models, but there may be differences in flowrates due to different computational procedures and the many different features in the operation of these models. For example, the RAFTS model in DRAINS is simpler and has less features that the xprafts program provided by xp solutions. Designers and reviewers will need to ensure that the correct parameters for a location are applied. These may come from published relationships such as those in Chapter 9 of ARR87 (Book 5, Section 3 of the 1998 version), or by calibrating the storage routing model to rural model peak flow estimates from Chapter 5 of ARR87 (Book 4, Section 1 in the 1998 version).

8.5 Pit Inlet Capacities

8.5.1 General

The inlet capacity of pits is a vital factor in the modelling of piped stormwater drainage systems in major storm events, separating surface overflows from underground pipe flows. Pits can be distinguished by their *form*, as grated pits, kerb inlets, or as combinations of these. The latter two types are preferred in Australia. Pits can also be distinguished by the situation in which they are applied. On-grade pits, shown in Figure 8.19, are located on slopes in a channel such as a street gutter, with water flowing to them, and with any bypass flows escaping. Sag pits are located in hollows or depression, where the incoming flows for a pond over the pit. These situations are hydraulically different and different forms of relationships are used to describe their inlet capacities.

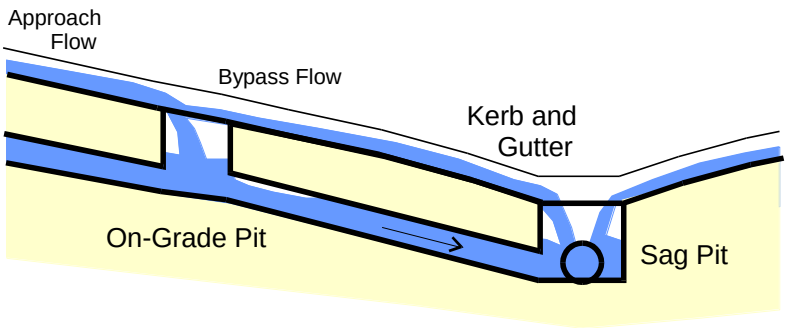


Figure 8.19 On-Grade and Sag Pits

On-grade pit inlet capacities are defined as a relationship between the inlet flow or capture and the approaching flow. This flow is affected by the road cross-section properties and its longitudinal slope, as well as the characteristics of the inlet. Different road and gutter cross-sections and roughnesses will create different widths and velocities of flow approaching the pit. Since there is no direct theoretical relationship covering all of these factors, empirical relationships have been established from laboratory tests and field observations.
Figure 8.20 shows the relationships for kerb inlets on grade measured in hydraulic model studies published by the N.S.W. Department of Main Roads (1979). As the magnitude of the approach flow increases, the percentage of the flow captured will decrease. This is represented by the curved line becoming gradually flatter and crossing the dotted lines that indicate various percentages of capture.

Sag pits can be modelled more easily, as the theory of weir and orifice flow can be applied to relate inlet capacities to depths of ponding. Experimental investigations have confirmed the following weir equation given in *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987, page 303).

$Q_i = 1.66 \cdot P \cdot d^{1.5}$ up to about 0.12 m of ponding … (Equation 8.16)

where Q_i is inlet flowrate (m^3/s),
P is the perimeter length of a grated pit, excluding the section against the kerb, and
d is the average depth of ponding (m).

Orifice flow can occur above 0.12 m for a grate and 1.4 times the slot height for a kerb inlet, though there is a large transition zone for grates, in which either flow mechanism may occur. Most cases of interest to designers, including major flows, are described by the weir equation.

At low flows all of the approach flow will be captured, but at a certain flow, some bypass will start to occur.

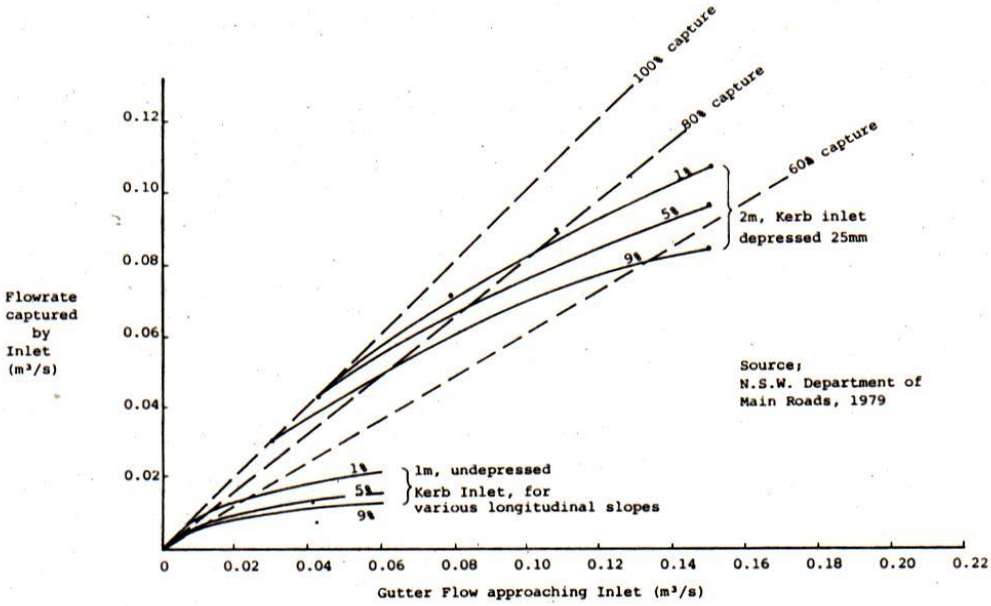


Figure 8.20 Entry Capacities for Kerb Inlets on Grade

There have been many sets of hydraulic tests undertaken to define inlet capacities. Tests have been conducted in Australia by the NSW Public Works Department for the NSW Department of Main Roads (now NSW Roads and Maritime Services) and NSW Department of Housing, by the University of South Australia for various Queensland, Australian Capital Territory and South Australian bodies, and by the Victorian Country Roads Board (VicRoads). These have produced a rather confusing array of results, from which it is difficult to generalise.

In addition, the published relationships do not cover the range of high flows expected to occur in severe storm events such as 100 year average recurrence interval and probable maximum precipitation events. Almost all studies were intended to develop relationships for routine design, and did not deal with very high flows. Extrapolation of these relationships is an uncertain process.

The main factors influencing inlet capacity of on-grade pits are the length of the pit, the depression or crossfall of the gutter at the pit, and the longitudinal slope. Generally the greater the longitudinal slope, the lower the capture rate. Pit size and grate type are the main factors affecting sag pit capacities.
The US Federal Highway Administration Hydraulic Engineering Circular No. 22, *Urban Drainage Design* (2009) includes a set of semi-theoretical procedures for defining inlet capacity relationships. Pezzaniti, O'Loughlin and Argue (2005) have used these as a basis for extrapolating existing relationships, and for developing relationships where none are available.

8.5.2 Pit Inlet Capacities in DRAINS

At every time step in DRAINS calculations, the program applies pit inlet capacity relationships to the surface flow arriving at each inlet. If the flowrate arriving at an on-grade pit causes the storage to exceed its specified volume, the surplus flow becomes a bypass. If overflows occur due to limitations on pipe reach capacity, these are added to the bypass flows.

Two types of entry conditions can be modelled in DRAINS:

- sag pit, at a low point where water will pond, up to some limit, with any overflows being directed downstream or out of the system, when the ponded water level rises to the spill level.
- on-grade inlet, on a sloping gutter, from which any flows bypassing the inlet can run away, with bypasses or overflows being directed to downstream pits or out of the system.

At one stage there was also an ILLUDAS pit type that no longer appears in DRAINS. It is described in the Help System.

Initially, DRAINS followed ILSAX (O'Loughlin, 1993) by using equations employing various curve-fitting factors, but this approach was superseded by inlet capacity relationships defined as a series of points, as shown in Section 5.4.6, rather than by equations. Further information is given in the DRAINS Help system. Sets of inlet capacity relationships are available to users of DRAINS in the new format. These were obtained from published sources, mostly smoothed graphs fitted to experimental data from the testing rigs operated by the University of South Australia (www.unisa.edu.au/uwrc/rig.htm) and the New South Wales Government Manly Hydraulics Laboratory (http://mhl.nsw.gov.au/www/welcome.html).

The new relationships have been extrapolated well beyond the ranges of the published relationships using hydraulic principles, allowing for approach flows up to 2.5 m^3/s for on-grade pits and depths of ponding of up to 0.6 m for sag pits. None of these relationships have been approved by the originating authorities. It is up to each user of DRAINS to determine whether they are suitable for their purposes. Users can readily modify the relationships.

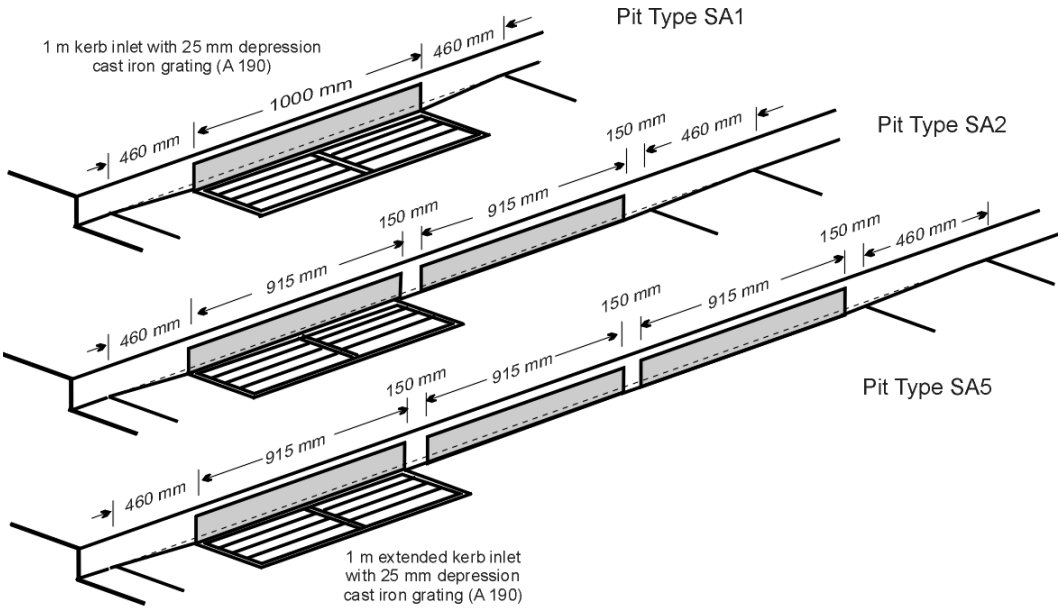
The available relationships for New South Wales apply to the pits described in Table 8.18.

Table 8.18 New South Wales Pits

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
NSW Roads and Maritime Services, (formerly called the RTA and DMR) pits (DMR, 1979; O'Loughlin, Darlington and House, 1992) and tests carried out for the RTA in the 1990s	SA1	1.0 m wide x 0.15 m high	1 m x 0.45 m	A kerb inlet-grate combination depressed by 25 mm below normal gutter levels
	SA2	1.83 m wide x 0.15 m high	0.915 m x 0.45 m	As above
	SA3	2.745 m wide x 0.15 m high	0.915 m x 0.45 m	As above
	SF1	Median pit with cover	none	As above
	SO V-Channel	None	0.7 x 0.7 m or 0.7 x 1.4 m	V shaped pits located in V-Channels
	SK V-Channel	None	0.825 x 0.7 m or 0.825 x 1.4 m	V shaped pits located in V-Channels
Hornsby Council Pits	0.9, 1.2, 1.8, 2.4, 3.0, 3.6 and 4.2 m wide lintel	0.9, 1.2, 1.8, 2.4, 3.0, 3.6 or 4.2 m wide x 0.15 m high	0.915 m x 0.45 m	Essentially the same type as the RTA Pits
NSW Dept. of Housing (1987) RM10 Pit	1.68, 1.8, 2.4 or 3.0 m lintel	1.68, 1.8, 2.4 or 3.0 m wide by 0.15 m high	0.9 m x 0.5 m	A similar type of pit to the RTA pits
NSW Dept. of Housing (1987) RM7 Pit		none	0.9 m x 0.5 m	A grated pit used on accessways
Sutherland Shire Council (1992)	0.85, 1.2, 1.8, 2.4 and 3.0 m lintel	0.85, 1.2, 1.8, 2.4 and 3.0 m wide by 0.15 m high	0.9 m x 0.5 m	No grate or Durham Cast iron grate

The set of pits shown in Figure 8.21 was the basis of both the RMS (RTA) and Hornsby Council relationships, which have different forms. The former allows for longitudinal slopes while the latter provides a single relationship for all slopes.

Relationships developed for Australian Capital Territory are detailed in Table 8.19



NSW Road and Traffic Authority Kerb Inlets with Depressed Grates, tested in 1979

Figure 8.21 Type SA1, SA2 and SA5 Pits tested for the NSW Department of Main Roads

Table 8.19 ACT Pits

(Source: ACT Government *Urban Stormwater, Standard Engineering Practices*, Edition 1, www.act.gov.au/storm/)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Sump	QS	0.6 m long	none	Only for sags, in three types of gutters
Sump	R	1.3 m long	none	In three types of gutters: KG, MLBK & MKG
Sump	Double R	2.6 m long	none	As above
Sump	Triple R	3.9 m long	none	As above

Victorian relationships obtained by extrapolating the curves given in the VicRoads *Road Design Guidelines Part 7, Drainage*, 1995 are available for the pits shown in Table 8.20.

Table 8.20 Victorian VicRoads Pits

(Source: VicRoads Manual)

Pit Type	**Size**	**Kerb Inlet Dimensions**	**Grate Size**	**Comments**
VicRoads	1.0 and 1.5 m side entry pits	1.0 and 1.5 m wide by 0.10 m deep	none	
VicRoads	1 m grated inlet pit	none	Transverse grates A & B - 1.0 m wide x 0.75, 1.0, 1.5, 2.0 or 2.5 m long	
VicRoads	Grated side entry pit	1.0 m wide x 0.1 m deep	assumed 1.0 m x 0.45 m	

Queensland relationships are outlined in Table 8.21. Queensland has the most comprehensive data of any Australian state. There has been an extensive revision of the original Queensland 2003 relationships, because of the introduction of new pit types and relationships, and new extrapolation procedures.

Table 8.21 Queensland Pits

(2008 Version, Various sources, see Column 1)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Brisbane City Council Pits (from BCC Standard Drawings)	S, M and L, nominally 2400, 3600 and 4800 mm lintel lengths	lintels - 2.04, 3.24 and 4.44 m long x 0.12 or 0.14 m deep	0.90 m x 0.61 m	Separate lip in line (recessed) relationships for D (mountable) and E (barrier) kerbs and two sets of kerb in line relationships for both D & E kerbs. The new relationships supersede the older ones that appear in the DMR *Road Drainage design Manual* (2002) and other manuals. Relationships are given for 2.5 and 3.3% crossfalls and grades from 0.25% to 16% plus sags.
Gold Coast City Council Pits (from GCCC Manuals)	As above	As above	0.90 m x 0.50 m	Separate lip in line relationships for (a) barrier or roll-top kerbs and (b) transverse or longitudinal grates, (c) 2.5% or 3% crossfalls and (d) grades from 0.25% to 16% and sags.
Max Q Drainway Plus (from Max Q catalogue, 2003)	0TP/X, 1TP/X, 2TP/X and 3TP/X	1.0, 2.3, 3.6 and 4.0 m wide x 0.1 m deep lintels	0.66 m x 0.614 m Maxflow and Mannflow Grates or Draincover	With (a) mountable kerb, barrier kerbs with 300 mm and 450 mm channels, (b) 2.5% or 3% crossfalls, (c) 0.25 to 16% grades and sags.
Max Q Stormway (from Max Q catalogue, 2003)	S1000/A, S1600/A, S2400/A, S3600/A and S4800/A	1.0, 2.3, 3.6 and 4.0 m wide x 0.1 m deep lintels	0.85 x 0.51m Macadam, Manning, Grates or Stormcover	With (a) mountable kerb, rollover kerb, barrier kerbs with 300 mm and 450 mm channels, (b) 2.5% or 3% crossfalls, (c) 0.25 to 16% grades and sags.
Max Q Stormway (catalogue)	S1000/H	1.0 m lintel	0.675 x 0.31 m Hazen Grate	For mountable kerbs, 2.5 and 3% crossfalls and grades from 1% to 16% and sags
Humes Drainway Pits (obsolete)	0TC, 1TC, 2TC and 3TC	1.35, 2.7, 4015 and 5.4 m wide x 0.14 m deep	One or two 0.5 m x 0.5 m Hydraflow grate or infill cover	A modular system built around one or two pits with grates
BroPit (obsolete)	1C0T, 1C1T, 1C2T	0.75 m, 2.1 m and 3.45 m wide x 0.10 m deep	none	A modular system made up of pits (C) and troughs (T)
DMR Field Inlet	Single and double	-	0.6 x 0.9 m or 0.6 x 1.8 m	Nominally for sags only, but an on-grade relation assuming 1% grade is included

South Australian relationships are provided in Figure 8.17. Relationships for Western Australian and Tasmanian Pits derived using US Federal Highway Administration HEC-22 procedures are shown in Table 8.23 and

Table 8.24.

For both on-grade and sag pits, a choke factor can be applied to simulate blockage of the pit. This is 0.0 for no blockage and 1.0 for complete blockage. There is considerable uncertainty about appropriate factors. *Australian Rainfall and Runoff* 1987 indicated typical values of 0.2 for an on-grade pit and 0.5 for a sag. Some Queensland practice applies values of 0.1 for both. It could be argued that a factor of 0.0 should be applied to on-grade pits, which are much less likely to block than sag pits. These are multiplied by the capacity defined by the inlet capacity relationships, whatever magnitude this may be. While this is acceptable for the type of blockage that might occur for sag pits, it may not be realistic for on-grade pits.

If you have doubts about this, it would be better to define the required inlet capacity relationship in the pit data base, and to employ this with a blocking factor of zero.

Table 8.22 South Australian Pits

(Source: html files developed by the Urban Water Research Centre of the University of South Australia)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Transport SA	Single Bay	0.9 m long	none	On-grade relationships with and without deflectors
	Double Bay	1.9 m long	none	On-grade and sag relationships with and without deflectors
City of Adelaide	Single Pit	0.9 m long	0.5 m long x 0.54 m wide	On-grade and sag
	Double Pit	1.9 m long	As above	Sag only
City of Campbelltown	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors
City of Charles Sturt	Single Pit	0.9 m long	none	On-grade and sag, with and without deflectors and transitions
	Double Pit	1.9 m long	none	As above
City of Marion	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors
City of Mitcham	Single Bay	0.9 m long	0.9m x 0.45m	On-grade without deflectors
	Double Bay	1.9 m long	none	On-grade and sag, with and without deflectors
City of Onkaparinga	Double Pit	1.9 m long	none	As above
City of Playford	Double Pit	1.9 m long	none	As above
City of Port Adelaide/ Enfield	Double Pit	1.9 m long	none	On-grade, with and without deflectors
	Triple Pit	1.9 m long	none	Different bay arrangement, On-grade, with and without deflectors
City of Salisbury	Double Pit	1.9 m long	none	On-grade and sag,' with and without deflectors
City of Tea Tree Gully	Double Pit	1.9 m long	none	On-grade and sag, without deflectors
City of West Torrens	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors

Table 8.23 Western Australian Pits

(Developed from Department of Main Roads drawings and Generic Spreadsheet using HEC-22 procedures. None are based on measured data.)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Main Roads Side Entry Gully, Type TEN to DEN	Single Gully	0.88 m long	none	On-grade relationships with allowance for deflectors
Main Roads Gully, TGT to DGT	Single Pit	none	0.92 m long x 0.425 m wide	On-grade and sag
Main Roads Normal Catchpit	Single Grate	none	As above	On-grade and sag, assumed to be used in swales
Main Roads High Flow Catchpit	Single Grate	none	As above, 150 mm above surface	As above

Table 8.24 Tasmanian Pits

(Developed from government drawings and Generic Spreadsheet using HEC-22 procedures. No measured data.)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
IPWEA	Single grated Grated deflector Double grated	0.9 m wide 1.865 m wide 1.9 m wide	0.9 x 0.45 m 0.9 x 0.45 m + deflector 1.9 x 0.45 m	At some slopes the double grate pit has the highest capacity; at other grades it is the grated deflector pit
City of Devonport	Double grated extended kerb inlet	1.68 m wide	0.89 x 0.40 m	
Dept. of Infrastructure, Energy & Resources	Mountable kerb	1.0 m wide 1.8 m wide 0.9 m wide	None 0.9 x 0.35 m + deflector 0.9 x 0.35	
	Barrier kerb	As above	As above	
	V-Channel	none	0.98 m x 0.64 m	

8.5.3 US Federal Highway Administration (HEC22) Procedures

The *Hydraulic Engineering Circular No. 22* of the US Federal Highway Administration (2009) (available from www.fhwa.dot.gov/bridge/hyd.htm) contains the only general methodology available for defining inlet capacities for all kinds of rectangular pit. It is applied as a series of equations and procedures, with a semi-theoretical basis. These procedures have been included in a comprehensive 'generic' pit capacity spreadsheet available to DRAINS users and the on-grade pit procedures have been incorporated into DRAINS via wizards located in the Pit Data base opened from the **Project** menu.

For the gutter and pit shown in Figure 8.22, the on-grade procedure shown in Figure 8.23 applies.

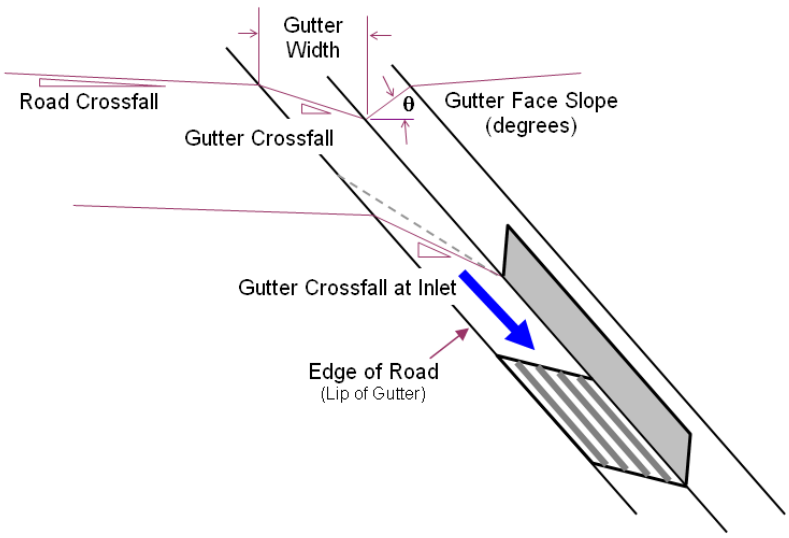
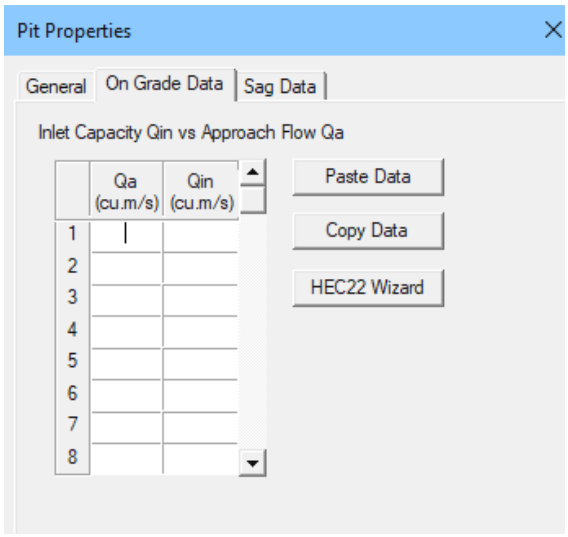


Figure 8.22 Road and Pit Characteristics

Flow is assumed to approach a pit along a gutter. At the pit, the gutter crossfall may become steeper to provide a depression. The pit may be a kerb inlet, a grate, or a combination inlet with both. The latter kerb inlet is assumed to project beyond the grate so that the approaching flow encounters this first. The method requires information on the road cross-section as well as on the inlet characteristics. The grate types detailed in the HEC22 manual are shown in Figure 8.24.



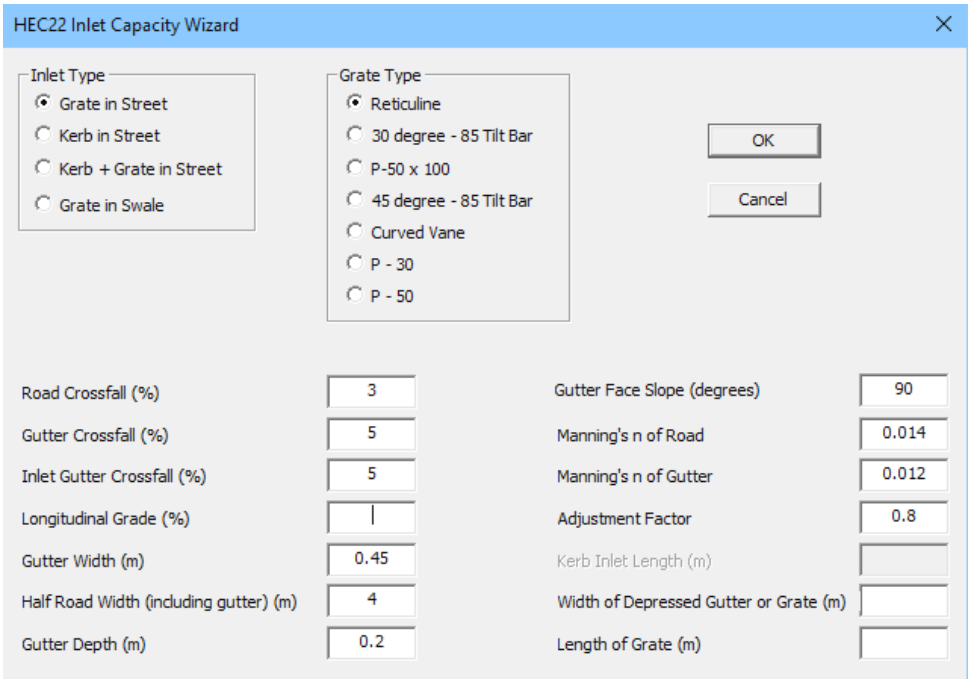


Figure 8.23 HEC22 On-Grade Input Procedure

Once the required data is entered, the required relationship will appear in the Pit Data Base property sheet. This can be checked by copying this and displaying it in a spreadsheet. This procedure can be applied to pits in swales, as well as in street gutters or channels. The dialog box is shown in Figure 8.25, covering the situation shown in Figure 8.26.

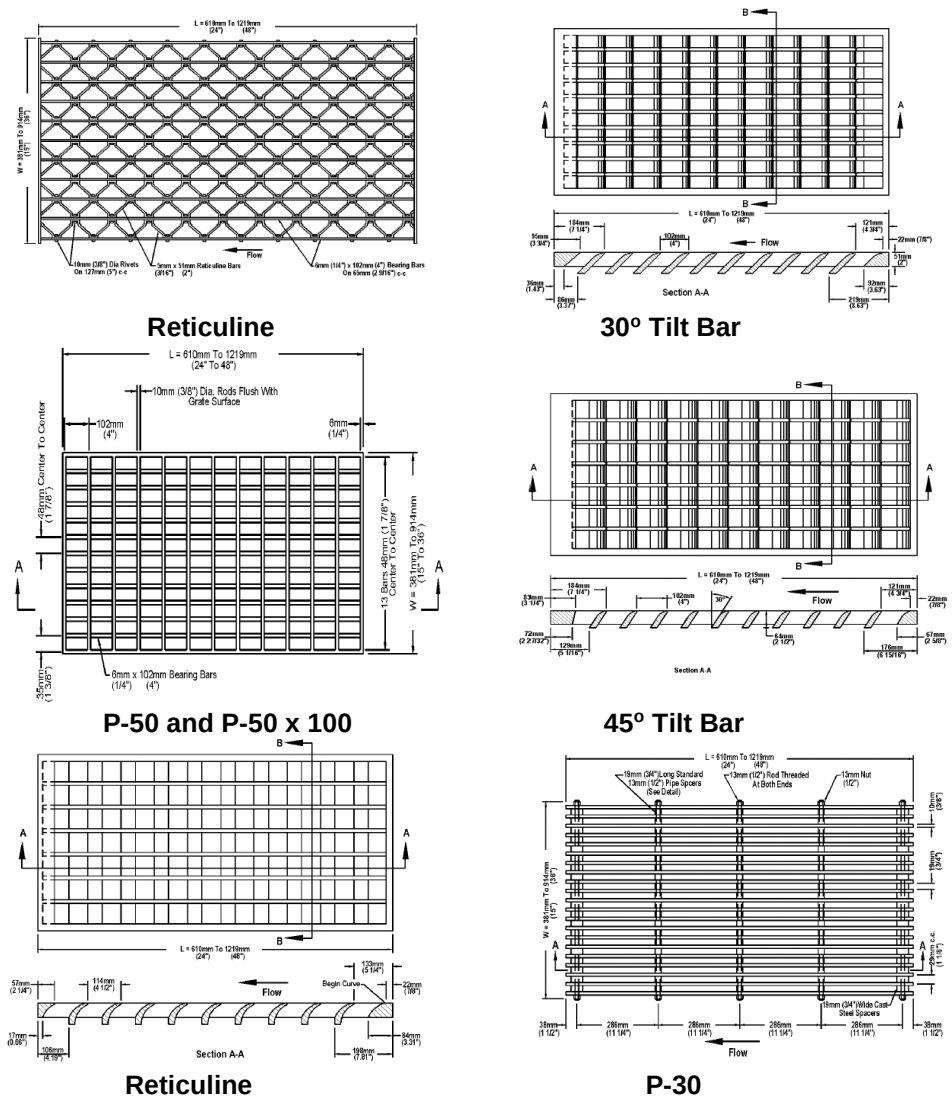


Figure 8.24 HEC22 Pit Types

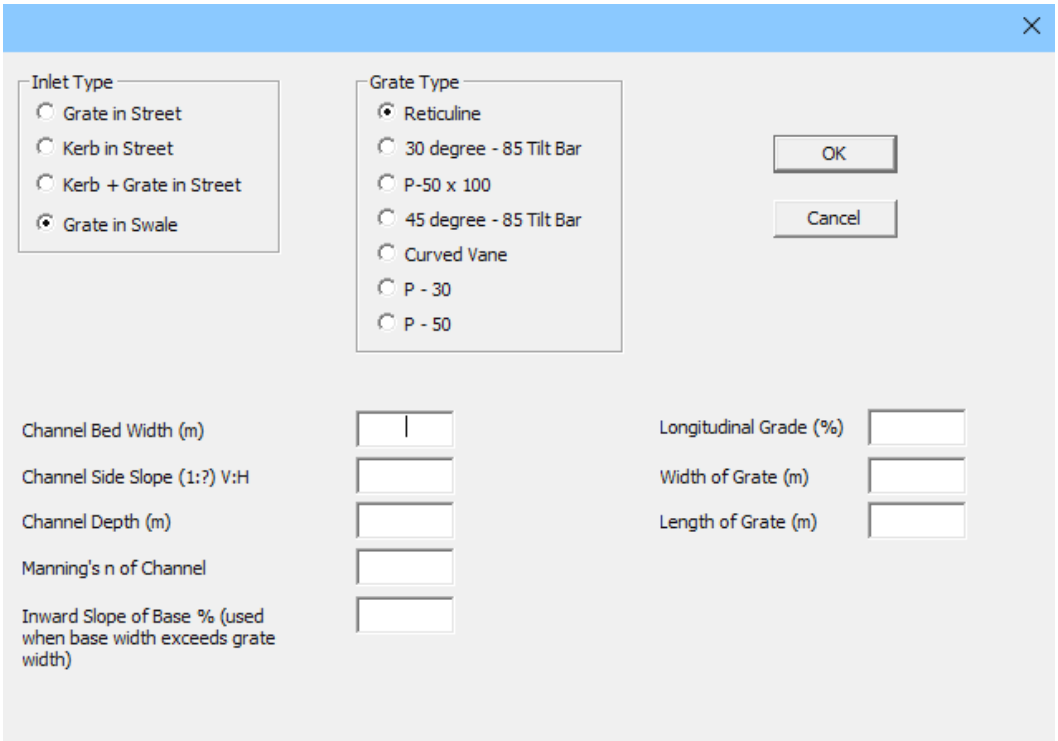


Figure 8.25 Dialog Box for a Pit in a Swale

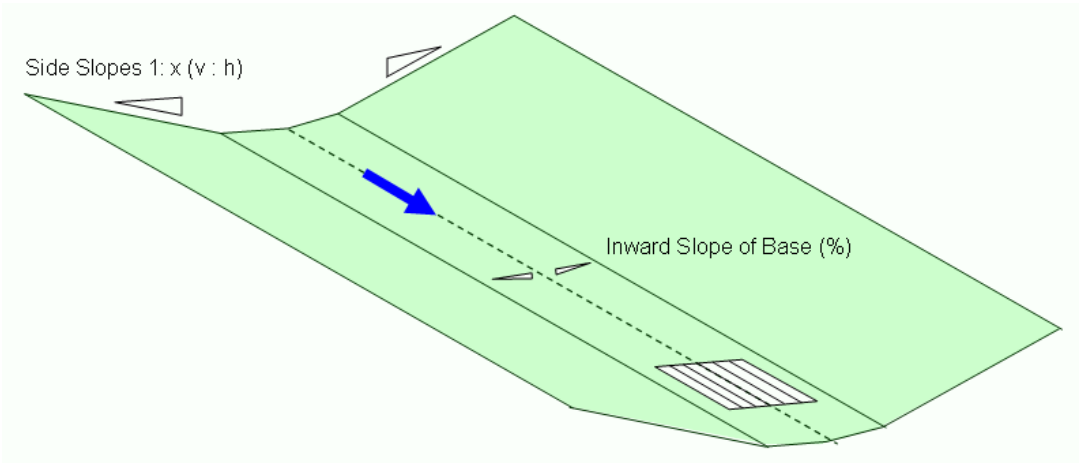


Figure 8.26 Pit in Swale

A similar procedure applies for sag pits. The DRAINS wizard shown in Figure 8.27 only operates for grated inlets. This requires information on grate dimensions. (For kerb inlets or combination (kerb inlet + grate) inlets, you can use the 'generic' spreadsheet supplied to DRAINS users to develop relationships that can be pasted into the DRAINS pit data base.)

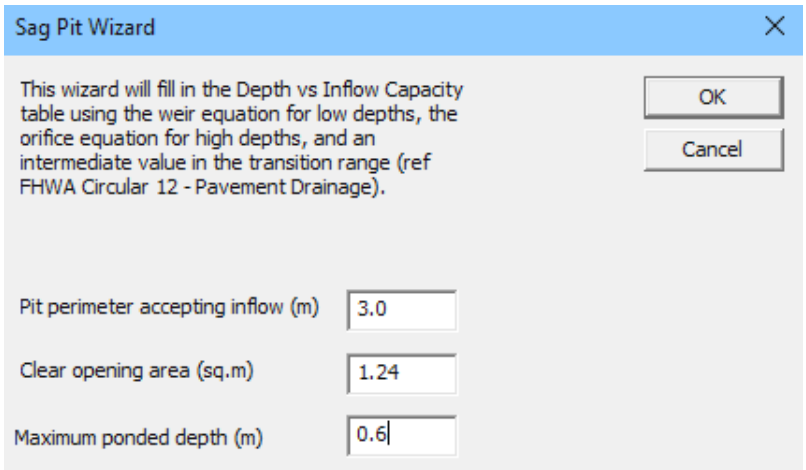


Figure 8.27 Dialog Box for Sag Pit

The calculations associated with these methods produce results that match laboratory results on pit capacities well in some cases, but rather poorly in others. This issue has been studied by Pezzaniti, O'Loughlin and Argue (2005), who produced the assessments of the accuracy of the HEC22 procedures for on-grade pits shown in Table 8.25. This can be used as a guide to adjusting relationships produced by the HEC22 procedure. Adjustments can be made by copying the relationship produced to a spreadsheet, modifying this as required, and then pasting it back into the Pit Data Base table. Using these procedures, it is possible to derive inlet capacity relationships for all types of pits, including unusual or modified ones.

8.6 Pipe System Hydraulics

8.6.1 General

The hydraulic models used in design and analysis of urban stormwater drainage systems can be considered to operate at three levels:

- open channel hydraulics assuming steady flow and normal depth conditions, described as 'pipe full but not under pressure' in Australia,
- part- or full-pipe flow calculations determining hydraulic grade lines (HGLs) and water surface profiles,
- full hydrodynamic modelling, usually involving a finite difference solution of the partial differential equations for conservation of mass and momentum, the St. Venant Equations.

ILSAX calculations operate at the first level, so their hydraulics is quite limited. The same applies to the calculation of flow characteristics in overflow routes in the standard and obsolete basic hydraulic models.

Table 8.25 Qualitative Indication of the Accuracy of the HEC22 Procedures
(Inlet Capacities from HEC22 Procedure relative to Laboratory Results)

Inlet Type	Approach Flow Range	Approximate Length of On-Grade Inlet		
		1 m or Shorter	Between 1 & 3 m	3 m and Longer
Grate Only	< 0.15 m^3/s	OK	OK	-
Grate Only	0.15 to 0.5 m^3/s	OK	-	
Grate Only	> 0.5 m^3/s	Underestimates by about 25%	-	-
Kerb Inlet Only	< 0.15 m^3/s	25% over for un-depressed inlet, 50% under for depressed	25% underestimate	20% underestimate
Kerb Inlet Only	0.15 to 0.5 m^3/s	25% underestimate	33% underestimate	10% underestimate
Kerb Inlet Only	> 0.5 m^3/s	45% underestimate	33% underestimate	OK
Combination with 1 m Grate	< 0.15 m^3/s	OK	OK	OK
Combination with 1 m Grate	0.15 to 0.5 m^3/s	5% overestimate	OK	OK
Combination with 1 m Grate	> 0.5 m^3/s	20% overestimate	20% overestimate	10% underestimate

Velocities, depths and other characteristics are obtained from normal depth calculations using the specified cross-section (from the overflow route cross-section data base), slope and roughness.
The HGL calculations associated with rational method in the urban stormwater drainage chapter of *Australian Rainfall and Runoff*, and those in steady state hydraulics programs such as HEC-2 and HEC-RAS, are at the second level. Several programs, mostly proprietary ones, offer full hydrodynamic modelling options using complex finite difference calculations. These can give the most accurate results with an experienced, hydraulically-knowledgeable operator, but can be subject to stability problems.

8.6.2 Pipe Design Calculations

In a design run, DRAINS determines pipe sizes and invert level positions by calculating the peak flows of hydrographs entering a pipe system and designing for these in a downwards pass, making certain assumptions. The method considers both minor and major storms of different average recurrence intervals. Pit sizes are also designed to keep overflows within safe limits defined in the overflow route data base.

The design procedure must be followed by analysis runs using the same design storms to simulate and display the performance of the system in detail. The designer can than assess whether this is satisfactory, and make further changes and re-runs to refine the system.

8.6.3 Basic Hydraulic Calculations

In DRAINS, the now obsolete basic hydraulic model provided a conservative procedure for tracing hydraulic grade lines through drainage systems, working upwards from tailwater levels at the outlet at each calculation time step. At each time step in an analysis, this model made a pass downwards through the drainage system, determining flows into pits, possible bypass flows and the flows along pipes. It then retraced this path from a specified tailwater level at the system's outfall, determining hydraulic grade lines and water levels in pits. Allowance was made for pipe friction and pit pressure changes, and both part-full and full-pipe flows were modelled. The possibility of water upwelling from pits due to the flow capacity of the downstream pipe system being exceeded was also considered. With this model, DRAINS used a hydraulic engine from the PIPES program to model pressurised flows. It switched to this when pipes surcharged, going from part-full to full pipe flow, and handled the complex timing and flow volume transitions involved in transferring between calculation methods.

8.6.4 Unsteady Flow Calculations in Standard and Premium Hydraulic Models

As noted in Section 7.2.7, the unsteady hydraulic method applied in the standard and premium hydraulic models is quite different to method used by the basic hydraulic model. The unsteady model in DRAINS solves the full St. Venant equations of momentum and continuity using an implicit finite difference scheme with a staggered H, Q grid. This solution scheme is widely used in other software such as SWMM. Links are divided into an odd number of reaches (1, 3, 5, etc.) with DRAINS automatically determining a suitable number to use. When DRAINS reports the flow in a link it is referring to the flow calculated at this central grid point.

The method applies the Saint Venant Equations for conservation of mass and momentum in unsteady flow:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad \text{(Continuity or Mass)} \qquad \text{... (Equation 8.17)}$$

$$\frac{1}{gA}\left(\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(Q^2/A\right) \right) + \frac{\partial H}{\partial x} + S_f = 0 \quad \text{(Momentum)} \qquad \text{... (Equation 8.18)}$$

where Q is flow, A is cross-sectional area,
H is water surface level, t is time,
x is distance along a channel, g is gravitational acceleration,
S_f is friction slope

The calculation procedure applied in DRAINS involves the solution of these equations to determine H and Q at all points in a system at each time step of the simulation. Equations are gathered into a matrix and solved, allowing for different types of boundary conditions imposed by flows entering pipe and channel systems, downstream tailwater levels and the hydraulic features at on-grade and sag pits, headwalls and other features.

In the premium hydraulic model, pipes, open channels and overflow routes are all modelled by the same procedures, based on open channels. Closed pipes can be treated as being open by using a Priessmann slot (Figure 8.28). Each link has a representative cross-section, so it is necessary to divide open channels and overflow routes into separate links where their geometric characteristics change.

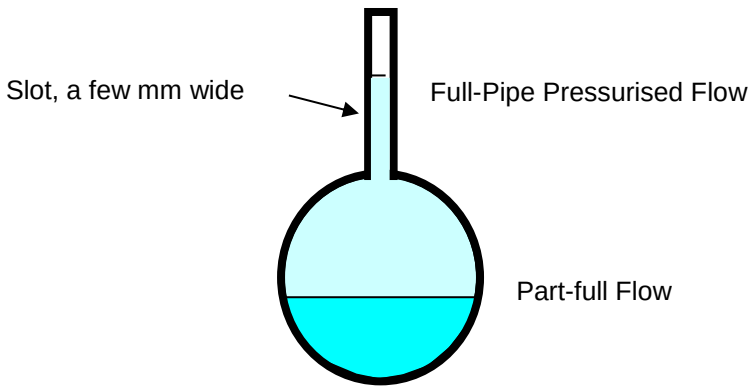


Figure 8.28 Priessmann Slot for Modelling Pipes as Open Channels

At sag pits there will be two HGL levels, one describing the water level in the ponded runoff at the surface and the other describing the pipe HGL.

Calculations for outlet weirs from sag pits, detention basins, headwalls, and culverts use tables of elevation vs. discharge. To cover the situation where tailwater levels below these controls are high, in the premium hydraulic model, DRAINS uses the Villemonte equation to modify the table if the downstream water level is above the weir crest (the level in the table at which Q=0). The Villemonte equation allows for submergence of the weir:

$$Q = C_{df} \cdot C_d \cdot {}^2/_3 \; (2g)^{0.5} \cdot b \cdot h^{1.5} \qquad \text{…(Equation 8.19)}$$

where Q is the flowrate (m^3/s),
C_d is the discharge coefficient (dimensionless),

g is acceleration due to gravity (9.80 m/s^2),
b is the effective width of the weir (m),
h is the effective head (m), and
C_{df} is a drowning factor, equal to $C_{df} = A\,(1 - (h_2/h_1)^{1.5})^n$
where A and n are coefficients,
h_1 is the upstream measured water level above the weir, and
h_2 is the downstream measured water level below the weir.

At headwalls and culverts the flow capacity is often limited by inlet control. All flow models in DRAINS use the equations for culverts and headwalls presented in this manual to check for inlet control at these structures. DRAINS also allows for the specified inlet capacity relationships at on-grade pits as long as these are not submerged.

For sag pits a truncated inverted pyramid shape is assumed, with the base length at the gutter invert level being half that at the overflow level. Alternatively, the user can specify a table of elevation versus surface area. With the premium hydraulic model, users must provide a weir control specification in the Overflow Route property sheet and water can rise above the maximum ponded level. With the standard and basic hydraulic models water does not rise above the maximum ponded level, rather any water above this level is assumed to immediately spill into the overflow route.

8.6.5 Pipe Friction Equations

For circular pipes, you have a choice of the Colebrook-White Equation or Manning's Formula.
The Colebrook-White Equation employs the formula:

$$V = -0.87.\sqrt{2g \cdot D \cdot S} \cdot \log_e\left(\frac{k}{3.7 \cdot D} + \frac{2.51 \cdot \upsilon}{D \cdot \sqrt{2g \cdot D \cdot S}}\right) \qquad \text{.... (Equation 8.20)}$$

where g is gravitational acceleration (m/s^2), generally 9.80 m/s^2 at sea level,
D is diameter (m),
S is energy line slope (m/m),
k is pipe wall roughness (mm), sometimes termed e, and
υ is the kinematic viscosity (taken as 1.14 x 10^{-6} m^2/s at 15°C).

The pipe wall roughness values in Table 8.26 are recommended by Hydraulics Research (1983) and the Standards Association of Australia (1978). Values for other materials are also given in these publications.

Table 8.26 Recommended Colebrook-White Roughnesses, k

Pipe Material	**Hydraulics Research Recommendations: k values** (mm) **for pipe condition:**			**SAA Recommendations: for concentrically-jointed, clean pipes**
	Good	**Normal**	**Poor**	
Concrete				
Precast, with 'O' Ring Joints	0.06	0.15	0.6	0.03 to 0.15
Spun precast, with 'O' Rings	0.06	0.15	0.3	
Monolithic construction, against steel forms	0.3	0.6	0.15	
Monolithic construction, against rough forms	0.6	1.5	-	
Asbestos Cement	0.015-0.03			0.015 to 0.06
UPVC				
Chemically-cemented joints		0.03		0.003 to 0.015
Spigot and Socket Joint		0.06		

Manning's Equation is

$$V = \frac{1}{n}.R^{0.667}\ S^{0.5} \qquad \text{.... (Equation 8.21)}$$

in which V is velocity (m/s),
n is a roughness coefficient
R is the cross-section hydraulic radius (m) (= area / wetted perimeter, A/P), and
S is longitudinal slope (m/m).

8.6.6 Pit Pressure Changes

(a) General

The head losses and changes to the energy grade line and hydraulic grade line at pits and junctions are extremely important in determining pipe system behaviour accurately. Figure 8.29 shows how these are represented by two functions of the pit outlet velocity V_o, for full-pipe flow.

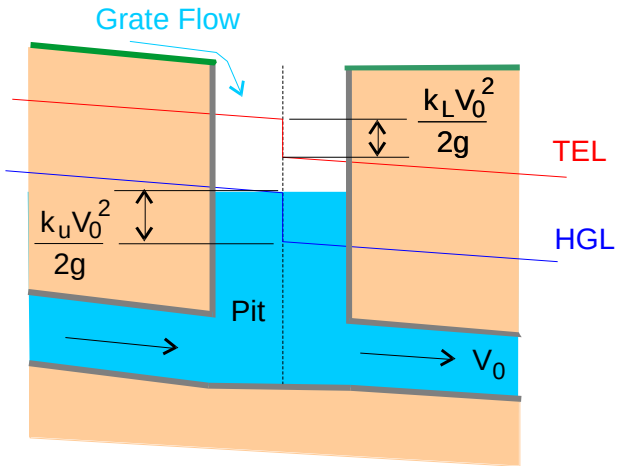


Figure 8.29 Pit Energy Losses and Pressure Changes

The TEL will drop by the amount of the head loss for the pit, which can be expressed as:

$$h_L = k_L \cdot \frac{V_o^2}{2g} \qquad \text{…(Equation 8.22)}$$

where h_L is head loss (m),
k_L is the head loss coefficient (dimensionless),
Vo is the full-pipe velocity in the outlet pipe from the pit (m/s), and
g is acceleration due to gravity (9.80 m/s^2).

More importantly for design, the pressure change is given by:

$$h_u = k_u \cdot \frac{V_o^2}{2g} \qquad \text{… (Equation 8.23)}$$

where h is head loss (m), and
k_u is the head loss coefficient (dimensionless, also expressed as K_u).

Generally k_u is positive, with the HGL dropping down, but it is sometimes negative, with the line rising due to the downstream pipe having a larger diameter and slower velocity than the upper one. This has been termed 'static regain'.

It is assumed that head losses and pressure changes take place at the centre of the pit, while actual losses occur mainly in the outlet pipe just downstream of the pit. Where significant turbulence occurs in the pit, the water level may be higher than the incoming HGL. A higher factor k_w may be used in place of k_u to establish water levels where information on these factors is available. A different factor to the main branch k_u may also be applied to side branches.

There are an infinite number of combinations of factors affecting the magnitudes of k_L and k_u. These include relative flows in upstream flows, the local inlet and the downstream pipe, the relative diameters of upstream and downstream pipes, the angles of the pipes and the positions of their obverts and inverts, the presence of benching in a pit, the degree of submergence of the pit, and the pit shape. The 'Missouri Charts' (Sangster et al., 1958) are the primary source of information on pressure changes, with the paper by Hare (1983) being useful. However, there are many cases that are not covered by these and other references. The *Queensland Urban Drainage Manual* (Queensland Department of Natural Resources

and Water, 2008) provides a good coverage of available information on this topic, together with a rather complex procedure for selecting pressure change coefficients using selected Missouri and Hare Charts.

There are theoretical relationships for pressure changes based on conservation of momentum calculations (Hare and O'Loughlin, 1991), but these do not cover all cases. 1.5 is given as a default value for k_u in the DRAINS' Drainage Pit property sheet.

A review of pit pressure changes and head losses (O'Loughlin and Stack (2002) discussed possible algorithms or methods that might be used to determine pressure changes. Two procedures, the Mills equation and the QUDM Method described below have been implemented.

(b) Mills Equation

In the DRAINS **Run** menu, there is the option named **Revise Pit Loss Coefficients**. This alters the coefficients using an adaptation of an approximate method devised by Mills (Mills and O'Loughlin, 1982-98). Basically, this is

$$k_u = 0.5 + 2.\left(\frac{Q_m}{Q_o}\right) + 4.\left(\frac{Q_g}{Q_o}\right) \qquad \text{...(Equation 8.24)}$$

where Q_m is the inflow from upstream pipes that are misaligned,
Q_a is the aligned flow,
Q_g is the grate inflow, and
Q_o is the outflow, equal to $Q_m + Q_a + Q_g$

DRAINS assumes that pipes at angles of 45° or more to the outlet pipe are misaligned. A value of 0.5 is subtracted if the outlet pipe diameter is larger than that of any of the inlet pipes. For a drop pit, the incoming flow from a pipe may be classed as grate flow if the inlet pipe's invert is located above the pit water level. Mill's assessment of misalignment of incoming pipes cannot be judged automatically by DRAINS.

This procedure is implemented by performing a Design run, and then choosing the option **Revise Pit Loss Coefficients** in the **Run** menu. This changes the original coefficients, using the flows determined in the previous design run, thus overcoming the difficulty of having to estimate k_u factors roughly in advance when exact flows are not known. The procedure can also be implemented after an Analysis run. This may lead to somewhat different coefficients because the relative values of Q_m, Q_o and Q_g may be different. The process can be repeated to refine the result. It must be noted that this procedure is approximate and may give poor estimates for some situations. The estimated coefficients need to be checked and corrected where necessary.

(c) The QUDM Method

As noted above, the *Queensland Urban Drainage Manual* (Queensland Department of Natural Resources and Water, 2008) contains a procedure that guides a designer through a set of Missouri and Hare Charts, enabling k_u, and if appropriate water level factor k_w and branch pipe factor k_l to be determined. This procedure has been outlined in Section 6.4.4, with the related spreadsheet outputs for rational method calculations being set out in Section 6.5.4. It involves a search through several graphs based on criteria set out in Appendix 4 in QUDM Volume 2. In complex cases where there is no appropriate chart, an estimate from the momentum equations described by Hare and O'Loughlin (1991) is used.

The procedure in DRAINS allows k_u coefficients to be determined automatically, without consideration of all circumstances. It is therefore important to carry out checks using the appropriate charts.

(d) Part-Full Pipe Pressure Changes

Information on part-full pit pressure changes is sketchy, because researchers have concentrated on the full-pipe flow case that is more likely to occur at peak flows through pipe systems. The treatment of part-full pressure changes has varied in DRAINS, as additional information has become available, and the needs of the hydraulic modelling procedures have changed.

Currently, in the standard and premium unsteady flow models, a constant pit pressure change coefficient k_u is assumed to apply to both full-pipe and part-full flows. This is assumed in the interests of stability of calculations, and is likely to conservatively overestimate changes.

8.6.7 Tailwater Levels

DRAINS calculations require a downstream boundary condition, with the levels of the receiving water being specified in advance. This can be a level specified by the user in the Outlet Node property sheet, or one assumed from conditions at the outlet. For steep pipe slopes (supercritical flow), it will be assumed to be the normal depth, and for mild pipe slopes (subcritical flow), it will be assumed to be the critical depth in the standard and premium hydraulic models.

Setting an appropriate tailwater level can be difficult. The For a pipe system discharging to a free water body such as a lake, large stream or the sea, the tailwater will be the water level occurring in this body at the time that the storm passing through the drainage system occurs. Using DRAINS, you must determine the most likely level coinciding with the storm for normal design or analysis, and high values such as high tide levels in marine waters for modelling of extreme conditions. The DRAINS *Utility Spreadsheet* includes a procedures for modelling a tailwater level that changes with time during a storm event.

Where the drainage system catchment is significantly smaller than the catchment of the larger, receiving water body, it is likely that the rainfalls over the two catchments will differ in intensity and timing. The estimation of appropriate events to define critical conditions requires some statistical skill and knowledge of local storms. Where the system being analysed is a pipe system discharging into a larger pipe or trunk drain, the level to be selected should be the higher of the receiving pipe's HGL or receiving open channel's water surface level at the junction. Hydraulic calculations may be necessary to establish these levels, but valid results cannot be obtained unless appropriate tailwater levels are used.

8.7 Hydraulics of Open Channels

The basic hydraulic method, now obsolete, projected water surface upstream along open channels using the standard step method (Chow, 1959, Henderson, 1966 and other texts) for subcritical flows, For supercritical flows, the critical depth line is traced, and water depths are assumed not to fall below this, providing a conservative estimate of depths.

The unsteady flow procedures applied to open channels in the standard and premium model are the same as those for pipes, outlined in Section 8.6.4, solving the mass and momentum flow equations. Manning's equation is used to define channel friction. Suggested roughness values for channels are given in Table 8.27. More comprehensive lists are given in texts and manuals on open channel flow and in Chapter 4 of *Australian Rainfall and Runoff*, 1987.

Table 8.27 Manning's Roughness Coefficients, n

Surface Type	Suggested n Values
Concrete Pipes or Box Sections	0.012
Concrete (trowel finish)	0.012 - 0.015
Concrete (formed, without finishing)	0.013 - 0.018
Concrete (gunite)	0.016 - 0.020
Bricks	0.014 - 0.016
Pitchers or Dressed Stone in Mortar	0.015 - 0.017
Random Stones in Mortar or Rubble Masonry	0.020 - 0.035
Rock Lining or Rip-Rap	0.025 - 0.030
Earth (clear)	0.018 - 0.025
Earth (with weeds or gravel)	0.025 - 0.035
Rock Cut	0.035 - 0.040
Short Grass	0.030 - 0.035
Long Grass	0.035 - 0.050

Various energy losses can occur at changes or transitions in channel sections. These are covered by contraction and expansion losses, typically 0.1 and 0.3, respectively. These factors allow for energy losses due to changes in cross-sections and velocities through these. If the velocity increases or decreases between two cross-sections, the HGL is lowered by a coefficient multiplied by the difference in velocity heads at the two sections. For example, if the upper and lower sections are labelled 1 and 2, the losses for the two cases will be:

Contraction coefficient . $\left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right)$ … (Equation 8.25)

Expansion coefficient . $\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)$ … (Equation 8.26)

Table 8.28, taken from the HEC.RAS Version 3.1 *Hydraulic Reference Manual* (2002), Chapter 3, gives values of coefficients.

Table 8.28 Contraction and Expansion Coefficients for Open Channel Flows

Situation	Contraction Coefficient	Expansion Coefficient
No transition Loss	0.0	0.0
Gradual Transitions	0.1	0.3
Typical Bridge Sections	0.3	0.5
Abrupt Transitions	0.6	0.8

8.8 Detention Basin Hydraulic

8.8.1 Routing

DRAINS performs accurate reservoir routing calculations for detention storages, employing the height-storage-outflow relationship and initial storage supplied by the user. The method used is an extension of the Modified Puls Method, based on the continuity equation applied over a time step, Δt,

$$\frac{I_i + I_{i+1}}{2} - \frac{Q_i + Q_{i+1}}{2} = \frac{S_{i+1} - S_i}{\Delta t} \quad \text{... (Equation 8.27)}$$

Average of Inflow rates at the start of a period, I_i and at the end, I_{i+1} — Average outflow rate over the period — Rate of change of storage

together with a relationship linking outflow rates with corresponding storages for various water levels in a reservoir or basin.

Reservoir routing procedures work on a finite-difference step-by-step procedure, working through the time periods from the start of a known inflow hydrograph. Conditions at the beginning of each time step are known, and relationships are used to derive conditions at the end. There are many ways of setting up these calculations, both direct and iterative, but the following way, used in ILSAX, is probably the simplest.

Equation 6.32 can be rearranged so that the known terms are placed on the left hand side (LHS):

$$I_i + I_{i+1} - Q_i + \frac{2S_i}{\Delta t} = Q_{i+1} + \frac{2S_{i+1}}{\Delta t} \quad \text{… (Equation 8.28)}$$

Inflow values I_i, I_{i+1}, etc. are known in advance, and outflow Q_i and storage S_i at the beginning of each period are known. Routing procedures estimate values for Q_{i+1} and S_{i+1} by various methods of graphical or numerical interpolation.

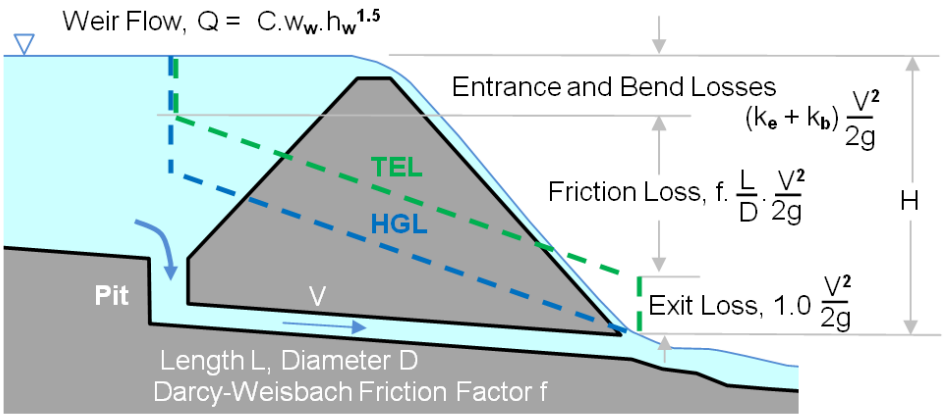
DRAINS applies this procedure at each time step, but also allows for tailwater effects that might alter the elevation-discharge (or height-outflow) relationship.

A height-storage-outflow relationship can be developed from:

(a) a height-storage relation, derived from contour information on the topography of the storage area,

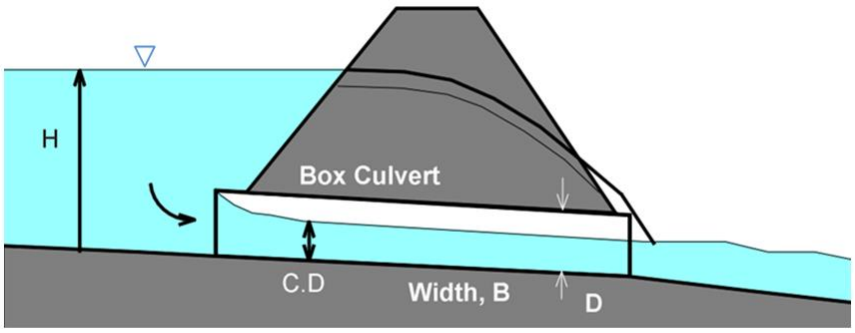
(b) a height-outflow relation, constructed from the hydraulic relationships for the outlet structures for the reservoir, which can be orifices, pipe systems, weirs, or combinations of these.

DRAINS allows for separate height-outflow relationships for low- and high-level outlets of the type shown in Figure 8.30 and Figure 8.31. Routing is performed with a combined relationship, but outflows via high-level outlets, such as diversion weirs, can be directed out of the system or to reaches other than the one immediately downstream.



$$\text{Pipe Flow, } Q = A.V = \frac{\pi}{4} D^2 \sqrt{\frac{2gH}{(k_e + k_b + f.\frac{L}{D} + 1.0)}}$$

Figure 8.30 Detention Basin Outlet under Outlet Control



$$\text{Orifice Control, } Q = A.V = C.B.D\sqrt{2g\,(H - C.D)}$$

Figure 8.31 Detention Basin Outlet under Inlet (Orifice) Control

8.8.2 Overflows from Basins

Low-level outlets from basins consist of culvert or drop pit pipe systems. The outflow rate for these is dependent on the headwater and tailwater levels, and energy losses through the pipe system. Height-outflow (or depth-discharge) relationships for various kinds of outlets are given in textbooks and manuals on hydraulics. The equations shown in the box on the following pages are used for calculating height-outflow relationships in DRAINS for detention basins, culverts and headwalls.

In most cases, *inlet control* will govern, with the greatest restriction on flow capacity occurring at the culvert entrance. However, in some cases outlet *control* will apply, with the cause being high tailwater levels, or friction in relatively long and flat culverts.
High-level outlets such as weirs and slots are usually governed by the weir equation:

$$Q = C \,.\, w \,.\, h_w^{1.5} \qquad \text{.... (Equation 8.44)}$$

where Q is the outflow rate (m^3/s),
C is a weir coefficient, depending on the weir shape, roughness and length of the weir crest in the direction of flow,
w is the width of the weir (m), at right angles to the flow direction, and
h_w is the depth of water in the basin above the weir sill or crest.

Laurenson and Mein (1990) provide the weir coefficients shown in Figure 8.32. Further information can be obtained in the US Federal Highway Administration HDS-5 manual (Normann et al., 2005).

Equations for Determining Height-Outflow Relations used in the Detention Basin, Culvert and Headwall Calculations

Outlets with Circular Cross-Sections

These depend on the threshold level, TH, which is usually the invert level at the upstream end of the outlet pipe or culvert (m AHD), and pipe diameter D (m).

For (HW - TH) < 0.8 D, the flowrate for Inlet Control is:

$$Q_i = N_c \cdot 1.50 \cdot (S_c/40)^{0.05} \cdot (HW - TH)^{1.9} \cdot D^{0.6} \quad \text{... (Equation 8.29)}$$

(inlet control, unsubmerged inlet, Henderson, 1966)

For 0.8 D < (HW - TH) < 1.2 D,

$$Q_i = N_c \cdot 1.38 \cdot (S_c/40)^{0.05} \cdot (HW - TH)^{1.5} \cdot D \quad \text{… (Equation 8.30)}$$

(inlet control, unsubmerged inlet, Henderson, 1966), and

For (HW - TH) > 1.2 D,

$$Q_i = N_c \cdot 1.62 \cdot (HW - TH)^{0.63} \cdot D^{1.87} \quad \text{… (Equation 8.31)}$$

(inlet control, submerged inlet, Boyd, 1986)

The flowrate for Outlet Control is:

$$Q_o = N_c \cdot \frac{\pi}{4} \cdot D^2 \cdot ((HW - TW) \cdot 2g / (k_e + k_b + Factor + 1))^{0.5} \quad \text{…(Equation 8.32)}$$

(outlet control, full pipe flow)

The outflow rate, Q (m^3/s), corresponding to level in the basin or headwater level, HW (m AHD), is the lesser of the calculated Q_i and Q_o values. Parameters used in the four equations are:

N_c is the number of parallel conduits,
L_c and S_c are the conduit length (m) and slope (%),
g is acceleration due to gravity, taken as 9.80 m/s^2,
TW is the higher of :
(a) the tailwater level downstream of the outlet (m AHD), and
(b) a level half way between the outlet obvert level, equal to $(TH - S_c \cdot L_c + D)$
and the level of the critical depth of the flow at the pipe outlet, calculated from:

$$d_c = D \cdot \left(\frac{Q}{4.038 \cdot D^{2.5}}\right)^{0.287} \quad \text{for } \frac{d_c}{D} >= 0.82 \quad \text{… (Equation 8.33)}$$

and

$$d_c = D \cdot \left(\frac{Q}{3.005 \cdot D^{2.5}}\right)^{0.510} \quad \text{for } \frac{d_c}{D} < 0.82. \quad \text{… (Equation 8.34)}$$

Since Q is not known exactly when the tailwater level is being established, an iterative procedure must be used In the above equations.

k_e is the entrance loss factor,
k_b is the total of other loss factors, e.g. at bends, and
Factor is a friction factor. If Manning's Equation is used with a roughness n, it is

$$n^2 \cdot L_c \cdot 2g \cdot \left(\frac{D}{4}\right)^{-4/3} \quad \text{… (Equation 8.35)}$$

If the Colebrook-White Equation is used, the Factor is $f.\frac{L_c}{D}$, where f is the Darcy-Weisbach friction factor. This can be obtained using an initial value given by the Swamee-Jain equation:

$$f = 1.325 / (\log_e(k/(3700 . D) + 5.74 / N_R^{0.9}))^2 \quad \text{… (Equation 8.36)}$$

and iterations using the Colebrook-White Equation:

$$f = 1.325 / (\log_e(k/(3700 . D) + 2.51 / (N_R.f^{0.5}))) ^2 \quad \text{… (Equation 8.37)}$$

in which,

k is the Colebrook-White wall roughness height (mm),
N_R is the Reynolds Number of the flow (This is unknown when calculations are performed, but it can be estimated roughly as:

$$\frac{V \cdot D}{\upsilon} = \frac{Q_i}{\frac{\pi}{4} \cdot D^2} \cdot \frac{D}{\upsilon} \quad \text{… (Equation 8.38)}$$

V is the velocity of flow (m/s), and υ is the kinematic viscosity of water (1.14×10^{-6} m^2/s at 15^oC). Note that the flowrate is assumed to be to be the inlet flow estimate and the pipe is assumed to be flowing full. This is not exact, and an iterative procedure should be used. However, the value of f is insensitive to the N_R used, and this approximation should be adequate.)

Outlets with Rectangular Cross-Sections

These are based on the threshold level TH (m AHD), usually the invert at the upstream end of the culvert, and the height of the culvert, H (m).

If (HW - TH) < 1.35 H, the flowrate for Inlet Control is:

$$Q_i = Nc . 1.70 . (HW- TH)^{1.50} . B \quad \text{… (Equation 8.39)}$$

(inlet control, submerged inlet, Boyd, 1986)

If (HW - TH) ≥ 1.35 Height of Culvert:

$$Q_i = Nc . 2.20. (HW- TH)^{0.61} . H^{0.89} . B \quad \text{… (Equation 8.40)}$$

(inlet control, submerged inlet, Boyd, 1986)

The flowrate for Outlet Control is:

$$Q_o = Nc . H . B . ((HW - TW) . 2g / (k_e + k_b + Factor + 1))^{0.5} \quad \text{… (Equation 8.41)}$$

(outlet control, full pipe flow)

As for circular pipes, the outflow rate, Q (m^3/s), corresponding to level, HW, is the lesser of the calculated Q_i and Q_o values. B is its breadth or width of the conduit (m), and the other factors are as described above.

In the calculations concerning tailwater, the critical depth is determined as:

$$d_c = \left(\frac{Q^2}{g \cdot B^2}\right)^{0.333} \quad \text{… (Equation 8.42)}$$

In the equations for finding the friction factor, diameter D is taken to be 4 times the hydraulic radius (m), equal to:

$$\text{Area / Wetted Perimeter} = \frac{H \cdot B}{2(H + B)} \quad \text{… (Equation 8.43)}$$

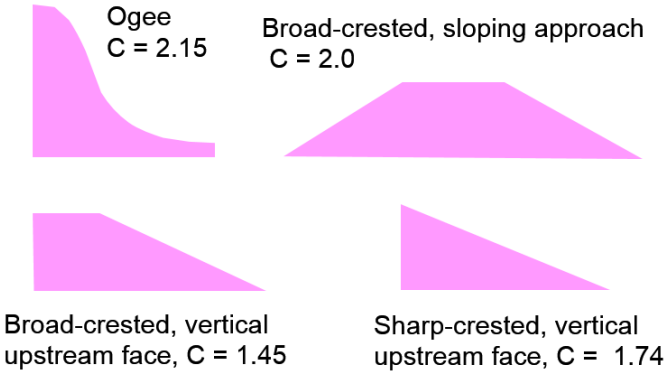


Figure 8.32 Weir Coefficients

8.8.3 On-Site Stormwater Detention

DRAINS is set up to model on-site stormwater detention (OSD) storages of the type shown in Figure 8.33, including high-early discharge (HED) systems, as shown in Figure 8.. These can provide a considerable reduction of the storage needed to limit outflows to a prescribed limit.

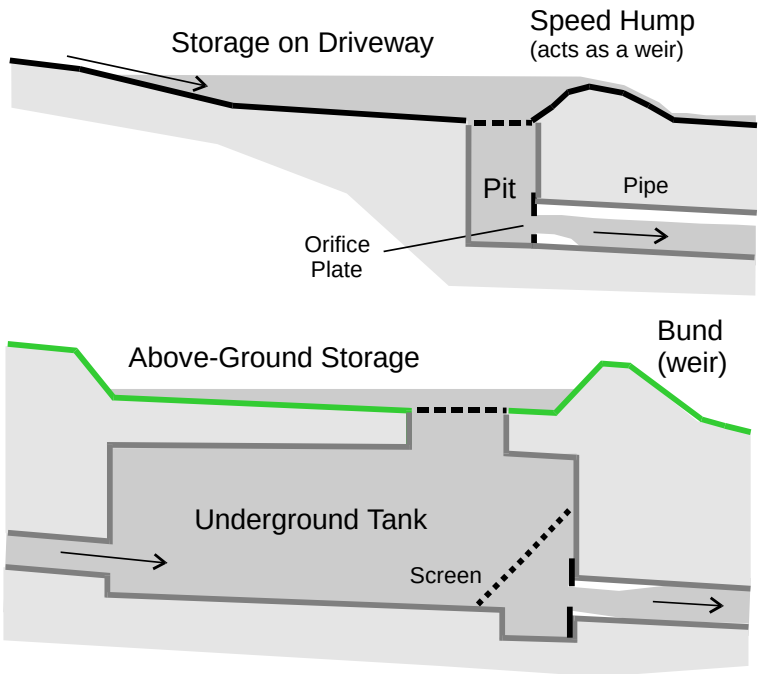


Figure 8.33 On-Site Detention (OSD) Storages

OSD storages are usually controlled by circular orifices with the discharge equation being:

$$Q = C_c \cdot \frac{\pi}{4} d^2 \cdot (2gh)^{0.5} \qquad \text{… (Equation 8.45)}$$

where C_c is a contraction coefficient, taken as a constant of 0.6 in DRAINS,
d is the orifice diameter (m),
g is the acceleration due to gravity (m/s^2), and
h is the height from the water surface to the centre of the orifice (m).

8.8.4 Infiltration

The second panel on the detention basin property sheet (Figure 5.43) displays data that can be used to model stormwater infiltration out of a storage that has a permeable base and/or permeable sides. The calculations involved are simple; the exposed surface of the storage at any time is multiplied by the hydraulic conductivity to define an outflow. The greater the depth in the storage, the larger the infiltration rate. Allowance is made for storages having permeable or impermeable floors and walls.

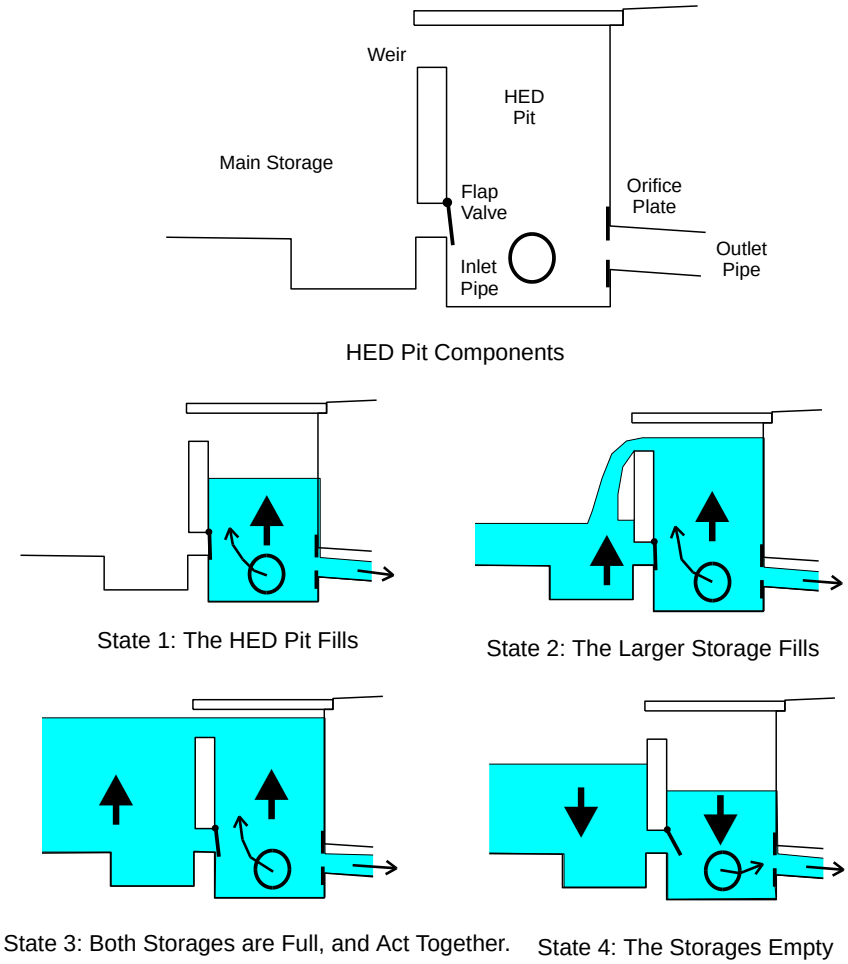


Figure 8.45 A High Early Discharge (HED) Pit

Infiltration procedures are discussed in detail in Argue, J.R. (editor) (2004) *WSUD: Basic Procedures for 'Source Control' of Stormwater*, University of South Australia Water Resources Centre, Adelaide. Indicative values of hydraulic conductivity (p. 44) are given in Table 8.29. Specific values for a site can be obtained from on-site tests and modified using factors provided in the above publication.

Table 8.29 Hydraulic Conductivities for Infiltration Calculations

Soil Type	Hydraulic Conductivity
Sandy soil	> 5 x 10^{-5} m/s
Sandy clay	between 1 x 10^{-5} and 5 x 10^{-5} m/s
Medium clay and some rock	between 1 x 10^{-6} and 1 x 10^{-5} m/s
Heavy clay	between 1 x 10^{-8} and 1 x 10^{-6} m/s
Constructed clay	< 1 x 10^{-8} m/s

8.9 Culvert and Bridge Hydraulics

8.9.1 Culverts

There are two meanings to the word, culvert. The first is a long pipe; the second is a pipe, usually short, constructed to allow flows in streams and artificial open channels to pass under road and railway embankments. The culvert component in DRAINS models the latter case. The first type of conduit should be modelled as a channel, or if storage and overflows are important, as a detention basin.

Culverts convey flows in pipes or rectangular conduits that through road embankments, usually obstructing flows by reducing the available waterway areas. Upstream water levels are raised, creating a headwater level higher than the water levels occurring under unobstructed flows. Downstream levels are lower, since flow emerges rapidly from the culvert, creating supercritical flow conditions until a hydraulic

jump occurs. Several procedures are available for the design of culverts and analysis of their behaviour. In DRAINS the sets of equations presented by Henderson (1966) and Boyd (1986) given in Section 8.7 are used to determine the headwater levels occurring with a given flowrate and downstream tailwater level at each calculation time step. These equations allow for inlet control, where the constriction at the opening of the culvert is the determining factor, and for outlet control, where a high tailwater level and significant head losses make the conduit flow full.

In DRAINS, the flowrate and the downstream water level at each time step are established, and the corresponding headwater level is determined using the above equations. When either of two equations can be used because there are two possible states of flow, the equation giving the highest headwater level is selected.

A considerable amount of information on road culverts is available from the US Federal Highway Administration in manuals and software available at www.fhwa.dot.gov/bridge/hyd.htm. Mays (2001) also provides considerable information on culverts.

8.9.2 Bridges

Bridge hydraulics is particularly complicated because it is necessary to allow for the transitions from a broad channel cross-section to a constricted bridge cross-section and back to a channel section. The bridge abutments, piers and possibly the deck can all obstruct flows. Hydraulic expertise is required to interpret results.

The U.S. Federal Highway Administration has published methods by Bradley (1970) which have been used in the AUSTROADS waterway manual (1994). More extensive procedures are incorporated in the HEC-RAS computer program (Hydrologic Engineering Center, 1997). You are referred to these references for further details. DRAINS covers relatively simple bridge layouts. Use of HEC-RAS is recommended for complex arrangements involving multiple openings and broad channel cross-sections.

DRAINS uses the AUSTROADS procedures to define the afflux or rise in upstream water level caused by a bridge constriction. It does this at each calculation time step, for the current flowrate and downstream water level. As with culverts, allowance is made for possible overtopping and submergence of the bridge deck, treating this as a weir. Any overflows are added to the flows through the bridge opening occurring at the same time.

8.10 File Formats

8.10.1 General

This section provides some notes on file formats, as a guide to persons exchanging data between DRAINS and other programs.

8.10.2 Drawing File Formats

DRAINS can import and export graphical data in DXF format. As shown in Figure 8.34, this is an ASCII format, which can be edited on a text editor.

8.10.3 GIS File Formats

(a) GIS Systems

Geographic Information System (GIS) programs combine a mapping facility with a data base of information on the spatial position of components, such as drainage pits and pipes, and on their other attributes, such as pipe diameters. Objects displayed in different ways, according to one or more of their attributes. Maps can be produced on paper or can be inspected electronically.

The most common products used in Australia are ArcView (produced by ESRI (www.esri.com) and MapInfo (produced by MapInfo Corporation (www.mapinfo.com), but Autodesk Map (www.autodesk.com) and Intergraph (www.intergraph.com). There are also a number of companies that provide systems based on the main types of software. GIS file structures can be complex. In MapInfo, two file types, with suffixes MID and MIF, are required, so that 12 files are generated in a transfer from DRAINS.

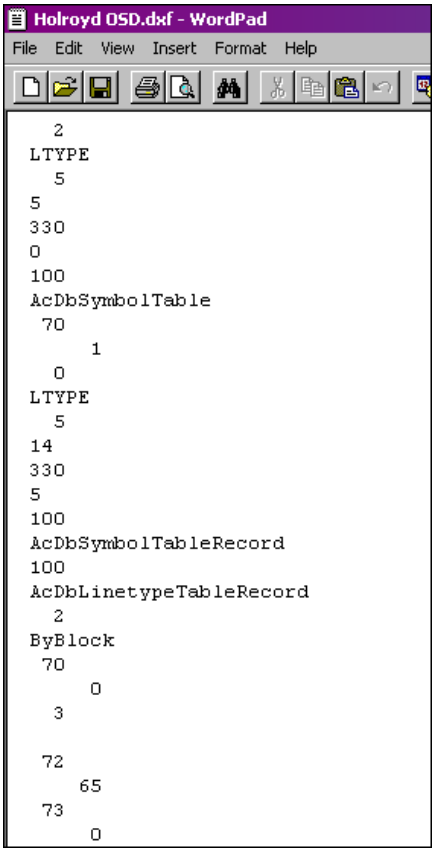


Figure 8.34 ASCII File in an Editor

(b) ESRI (ArcView) Formats

ArcView stores spatial information in various formats. The data imported or exported by DRAINS are in a set of three binary files, all having the same initial part of their name:

- a SHP file, the main file defining a number of records for shapes (points, lines, poly-lines or polygons), defined by the coordinates of their vertices,
- a SHX file acting as an index to the records in the main file,
- a DBF file containing a DBASE table of attributes associated with each record.

To specify an object such as a pipe fully, a set of these three files is established. The transfers to and from DRAINS involve files for up to six objects - pits, sub-catchments, pipes, overflow routes, survey data on ground levels along pipe routes and positions of other services, a total of 18 files, plus a DXF file containing the background to the drainage system, which can be transferred at the same time.

For nodes, a table with the following 13 headers for columns or 'fields' are required:

1	Shape	the nature of the object (point)
2	Name	any name up to 10 characters
3	DRAINSid	an internal number used by DRAINS to connect nodes and link this must be kept blank
4	Type	type of node: 'OnGrade', 'Sag' or 'Node'
5	Family	the pit family, corresponding to a family in the pit data base in the DRAINS model to which the data is being transferred, or 'N/A'
6	Size	a pit size within the nominated pit family, or 'N/A'
7	PondingVol	the volume of water that can pond over a sag pit (m^3)
8	Ku	the pit pressure change coefficient (Use 'N/A' for simple nodes)
9	SurfaceEl	the surface elevation at the node (m)
10	PondDepth	the depth to which water ponds until it starts to overflow (m)
11	BaseFlow	any constant baseflow (m^3/s) originating at the node
12	BlockFactr	a blocking factor to be applied at pits ('N/A' is used for nodes),
13	BoltDnLid	a 'Yes', 'No' or 'N/A' as to whether there is a bolt down lid

In a shapefile exported from DRAINS, there may also be:

Hgl_XXXXX - optionally, one or more HGL levels taken from a series of runs for. Different storms. 'XXXXX' takes different values.

For pipes, a table with the following 12 headers for columns or 'fields' are required:

1	Shape	the nature of the object (line or poly-line),
2	Name	any name up to 10 characters
3	DRAINSid	an internal number used by DRAINS to connect nodes and links - this must be kept blank
4	Length	the pipe length (m),
5	UpstreamIL	the invert level at the upstream end of the pipe (m),
6	DownStrmIL	the downstream invert level (m),
7	Slope_pct	the pipe slope (%),
8	Type	the pipe type, which must correspond to a type in the pipe database of the DRAINS model to which the data is being transferred
9	NomDia	the nominal pipe diameter (mm) corresponding to diameters in the pipe type nominated
10	Roughness	a Colebrook-White or Manning's roughness coefficient
11	Status	'New' or 'NewFixed' or 'Existing'
12	NumPipes	the number of parallel pipes, usually 1

In a shapefile exported from DRAINS, there may also be:

Flow_XXXXX - optionally, one or more flowrates from different storms, designated by XXXXX,
V_XXXXX - optionally, one or more velocities from different storms, for example'50Yr'.
For information on the other four components, you can refer to the formats of exported ESRI files in the MIF files. Note that all numbers are exported as text and not as numbers. They will need to be converted in an ESRI program if the attributes are to be used as the basis for colour-coded thematic mapping.

(c) MapInfo Formats

MapInfo stores spatial information in a set of two ASCII files, both having the same initial part of their name:

- a MIF (MapInfo Interchange File) is the main file defining a format for data records associated with objects (points, lines or polygons) and the coordinates of the vertices of objects,
- a MID file containing the contents of a table of attributes associated with each object.

The data for nodes (pits) in the MID file is in a table with the following 12 headers:

1	Name	any name up to 11 characters
2	DRAINSid	an internal number used by DRAINS to connect nodes and links - this must be kept blank
3	Type	type of node: 'OnGrade', 'Sag' or 'Node'
4	Family	the pit family, corresponding to a family in the pit data base in the DRAINS model to which the data is being transferred, or 'N/A',
5	Size	a pit size within the nominated pit family, or 'N/A',
6	PondingVol	the volume of water that can pond over a sag pit (m^3)
7	Ku	the pit pressure change coefficient (Use 'N/A' for simple nodes),
8	SurfaceEl	the surface elevation at the node (m),
9	PondDepth	the depth to which water ponds until it starts to overflow (m)
10	BaseFlow	any constant baseflow (m^3/s) originating at the node
11	BlockFactr	a blocking factor to be applied at pits ('N/A' is used for nodes)
12	BoltDnLid	a 'Yes', 'No' or 'N/A' as to whether there is a bolt down lid

In a MID file exported from DRAINS, there may also be:

HGL_XXXXX - optionally, one or more HGL levels taken from a series of runs for. Different storms. 'XXXXX' takes different values, for example, '5 Yr'.

For pipes, the table includes the following 11 or more headers:

1	Name	any name up to 11 characters
2	DRAINSid	an internal number used by DRAINS to connect nodes and links - this must be kept blank
3	Length	the pipe length (m),
4	UpStreamIL	the invert level at the upstream end of the pipe (m),
5	DownStrmIL	the downstream invert level (m),
6	Slope_pct	the pipe slope (%),
7	Type	the pipe type, which must correspond to a type in the pipe database of the DRAINS model to which the data is being transferred
8	NomDia	the nominal pipe diameter (mm) corresponding to diameters in the pipe type nominated
9	Roughness	a Colebrook-White or Manning's roughness coefficient
10	Status	'New' or 'NewFixed' or 'Existing'
11	NumPipes	the number of parallel pipes, usually 1

In a MID file exported from DRAINS, there may also be:

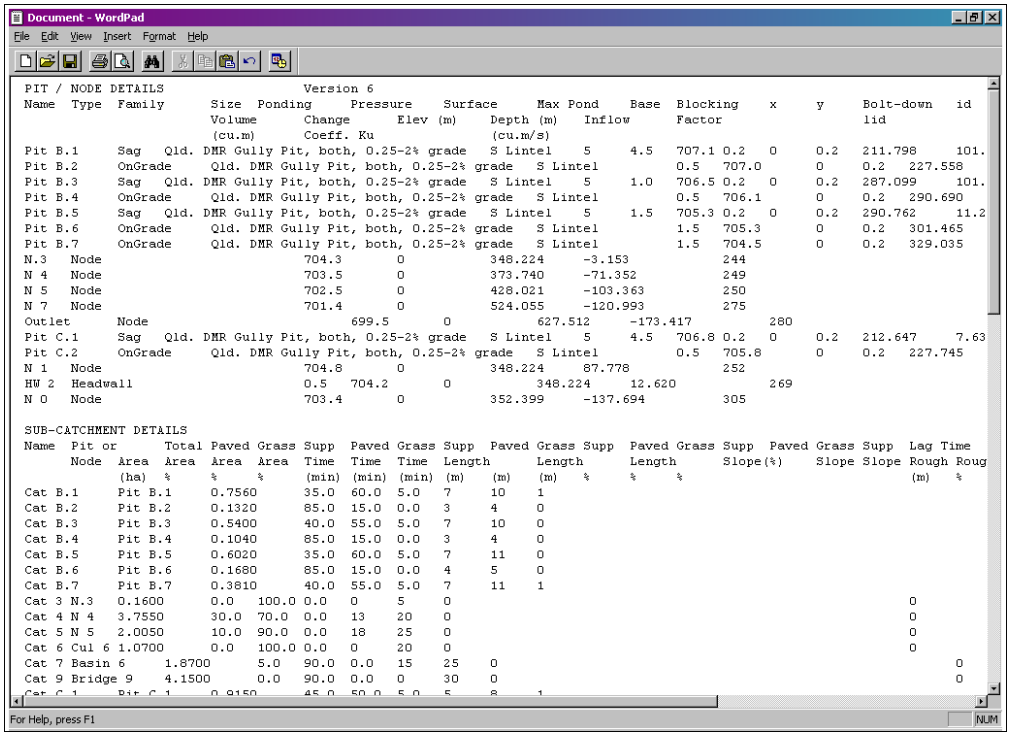
Flow_XXXXX - optionally, one or more flowrates from different storms, designated by XXXXX,
V_XXXXX - optionally, one or more velocities from different storms.

For information on the other four components, you can refer to the formats of exported MapInfo files, reading the MIF file with a text editor.

Note that all numbers are exported as text and not as numbers. They will need to be converted in MapInfo if attributes are to be used as the basis for colour-coded plotting.

8.10.4Spreadsheet File Formats

DRAINS transfers data to spreadsheet programs in the space-delimited ASCII format shown in Figure 8.35. This appears in cells when opened in a spreadsheet program, as shown in Figure 2.78.



```
PIT / NODE DETAILS                  Version 6
Name  Type  Family      Size  Ponding     Pressure    Surface     Max Pond    Base  Blocking    x     y     Bolt-down   id
                        Volume      Change      Elev (m)    Depth (m)   Inflow      Factor                    lid
                        (cu.m)      Coeff. Ku               (cu.m/s)
Pit B.1     Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5     4.5   707.1 0.2   0     0.2   211.798     101.
Pit B.2     OnGrade     Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   707.0       0     0.2   227.558
Pit B.3     Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5     1.0   706.5 0.2   0     0.2   287.099     101.
Pit B.4     OnGrade     Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   706.1       0     0.2   290.690
Pit B.5     Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5     1.5   705.3 0.2   0     0.2   290.762     11.2
Pit B.6     OnGrade     Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          1.5   705.3       0     0.2   301.465
Pit B.7     OnGrade     Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          1.5   704.5       0     0.2   329.035
N.3   Node                          704.3       0           348.224     -3.153            244
N 4   Node                          703.5       0           373.740     -71.352           249
N 5   Node                          702.5       0           428.021     -103.363          250
N 7   Node                          701.4       0           524.055     -120.993          275
Outlet      Node                        699.5       0           627.512     -173.417          280
Pit C.1     Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5     4.5   706.8 0.2   0     0.2   212.647     7.63
Pit C.2     OnGrade     Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   705.8       0     0.2   227.745
N 1   Node                          704.8       0           348.224     87.778            252
HW 2  Headwall                      0.5   704.2       0           348.224     12.620            269
N 0   Node                          703.4       0           352.399     -137.694          305

SUB-CATCHMENT DETAILS
Name  Pit or      Total Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Lag Time
      Node  Area  Area  Area  Area  Time  Time  Time  Length      Length      Length      Length      Slope(%)    Slope Slope Rough Roug
            (ha)  %     %     %     (min) (min) (min) (m)   (m)   (m)   %     %     %                                       (m)   %
Cat B.1     Pit B.1     0.7560      35.0  60.0  5.0   7     10    1
Cat B.2     Pit B.2     0.1320      85.0  15.0  0.0   3     4     0
Cat B.3     Pit B.3     0.5400      40.0  55.0  5.0   7     10    0
Cat B.4     Pit B.4     0.1040      85.0  15.0  0.0   3     4     0
Cat B.5     Pit B.5     0.6020      35.0  60.0  5.0   7     11    0
Cat B.6     Pit B.6     0.1680      85.0  15.0  0.0   4     5     0
Cat B.7     Pit B.7     0.3810      40.0  55.0  5.0   7     11    1
Cat 3 N.3   0.1600      0.0   100.0 0.0   0     5     0                                                       0
Cat 4 N 4   3.7550      30.0  70.0  0.0   13    20    0                                                       0
Cat 5 N 5   2.0050      10.0  90.0  0.0   18    25    0                                                       0
Cat 6 Cul 6 1.0700      0.0   100.0 0.0   0     20    0                                                       0
Cat 7 Basin 6     1.8700      5.0   90.0  0.0   15    25    0                                                             0
Cat 9 Bridge 9    4.1500      0.0   90.0  0.0   0     30    0                                                             0
```

Figure 8.35 DRAINS **Spreadsheet Output displayed in an Editor**

8.10.5TUFLOW TS1 File Formats

Using the **File → Export → Tuflow TS1 Files…** option described in Section 6.5.6, DRAINS can transfer calculated hydrographs to TUFLOW and other programs in the format shown in Figure 8.36, which can readily be imported into spreadsheet programs.

```
! File created from: C:\2007 DRAINS Files\Manual Example Files - March 2007
! Storm event:AR&R 100 year, 15 minutes storm, average 140 mm/h, Zone 1
! Timestep: 0.111111 min
! Number of timesteps: 853
! Number of catchments: 5
5,853
Start_Index,1,1,1,1,1
End_Index,853,853,853,853,853
Time (min),Cat 5,Cat 4,Cat 3,Cat 2,Cat 1
0.111,0.000,0.000,0.000,0.000,0.000
0.222,0.000,0.000,0.000,0.000,0.000
0.333,0.000,0.000,0.000,0.000,0.000
0.444,0.000,0.000,0.000,0.000,0.000
0.556,0.001,0.003,0.001,0.000,0.000
0.667,0.001,0.005,0.002,0.001,0.000
0.778,0.002,0.007,0.003,0.001,0.000
0.889,0.003,0.010,0.003,0.002,0.000
1.000,0.003,0.012,0.004,0.002,0.000
1.111,0.004,0.015,0.005,0.002,0.000
1.222,0.005,0.017,0.006,0.003,0.000
1.333,0.005,0.019,0.007,0.003,0.000
1.444,0.006,0.022,0.008,0.004,0.000
1.556,0.007,0.024,0.009,0.004,0.000
1.667,0.007,0.027,0.009,0.004,0.000
```

Figure 8.36 TUFLOW TS1 Output Displayed in an Editor

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