

Water Safety Plans: Book 4
IRA-WDS Software and Manual for
Risk Assessment of Contaminant Intrusion
into Water Distribution Systems

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IRA-WDS Software and Manual for Risk Assessment of Contaminant Intrusion into Water Distribution Systems

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Water, Engineering and Development Centre
Loughborough University
2006



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Vairavamoorthy, K., Gorantiwar, S. D.,
Yan, J. M., and Galgale, H. M., (2006)
Water Safety Plans: Book 4
IRA-WDS Software and Manual for Risk Assessment of
Contaminant Intrusion into Water Distribution Systems
WEDC, Loughborough University, UK.

ISBN Paperback 1 84380 103 5

This document is an output from a project funded by the UK
Department for International Development (DFID)
for the benefit of low-income countries.
The views expressed are not necessarily those of DFID.

Designed and produced at WEDC

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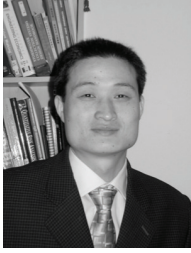
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Acknowledgements

The financial support of the UK Department for International Development (DFID) is gratefully acknowledged. The authors would also like to thank those who have contributed to the development of these guidelines.

KAKTOS Consult, Hyderabad, India
India Institute of Technology (IIT), Chennai, India
Guntur Municipal Corporation, Municipal Corporation of Hyderabad, India
Public Health Engineering Department of Guntur, India

Finally, the authors wish to acknowledge Dr Guy Howard, DFID, Bangladesh and Dr Sam Godfrey, UNICEF, India for their intellectual input; Ian Smout, Director, WEDC for his constructive suggestions; Mukund G. Shinde, Li Huipeng and Yibo Shen, Research Scholars, WEDC for testing IRA-WDS; and Rod Shaw, Sue Plummer and Karen Betts of the WEDC Publications Office.

Who should read this book

This book has been written specifically for practitioners involved in the operation, maintenance and management of piped water distribution systems in urban areas of developing countries. These practitioners include engineers, planners, managers, and water professionals involved in the monitoring, control and rehabilitation of water distribution networks.

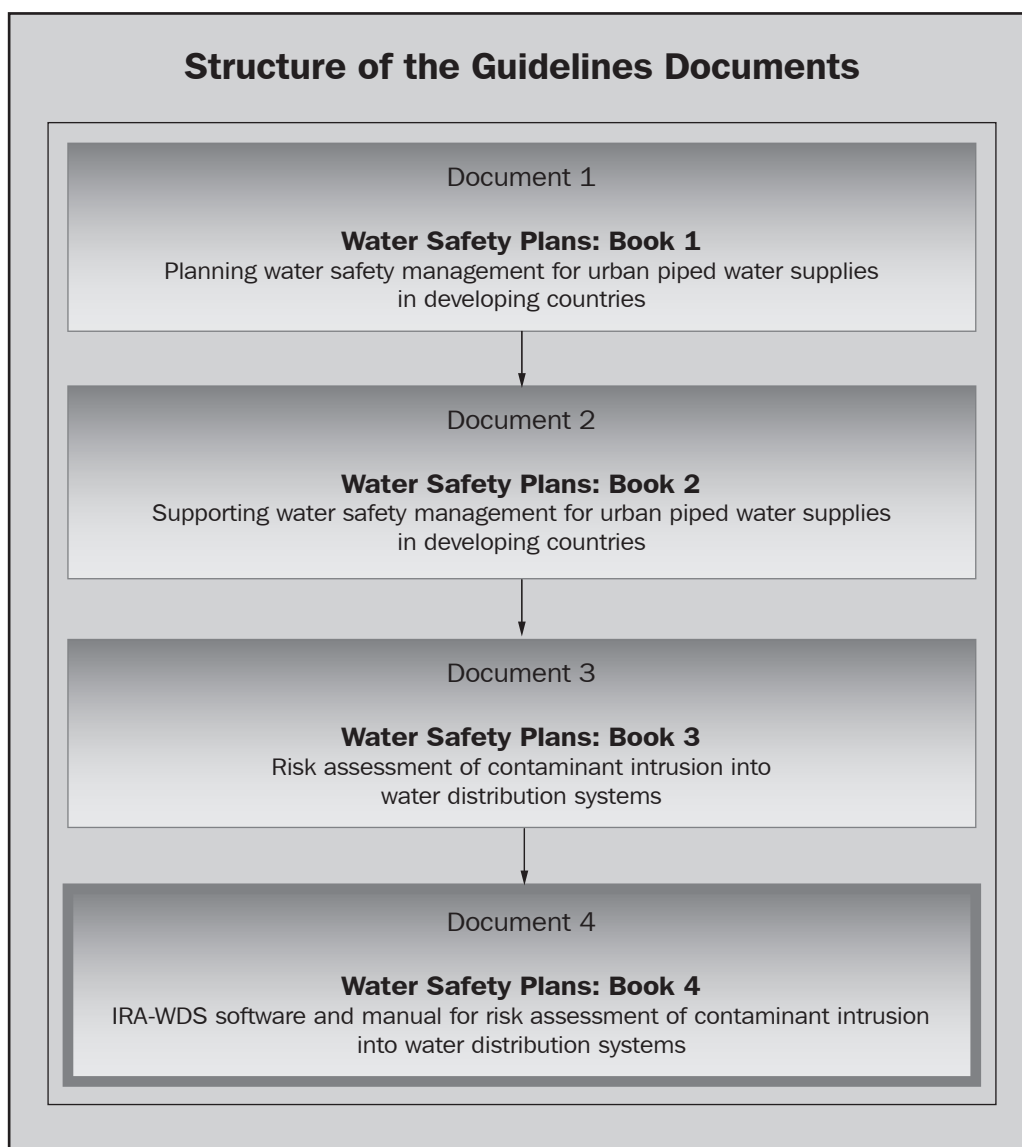
This book is a manual for using the developed software, IRA-WDS (Improved Risk Assessment for Water Distribution System), a Geographical Information System (GIS) that aids in evaluating the risk of deterioration of the water distribution network of a water supply system. The manual is a structured document and explains a step-by-step procedure for using the IRA-WDS, with examples.

How to use this book

The software IRA-WDS has been developed to evaluate risks to piped water distribution systems of urban areas in developing countries. This manual enables the use of this software. The software consists of three models, namely the Contaminant Ingress Model, Pipe Condition Assessment Model and Risk Assessment Model. The IRA-WDS is designed to use these models together or individually. This manual provides a step-by-step procedure for using these models and obtaining results. Book 3, also developed in this series, should be used along with the software and this manual. This will enable readers to understand and analyse their results.

How does this book fit into the overall guidelines?

This book is Book 4 in the guidelines series developed for Project KaR R8029, Improved Risk Assessment and Management for Piped Urban Water Supplies. It provides details of how to use IRA-WDS, a Geographical Information System (GIS) based software that estimates the risk of contaminant intrusion into water distribution systems from sewers and foul surface water bodies. The technical background to IRA-WDS is presented in Book 3, and readers are encouraged to read Book 3 prior to reading this one. It is also important to recognize that to use IRA-WDS, institutions and authorities responsible for water management need to be committed to the collection and maintenance of data and to developing technical expertise. Therefore, it is recommended that users should also read Book 2 and consider the implementation of IRA-WDS in light of that document's content.



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CHAPTER ONE

IRA-WDS: Overview

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems

Chapter-1 IRA-WDS: Overview



Chapter-2 Data Preparation



Chapter-3 Contaminant Ingress Model



Chapter-4 Pipe Condition Assessment Model



Chapter-5 Risk Assessment Model

Chapter 1: IRA-WDS Overview

1.1 System setup

The recommended screen settings for IRA-WDS are 1024 x 768. Lower settings may result in some parts of the input dialogue boxes being partially displayed.

1.1.1 Hardware and software requirements

Hardware and software requirements for IRA-WDS are similar to those of standard PC-based ArcView 3.1 or 3.2. Memory and compatibility requirements for the installation of IRA-WDS are presented in Table 1.1, below.

For three-dimensional visualization of the results from IRA-WDS, ArcView 3D Analyst and Spatial Analyst software need to be installed with ArcView, these having to be obtained separately.

Table 1.1. Hardware and software requirements		
Hardware/Software	Minimum requirements	Preferred requirements
Processor	Pentium III 1GHz	Pentium IV 2.2GHz or above
Hard disk space	100MB	1GB
Random Access Memory (RAM)	128Mb of RAM plus 256Mb of permanent virtual memory swap space	512Mb of RAM plus 512Mb of permanent virtual memory swap space
Colour monitor	Configured for 16-bit high colours, resolution 1024 x 768	Configured for 32-bit true colours, resolution 1024 x 768
Operating system	Windows 98, 2000, NT	Windows 2000 or Windows XP professional
ArcView	ArcView Version 3.2, 3D Analyst	ArcView 3.2, 3D and Spatial Analyst

Microsoft Excel 2000/XP is recommended for use. Internet Explorer 6.0 or a more recent version is required to view help files.

1.1.2 Arc View 3.1/3.2

ArcView is not software in the public domain. It is a desktop Geographic Information System developed by ESRI. With ArcView, one can create intelligent, dynamic maps using data from virtually any source and across most popular computing platforms. ArcView provides the tools to allow the user to work with maps, database tables, charts and graphics all at once. One can also use multimedia links to add pictures, sound and video to the maps generated. ArcView makes it easy to integrate data from overall organization and work with the data geographically. Using ArcView software's powerful visualization tools, one can access records from existing databases and display them on maps. Using Avenue, which is ArcView software's built-in object-oriented scripting language, one can develop custom tools, interfaces and complete applications.

ArcView can be purchased from the ESRI store direct and costs approximately \$1,195.00 for the Windows platform and \$2,195.00 for the UNIX platform. More information can be obtained from <http://www.esri.com/software/arcview/how-to-buy.html> or by contacting a local ESRI distributor.

ArcView comes with several extensions for carrying out different tasks. Extensions are plug-ins that one can load and unload according to need. 3D Analyst and Spatial Analyst are the most useful extensions in environmental modelling studies. However, these are supplied as optional extensions and one has to procure or purchase them separately. IRA-WDS has been developed using ArcView's built-in macro language, Avenue.

The extensions, 3D Analyst and Spatial Analyst are not necessary for running IRA-WDS software. However, in order to view results in a three-dimensional or perspective view, one must have ArcView's 3D Analyst extension installed. At the same time, if one is to perform spatial analysis of results by buffering, overlaying and so on, one must have ArcView's Spatial Analyst extension installed on the computer.

1.2 Installing the interface

The set-up installs the ArcView interface for IRA-WDS, which has been formatted to create a two separate directory structure on the local hard disk.

First it creates an 'AVIRAWDS' folder on the 'C:\' drive. In this folder, subdirectories named 'Legends' and 'Help' are created. The ArcView Legend files for various themes are copied to the 'C:\AVIRAWDS\Legends' subdirectory. The IRA-WDS html Help files are copied to the 'C:\AVIRAWDS\Help' subdirectory.

The second folder is created in a user-specified path. In this folder, four subdirectories named 'Help', 'Logo', 'Project' and 'Sample Data' are created. The Excel files stating the data requirements for Ingress and Pipe Condition Assessment themes are copied to the 'Help' subdirectory. The Logo files are copied to 'Logo' subdirectory. The IRA-WDS default start-up ArcView Project File 'irawds.apr' is copied to the 'Project'


subdirectory. The sample data for analysis of the model is copied to the ‘Sample Data’ subdirectory.


The IRA-WDS ArcView extension file ‘ira-wds.avx’ is copied to ArcView’s EXT32 folder, which is normally placed in the ‘C:\ESRI\AV_GIS30\ARCVIEW\EXT32’ path. The dynamic link libraries of the Contamination Ingress Model ‘ingress.dll’, Pipe Condition Assessment Model ‘pca.dll’, Risk Assessment Model ‘risk.dll’ and Analytical Hierarchy Process sub model ‘ahp.dll’ are copied to ArcView’s ‘BIN32’ folder, which is normally placed in the ‘C:\ESRI\AV_GIS30\ARCVIEW\BIN32’ path.


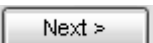
To install the interface:

- 1 Double click on the IRA-WDS Setup.exe




- 2 ‘Welcome’ screen will appear. Click 

- 3 ‘Information’ screen will appear. Click 

- 4 ‘License Agreement’ screen will appear. Click  I agree with the above terms and conditions and then click 

- 5 Choose the installation directory. And then click 

- 6 ‘Confirmation’ screen will appear. Click 

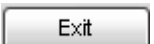
The setup will copy ‘ira-wds.avx’ file to the ArcView extension directory.

The setup will copy ‘ahp.dll’, ‘ingress.dll’, ‘pca.dll’ and ‘risk.dll’ to ‘\$AVBIN’.

The setup will copy the Sample Data files, Project file and Uninstallation file to the directory chosen by the user.

If the Installation directory is other than ‘C:\AVIRAWDS’, then set-up will create a folder ‘AVIRAWDS’ on the C: drive and will copy Legend and Help files into the Legend and Help directories.

- 7 ‘End’ screen will appear. Click 

‘Clickteam Installation Creator Pro’ screen will appear. Click 

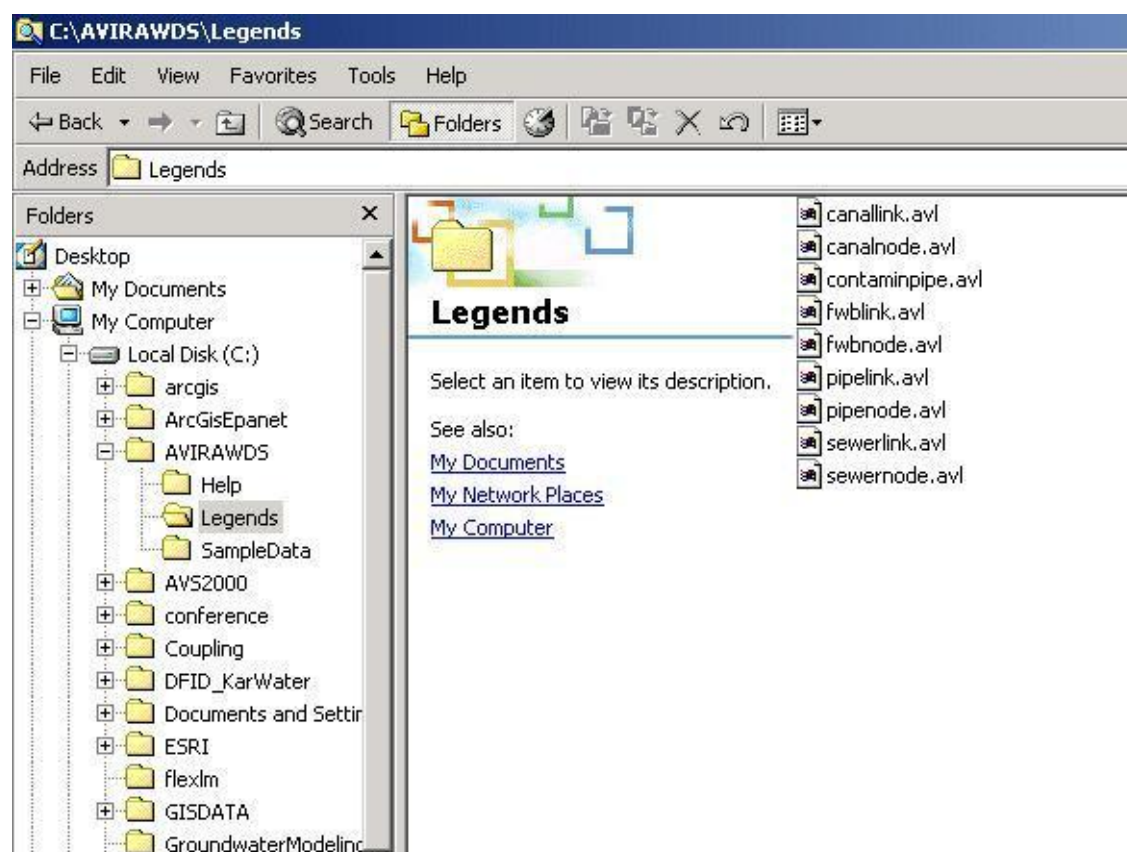
Installation is complete. Shortcut



will appear on desktop and





IRA-WDS is ready for use.

The directory structure created by installation of the IRA-WDS interface is displayed below:



1.3 Uninstalling the interface

The IRA-WDS interface can be uninstalled in number of ways. It is recommended to uninstall the software by running the 'uninstal.exe' from the installation directory. The uninstalling steps are given below.

- 1 Click  on desktop.
- 2 Go to  Programs
- 3 Go to  IRA - WDS
- 4 Click on the  Uninstall IRA - WDS

Uninstallation removes IRA-WDS from the programs menu, deletes 'ahp.dll', 'ingress.dll', 'pca.dll', 'risk.dll' and 'IRA-WDS.avx' from ArcView installation paths and removes all legend files, help files, sample data files and 'IRA-WDS.apr' from the respective installation directories.

1.4 Using IRA-WDS

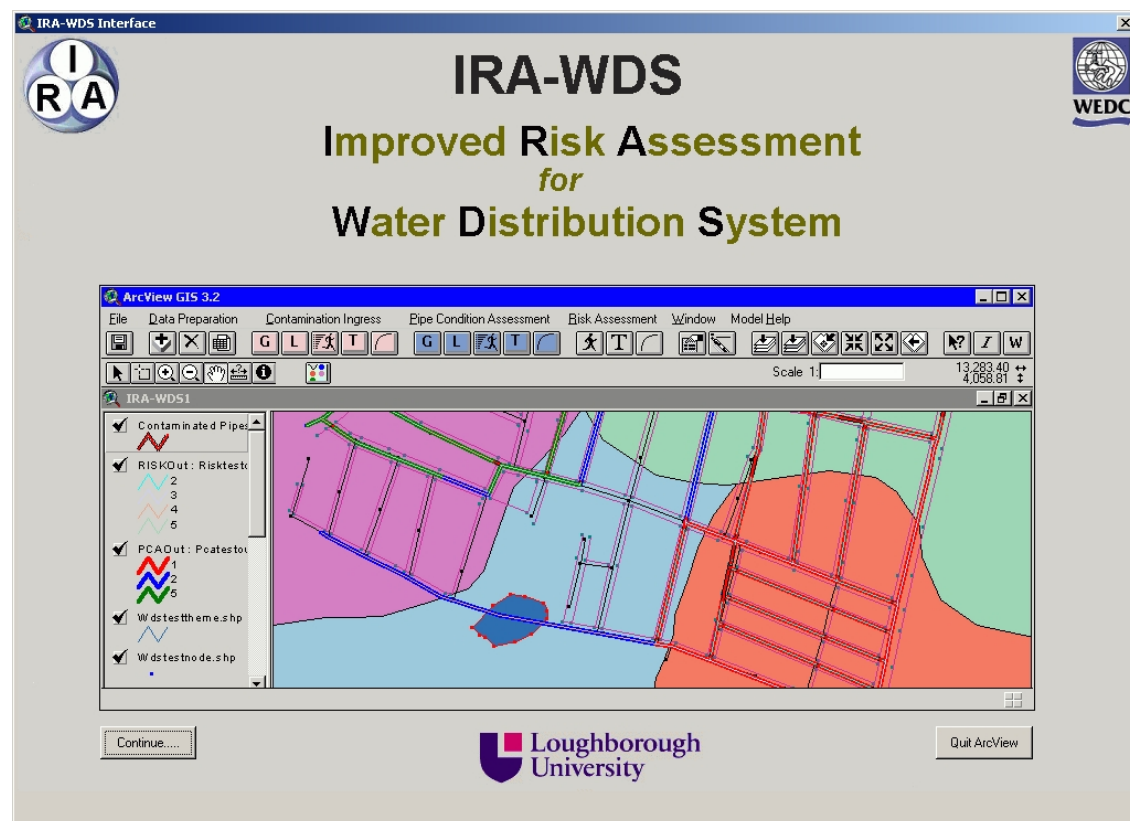
IRA-WDS can be run either by double clicking



or from taskbar as



Then following IRA-WDS 'Welcome' screen will appear:



Clicking

Quit ArcView

will exit IRA-WDS

and clicking

Continue.....

will take you to following screen:

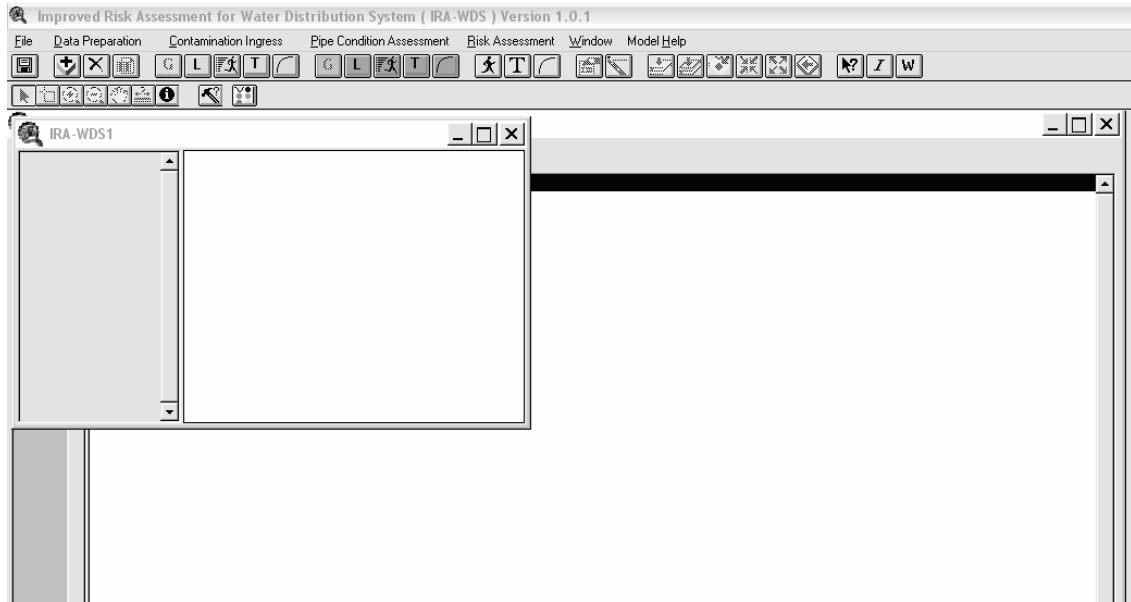


After double clicking on



from the menu on the left, the following

main IRA-WDS screen will appear:

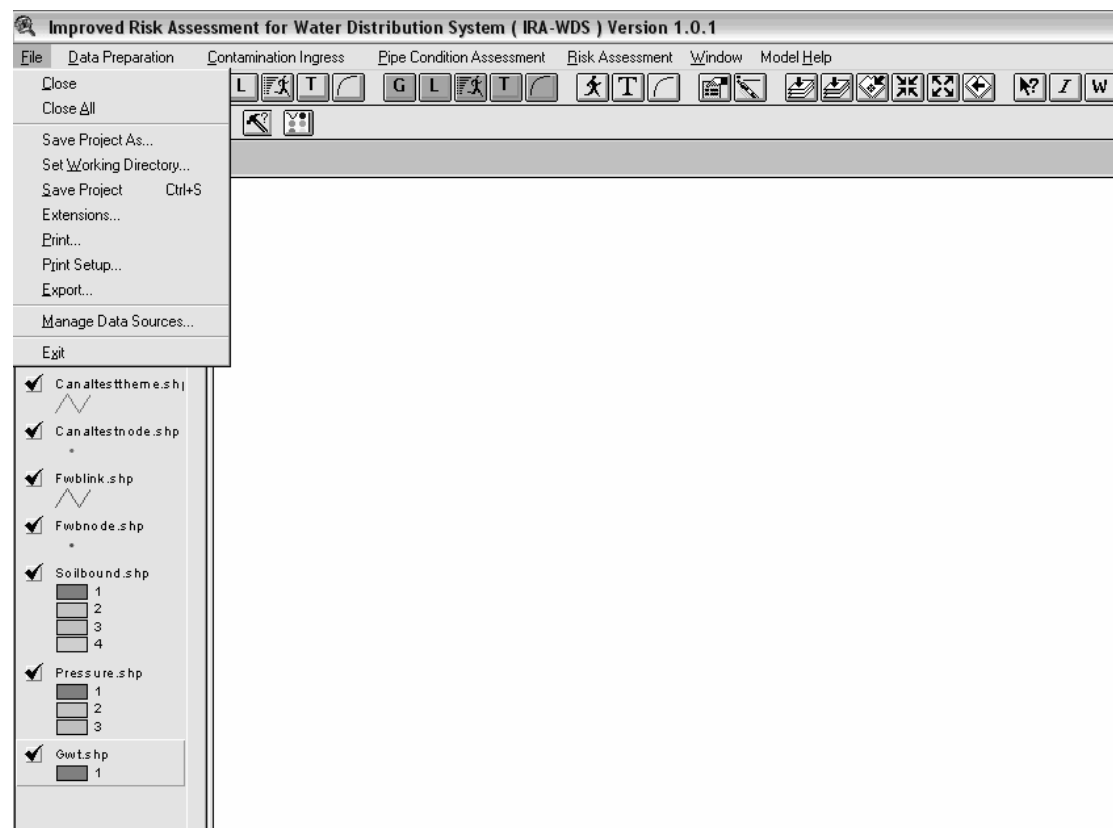


IRA-WDS has following seven main menus. One or more of these menus needs to be used in order to obtain results from IRA-WDS.

- 1 **File**
- 2 **Data Preparation**
- 3 **Contamination Ingress**
- 4 **Pipe Condition Assessment**
- 5 **Risk Assessment**
- 6 **Window**
- 7 **Model Help**

1.4.1 File menu

After clicking on 'File', the user gains access to following options:



1. Close and Close All:

Helps in closing a single opened document or Graphical User Interface (GUI) or all opened documents or GUIs.

2. Save Project and Save Project As:

Helps in saving the current project or saving it with a different name.

3. Set Working Directory:

Helps in setting the current project work directory so that the user will be prompted to 'Choose/Save/Load' his or her work to or from the directory set at every instance of the file 'Open/Save' dialogue box.

4. Extensions:

Helps the user to load other extensions to the IRA-WDS interface, if required.

5. Print:

Helps the user to set the printer and printing properties, and to print the maps he or she has generated.

6. Export:

Helps the user to export the maps he or she has generated in various other image formats so that he or she can use them for publication or presentation purposes.

7. Manage data source:

Helps the user to manage the shape files data he or she has generated. It also helps the user to perform operations such as copying, renaming and deleting shape files easily.

8. Exit:

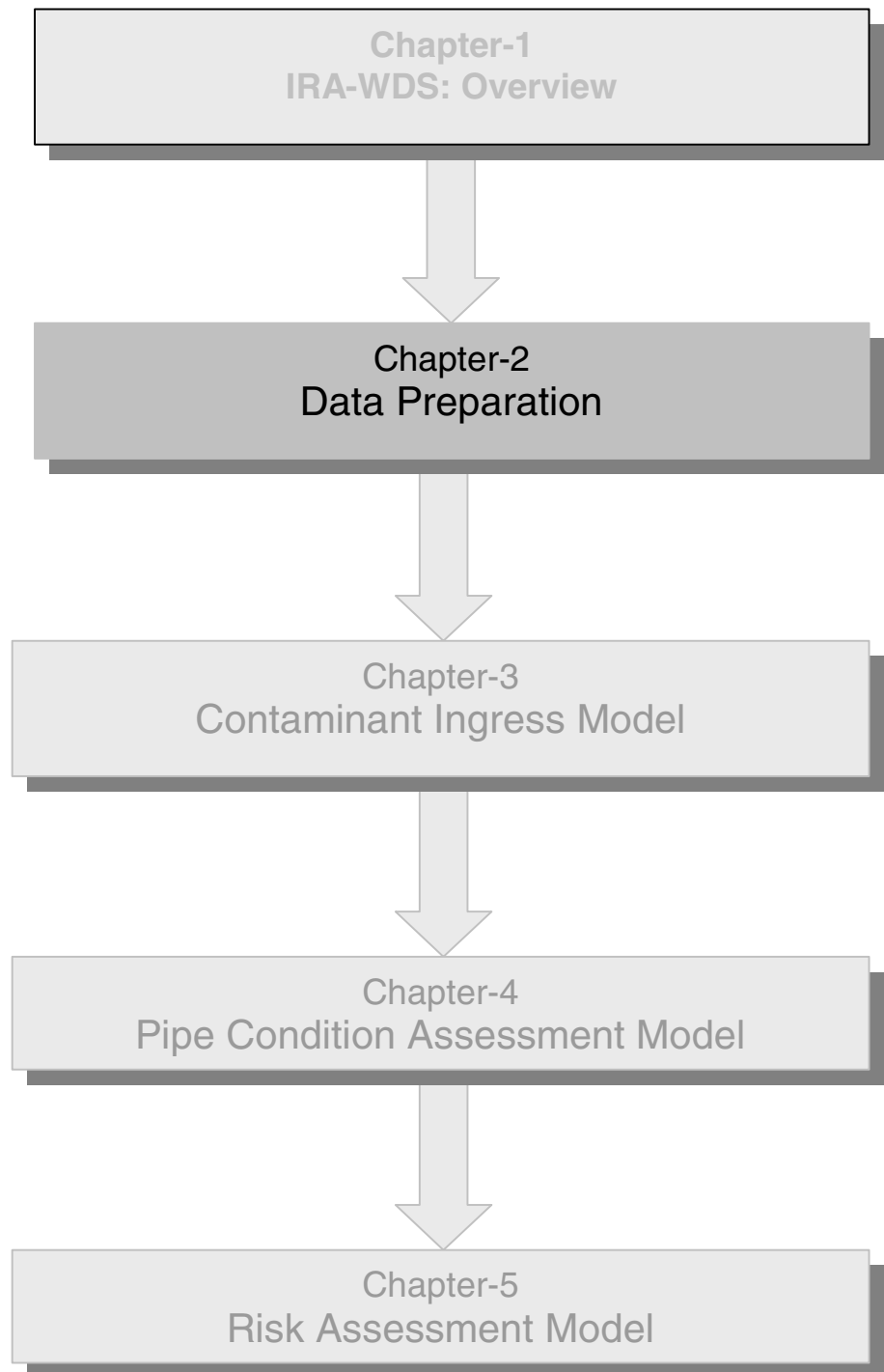
Helps the user to exit from the IRA-WDS interface and ArcView.

Note: Details of the menus Data Preparation, Contaminant Ingress, Pipe Condition and Risk Assessment are provided in Chapters 2, 3, 4 and 5, respectively.

CHAPTER TWO

Data Preparation

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution System



Chapter 2: Data Preparation

2.1 Introduction

Data preparation for the IRA-WDS program involves two major steps:

1. The creation of appropriate shape files: these are GIS files that contain the spatial information on all objects considered by the IRA-WDS program; and
2. Input of additional model data: these files contain specific characteristics of the objects generated in the shape files.

2.2 Creating shape files

The first step in using IRA-WDS is to create a series of **shape files** (for ArcView). These shape files contain spatial information on the various objects considered by IRA-WDS. These include: pollution sources, water distribution systems, base maps (that is, infrastructure and contour maps) and environmental maps (for example, soil type, groundwater and so on). The shape files are generated by digitizing maps containing the various objects (pollution sources, water distribution systems, base maps etc.); see Figures 2.1 and 2.2, below. Shape files can be divided into two categories:

- Thematic layers: base maps and environmental maps; and
- Network databases: pollution sources and water distribution systems.

As mentioned above, pollution sources and water distribution pipes are all represented as networks within IRA-WDS. For the purposes of modelling, the geometry of the networks has to be expressed as a network consisting of links and nodes. The links and nodes act as a framework on which all other kinds of relevant information are hung. The shape files so generated contain the following information:

- Nodal shape files: *Node id*, *x-coord*, *y-coord* and *Elevation*; and
- Link shape files: *Link id*, *Start node*, *End node* and *Length*.

The shape files required for IRA-WDS are as follows:

- Sewer node and link shape files;
- Canal node and link shape files;
- Foul surface water body node and link shape files; and
- Water distribution node and link shape files.

Note that in the user's working directory, each shape file generated will have five separate files associated with it with the following extensions: *.*shp*, *.*shr*, *.*sbx*, *.*spn* and *.*dbf*. For example, a sewer node shape file will have five associated files.

Among these five files, the most important ones are the '**shp**' and '**dbf**' files:

- The '**shp**' files are uploaded through the GIS interface to run the program; and
- The '**dbf**' files contain all the attribute data for nodes and links. These files are expanded during the data preparation stage (described in Section 2.3), to include specific characteristics of the nodes and links.

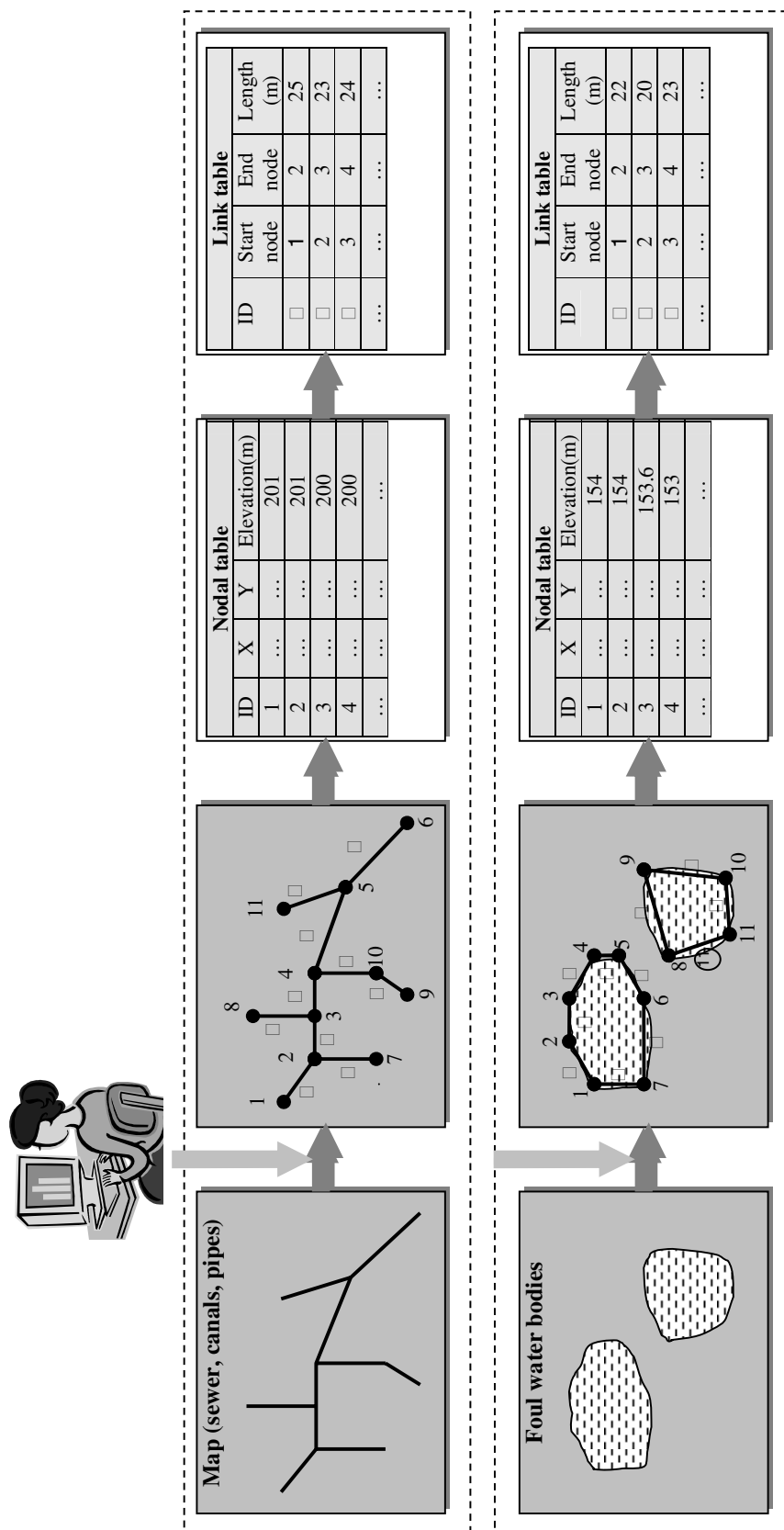


Figure 2.1. Digitization of real-world network

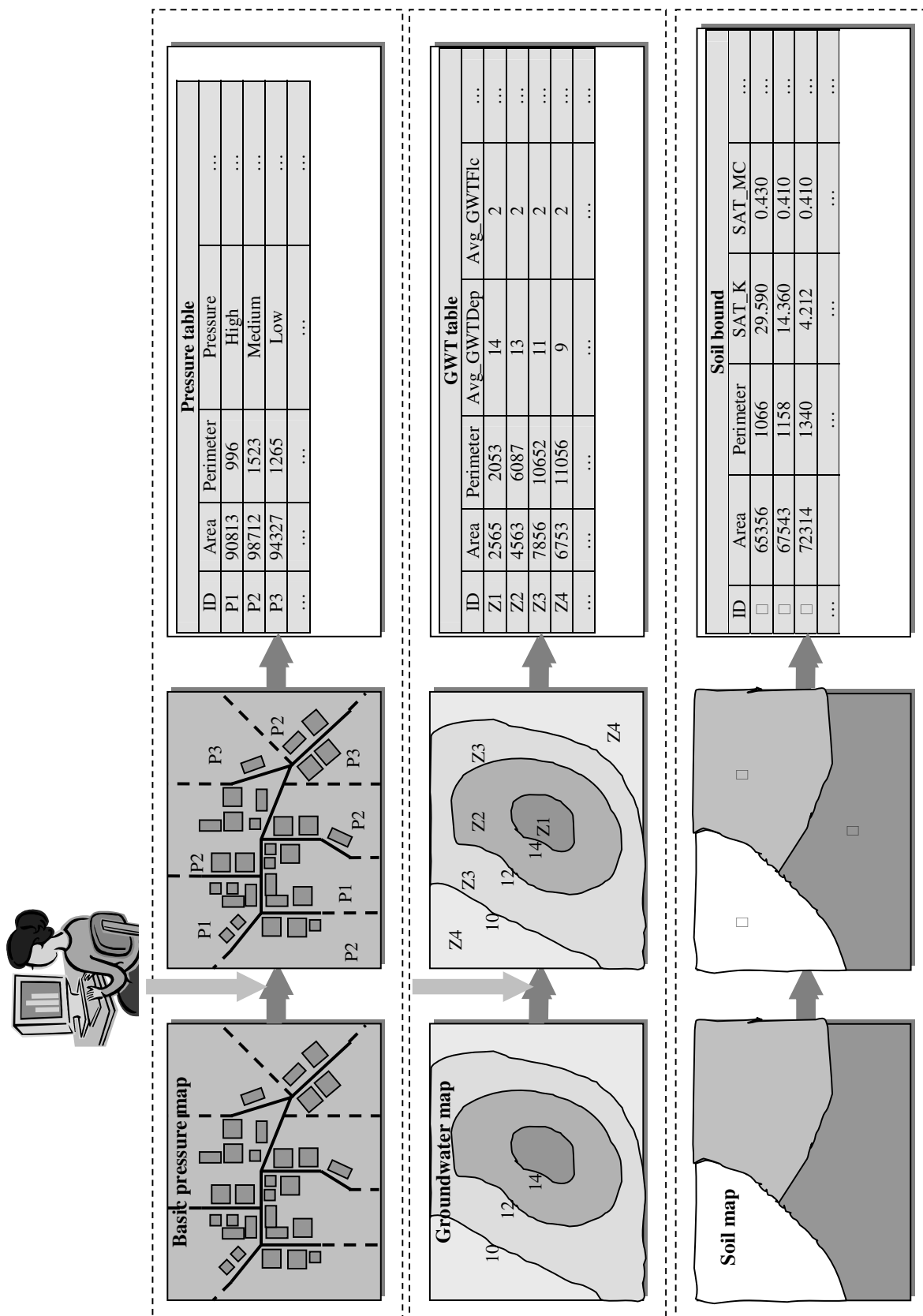


Figure 2.2. Digitization of thematic maps

Output

On completion of this step (creating shape-files) a number of shape files will have been created. These may include:

Thematic Layers

- Base maps:
 - Infrastructure – *Line and Polygon shape files*
 - Contour – *Line shape files*
- Environmental maps:
 - Soil – *Polygon shape files*
 - Groundwater – *Polygon shape files*
 - Pressure – *Polygon shape files*

Network databases

- Sewer – *Node and Link shape files*
- Canal – *Node and Link shape files*
- Foul water body – *Node and Link shape files*
- Water distribution – *Node and Link shape files*

2.3 Input of additional model data

2.3.1 Enclosed Excel spreadsheet (DataInput.xls)

In this section, details of how to add additional node and link data to the shape files are presented. To assist in this, an Excel file has been included with IRA-WDS (DataInput.xls) that contains a template. Figure 2.3, below, shows example worksheets from the Excel file.

The first thing for the user to do is to copy this Excel file into his or her working directory and rename it as appropriate (for example, the project name). The Excel spread sheet contains several worksheets to assist with data entry.

The first worksheet labelled ‘General Description’ gives an overview of all the other worksheets and provides information on data requirements for those other worksheets (see Figure 2.3). Hyperlinks are provided in this worksheet to help navigate between the other worksheets.

In addition to the General Description worksheet, there are 12 other worksheets (see the tabs at the bottom of the worksheet shown in Figure 2.3). In each of these 12 worksheets, attribute data for the various objects are added by the user. On completion of these worksheets, the data contained in them are then transferred to the objects’ respective shape files (details of how this is done is given in Section 2.4).

Note that this Excel spreadsheet has several columns in each worksheet, where the data have already been generated and stored in the shape files (in the file with extension dbf). These data mainly relate to the spatial location of the objects, but also include information related to elevation and lengths of links.

Microsoft Excel - Data requirement Ingress Model

File Edit View Insert Format Tools Data Window Help

Security... No themes

A	B	C	D	E	F	G	H	I	J	K
No of themes	Maximum	9								
	Minimum	4								
Themes		1 Water Distribution Pipe Theme			(Required)					
		2 Water Distribution Node Theme			(Required)					
		3 Sewer Pipe Theme			(Required)					
		4 Sewer Node Theme			(Required)					
		5 Canal Link Theme			(Optional)					
		6 Canal Node Theme			(Optional)					
		7 Foul Water body link theme			(Optional)					
		8 Foul Water body node theme			(Optional)					
		9 Soil theme			(Optional)					
Sr. No.	Field Name	Unit	Data Type	Field Precision	Description					
1	ID		Integer		Node ID					
2	X_CORRD	Meters	Float	3	X-Coordinate					
3	Y_COORD	Meters	Float	3	Y-Coordinate					
4	Z_COORD	Meters	Float	3	Z-Coordinate					
5	BURYDEPTH	Meters	Float	3	Bury depth					
6	ELEVATION	Meters	Float	3	Surface Elevation					
Canal Link	(Optional)									
Sr. No.	Field Name	Unit	Data Type	Field Precision	Description					
1	ID		Integer		Link ID					
2	STARTNODE		Integer		Start Node ID					
3	ENDNODE		Integer		End Node ID					
4	LENGTH	Meters	Float	3	Length of Canal					
5	LINED	Yes/No	Character		Lined or Unlined					
6	CROSS_SECT		Character		Type of Cross Section for eg., Rectangular, Trapezoidal					
7	TOPWIDTH	Meters	Float	3	Topwidth of Cross section					
8	BOTWIDTH	Meters	Float	3	Bottom Width of Cross section					
9	DEPTH	Meters	Float	3	Depth of Cross Section					
10	SEEP_RATE	Meter/day	Float	3	Seepage rate from Canal					
Canal Node	(Optional)									
Sr. No.	Field Name	Unit	Data Type	Field Precision	Description					
1	ID		Integer		Node ID					
2	X_CORRD	Meters	Float	3	X-Coordinate					
3	Y_COORD	Meters	Float	3	Y-Coordinate					
4	Z_COORD	Meters	Float	3	Z-Coordinate					
5	ELEVATION	Meters	Float	3	Surface Elevation					

General Description / Water Pipe / Water Node / Sewer Pipe / Sewer Node / Canal Link / Canal Node / Waterbody Link / Waterbody Node / Soil

2.3.2 Contaminant Ingress Model

- Pollutant sources;
- Water distribution pipes; and
- Environmental data (soil type and so on).

IRA-WDS considers the following pollutant sources: sewers/drains, canals and ponds/ditches. As described earlier, the spatial information about the pollution sources is contained in the generated shape files. This section provides details on how additional attribute data are added.

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
ID	X_CORRD	Y_COORD	Z_COORD	BURYDEPTH	ELEVATION										
249	13323.932000	4386.384000	18.200001	2.00	20.200001										
270	13317.545000	4357.836000	18.390001	1.80	20.190001										
293	13311.616000	4323.376000	18.320001	1.80	20.120001										
294	13299.661000	4322.115000	18.450000	1.70	20.150000										
300	13340.474000	4317.265000	18.459999	1.90	20.359999										
312	13374.868000	4309.980000	18.639999	1.80	20.439999										
327	13292.297000	4295.322000	18.860001	1.50	20.360001										
328	13447.460000	4294.630000	18.020000	2.00	20.020000										
341	13311.906000	4282.414000	18.870002	1.80	20.670002										
343	13520.606000	4279.257000	18.400001	1.80	20.200001										
345	13364.874000	4276.078000	19.150006	1.80	20.950006										
348	13363.594000	4271.734000	19.150006	1.80	20.950006										
350	13557.620000	4270.723000	19.230008	2.10	21.330008										
351	13223.673000	4268.724000	18.940004	1.50	20.440004										
353	13336.528000	4267.478000	19.339999	1.80	21.139999										
358	13399.932000	4263.904000	18.710005	2.00	20.710005										
359	13400.493000	4263.783000	18.719999	2.00	20.719999										
365	13360.849000	4260.602000	19.430004	1.50	20.930004										
366	13241.790000	4260.068000	18.990002	1.50	20.490002										
367	13610.263000	4258.909000	17.999999	2.20	20.199999										
369	13609.968000	4257.524000	18.050001	2.15	20.200001										
370	13305.747000	4257.515000	18.900003	1.80	20.700003										
371	13305.591000	4256.897000	18.900003	1.80	20.700003										
374	13440.306000	4254.082000	19.310002	2.10	21.410002										
375	13514.818000	4251.146000	19.620003	2.00	21.620003										
378	13190.842000	4249.279000	18.970005	1.60	20.570005										
380	13475.860000	4247.351000	19.550001	1.90	21.450001										
384	13330.106000	4244.451000	19.010001	1.80	20.610001										
385	13201.506000	4243.253000	19.190001	1.60	20.790001										
390	13512.935000	4241.995000	19.980003	2.00	21.980003										
398	13300.016000	4234.863000	18.829999	1.80	20.629999										
400	13549.377000	4233.656000	20.710004	1.80	22.510004										
405	13510.831000	4229.054000	19.920000	2.00	21.920000										
409	13231.340000	4226.397000	19.500006	1.60	21.100006										
413	13602.268000	4221.318000	23.290015	2.10	25.390015										
414	13175.817000	4221.035000	19.720007	1.50	21.220007										
420	13470.802000	4215.746000	19.840000	1.90	21.740000										
423	13600.590000	4214.282000	23.450001	2.10	25.550001										

Figure 2.6. Node data entry for sewer

Table 2.1. Sewer link data for Contaminant Ingress Model

Field name	Unit	Description
SEWER_DIA	mm	Sewer diameter
SEEP_RATE	Metre/day	Seepage rate from sewer pipe

Table 2.2. Sewer node data for Contaminant Ingress Model

Field name	Unit	Description
BURYDEPTH	Metres	Buried depth of node

2.3.2.2 Water distribution system

In addition to pollutant sources, IRA-WDS requires additional attribute data for the water distribution system. As described earlier, the spatial information about the water distribution system (WDS) is contained in the shape files generated earlier. In this section, details are given on how additional attribute data are added.

Figure 2.7, below, shows the relevant worksheet from the enclosed Excel file for the water distribution system. At this stage, the shaded columns shown in Figure 2.7 should have been filled from the data in the dbf shape files (see Section 2.4).

The next stage is for the user to complete the remaining fields on the worksheets (the unshaded columns of the table in Figure 2.7). For details, see Table 2.3.

Table 2.3. WDS node data for Contaminant Ingress Model		
Field name	Unit	Description
BURYDEPTH	Metres	Bury depth
Z- Coordinate	Metres	Surface elevation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	ID	X, CORR	Y, COORD	Z, COORD	BURYDEPTH	ELEVATION											
1	631	13269.16797	4389.78516	18.700003	1.700000	20.400003											
2	632	13270.47363	4389.65967	18.720004	1.700000	20.420004											
3	643	13321.44238	4384.75781	18.520001	1.700000	20.220001											
4	660	13259.09668	4370.46045	18.620002	1.700000	20.320002											
5	696	13312.62012	4336.76563	18.410001	1.700000	20.110001											
6	713	13310.14160	4323.28516	18.429999	1.700000	20.129999											
7	719	13232.79980	4319.07568	18.519999	1.700000	20.219999											
8	728	13374.45703	4309.44971	18.740001	1.700000	20.440001											
9	732	13223.68652	4304.34082	18.470000	1.700000	20.170000											
10	734	13222.39160	4303.02197	18.470000	1.700000	20.170000											
11	739	13411.48828	4301.48340	18.450001	1.500000	19.950001											
12	740	13240.89746	4298.76318	18.520001	1.700000	20.220001											
13	747	13472.19531	4288.30273	18.980009	1.500000	20.480009											
14	753	13311.42773	4282.53174	19.160002	1.500000	20.660002											
15	758	13519.72949	4277.98242	18.900001	1.300000	20.200001											
16	760	13338.45508	4276.81152	19.750000	1.500000	21.250000											
17	765	13363.68066	4272.02393	19.450006	1.500000	20.950006											
18	769	13556.93750	4269.83838	20.040000	1.300000	21.340000											
19	777	13400.15918	4263.17334	19.220005	1.500000	20.720005											
20	780	13360.23828	4259.75342	19.430000	1.500000	20.930000											
21	781	13179.65039	4259.49023	18.660001	1.700000	20.360001											
22	785	13176.87988	4257.25635	18.670001	1.700000	20.370001											
23	786	13177.10059	4257.04150	18.670001	1.700000	20.370001											
24	788	13610.07910	4256.94189	18.909999	1.300000	20.209999											
25	789	13440.01074	4254.76416	19.900002	1.500000	21.400002											
26	800	13193.69824	4247.54199	18.940003	1.700000	20.640003											
27	801	13475.86035	4246.86523	19.950001	1.500000	21.450001											
28	806	13511.87598	4241.67773	20.670003	1.300000	21.970003											
29	807	13512.38184	4241.57227	20.680003	1.300000	21.980003											
30	814	13153.42285	4238.34375	18.939999	1.700000	20.639999											
31	815	13150.52734	4236.94531	18.960000	1.700000	20.660000											
32	821	13549.28613	4233.90332	21.210004	1.300000	22.510004											
33	822	13550.39551	4233.67285	21.210004	1.300000	22.510004											
34	823	13140.20898	4231.96143	19.140004	1.700000	20.840004											
35	827	13224.21289	4230.07764	19.420001	1.700000	21.120001											
36	834	13601.71875	4222.04688	24.070005	1.300000	25.370005											
37	836	13175.94434	4220.11670	19.560002	1.700000	21.260002											
38	837	13471.08105	4216.01758	20.430000	1.300000	21.730000											

Figure 2.7. Node data entry for water distribution system

2.3.2.3 Environmental factors

In addition to the pollutant sources and water distribution system, IRA-WDS requires information on soil characteristics. Shape files have already been constructed for soil data, groundwater and pressure zones. In this section, details on are given how additional attribute data are added.

Figure 2.8, below, shows the relevant worksheet from the enclosed Excel file for soil characteristics. At this stage, the shaded columns shown in Figure 2.8 should have already been filled from the data in the dbf shape files (see Section 2.4).

The next stage is for the user to complete the remaining fields on the worksheets (the unshaded columns of the table in Figure 2.8). For details, see Table 2.4.

Table 2.4. Soil data for Contaminant Ingress Model		
Field name	Unit	Description
SAT_K	cm/hr	Saturated hydraulic conductivity
SAT_MC		Saturated moisture content
INI_MC		Initial moisture content
BULK_DEN	gm/cm ³	Bulk density
KOC		Soil organic carbon coefficient
AIR_ENTRY	cm	Air entry head
PORESIZE		Pore size index
DIFF_COEFF	cm ² /day	Diffusion coefficient
SOIL_FOC		Soil fraction of organic content
LIQ_DECAY	per hr	Liquid phase decay
CHAR_COEFF		Soil characteristic curve coefficient

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	SOIL_ID	SAT_K	SAT_MC	INI_MC	BULK_DEN	KOC	AIR_ENTRY	PORESIZ	DIFF_COEFF	SOIL_FOC	LIQ_DECAY	CORROSIVIT	CHAR_COEFF				
1	1	29.590	0.430	0.047	1.650	1.000	7.020	1.670	1.000	0.007	1.000	25000.000	0.078				
2	2	14.360	0.410	0.057	1.600	2.000	9.580	1.270	2.000	0.006	2.000	15000.000	1.023				
3	3	4.212	0.410	0.064	1.500	3.000	17.700	0.892	3.000	0.007	3.000	7000.000	1.230				
4	4	1.163	0.390	0.101	1.450	4.000	26.200	0.479	4.000	0.002	4.000	2000.000	1.560				
5																	
6																	
7																	
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10																	
11																	
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Figure 2.8. Soil data entry

2.3.3 Pipe Condition Assessment Model

Data requirements for the Pipe Condition Assessment Model are related to the factors that affect the condition of the pipe. A description of these various factors and how they are represented in the model can be found in Chapter 3, below.

It should be noted that this model requires some data in the form of fuzzy (qualitative) numbers (such as link joint type, surface type, traffic load and so on) and others as crisp (quantitative) numbers (such as link material, diameter, length and so on). Therefore the data in the form of fuzzy numbers will require the user to input fuzzy membership functions. Table 3.1 in Chapter 3 of Book 3 shows which data is fuzzy and which is crisp.

Figure 2.9, below, shows the relevant worksheet from the enclosed Excel file for the Pipe Condition Assessment Model. At this stage, the shaded columns shown in Figure 2.9 should have already been filled from the data in the dbf shape files (see Section 2.4) and during data preparation for the Contaminant Ingress Model. The next stage is for the user to complete the remaining fields on the worksheets (the unshaded columns in Figure 2.9 and Table 2.5).

Table 2.5. WDS link data for Pipe Condition Assessment Model		
Field name	Unit	Description
STRJOINT		Joint method at start node
ENDJOINT		Joint method at end node
MATERIAL		Material type
TRAFFIC		Traffic load
SURFACE		Surface type
INTPROT		Internal protection
EXTPROT		External protection
BEDCOND		Bedding condition
WORKMANS		Workmanship
DIAMETER	<i>mm</i>	Diameter of pipe
INSTYEAR	<i>yyyy</i>	Installation year
LENGTH	<i>Metres</i>	Length of pipe
STRDEPTH	<i>Metres</i>	Start node bury depth
ENDDEPTH	<i>Metres</i>	End node bury depth
NOCONNEC		No. of pipes joined with diameter less than minimum considered
BREAKAGE	<i>Per year</i>	No. of breaks per year
LEAKAGE	<i>lps</i>	Leakage rate
VALVES		No. of valves
DURATION	<i>Hrs/day</i>	Duration of water supply per day
NOOPER	<i>Per day</i>	No. of times water supplied per day

PIPEID	STARTNODE	ENDNODE	STRJOINT	ENDJOINT	MATERIAL	TRAFFIC	SURFACE	INTPROT	EXTPROT	BEDCOND	WORKMANS	DIAMETER	INSTYEAR	LENGTH	STRDEPTH
689	631	632	Very Good	Very Good	AC	Normal	Very Hard	Medium	Bad	Very Bad	Very Good	500	1955	1.312	1.700
703	632	643	Bad	Bad	AC	Normal	Grassed	Medium	Very Good	Very Good	Bad	500	1955	51.204	1.700
722	660	631	Bad	Bad	RCC	Normal	Grassed	Medium	Very Good	Good	Bad	500	1955	21.792	1.700
762	643	696	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	48.796	1.700
781	696	713	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	13.706	1.700
786	719	680	Medium	Medium	RCC	Normal	Grassed	Medium	Very Good	Bad	Medium	500	1955	57.723	1.700
796	713	728	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	65.787	1.700
800	732	719	Medium	Medium	RCC	Normal	Grassed	Medium	Very Good	Bad	Medium	500	1955	17.325	1.700
803	734	732	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	500	1955	1.848	1.700
808	728	739	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Good	400	1970	37.878	1.500
809	740	734	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	500	1955	18.990	1.700
818	739	747	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Good	400	1970	62.121	1.500
824	753	740	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	200	1955	72.374	1.700
830	747	758	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	48.642	1.300
831	760	753	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1955	27.626	1.500
836	765	728	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Medium	400	1985	38.946	1.500
837	765	760	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1985	25.676	1.500
842	758	769	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	38.089	1.300
852	777	765	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1970	37.537	1.500
855	780	765	Medium	Medium	AC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1985	12.744	1.500
856	781	734	Medium	Medium	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	500	1955	61.007	1.700
861	785	781	Medium	Medium	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	3.559	1.700
862	786	785	Medium	Medium	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	0.308	1.700
865	769	788	Bad	Bad	AC	Quite	Very Hard	Medium	Bad	Good	Very Good	400	1970	54.684	1.300
866	789	777	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Good	Good	200	1970	40.729	1.500
879	800	786	Bad	Bad	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	19.124	1.700
880	789	801	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Good	200	1970	36.710	1.500
883	801	806	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	36.387	1.300
884	807	758	Medium	Medium	RCC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	37.144	1.300
885	806	807	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	0.517	1.300
892	814	785	Bad	Bad	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	30.132	1.700
893	815	814	Bad	Bad	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	3.216	1.700
898	807	821	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	37.693	1.300
899	821	822	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	1.133	1.300
900	823	815	Bad	Bad	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	11.459	1.700
905	827	800	Bad	Bad	U1	Very Quite	Grassed	Bad	Very Good	Bad	Medium	200	1985	35.159	1.700
914	834	788	Bad	Bad	AC	Quite	Very Hard	Medium	Bad	Good	Very Good	400	1970	35.883	1.300
915	822	834	Bad	Bad	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	52.624	1.300

Figure 2.9. Water distribution pipe condition assessment data

2.4 Creating a dbf


At this stage, all data for the model have been completed and entered into the Excel spreadsheet provided. This Excel file should have been stored in the working directory for the project.

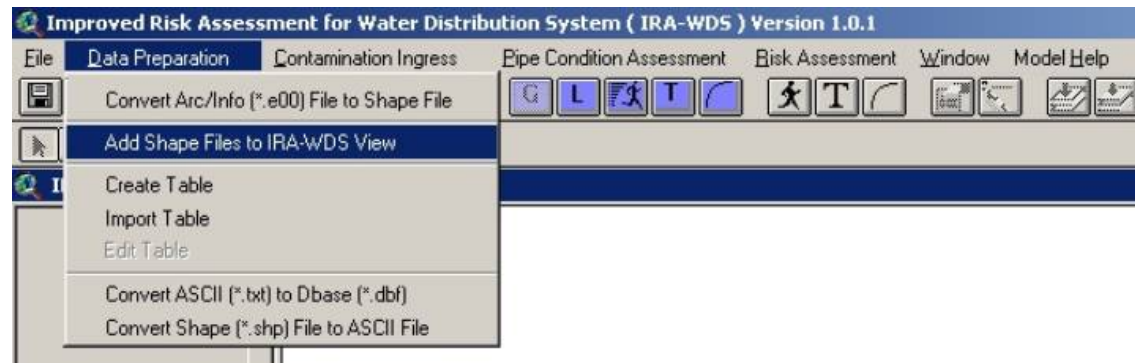
The next step is for the user to link the data in the Excel spreadsheet with the relevant shape files. In order to achieve this, each worksheet from the Excel spreadsheet must be saved as a dbf file with a filename identical to the relevant shape file.

For example, to create the link data shape file for a water distribution system:

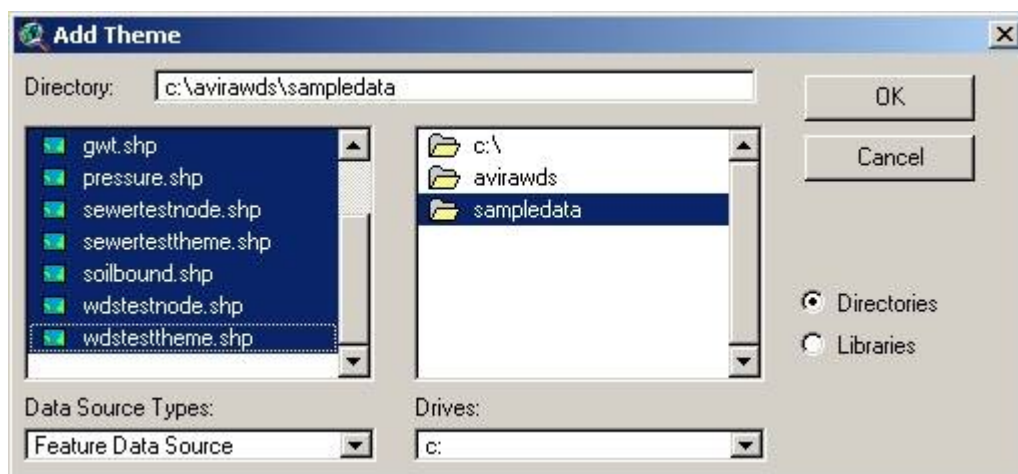
1. If the name of the shape file is 'waterpipe.shp'
2. In the Excel spreadsheet select the 'WDSlink' worksheet
3. While this worksheet is active, do the following:
 - File – Save As: 'waterpipe.dbf' (this name is the same as the shape file)
 - Make sure the file is saved to the working directory (that contains the shape files)
 - Note: the original 'waterpipe.dbf' file will be overwritten with the new dbf file. Therefore, make sure all the information in the original dbf file has been copied to the new one.

2.5 Add shape files to GIS

The next step is for the user to add the necessary shape files to IRA-WDS, so that the data can be viewed and used by the three models (the Contamination Ingress Model, Pipe Condition Assessment Model and Risk Assessment Model). This can be done by clicking on the Tool icon  which is just below the 'Data Preparation' menu or by clicking on the 'Data Preparation' menu and then clicking on the submenu 'Add Shape Files to IRA-WDS View', as shown in the screen below:



This opens the 'Add Theme' form, as shown below:



After the user selects the shape files to be added to the IRA-WDS View, he/she can click on the 'OK' button, which will load the shape files to the IRA-WDS View, and corresponding dbf files in the Table GUI of the ArcView.

CHAPTER THREE

Contaminant Ingress Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems

Chapter-1
IRA-WDS: Overview



Chapter-2
Data Preparation



Chapter-3
Contaminant Ingress Model



Chapter-4
Pipe Condition Assessment Model



Chapter-5
Risk Assessment Model

Chapter 3: Contaminant Ingress Model

3.1 Introduction

The ‘Contaminant Ingress’ menu contains several submenus. This chapter describes the use of these submenus and associated commands to run the Contaminant Ingress Model. Figure 3.1, below, shows the steps involved in executing this component of the software.

The following steps need to be performed to run the Contaminant Ingress Model:

- Adding the data (if not already done so)
- Rearranging the data (optional)
- Generating an input file
- Viewing Ingress input file (optional)
- Loading input file
- Running model
- Displaying output (optional)

The example files given in Table 3.1 are used for illustration purposes to describe the use of the Contaminant Ingress Model with the help of IRA-WDS.

Table 3.1. Example input files	
Themes	Filenames
Water distribution	wdstesttheme.shp
	wdstestnode.shp
Sewer	sewertesttheme.shp
	sewertestnode.shp
Canal	canaltesttheme.shp
	canaltestnode.shp
Foul water body	fwblink.shp
	fwbnode.shp
Soil type	soilbound.shp

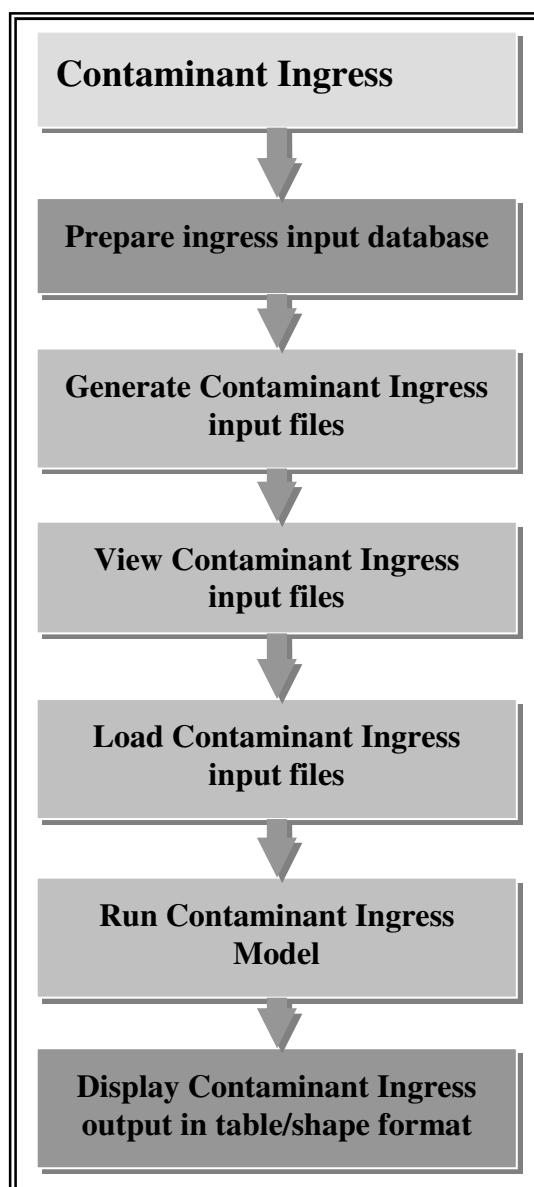

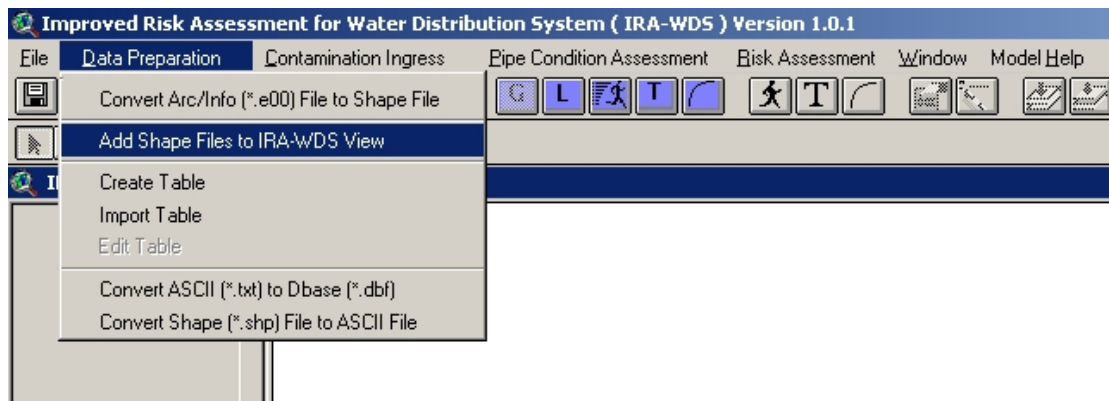


Figure 3.1. Overview of Contaminant Ingress Model of IRA-WDS

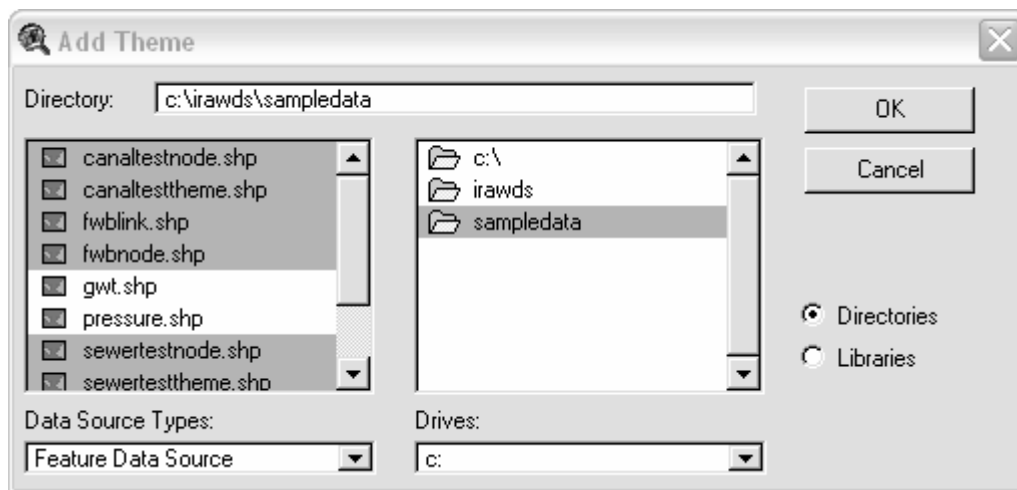
3.2 Shape files

3.2.1 Adding shape files

Adding shape files can be done by clicking on the Tool icon  which is just below the 'Data Preparation' menu or by clicking on the 'Data Preparation' menu and then clicking on the submenu 'Add Shape Files to IRA-WDS View', as shown in the screen below:

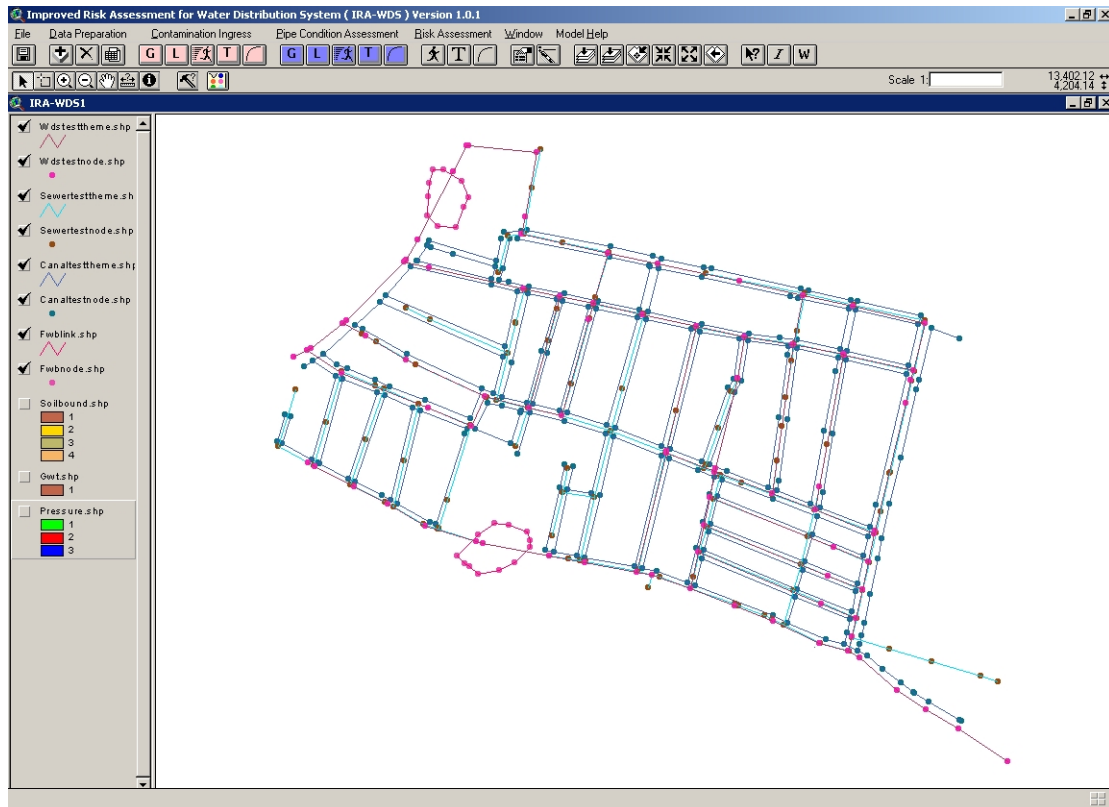


This opens the Add Theme form, as shown below, and the user is then required to select the desired files. At this stage, these files are those relating to: water distribution link and node; sewer pipe link and node; canal link and node; foul water bodies link and node; and soil polygon map.

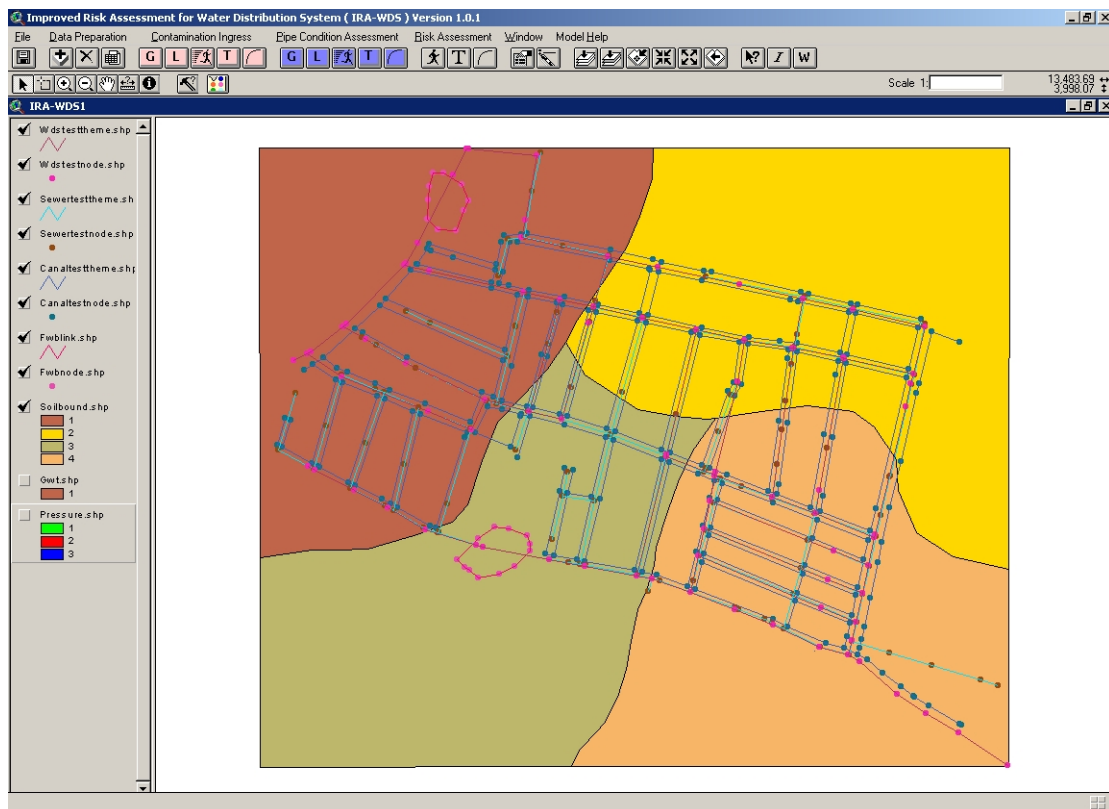


3.2.2 Rearranging shape files

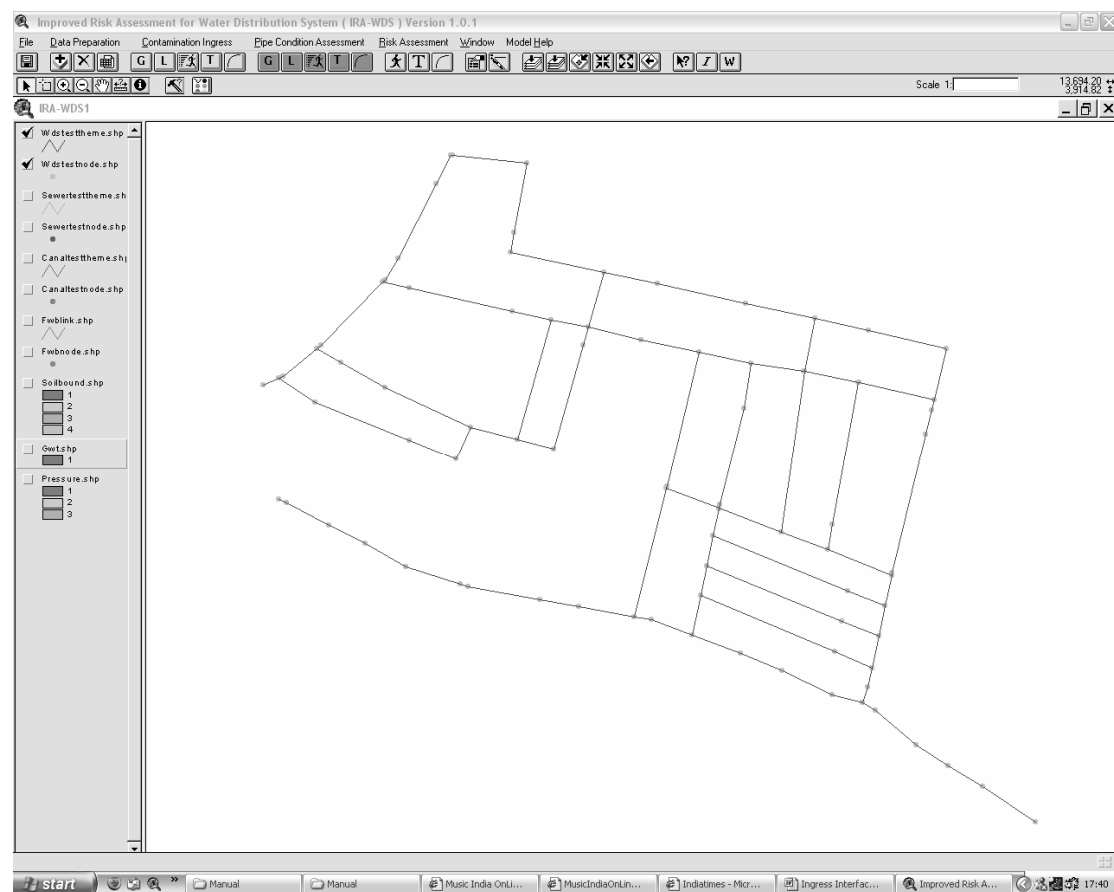
Once the data are added, these can be rearranged for viewing purposes. This can be done by selecting (☑) and/or omitting (☐) different themes (on the left hand side) and changing the preference order of different themes by dragging them above or below the other themes. For example, the view with only line and node themes is as below:



However, if a polygon theme such as soil is to be viewed with these themes, the user should select 'Soilbound.shp'. The view with line and node themes and different soil types is then as below:




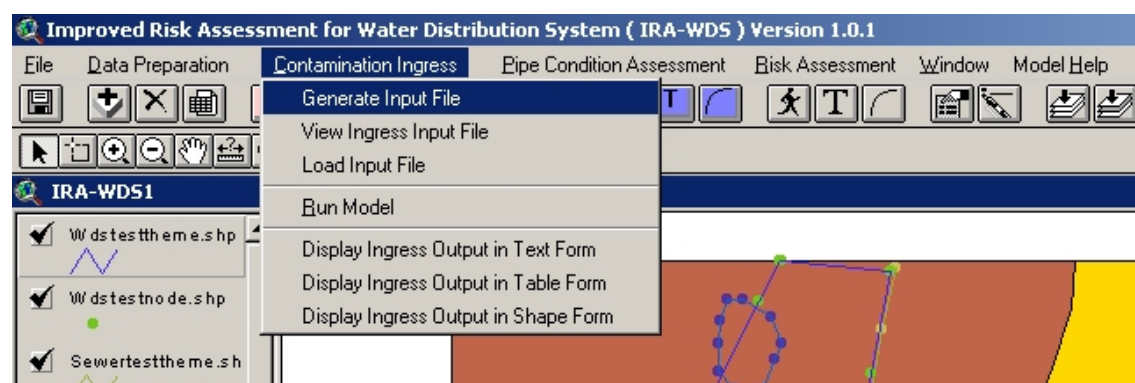
Similarly, if only the water distribution network theme is to be viewed, the user should select 'wdstesttheme.shp' and 'wdstestnode.shp', as shown below:



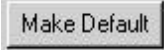


3.3 Generating an input file

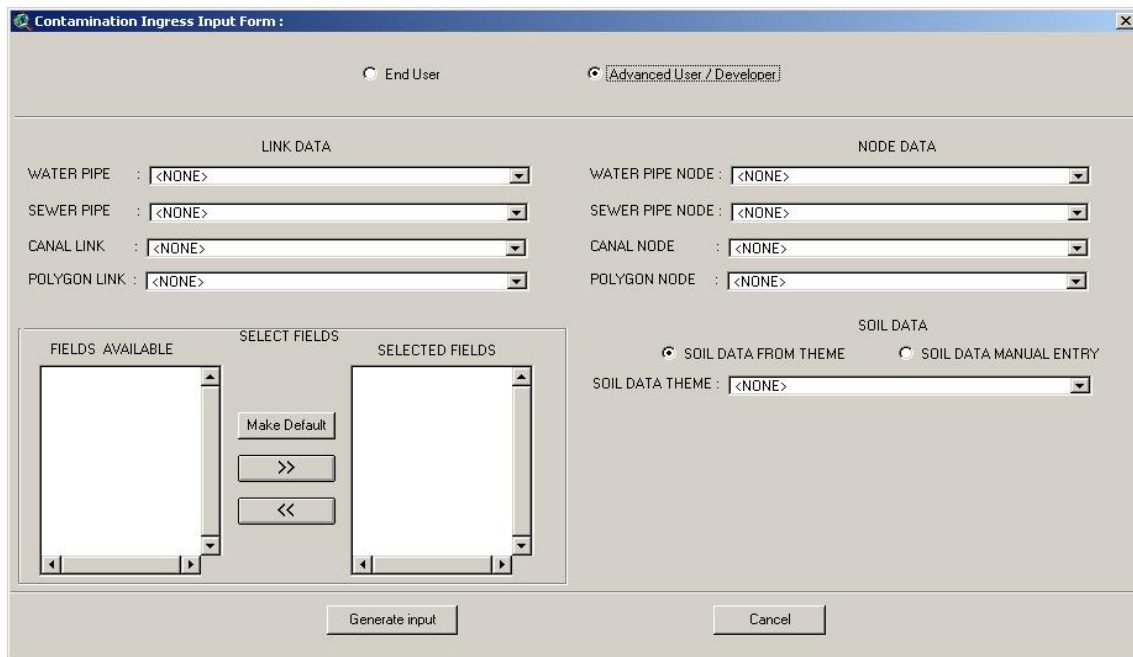
3.3.1 Background to Contaminant Ingress Model input

An input file can be generated by clicking on the Tool icon  which is just below the 'Contamination Ingress' menu or by clicking on the 'Contamination Ingress' menu and then clicking on the submenu 'Generate Input File', as shown in the screen below:



The Contamination Ingress Input Form has two radio button options: **Advanced User** and **End User**.

Advanced users can click on the radio button next to Advanced User/Developer, which allows the user to add or remove fields to or from the ‘SELECTED FIELDS’ list box. The user can click the  button to select the default field names. Advanced users can add fields to the ‘SELECTED FIELDS’ list box by selecting those fields in the ‘FIELDS AVAILABLE’ list box and then clicking on  button, or can remove fields from the ‘SELECTED FIELDS’ list box by selecting those fields in the ‘SELECTED FIELDS’ list and then clicking on  button.

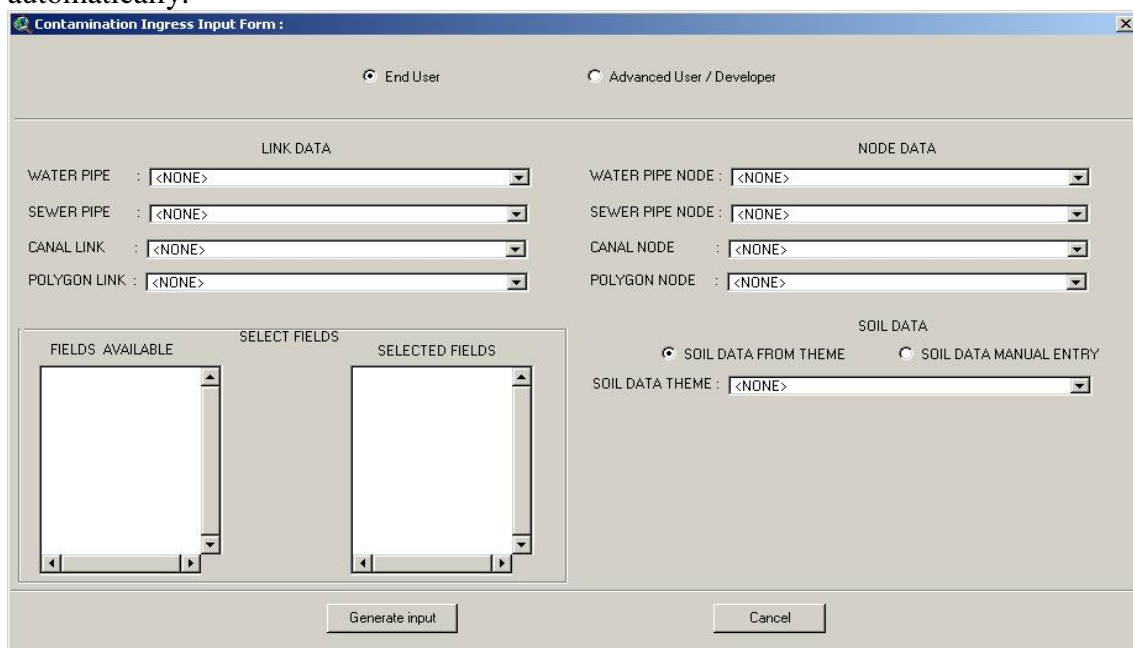


The screenshot shows the 'Contamination Ingress Input Form' window. At the top, the 'Advanced User / Developer' radio button is selected. The form is divided into several sections:

- LINK DATA:** Four dropdown menus for 'WATER PIPE', 'SEWER PIPE', 'CANAL LINK', and 'POLYGON LINK', all currently set to '<NONE>'.
- NODE DATA:** Four dropdown menus for 'WATER PIPE NODE', 'SEWER PIPE NODE', 'CANAL NODE', and 'POLYGON NODE', all currently set to '<NONE>'.
- SELECT FIELDS:** A section with two list boxes: 'FIELDS AVAILABLE' and 'SELECTED FIELDS'. Between them are three buttons: 'Make Default', '>>', and '<<'. Both list boxes are currently empty.
- SOIL DATA:** Two radio buttons, 'SOIL DATA FROM THEME' (selected) and 'SOIL DATA MANUAL ENTRY'. Below them is a dropdown menu for 'SOIL DATA THEME' set to '<NONE>'.

At the bottom of the form are two buttons: 'Generate input' and 'Cancel'.

End users are not provided with the option of adding or deleting fields to or from the ‘SELECTED FIELDS’ list box. With the End User option, the fields are selected automatically.



This screenshot shows the same 'Contamination Ingress Input Form' window, but with the 'End User' radio button selected. The layout and fields are identical to the previous screenshot, including the 'LINK DATA', 'NODE DATA', 'SELECT FIELDS', and 'SOIL DATA' sections. The 'Generate input' and 'Cancel' buttons are also present at the bottom.

3.3.2 Adding shape files

3.3.2.1 Water and sewer distribution data

The themes added by the user in the IRA-WDS View need to be defined in terms of which theme represents what (that is, the user needs to define which theme represents water distribution system pipe/node theme, sewer pipe/node theme, canal link/node theme and foul water body (polygon) link/node theme). All polyline shape files in the IRA-WDS View are listed in each combo box placed under the 'LINK DATA' so that user can choose each respective theme from the list to represent WATER PIPE, SEWER PIPE, CANAL LINK and POLYGON LINK in the IRA-WDS View. All point shape files in the IRA-WDS View are listed in each combo box placed under the 'NODE DATA' so that user can choose each respective theme from the list to represent WATER PIPE NODE, SEWER PIPE NODE, CANAL NODE and POLYGON NODE in the IRA-WDS View.

The screenshot shows the 'Contamination Ingress Input Form' with the following sections:

- LINK DATA:** Four dropdown menus for WATER PIPE, SEWER PIPE, CANAL LINK, and POLYGON LINK, each with a shape file selected (e.g., 'Wdstesttheme.shp').
- NODE DATA:** Four dropdown menus for WATER PIPE NODE, SEWER PIPE NODE, CANAL NODE, and POLYGON NODE, each with a shape file selected (e.g., 'Wdstestnode.shp').
- SOIL DATA:** A radio button for 'SOIL D' is selected, followed by a 'SOIL DATA THEME' dropdown menu showing a list of shape files including '<NONE>', 'Wdstestnode.shp', 'Sewertestnode.shp', 'Canaltestnode.shp', and 'Fwbnode.shp'.
- FIELD SELECTION:** A section with three columns: 'FIELDS AVAILABLE' (listing Shape, Id, X_coord, Y_coord, Z_coord, Polygon, Water_dep, Soil_id), 'SELECT FIELDS' (empty), and 'SELECTED FIELDS' (listing Id, X_coord, Y_coord, Z_coord, Water_dep, Soil_id).
- Buttons:** 'Generate input' and 'Cancel' buttons at the bottom.

3.3.2.2 Soil data

SOIL DATA for Contamination Ingress can be defined either through the soil theme, through manual input or through the soil database built within IRA-WDS. All polygon shape files in the IRA-WDS View are listed in combo box placed under the 'SOIL DATA' so that user can choose each respective theme from the list to represent SOIL DATA THEME in the IRA-WDS View.

3.3.2.3 Soil data from theme

The figure below shows the user how to select soil data from the shape files.

The screenshot shows the 'Contamination Ingress Input Form' with the 'End User' radio button selected. The 'LINK DATA' section contains four dropdown menus: 'WATER PIPE' (Wdstesttheme.shp), 'SEWER PIPE' (Sewertesttheme.shp), 'CANAL LINK' (Canaltesttheme.shp), and 'POLYGON LINK' (Fwblink.shp). The 'NODE DATA' section contains four dropdown menus: 'WATER PIPE NODE' (Wdstestnode.shp), 'SEWER PIPE NODE' (Sewertestnode.shp), 'CANAL NODE' (Canaltestnode.shp), and 'POLYGON NODE' (Fwbnode.shp). The 'SOIL DATA' section has two radio buttons: 'SOIL DATA FROM THEME' (selected) and 'SOIL DATA MANUAL ENTRY'. Below these, a dropdown menu for 'SOIL DATA THEME' shows a list with '<NONE>', 'Soilbound.shp' (highlighted), and 'Gwt.shp'. To the left of the 'SOIL DATA' section, there are two lists: 'FIELDS AVAILABLE' (Shape, Area, Perimeter, Soilbound_, Soil_id, Soil_type, Sat_k, Sat_mc) and 'SELECTED FIELDS' (Soil_id, Sat_k, Sat_mc, Ini_mc, Bulk_den, Koc, Air_entry, Poresize). At the bottom are 'Generate input' and 'Cancel' buttons.

3.3.2.4 Soil data manual input

With the soil data manual entry option, the user inputs the soil data desired in a box provided before each soil parameter, as shown below:

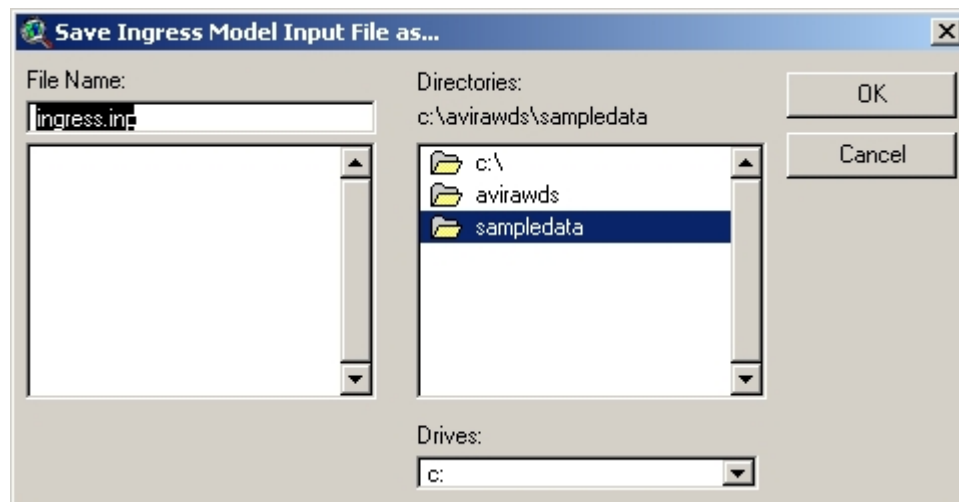
The screenshot shows the 'Contamination Ingress Input Form' with the 'Advanced User / Developer' radio button selected. The 'LINK DATA' and 'NODE DATA' sections are identical to the previous screenshot. The 'SOIL DATA' section has two radio buttons: 'SOIL DATA FROM THEME' and 'SOIL DATA MANUAL ENTRY' (selected). Below these, there are several input fields: 'Soil Type' (dropdown with '<User>' selected), 'Soil T' (dropdown with '<User>' selected), 'Saturated HC (Ks, c' (dropdown with 'Sand' and 'Loamy Sand' options), 'Initial SMC (Qo, cm3/cm3)' (text input), 'Air Entry Head [he, cm]' (text input), 'Pore Size Index' (text input), 'Soil Characteristic Curve Coeff.' (text input), 'Fraction Organic Content (Foc)' (text input), 'Diffusion Coeff. (Dp, cm2/day)' (text input), 'Organic Carbon Coeff (Koc)' (text input), and 'Liquid Phase Decay (LPD, per hr)' (text input). At the bottom are 'Generate input' and 'Cancel' buttons.

3.3.2.5 Soil data from database

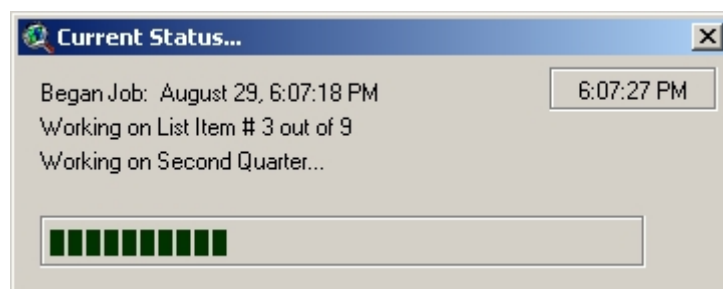
With the soil data from database option, the user chooses the soil type from the Soil Type menu, which consists of different soil properties. The user can also modify the soil properties by using the empty boxes next to some soil properties. The some soil properties depend on the interaction of different soils with contaminants (for example, fraction organic content). The user is required to input the values of these properties.

3.4 Generating the input file for the model

After completing the data definition, the next step is for the user to generate the input file to run the Contamination Ingress Model. The Contamination Ingress input file is generated by clicking on the 'Generate Input' button on the 'Contamination Ingress Input Form'. For example, if the soil theme is selected, a spatial analysis is performed by the program to identify the pipes and corresponding soil types in which they are buried; then the soil data is appended according to the node themes of the water distribution system, sewer system, canal and foul water body. Then the user opens the 'File Save' dialogue box to save the file with a user-defined name, as below:



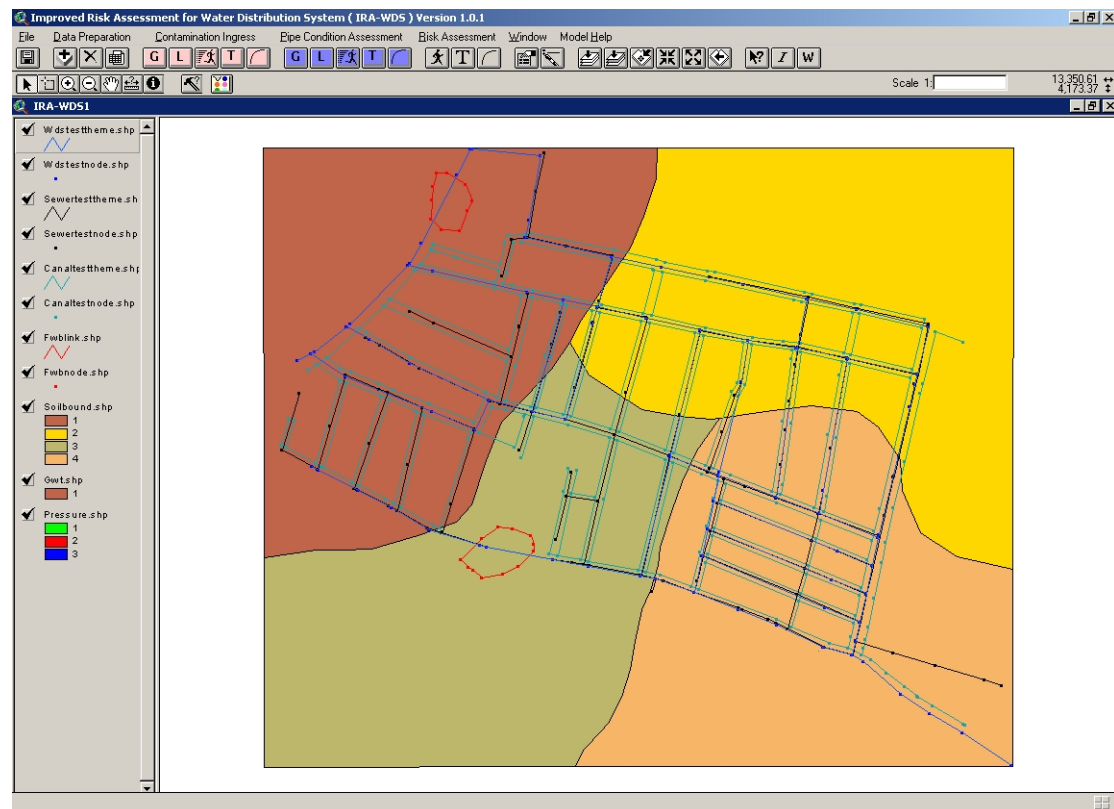
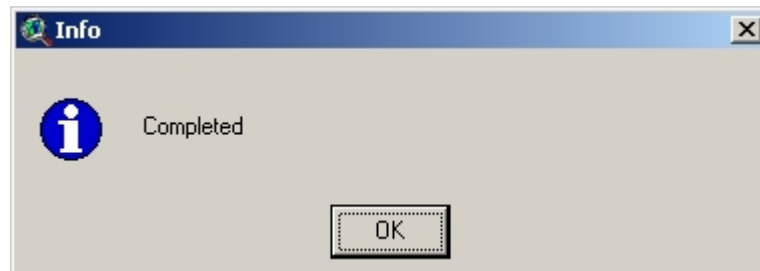
The data generation and writing progress is shown in the Progress Bar as below:




Before the completion of data writing, the model prompts an Input box asking for 'Time of Analysis' (See Appendix B) as shown on next page.



After successfully generating the input file, an Info Message box indicating task completion is displayed as shown below:



3.4.1 Viewing Ingress input file

The user can view the input file in the notepad by clicking on the  button and browsing the appropriate output file to view.

ingress - Notepad

File Edit Format Help

[POLYGON NODE 2]

Id	X_coord	Y_coord	Z_coord	water_Depth	soil_ID
76	13289.500		4108.500	22.590	0.500 3
77	13300.500		4106.720	22.530	0.500 3
78	13314.000		4101.690	22.470	0.500 3
79	13277.300		4100.020	22.750	0.500 3
80	13316.600		4095.650	22.490	0.500 3
81	13316.200		4090.520	22.520	0.500 3
82	13261.800		4084.040	23.070	0.500 3
83	13305.100		4079.250	22.670	0.500 3
84	13267.400		4078.040	23.080	0.500 3
85	13271.000		4076.200	23.060	0.500 3
86	13293.300		4073.100	22.800	0.500 3
87	13277.500		4070.190	23.020	0.500 3

[SOIL DATA]

Soil_id	Sat_k	Sat_mc	Ini_mc	Bulk_den	KOC	Air_Entry	Poresize	Diff_coeff	FOC	Liq_de
1	29.590	0.430	0.047	1.650	1.000	7.020	1.670	1.000	0.007	1.000 0.07
2	14.360	0.410	0.057	1.600	2.000	9.580	1.270	2.000	0.006	2.000 1.02
3	4.212	0.410	0.064	1.500	3.000	17.700	0.892	3.000	0.007	3.000 1.23
4	1.163	0.390	0.101	1.450	4.000	26.200	0.479	4.000	0.002	4.000 1.56


[TIME]

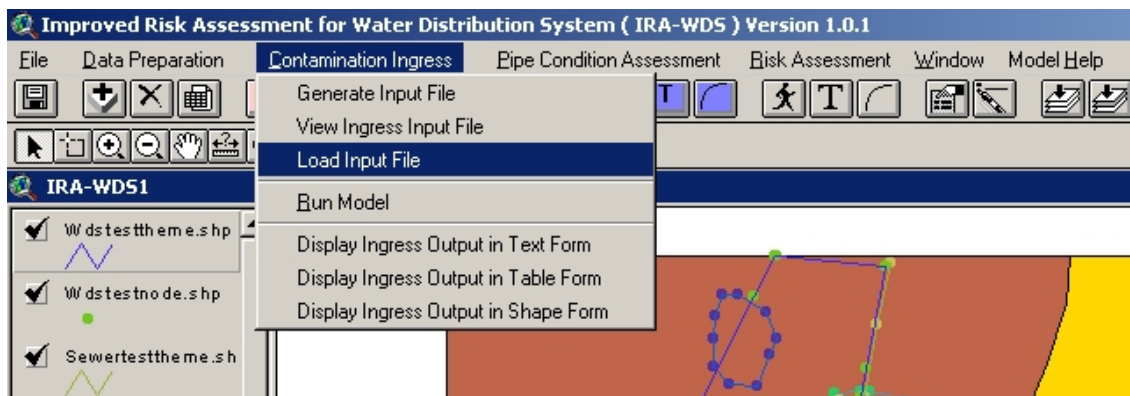
TIME

500

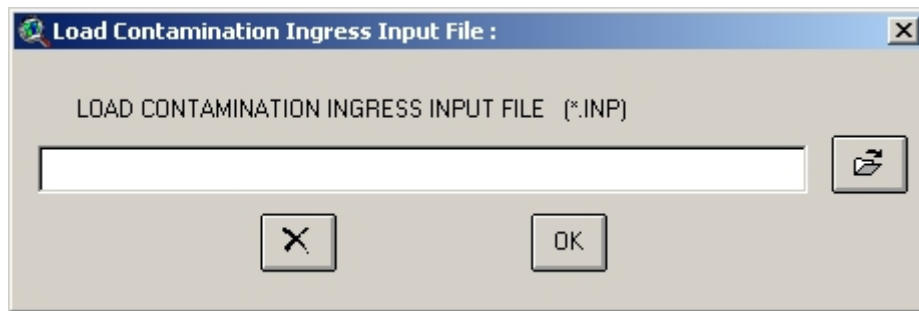
IRA-WDS data viewer


3.4.2 Loading input file

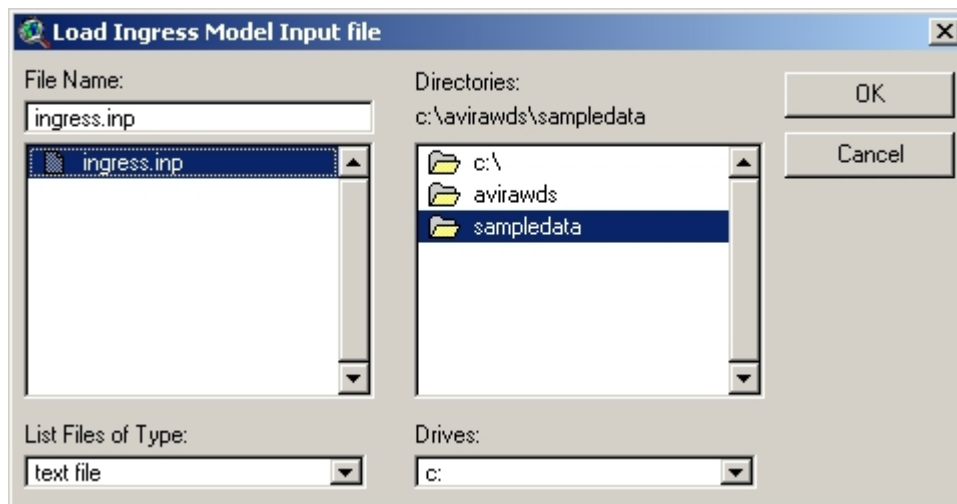
The input file to be used for running the Contaminant Ingress Model is loaded using tool  which is just below the 'Contamination Ingress' menu or by clicking on the 'Contamination Ingress' menu and then clicking on the submenu 'Load Input File', as shown on the screen below:



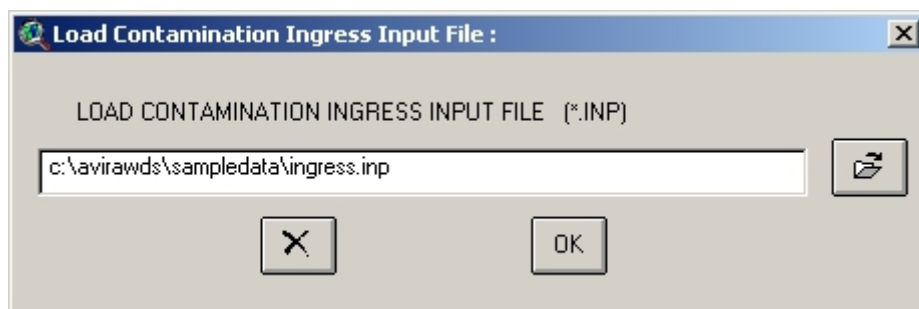
The 'Load Contamination Ingress Input File' dialogue box is as shown below:





The user can browse through the computer by clicking on the  button on the 'Load Contamination Ingress Input File' dialogue box. This opens the 'File Load' dialogue box, as shown below:




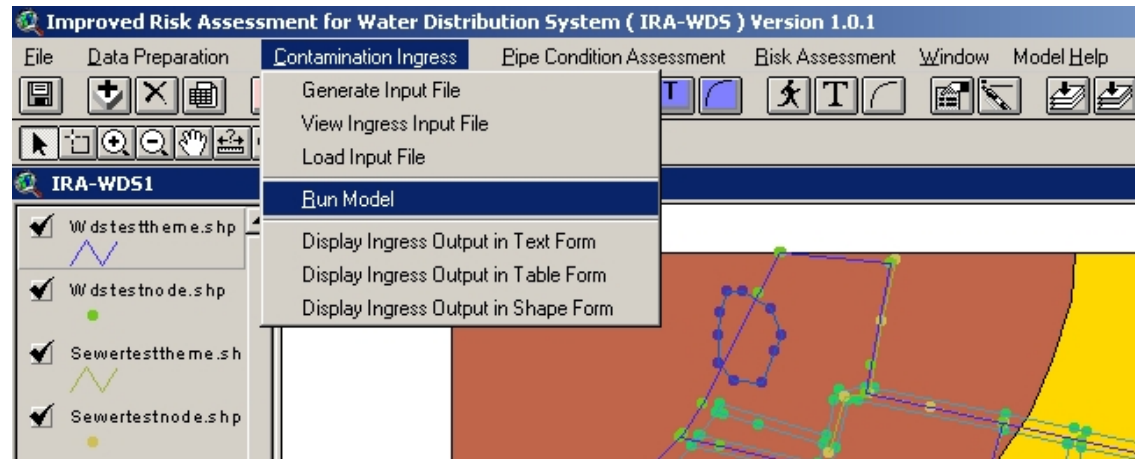
After the appropriate file has been selected, the user presses the 'OK' button on the 'Load Contamination Ingress Input File' dialogue box where the filename appears.



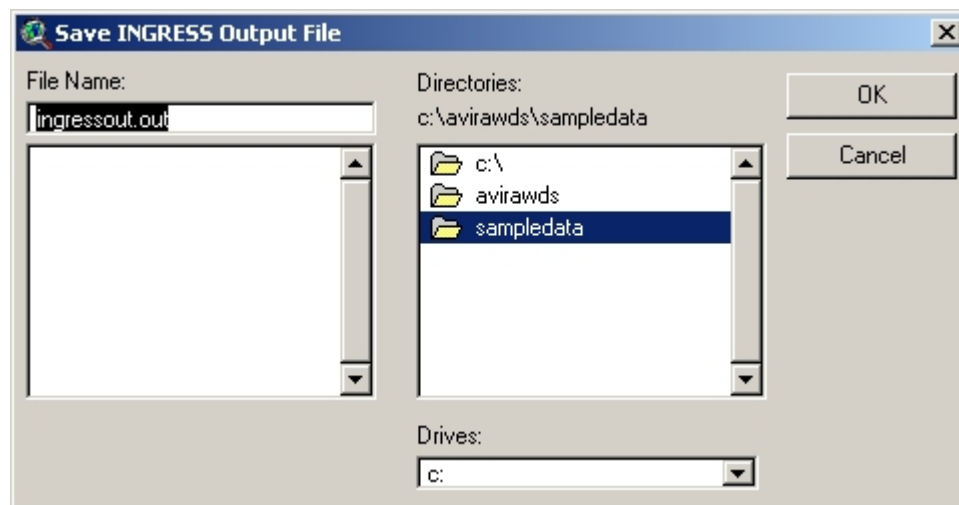
If the user wants to change the filename, he or she can do this by clicking the button , which clears the filename from the 'Load Contamination Ingress Input File' dialogue box. If user is sure of the input file selected, then the file can be loaded by clicking on the  button, which also closes 'Load Contamination Ingress Input File' dialogue box.

3.5 Running the Contaminant Ingress Model

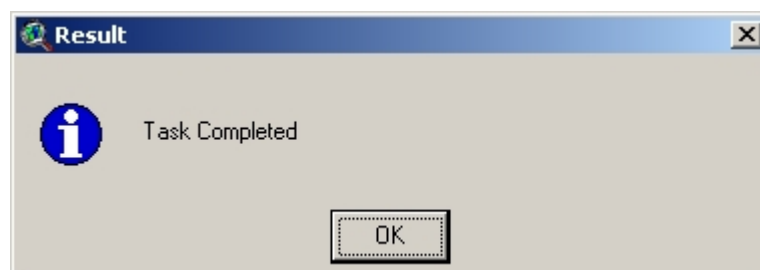
To run the model, the user clicks on the  button, which is just below the 'Contamination Ingress' menu or he or she clicks on the 'Contamination Ingress' menu and then clicks on the submenu 'Run Model', as shown on the screen below:



This opens the 'File Save' dialogue box for saving the Contamination Ingress Model output file as *.out. Once the user types the appropriate name and clicks 'OK', then the outputs are generated as specified by the user.




The program then displays the 'Task Completed' Result Message Box, as shown below:

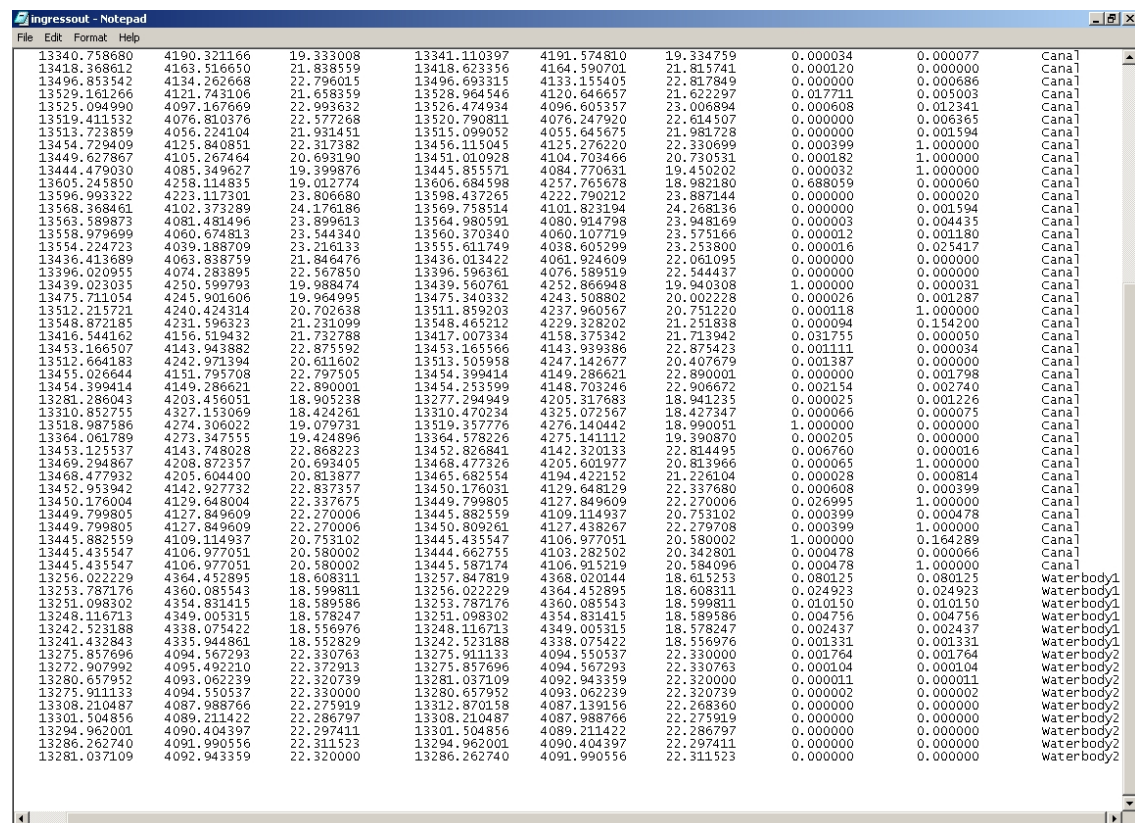
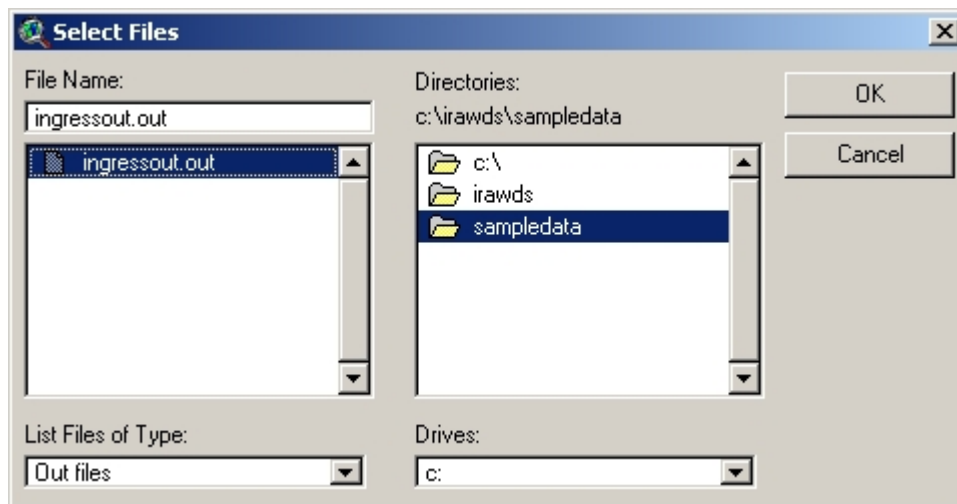


3.6 Displaying output

Outputs can be displayed in text, table and shape forms

3.6.1 Displaying Ingress output in text form

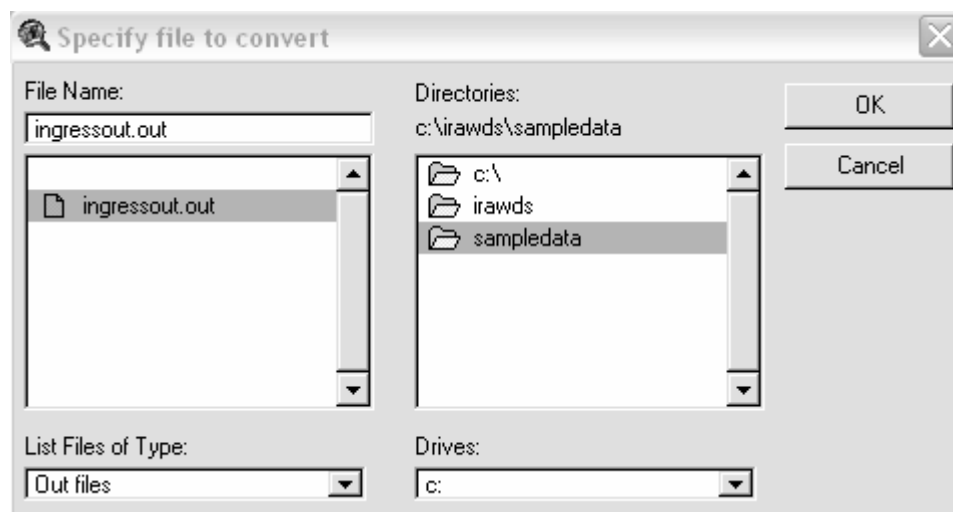
The user can view the output file in text form using the notepad by clicking on the  button or by selecting the Display Output in Text Form submenu from the Contaminant Ingress menu and browsing the appropriate output file to view.



13340.758680	4190.321166	19.333008	13341.110397	4191.574810	19.334759	0.000034	0.000077	Canal
13418.368612	4163.516650	21.838559	13418.623356	4164.590701	21.815741	0.000120	0.000000	Canal
13496.853542	4134.262668	22.796015	13496.693315	4133.155405	22.817849	0.000000	0.000686	Canal
13529.161266	4121.743106	21.658359	13528.964546	4120.646657	21.622297	0.017711	0.005003	Canal
13525.094990	4097.167669	22.993632	13526.474934	4096.605357	23.006894	0.000608	0.012341	Canal
13510.411532	4076.810376	22.577268	13520.790811	4076.247920	22.614507	0.000000	0.006365	Canal
13513.723859	4056.224104	21.931451	13515.099052	4055.645675	21.981728	0.000000	0.001594	Canal
13454.729409	4125.840851	22.317382	13456.115045	4125.276220	22.330699	0.000399	1.000000	Canal
13449.627867	4105.267464	20.693190	13451.010928	4104.703466	20.730531	0.000182	1.000000	Canal
13444.479030	4085.349627	19.399876	13445.855571	4084.770631	19.450202	0.000032	1.000000	Canal
13605.245850	4258.114835	19.012774	13606.684598	4257.765678	18.982180	0.688059	0.000060	Canal
13596.993322	4223.117301	23.806680	13598.437265	4222.790212	23.887144	0.000000	0.000020	Canal
13568.368461	4102.373289	24.176186	13569.758514	4101.823194	24.268136	0.000000	0.001594	Canal
13563.589873	4081.481496	23.899613	13564.980591	4080.914798	23.948169	0.000003	0.004435	Canal
13558.979693	4060.674813	23.544340	13560.370547	4060.107719	23.575166	0.000012	0.001180	Canal
13554.224723	4039.188709	23.216133	13555.611749	4038.605299	23.253800	0.000016	0.025417	Canal
13436.413689	4063.838759	21.846476	13436.013422	4061.924609	22.061095	0.000000	0.000000	Canal
13396.020955	4074.283895	22.567850	13396.596361	4076.589519	22.544437	0.000000	0.000000	Canal
13439.023035	4250.599793	19.988474	13439.560761	4252.866948	19.940308	1.000000	0.000031	Canal
13475.711054	4245.901606	19.964995	13475.340332	4243.508802	20.002228	0.000026	0.001287	Canal
13512.215721	4240.424314	20.702638	13511.859203	4237.960567	20.751220	0.000118	1.000000	Canal
13548.872185	4231.596323	21.231099	13548.465212	4229.328202	21.251838	0.000094	0.154200	Canal
13416.544162	4156.519432	21.732788	13417.007334	4158.375342	21.713942	0.031755	0.000050	Canal
13453.166507	4143.943682	22.871592	13453.165366	4143.939386	22.875423	0.001111	0.000034	Canal
13512.684183	4242.971394	20.611602	13513.505958	4247.142677	20.407679	0.001387	0.000000	Canal
13455.026644	4151.795708	22.797505	13454.399414	4149.286621	22.890001	0.000000	0.001798	Canal
13454.399414	4149.286621	22.890001	13454.253599	4148.703246	22.906672	0.002154	0.002740	Canal
13281.286043	4203.456051	18.905238	13277.294949	4205.317683	18.941235	0.000025	0.001226	Canal
13310.852755	4327.133069	18.424261	13310.470234	4325.072567	18.427347	0.000066	0.000075	Canal
13518.987586	4274.306022	19.079731	13519.357776	4276.140442	18.990051	1.000000	0.000000	Canal
13364.061789	4273.347555	19.424896	13364.578226	4275.141112	19.390870	0.000205	0.000000	Canal
13453.125537	4143.748028	22.868223	13452.826841	4142.320133	22.814495	0.006760	0.000016	Canal
13469.294867	4208.872337	20.693405	13468.477326	4205.601977	20.813966	0.000065	1.000000	Canal
13468.477932	4205.604400	20.813877	13465.682554	4194.422152	21.226104	0.000028	0.000814	Canal
13452.953942	4142.927732	22.837357	13450.176031	4129.548129	22.337680	0.000608	0.000399	Canal
13450.176004	4129.648004	22.337675	13449.799805	4127.849609	22.270006	0.026995	1.000000	Canal
13449.799805	4127.849609	22.270006	13445.882559	4109.114937	20.753102	0.000399	0.000478	Canal
13449.799805	4127.849609	22.270006	13450.809261	4127.438267	22.279708	0.000399	1.000000	Canal
13445.882559	4109.114937	20.753102	13445.435547	4106.977051	20.580000	1.000000	0.164289	Canal
13445.435547	4106.977051	20.580000	13444.662755	4103.282502	20.342801	0.000478	0.000066	Canal
13445.435547	4106.977051	20.580000	13445.587174	4106.915219	20.584096	0.000478	1.000000	Canal
13256.022229	4364.452895	18.608311	13257.847819	4368.020144	18.615253	0.080125	0.080125	waterbody1
13253.787176	4360.085543	18.599811	13256.022229	4364.452895	18.608311	0.024923	0.024923	waterbody1
13251.098302	4354.831415	18.589586	13253.787176	4360.085543	18.599811	0.010150	0.010150	waterbody1
13248.116713	4349.003315	18.578247	13251.098302	4354.831415	18.589586	0.004756	0.004756	waterbody1
13242.523188	4338.075422	18.556976	13248.116713	4349.003315	18.578247	0.002437	0.002437	waterbody1
13241.432843	4335.944861	18.552829	13242.523188	4338.075422	18.556976	0.001331	0.001331	waterbody1
13275.857696	4094.567293	22.330763	13275.911133	4094.550537	22.330000	0.001764	0.001764	waterbody2
13272.907992	4095.492210	22.372913	13275.857696	4094.567293	22.330763	0.000104	0.000104	waterbody2
13280.657952	4093.062239	22.320739	13281.037109	4092.943359	22.320000	0.000011	0.000011	waterbody2
13275.911133	4094.550537	22.330000	13280.657952	4093.062239	22.320739	0.000002	0.000002	waterbody2
13308.210487	4087.988766	22.275919	13312.870158	4087.139156	22.268360	0.000000	0.000000	waterbody2
13301.504856	4089.211422	22.286797	13308.210487	4087.988766	22.275919	0.000000	0.000000	waterbody2
13294.962001	4090.404397	22.297411	13301.504856	4089.211422	22.286797	0.000000	0.000000	waterbody2
13286.262740	4091.990556	22.311523	13294.962001	4090.404397	22.297411	0.000000	0.000000	waterbody2
13281.037109	4092.943359	22.320000	13286.262740	4091.990556	22.311523	0.000000	0.000000	waterbody2


3.6.2 Displaying Ingress output in table form

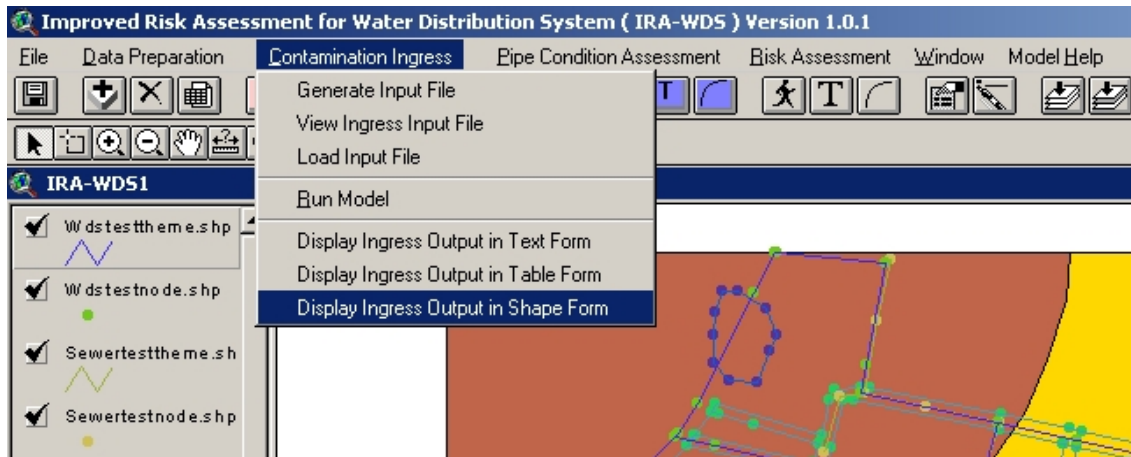
The user can view the output file in table form by selecting the Display Output in Table Form submenu from the Contaminant Ingress menu and specifying the appropriate output file to view by browsing as below:



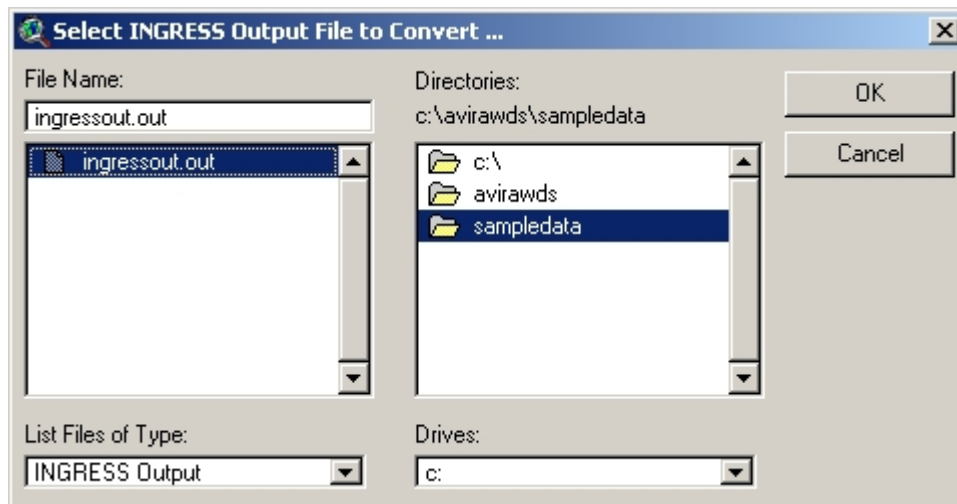
PipeID	StartX	StartY	StartZ	EndX	EndY	EndZ	StartConc	EndConc	Q
898	13529.700	4237.970	20.929	13547.300	4234.320	21.181	0.383	1.000	Sewer
884	13512.400	4241.870	20.665	13512.500	4242.250	20.647	1.000	0.000	Sewer
865	13609.600	4257.060	18.920	13610.100	4256.940	18.910	1.000	0.000	Sewer
914	13605.700	4238.720	21.605	13610.100	4256.940	18.910	1.000	0.000	Sewer
917	13175.500	4220.390	19.550	13175.700	4220.280	19.554	0.000	0.039	Sewer
808	13374.600	4309.420	18.739	13374.800	4309.380	18.737	1.000	0.000	Sewer
842	13520.100	4277.900	18.912	13520.500	4277.810	18.924	0.000	1.000	Sewer
1151	13559.000	4009.350	22.300	13559.000	4009.350	22.300	0.016	1.000	Canal
1151	13559.100	4009.290	22.302	13559.100	4009.290	22.302	0.000	0.046	Canal
1143	13553.600	4015.380	21.915	13554.100	4017.120	21.724	0.000	0.000	Canal
809	13230.400	4301.180	18.492	13228.800	4301.540	18.487	0.000	0.000	Canal
879	13184.300	4252.940	18.787	13182.900	4253.710	18.765	0.000	0.000	Canal
917	13157.900	4232.040	19.135	13159.300	4231.150	19.167	0.000	0.002	Canal
836	13373.500	4306.110	18.803	13373.900	4307.420	18.778	0.025	0.000	Canal
855	13362.600	4268.160	19.444	13362.900	4269.390	19.446	0.000	0.000	Canal
944	13337.900	4275.000	19.733	13337.600	4273.700	19.721	0.000	0.000	Canal
944	13316.200	4197.620	19.021	13315.900	4196.530	19.009	0.002	0.000	Canal
950	13340.800	4190.320	19.333	13341.100	4191.570	19.336	0.000	0.000	Canal
975	13418.400	4163.520	21.839	13418.600	4164.590	21.816	0.000	0.000	Canal
1016	13496.900	4134.260	22.796	13496.700	4133.160	22.818	0.000	0.001	Canal
1029	13529.200	4121.740	21.658	13529.000	4120.650	21.622	0.018	0.005	Canal
1064	13525.100	4097.170	22.994	13526.500	4096.610	23.007	0.001	0.012	Canal
1085	13519.400	4076.810	22.577	13520.800	4076.250	22.615	0.000	0.006	Canal
1107	13513.700	4056.220	21.932	13515.100	4055.650	21.982	0.000	0.002	Canal
1064	13454.700	4125.840	22.317	13456.100	4125.280	22.331	0.000	1.000	Canal
1085	13449.600	4105.270	20.693	13451.000	4104.700	20.730	0.000	1.000	Canal
1107	13444.500	4085.350	19.400	13445.900	4084.770	19.450	0.000	1.000	Canal
865	13605.200	4258.110	19.013	13606.700	4257.770	18.982	0.688	0.000	Canal
915	13597.000	4223.120	23.807	13598.400	4222.790	23.887	0.000	0.000	Canal
1047	13568.400	4102.370	24.176	13569.800	4101.820	24.268	0.000	0.002	Canal
1078	13563.600	4081.480	23.900	13565.000	4080.910	23.948	0.000	0.004	Canal
1100	13559.000	4060.670	23.544	13560.400	4060.110	23.575	0.000	0.001	Canal
1114	13554.200	4039.190	23.216	13555.600	4038.610	23.254	0.000	0.025	Canal
1097	13436.400	4063.840	21.846	13436.000	4061.920	22.061	0.000	0.000	Canal
1082	13396.000	4074.280	22.568	13396.600	4076.590	22.544	0.000	0.000	Canal
975	13439.000	4250.600	19.988	13439.600	4252.870	19.940	1.000	0.000	Canal
918	13475.700	4245.900	19.965	13475.300	4243.510	20.002	0.000	0.001	Canal
1016	13512.200	4240.420	20.703	13511.900	4237.960	20.751	0.000	1.000	Canal
1012	13548.900	4231.600	21.231	13548.500	4229.330	21.252	0.000	0.154	Canal
1082	13416.500	4156.520	21.733	13417.000	4158.380	21.714	0.032	0.000	Canal
1019	13453.200	4143.940	22.876	13453.200	4143.940	22.875	0.001	0.000	Canal
984	13512.700	4242.970	20.612	13513.500	4247.140	20.408	0.000	0.000	Canal
989	13455.000	4151.800	22.797	13454.400	4149.290	22.890	0.000	0.002	Canal
993	13454.400	4149.290	22.890	13454.300	4148.700	22.907	0.002	0.003	Canal
936	13281.300	4203.460	18.905	13277.300	4205.320	18.941	0.000	0.001	Canal

3.6.3 Displaying Ingress output in shape form

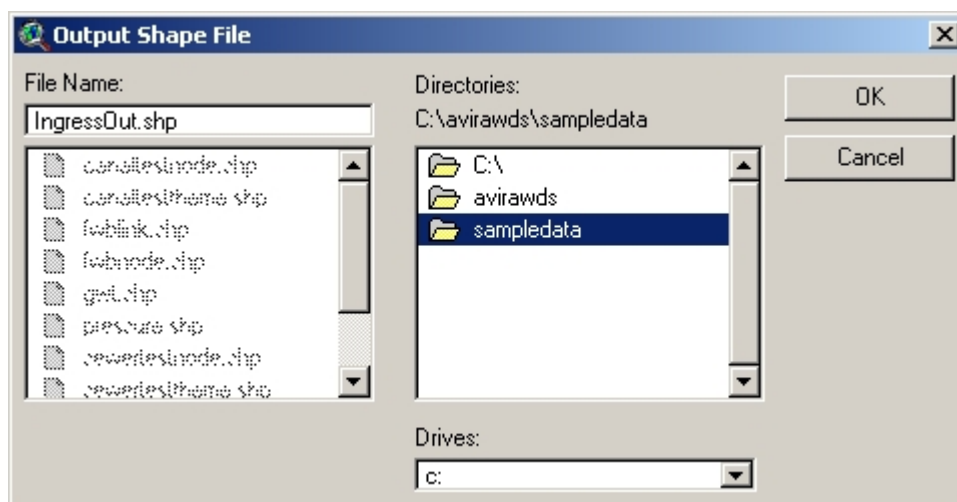
To view the Contamination Ingress Model output in shape file form click on the  button, which is just below the 'Contamination Ingress' menu or by clicking on the 'Contamination Ingress' menu and then clicking on the submenu 'Display Ingress Output in Shape Form', as shown in the screen below:



This opens the 'File Select' dialogue box for selecting the Contamination Ingress output file as *.out, which has to be converted to shape file as shown below:

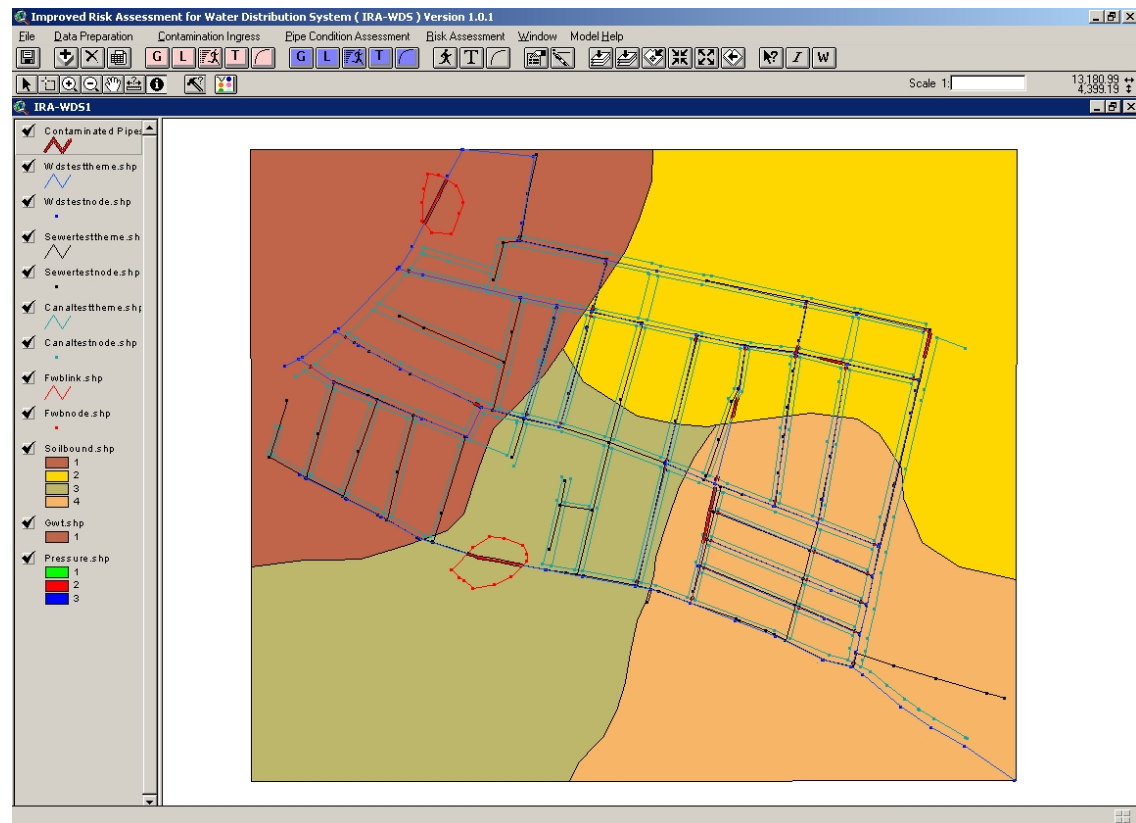


Once the user has selected the appropriate filename and clicked 'OK', this opens the 'File Save' dialogue box and asks the user to type in the output shape filename:



After typing or selecting the appropriate name, the user needs to click the 'OK' button, which then generates the shape file with information from the Contamination

Ingress output shape file and loads that file into the IRA-WDS data viewer with contamination legend as shown below:



CHAPTER FOUR

Pipe Condition Assessment Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems

Chapter-1
IRA-WDS: Overview



Chapter-2
Data Preparation



Chapter-3
Contaminant Ingress Model



Chapter-4
Pipe Condition Assessment Model



Chapter-5
Risk Assessment Model

Chapter 4: Pipe Condition Assessment Model

4.1 Introduction

There are several submenus under the Pipe Condition Assessment menu. This chapter describes the use of these submenus and associated commands for running the Pipe Condition Assessment Model. Figure 4.1 shows the steps involved in executing this component of the software.

The example files given in Table 4.1 are used for illustration purposes to describe the Pipe Condition Assessment Model with the help of IRA-WDS.

Table 4.1. Example input files	
Themes	Filenames
Water distribution	wdstesttheme.shp
	wdstestnode.shp
Groundwater	gwt.shp
Pressure zone	pressure.shp
Soil type	soilbound.shp

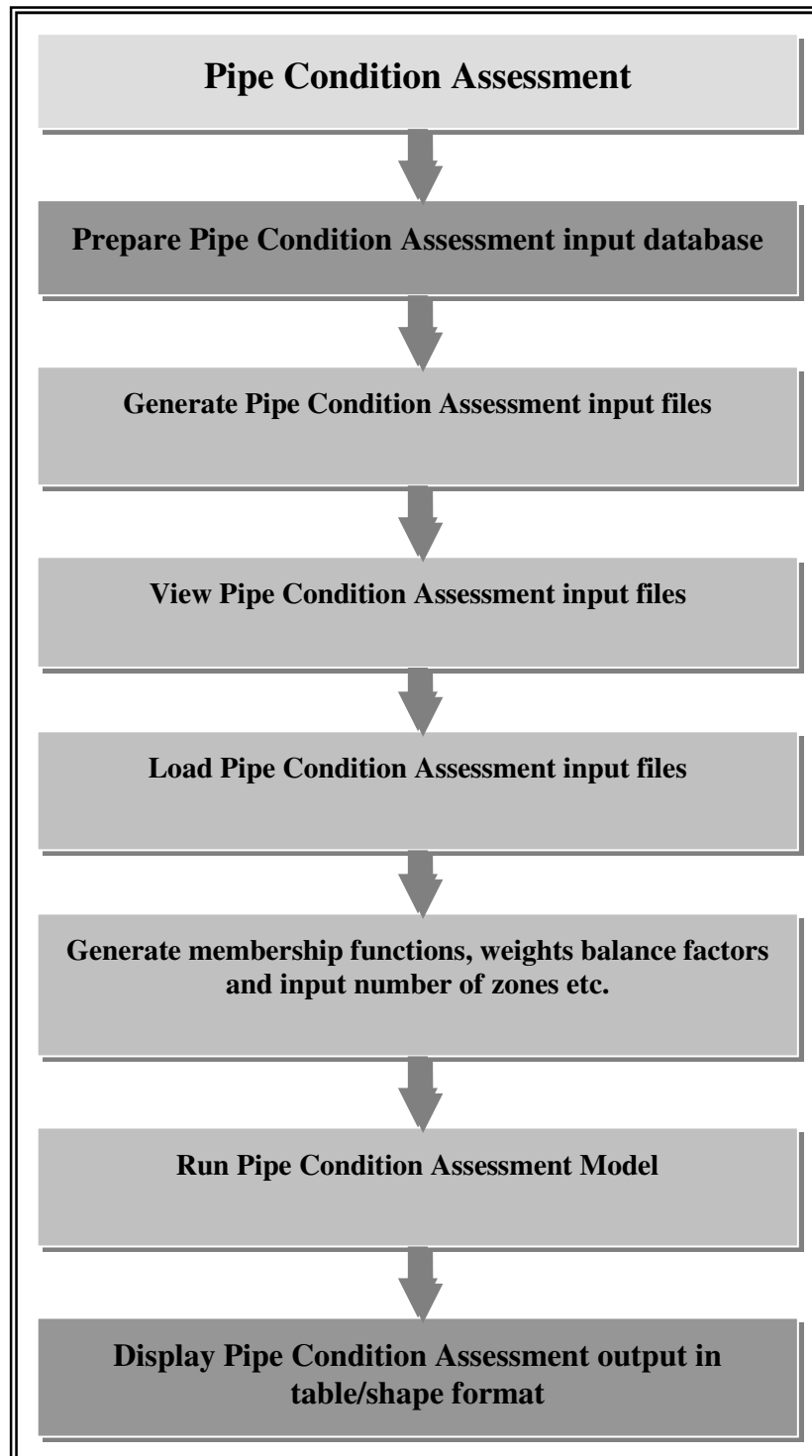


Figure 4.1. Overview of Pipe Condition Assessment Model of IRA-WDS


The following steps need to be performed for running the Pipe Condition Assessment (PCA). These are:

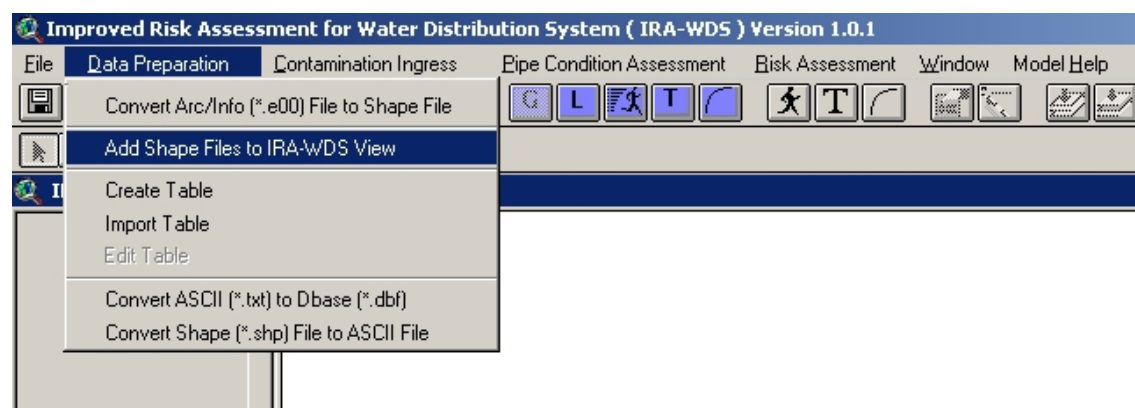
- Adding the data (if not already done so)
- Rearranging the data (optional)
- Generating an input file

- Viewing PCA input file (optional)
- Loading input file
- Running model
- Displaying output (optional)

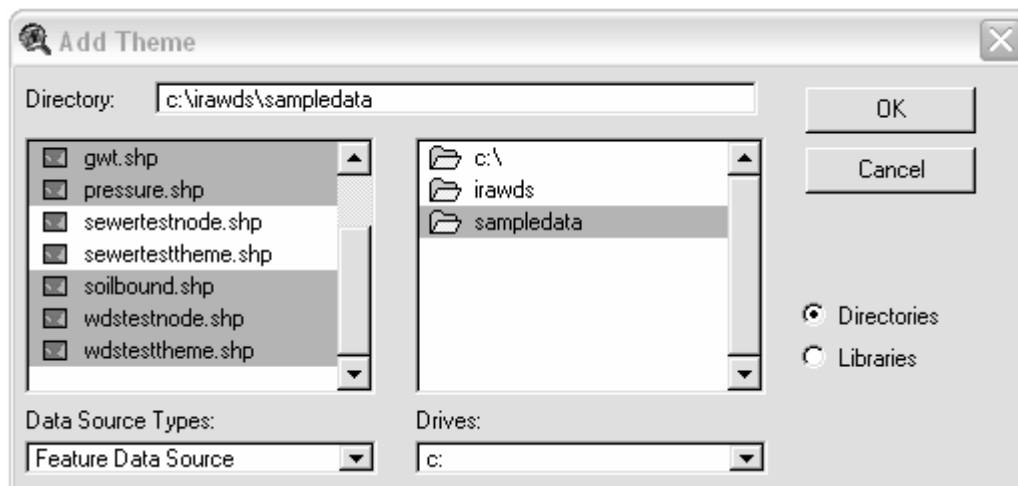
4.2 Shape files

4.2.1 Adding shape files

Adding shape files can be done by clicking on the Tool icon  which is just below the 'Data Preparation' menu or by clicking on the 'Data Preparation' menu and then clicking on the submenu 'Add Shape Files to IRA-WDS View', as shown in the screen below:

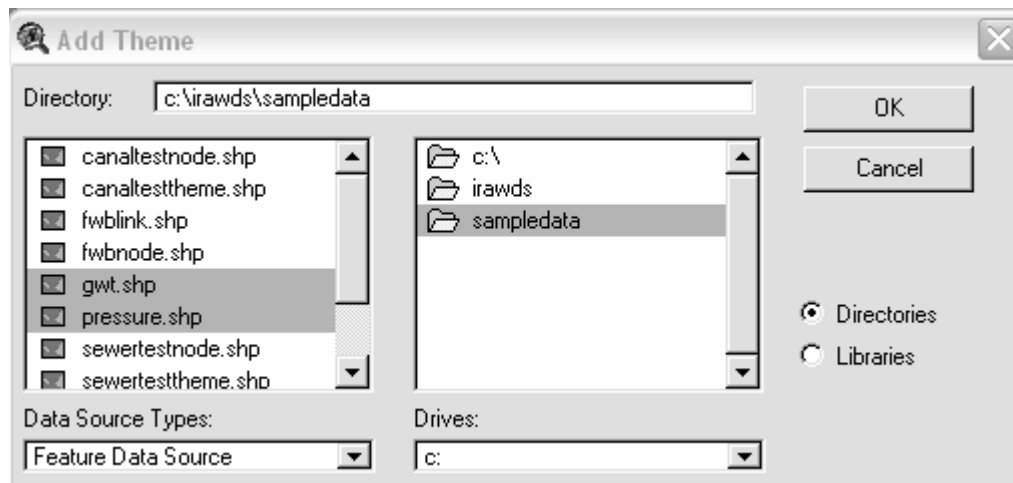


This opens the 'Add Theme' form, as shown below, and the user is then required to select the desired files. At this stage, these files are those relating to: water distribution link and node; soil polygon map; groundwater zone polygon map; and pressure zone polygon map.



If the user is continuing on from the Contaminant Ingress Model, then water distribution link and node data and the soil polygon map will have already been added. (Note that the sewer pipe, canal and foul water bodies link and node data, which are all needed for pipe condition assessment, will also have been added in this

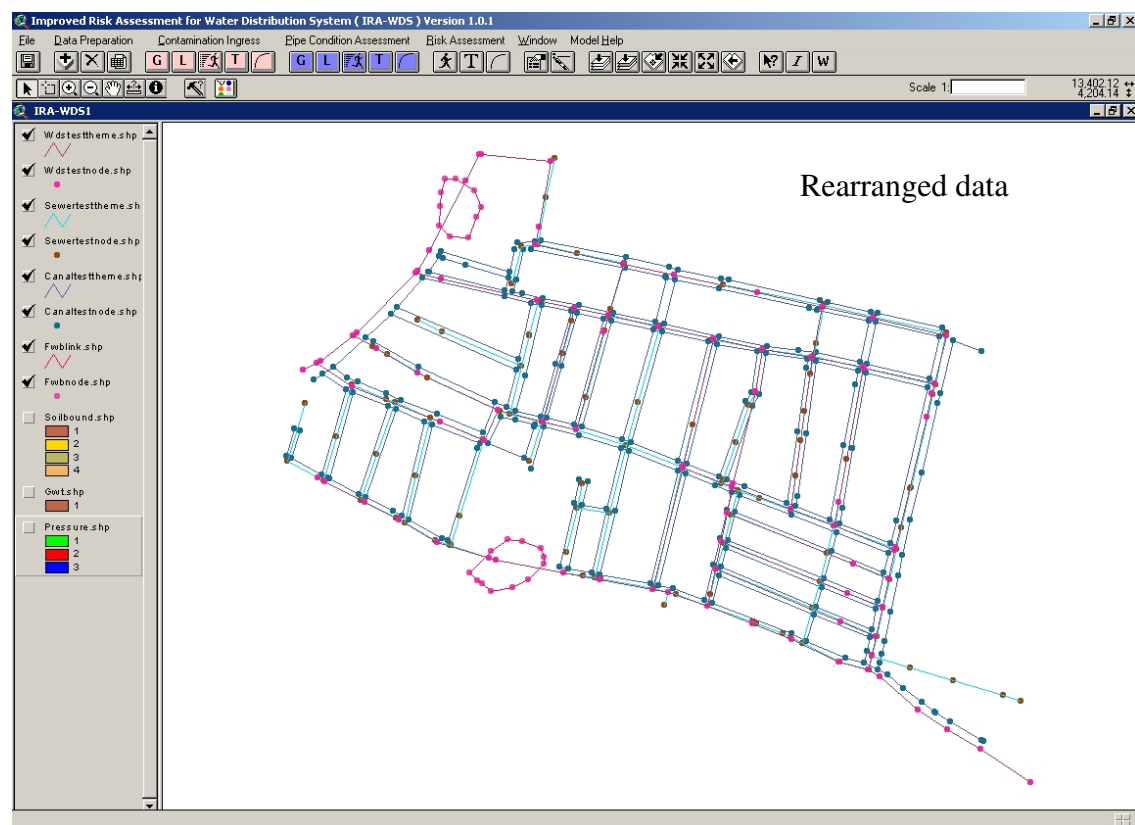
case). Only the groundwater zone polygon map and the pressure zone polygon map need to be added by the user as below.

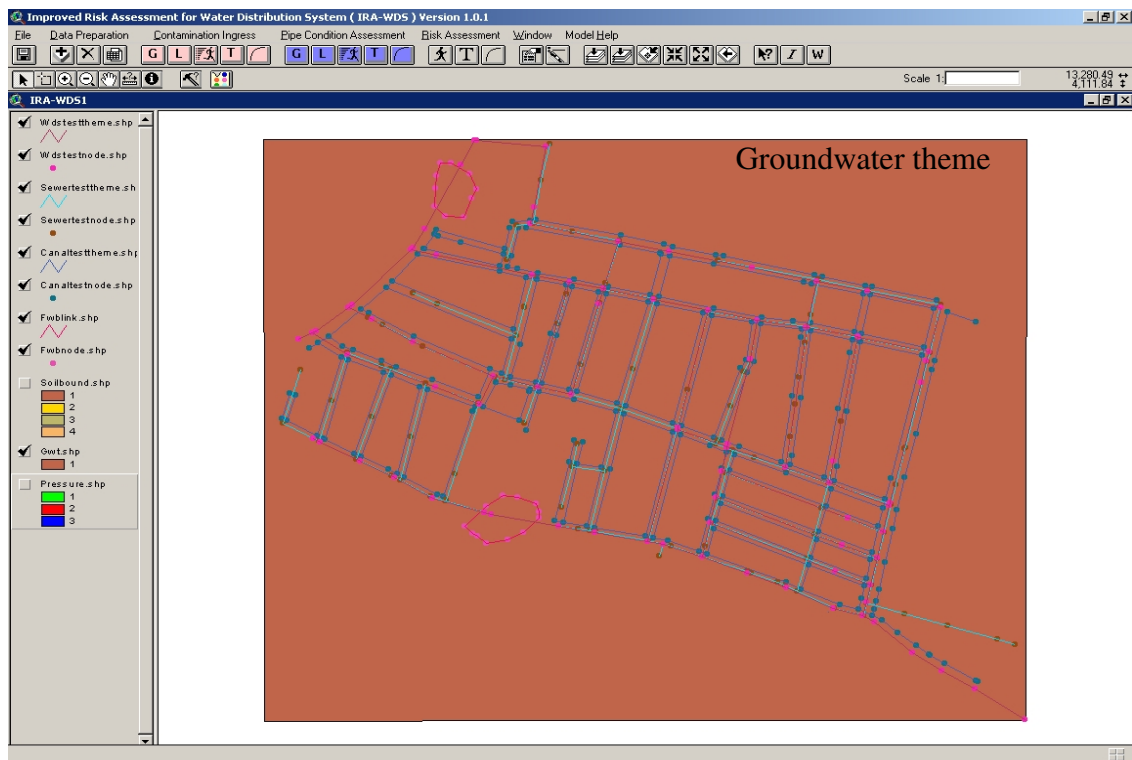
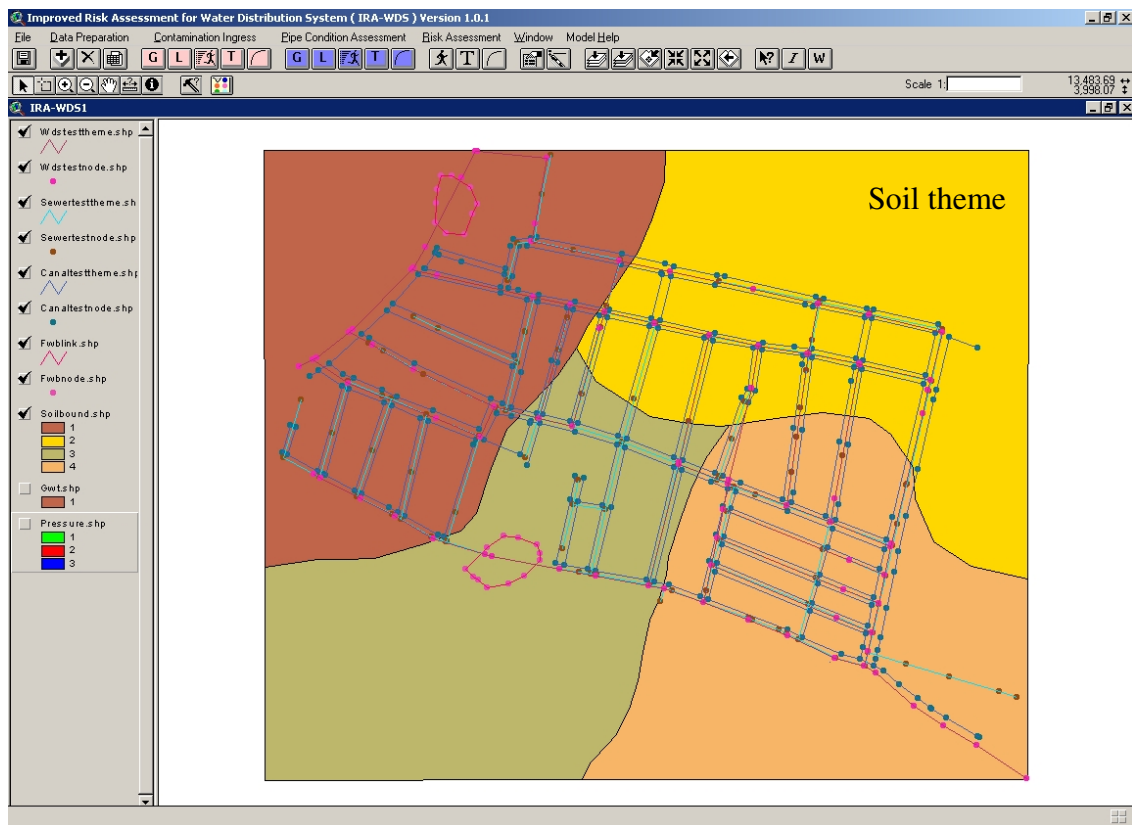


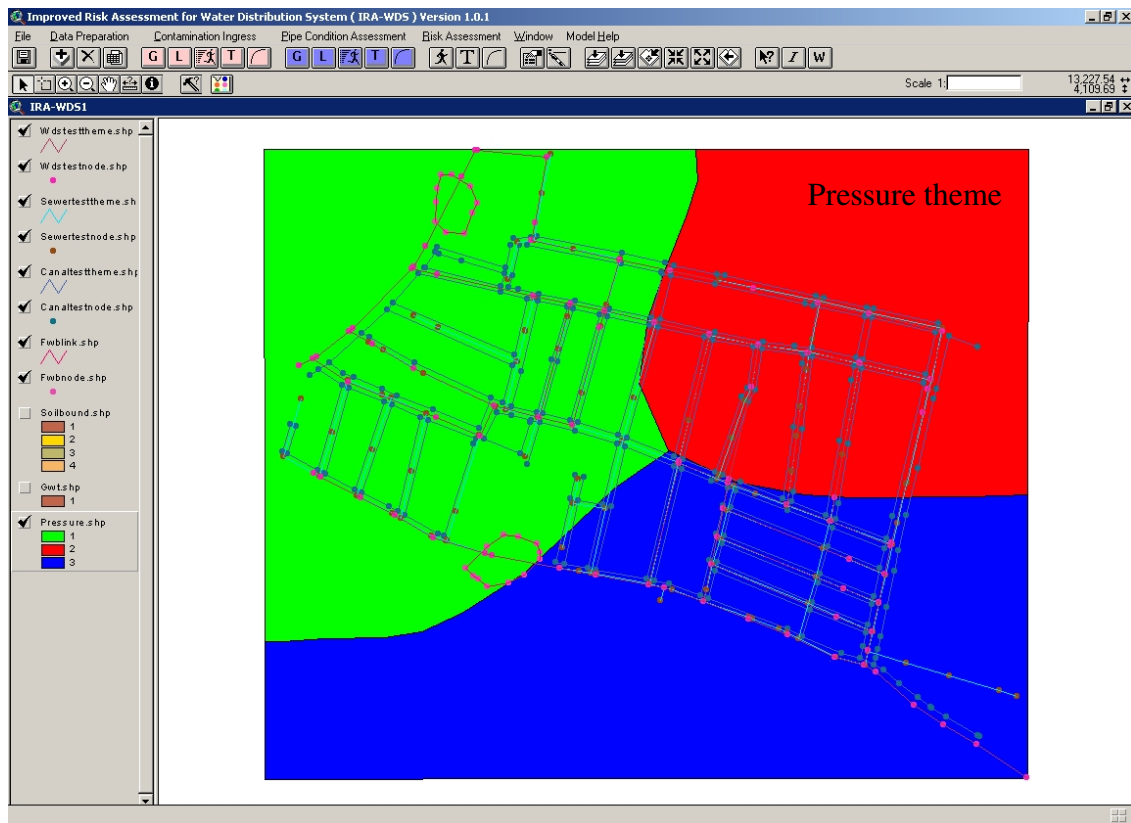
4.2.2 Rearranging shape files

If the user wishes to do so, he or she can rearrange the data to view and query different themes. The following snapshots show:

- Rearranged link and node data
- A soil theme map
- A groundwater theme map
- A pressure theme map




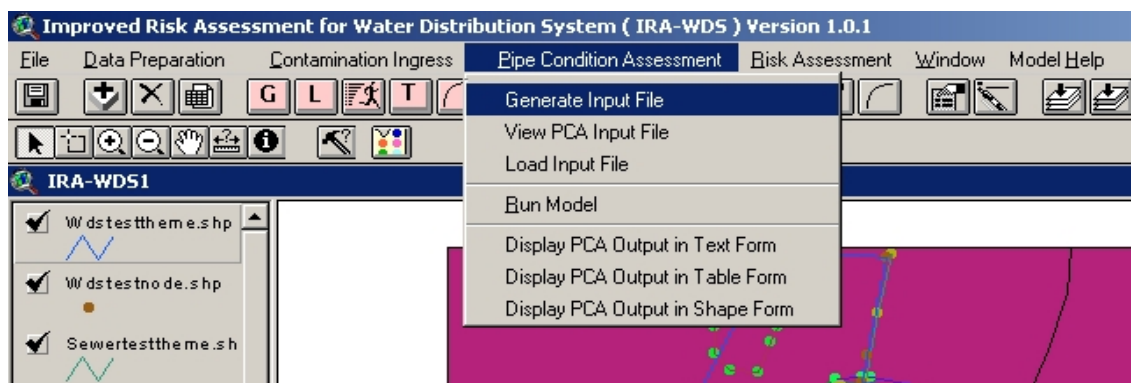





4.3 Generating an input file



4.3.1 Background to Pipe Condition Assessment Model input

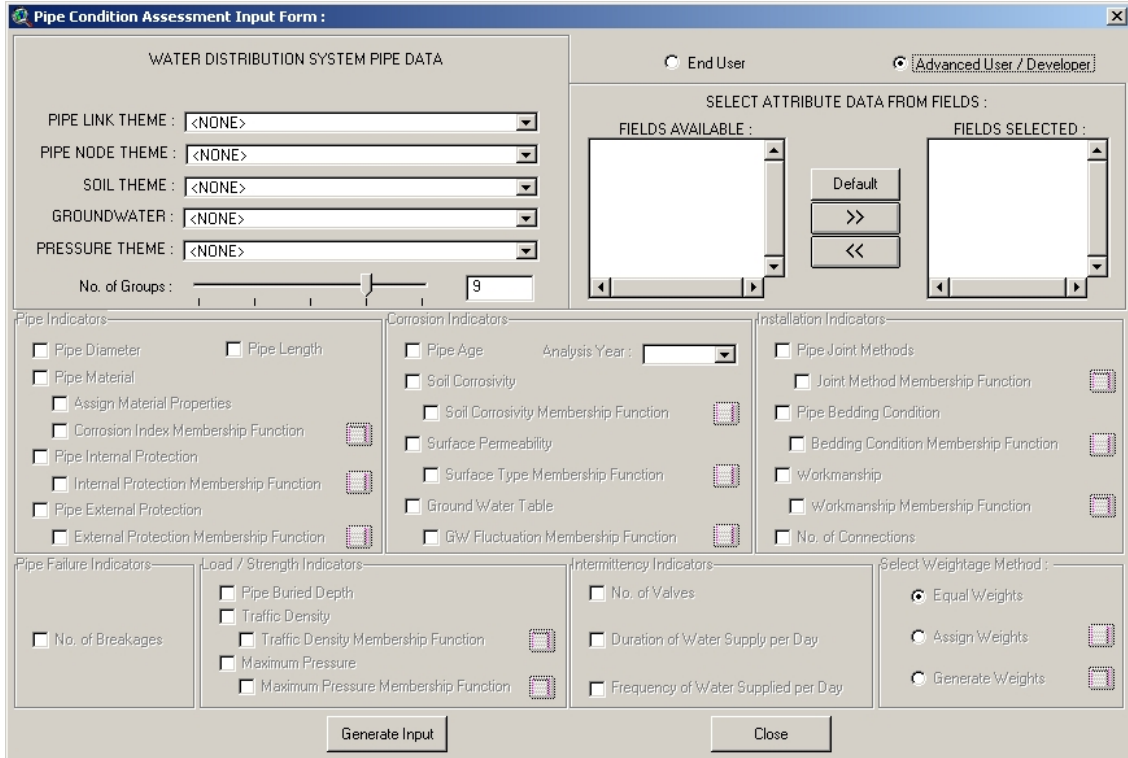
An input file can be generated by clicking on the Tool icon  which is just below the 'Pipe Condition Assessment' menu or by clicking on the 'Pipe Condition Assessment' menu and then clicking on the submenu 'Generate Input File', as shown on the screen below:



The 'Pipe Condition Assessment Input Form' has two radio button options: '**Advanced User**' and '**End User**'.

Advance Users can click on the radio button next to Advance User / Developer, which will allow the user to add or remove fields to or from the 'SELECTED FIELDS' list box. The user can click the  button to select the default field names. Advanced users can add fields to the 'SELECTED FIELDS' list box by selecting

those fields in the 'FIELDS AVAILABLE' list box and then clicking on the  button. To remove fields from the 'SELECTED FIELDS' list box, the user can select those fields in the 'SELECTED FIELDS' list box and remove by clicking on the  button.



Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

SELECT ATTRIBUTE DATA FROM FIELDS :

☐ End User ☒ Advanced User / Developer

FIELDS AVAILABLE :

FIELDS SELECTED :

Default

>>

<<

Pipe Indicators

☐ Pipe Diameter ☐ Pipe Length

☐ Pipe Material

☐ Assign Material Properties

☐ Corrosion Index Membership Function

☐ Pipe Internal Protection

☐ Internal Protection Membership Function

☐ Pipe External Protection

☐ External Protection Membership Function

Corrosion Indicators

☐ Pipe Age Analysis Year :

☐ Soil Corrosivity

☐ Soil Corrosivity Membership Function

☐ Surface Permeability

☐ Surface Type Membership Function

☐ Ground Water Table

☐ GW Fluctuation Membership Function

Installation Indicators

☐ Pipe Joint Methods

☐ Joint Method Membership Function

☐ Pipe Bedding Condition

☐ Bedding Condition Membership Function

☐ Workmanship

☐ Workmanship Membership Function

☐ No. of Connections

Pipe Failure Indicators

☐ No. of Breakages

Load / Strength Indicators

☐ Pipe Buried Depth

☐ Traffic Density

☐ Traffic Density Membership Function

☐ Maximum Pressure

☐ Maximum Pressure Membership Function

Intermittency Indicators

☐ No. of Valves

☐ Duration of Water Supply per Day

☐ Frequency of Water Supplied per Day

Select Weightage Method :

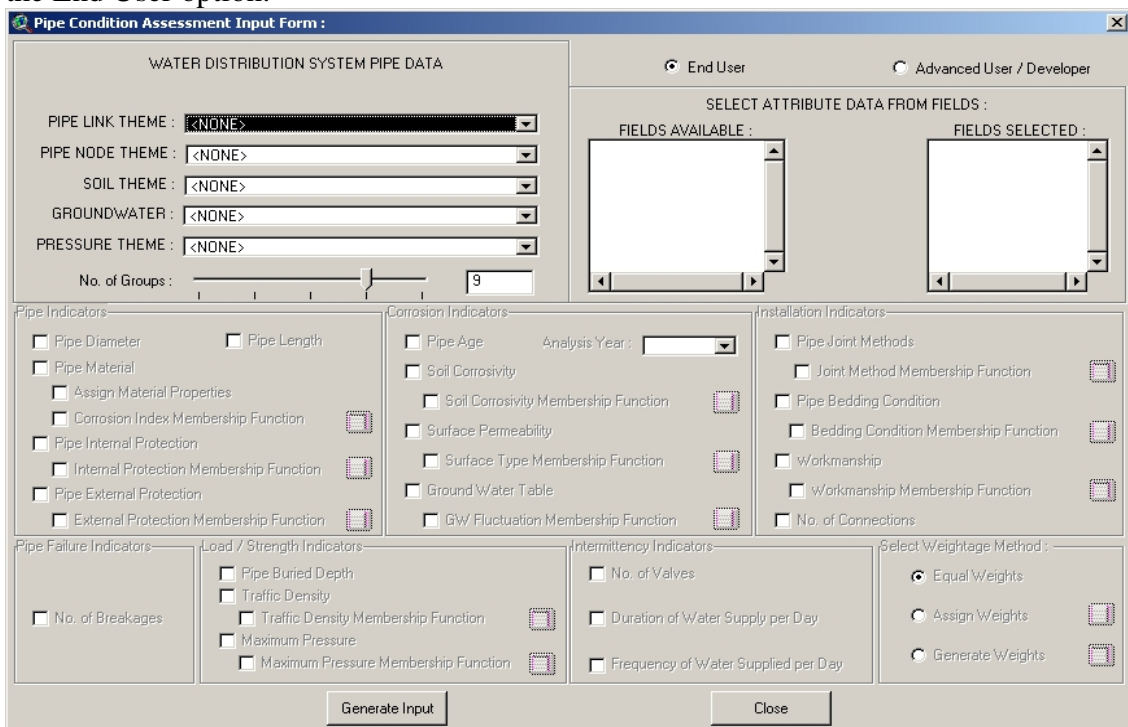
☒ Equal Weights

☐ Assign Weights

☐ Generate Weights

Generate Input **Close**

End Users are not provided with an option for adding or deleting fields to or from the 'SELECTED FIELDS' list box. In this case, the fields are automatically selected with the End User option.



Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

SELECT ATTRIBUTE DATA FROM FIELDS :

☒ End User ☐ Advanced User / Developer

FIELDS AVAILABLE :

FIELDS SELECTED :

Pipe Indicators

☐ Pipe Diameter ☐ Pipe Length

☐ Pipe Material

☐ Assign Material Properties

☐ Corrosion Index Membership Function

☐ Pipe Internal Protection

☐ Internal Protection Membership Function

☐ Pipe External Protection

☐ External Protection Membership Function

Corrosion Indicators

☐ Pipe Age Analysis Year :

☐ Soil Corrosivity

☐ Soil Corrosivity Membership Function

☐ Surface Permeability

☐ Surface Type Membership Function

☐ Ground Water Table

☐ GW Fluctuation Membership Function

Installation Indicators

☐ Pipe Joint Methods

☐ Joint Method Membership Function

☐ Pipe Bedding Condition

☐ Bedding Condition Membership Function

☐ Workmanship

☐ Workmanship Membership Function

☐ No. of Connections

Pipe Failure Indicators

☐ No. of Breakages

Load / Strength Indicators

☐ Pipe Buried Depth

☐ Traffic Density

☐ Traffic Density Membership Function

☐ Maximum Pressure

☐ Maximum Pressure Membership Function

Intermittency Indicators

☐ No. of Valves

☐ Duration of Water Supply per Day

☐ Frequency of Water Supplied per Day

Select Weightage Method :

☒ Equal Weights

☐ Assign Weights

☐ Generate Weights

Generate Input **Close**

4.3.2 Adding shape files

The user needs to define which theme in the IRA-WDS View represents the water distribution system pipe theme, the node theme, the soil theme, the groundwater theme and the pressure theme. All polyline / line themes added to the IRA-WDS viewer are added to the 'PIPE LINK THEME' combo box. All point / node themes added to the IRA-WDS viewer are added to the 'PIPE NODE THEME' combo box. All polygon themes added to the IRA-WDS viewer are added to the 'SOIL THEME', 'GROUNDWATER THEME' and 'PRESSURE THEME' boxes.

The user is required to select the theme that represents the water distribution pipe theme, the node theme, the soil theme, the groundwater theme and the pressure theme from the combo box. Initially, before selection of the themes, all other menus are disabled. During the selection of themes, the list of fields available and fields that will be selected from that theme are listed in the 'FIELDS AVAILABLE' and 'FIELDS SELECTED' list boxes (just below 'SELECT ATTRUBUTE DATA FROM FIELDS').

4.3.2.1 Pipe (water distribution) link theme

Selecting the water distribution theme in the pipe link theme box lists the fields available and fields selected. It also goes through the first record of the theme and finds which data are available and then enables the further options for data definition accordingly. For example, if the Pipe Diameter has a numeric value in its database, then it enables the Pipe Diameter check box in the Input Form so that the user can choose this for assessing the pipe condition and so on, as shown below:

Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

☒ End User ☐ Advanced User / Developer

SELECT ATTRIBUTE DATA FROM FIELDS :

FIELDS AVAILABLE :

- Shape
- Pipeid
- Startnode
- Endnode
- Strjoint

FIELDS SELECTED :

- Pipeid
- Startnode
- Endnode
- Strjoint
- Endpoint

Pipe Indicators

☐ Pipe Diameter ☐ Pipe Length

☐ Pipe Material

☐ Assign Material Properties

☐ Corrosion Index Membership Function

☐ Pipe Internal Protection

☐ Internal Protection Membership Function

☐ Pipe External Protection

☐ External Protection Membership Function

Corrosion Indicators

☐ Pipe Age Analysis Year :

☐ Soil Corrosivity

☐ Soil Corrosivity Membership Function

☐ Surface Permeability

☐ Surface Type Membership Function

☐ Ground Water Table

☐ GW Fluctuation Membership Function

Installation Indicators

☐ Pipe Joint Methods

☐ Joint Method Membership Function

☐ Pipe Bedding Condition

☐ Bedding Condition Membership Function

☐ Workmanship

☐ Workmanship Membership Function

☐ No. of Connections

Pipe Failure Indicators

☐ No. of Breakages

Load / Strength Indicators

☐ Pipe Buried Depth

☐ Traffic Density

☐ Traffic Density Membership Function

☐ Maximum Pressure

☐ Maximum Pressure Membership Function

Intermittency Indicators

☐ No. of Valves

☐ Duration of Water Supply per Day

☐ Frequency of Water Supplied per Day

Select Weightage Method :

☒ Equal Weights

☐ Assign Weights

☐ Generate Weights

4.3.2.2 Pipe node (water distribution) theme

Selecting the water distribution theme in the pipe node theme box updates the list of fields available and selected.

4.3.2.3 Soil, groundwater and pressure themes

If any of the soil, groundwater or /pressure themes is already selected, then the check box options corresponding to 'Soil Corrosivity', 'Ground Water Table' or 'Maximum Pressure' will be enabled, or else these options will remain disabled, as shown below:

Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

☒ End User ☐ Advanced User / Developer

SELECT ATTRIBUTE DATA FROM FIELDS :

FIELDS AVAILABLE :

- Shape
- Id
- X_coord
- Y_coord
- Z_coord

FIELDS SELECTED :

- Id
- X_coord
- Y_coord
- Z_coord
- Burydepth

Pipe Indicators

☐ Pipe Diameter ☐ Pipe Length

☐ Pipe Material

☐ Assign Material Properties

☐ Corrosion Index Membership Function

☐ Pipe Internal Protection

☐ Internal Protection Membership Function

☐ Pipe External Protection

☐ External Protection Membership Function

Corrosion Indicators

☐ Pipe Age Analysis Year :

☐ Soil Corrosivity

☐ Soil Corrosivity Membership Function

☐ Surface Permeability

☐ Surface Type Membership Function

☐ Ground Water Table

☐ GW Fluctuation Membership Function

Installation Indicators

☐ Pipe Joint Methods

☐ Joint Method Membership Function

☐ Pipe Bedding Condition

☐ Bedding Condition Membership Function

☐ Workmanship

☐ Workmanship Membership Function

☐ No. of Connections

Pipe Failure Indicators

☐ No. of Breakages

Load / Strength Indicators

☐ Pipe Buried Depth

☐ Traffic Density

☐ Traffic Density Membership Function

☐ Maximum Pressure

☐ Maximum Pressure Membership Function

Intermittency Indicators

☐ No. of Valves

☐ Duration of Water Supply per Day

☐ Frequency of Water Supplied per Day

Select Weightage Method :

☒ Equal Weights

☐ Assign Weights

☐ Generate Weights

4.3.2.4 Soil theme

Selecting the soil theme updates the list of available and selected fields. This also enables check box options corresponding to 'Soil Corrosivity' (see screen below). If the water distribution (pipe) node theme is not already selected, then the check box options corresponding to 'Soil Corrosivity' will remain disabled.

The screenshot shows the 'Pipe Condition Assessment Input Form' with the 'Soil theme' selected. The form is divided into several sections:

- WATER DISTRIBUTION SYSTEM PIPE DATA:** Includes dropdowns for 'PIPE LINK THEME' (Wdtesttheme.shp), 'PIPE NODE THEME' (Wdtestnode.shp), 'SOIL THEME' (Soilbound.shp), 'GROUNDWATER' (<NONE>), and 'PRESSURE THEME' (<NONE>). A 'No. of Groups' slider is set to 9.
- SELECT ATTRIBUTE DATA FROM FIELDS:** A list of 'FIELDS AVAILABLE' (Shape, Area, Perimeter, Soilbound_, Soil_id) and a list of 'FIELDS SELECTED' (Soil_id, Corrosivit).
- Pipe Indicators:** Checkboxes for 'Pipe Diameter', 'Pipe Length', 'Pipe Material', 'Assign Material Properties', 'Corrosion Index Membership Function', 'Pipe Internal Protection', 'Internal Protection Membership Function', 'Pipe External Protection', and 'External Protection Membership Function'.
- Corrosion Indicators:** Checkboxes for 'Pipe Age' (with 'Analysis Year' dropdown), 'Soil Corrosivity', 'Soil Corrosivity Membership Function', 'Surface Permeability', 'Surface Type Membership Function', 'Ground Water Table', and 'GW Fluctuation Membership Function'.
- Installation Indicators:** Checkboxes for 'Pipe Joint Methods', 'Joint Method Membership Function', 'Pipe Bedding Condition', 'Bedding Condition Membership Function', 'Workmanship', 'Workmanship Membership Function', and 'No. of Connections'.
- Pipe Failure Indicators:** Checkboxes for 'No. of Breakages'.
- Load / Strength Indicators:** Checkboxes for 'Pipe Buried Depth', 'Traffic Density', 'Traffic Density Membership Function', 'Maximum Pressure', and 'Maximum Pressure Membership Function'.
- Intermittency Indicators:** Checkboxes for 'No. of Valves', 'Duration of Water Supply per Day', and 'Frequency of Water Supplied per Day'.
- Select Weightage Method:** Radio buttons for 'Equal Weights', 'Assign Weights', and 'Generate Weights'.

Buttons at the bottom include 'Generate Input' and 'Close'.

4.3.2.5 Groundwater theme

Selecting the groundwater theme updates the list of available and selected fields. This also enables check box options corresponding to 'Ground Water Table' (see screen below). If the water distribution node theme is not already selected, then the check box options corresponding to 'Ground Water Table' will remain disabled.

Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

SELECT ATTRIBUTE DATA FROM FIELDS :

FIELDS AVAILABLE :

- Shape
- Area
- Perimeter
- Gwf_id
- Avg_gwtdep

FIELDS SELECTED :

- Gwf_id
- Avg_gwtdep
- Avg_gwtflc

Pipe Indicators

- ☐ Pipe Diameter
- ☐ Pipe Length
- ☐ Pipe Material
- ☐ Assign Material Properties
- ☐ Corrosion Index Membership Function
- ☐ Pipe Internal Protection
- ☐ Internal Protection Membership Function
- ☐ Pipe External Protection
- ☐ External Protection Membership Function

Corrosion Indicators

- ☐ Pipe Age
- ☐ Soil Corrosivity
- ☐ Soil Corrosivity Membership Function
- ☐ Surface Permeability
- ☐ Surface Type Membership Function
- ☐ Ground Water Table
- ☐ GW Fluctuation Membership Function

Installation Indicators

- ☐ Pipe Joint Methods
- ☐ Joint Method Membership Function
- ☐ Pipe Bedding Condition
- ☐ Bedding Condition Membership Function
- ☐ Workmanship
- ☐ Workmanship Membership Function
- ☐ No. of Connections

Pipe Failure Indicators

- ☐ No. of Breakages

Load / Strength Indicators

- ☐ Pipe Buried Depth
- ☐ Traffic Density
- ☐ Traffic Density Membership Function
- ☐ Maximum Pressure
- ☐ Maximum Pressure Membership Function

Intermittency Indicators

- ☐ No. of Valves
- ☐ Duration of Water Supply per Day
- ☐ Frequency of Water Supplied per Day

Select Weightage Method :

- ☒ Equal Weights
- ☐ Assign Weights
- ☐ Generate Weights

Generate Input **Close**

4.3.2.6 Pressure theme

Selecting the pressure theme updates the list of available and selected fields. This also enables check box options corresponding to 'Maximum Pressure' (see screen below). If the water distribution node theme is not already selected, then the check box options corresponding to 'Maximum Pressure' will remain disabled.

Pipe Condition Assessment Input Form :

WATER DISTRIBUTION SYSTEM PIPE DATA

PIPE LINK THEME :

PIPE NODE THEME :

SOIL THEME :

GROUNDWATER :

PRESSURE THEME :

No. of Groups :

SELECT ATTRIBUTE DATA FROM FIELDS :

FIELDS AVAILABLE :

- Shape
- Area
- Perimeter
- Pressure_
- Pres_zone

FIELDS SELECTED :

- Pres_zone
- Pressure

Pipe Indicators

- ☐ Pipe Diameter
- ☐ Pipe Length
- ☐ Pipe Material
- ☐ Assign Material Properties
- ☐ Corrosion Index Membership Function
- ☐ Pipe Internal Protection
- ☐ Internal Protection Membership Function
- ☐ Pipe External Protection
- ☐ External Protection Membership Function

Corrosion Indicators

- ☐ Pipe Age
- ☐ Soil Corrosivity
- ☐ Soil Corrosivity Membership Function
- ☐ Surface Permeability
- ☐ Surface Type Membership Function
- ☐ Ground Water Table
- ☐ GW Fluctuation Membership Function

Installation Indicators

- ☐ Pipe Joint Methods
- ☐ Joint Method Membership Function
- ☐ Pipe Bedding Condition
- ☐ Bedding Condition Membership Function
- ☐ Workmanship
- ☐ Workmanship Membership Function
- ☐ No. of Connections

Pipe Failure Indicators

- ☐ No. of Breakages

Load / Strength Indicators

- ☐ Pipe Buried Depth
- ☐ Traffic Density
- ☐ Traffic Density Membership Function
- ☐ Maximum Pressure
- ☐ Maximum Pressure Membership Function

Intermittency Indicators

- ☐ No. of Valves
- ☐ Duration of Water Supply per Day
- ☐ Frequency of Water Supplied per Day

Select Weightage Method :

- ☒ Equal Weights
- ☐ Assign Weights
- ☐ Generate Weights

Generate Input **Close**

4.4 Indicator data

Depending on the data available on various themes, the options for entering data for the following different indicators will be enable or disenabled.

1. Pipe Indicators
2. Corrosion Indicators
3. Installation Indicators
4. Pipe Failure Indicators
5. Load/Strength Indicators
6. Intermittency Indicators

The user needs to select which parameters of these indicators he or she wants to use for pipe condition assessment. The data used for these parameters are not only quantitative (crisp value data) but also qualitative (fuzzy data). In case of fuzzy data, the user needs to define the membership functions for the fuzzy data sets.

Pipe material

Various material properties are considered while deciding the condition of the pipe. These properties are:

1. Resistance to corrosion (a fuzzy parameter)
2. Maximum pressure it can sustain
3. Maximum impact load it can sustain
4. Minimum and maximum diameters in which pipes are made
5. Minimum and maximum lengths in which pipes are made
6. Maximum design life
7. Age-Hazen-William Roughness Coefficient (C) relationship

The input for pipe material properties is made in two different input forms. After opening the form 'Pipe Material', the user checks the "Assign Material Properties" box (see screen below). This form lists the available pipe materials in the water distribution pipe theme. If the default database for the pipe material in the IRA-WDS contains the pipe material listed in water distribution pipe theme, then it populates the respective fields for those pipe material properties for which data are available; otherwise nothing is written. For example, in the screen below the IRA-WDS database has all the necessary data for the pipe material 'AC' listed in the water distribution pipe theme, hence all the pipe material properties' check boxes are filled. However, for the pipe material 'U1', the IRA-WDS database has no pipe material data and hence all the pipe material properties' check boxes are empty. The user needs to fill in all the empty fields in the form appropriately. He or she can also modify the data if they do not agree with the IRA-WDS default database. An input form having some default data from the database and some material to be defined by the user is shown on next page.

Pipe Material Properties Input Form :

Pipe Material	Corrosion Index	Max. Pressure	Max. Load	Design Life	Max. Diameter	Min. Diameter
AC	Very Strong	35.700	23.500	60	2500.000	50.000
RCC	Very Strong	30.000	30.000	60	1200.000	400.000
U1	Very Strong					
PVC	Very Strong	15.300	4.400	60	1200.000	75.000
CI	Very Strong	97.920	150.000	70	2000.000	75.000

☐ Assign 'C' Values OK

The completed data form is shown below:

Pipe Material Properties Input Form :

Pipe Material	Corrosion Index	Max. Pressure	Max. Load	Design Life	Max. Diameter	Min. Diameter
AC	Very Strong	35.700	23.500	60	2500.000	50.000
RCC	Very Strong	30.000	30.000	60	1200.000	400.000
U1	Very Strong	15.000	25.000	50	1000.000	300.000
PVC	Very Strong	15.300	4.400	60	1200.000	75.000
CI	Very Strong	97.920	150.000	70	2000.000	75.000

☐ Assign 'C' Values OK

To define the 'Pipe Material: Age-C' relationship, the user should click on the check box 'Assign 'C' Values' on the 'Pipe Material Properties Input Form'. This opens the 'Pipe Material: Age-'C' Values Relation Input Form'. Again, if the default database for the pipe material in the IRA-WDS program contains the pipe material listed in

water distribution pipe theme, 'C' values appear in the check boxes; otherwise the check boxes remain empty. (Note that values are assigned up to the designed age of the pipe and '0' 'C' values are assigned for any ages greater than the designed age of the pipe). An input form filled in with values from the database is shown below:

Pipe Material : Age - 'C' Values Relation Input Form

Material \ Age	0 - 10 yrs	11 - 20 yrs	21 - 30 yrs	31 - 40 yrs	41 - 50 yrs	51 - 60 yrs	61 - 70 yrs	71 - 80 yrs	81 - 90 yrs	91 - 100 yrs
AC	150	130	130	120	120	120	100	0	0	0
RCC	130	120	110	95	70	70	70	0	0	0
U1										
PVC	150	140	140	140	140	140	130	0	0	0
CI	150	110	100	90	80	70	70	60	0	0

OK

The user needs to complete the form appropriately by entering values in any blank fields. He or she can also modify the data if they do not agree with the default database. The completed data form is shown below:

Pipe Material : Age - 'C' Values Relation Input Form

Material \ Age	0 - 10 yrs	11 - 20 yrs	21 - 30 yrs	31 - 40 yrs	41 - 50 yrs	51 - 60 yrs	61 - 70 yrs	71 - 80 yrs	81 - 90 yrs	91 - 100 yrs
AC	150	130	130	120	120	120	100	0	0	0
RCC	130	120	110	95	70	70	70	0	0	0
U1	120	120	110	110	100	50	0	0	0	0
PVC	150	140	140	140	140	140	130	0	0	0
CI	150	110	100	90	80	70	70	60	0	0

OK

4.5 Other data

The remaining data used is in quantitative (crisp data) and qualitative (fuzzy data) forms, which are described below.

Crisp data

The parameters that are quantitative in nature are: 'Pipe Diameter', 'Pipe Length', 'Pipe Material', 'Pipe Age', 'Number of Connections', 'Number of Breakages', 'Pipe Buried Depth', 'Number of Valves', 'Duration of Water Supply per Day' and 'Frequency of Water Supplied per Day'. Except for the 'Pipe Age', the remainder of the parameters do not require any more information. These parameters need to be selected if required. For 'Pipe Age', further information pertaining to the 'Analysis Year' is required, which can be selected from the combo box, as shown below:

The screenshot displays the 'Pipe Condition Assessment Input Form' with the following sections and controls:

- WATER DISTRIBUTION SYSTEM PIPE DATA:** Includes dropdown menus for 'PIPE LINK THEME' (Wdtesttheme.shp), 'PIPE NODE THEME' (Wdtestnode.shp), 'SOIL THEME' (Soilbound.shp), 'GROUNDWATER' (Gwt.shp), and 'PRESSURE THEME' (Pressure.shp). A 'No. of Groups' slider is set to 9.
- User Selection:** Radio buttons for 'End User' (selected) and 'Advanced User / Developer'.
- SELECT ATTRIBUTE DATA FROM FIELDS:** Two list boxes. 'FIELDS AVAILABLE' contains Shape, Area, Perimeter, Pressure_, and Pres_zone. 'FIELDS SELECTED' contains Pres_zone and Pressure.
- Pipe Indicators:** Checkboxes for 'Pipe Diameter' (checked), 'Pipe Length' (checked), 'Pipe Material', 'Assign Material Properties', 'Corrosion Index Membership Function', 'Pipe Internal Protection', 'Internal Protection Membership Function', 'Pipe External Protection', and 'External Protection Membership Function'.
- Corrosion Indicators:** Checkboxes for 'Pipe Age' (checked), 'Soil Corrosivity', 'Soil Corrosivity Membership Function', 'Surface Permeability', 'Surface Type Membership Function', 'Ground Water Table', and 'GW Fluctuation Membership Function'. An 'Analysis Year' dropdown is set to 2005.
- Installation Indicators:** Checkboxes for 'Pipe Joint Methods', 'Joint Method Membership Function', 'Pipe Bedding Condition', 'Bedding Condition Membership Function', 'Workmanship', 'Workmanship Membership Function', and 'No. of Connections'.
- Pipe Failure Indicators:** Checkboxes for 'No. of Breakages' and 'Maximum Pressure'.
- Load / Strength Indicators:** Checkboxes for 'Pipe Buried Depth', 'Traffic Density', 'Traffic Density Membership Function', and 'Maximum Pressure Membership Function'.
- Intermittency Indicators:** Checkboxes for 'No. of Valves', 'Duration of Water Supply per Day', and 'Frequency of Water Supplied per Day'.
- Select Weightage Method:** Radio buttons for 'Equal Weights' (selected), 'Assign Weights', and 'Generate Weights'.
- Buttons:** 'Generate Input' and 'Close' at the bottom.

Fuzzy data

The parameters that are qualitative in nature are: the 'Pipe Material Corrosion Index', 'Pipe Internal and External Protection', 'Soil Corrosivity', 'Surface Type/Permeability', 'Ground Water Table Fluctuation', 'Traffic Density', 'Maximum Pressure', 'Pipe Joint Methods', 'Pipe Bedding Condition' and 'Workmanship'. All of these require further information regarding their membership function.

4.5.1 Membership functions

If any fuzzy parameter is clicked, its membership definition form appears. For example, if Pipe Material and then Corrosion Index Membership Function are clicked, its membership form appears (see screen below). The form is common for all the parameters except the title and group labels, which vary according to the indicator for which membership function is to be defined.

The form consists of five buttons and 20 text boxes for user input. The membership function is defined with the help of these text boxes. A trapezoidal or triangular membership function can be defined with this input form. If the 'Middle Left' and 'Middle Right' values of the membership form are the same, the membership function is triangular. The membership form that appears on the screen contains the default values membership function. However, the user can change the membership function. He or she is advised to refer to the Book-3 (Risk assessment of contaminant intrusion into water distribution systems) of this series for this purpose.

There are five buttons to facilitate defining membership functions. These are:

Default: Clicking this button loads the membership definition text boxes with default values defined for various indicators in the IRA-WDS database.

Clear All: Clicking this button clears all membership definition text boxes.

OK: By clicking this button, the membership definition is completed and the membership definition dialogue box is closed.

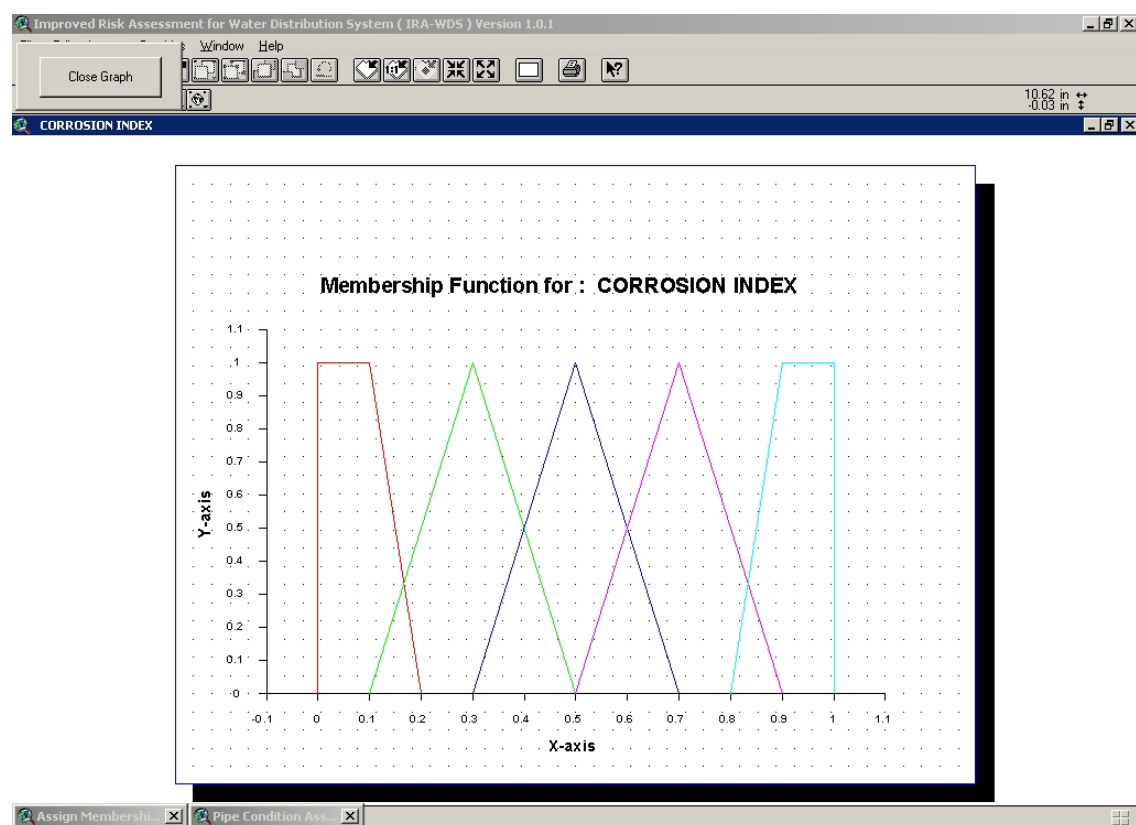
Cancel: By clicking this button the membership definition is cancelled and the dialogue box is closed.

Chart: By clicking this button, the membership definition and the 'Pipe Condition Assessment Input Form' are minimized and the layout dialogue box is opened within which the membership defined is shown graphically.

1. Pipe Material Corrosion Index

	Left	Middle Left	Middle Right	Right
Very Weak	0.0	0.0	0.1	0.2
Weak	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Strong	0.5	0.7	0.7	0.9
Very Strong	0.8	0.9	1.0	1.0

Buttons: Default, Clear All, OK, Cancel, Chart



2. Pipe Internal Protection

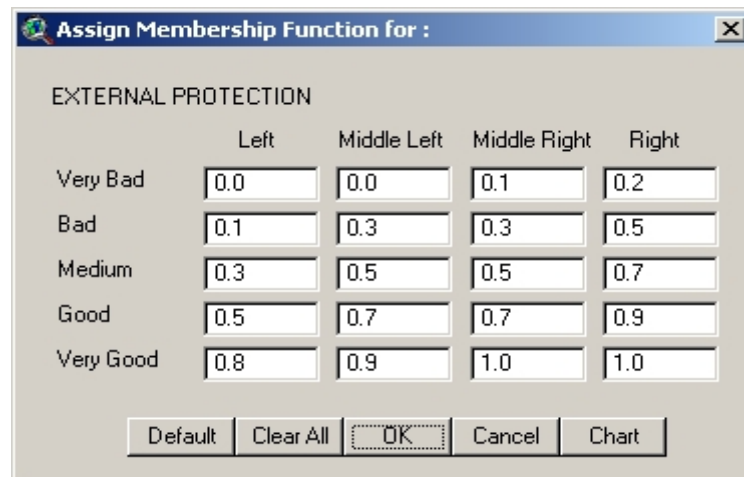
Assign Membership Function for :

INTERNAL PROTECTION

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Good	0.5	0.7	0.7	0.9
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

3. Pipe External Protection



Assign Membership Function for :

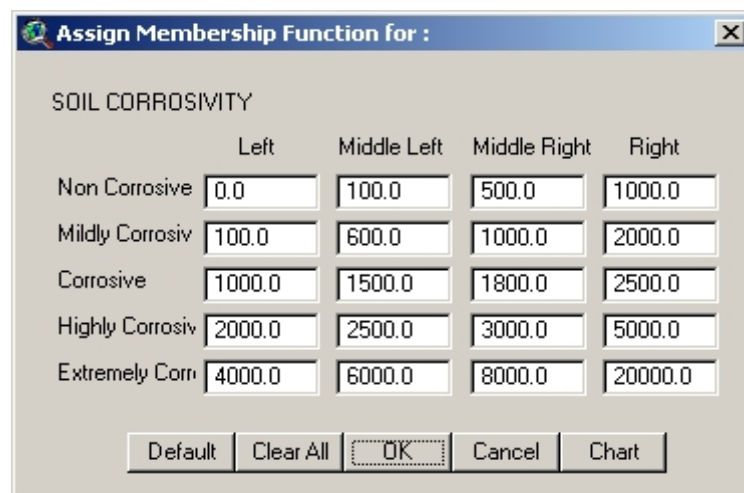
EXTERNAL PROTECTION

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Good	0.5	0.7	0.7	0.9
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

4. Soil Corrosivity

When defining the soil corrosivity membership function, the 'Soil Corrosivity' property is used.



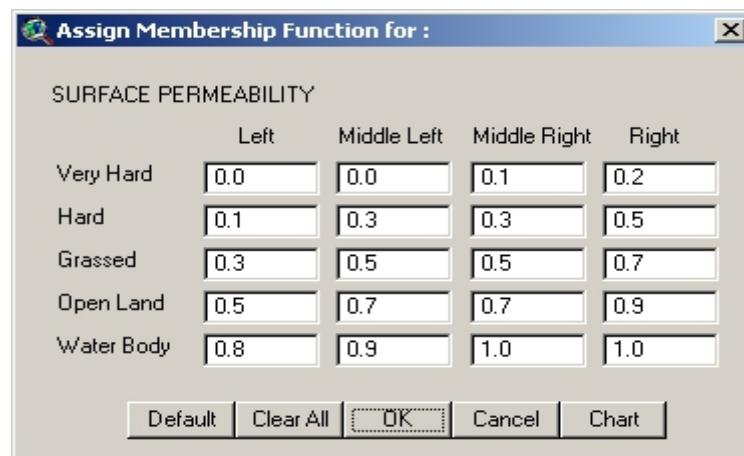
Assign Membership Function for :

SOIL CORROSIVITY

	Left	Middle Left	Middle Right	Right
Non Corrosive	0.0	100.0	500.0	1000.0
Mildly Corrosiv	100.0	600.0	1000.0	2000.0
Corrosive	1000.0	1500.0	1800.0	2500.0
Highly Corrosiv	2000.0	2500.0	3000.0	5000.0
Extremely Corn	4000.0	6000.0	8000.0	20000.0

Default Clear All OK Cancel Chart

5. Surface Type/Permeability



Assign Membership Function for :

SURFACE PERMEABILITY

	Left	Middle Left	Middle Right	Right
Very Hard	0.0	0.0	0.1	0.2
Hard	0.1	0.3	0.3	0.5
Grassed	0.3	0.5	0.5	0.7
Open Land	0.5	0.7	0.7	0.9
Water Body	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

6. Ground Water Table Fluctuation

Assign Membership Function for :

GROUND WATER FLUCTUATION

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Good	0.5	0.7	0.7	0.9
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

7. Traffic Density

When defining the traffic density membership function, the actual observed values of number of vehicles passing per hour should be used.

Assign Membership Function for :

TRAFFIC DENSITY

	Left	Middle Left	Middle Right	Right
Very Busy	45.0	50.0	60.0	80.0
Busy	35.0	40.0	45.0	50.0
Medium	25.0	30.0	35.0	40.0
Quite	10.0	20.0	25.0	30.0
Very Quite	0.0	5.0	10.0	15.0

Default Clear All OK Cancel Chart

8. Maximum Pressure

When defining the maximum pressure membership function, the values of pressure at the outlets should be used.

Assign Membership Function for :

MAXIMUM PRESSURE

	Left	Middle Left	Middle Right	Right
Very High	45.0	50.0	60.0	80.0
High	35.0	40.0	45.0	50.0
Medium	25.0	30.0	35.0	40.0
Low	10.0	20.0	25.0	30.0
Very Low	0.0	5.0	10.0	15.0

Default Clear All OK Cancel Chart

9. Joint Method

Assign Membership Function for :

JOINT METHOD

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.4	0.4	0.7
Medium	0.4	0.65	0.65	0.9
Good	0.6	0.8	1.0	1.0
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

10. Bedding Condition

Assign Membership Function for :

BEDDING CONDITION

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Good	0.5	0.7	0.7	0.9
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

11. Workmanship

Assign Membership Function for :

WORKMANSHIP

	Left	Middle Left	Middle Right	Right
Very Bad	0.0	0.0	0.1	0.2
Bad	0.1	0.3	0.3	0.5
Medium	0.3	0.5	0.5	0.7
Good	0.5	0.7	0.7	0.9
Very Good	0.8	0.9	1.0	1.0

Default Clear All OK Cancel Chart

4.5.2 Weightage methods

The user also needs to assign weights for various indicators and balance factors for various groups. Weight allows importance to be given to different parameters/indicators within a group. Balance factors reflect the importance of the maximal deviations between indicators (criteria) in the same group, where ‘maximal deviation’ means the maximum difference between an indicator value and the best value for that indicator. The larger the balancing factor, the greater the concern with respect to the maximal deviation. Low balancing factors are used for a high level of allowable compromise between indicators of the same group. A balancing factor equal to 1 means that there is a perfect compromise between indicators of the group. If the level of compromise between indicators is moderate, a balancing factor of 2 will be sufficient. A balancing factor of 3 or more reflects a situation of minimal compromise between indicators. In the present (Pipe Condition Assessment) model, three weightage methods are included. These are:

Equal Weights: With this method, equal weights are assigned to all the indicators of particular group. A balancing factor of 1 is assigned to all the groups.

Assign Weights: With this method, weights are assigned directly. The form in which they are assigned is shown below:

Assign Weights for Pipe Condition Assessment

Pipe Condition Assessment

Physical Indicators

Pipe Indicators

Diameter: 0.200

Length: 0.200

Material: 0.200

Int. Protect: 0.200

Ext. Protect: 0.200

Balance Factor: []

Pipe Weight: 0.5

Installation Weight: 0.5

Physical Balance Factor: []

Installation Indicators

Joint Method: 0.250

Bed. Condition: 0.250

Workmanship: 0.250

Connections: 0.250

Balance Factor: []

Environmental Indicators

Corrosion Indicators

Pipe Age: 0.250

Soil Corrosivity: 0.250

Surface Type: 0.250

Groundwater: 0.250

Balance Factor: []

Corrosion Weight: 0.5

Strength Weight: 0.5

Environmental Balance Factor: []

Strength Indicators

Buried Depth: 0.333

Traffic Density: 0.333

Pressure: 0.333

Balance Factor: []

Operational Indicators

Failure Indicators

Breakage: 1.000

Balance Factor: []

Failure Weight: 0.5

Intermittency Indicators

Valve Number: 0.333

Operation Time: 0.333

No. of Operations: 0.333

Balance Factor: []

Intermittency Weight: 0.5

Operational Balance Factor: []

Physical Weight: 0.333

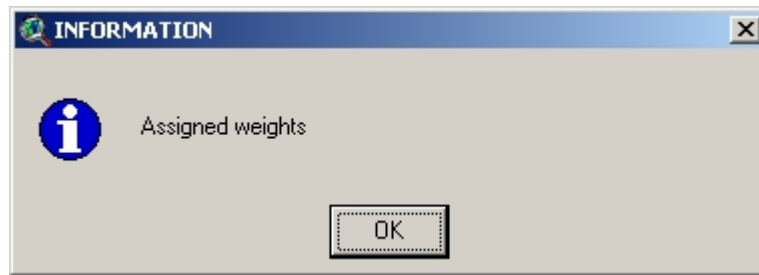
Environmental Weight: 0.333

Operational Weight: 0.333

Pipe Condition Assessment Balance Factor: []

Assign Weights Cancel

Depending on the number of indicators selected for the assessment, equal weights are assigned initially to all the indicators. The user can change the weights assigned to each indicator. However, it is necessary that the sum of the weights given in one group should be equal to 1 (see screen above). The user needs to input values for the balance factors of each group. After completing the form, the user can click on the ‘Assign Weights’ button to assign the weights and close the form. The program then displays the following Information message regarding weights assigned. Clicking on ‘OK’ closes this form.



Generated by AHP: Weights can also be generated using the pair-wise comparison, that is, by Analytical Hierarchy Process (AHP). Clicking on 'Generate Weights' causes the following 'Generate Weights using Analytical Hierarchy Process' form to appear.

Generate Weightings using Analytical Hierarchy Process

Pipe Condition Assessment :

Physical Indicators :

Pipe Indicators :

	Dia.	Len.	Mat.	InP.	ExP.	Wts.
Dia.	1.00					
Len.	x	1.00				
Mat.	x	x	1.00			
InP.	x	x	x	1.00		
ExP.	x	x	x	x	1.00	

Balance Factor for Level (I) : 1

Installation Indicators :

	BC	Wms	JM	NoC	Wts.
BC	1.00				
Wms	x	1.00			
JM	x	x	1.00		
NoC	x	x	x	1.00	

Balance Factor for Level (II) : 1

PIPE INSTALL Wts.

	PIPE	INSTALL	Wts.
PIPE	1.00		
INSTALL	x	1.00	

Physical Balance Factor : 1

Environmental Indicators :

Corrosion Indicators :

	Age	SC	SP	GWf	Wts.
Age	1.00				
SC	x	1.00			
SP	x	x	1.00		
GWf	x	x	x	1.00	

Balance Factor for Level (I) : 1

Strength Indicators :

	BD	TD	MP	Wts.
BD	1.00			
TD	x	1.00		
MP	x	x	1.00	

Balance Factor for Level (II) : 1

CORR. LOAD Wts.

	CORR.	LOAD	Wts.
CORR.	1.00		
LOAD	x	1.00	

Environ. Balance Factor : 1

Operational Indicators :

Failure Indicators :

	Brk.	Lek.	Bur.	Wts.
Brk.	1.00	n/a	n/a	
Lek.	n/a	n/a	n/a	
Bur.	n/a	n/a	n/a	

Balance Factor for Level (I) : 1

Intermittency Indicators :

	NoV	Dur.	Fre.	Wts.
NoV	1.00			
Dur.	x	1.00		
Fre.	x	x	1.00	

Balance Factor for Level (II) : 1

FAIL INTER Wts.

	FAIL	INTER	Wts.
FAIL	1.00		
INTER	x	1.00	

Operation Balance Factor : 1

Select Importance

Less Important

More Important

Phy Env Opr Wts

	Phy	Env	Opr	Wts
Phy	1.00			
Env	x	1.00		
Opr	x	x	1.00	

PCA Balance Factor : 1

Generate Weights OK Cancel

The matrix elements are enabled for those indicators that are selected in the 'Pipe Condition Assessment Input Form'. The slider on the right-hand side of the 'Generate Weightings using Analytical Hierarchy Process' form can be used to define the matrix element. The user needs to input values for the balance factors of each group. On completion of the matrix elements and inputting the balance factors, the form appears as shown in the example in next page.

Generate Weightings using Analytical Hierarchy Process

Pipe Condition Assessment :

Physical Indicators :

Pipe Indicators

	Dia.	Len.	Mat.	InP.	ExP.	Wts.
Dia.	1.00	0.25	0.20	0.25	2.00	
Len.	4.00	1.00	0.25	0.25	8.00	
Mat.	5.00	4.00	1.00	0.20	8.00	
InP.	4.00	4.00	5.00	1.00	8.00	
ExP.	0.50	0.13	0.13	0.13	1.00	

Balance Factor for Level (I) : 1

Installation Indicators

	BC	Wms	JM	NoC	Wts.
BC	1.00	5.00	5.00	2.00	
Wms	0.20	1.00	5.00	2.00	
JM	0.20	0.20	1.00	6.00	
NoC	0.50	0.50	0.17	1.00	

Balance Factor for Level (II) : 1

Physical Balance Factor : 1

PIPE INSTALL Wts.

	PIPE	INSTALL	Wts.
PIPE	1.00	0.33	
INSTALL	3.00	1.00	

Environmental Indicators :

Corrosion Indicators

	Age	SC	SP	GWf	Wts.
Age	1.00	0.33	2.00	2.00	
SC	3.00	1.00	0.33	2.00	
SP	0.50	3.00	1.00	5.00	
GWf	0.50	0.50	0.20	1.00	

Balance Factor for Level (I) : 1

Strength Indicators

	BD	TD	MP	Wts.
BD	1.00	5.00	0.33	
TD	0.20	1.00	5.00	
MP	3.00	0.20	1.00	

Balance Factor for Level (II) : 1

Corr. LOAD Wts.

	CORR.	LOAD	Wts.
CORR.	1.00	0.33	
LOAD	3.00	1.00	

Environ. Balance Factor : 1

Operational Indicators :

Failure Indicators

	Brk.	Lek.	Bur.	Wts.
Brk.	1.00	n/a	n/a	
Lek.	n/a	n/a	n/a	
Bur.	n/a	n/a	n/a	

Balance Factor for Level (I) : 1

Intermittency Indicators

	NoV	Dur.	Fre.	Wts.
NoV	1.00	6.00	6.00	
Dur.	0.17	1.00	0.50	
Fre.	0.17	2.00	1.00	

Balance Factor for Level (II) : 1

Operation Balance Factor : 1

FAIL INTER Wts.

	FAIL	INTER	Wts.
FAIL	1.00	6.00	
INTER	0.17	1.00	

Select Importance

Less Important

More Important

Phy Env Opr Wts

	Phy	Env	Opr	Wts
Phy	1.00	0.50	5.00	
Env	2.00	1.00	5.00	
Opr	0.20	0.20	1.00	

PCA Balance Factor : 1

Generate Weights OK Cancel

The user then clicks the 'Generate Weights' button, which opens the 'Save AHP Input File' dialogue box to save the AHP input matrix, as shown below:

Save AHP Input File

File Name:

Directories: c:\avirawds\sampldata

OK Cancel

Drives: C:

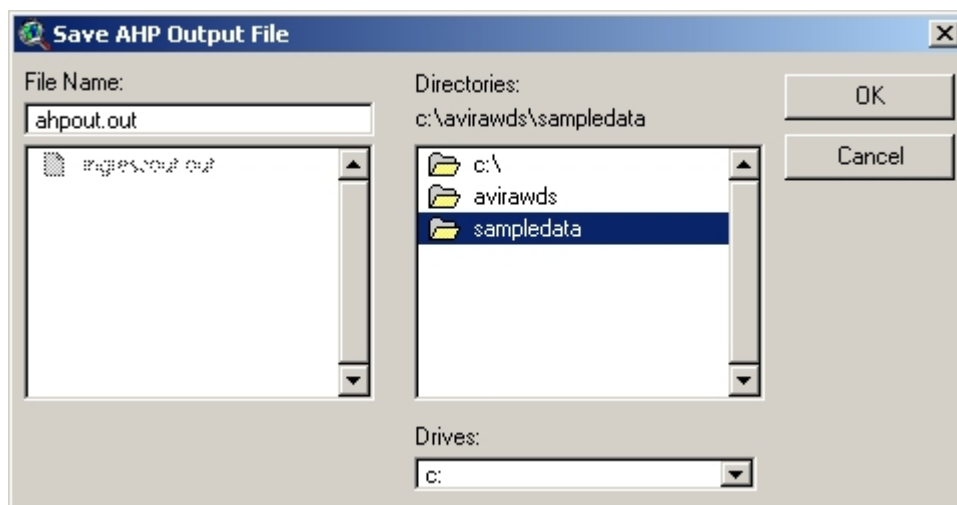
After selecting the input filename to save AHP input, the following dialogue box appears:

Info

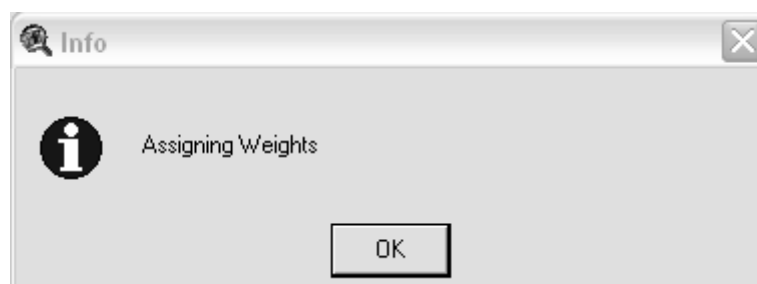
Generated the AHP Input File

OK

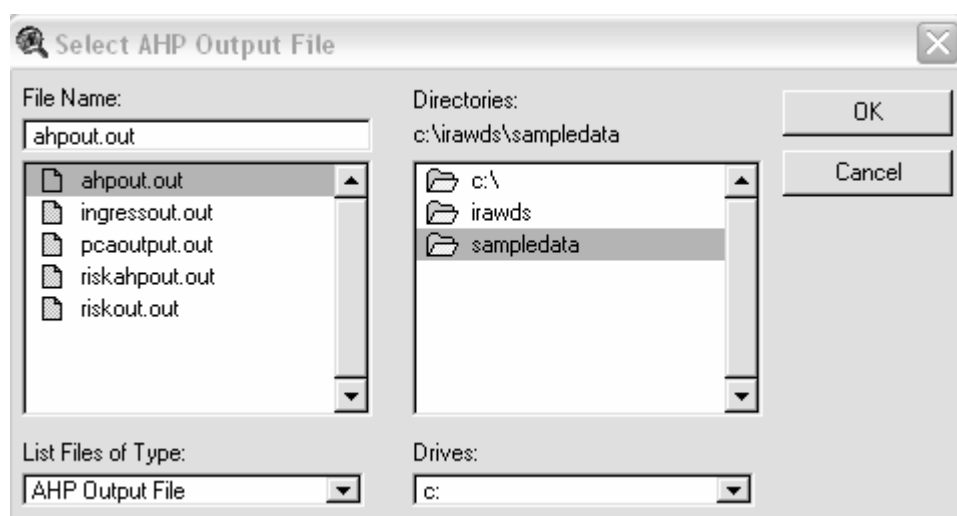
Confirming 'OK' on the 'Generated the AHP Input File' Info message box opens the 'Save AHP Output File' dialogue box and prompts the user about the filename to save the AHP output under, as shown below:



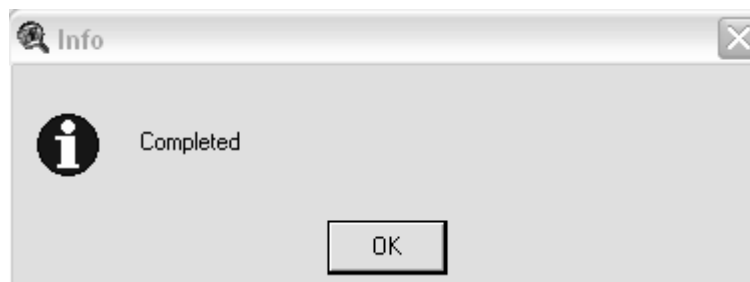
After selecting the output filename to save AHP output under, the following dialogue box appears:



Clicking 'OK' executes the AHP model, which generates the weight for each parameter considered in the 'Pipe Condition Assessment Input Form' and then asks the name of AHP output file for viewing, as shown below:



After the user gives the name of AHP output file, the following message appears:



After the user confirms 'OK', the weights can be seen (see screen below). If the weights generated using AHP are consistent, then those values are presented in the respective text boxes; otherwise '-99' appears in those boxes. If any particular indicator is not considered in the analysis, then '-999' appears in the text box as shown below:

The 'Generate Weightings using Analytical Hierarchy Process' window displays a complex interface for assigning weights to different indicators. It is organized into several sections:

- Pipe Condition Assessment:**
 - Physical Indicators:** A table with columns Dia., Len., Mat., InP., ExP., and Wts. containing numerical values.
 - Installation Indicators:** A table with columns BC, Wms, JM, NoC, and Wts. containing numerical values.
 - Balance Factor for Level (I):** A text box with the value '1'.
 - Balance Factor for Level (II):** A text box with the value '1'.
 - Physical Balance Factor:** A text box with the value '1'.
- Environmental Indicators:**
 - Corrosion Indicators:** A table with columns Age, SC, SP, GWf, and Wts. containing numerical values.
 - Balance Factor for Level (I):** A text box with the value '1'.
- Strength Indicators:**
 - A table with columns BD, TD, MP, and Wts. containing numerical values.
 - Balance Factor for Level (II):** A text box with the value '1'.
- Operational Indicators:**
 - Failure Indicators:** A table with columns Brk., Lek., Bur., and Wts. containing numerical values or 'n/a'.
 - Balance Factor for Level (I):** A text box with the value '1'.
- Intermittency Indicators:**
 - A table with columns NoV, Dur., Fre., and Wts. containing numerical values.
 - Balance Factor for Level (II):** A text box with the value '1'.
- Comparison Scale:** A vertical scale on the right side with a green arrow pointing up (labeled 'Less Important') and a red arrow pointing down (labeled 'More Important'). It includes a list of importance levels: Extremely, Very Strongly to Extremely, Very Strongly, Strongly to Very Strongly, Strongly, Moderately to Strongly, Moderately, Equally to Moderately, Equally, Equally to Moderately, Moderately, Moderately to Strongly, Strongly, Strongly to Very Strongly, Very Strongly, Very Strongly to Extremely, and Extremely.
- Weighting Summary:** A table at the bottom right showing the final weights for various indicators, including 'Phy', 'Env', 'Opr', and 'Wts'.
- Buttons:** 'Generate Weights', 'OK', and 'Cancel' buttons are located at the bottom right.

During this step the 'Generate Weights' button is disabled and 'OK' button is enabled. If the user clicks the 'OK' button, then the weights generated by AHP are assigned and a message is displayed as shown below:



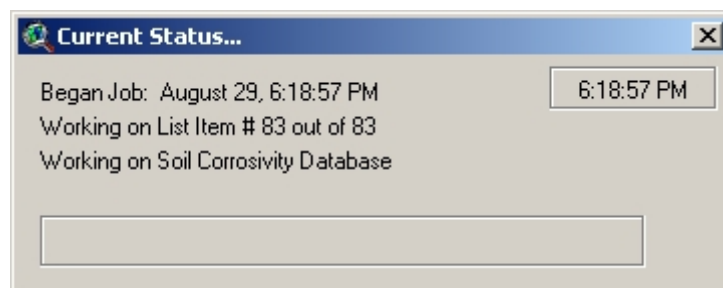
If the 'Cancel' button is clicked, then the 'Equal Weights' option will be selected and 'Weights by AHP' will not be selected.

4.6 Number of groups

The output of the PCA model is a ranking of different pipes depending on their respective conditions. These pipes can be placed in different groups on the basis of their conditions. The number of groups can be entered by sliding the bar in front of 'No. of Groups' on the 'PCA Input Form' or by entering a value for the number of groups in the box provided, as shown below:

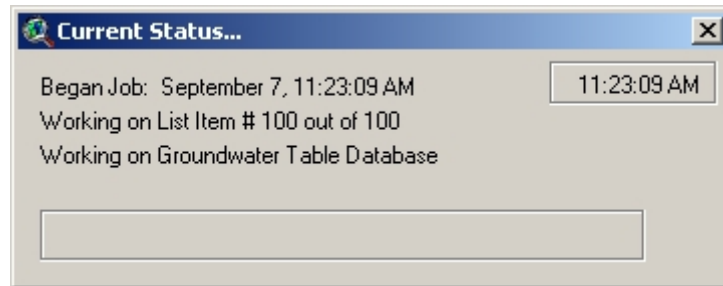
4.7 Generating the input file (PCA)

To generate the pipe condition assessment input file, the user should click on the 'Generate Input' button on the 'Pipe Condition Assessment Input Form'. If 'Soil Corrosivity' is selected, the model finds which pipe falls in which soil type and then appends the water distribution system pipe theme with soil corrosion category data accordingly.

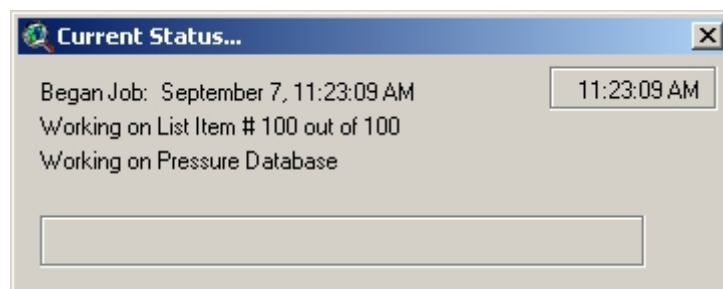


If the 'Ground Water Table' is selected, the interface finds the average groundwater table depth and groundwater fluctuation depth for each pipe. Then using the pipe

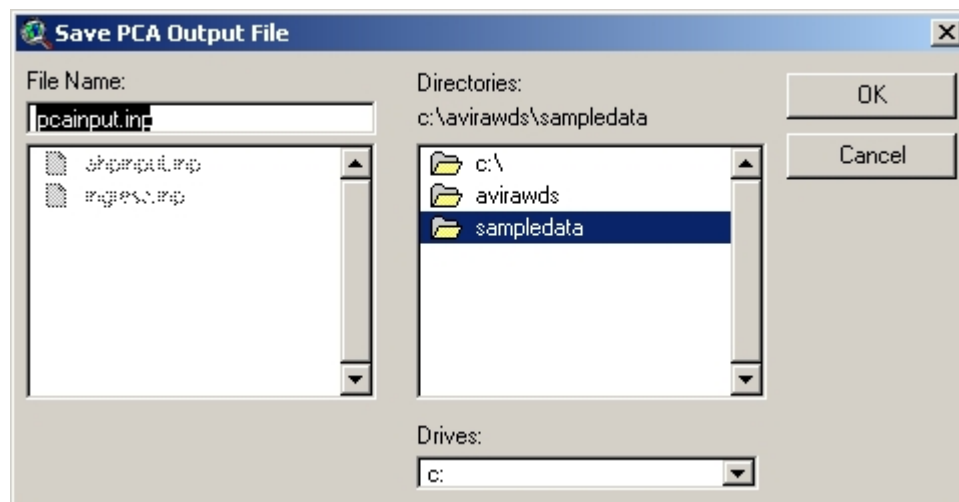
buried depth and the groundwater table data, it computes the groundwater category for each pipe and appends the water distribution pipe theme accordingly.



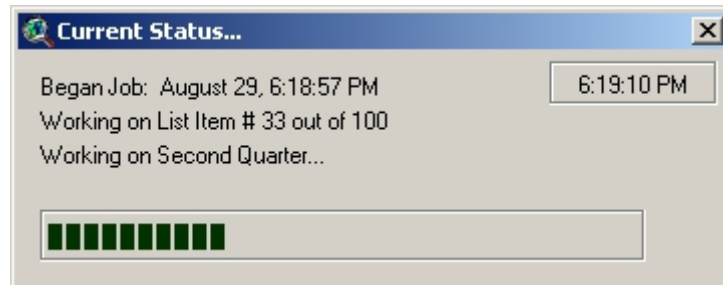
If the 'Maximum Pressure' is selected, the interface finds the pressure for each pipe and then appends the water distribution pipe theme according to the pressure category.



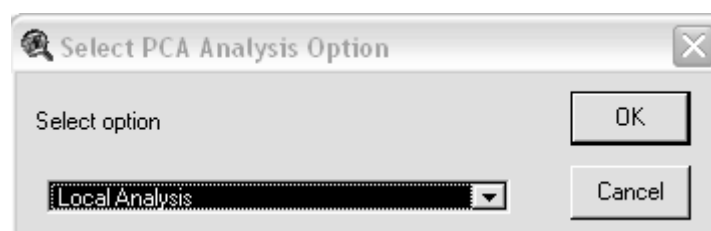
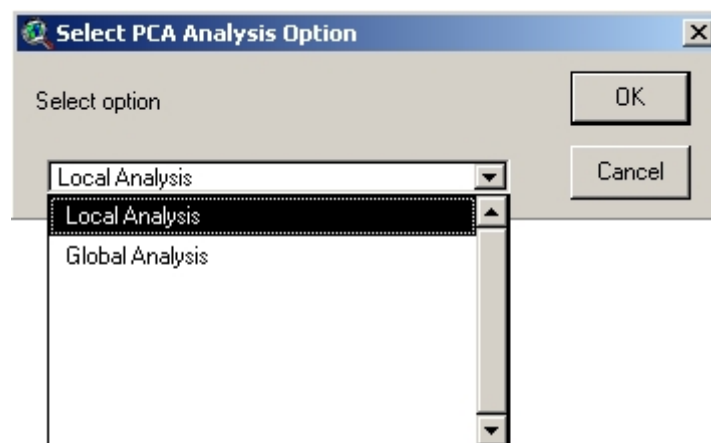
It then opens the 'File Save' dialogue box to save the file with the user-defined name.



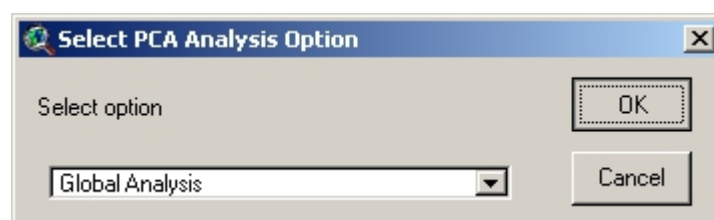
After the user writes/selects the input filename, the interface starts writing the input file. The data generation and writing progress is shown in the ‘Current Status...’ bar, as shown below:



Before completion of data writing, the model prompts an ‘Input Choice’ box asking the user for a ‘Local Analysis’ or ‘Global Analysis’ of pipe condition.

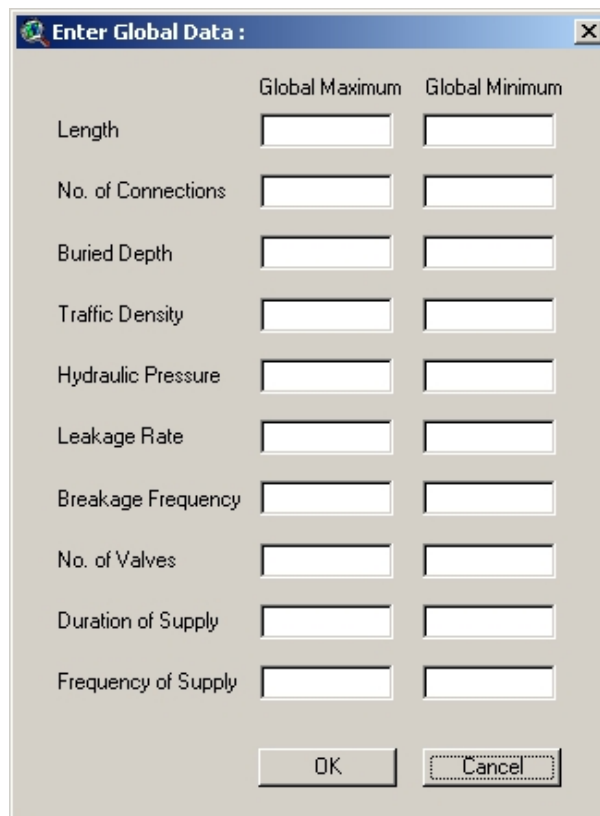


If user selects the ‘Local Analysis’ option, no more data input is required and the interface scans through the data input and finds the local maximum and minimum for the particular parameter required.



If the ‘Global Analysis’ option is selected, then one more input form is opened asking the user to fill in the maximum and minimum for certain parameters; these can then be

used to study and compare different networks in different conditions. The 'Global Data' input form is shown below:

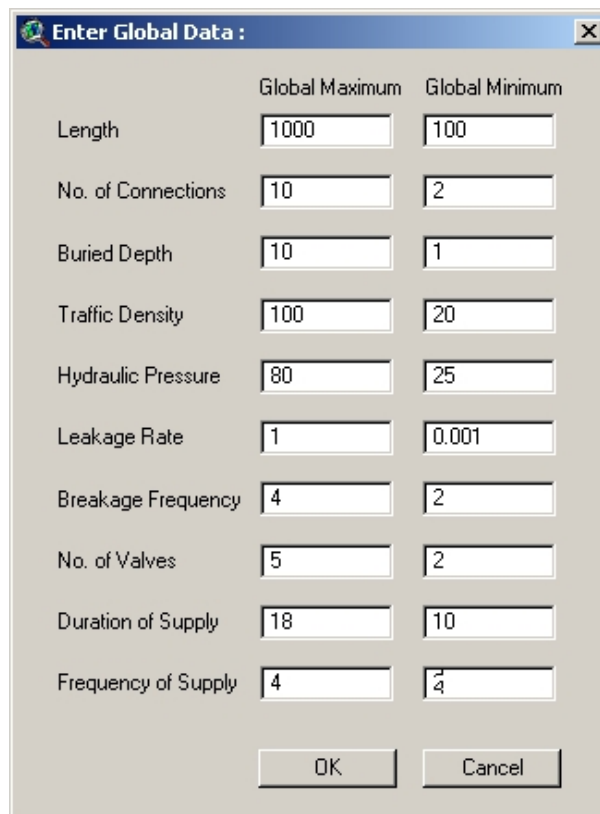


The 'Enter Global Data' dialog box contains the following parameters and their corresponding input fields:

	Global Maximum	Global Minimum
Length	<input type="text"/>	<input type="text"/>
No. of Connections	<input type="text"/>	<input type="text"/>
Buried Depth	<input type="text"/>	<input type="text"/>
Traffic Density	<input type="text"/>	<input type="text"/>
Hydraulic Pressure	<input type="text"/>	<input type="text"/>
Leakage Rate	<input type="text"/>	<input type="text"/>
Breakage Frequency	<input type="text"/>	<input type="text"/>
No. of Valves	<input type="text"/>	<input type="text"/>
Duration of Supply	<input type="text"/>	<input type="text"/>
Frequency of Supply	<input type="text"/>	<input type="text"/>

Buttons: OK, Cancel

After the user has completed the data, the 'Global Data' input form looks as shown below:

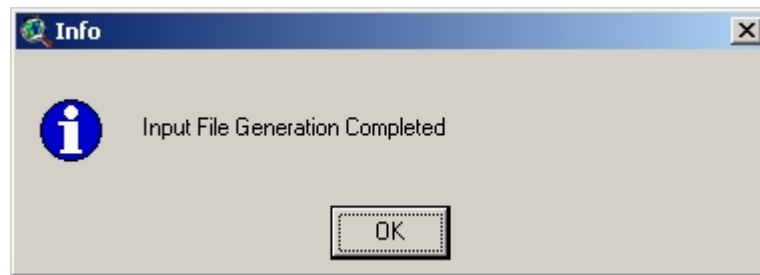


The 'Enter Global Data' dialog box now contains the following parameters with numerical values entered:


	Global Maximum	Global Minimum
Length	1000	100
No. of Connections	10	2
Buried Depth	10	1
Traffic Density	100	20
Hydraulic Pressure	80	25
Leakage Rate	1	0.001
Breakage Frequency	4	2
No. of Valves	5	2
Duration of Supply	18	10
Frequency of Supply	4	4

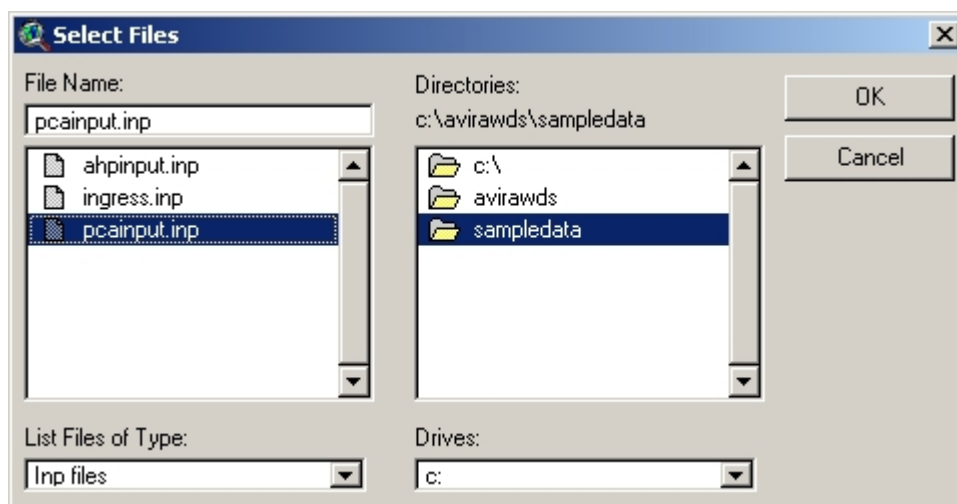
Buttons: OK, Cancel

After completing the data, the user can click on the 'OK' button. After generating the input file successfully, an 'Info' message box indicating 'Input File Generation completion' is displayed as shown below:



4.8 Viewing the PCA input files

The user can view the input file in the notepad by clicking on the  button or alternatively by selecting the 'View PCA Input Files' submenu from the 'Pipe Condition Assessment' menu and browsing the appropriate file to view.



pcainput - Notepad

File Edit Format Help

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WATER PIPELINE vulnerability Assessment Input

=====

[WATER PIPE]

ID	StNode	EndNode	StJoint	EndJoint	Material	Traffic	SurfPerm	InProtect	ExProtect	BedCond	workshop								
689	631	632	4	4	0	2	0	2	1	0	1	2	500	50	120	1.312			
703	632	643	1	1	0	2	2	2	4	4	1	0	1	1	2	500	50	120	51.20
722	660	631	1	1	1	2	2	2	4	3	1	0	1	1	2	500	50	70	21.79
762	643	696	2	2	0	2	2	2	4	3	2	0	1	1	2	400	50	120	48.79
781	696	713	2	2	0	2	2	2	4	3	2	0	1	1	2	400	50	120	13.70
786	719	660	2	2	1	2	2	2	4	1	2	0	1	1	2	500	50	70	57.72
796	713	728	2	2	0	2	2	2	4	3	2	0	1	1	2	400	50	120	65.78
800	732	719	2	2	1	3	2	2	4	1	2	0	1	1	2	500	50	70	17.32
803	734	732	2	2	1	3	2	2	4	1	2	0	1	1	2	500	50	70	1.848
808	728	739	2	2	0	2	0	2	1	3	4	1	1	1	1	400	35	120	37.87
809	740	734	2	2	1	3	2	2	4	1	2	0	1	1	2	500	50	70	18.99
818	739	747	2	2	0	2	0	2	1	3	3	1	1	1	1	400	35	120	62.12
824	753	740	2	2	1	3	2	2	4	1	2	0	1	1	2	200	50	70	72.37
830	747	758	2	2	0	2	0	2	1	3	4	1	4	1	1	400	35	120	48.64
831	760	733	2	2	1	3	0	2	1	1	4	1	0	1	2	200	50	70	27.62
836	765	728	2	2	0	2	0	2	1	3	2	1	1	1	2	400	20	130	38.94
837	765	760	2	2	1	3	0	2	1	1	2	1	1	1	2	200	20	120	25.67
842	758	769	2	2	0	2	0	2	1	3	4	1	1	4	1	400	35	120	38.08
852	777	765	2	2	1	3	0	2	1	1	2	1	1	1	2	200	35	95	37.53
855	780	765	2	2	0	3	0	2	1	1	2	1	1	1	2	200	20	130	12.74
856	781	734	2	2	2	4	2	1	4	1	2	0	1	1	2	500	50	100	61.00
861	785	781	2	2	2	4	2	1	4	1	2	0	1	1	2	200	20	120	3.559
862	786	785	2	2	4	2	1	4	1	2	4	0	1	1	2	200	20	120	0.308
865	769	788	1	1	0	3	0	2	1	3	4	1	4	1	1	400	35	120	54.68
866	789	777	2	2	1	3	0	2	1	1	3	1	1	1	1	200	35	95	40.72
879	800	786	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	19.12
880	789	801	2	2	1	3	0	2	1	1	3	1	1	1	1	200	35	95	36.71
883	801	806	2	2	1	3	0	2	1	1	4	1	1	4	1	200	35	95	36.38
884	807	758	2	2	1	3	0	2	1	3	4	1	4	1	1	400	35	95	37.44
885	806	807	2	2	1	3	0	2	1	1	4	1	4	1	1	200	35	95	0.517
892	814	785	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	30.13
893	815	814	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	3.216
898	807	821	2	2	1	3	0	2	1	1	4	1	1	4	1	200	35	95	37.69
899	821	822	2	2	1	3	0	2	1	1	4	1	1	4	1	200	35	95	1.133
900	823	815	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	11.45
905	827	800	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	35.15
914	834	788	1	1	0	3	0	2	1	1	3	4	1	1	1	400	35	120	35.88
915	822	834	1	1	1	3	0	2	1	1	4	1	1	4	1	200	35	95	52.62
917	815	836	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	30.48
918	801	837	2	2	0	1	0	2	1	1	3	1	4	1	1	200	35	120	31.21
920	839	834	1	1	0	3	0	2	1	1	4	1	4	1	1	200	35	120	7.589
936	852	827	1	1	2	1	0	1	1	1	2	0	1	1	2	200	20	120	64.84
942	858	839	1	1	0	3	0	2	1	1	4	1	4	1	1	200	35	120	17.21
944	760	860	2	2	0	1	0	2	1	1	2	1	1	1	2	200	20	130	85.53
945	852	860	2	2	0	1	0	2	1	1	2	1	1	1	2	200	20	130	33.33
949	836	863	1	1	2	4	2	1	4	1	2	0	1	1	2	200	20	120	69.51
950	865	780	2	2	0	1	0	2	1	1	2	1	1	1	2	200	20	130	74.34
951	860	865	2	2	1	1	0	2	1	1	2	1	1	1	2	200	20	130	25.65
956	869	852	1	1	2	1	0	1	1	1	2	0	1	1	2	200	20	120	24.21
957	863	869	1	1	2	3	0	1	1	1	2	0	1	1	2	200	20	120	35.20

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File Edit Format Help

1196	1039	1075	4	4	4	4	3	3	3	2	3	3	4	3	300	20	110	36.67
1220	1075	1095	4	4	4	4	3	3	3	3	3	3	4	3	300	20	110	26.47
1235	1095	1109	4	4	4	4	3	3	3	2	3	3	4	3	300	20	110	27.57
1269	1137	1109	4	4	4	4	3	3	3	2	3	3	4	3	300	20	110	44.32

[PIPE MATERIAL]
:0= AC
:1= RCC
:2= UL
:3= PVC
:4= CI

ID	Corros	Resis	Max P	MaxPres	MaxLoad	MaxDia	MinDia	MaxLife	Min D
ID	Corros	Max	P	Max L	Design Life	Max CFactor	Min CFactor	Max D	Min D
0	4	35.700		23.500	60	150	100	2500.000	50.000
1	4	30.000		30.000	60	130	70	1200.000	400.000
2	4	15.000		25.000	50	120	90	1000.000	300.000
3	4	15.300		4.400	60	150	130	1200.000	75.000
4	4	97.920		150.000	70	150	60	2000.000	75.000

[CORROSION RESISTANCE]
:0=very weak
:1=weak
:2=Medium
:3=Strong
:4=very Strong

ID	Left	MidLeft	MidRight	Right
0	0.0	0.0	0.1	0.2
1	0.1	0.3	0.3	0.5
2	0.3	0.5	0.5	0.7
3	0.5	0.7	0.7	0.9
4	0.8	0.9	1.0	1.0

[INTER PROTECTION]
:0=Very Bad
:1=Bad
:2=Medium
:3=Good
:4=very Good

ID	Left	MidLeft	MidRight	Right
0	0.0	0.0	0.1	0.2
1	0.1	0.3	0.3	0.5
2	0.3	0.5	0.5	0.7
3	0.5	0.7	0.7	0.9
4	0.8	0.9	1.0	1.0

[EXTER PROTECTION]
:0=Very Bad
:1=Bad
:2=Medium
:3=Good
:4=very Good

ID	Left	MidLeft	MidRight	Right
0	0.0	0.0	0.1	0.2
1	0.1	0.3	0.3	0.5
2	0.3	0.5	0.5	0.7
3	0.5	0.7	0.7	0.9
4	0.8	0.9	1.0	1.0

```

pcainput - Notepad
File Edit Format Help
26 0.352189
27 0.559065
28 0.559065

[BALANCE FACTOR]
;0=Pipe Members Balance Factor;
;1=Installation Members Balance Factor;
;2=Corrosion Members Balance Factor;
;3=Strength Members Balance Factor;
;4=Failure Members Balance Factor;
;5=Intermittency Members Balance Factor;
;6=Physical Members Balance Factor;
;7=Environmental Members Balance Factor;
;8=Operational Members Balance Factor;
;9=PCA Members Balance Factor;
-----
;ID balance factor
-----
0 1
1 1
2 1
3 1
4 1
5 1
6 1
7 1
8 1
9 1


[DATA BASE]
;0=Length;
;1=No. of connections;
;2=Buried depth;
;3=Traffic load;
;4=Hydraulic pressure;
;5=Leakage frequency;
;6=Breakage frequency;
;7=Valve operation;
;8=Duration of water supply;
;9=No of water supply operation;
-----
;ID Max Min
-----
0 1000 0.308
1 10 2
2 10 1
3 100 0
4 80 0
5 1 0
6 5 0
7 5 0
8 18 2
9 4 2

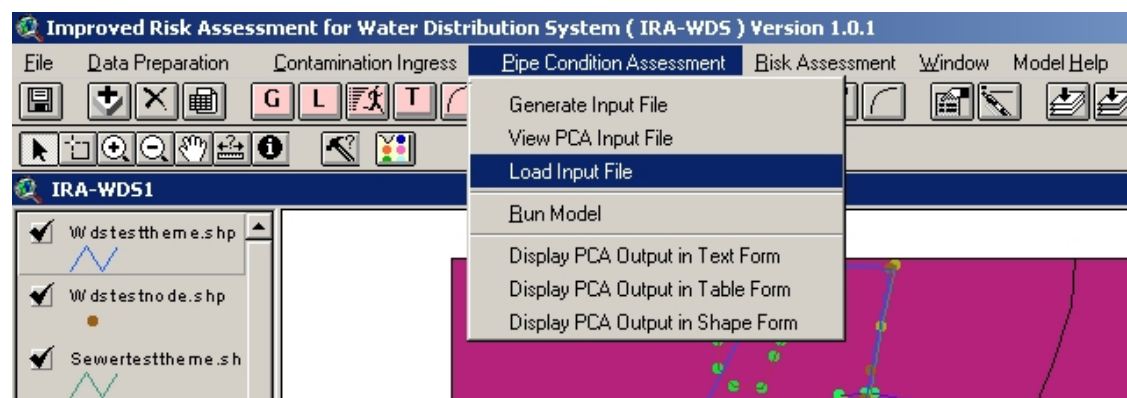
[GROUP]
7

[END]

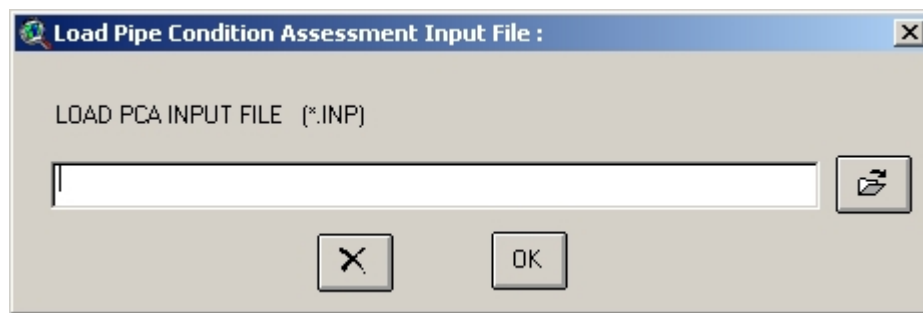
```


4.9 Loading the input file

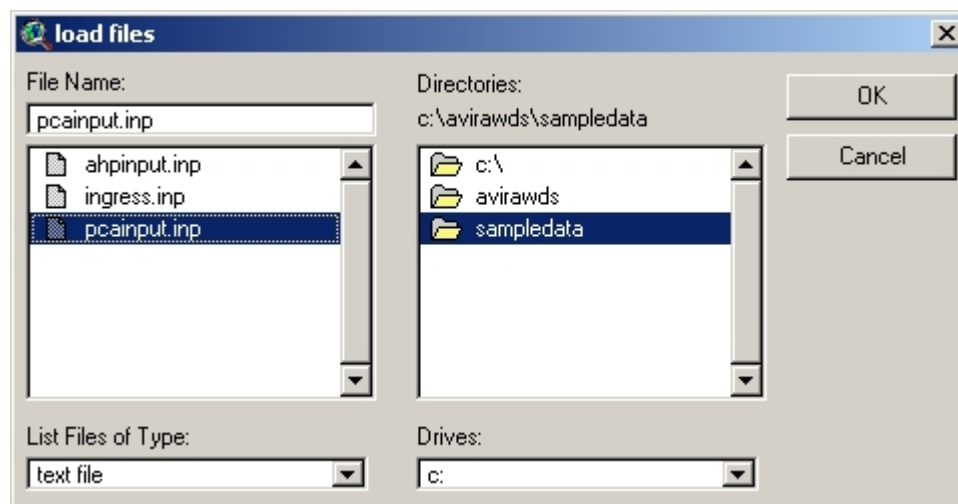
The input file to be used for running the Pipe Condition Assessment Model is loaded using the tool , which is just below the 'Pipe Condition Assessment' menu or by clicking on the 'Pipe Condition Assessment' menu and then clicking on the submenu 'Load Input File', as shown in the screen below:



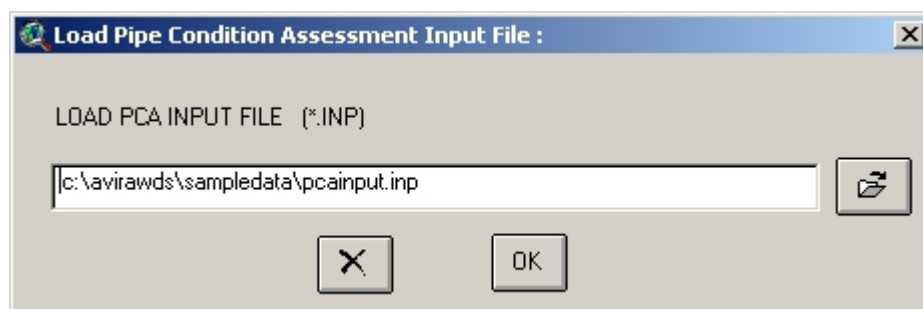
The 'Load Pipe Condition Assessment Input File' is shown below:





The user can browse through the computer by clicking on the  button on the 'Load Pipe Condition Assessment Input File' dialogue box. This opens the 'load files' dialogue box, as shown below:




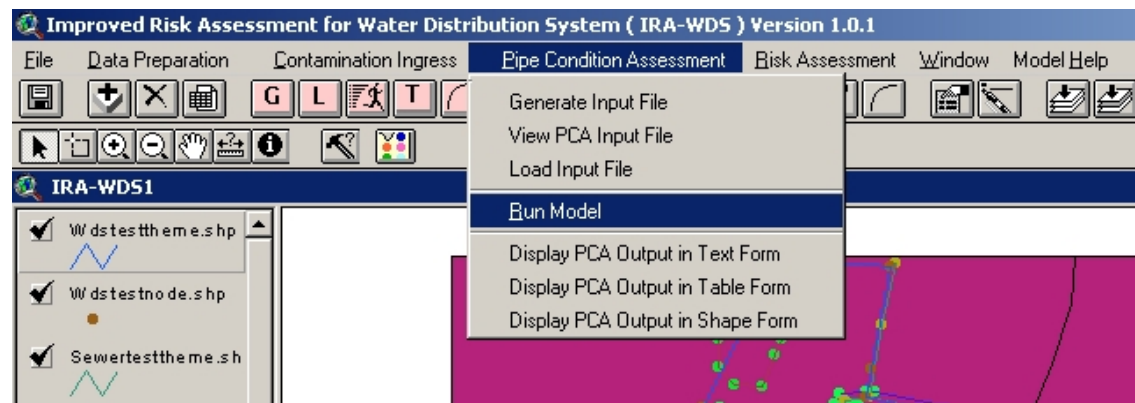
After the appropriate file has been selected and the user has pressed the 'OK' button on the filename, the filename appears in the 'Load Pipe Condition Assessment Input File' dialogue box.



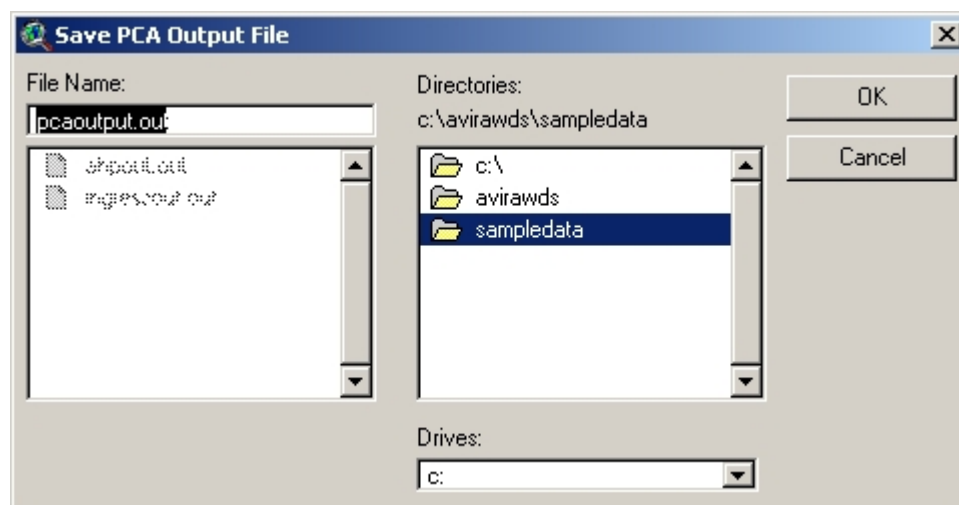
If the user wants to change the filename, he or she can do so by clicking the button , which clears the filename from the 'Load Pipe Condition Assessment Input File' dialogue box. If user is sure of the input file selected, he or she can load it by clicking on the  button. This also closes 'Load Pipe Condition Assessment Input File' dialogue box.

4.10 Running the Model (PCA)

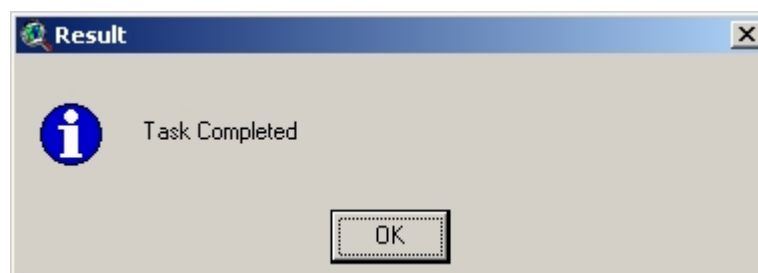
To run the model, the user should click on the  button, which is just below the 'Pipe Condition Assessment' menu or he or she should click on the 'Pipe Condition Assessment' menu and then click on the submenu 'Run Model', as shown on the screen below:



This opens the 'File Save' dialogue box for saving the Pipe Condition Assessment output file as *.out. Once the user has typed the appropriate name and clicked on 'OK', this generates the output selected by the user.



The interface then displays the 'Task Completed' Result message box, as shown below:




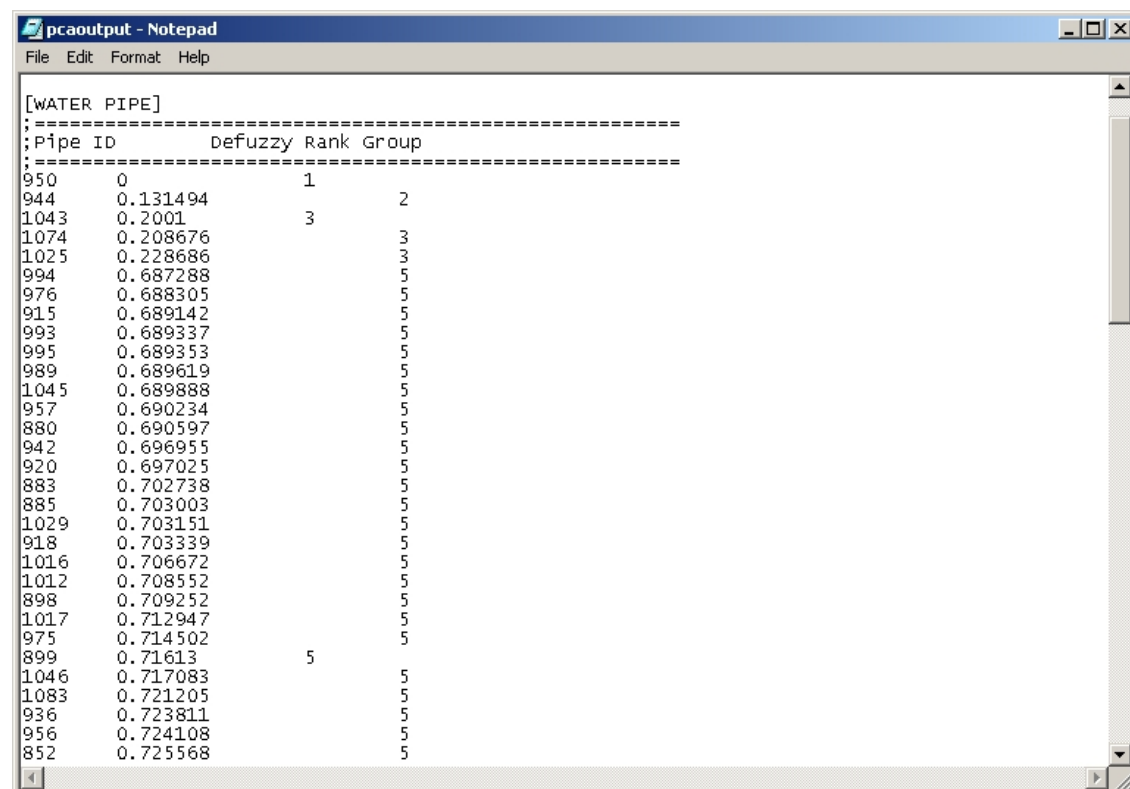
4.11 Displaying the output

Output can be displayed in the following three forms:

1. Display PCA Output in Text form
2. Display PCA Output in Table form
3. Display PCA Output in Shape form

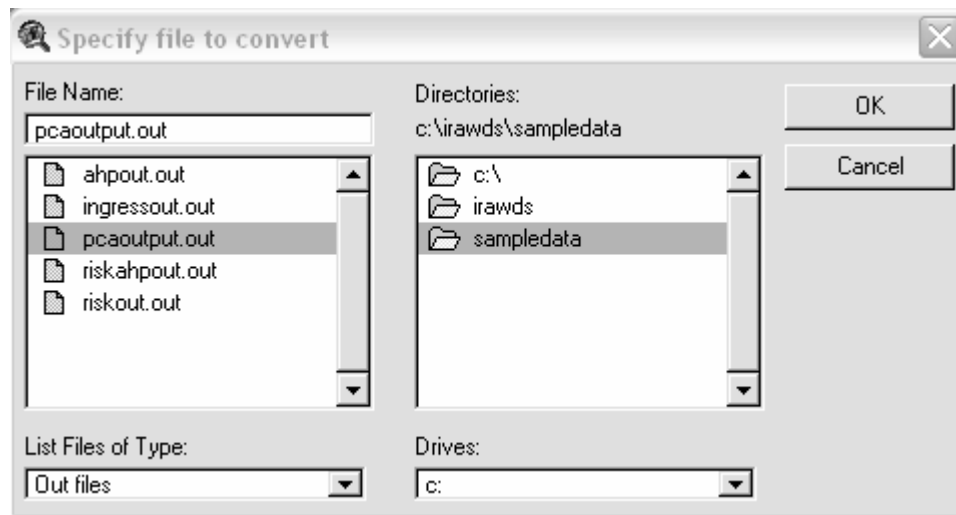
4.11.1 Displaying PCA output in text form

The user can view the output file in the text form in notepad by clicking on the  button or by selecting the 'Display PCA Output in Text Form' submenu from the 'Pipe Condition Assessment' menu and browsing the appropriate output file to view.




4.11.2 Displaying PCA output in table form

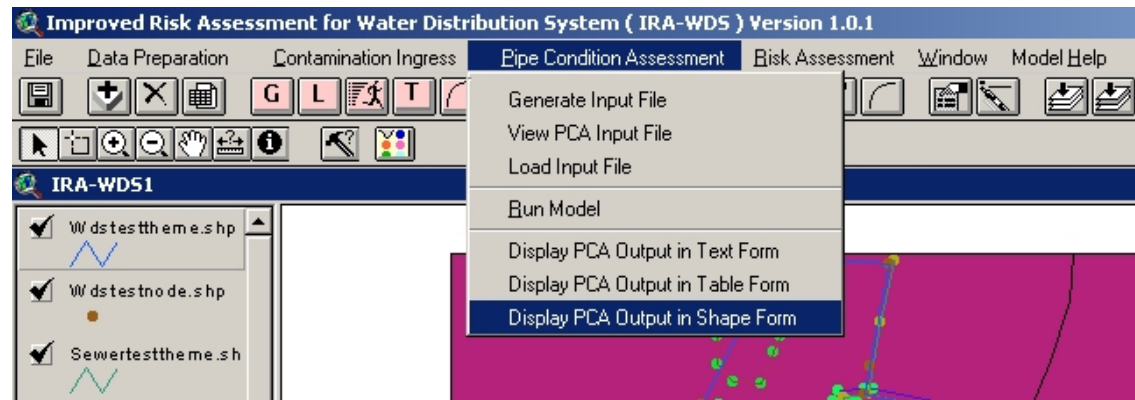
The user can view the output file in table form by selecting the 'Display PCA Output in Table Form' submenu from the 'Pipe Condition Assessment' menu and specifying the appropriate output file to view by browsing, as shown below:



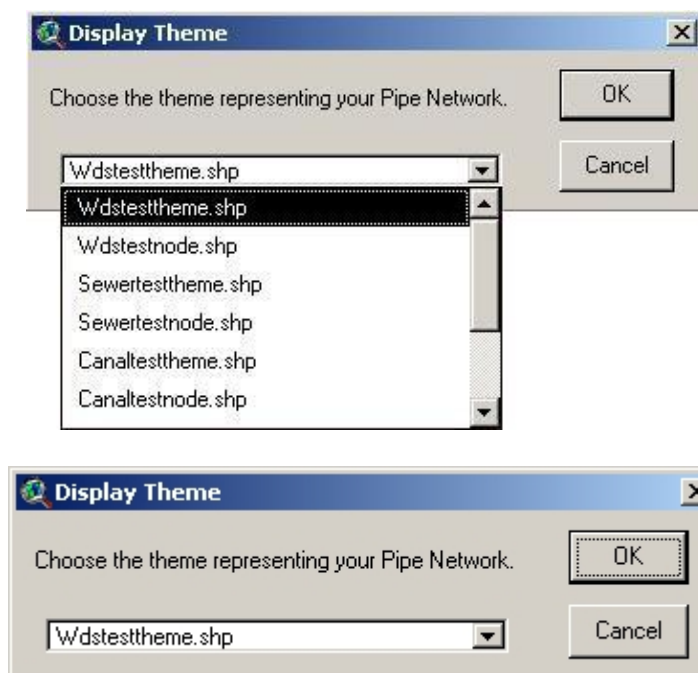
c:\irawds\sampledata\pcaoutput.dbf		
PipeID	DeFuzzy	Rank
950	0.000	1
944	0.283	3
1043	0.430	4
1074	0.448	4
1025	0.491	5
831	0.776	7
975	0.777	7
824	0.778	7
880	0.781	7
852	0.793	7
866	0.797	7
837	0.797	7
951	0.797	7
936	0.799	7
1083	0.799	7
957	0.800	8
809	0.802	8
989	0.804	8
883	0.805	8
994	0.805	8
945	0.806	8
956	0.806	8
915	0.808	8
786	0.809	8
885	0.811	8
1017	0.814	8
949	0.814	8
855	0.815	8
976	0.817	8
856	0.817	8
993	0.817	8

4.11.3 Displaying Pipe Condition Assessment output in shape form

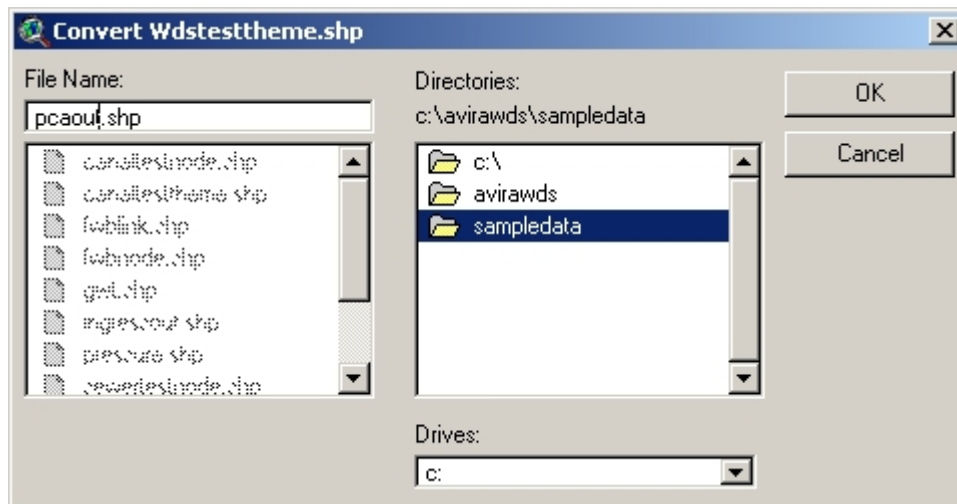
To view the Pipe Condition Assessment output in shape file form, the user should click on the  button, which is just below the 'Pipe Condition Assessment' menu or he or she can click on the 'Pipe Condition Assessment' menu and then click on the submenu 'Display Ingress Output in Shape Form', as shown on the screen below:



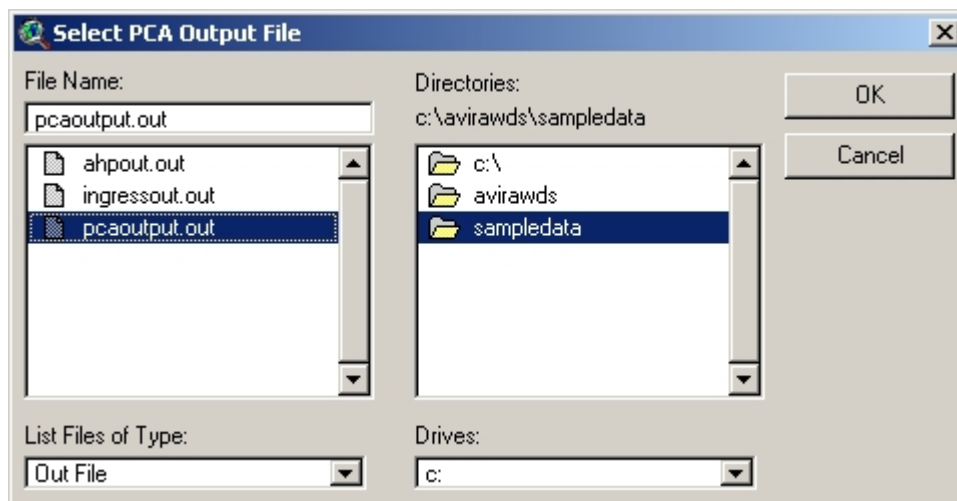
This opens the 'Display Theme' message box asking the user to specify which theme represents the water distribution system pipe theme, as shown below:



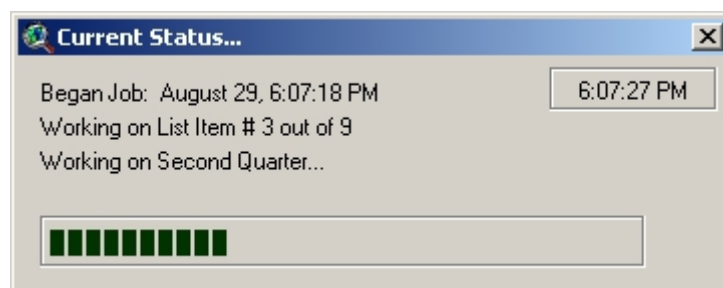
Once the user selects the appropriate theme representing the water distribution system pipe network and clicks on the 'OK' button, the 'Convert Theme' dialogue box appears on the screen and asks the user to give the name with which he or she wants to store/convert the selected theme, as shown on next page.



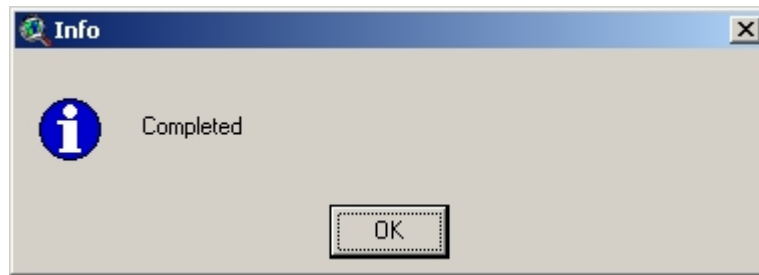
The interface then opens the 'File Select' dialogue box for selecting the Pipe Condition Assessment output file as *.out, from which attributes for pipe condition (PCAValue and PCARank) are to be added to the output theme, as shown below:



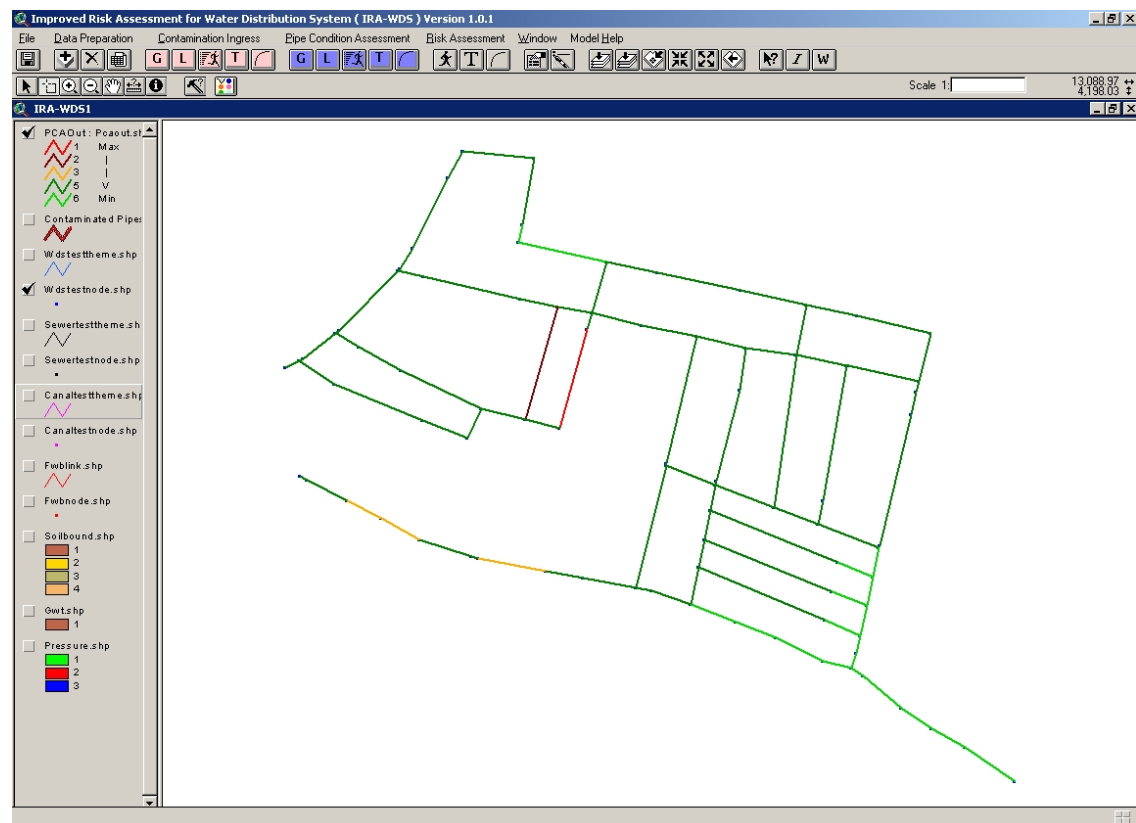
Once the user has selected the appropriate filename and clicked 'OK', the program shows the progress meter, as below:



On completion of theme generation and attribute addition, it displays the 'Completed' Info message box, as shown on next page.



After clicking the 'OK' button on this message box, the new shape-file is added to the IRA-WDS data viewer. The 'PCAOut' theme legend needs to be changed by the user and instead of viewing the theme in a single colour, it can be viewed by unique values of 'PCARank', as shown below:



CHAPTER FIVE

Risk Assessment Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems

Chapter-1
IRA-WDS: Overview



Chapter-2
Data Preparation



Chapter-3
Contaminant Ingress Model



Chapter-4
Pipe Condition Assessment Model



Chapter-5
Risk Assessment Model

Chapter 5: Risk Assessment Model

5.1 Introduction

There are several submenus under the 'Risk Assessment' menu. This chapter describes the use of these submenus and associated commands for running the Risk Assessment Model. Figure 5.1 show the steps involved in executing this component of the software.

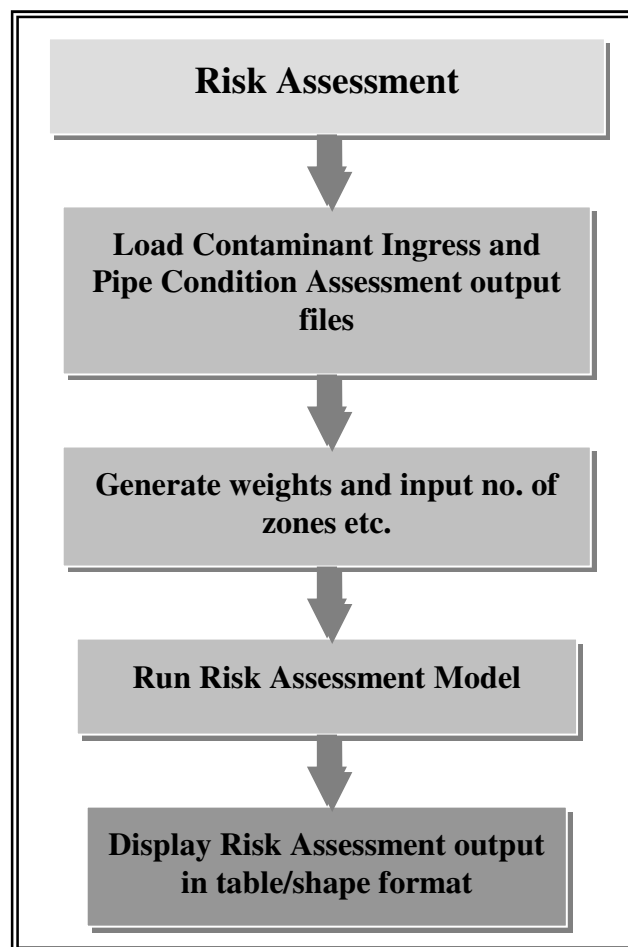


Figure 5.1. Overview of Risk Assessment Model of IRA-WDS


The following steps need to be performed in order to run the Risk Assessment Model.

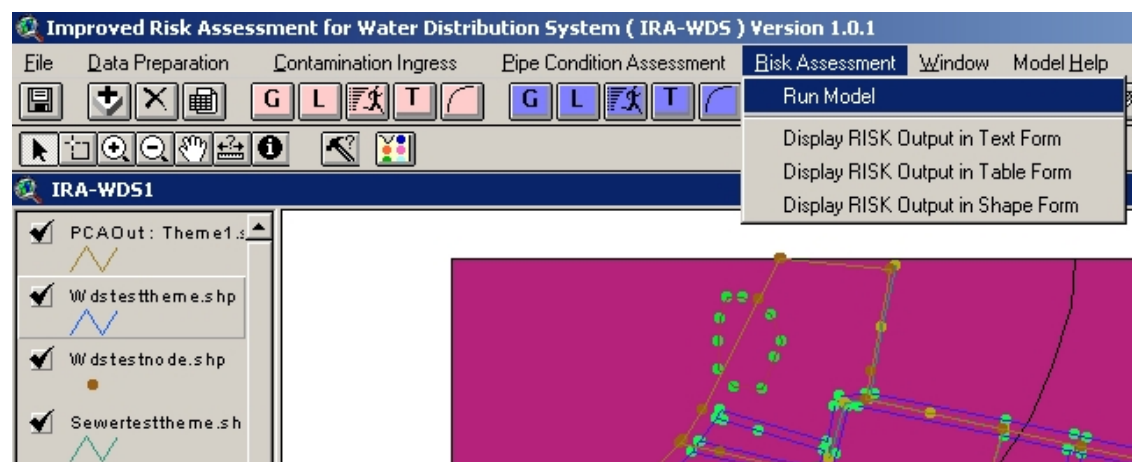
- Run Model
- Display output (optional)

The example files given in Table 5.1 are to be used for illustration purposes while describing the use of the Risk Assessment Model with the help of IRA-WDS.

Table 5.1. Example input files	
Filename	Descriptions
Pcaoutput.out	Pipe Condition Assessment Model output
Ingressoutput.out	Ingress Model output


5.2 Running the Risk Assessment Model

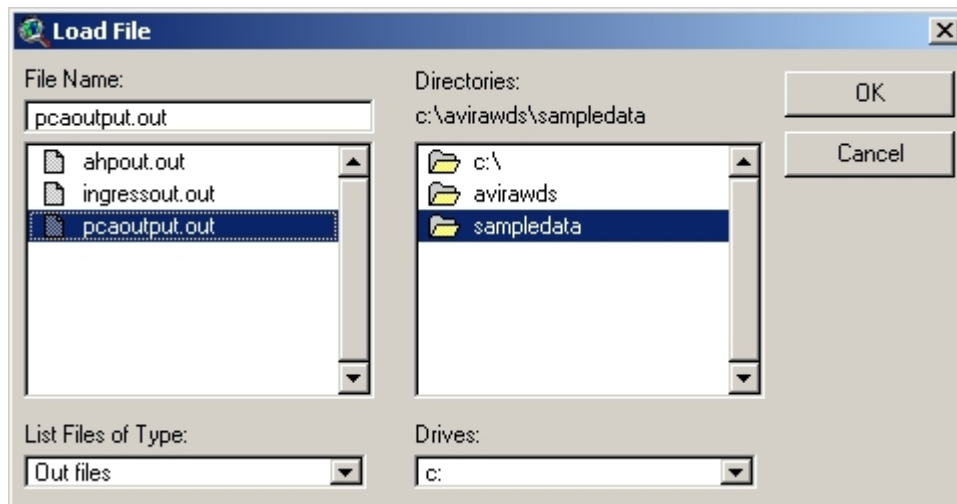
The Risk Assessment Model can be run by clicking on the Tool , which is just below the 'Risk Assessment' menu or by clicking on the 'Risk Assessment' menu and then clicking on the submenu 'Run Model', as shown on the screen below:




5.2.1 Loading the files

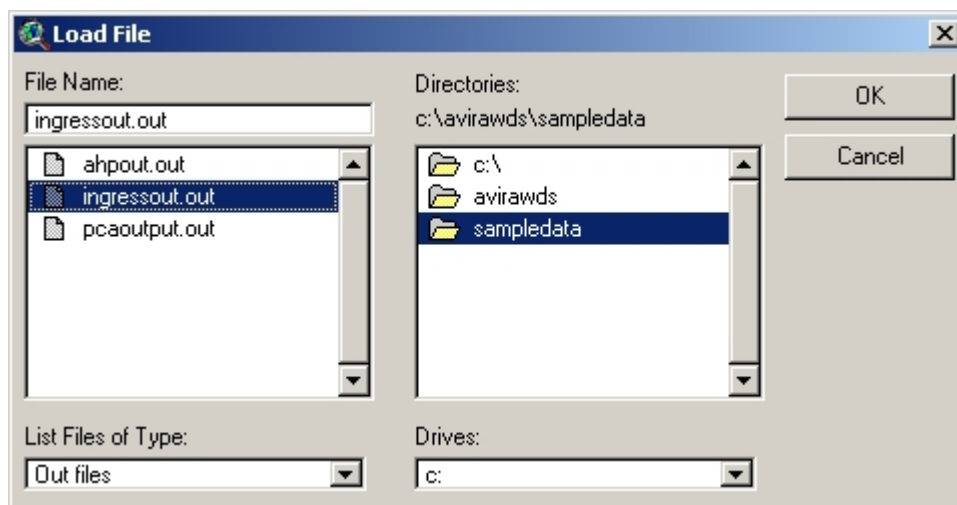
To run the Risk Assessment Model, the output files from the Contamination Ingress and Pipe Condition Assessment models are to be loaded onto the interface. To load

the PCA output file, the user should click on the  button on the interface in front of the 'PCA Output File' text box. This opens the 'Load File' dialogue box, as shown on next page.



After selecting the appropriate file, the user should click on the 'OK' button; this will close the 'Load File' dialogue box and will write the name of the selected file in the 'PCA Output File' text box.

To load the Contamination Ingress output file, the user should click on the  button on the interface in front of the 'Ingress Output File' text box. This opens the 'Load File' dialogue box, as shown below:



After selecting the appropriate file, the user should click on the 'OK' button; this will close the 'Load File' dialogue box and will write the name of selected file in the 'Ingress Output File' text box.

After selection of the output files from the Pipe Condition Assessment and Contamination Ingress models, the interface will look as shown on next page.

Risk Assessment Input Form :

☒ Assign Weights ☐ Weights by AHP

PCA Output File :

Ingress Output File :

No. of Groups : 3

	Hazard	Vulnerability	Weights
Hazard	<input type="text"/>	<input type="text"/>	<input type="text"/>
Vulnerability	<input type="text"/>	<input type="text"/>	<input type="text"/>

5.2.2 Weights

The 'Risk Assessment Input Form' has two options for giving importance to the Risk Assessment parameters ('Pipe Condition', 'Length of Contamination' and 'Concentration of Contamination'). These options are:

1. Assign Weights
2. Weights by AHP

The '**Assign Weights**' option allows the user to input weights directly. The user needs to type in the weights in the text box below the 'Weights' label and in front of the 'Hazard and Vulnerability' text boxes, as shown below:

Risk Assessment Input Form :

☒ Assign Weights ☐ Weights by AHP

PCA Output File :

Ingress Output File :

No. of Groups : 3

	Hazard	Vulnerability	Weights
Hazard	<input type="text"/>	<input type="text"/>	0.4
Vulnerability	<input type="text"/>	<input type="text"/>	0.6

The **‘Weights by AHP’** option allows the user to perform a pair-wise comparison and generate the weights using AHP. In this case, the user needs to enter pair-wise comparison values for the ‘Hazard and Vulnerability’ text boxes as shown below:

The 'Risk Assessment Input Form' dialog box contains the following elements:


- Two radio buttons at the top: 'Assign Weights' (selected) and 'Weights by AHP'.
- Two text input fields for 'PCA Output File' and 'Ingress Output File', each with a file selection icon to its right.
- A slider for 'No. of Groups' and a text box containing the value '3'.
- A sub-dialog box titled 'Risk' containing a table for pair-wise comparisons:

	Hazard	Vulnerability	Weights
Hazard	1.000	0.500	
Vulnerability	2.000	1.000	

At the bottom of the main dialog are 'Run' and 'Close' buttons.

The interface also allows the user to select the number of groups in which the risk is to be categorized by sliding the bar in front of ‘No. of Groups’ on the ‘Risk Assessment Input Form’ or by entering the number of groups in the box provided, as shown above.

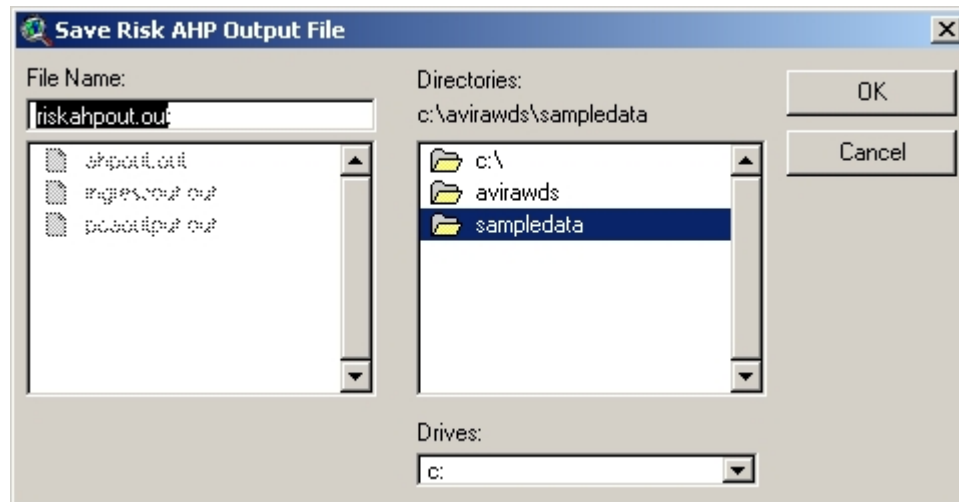
5.2.3 Running the Risk Model

To run the risk model, the user should click on the  button on the ‘Risk Assessment Input Form’. If ‘Weights by AHP’ has been selected, the model first writes the AHP input file for generating the weights. It then opens the ‘Save AHP Input File’ dialogue box to save the AHP input file generated, as shown below:

The 'Save AHP Input File' dialog box contains the following elements:

- A 'File Name' text box containing 'riskahpinput.inp'.
- A 'Directories' list box showing 'c:\avirawds\sampdata' as the current directory.
- A file list on the left showing 'shpinput.inp', 'ingress.inp', and 'pcaoutput.inp'.
- 'OK' and 'Cancel' buttons on the right.
- A 'Drives' dropdown menu at the bottom showing 'c:'.

After the user clicks on the 'OK' button on the 'Save AHP Input File' dialogue box, the program runs the AHP model and opens the 'Save Risk AHP Output File' dialogue box, as shown below:



After choosing the output file to write, the weights are generated and generated weights are written in text box 'Weights' as shown below:

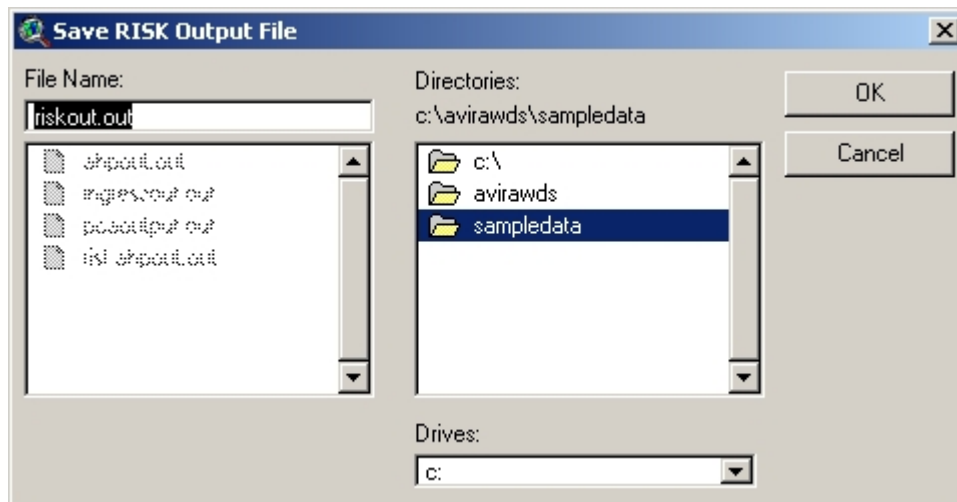
The 'Risk Assessment Input Form' dialog box has two radio buttons: 'Assign Weights' (selected) and 'Weights by AHP'. It includes fields for 'PCA Output File' and 'Ingress Output File' with file selection icons. A 'No. of Groups' slider is set to 3. A table titled 'Risk' shows the following data:

	Hazard	Vulnerability	Weights
Hazard	1.000	0.500	0.33
Vulnerability	2.000	1.000	0.67

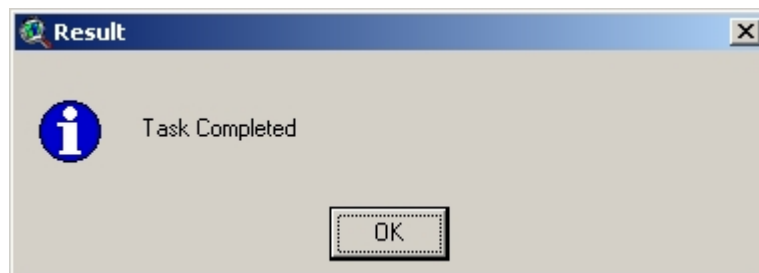
'Run' and 'Close' buttons are at the bottom.

If the weights so generated are not consistent, then '-99 will' be displayed in the weights box. In this case, the user should change the matrix of 'Hazard and Vulnerability' and run the model once again.

If '**Assign Weights**' is selected the above-mentioned steps are not performed, the program opens the 'Save RISK Output File' dialogue box; this asks the user to input the filename to 'Save Risk Output File', as shown below:



It then runs the Risk Assessment model and writes it to the file specified by the user. After completion, the program displays the 'Task Completed' Result message box, as shown below:




The user should click on OK to complete the task.

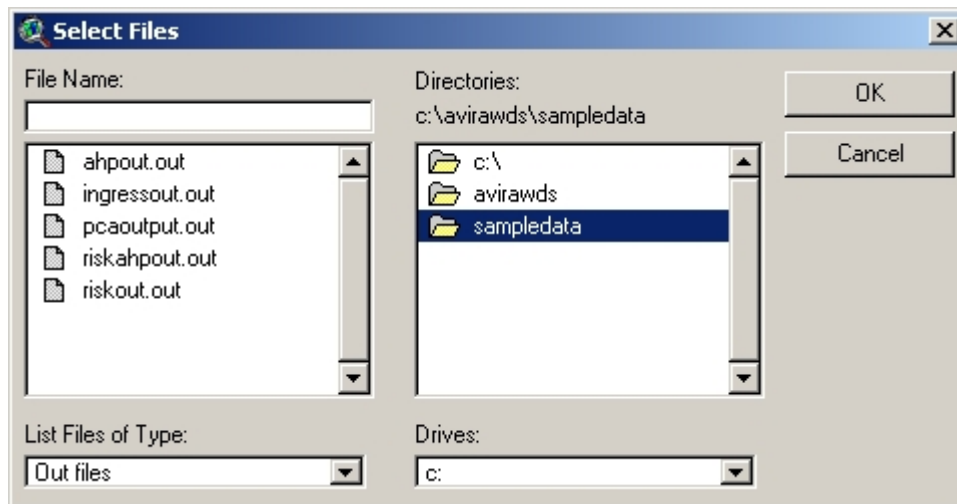
5.3 Displaying output

The output can be displayed in following three forms:

1. Display RISK Output in Text form
2. Display RISK Output in Table form
3. Display RISK Output in Shape form

5.3.1 Displaying Risk output in text form

The user can view the output file in text form in notepad by clicking on the  button or by selecting the 'Display RISK Output in Text Form' submenu from the 'Risk Assessment' menu and browsing the appropriate output file to view.



riskout - Notepad

File Edit Format Help

```

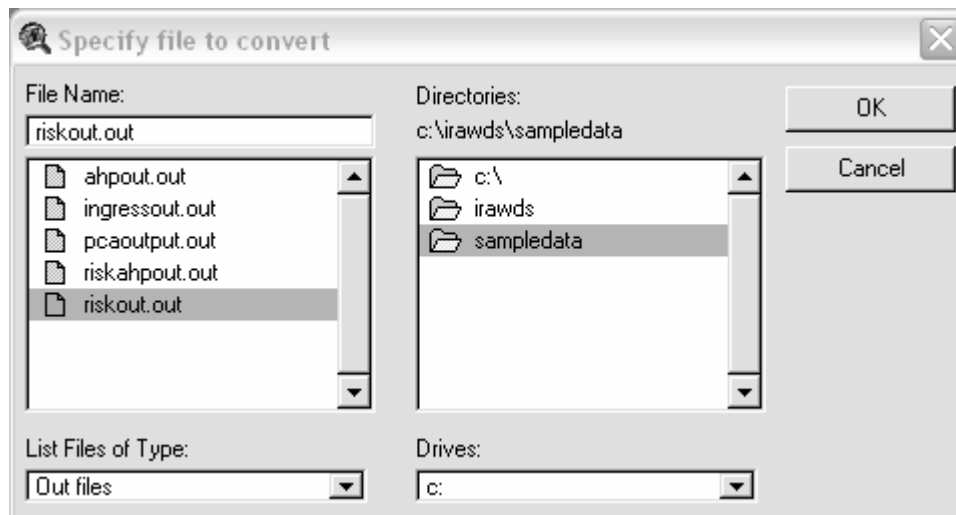
=====;
:      RISK ASSESSMENT
:=====;

[WATER PIPE]
=====;
:Pipe ID      Risk Index      Rank Group
:=====;
950      0.298093      2
944      0.368137      2
1043     0.56834      3
1074     0.409249      3
1025     0.583766      3
994      0.831248      4
976      0.831797      4
915      0.665181      4
993      0.665284      4
995      0.832362      4
989      0.665435      4
1045     0.832651      4
957      0.832838      4
880      0.833034      4
942      0.836465      4
920      0.836502      4
883      0.839585      4
885      0.839728      4
1029     0.672643      4
918      0.672743      4
1016     0.674518      4
1012     0.67552      4
898      0.675893      4
1017     0.845095      4
975      0.678689      4
899      0.846812      4
1046     0.847327      4
1083     0.849551      4

```

5.3.2 Displaying Risk output in table form

The user can view the output file in table form by selecting the 'Display RISK Output in Table Form' submenu from the 'Risk Assessment' menu and specifying the appropriate output file to view by browsing, as shown on next page.

 Specify file to convert

File Name: riskout.out


Directories: c:\irawds\sampledata

OK

Cancel


List Files of Type: Out files

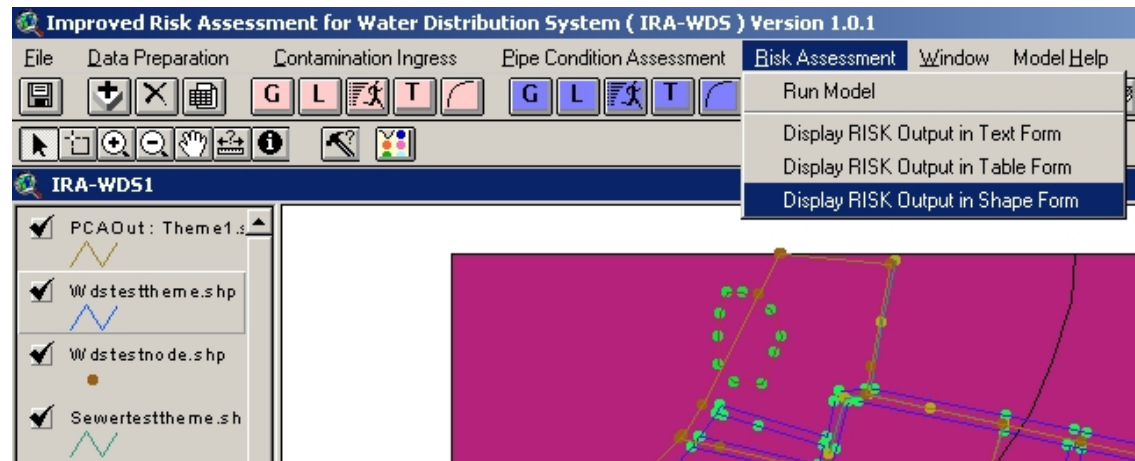
Drives: c:

 c:\irawds\sampledata\riskout.dbf

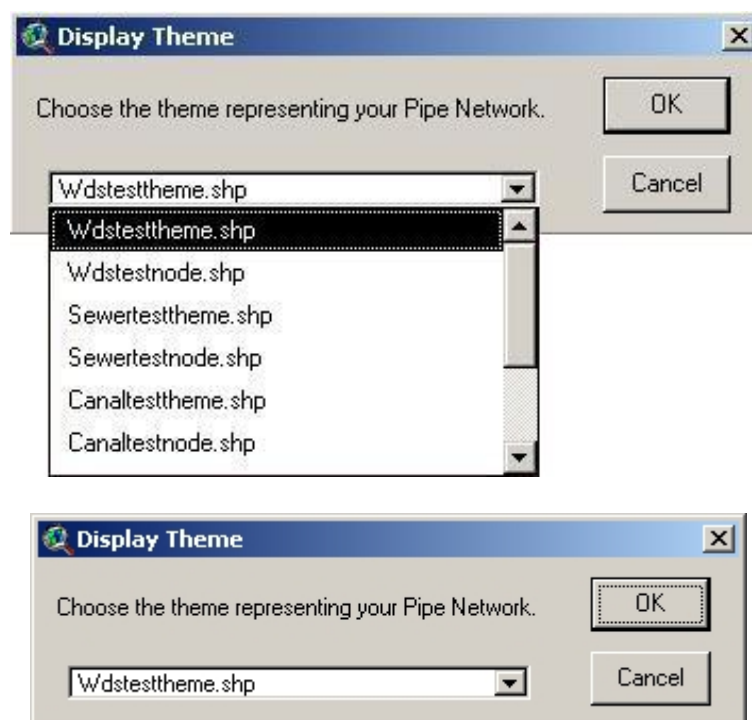
PipeID	RiskIndex	Rank
950	0.336	2
944	0.430	3
1043	0.810	4
1074	0.485	3
1025	0.830	4
831	0.925	5
975	0.594	3
824	0.926	5
880	0.927	5
852	0.931	5
866	0.932	5
837	0.932	5
951	0.932	5
936	0.602	4
1083	0.933	5
957	0.933	5
809	0.603	4
989	0.604	4
883	0.935	5
994	0.935	5
945	0.935	5
956	0.935	5
915	0.605	4
786	0.605	4
885	0.937	5
1017	0.938	5
949	0.938	5
855	0.607	4
976	0.939	5
856	0.939	5
993	0.608	4
1016	0.608	4
995	0.939	5
1045	0.940	5
1012	0.609	4
800	0.941	5
918	0.610	4
803	0.942	5
898	0.611	4
1029	0.612	4

5.3.3 Displaying Risk output in shape form

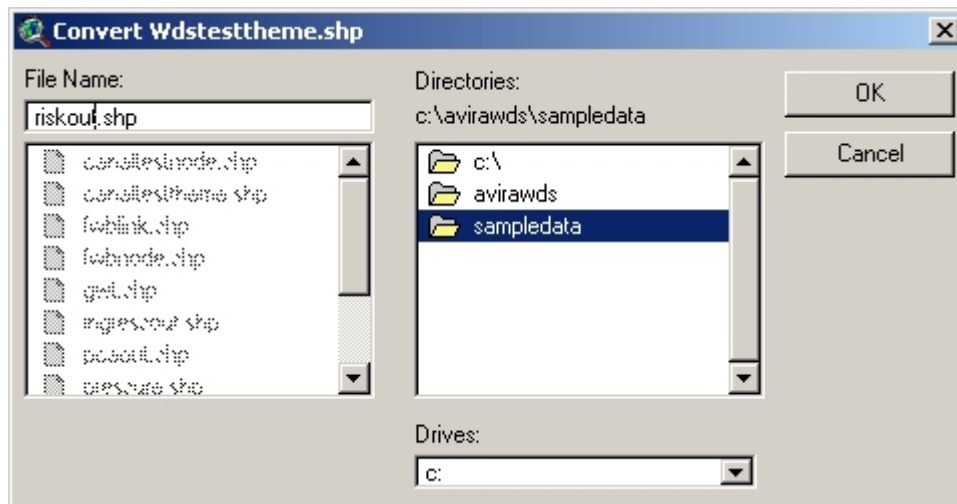
To view the Risk Assessment output in shape file form, the user should click on the  button, which is just below the 'Risk Assessment' menu or he or she should click on the 'Risk Assessment' menu and then click on the submenu 'Display RISK Output in Shape Form', as shown on the screen below:



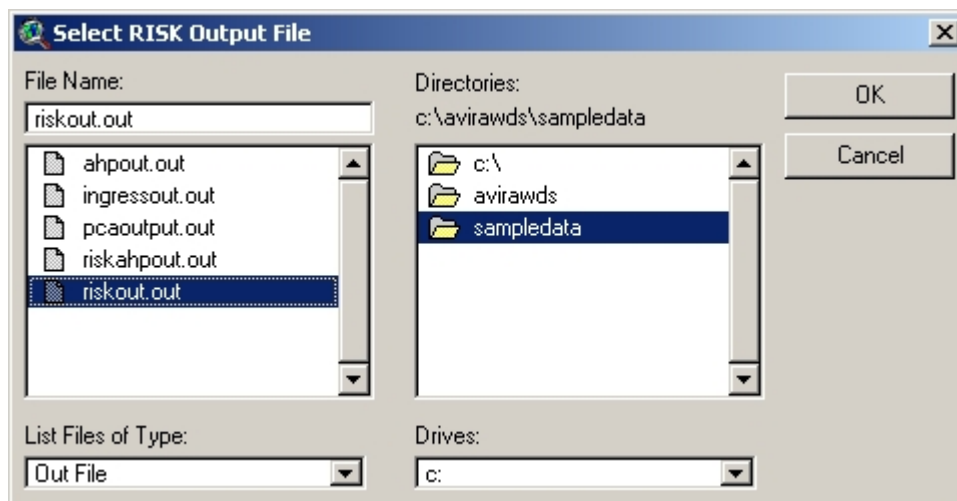
This opens the 'Display Theme' message box asking the user to specify which theme represents the water distribution system pipe theme, as shown below:



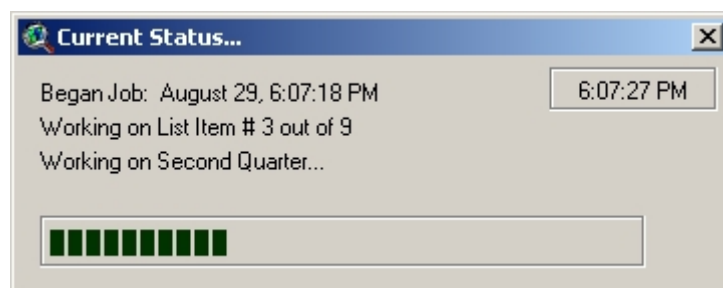
Once the user has selected the appropriate theme representing the water distribution system pipe network and has clicked on the 'OK' button, the 'Convert Theme' dialogue box appears on the screen; this asks the user to give the name with which he or she wants to store or convert the selected theme, as shown on next page.



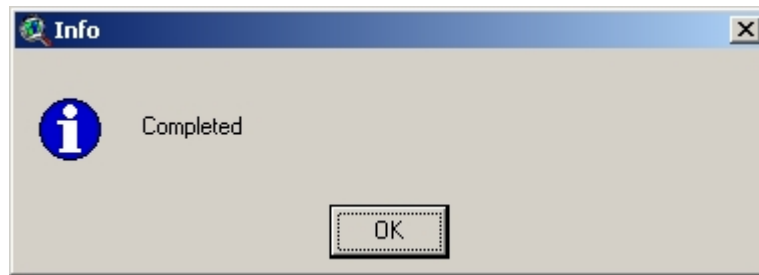
The program then opens the 'File Select' dialogue box for selecting the Risk Assessment output file as *.out, from which attributes for 'Risk Index' (RISKIndex and RISKRank) are to be added to the output theme, as shown below:



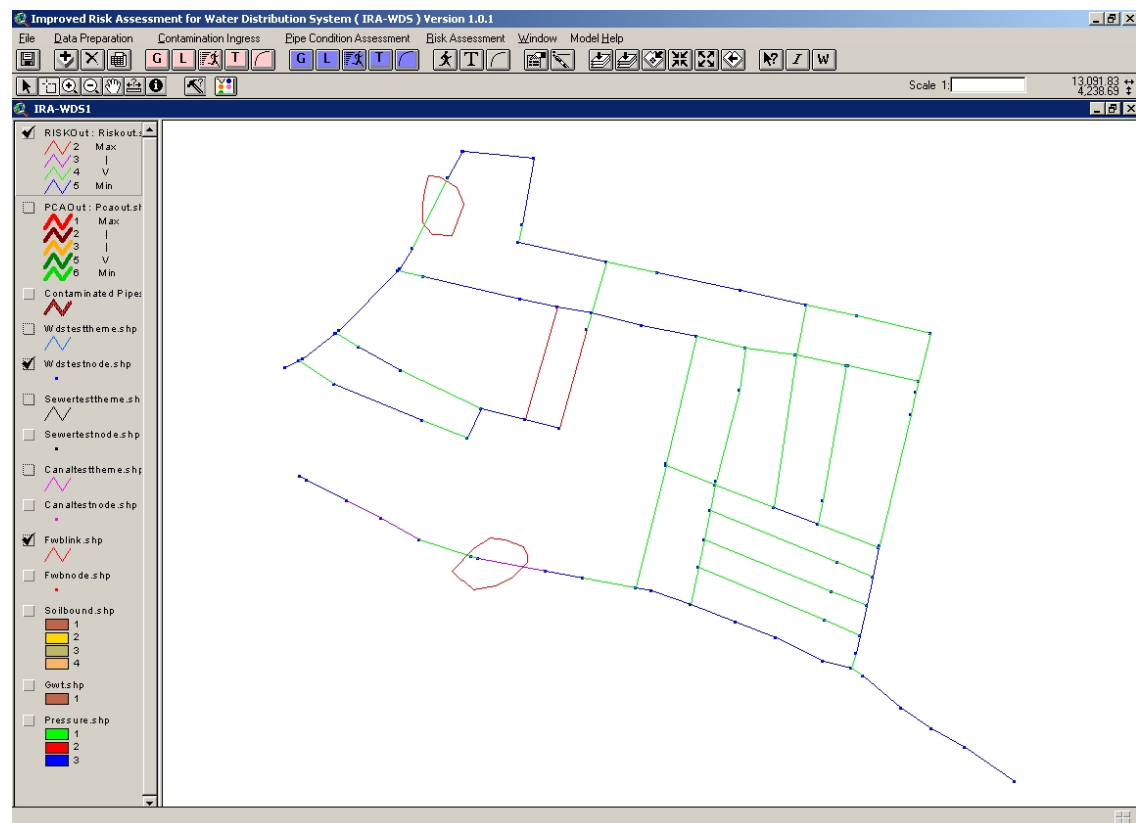
Once the user has selected the appropriate filename and clicked 'OK', the program shows the progress meter, as shown below:



On completion of theme generation and attribute addition, it displays the 'Completed' Info message box, as shown on next page.



After clicking the 'OK' button on this message box, the new shape-file is added to the IRA-WDS data viewer. The 'RISKOut' theme legend needs to be changed by the user and rather than viewing the theme in a single colour, it can be viewed by unique values of 'RISKRank', as shown below:



Appendix A

Inputting additional attribute data for canals and foul water bodies

1. Canals

Tables A.1. and A.2. and Figures A.1. and A.2. give details of the additional attributes required for link data and node data of canals.

Table A.1. Canal link data for Contaminant Ingress Model			
Field name	Unit	Description	Useful references
LINED	<i>Yes/No</i>	Lined or unlined	N/A
CROSS_SECT		Type of cross section	Section 2.3.2.1 of Book 3
TOPWIDTH	<i>Metres</i>	Top width of cross section	
BOTWIDTH	<i>Metres</i>	Bottom width of cross section	
DEPTH	<i>Metres</i>	Depth of cross section	
SEEP_RATE	<i>Metre/day</i>	Seepage rate from canal	

Table A.2. Canal node data for Contaminant Ingress Model			
Field name	Unit	Description	Useful references
ELEVATION	<i>Metres</i>	Elevation of the node	Section 2.3.2.1 of Book 3
WATER_DEPT	<i>Metres</i>	Depth of water in canal	

2. Foul water bodies

Table A.3. and Figure A.3. give details of the additional attributes required for node data of foul water bodies.

Table A.3. Foul water body node data for Contaminant Ingress Model			
Field name	Unit	Description	Useful references
WATER_DEP	<i>Metres</i>	Depth of water in water body	Section 2.3.2.2 of Book 3

Microsoft Excel - Data requirement Ingress Model															
File Edit View Insert Format Tools Data Window Help															
D1 = LENGTH															
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	ID	STARTNODE	ENDNODE	LENGTH	LINED	CROSS_SECT	TOPWIDTH	BOTWIDTH	DEPTH	SEEP_RATE					
2	600	2306	2192	39.489	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
3	601	2823	2809	6.713	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
4	602	2840	2823	5.147	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
5	603	2822	2840	10.978	No	Rectangular	1.500000	0.000000	1.000000	0.000000					
6	617	2459	2467	5.095	No	Rectangular	1.000000	0.000000	1.000000	0.000000					
7	618	2467	2468	1.019	No	Rectangular	1.000000	0.000000	1.000000	0.000000					
8	619	2468	2505	24.178	No	Rectangular	1.000000	0.000000	1.000000	0.000000					
9	709	2010	2003	4.044	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
10	710	2063	2047	6.081	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
11	711	2047	2010	13.706	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
12	712	2134	2116	6.940	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
13	713	2116	2063	28.294	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
14	714	2184	2134	24.821	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
15	715	2242	2184	32.572	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
16	716	2263	2242	8.903	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
17	735	2061	2065	6.189	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
18	736	1998	2040	69.836	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
19	737	2040	2058	30.164	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
20	738	2058	2061	1.299	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
21	739	2069	2064	5.526	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
22	740	2064	2045	32.241	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
23	743	2103	2069	68.219	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
24	746	2108	2103	6.200	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
25	747	2126	2108	32.297	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
26	750	2132	2126	4.800	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
27	751	2164	2132	48.366	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
28	752	2156	2065	33.373	Yes	Rectangular	0.300000	0.000000	0.300000	0.050000					
29	753	2168	2141	31.690	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
30	754	2170	2168	6.504	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
31	755	2141	2138	5.786	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
32	756	2138	2130	19.876	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
33	757	2124	2112	22.112	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
34	758	2130	2124	4.500	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
35	759	2112	2109	7.466	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
36	760	2230	2233	5.313	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
37	761	2230	2140	31.265	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
38	762	2233	2277	47.234	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
39	763	2134	2248	100.000	Yes	Rectangular	0.300000	0.000000	0.500000	0.050000					
General Description / Water Pipe / Water Node / Sewer Pipe / Sewer Node / Canal Link / Canal Node / Waterbody Link / Waterbody Node / Soil /															
Sum=1891348.993														NUM	

Figure A.1. Link data entry for canals

Microsoft Excel - Data requirement Ingress Model															
File Edit View Insert Format Tools Data Window Help															
E1 = ELEVATION															
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	PIPEID	X_COORD	Y_COORD	Z_COORD	ELEVATION	WATER_DEPTH									
2	1979	13314.038000	4326.405000	20.120001	20.120001	0.240000									
3	1981	13310.040000	4326.059000	20.120001	20.120001	0.240000									
4	1986	13297.233000	4324.951000	20.150000	20.150000	0.240000									
5	1997	13301.232000	4320.285000	20.150000	20.150000	0.320000									
6	1998	13306.861000	4320.182000	20.140001	20.140001	0.240000									
7	1999	13295.048000	4320.105000	20.170000	20.170000	0.400000									
8	2003	13241.460000	4318.540000	20.240000	20.240000	0.400000									
9	2010	13239.854000	4314.828000	20.220001	20.220001	0.400000									
10	2013	13376.041000	4313.977000	20.420000	20.420000	0.240000									
11	2015	13242.506000	4313.818000	20.230000	20.230000	0.400000									
12	2029	13259.170000	4308.878000	20.280001	20.280001	0.400000									
13	2038	13408.004000	4306.835000	19.980001	19.980001	0.240000									
14	2040	13375.331000	4306.434000	20.449999	20.449999	0.240000									
15	2045	13414.221000	4305.364000	19.990002	19.990002	0.240000									
16	2047	13231.565000	4303.913000	20.180000	20.180000	0.400000									
17	2048	13232.246000	4303.781000	20.180000	20.180000	0.400000									
18	2049	13291.261000	4303.485000	20.289999	20.289999	0.400000									
19	2058	13404.767000	4299.846000	19.960001	19.960001	0.240000									
20	2060	13290.336000	4299.639000	20.320000	20.320000	0.320000									
21	2061	13406.034000	4299.563000	19.940001	19.940001	0.240000									
22	2063	13227.886000	4299.070000	20.170000	20.170000	0.400000									
23	2064	13445.794000	4298.835000	19.990000	19.990000	0.400000									
24	2065	13412.074000	4298.211000	20.000002	20.000002	0.400000									
25	2066	13296.128000	4298.117000	20.330000	20.330000	0.320000									
26	2069	13451.193000	4297.662000	20.010000	20.010000	0.400000									
27	2078	13444.176000	4291.501000	20.030001	20.030001	0.400000									
28	2084	13287.697000	4290.278000	20.390001	20.390001	0.400000									
29	2087	13293.581000	4289.088000	20.430000	20.430000	0.400000									
30	2090	13300.322000	4287.692000	20.490002	20.490002	0.400000									
31	2098	13287.668000	4285.647000	20.440001	20.440001	0.400000									
32	2100	13315.684000	4284.511000	20.710003	20.710003	0.400000									
33	2103	13517.854000	4283.167000	20.230000	20.230000	0.400000									
34	2108	13523.893000	4281.761000	20.200001	20.200001	0.400000									
35	2109	13307.285000	4281.043000	20.630001	20.630001	0.400000									
36	2112	13314.554000	4279.337000	20.770000	20.770000	0.400000									
37	2113	13341.776000	4279.067000	21.180002	21.180002	0.400000									
38	2116	13209.078000	4277.934000	20.379999	20.379999	0.400000									
39	2119	13509.846000	4277.221000	20.320002	20.320002	0.400000									
General Description / Water Pipe / Water Node / Sewer Pipe / Sewer Node / Canal Link / Canal Node / Waterbody Link / Waterbody Node / Soil /															
Sum=4457128.622														NUM	

Figure A.2. Node data entry for canals

Microsoft Excel - Data requirement Ingress Model																	
File Edit View Insert Format Tools Data Window Help																	
A1 Security... ID																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	ID	X_COORD	Y_COORD	Z_COORD	WATER DEP												
2	76	13289.500	4108.500	22.590	0.500												
3	77	13300.500	4106.720	22.530	0.500												
4	78	13314.000	4101.690	22.470	0.500												
5	79	13277.300	4100.020	22.750	0.500												
6	80	13316.600	4095.650	22.490	0.500												
7	81	13316.200	4090.520	22.520	0.500												
8	82	13261.800	4084.040	23.070	0.500												
9	83	13305.100	4079.250	22.670	0.500												
10	84	13267.400	4078.040	23.080	0.500												
11	85	13271.000	4076.200	23.060	0.500												
12	86	13293.300	4073.100	22.800	0.500												
13	87	13277.500	4070.190	23.020	0.500												
14	134	13244.200	4371.900	21.680	0.300												
15	135	13252.200	4371.620	21.640	0.300												
16	136	13265.300	4363.270	21.580	0.300												
17	137	13241.400	4361.590	21.680	0.300												
18	138	13240.400	4351.170	21.670	0.300												
19	139	13270.100	4351.040	21.540	0.300												
20	140	13267.100	4343.680	21.540	0.300												
21	141	13240.000	4337.500	21.650	0.300												
22	142	13247.500	4329.360	21.610	0.300												
23	143	13261.300	4328.610	21.560	0.300												
24																	
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39																	
General Description / Water Pipe / Water Node / Sewer Pipe / Sewer Node / Canal Link / Canal Node / Waterbody Link / Waterbody Node / Soil /																	
Ready														Sum=387446		NUM	

Figure A.3. Node data entry for foul water bodies

Appendix B

Time required for steady conditions

The time required for flow to establish steady conditions is determined by Philip's Equation (Philip, 1969) (B1) as being approximately equal to:

$$t_0 = \frac{5S^2}{2K_s^2} \quad (\text{B1})$$

where

S – sorptivity (L/T²)

K_s – saturated hydraulic conductivity.

The estimated time to establish steady flow conditions is given in Table B.1.

Table B.1. Steady flow conditions	
Soil texture	Time (hours)
Sand	0.08
Loamy sand	0.50
Sandy loam	1.00
Silt loam	35.50
Loam	11.50
Sandy clay loam	6.93
Silt clay loam	38.50
Clay loam	55.50
Sandy clay	12.25
Silty clay	63.50
Clay	50.50

Reference

Philip, J. R. (1969) Theory of Infiltration. *Advances in Hydro Sciences*, Vol 5, pp 215-290.