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

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Kalanithy Vairavamoorthy, Sunil D. Gorantiwar, Jimin Yan & Harshal M. Galgale

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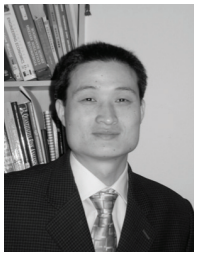

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Who should read this book

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.

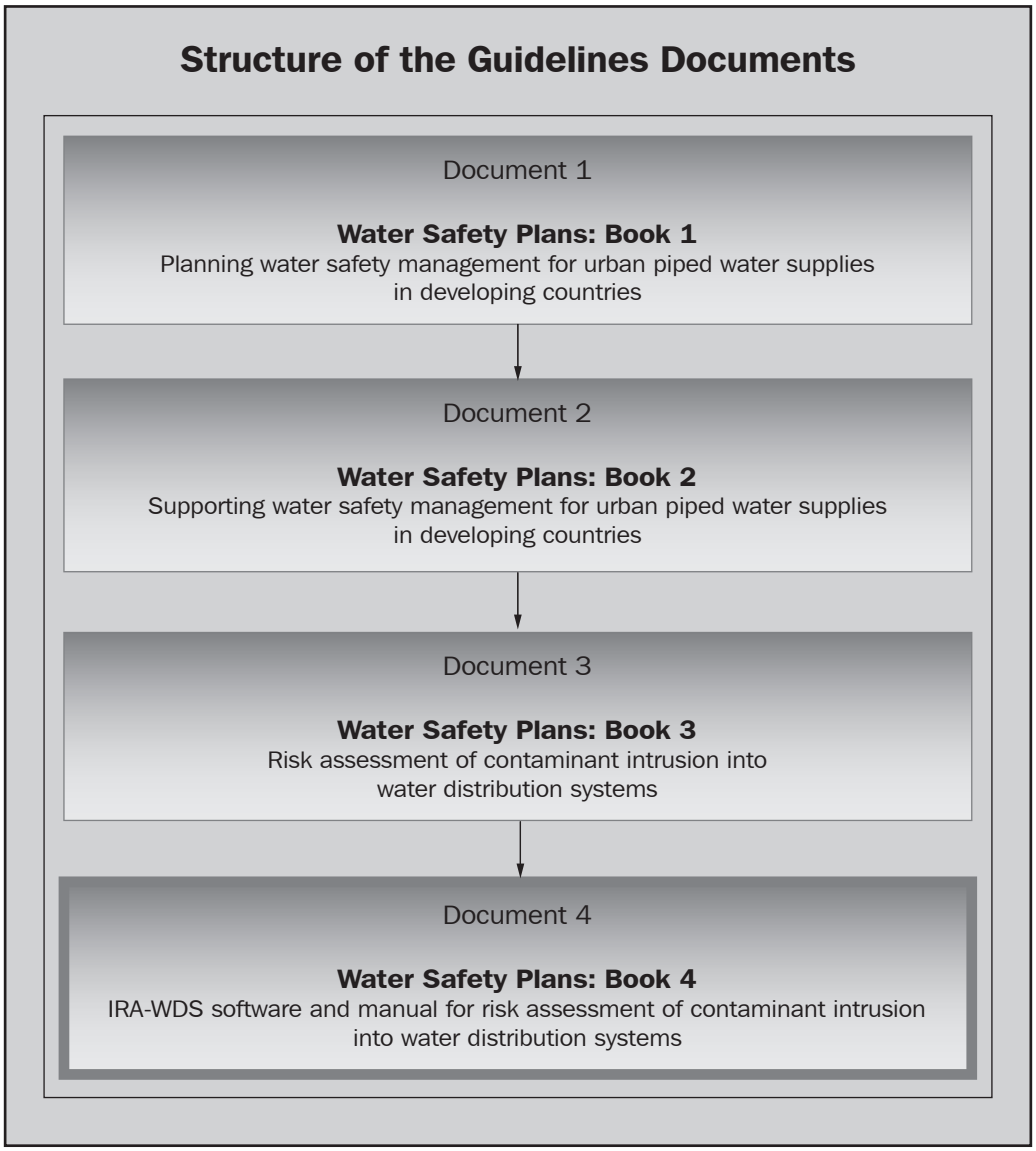
This book is a manual for using the developed software, IRA-WDS (Improved Risk Assessment for Water Distribution System), a Geographical Information System (GIS) that aids in evaluating the risk of deterioration of the water distribution network of a water supply system. The manual is a structured document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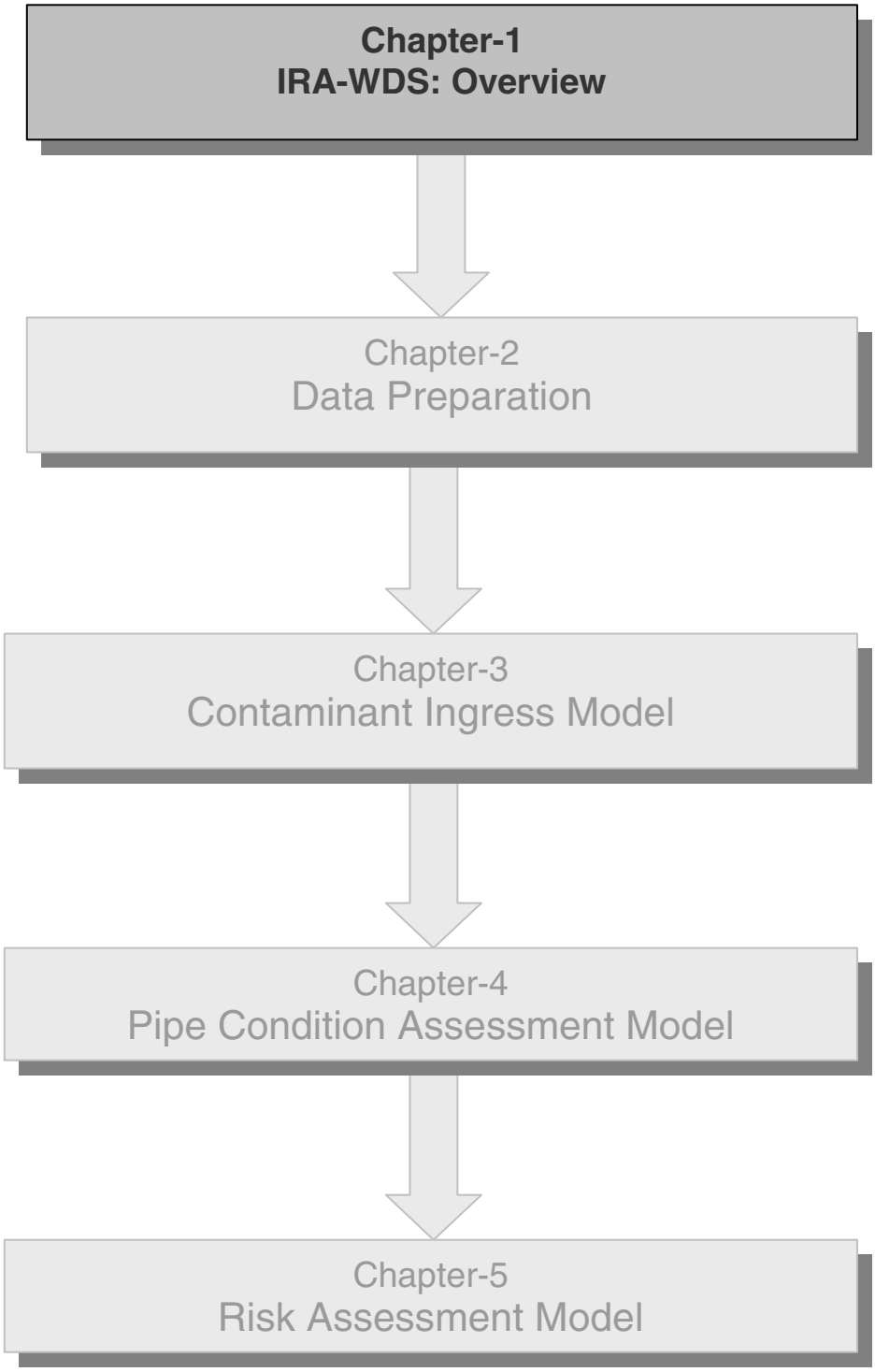
CHAPTER ONE

IRA-WDS: Overview

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems



Chapter 1: IRA-WDS Overview

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 datageographically. 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 

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 

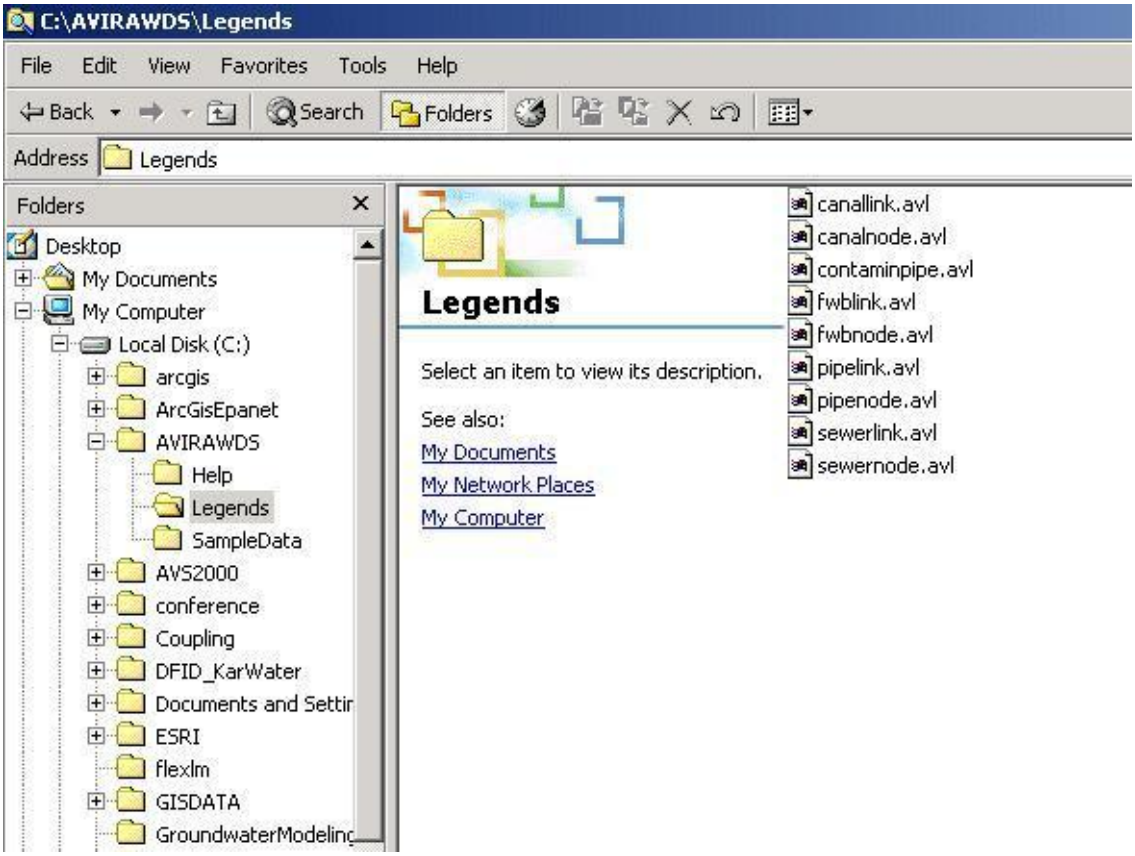
'Clickteam Installation Creator Pro' screen will appear. Click 

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 

3 Go to 

4 Click on the 

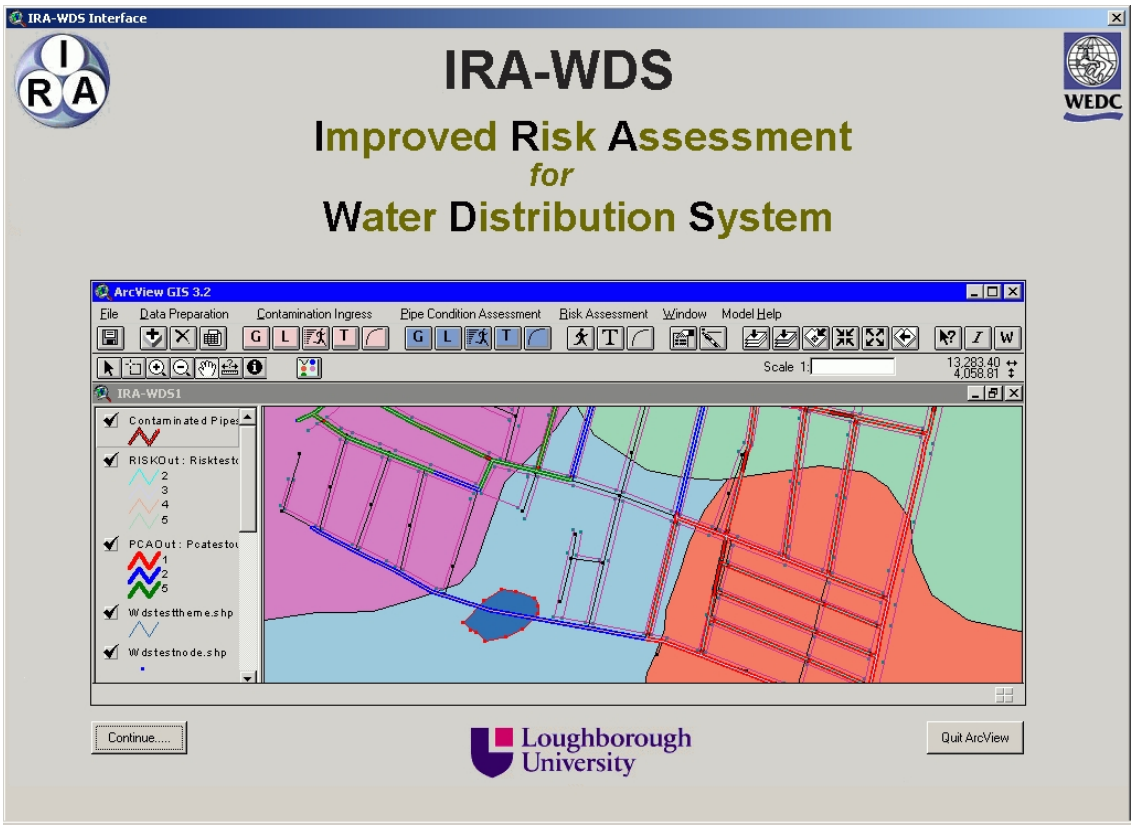
Uninstallation removes IRA-WDS from the programs menu, deletes 'ahp.dll', 'ingress.dll', 'pca.dll', 'risk.dll' and 'IRA-WDS.avx' from ArcView installation paths and removes all legend files, help files, sample data files and 'IRA-WDS.apr' from the respective installation directories.

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:

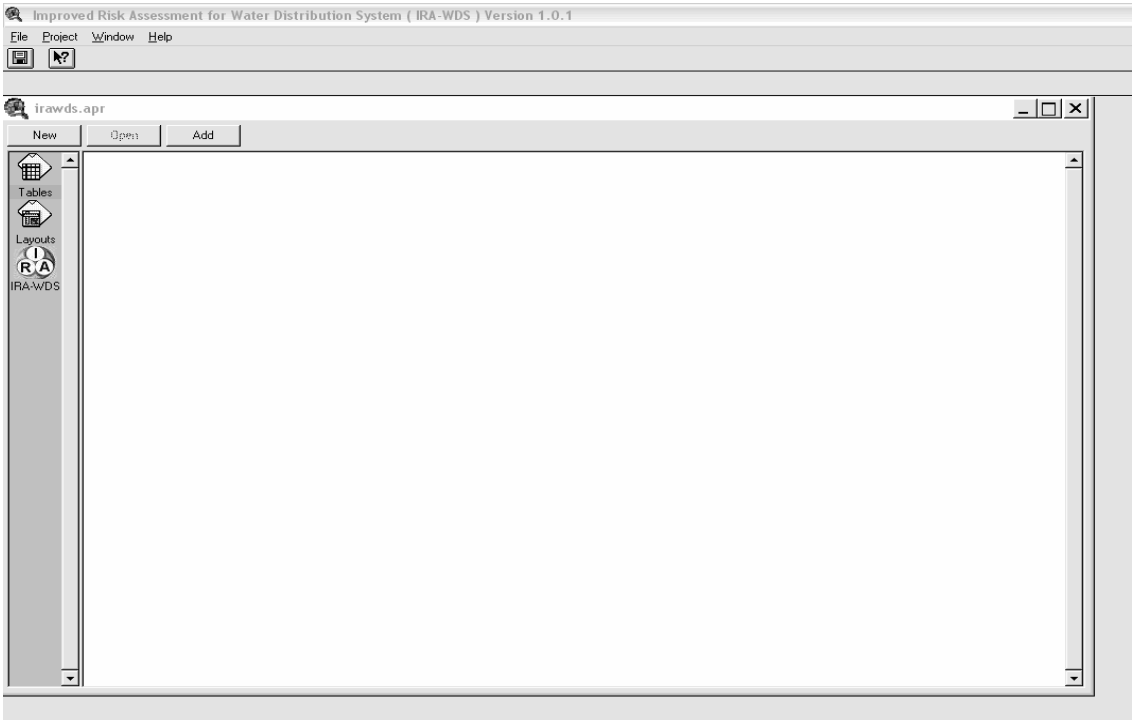


Clicking 

will exit IRA-WDS

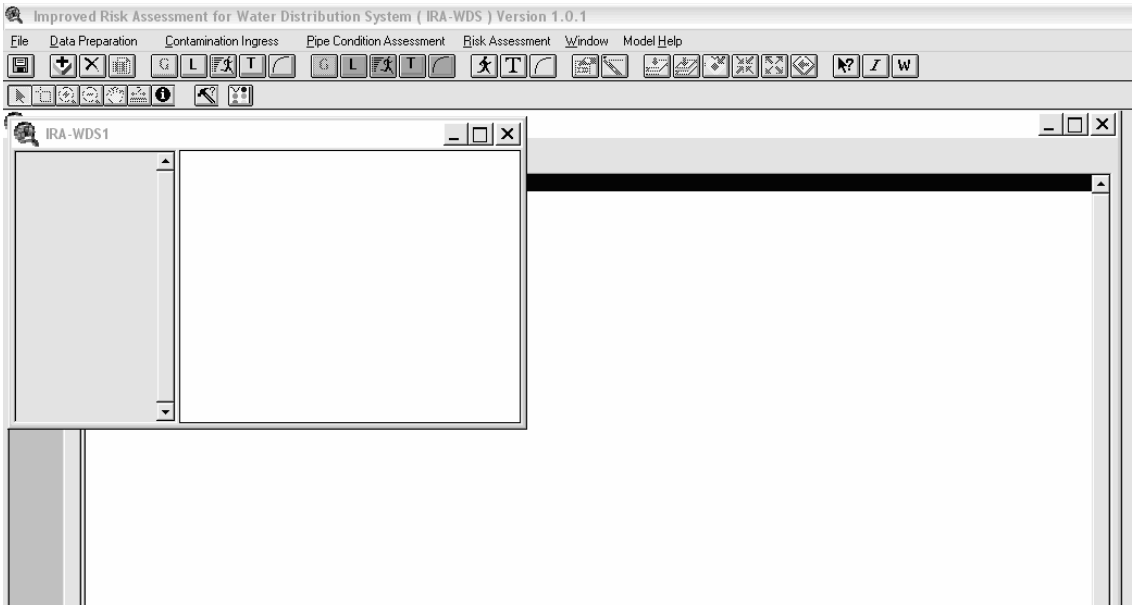
and clicking 

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

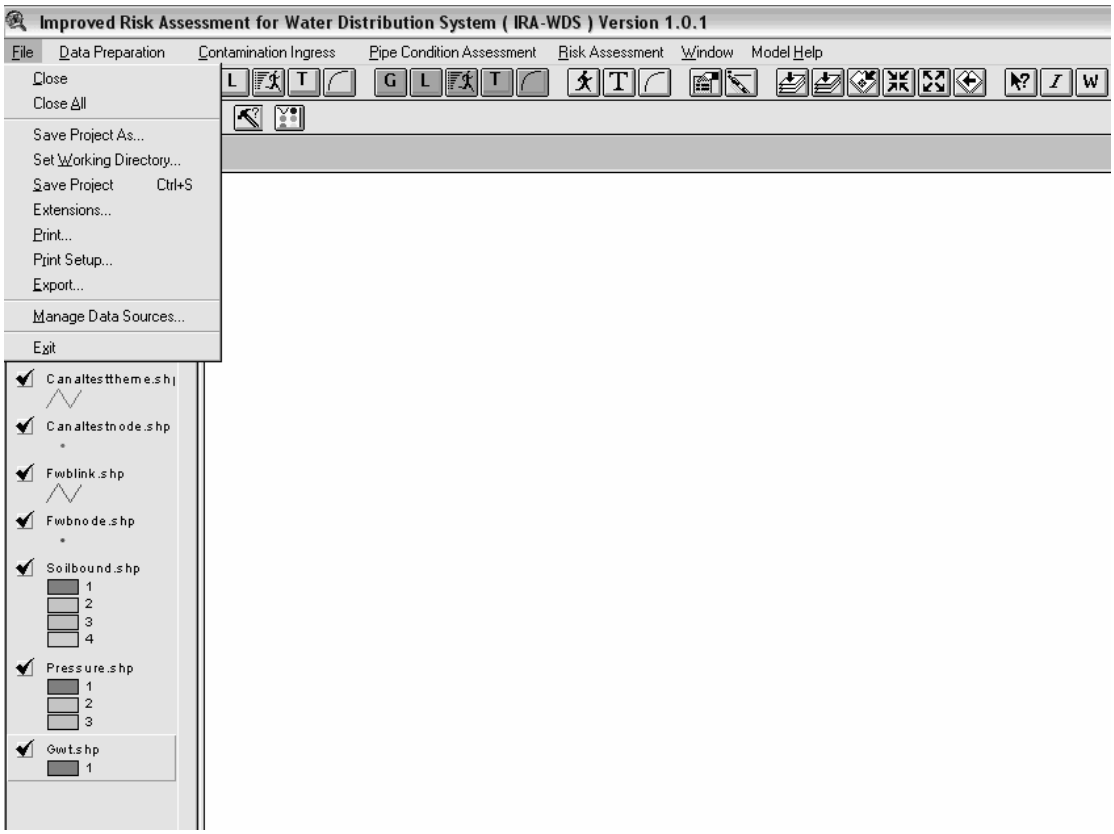
5 Risk Assessment

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:**

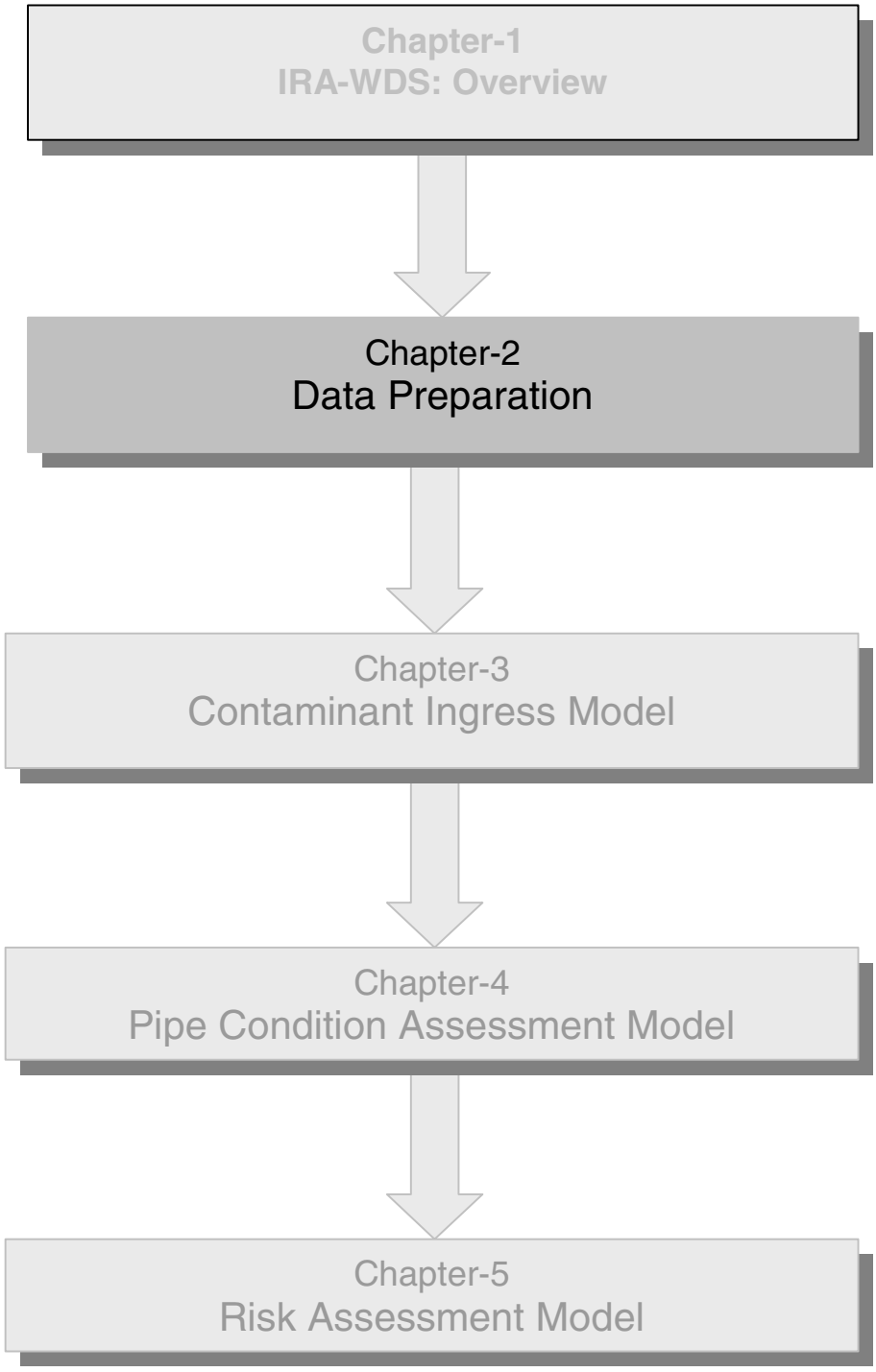
   Helps the user to exit from the IRA-WDS interface and ArcView.

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.

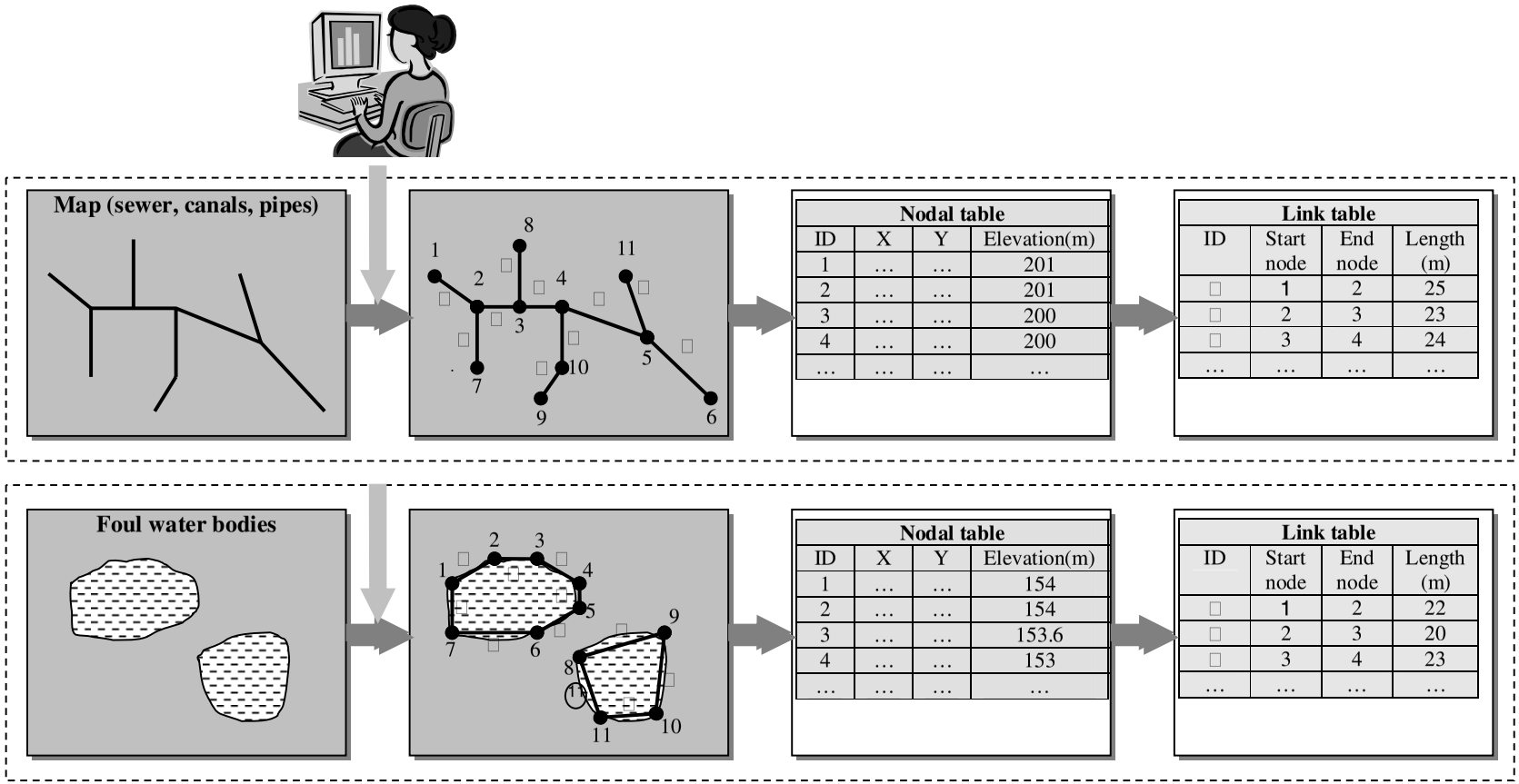


Figure 2.1. Digitization of real-world network

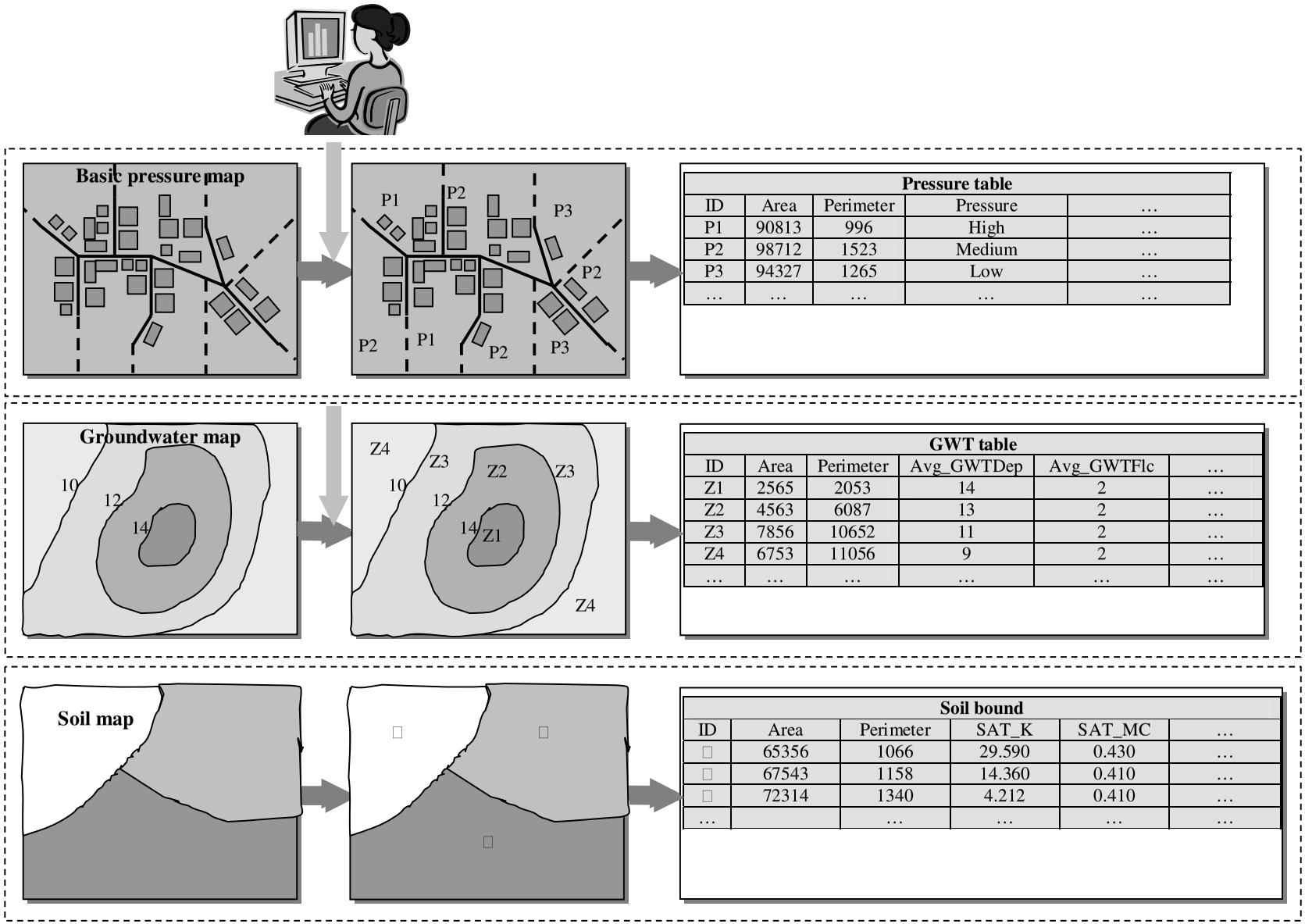


Figure 2.2. Digitization of thematic maps

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.

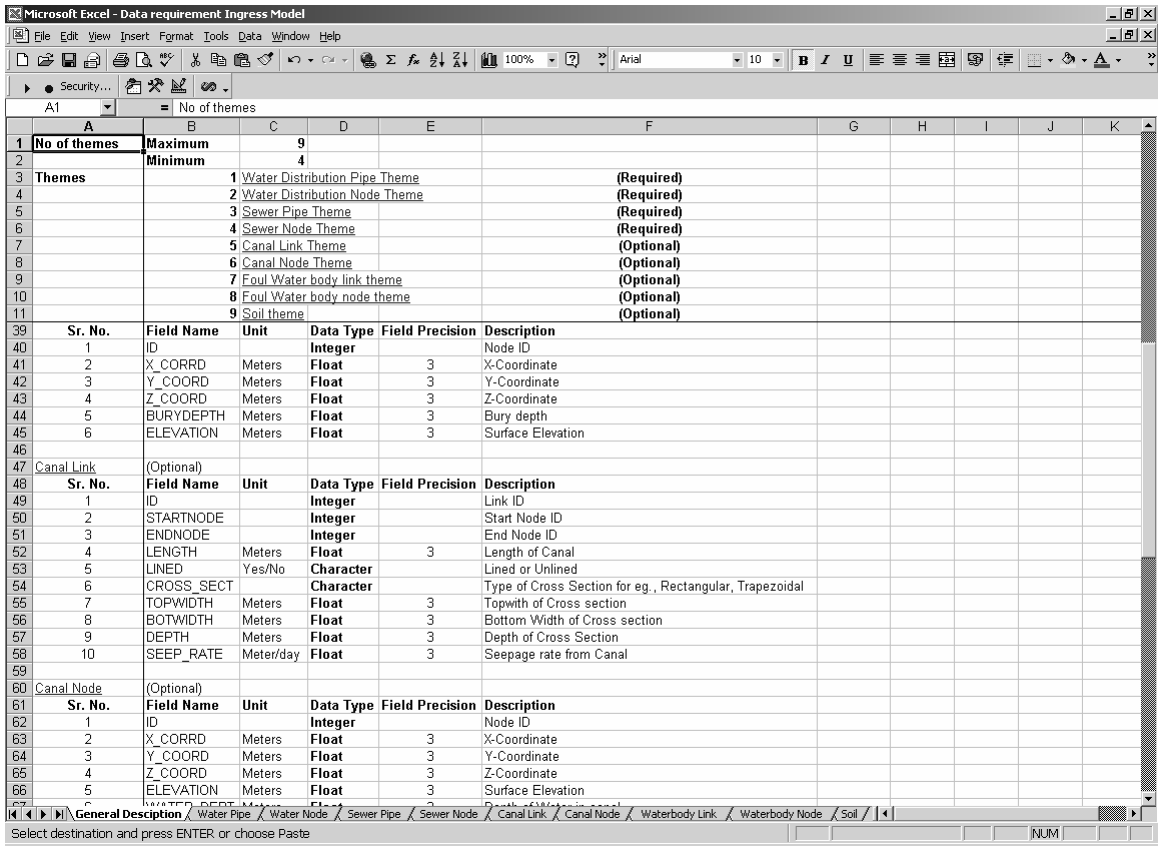
The first thing for the user to do is to copy this Excel file into his or her working directory and rename it as appropriate (for example, the project name). The Excel spread sheet contains several worksheets to assist with data entry.

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.

Therefore the authors suggest that the data from the shape files (dbf) are copied and pasted into the appropriate worksheet of the Excel file.



Microsoft Excel - Data requirement Ingress Model

	A	B	C	D	E	F	G	H	I	J	K
1	**No of themes**	**Maximum**	**9**								
2		**Minimum**	**4**								
3	**Themes**	**1**	Water Distribution Pipe Theme			**(Required)**					
4		**2**	Water Distribution Node Theme			**(Required)**					
5		**3**	Sewer Pipe Theme			**(Required)**					
6		**4**	Sewer Node Theme			**(Required)**					
7		**5**	Canal Link Theme			**(Optional)**					
8		**6**	Canal Node Theme			**(Optional)**					
9		**7**	Foul Water body link theme			**(Optional)**					
10		**8**	Foul Water body node theme			**(Optional)**					
11		**9**	Soil theme			**(Optional)**					
39	**Sr. No.**	**Field Name**	**Unit**	**Data Type**	**Field Precision**	**Description**					
40	1	ID		**Integer**		Node ID					
41	2	X_CORRD	Meters	**Float**	3	X-Coordinate					
42	3	Y_COORD	Meters	**Float**	3	Y-Coordinate					
43	4	Z_COORD	Meters	**Float**	3	Z-Coordinate					
44	5	BURYDEPTH	Meters	**Float**	3	Bury depth					
45	6	ELEVATION	Meters	**Float**	3	Surface Elevation					
46											
47	Canal Link	(Optional)									
48	**Sr. No.**	**Field Name**	**Unit**	**Data Type**	**Field Precision**	**Description**					
49	1	ID		**Integer**		Link ID					
50	2	STARTNODE		**Integer**		Start Node ID					
51	3	ENDNODE		**Integer**		End Node ID					
52	4	LENGTH	Meters	**Float**	3	Length of Canal					
53	5	LINED	Yes/No	**Character**		Lined or Unlined					
54	6	CROSS_SECT		**Character**		Type of Cross Section for eg., Rectangular, Trapezoidal					
55	7	TOPWIDTH	Meters	**Float**	3	Topwith of Cross section					
56	8	BOTWIDTH	Meters	**Float**	3	Bottom Width of Cross section					
57	9	DEPTH	Meters	**Float**	3	Depth of Cross Section					
58	10	SEEP_RATE	Meter/day	**Float**	3	Seepage rate from Canal					
59											
60	Canal Node	(Optional)									
61	**Sr. No.**	**Field Name**	**Unit**	**Data Type**	**Field Precision**	**Description**					
62	1	ID		**Integer**		Node ID					
63	2	X_CORRD	Meters	**Float**	3	X-Coordinate					
64	3	Y_COORD	Meters	**Float**	3	Y-Coordinate					
65	4	Z_COORD	Meters	**Float**	3	Z-Coordinate					
66	5	ELEVATION	Meters	**Float**	3	Surface Elevation					

Figure 2.3. Enclosed Excel file DataInput.xls

2.3.2 Contaminant Ingress Model

The data required for the Contaminant Ingress Model are as follows:

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

2.3.2.1 Pollutant sources

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.

Figure 2.4, below, shows the relevant worksheet for pollutant sources from the enclosed Excel file.

47	Canal Link	(Optional)				
48	**Sr. No.**	**Field Name**	**Unit**	**Data Type**	**Field Precision**	**Description**
49	1	ID		**Integer**		Link ID
50	2	STARTNODE		**Integer**		Start Node ID
51	3	ENDNODE		**Integer**		End Node ID
52	4	LENGTH	Meters	**Float**	3	Length of Canal
53	5	LINED	Yes/No	**Character**		Lined or Unlined
54	6	CROSS_SECT		**Character**		Type of Cross Section for eg., Rectangular, Trapezoidal
55	7	TOPWIDTH	Meters	**Float**	3	Topwith of Cross section
56	8	BOTWIDTH	Meters	**Float**	3	Bottom Width of Cross section
57	9	DEPTH	Meters	**Float**	3	Depth of Cross Section
58	10	SEEP_RATE	Meter/day	**Float**	3	Seepage rate from Canal
59						
60	Canal Node	(Optional)				
61	**Sr. No.**	**Field Name**	**Unit**	**Data Type**	**Field Precision**	**Description**
62	1	ID		**Integer**		Node ID
63	2	X_CORRD	Meters	**Float**	3	X-Coordinate
64	3	Y_COORD	Meters	**Float**	3	Y-Coordinate
65	4	Z_COORD	Meters	**Float**	3	Z-Coordinate
66	5	ELEVATION	Meters	**Float**	3	Surface Elevation

Pollution Source Data Tabs

General Desciption | Water Pipe | Water Node | Sewer Pipe | Sewer Node | Canal Link | Canal Node | Waterbody Link | Waterbody Node | Soil

Select destination and press ENTER or choose Paste

Figure 2.4. Worksheet for pollutant sources

At this stage:

- The Excel spreadsheet should have been saved in the user's working directory; and
- The shaded columns shown in Figures 2.5 and Figure 2.6 should be filled from the data in the dbf shape files (see Section 2.4).

Microsoft Excel - Data requirement Ingress Model

File Edit View Insert Format Tools Data Window Help

E1 = LENGTH

	A	B	C	D	E	F	G
1	ID	STARTNODE	ENDNODE	SEWER_DIA	LENGTH	MATERIAL	SEEP_RATE
2	11	503	504	900.000000	0.997	RCC	0.002
3	12	486	503	900.000000	30.308	RCC	0.002
4	13	524	525	900.000000	2.459	RCC	0.002
5	14	504	524	900.000000	29.441	RCC	0.002
6	15	525	541	900.000000	26.172	RCC	0.002
7	16	541	545	900.000000	7.485	RCC	0.002
8	17	545	565	900.000000	25.857	RCC	0.002
9	18	565	570	900.000000	11.469	RCC	0.002
10	19	608	618	900.000000	39.146	RCC	0.002
11	20	618	622	900.000000	11.037	RCC	0.002
12	21	622	625	900.000000	6.212	RCC	0.002
13	22	625	635	900.000000	24.127	RCC	0.002
14	23	635	644	900.000000	35.459	RCC	0.002
15	24	644	645	900.000000	2.525	RCC	0.002
16	25	645	649	900.000000	20.535	RCC	0.002
17	26	649	655	900.000000	6.865	RCC	0.002
18	27	655	661	900.000000	9.120	RCC	0.002
19	101	434	486	200.000000	43.772	SWP	0.002
20	102	432	448	200.000000	28.669	SWP	0.002
21	103	534	606	200.000000	48.057	SWP	0.002
22	104	530	534	200.000000	23.873	SWP	0.002
23	105	530	509	200.000000	18.050	SWP	0.002
24	106	574	530	200.000000	32.914	SWP	0.002
25	107	473	534	200.000000	51.029	SWP	0.002
26	108	473	460	200.000000	37.761	SWP	0.002
27	109	460	450	200.000000	26.204	SWP	0.002
28	110	450	445	200.000000	23.875	SWP	0.002
29	111	450	485	200.000000	29.427	SWP	0.002
30	112	445	399	200.000000	35.854	SWP	0.002
31	113	493	473	200.000000	43.577	SWP	0.002
32	114	493	507	400.000000	31.504	SWP	0.002
33	115	507	516	400.000000	13.101	SWP	0.002
34	116	533	550	400.000000	33.549	SWP	0.002
35	117	550	573	400.000000	48.509	SWP	0.002
36	118	573	609	500.000000	22.339	RCC	0.002
37	119	609	636	500.000000	21.234	RCC	0.002
38	120	636	651	500.000000	21.402	RCC	0.002
39	121	651	637	400.000000	51.532	SWP	0.002

General Desciption | Water Pipe | Water Node | Sewer Pipe | Sewer Node | Canal Link | Canal Node | Waterbody Link | Waterbody Node | Soil

Select destination and press ENTER or choose Paste — Sum=188373.620

Figure 2.5. Link data entry for sewer

The next stage is for the user to complete the remaining fields on the worksheets (that is, the unshaded columns of the tables in Figures 2.5 and 2.6). Tables 2.1 and 2.2, below, give details of the additional attributes required for link data and node data respectively for the sewer.

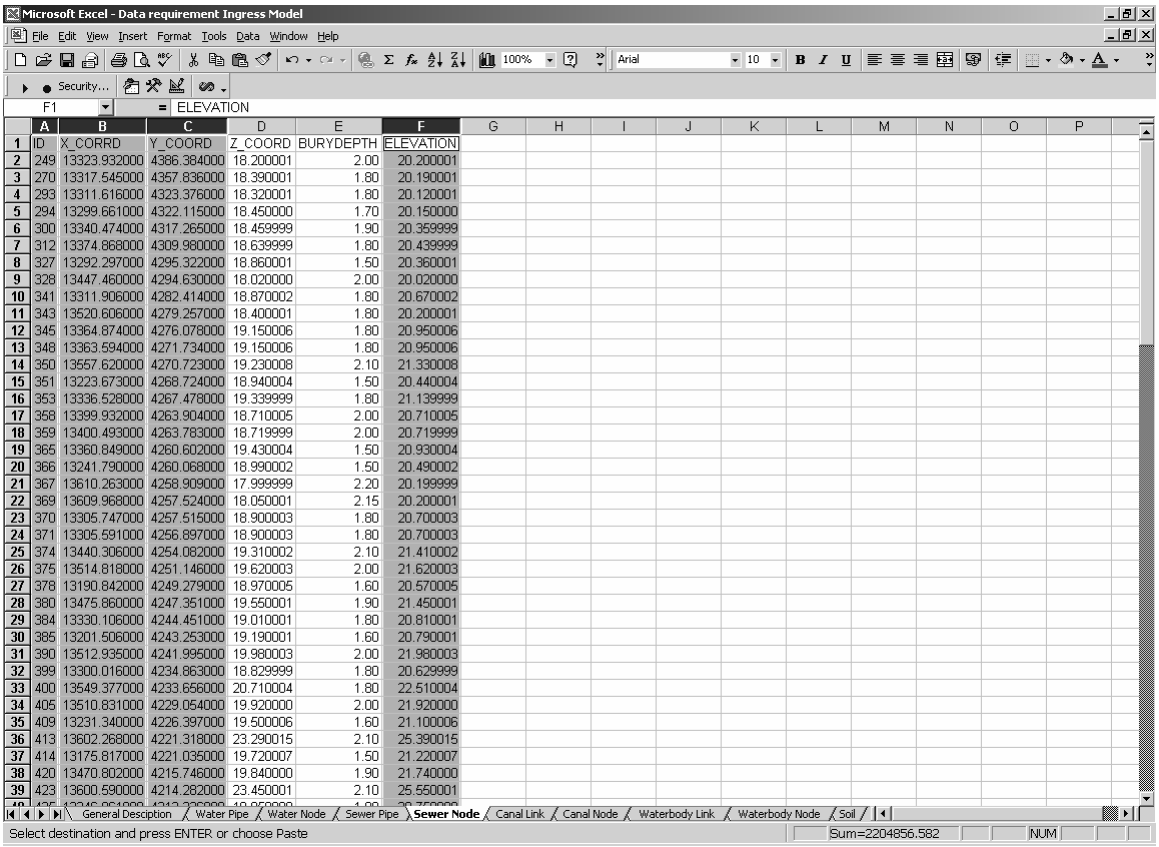


Figure 2.6. Node data entry for sewer

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

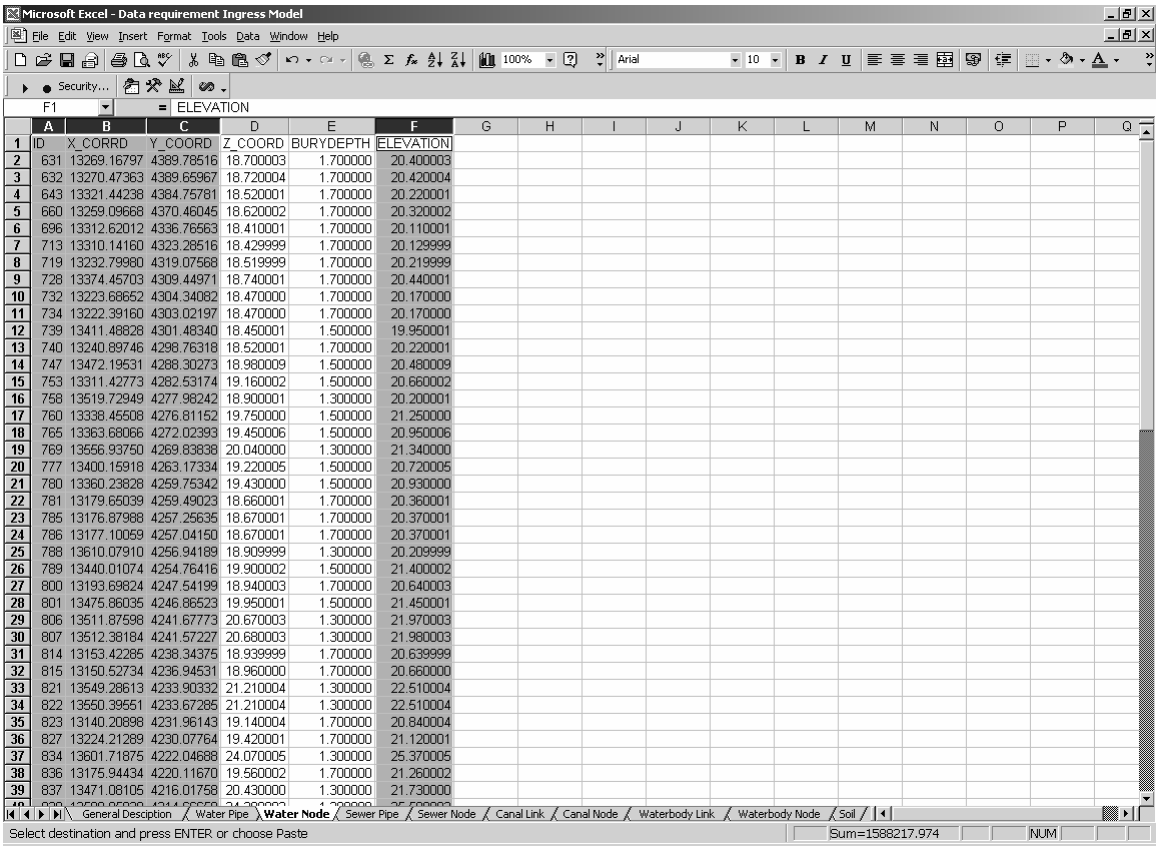


Figure 2.7. Node data entry for water distribution system

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

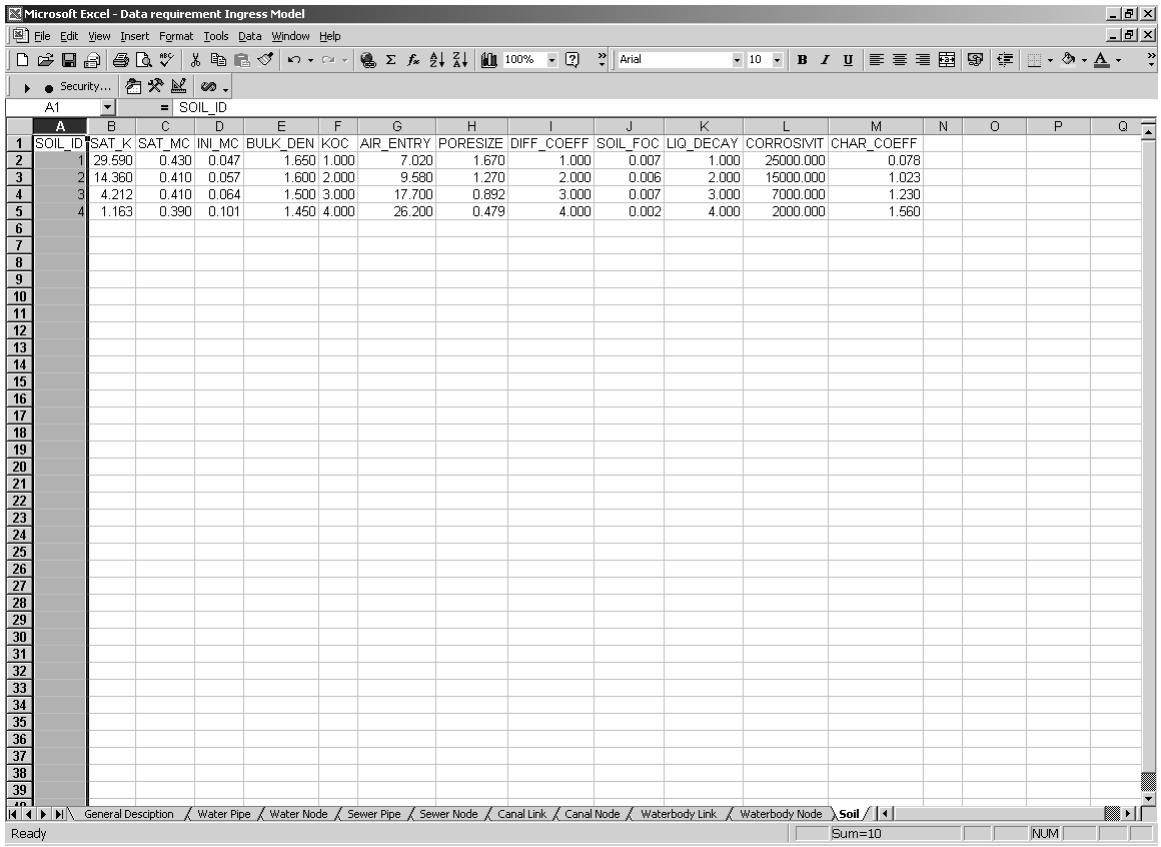


Figure 2.8. Soil data entry

2.3.3 Pipe Condition Assessment Model

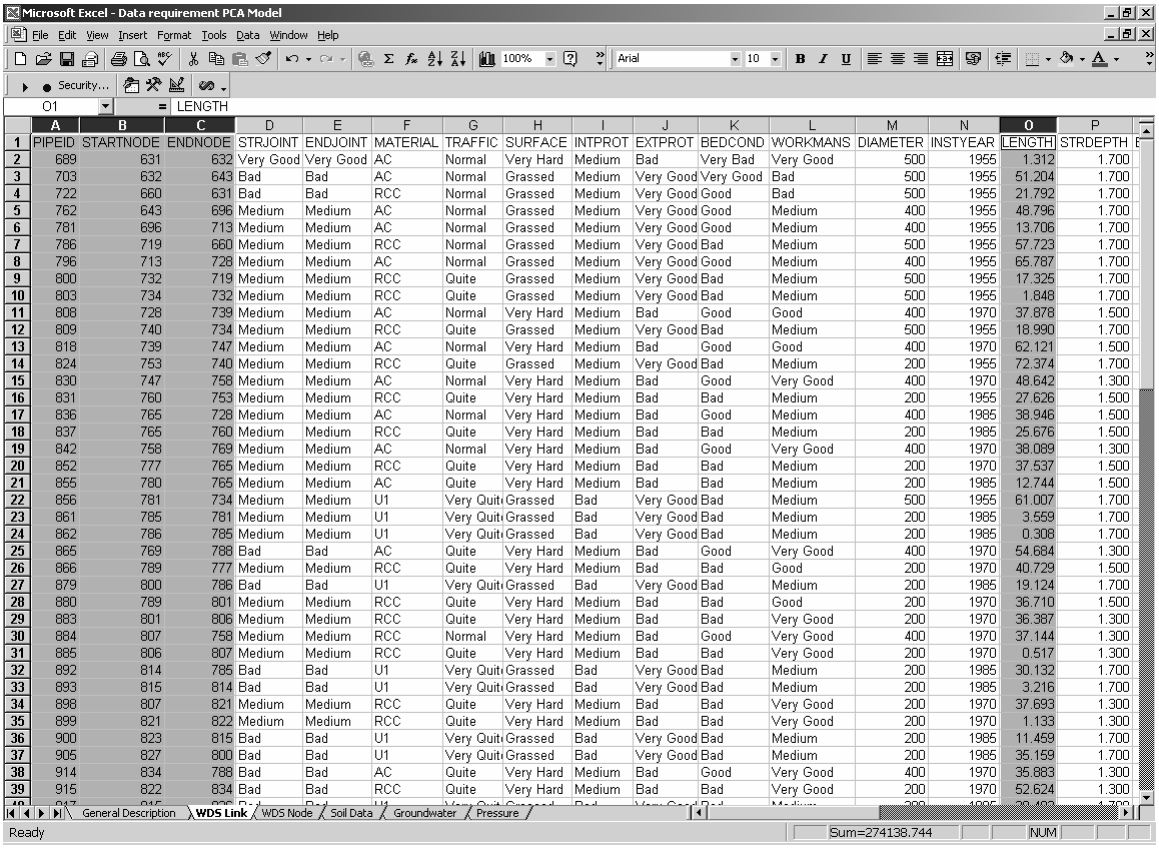
Data requirements for the Pipe Condition Assessment Model are related to the factors that affect the condition of the pipe. A description of these various factors and how they are represented in the model can be found in Chapter 3, below.

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	*mm*	Diameter of pipe
INSTYEAR	*yyyy*	Installation year
LENGTH	*Metres*	Length of pipe
STRDEPTH	*Metres*	Start node bury depth
ENDDEPTH	*Metres*	End node bury depth
NOCONNEC		No. of pipes joined with diameter less than minimum considered
BREAKAGE	*Per year*	No. of breaks per year
LEAKAGE	*lps*	Leakage rate
VALVES		No. of valves
DURATION	*Hrs/day*	Duration of water supply per day
NOOPER	*Per day*	No. of times water supplied per day



Microsoft Excel - Data requirement PCA Model

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Security...

O1 = LENGTH

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	PIPEID	STARTNODE	ENDNODE	STRJOINT	ENDJOINT	MATERIAL	TRAFFIC	SURFACE	INTPROT	EXTPROT	BEDCOND	WORKMANS	DIAMETER	INSTYEAR	LENGTH	STRDEPTH
2	689	631	632	Very Good	Very Good	AC	Normal	Very Hard	Medium	Bad	Very Bad	Very Good	500	1955	1.312	1.700
3	703	632	643	Bad	Bad	AC	Normal	Grassed	Medium	Very Good	Very Good	Bad	500	1955	51.204	1.700
4	722	660	631	Bad	Bad	RCC	Normal	Grassed	Medium	Very Good	Good	Bad	500	1955	21.792	1.700
5	762	643	696	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	48.796	1.700
6	781	696	713	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	13.706	1.700
7	786	719	660	Medium	Medium	RCC	Normal	Grassed	Medium	Very Good	Bad	Medium	500	1955	57.723	1.700
8	796	713	728	Medium	Medium	AC	Normal	Grassed	Medium	Very Good	Good	Medium	400	1955	65.787	1.700
9	800	732	719	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	500	1955	17.325	1.700
10	803	734	732	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	500	1955	1.848	1.700
11	808	728	739	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Good	400	1970	37.878	1.500
12	809	740	734	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	500	1955	18.990	1.700
13	818	739	747	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Good	400	1970	62.121	1.500
14	824	753	740	Medium	Medium	RCC	Quite	Grassed	Medium	Very Good	Bad	Medium	200	1955	72.374	1.700
15	830	747	758	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	48.642	1.300
16	831	760	753	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1955	27.626	1.500
17	836	765	728	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Medium	400	1985	38.946	1.500
18	837	765	760	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1985	25.676	1.500
19	842	758	769	Medium	Medium	AC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	38.089	1.300
20	852	777	765	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1970	37.537	1.500
21	855	780	765	Medium	Medium	AC	Quite	Very Hard	Medium	Bad	Bad	Medium	200	1985	12.744	1.500
22	856	781	734	Medium	Medium	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	500	1955	61.007	1.700
23	861	785	781	Medium	Medium	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	3.559	1.700
24	862	786	785	Medium	Medium	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	0.308	1.700
25	865	769	788	Bad	Bad	AC	Quite	Very Hard	Medium	Bad	Good	Very Good	400	1970	54.684	1.300
26	866	789	777	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Good	200	1970	40.729	1.500
27	879	800	786	Bad	Bad	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	19.124	1.700
28	880	789	801	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Good	200	1970	36.710	1.500
29	883	801	806	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	36.387	1.300
30	884	807	758	Medium	Medium	RCC	Normal	Very Hard	Medium	Bad	Good	Very Good	400	1970	37.144	1.300
31	885	806	807	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	0.517	1.300
32	892	814	785	Bad	Bad	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	30.132	1.700
33	893	815	814	Bad	Bad	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	3.216	1.700
34	898	807	821	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	37.693	1.300
35	899	821	822	Medium	Medium	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	1.133	1.300
36	900	823	815	Bad	Bad	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	11.459	1.700
37	905	827	800	Bad	Bad	U1	Very Quit	Grassed	Bad	Very Good	Bad	Medium	200	1985	35.159	1.700
38	914	834	788	Bad	Bad	AC	Quite	Very Hard	Medium	Bad	Good	Very Good	400	1970	35.883	1.300
39	915	822	834	Bad	Bad	RCC	Quite	Very Hard	Medium	Bad	Bad	Very Good	200	1970	52.624	1.300

General Description | WDS Link | WDS Node | Soil Data | Groundwater | Pressure

Ready

Sum=274138.744

NUM

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.

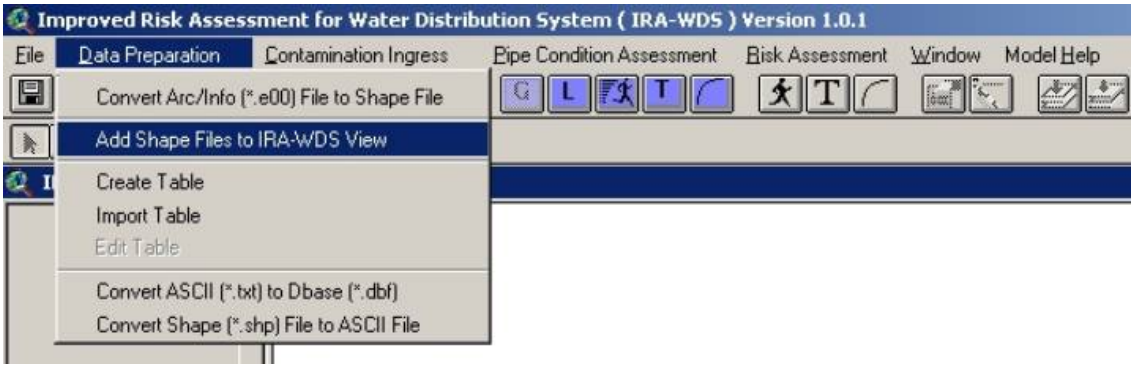
The next step is for the user to link the data in the Excel spreadsheet with the relevant shape files. In order to achieve this, each worksheet from the Excel spreadsheet must be saved as a dbf file with a filename identical to the relevant shape file.

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

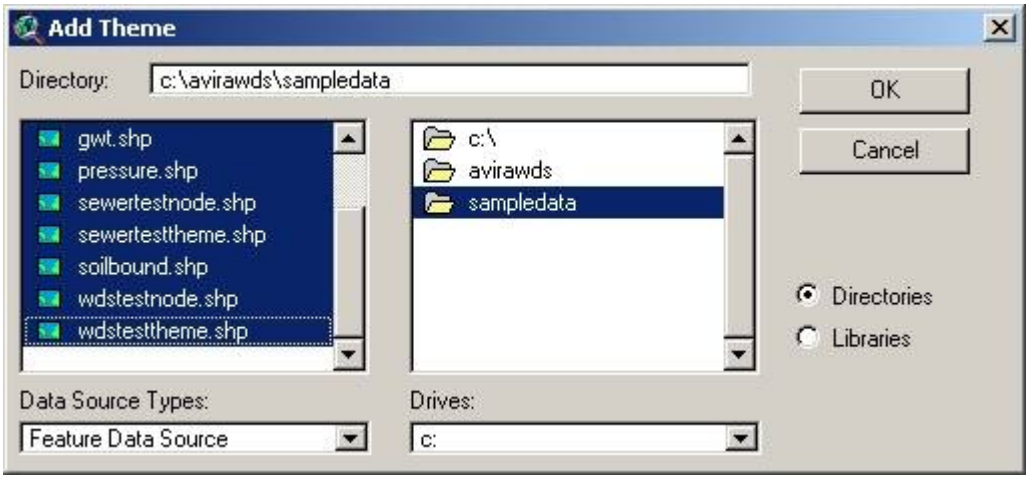
1. If the name of the shape file is ‘waterpipe.shp’
2. In the Excel spreadsheet select the ‘WDSlink’ worksheet
3. While this worksheet is active, do the following:
   - File – Save As: ‘waterpipe.dbf’ (this name is the same as the shape file)
   - Make sure the file is saved to the working directory (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:

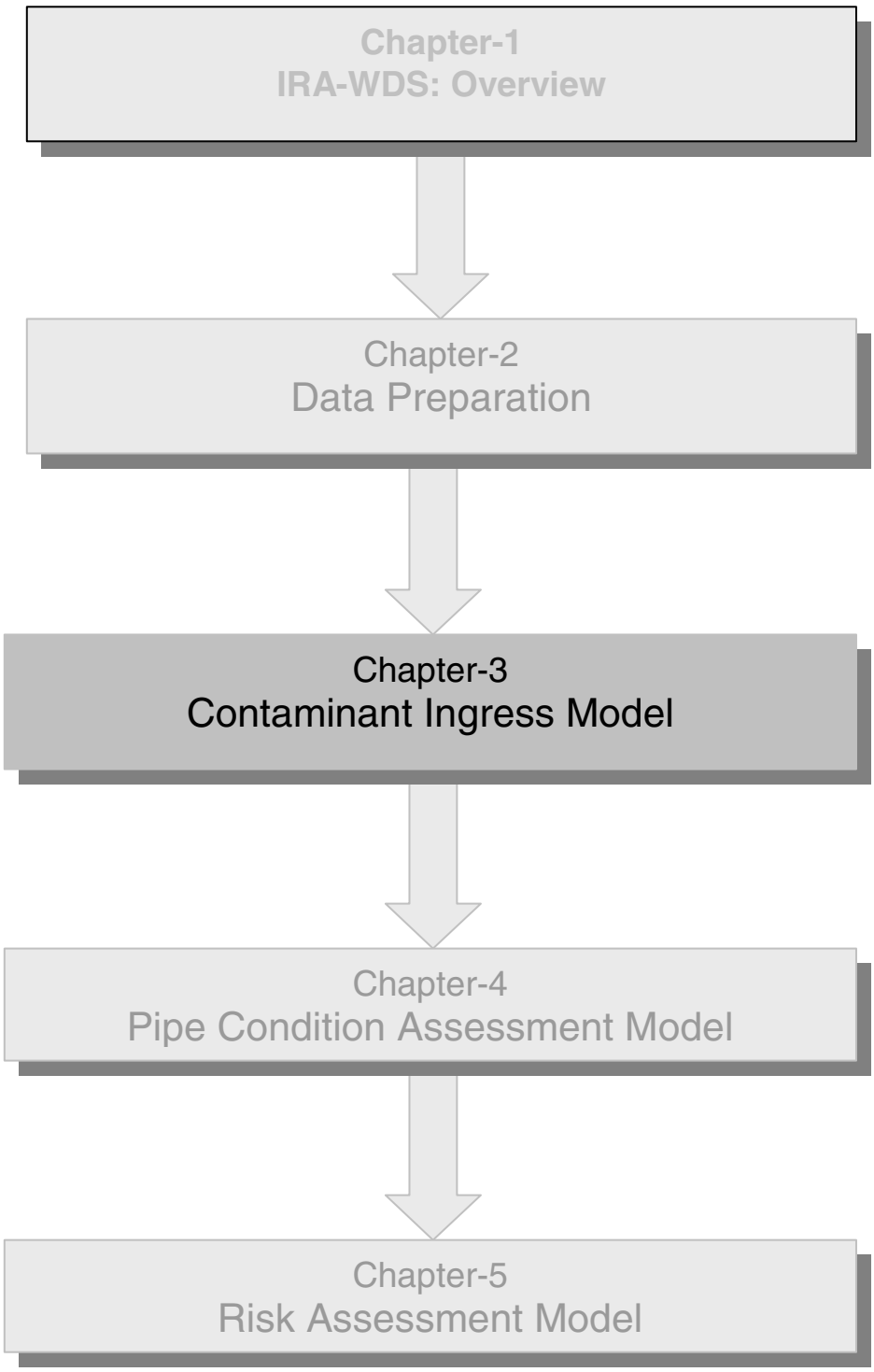


After the user selects the shape files to be added to the IRA-WDS View, he/she can click on the 'OK' button, which will load the shape files to the IRA-WDS View, and corresponding dbf files in the Table GUI of the ArcView.

CHAPTER THREE

Contaminant Ingress Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems



Chapter 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

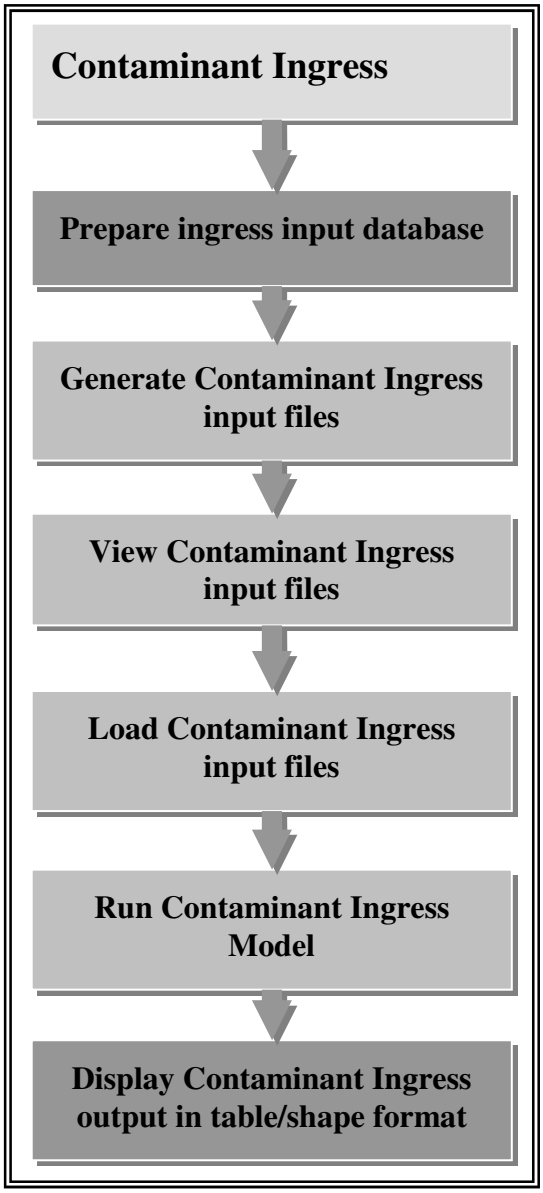
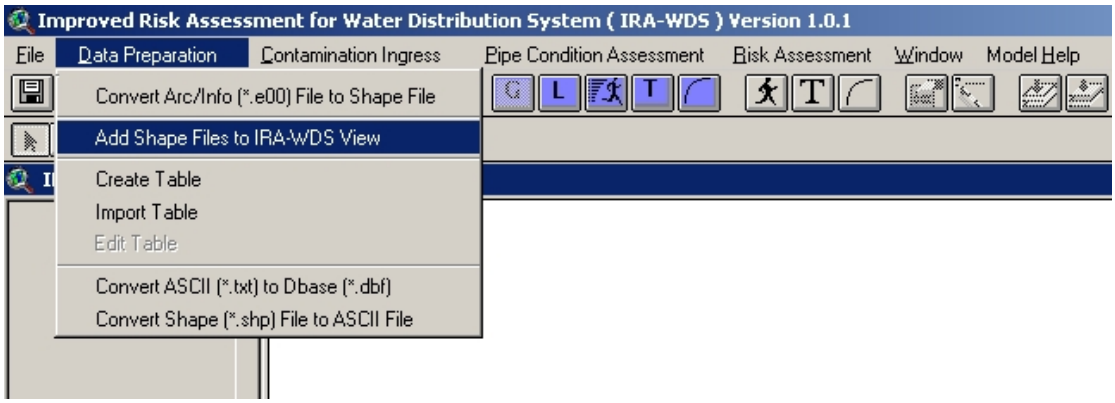


Figure 3.1. Overview of Contaminant Ingress Model of IRA-WDS

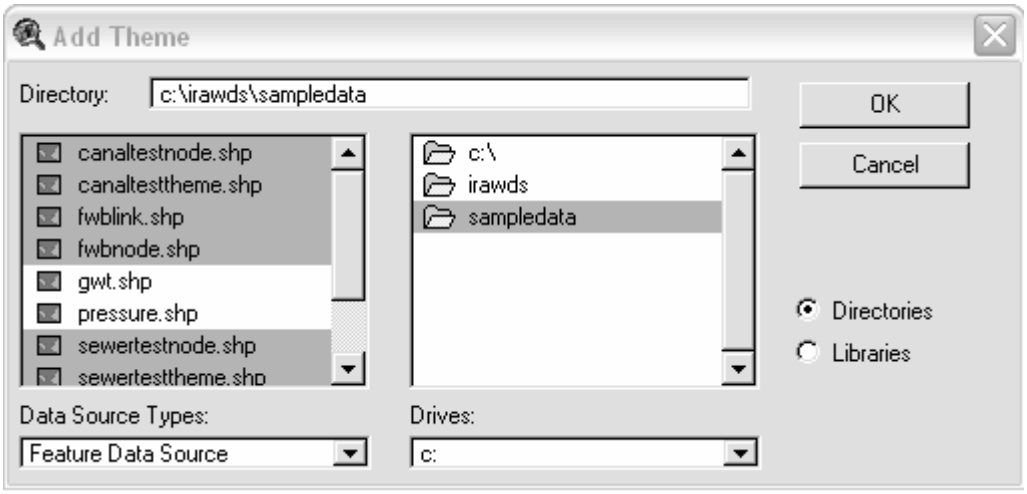
3.2 Shape files

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:

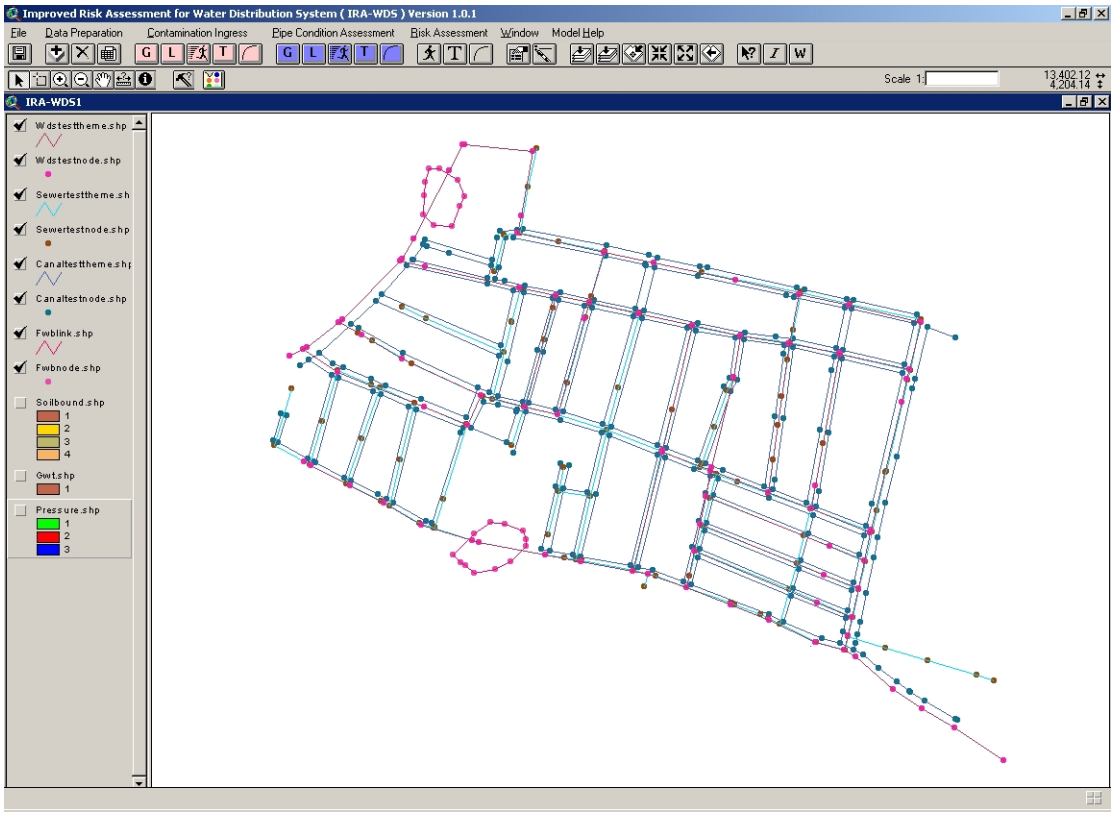


This opens the Add Theme form, as shown below, and the user is then required to select the desired files. At this stage, these files are those relating to: water distribution link and node; sewer pipe link and node; canal link and node; foul water bodies link and node; and soil polygon map.

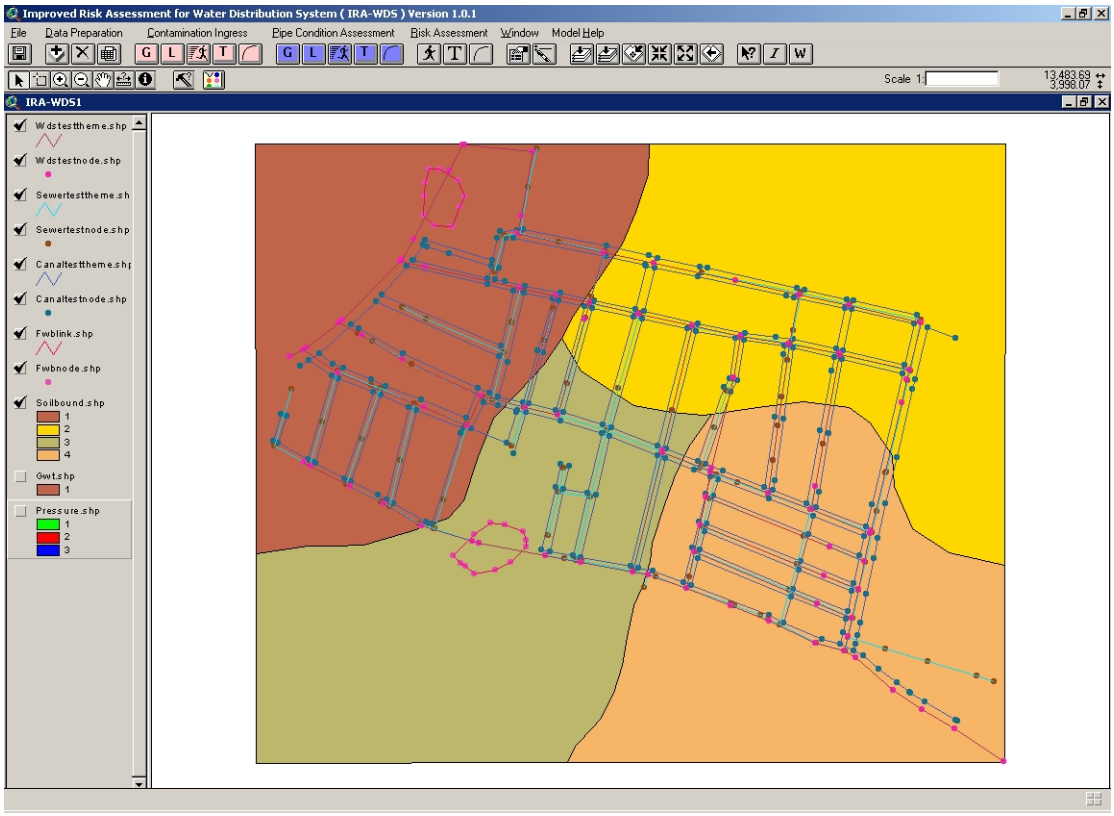


3.2.2 Rearranging shape files

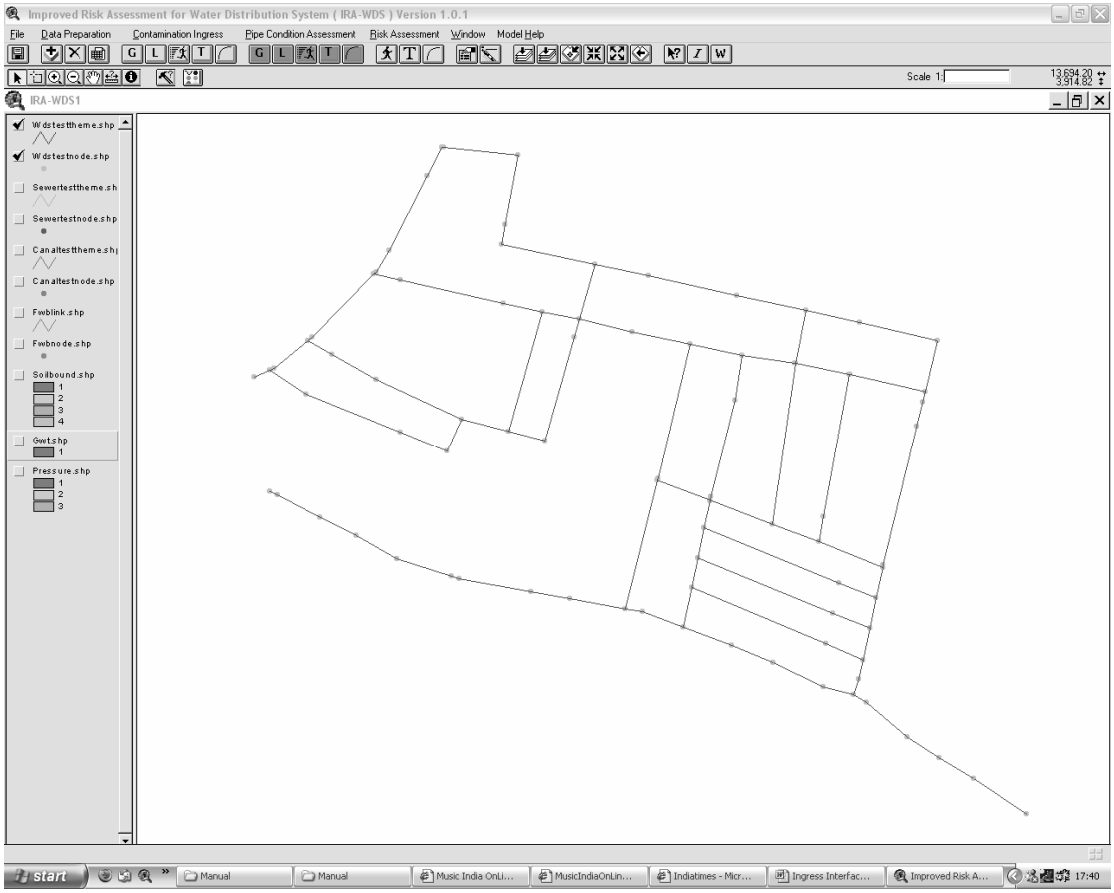
Once the data are added, these can be rearranged for viewing purposes. This can be done by selecting (☑) and/or omitting (☐) different themes (on the left hand side) and changing the preference order of different themes by dragging them above or below the other themes. For example, the view with only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



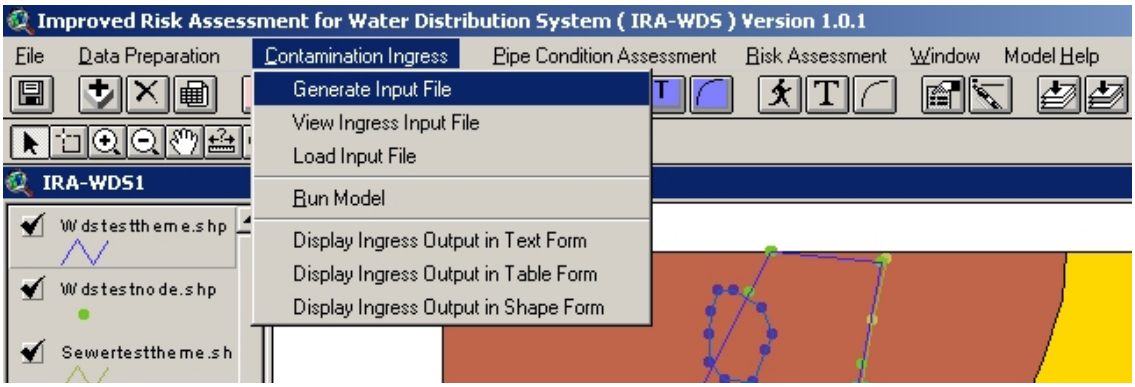
Similarly, if only the water distribution network theme is to be viewed, the user should select '*wdstesttheme.shp'* and '*wdstestnode.shp',* as shown below:



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:



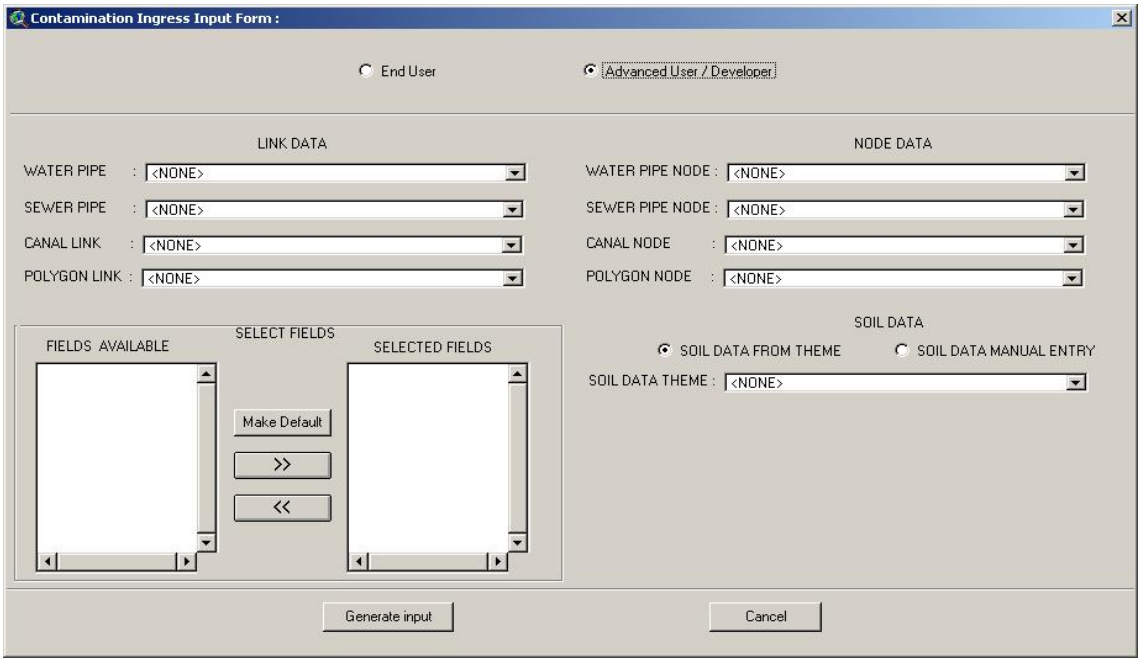
The Contamination Ingress Input Form has two radio button options: **Advanced User** and **End User**.

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 

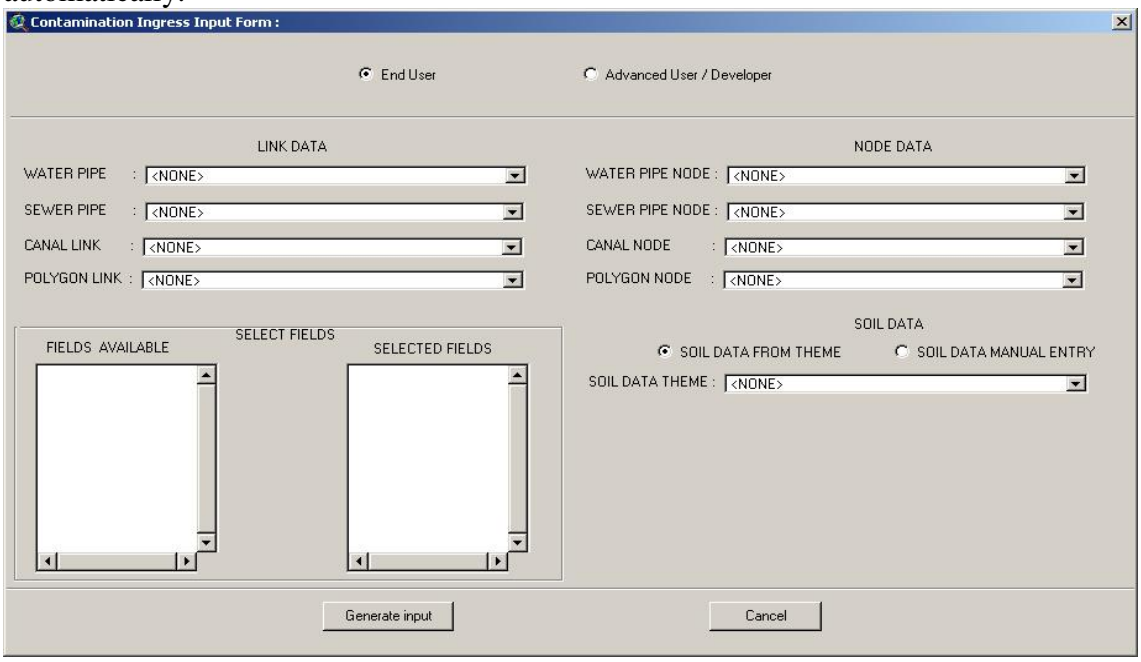
button to select the default field names. Advanced users can add fields to the 'SELECTED FIELDS' list box by selecting those fields in the 'FIELDS AVAILABLE' list box and then clicking on 

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.



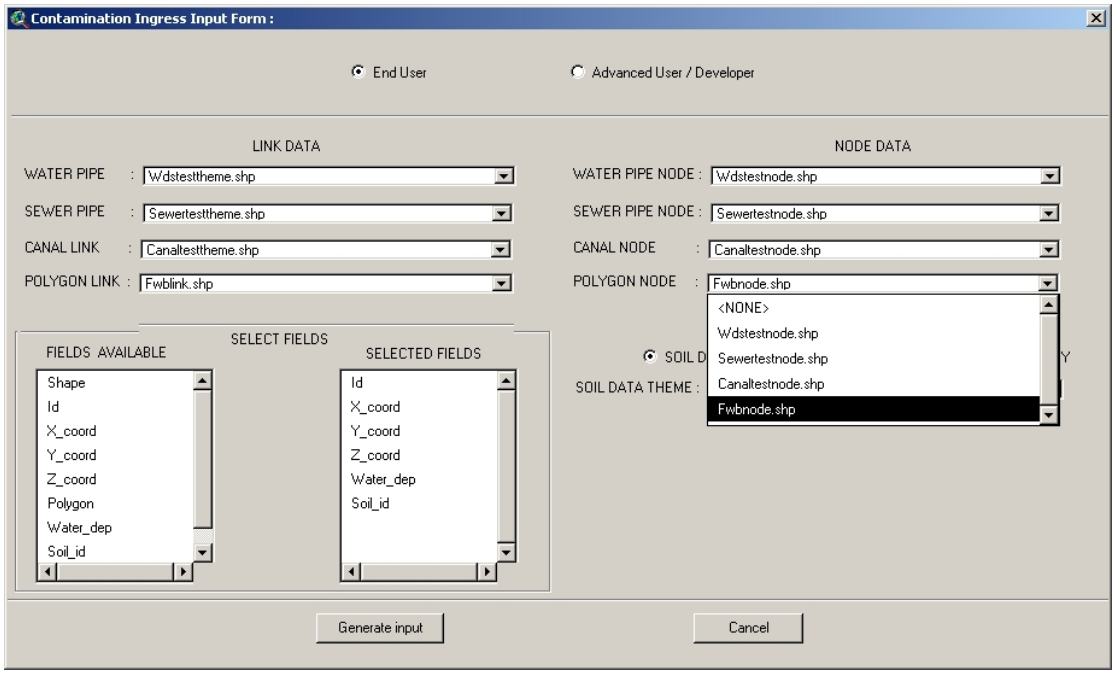
End users are not provided with the option of adding or deleting fields to or from the 'SELECTED FIELDS' list box. With the End User option, the fields are selected automatically.



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.

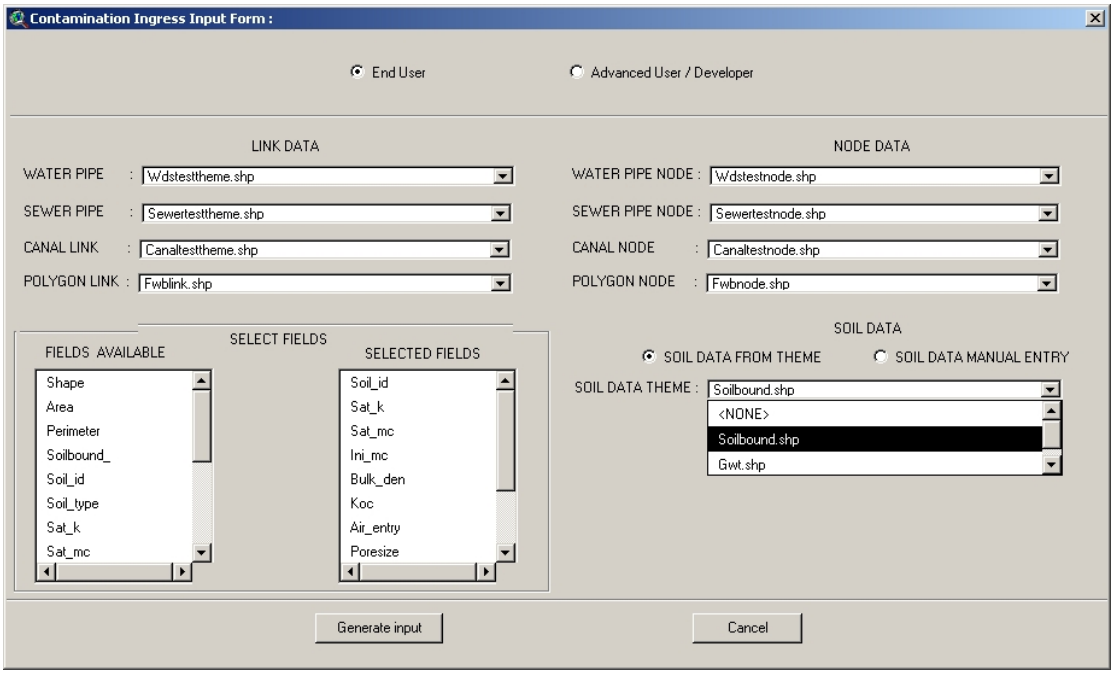


3.3.2.2 Soil data

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.

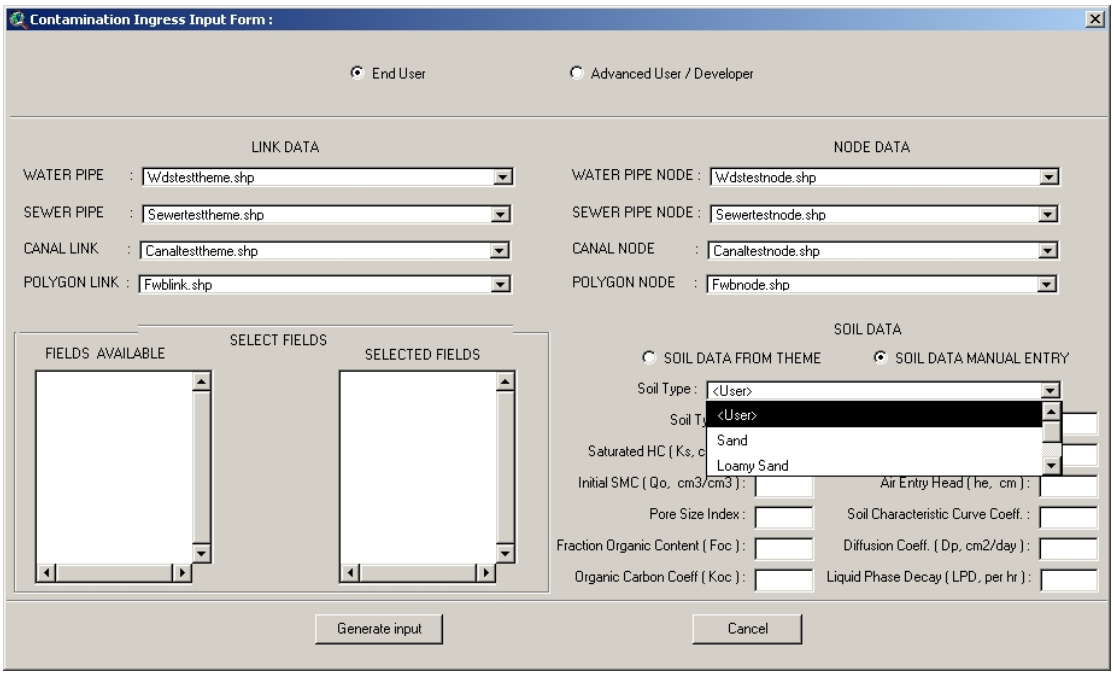
3.3.2.3 Soil data from theme

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



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:

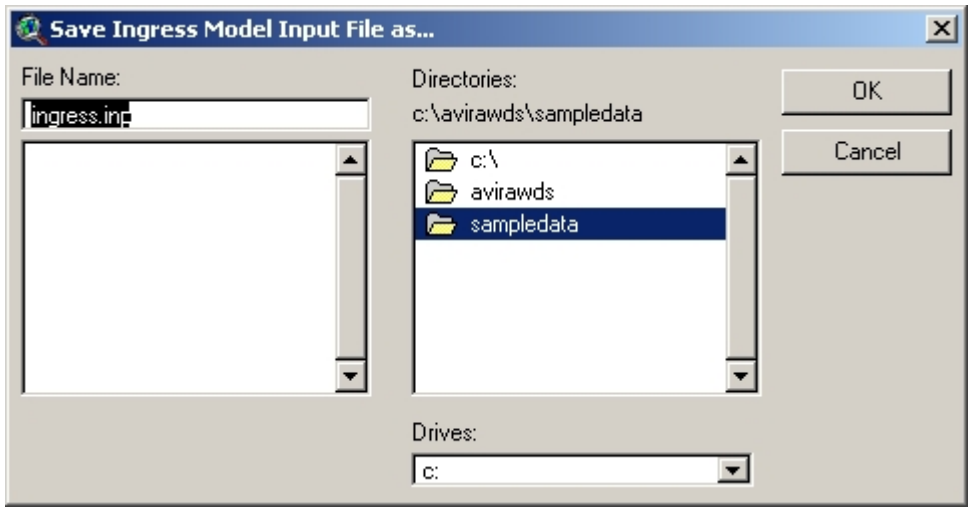


3.3.2.5 Soil data from database

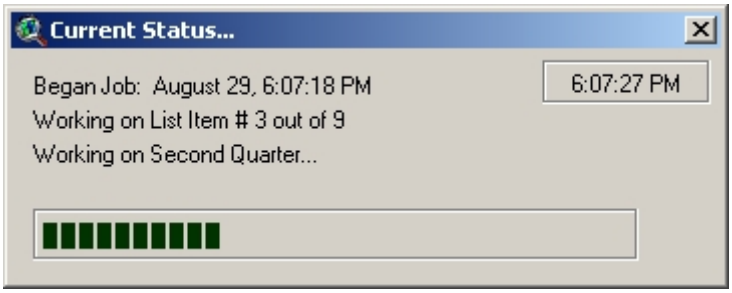
With the soil data from database option, the user chooses the soil type from the Soil Type menu, which consists of different soil properties. The user can also modify the soil properties by using the empty boxes next to some soil properties. The some soil properties depend on the interaction of different 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:

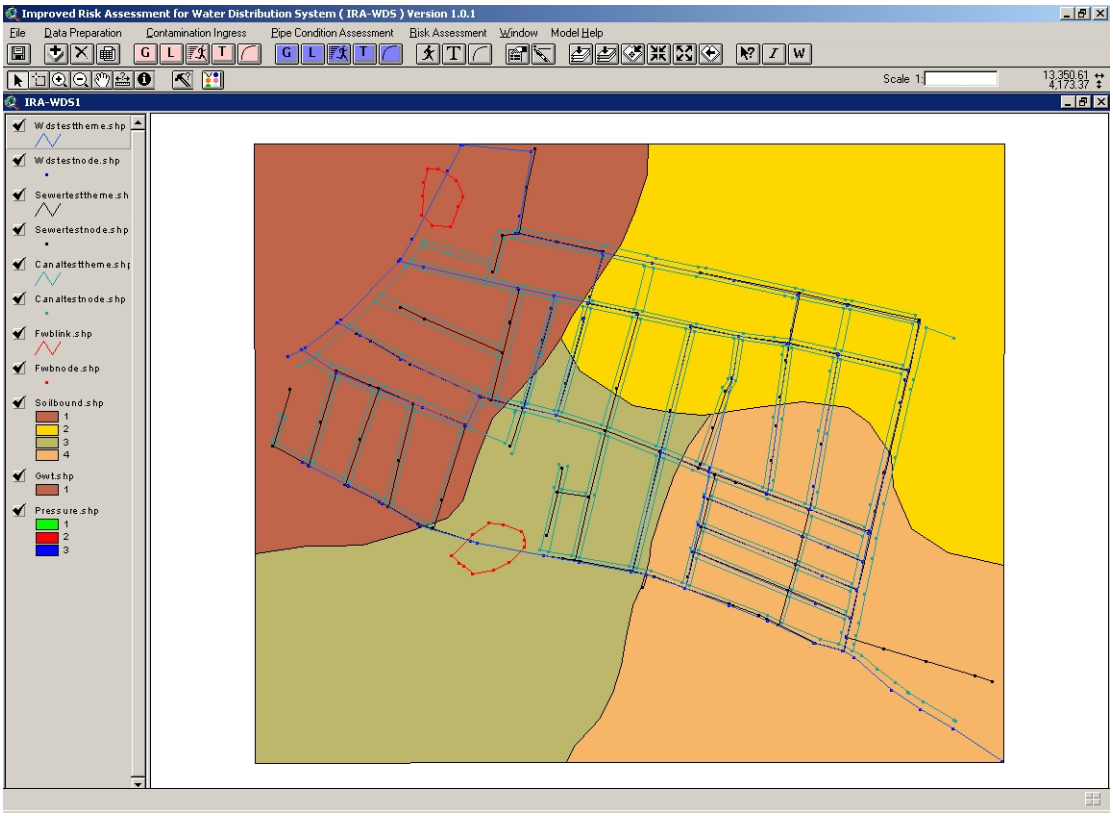


The data generation and writing progress is shown in the Progress Bar as below:



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.

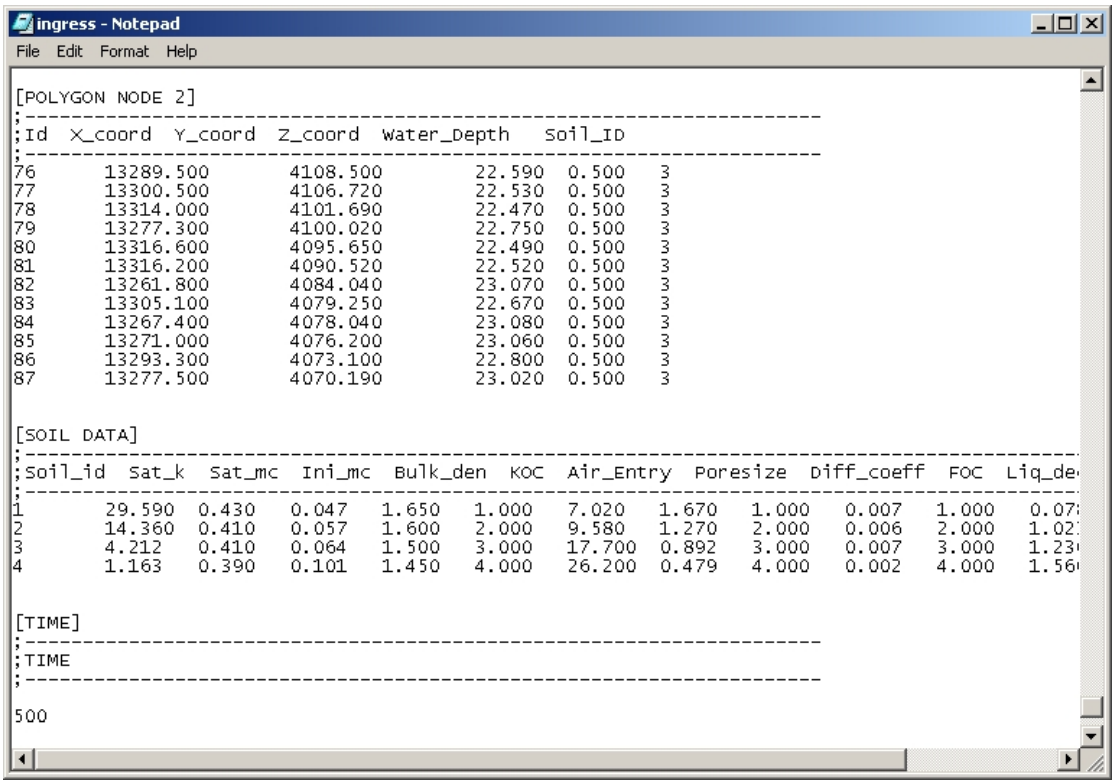
After successfully generating the input file, an Info Message box indicating task completion is displayed as shown below:



3.4.1 Viewing Ingress input file

The user can view the input file in the notepad by clicking on the 

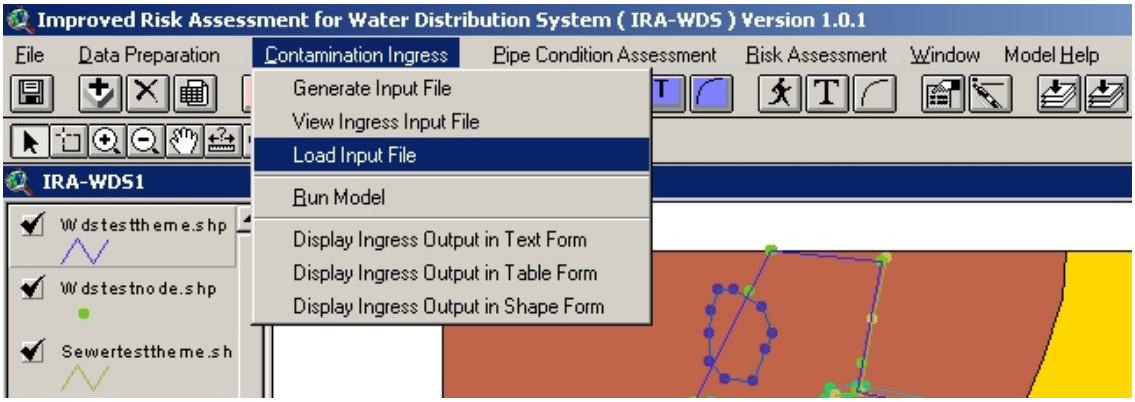
button and browsing the appropriate output file to view.



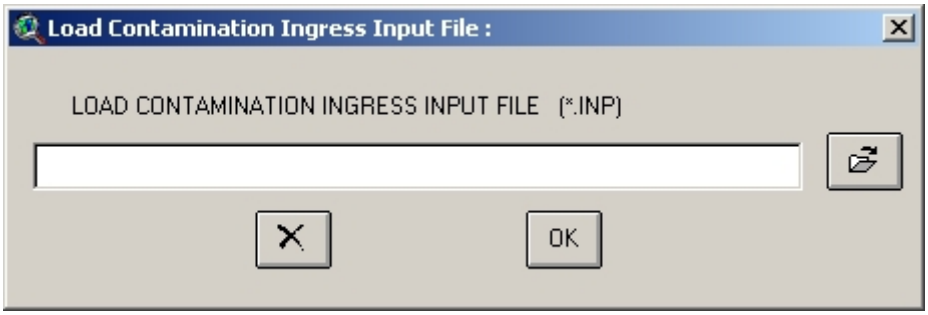
IRA-WDS data viewer

3.4.2 Loading input file

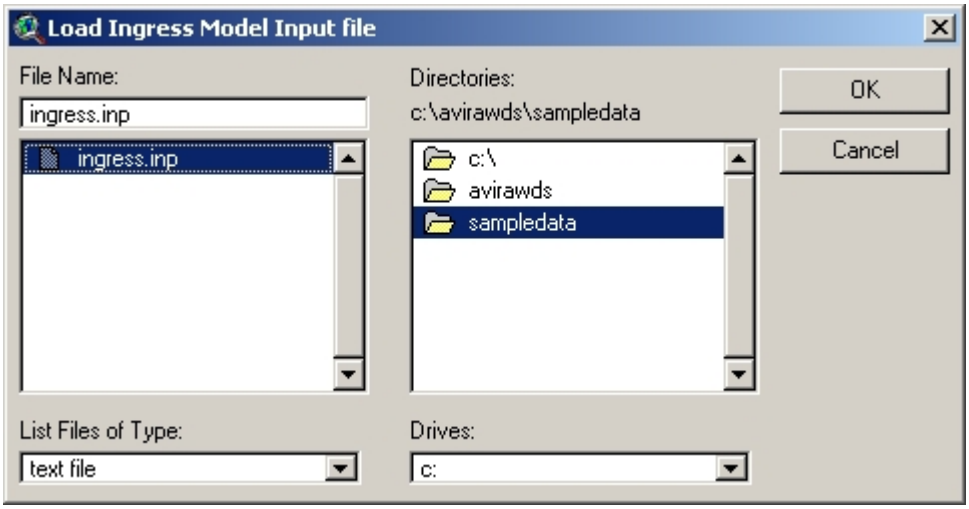
The input file to be used for running the Contaminant Ingress Model is loaded using tool  which is just below the 'Contamination Ingress' menu or by clicking on the 'Contamination Ingress' menu and then clicking on the submenu 'Load Input File', as shown on the screen below:



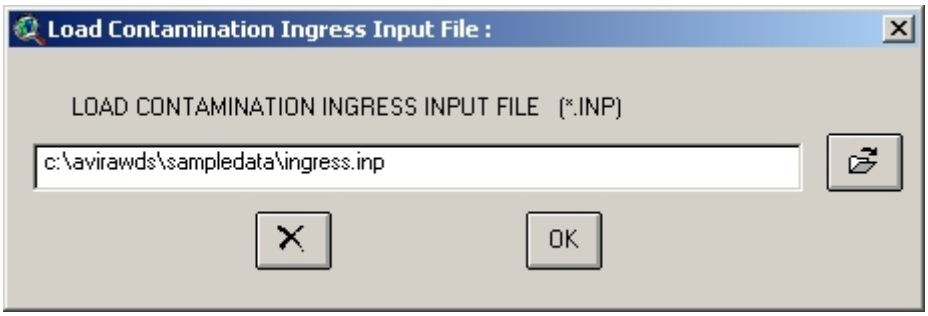
The ‘Load Contamination Ingress Input File’ dialogue box is as shown below:



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:



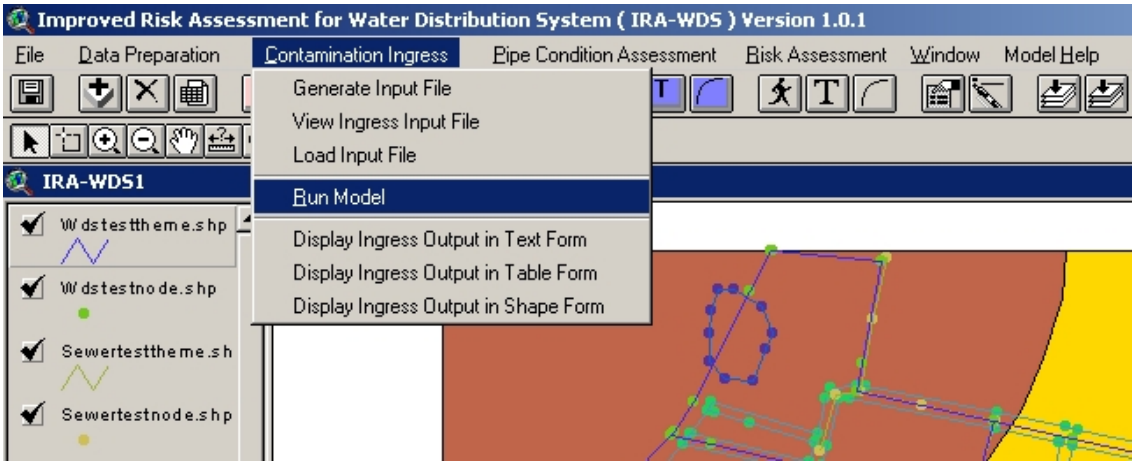
After the appropriate file has been selected, the user presses the ‘OK’ button on the ‘Load Contamination Ingress Input File’ dialogue box where the filename appears.



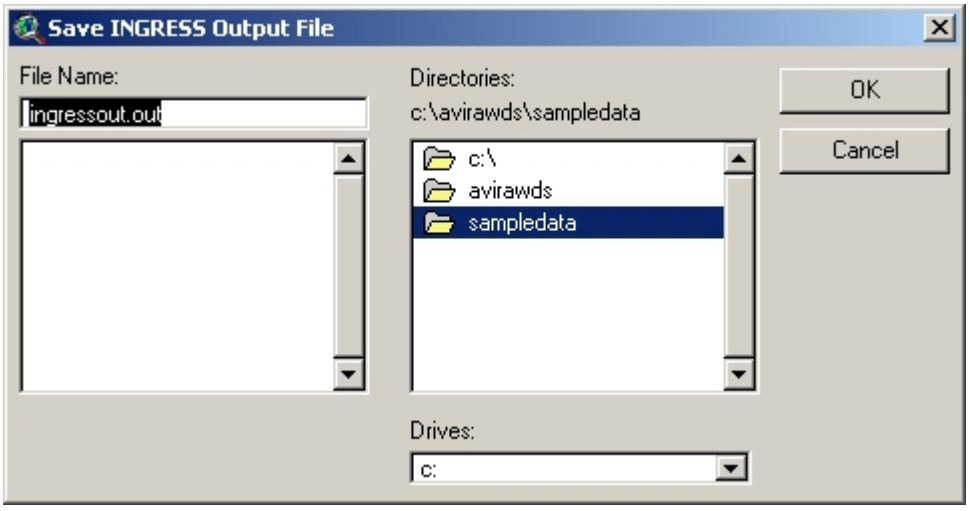
If the user wants to change the filename, he or she can do this by clicking the button  , which clears the filename from the ‘Load Contamination Ingress Input File’ dialogue box. If user is sure of the input file selected, then the file can be loaded by clicking on the  button, which also closes ‘Load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



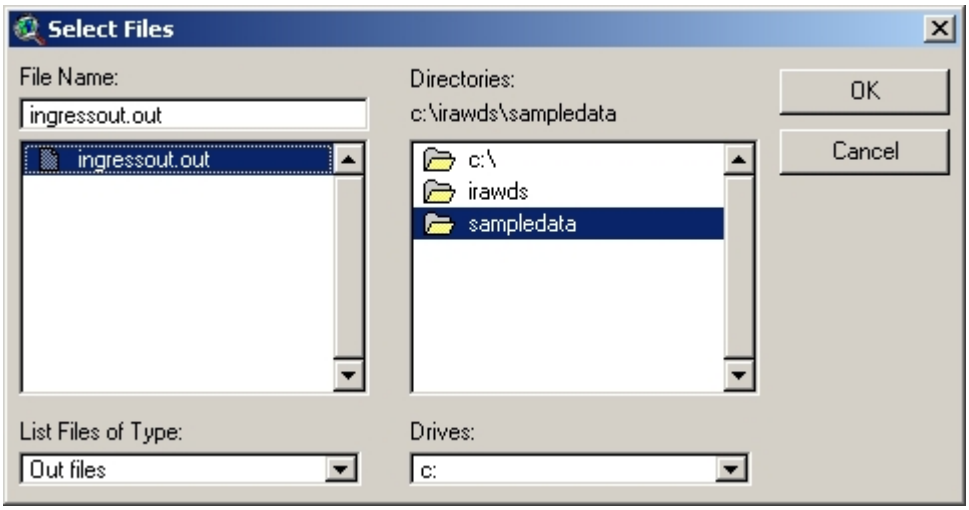
The program then displays the 'Task Completed' Result Message Box, as shown below:

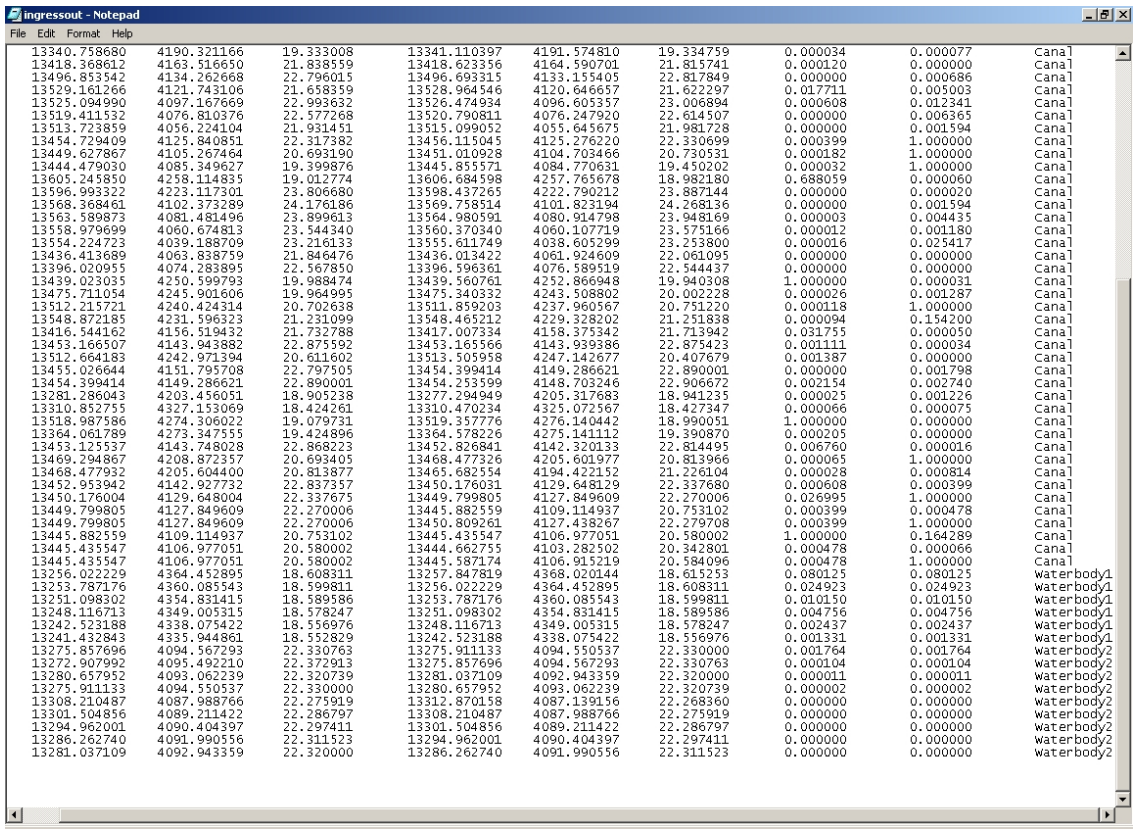
3.6 Displaying output

Outputs can be displayed in text, table and shape forms

3.6.1 Displaying Ingress output in text form

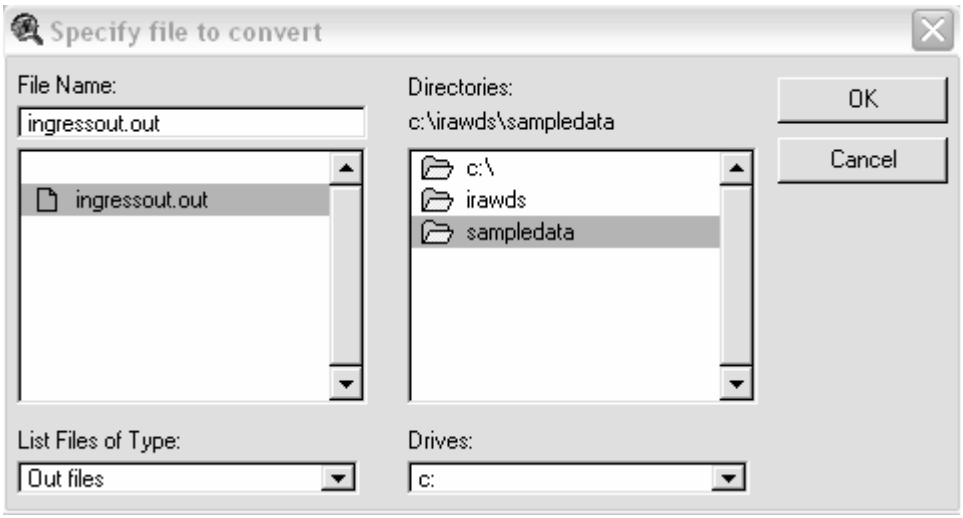
The user can view the output file in text form using the notepad by clicking on the  button or by selecting the Display Output in Text Form submenu from the Contaminant Ingress menu and browsing the appropriate output file to view.





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:

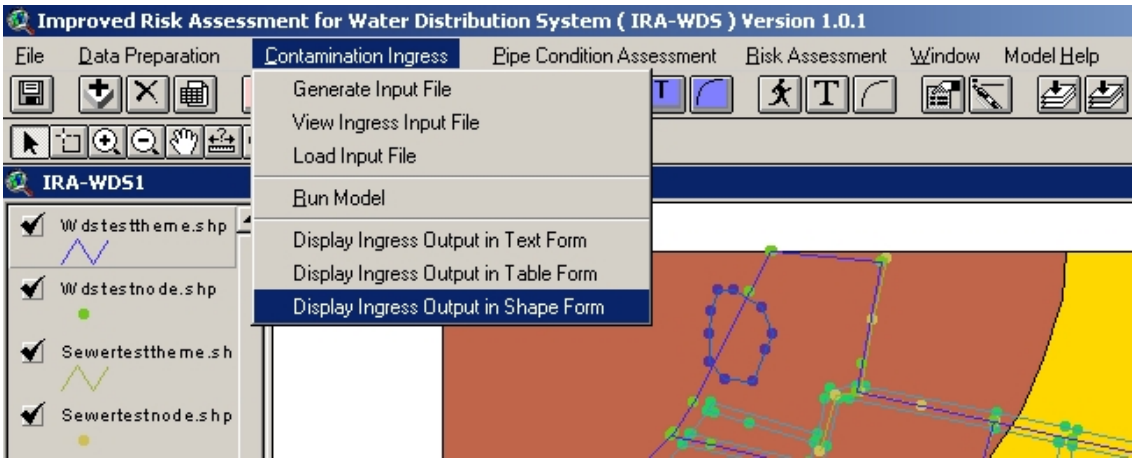


c:\irawds\sampledata\ingressout.dbf

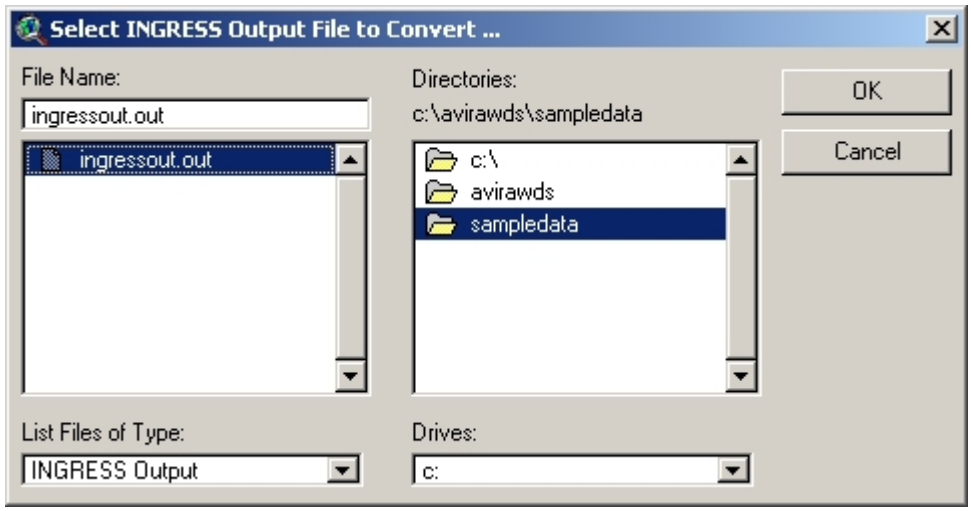
PipeID	StartX	StartY	StartZ	EndX	EndY	EndZ	StartConc	EndConc	C
898	13529.700	4237.970	20.929	13547.300	4234.320	21.181	0.383	1.000	Sewer
884	13512.400	4241.870	20.665	13512.500	4242.250	20.647	1.000	0.000	Sewer
865	13609.600	4257.060	18.920	13610.100	4256.940	18.910	1.000	0.000	Sewer
914	13605.700	4238.720	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	4197.820	19.021	13315.900	4196.530	19.009	0.002	0.000	Canal
950	13340.800	4190.320	19.333	13341.100	4191.570	19.335	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
884	13512.700	4242.970	20.612	13513.500	4247.140	20.408	0.001	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

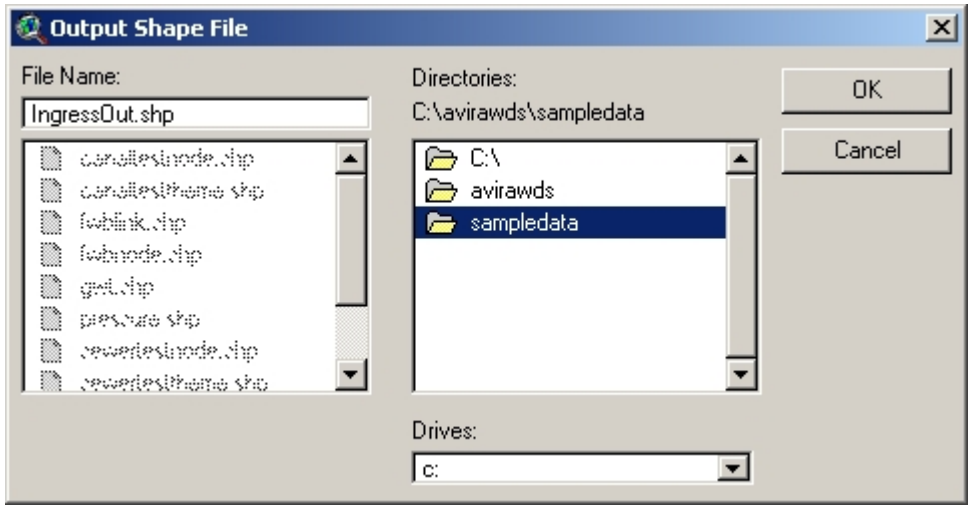
To view the Contamination Ingress Model output in shape file form click on the  button, which is just below the 'Contamination Ingress' menu or by clicking on the 'Contamination Ingress' menu and then clicking on the submenu 'Display Ingress Output in Shape Form', as shown in the screen below:



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:

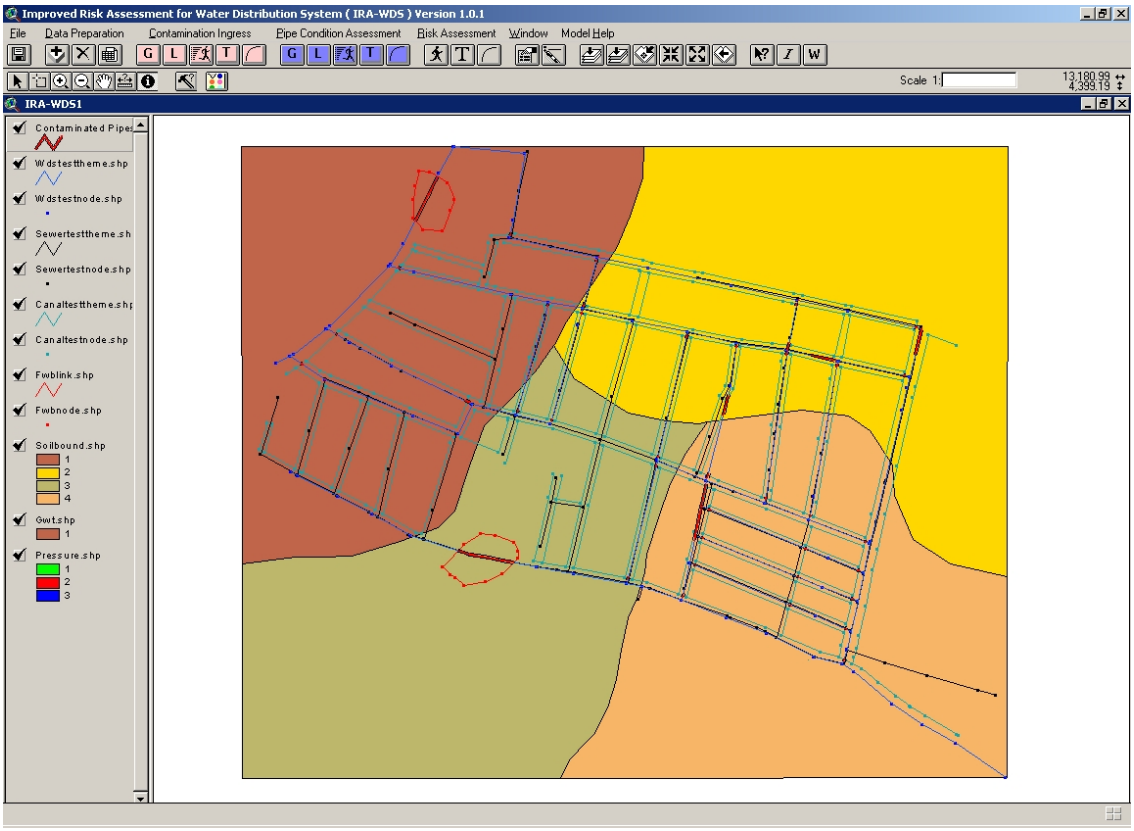


Once the user has selected the appropriate filename and clicked 'OK', this opens the 'File Save' dialogue box and asks the user to type in the output shape filename:



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

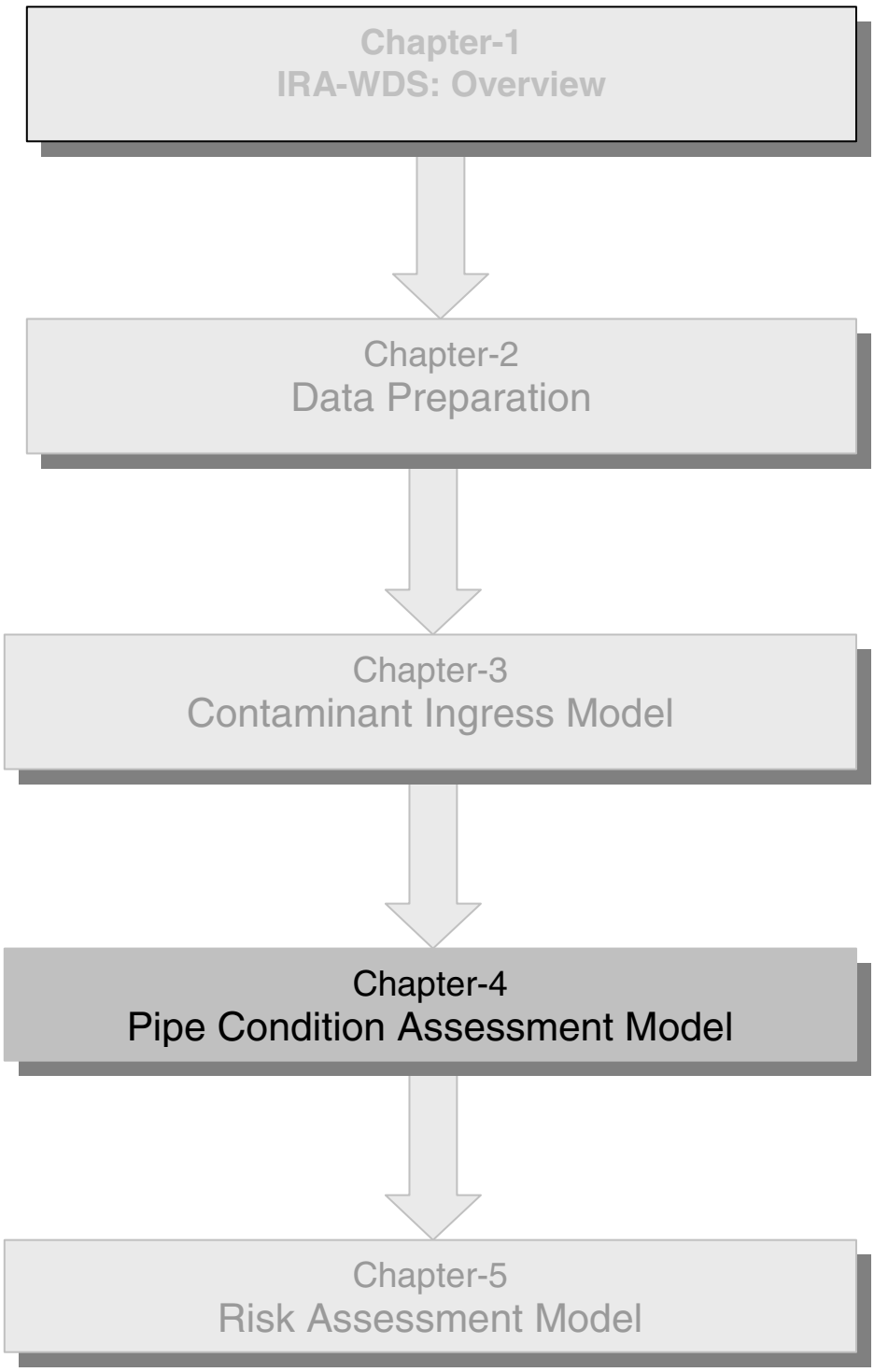
Ingress output shape file and loads that file into the IRA-WDS data viewer with contamination legend as shown below:



CHAPTER FOUR

Pipe Condition Assessment Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems



Chapter 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

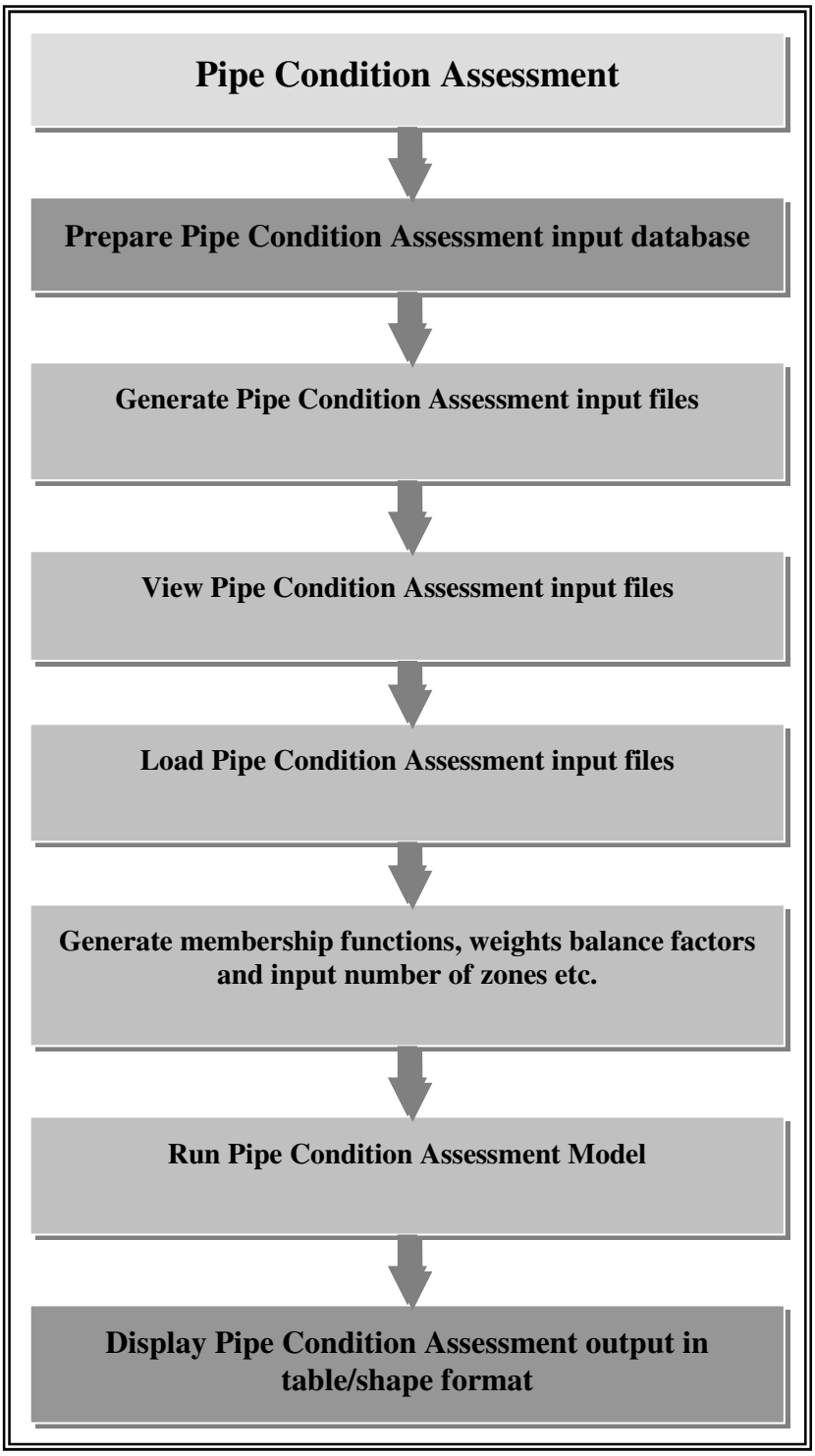


Figure 4.1. Overview of Pipe Condition Assessment Model of IRA-WDS

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

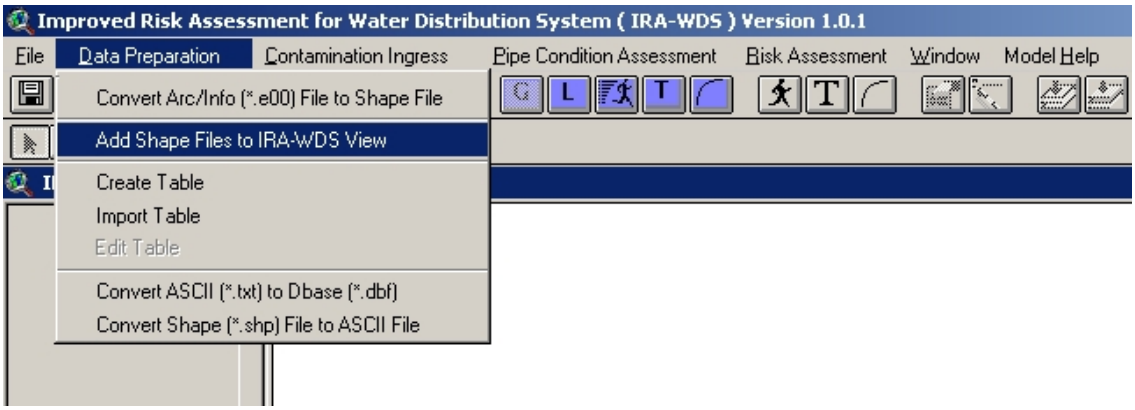
- Adding the data (if not already done so)
- Rearranging the data (optional)
- Generating an input file

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

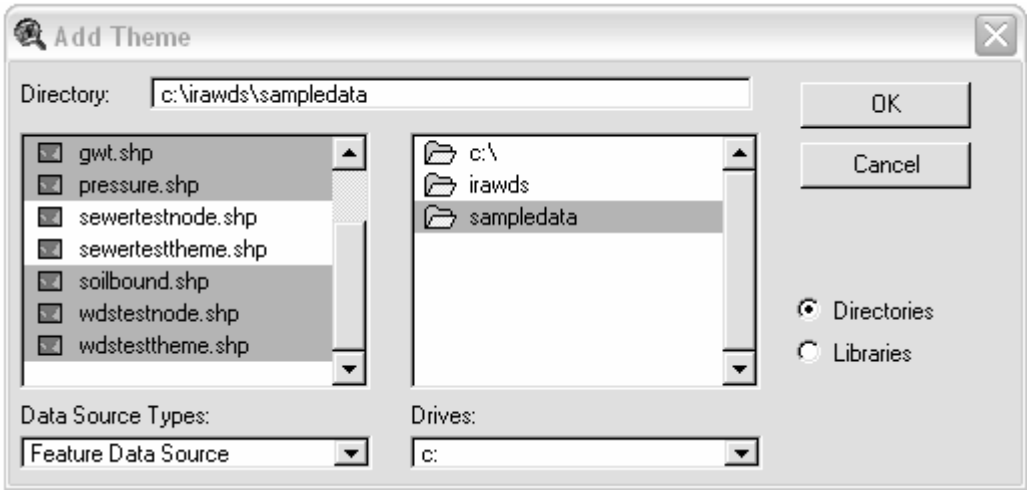
4.2 Shape files

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:

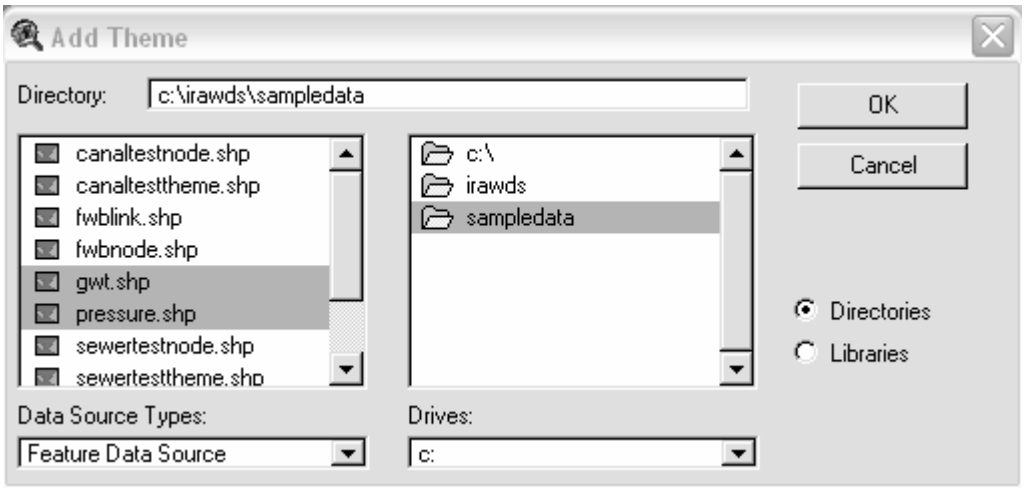


This opens the 'Add Theme' form, as shown below, and the user is then required to select the desired files. At this stage, these files are those relating to: water distribution link and node; soil polygon map; groundwater zone polygon map; and pressure zone polygon map.



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

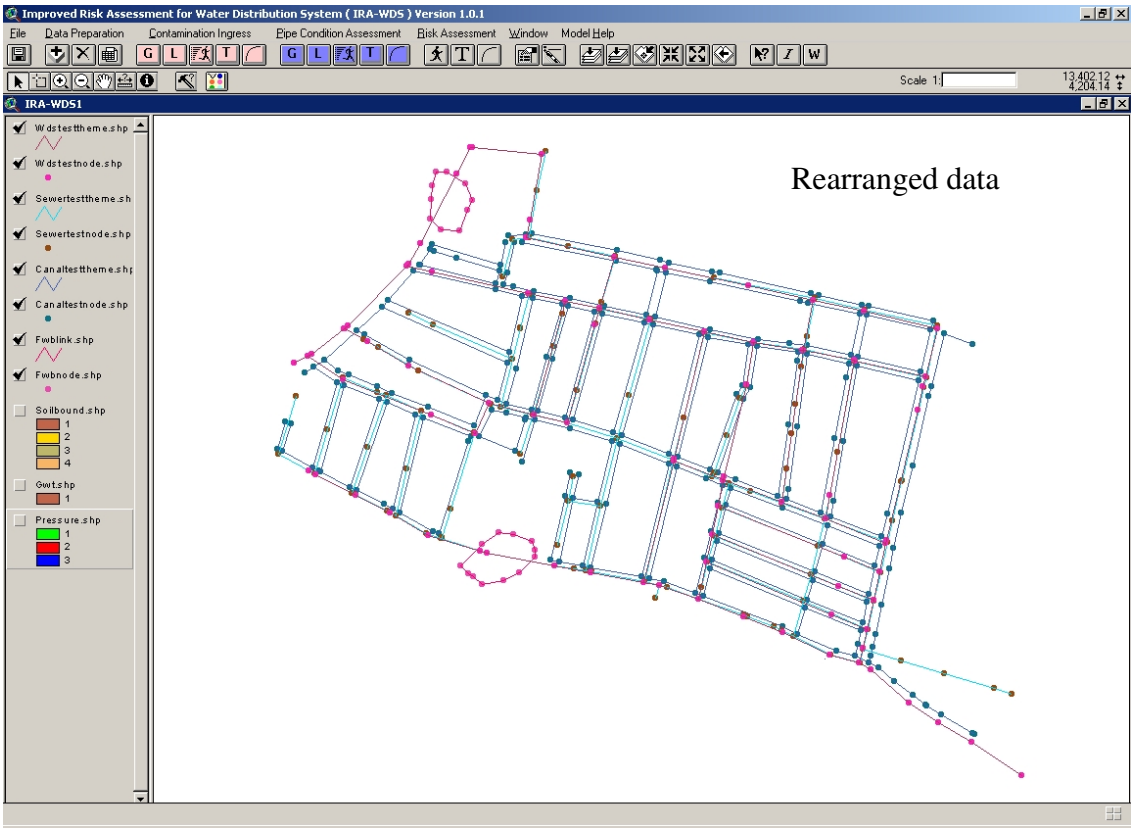
case). Only the groundwater zone polygon map and the pressure zone polygon map need to be added by the user as below.

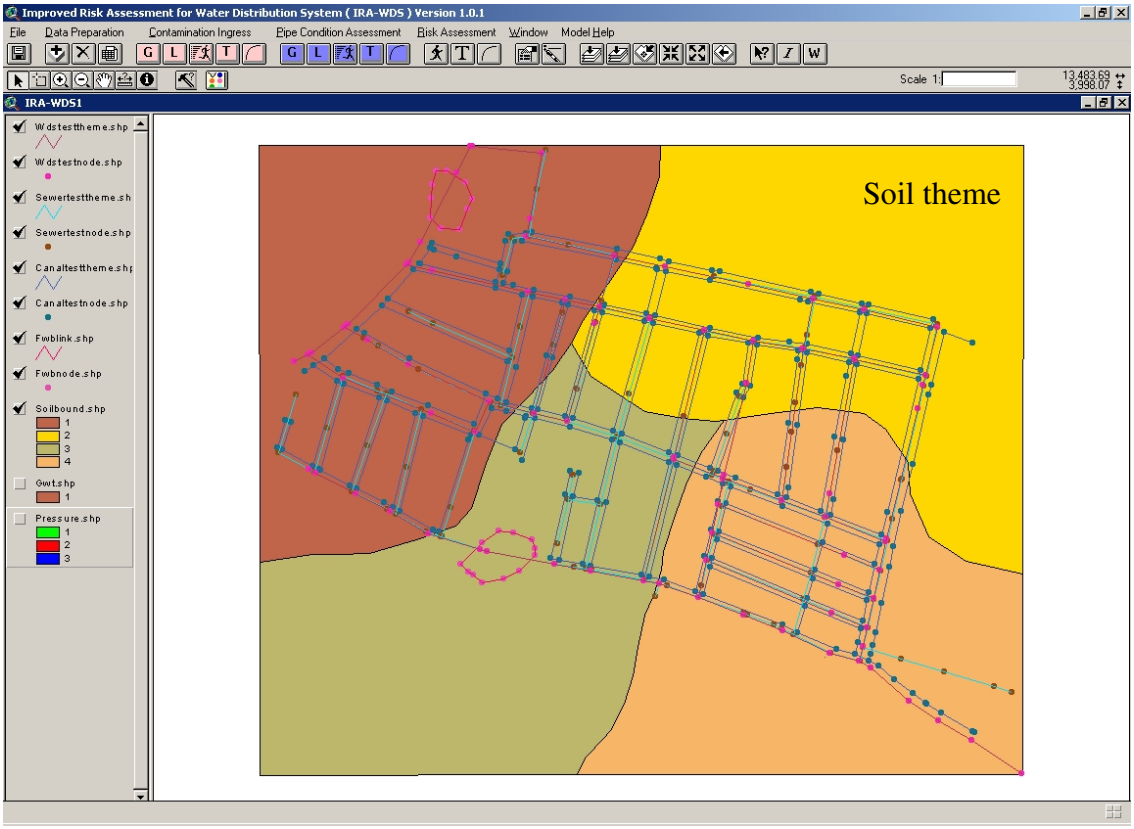


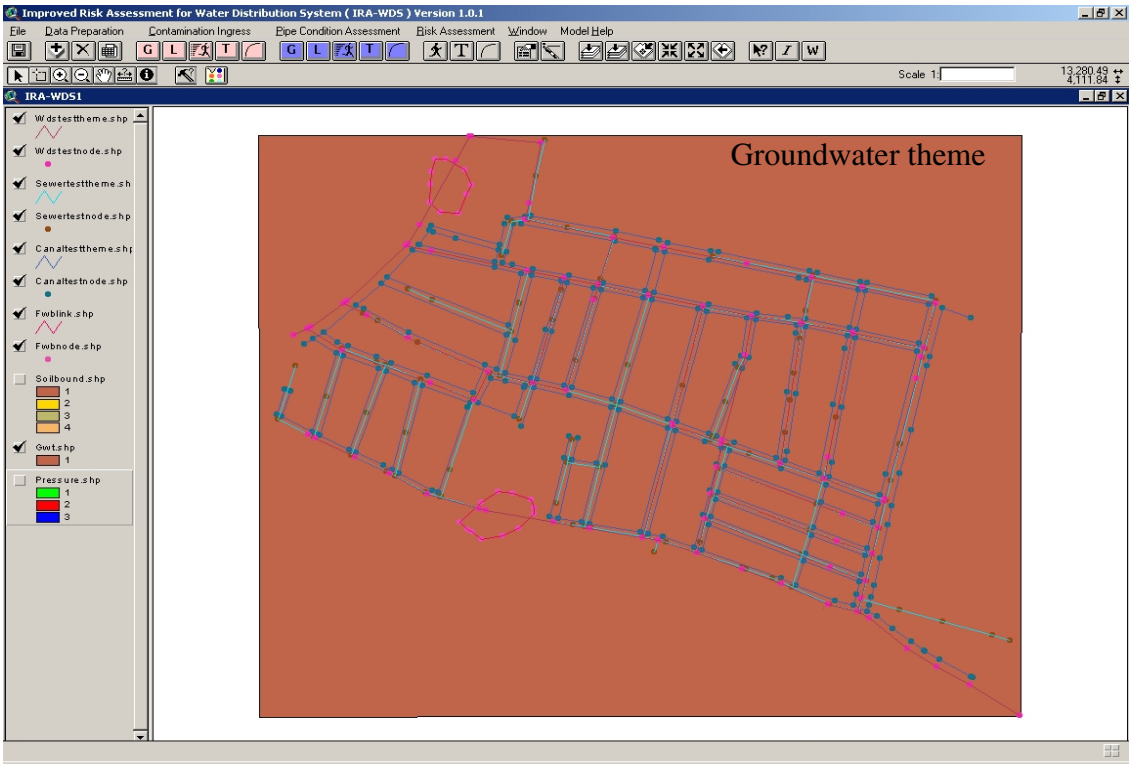
4.2.2 Rearranging shape files

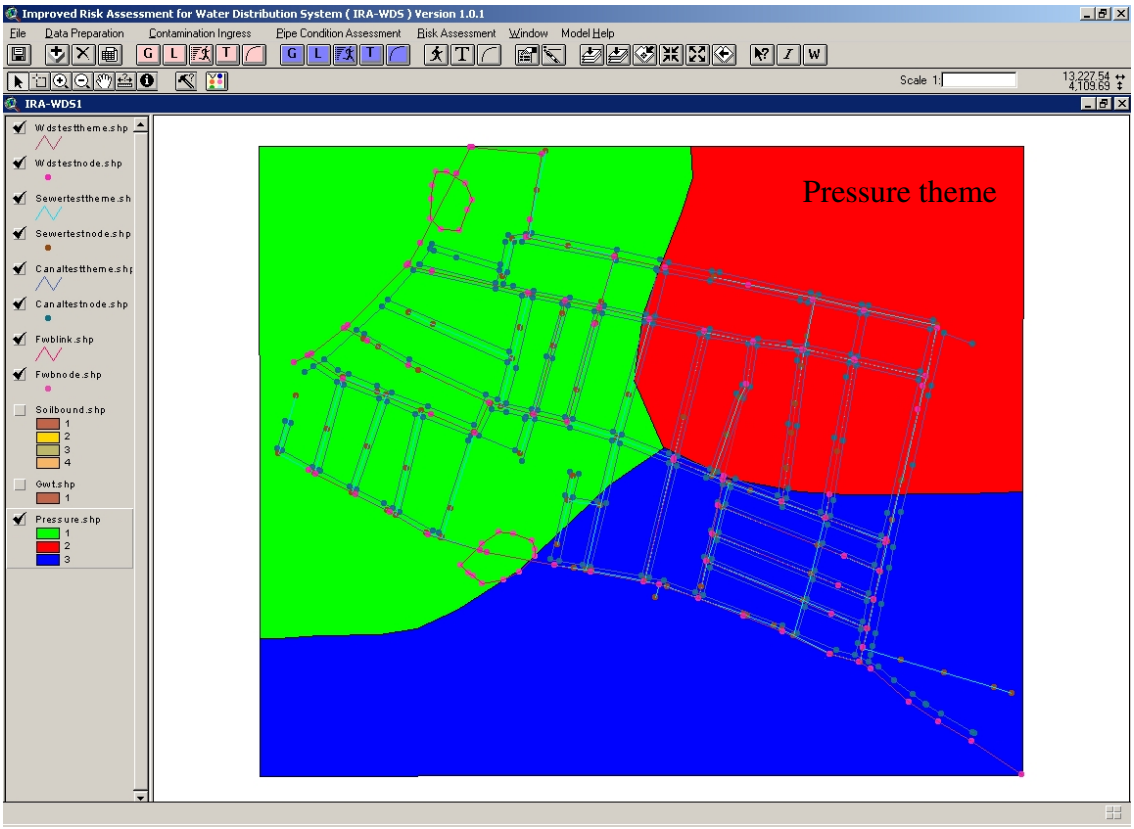
If the user wishes to do so, he or she can rearrange the data to view and query different themes. The following snapshots show:

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




Improved Risk Assessment for Water Distribution System (IRA-WDS) Version 1.0.1
File
Data Preparation
Contamination Ingress
Pipe Condition Assessment
Risk Assessment
Window
Model Help
Scale 1:
IRA-WDS1
Wdstestttheme.shp
Wdstestnode.shp
Sewertesttheme.sh
Sewertestnode.shp
Canaltesttheme.shp
Canaltestnode.shp
Fwblink.shp
Fwbnode.shp
Soilbound.shp
1
2
3
4
Gwt.shp
1
Pressure.shp
1
2
3
Soil theme

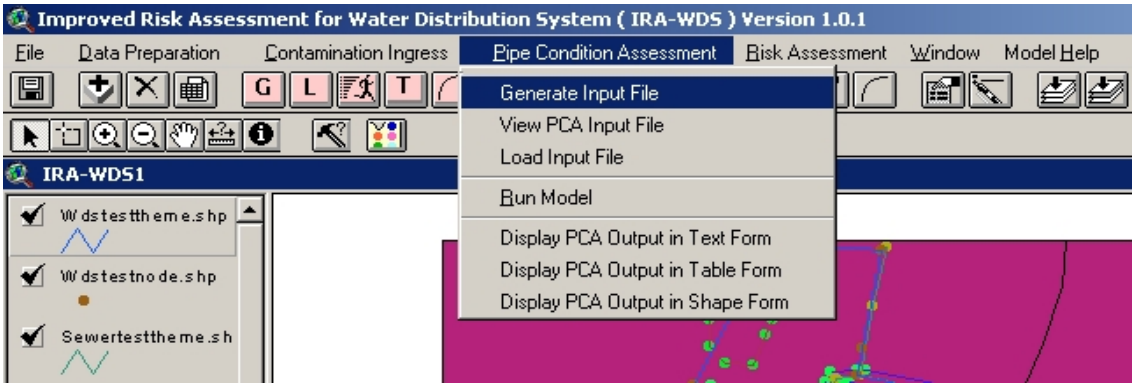

Improved Risk Assessment for Water Distribution System (IRA-WDS) Version 1.0.1
File
Data Preparation
Contamination Ingress
Pipe Condition Assessment
Risk Assessment
Window
Model Help
Scale 1:
IRA-WDS1
Wdstestttheme.shp
Wdstestnode.shp
Sewertesttheme.sh
Sewertestnode.shp
Canaltesttheme.shp
Canaltestnode.shp
Fwblink.shp
Fwbnode.shp
Soilbound.shp
1
2
3
4
Gwt.shp
1
Pressure.shp
1
2
3
Groundwater theme



4.3 Generating an input file

4.3.1 Background to Pipe Condition Assessment Model input

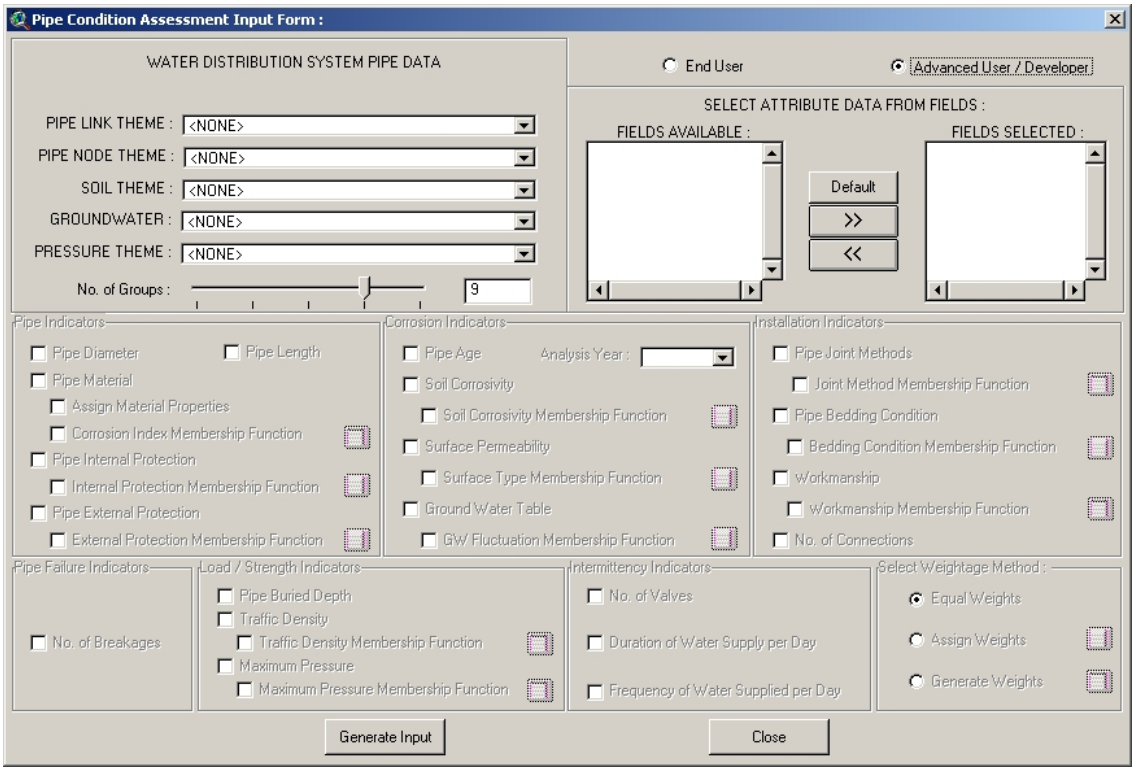
An input file can be generated by clicking on the Tool icon G which is just below the 'Pipe Condition Assessment' menu or by clicking on the 'Pipe Condition Assessment' menu and then clicking on the submenu 'Generate Input File', as shown on the screen below:



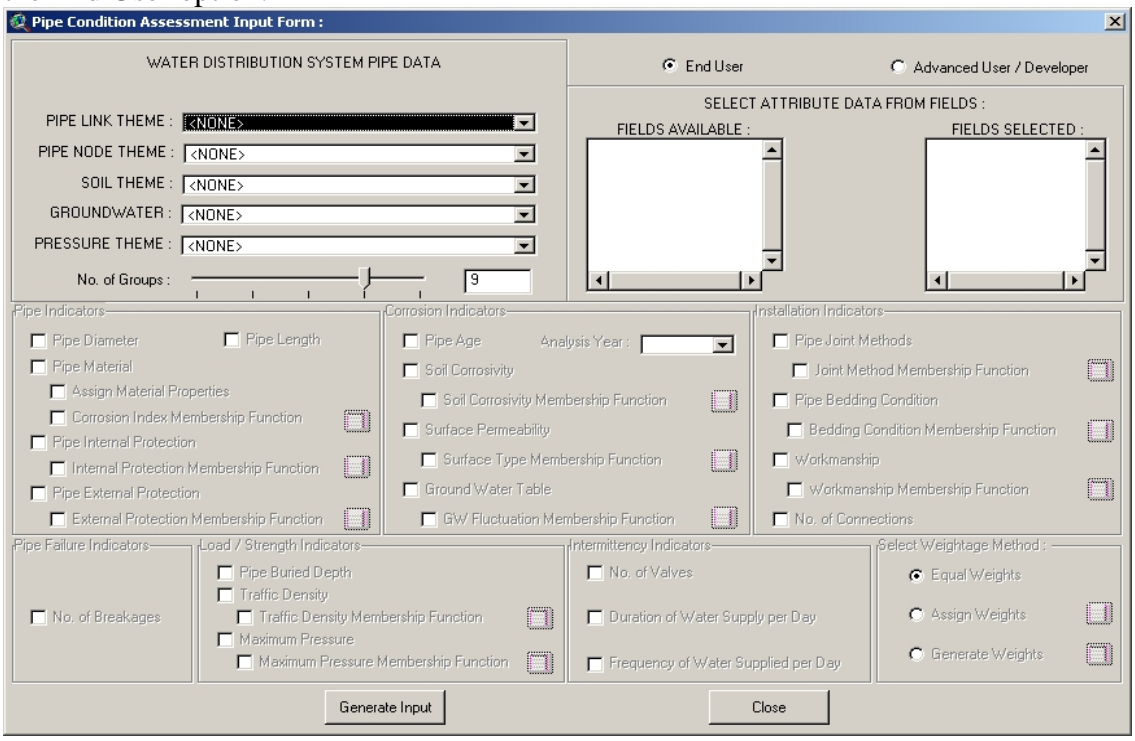
The 'Pipe Condition Assessment Input Form' has two radio button options: '**Advanced User'** and '**End User'**.

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 Make Default 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.

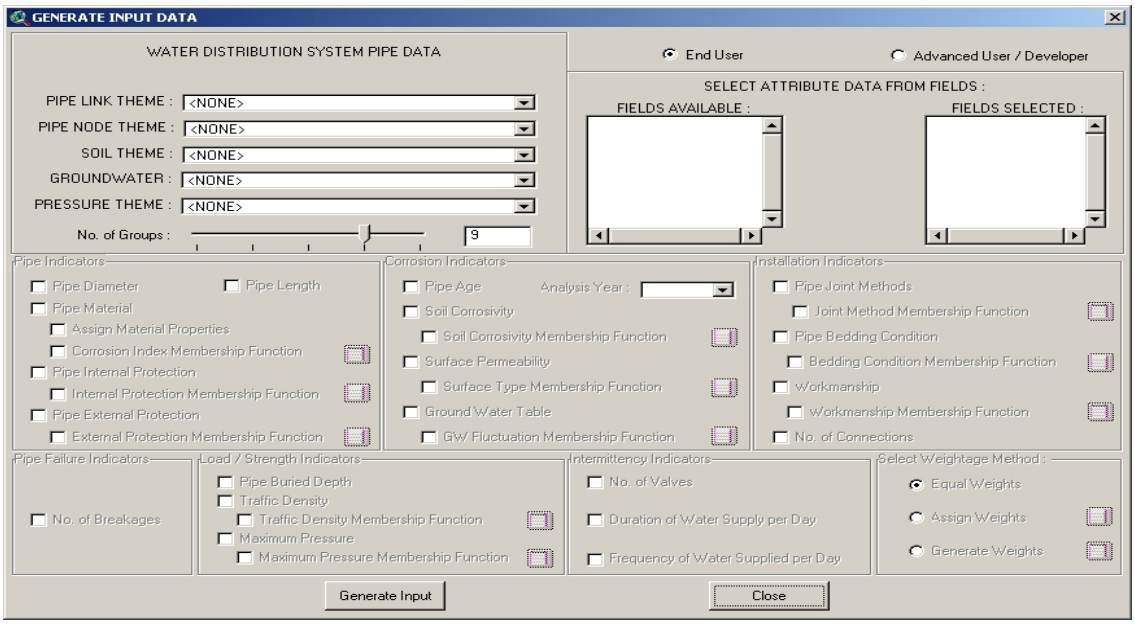


End Users are not provided with an option for adding or deleting fields to or from the 'SELECTED FIELDS' list box. In this case, the fields are automatically selected with the End User option.



4.3.2 Adding shape files

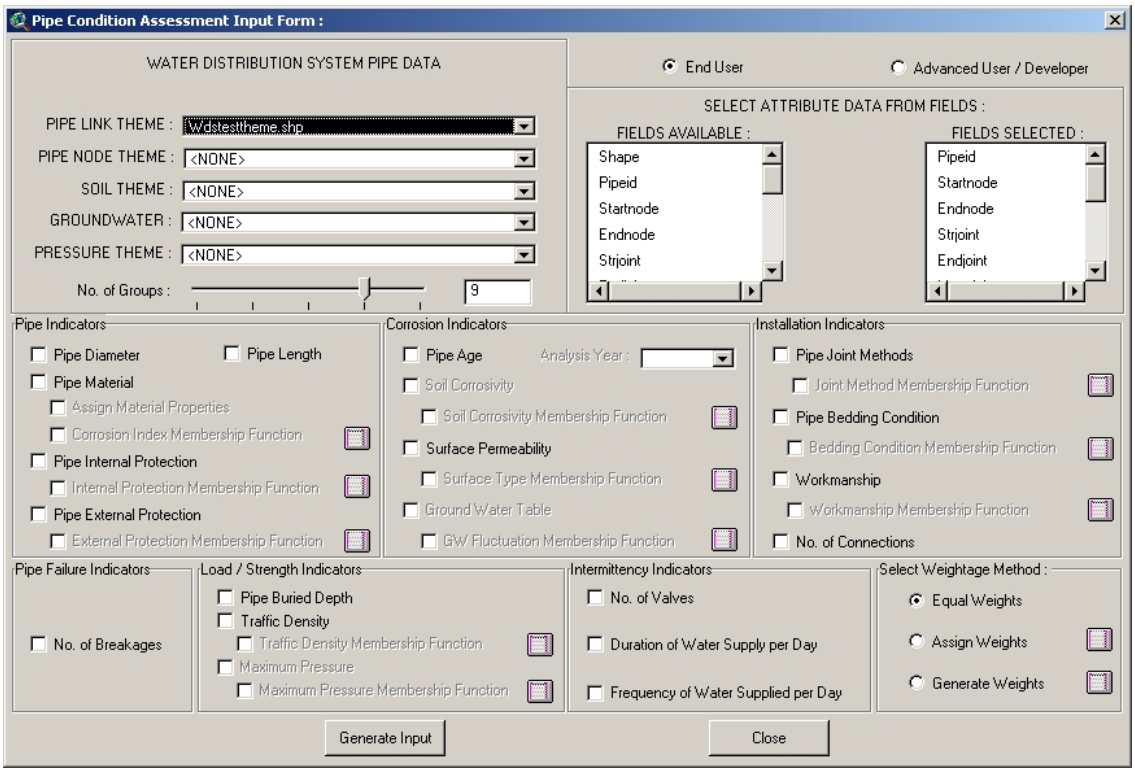
The user needs to define which theme in the IRA-WDS View represents the water distribution system pipe theme, the node theme, the soil theme, the groundwater theme and the pressure theme. All polyline / line themes added to the IRA-WDS viewer are added to the 'PIPE LINK THEME' combo box. All point /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

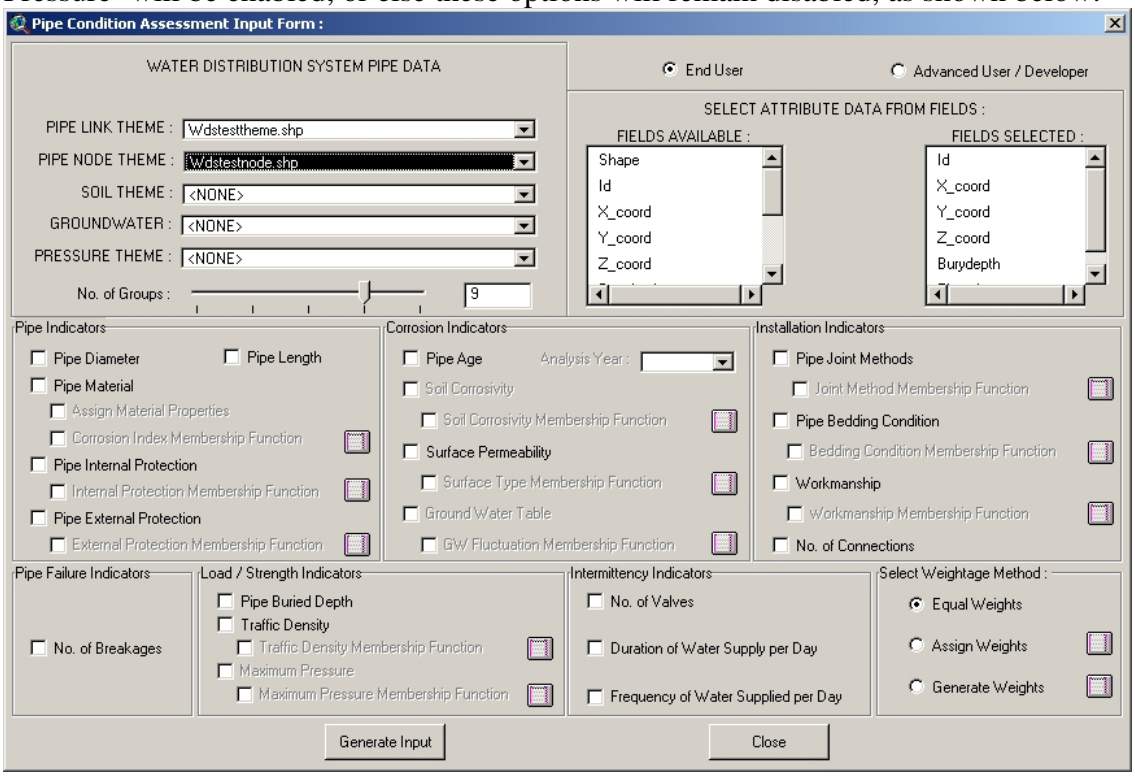


4.3.2.2 Pipe node (water distribution) theme

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

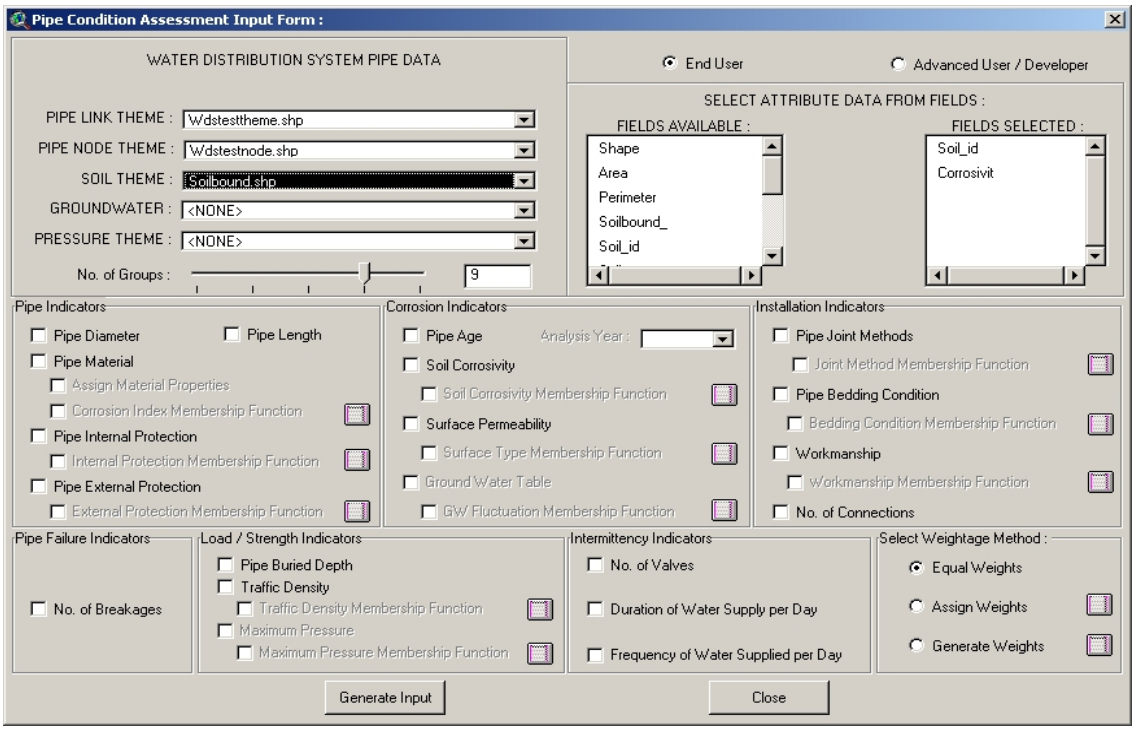
4.3.2.3 Soil, groundwater and pressure themes

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:



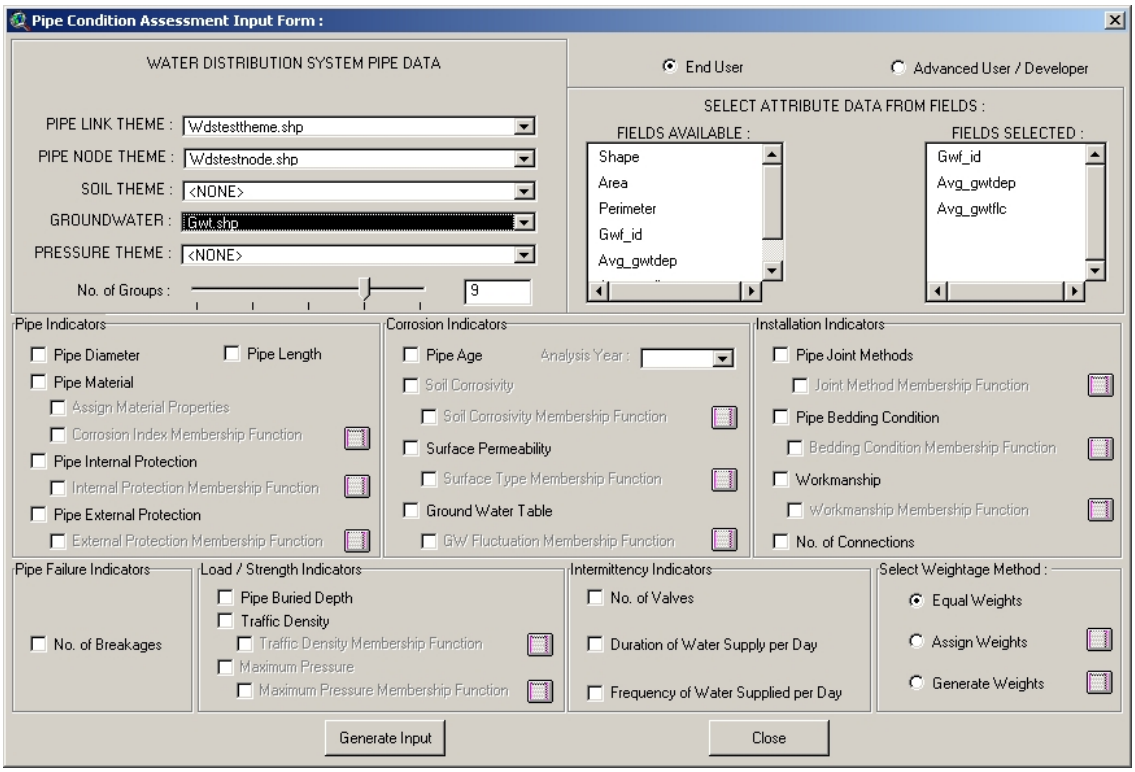
4.3.2.4 Soil theme

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.



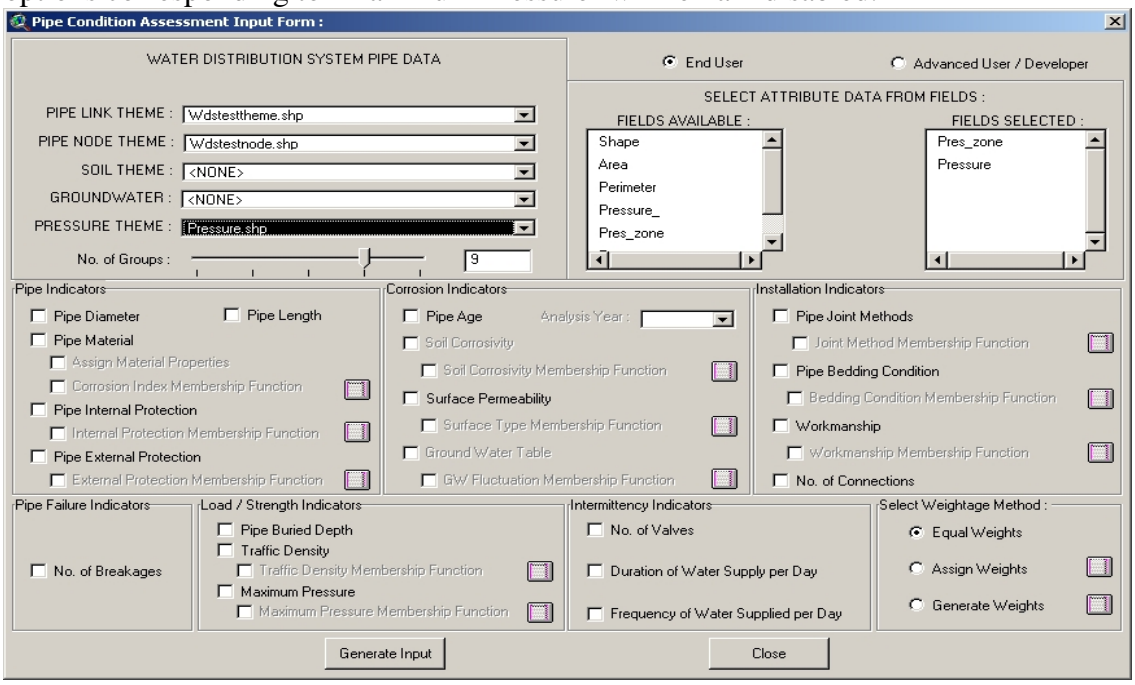
4.3.2.5 Groundwater theme

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.



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.



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.

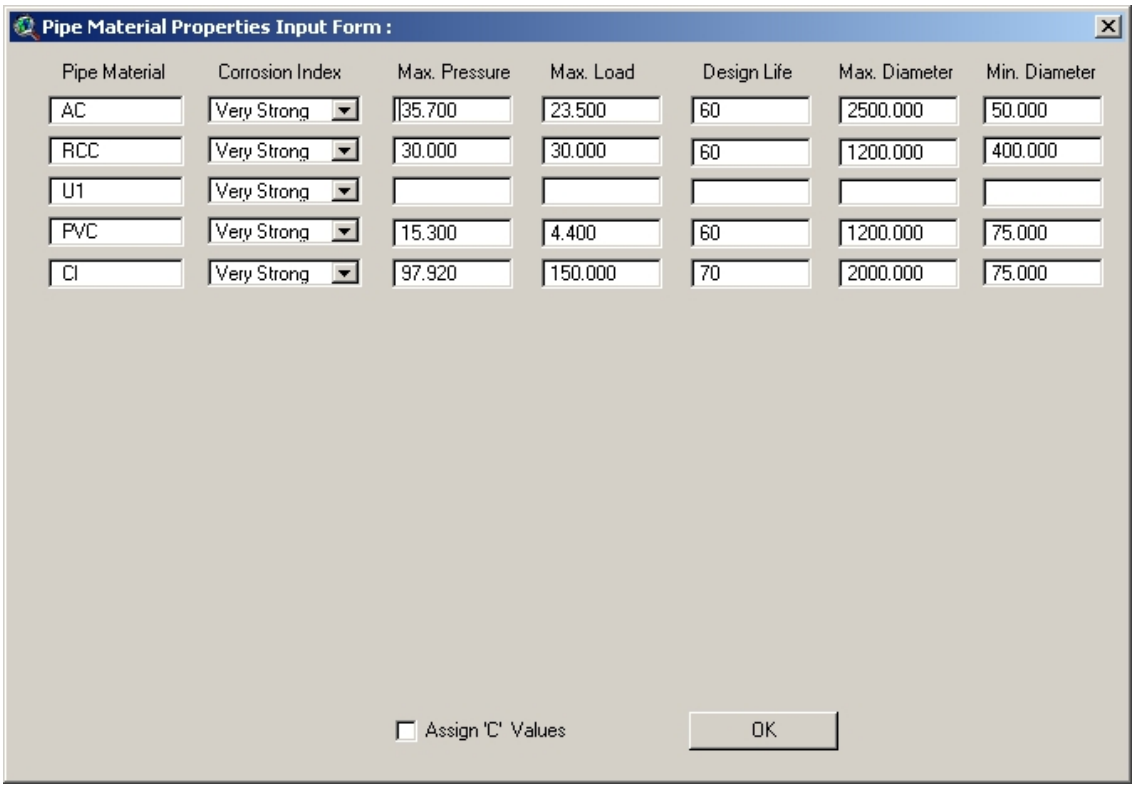
1. Pipe Indicators
2. Corrosion Indicators
3. Installation Indicators
4. Pipe Failure Indicators
5. Load/Strength Indicators
6. Intermittency Indicators

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.

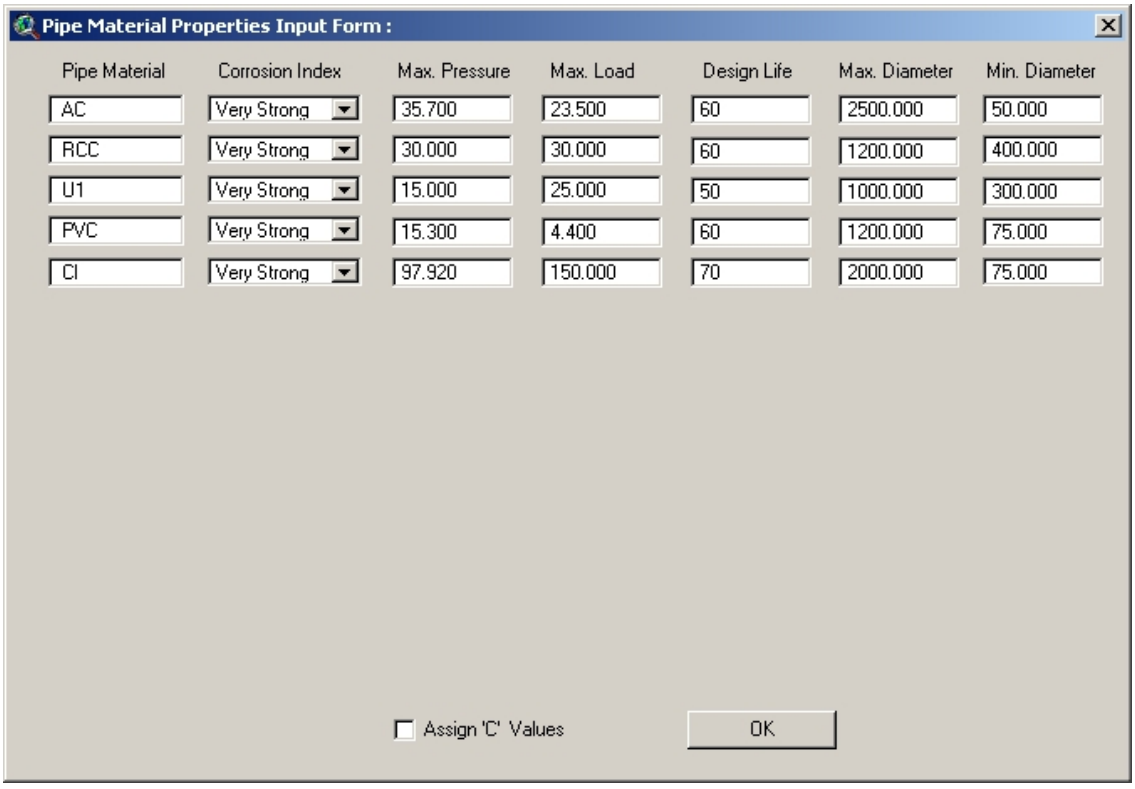
Pipe material
Various material properties are considered while deciding the condition of the pipe. These properties are:

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.

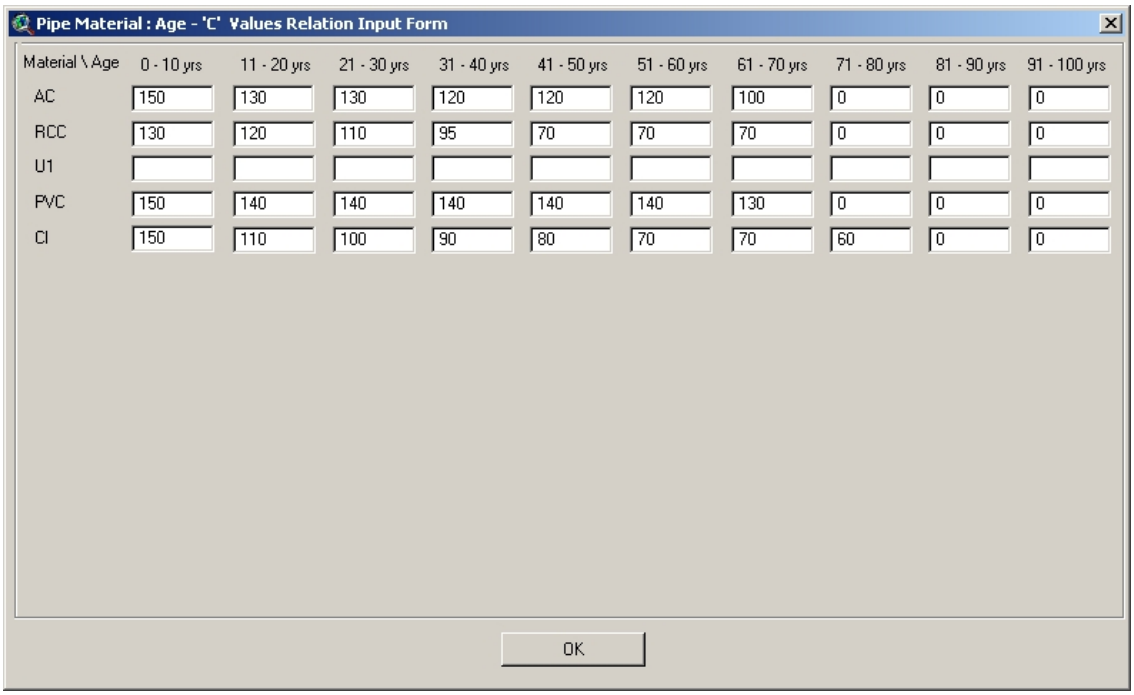


The completed data form is shown below:

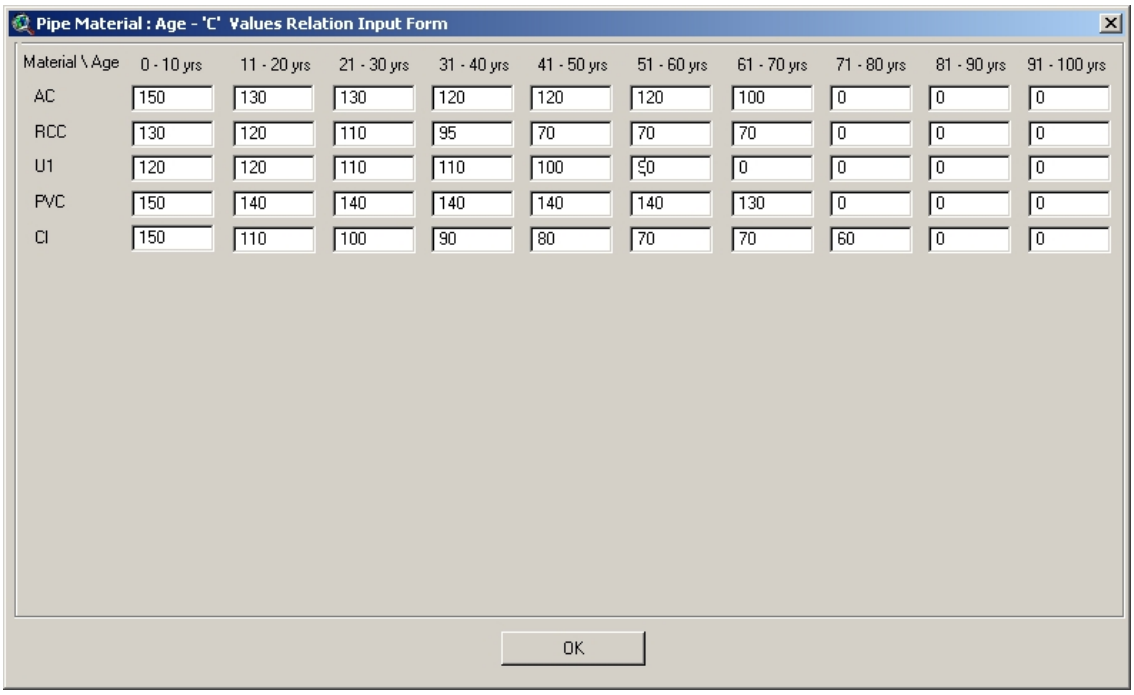


To define the 'Pipe Material: Age-C' relationship, the user should click on the check box 'Assign 'C' Values' on the 'Pipe Material Properties Input Form'. This opens the 'Pipe Material: Age-'C' Values Relation Input Form'. Again, if the default database for the pipe material in the IRA-WDS program contains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



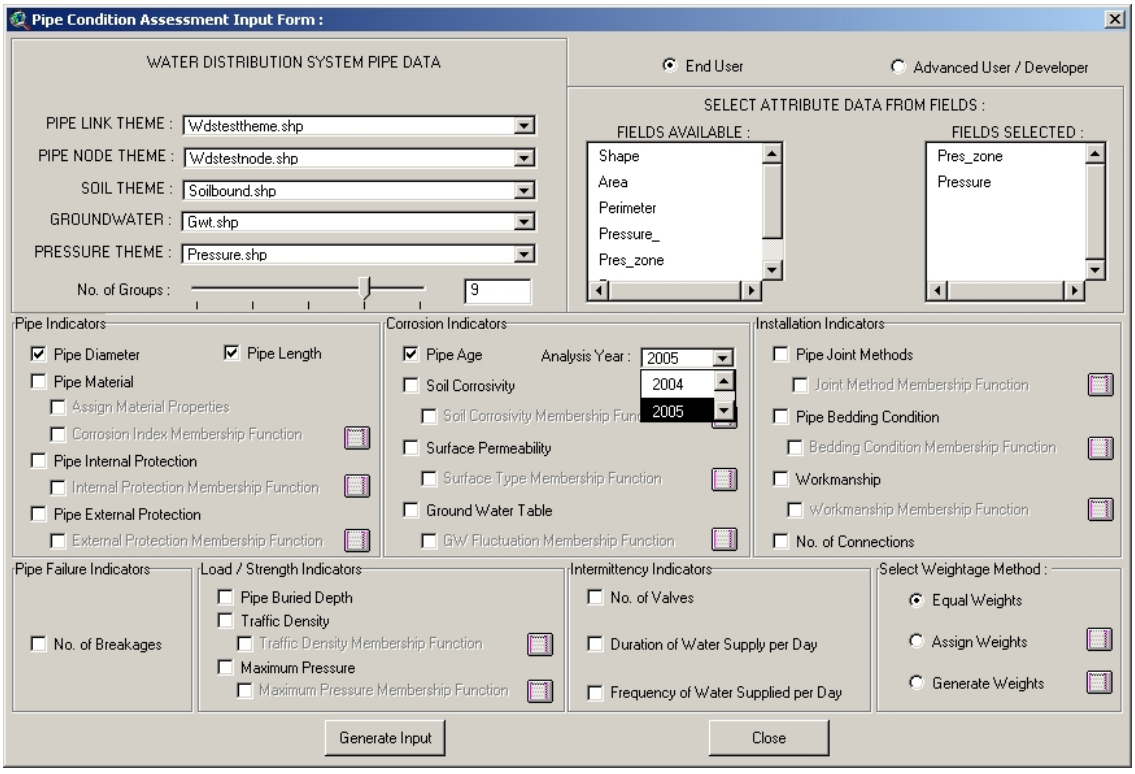
The user needs to complete the form appropriately by entering values in any blank fields. He or she can also modify the data if they do not agree with the default database. The completed data form is shown below:



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:



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.

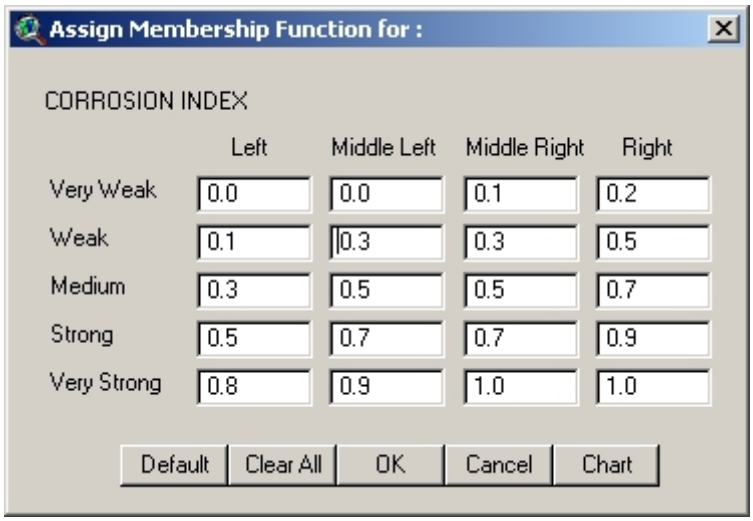
4.5.1 Membership functions

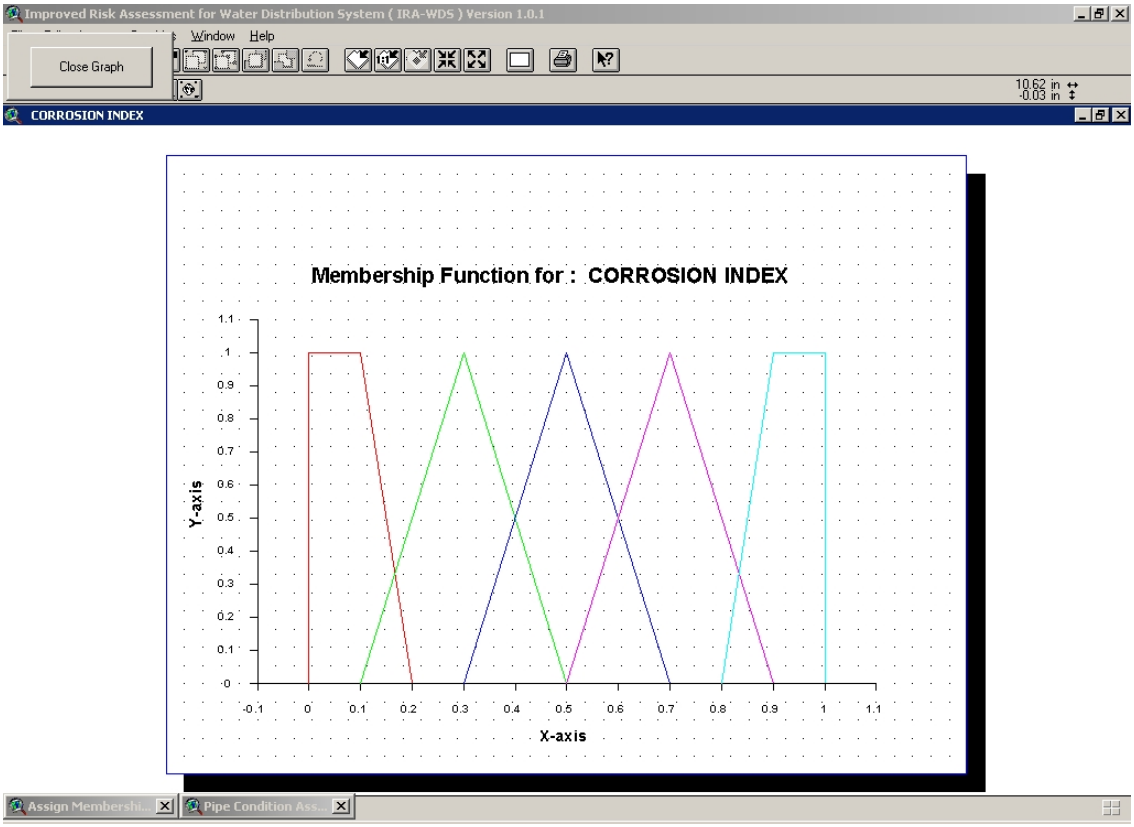
If any fuzzy parameter is clicked, its membership definition form appears. For example, if Pipe Material and then Corrosion Index Membership Function are clicked, its membership form appears (see screen below). The form is common for all the parameters except the title and group labels, which vary according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

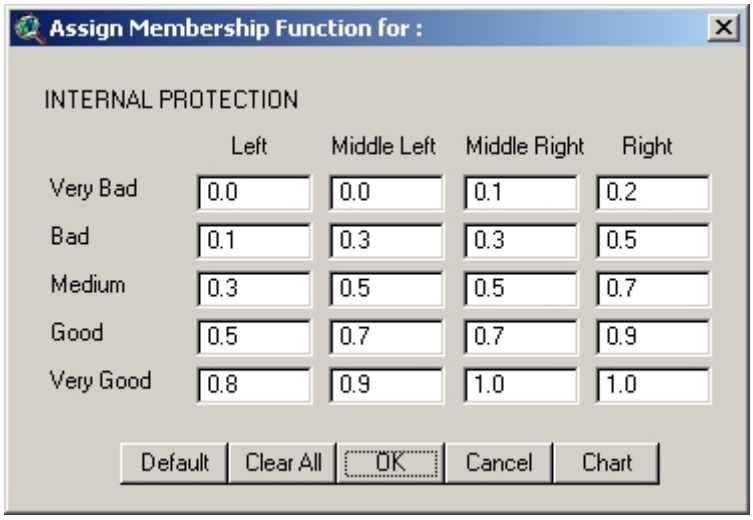
There are five buttons to facilitate defining membership functions. These are:
Default: Clicking this button loads the membership definition text boxes with default values defined for various indicators in the IRA-WDS database.
Clear All: Clicking this button clears all membership definition text boxes.
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

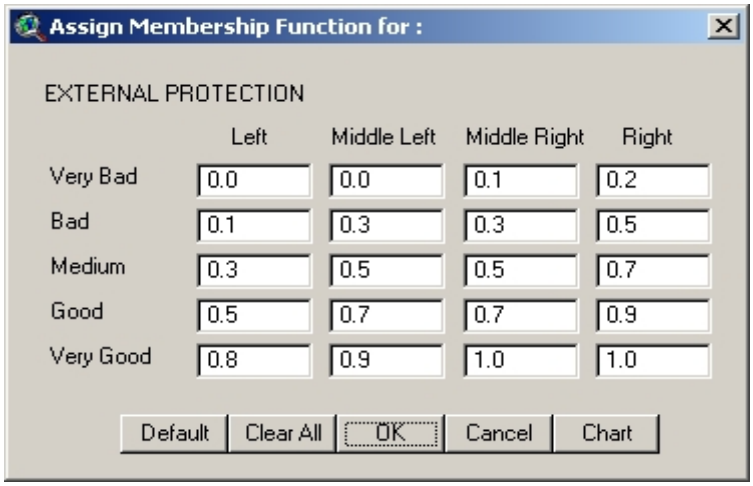




2. Pipe Internal Protection

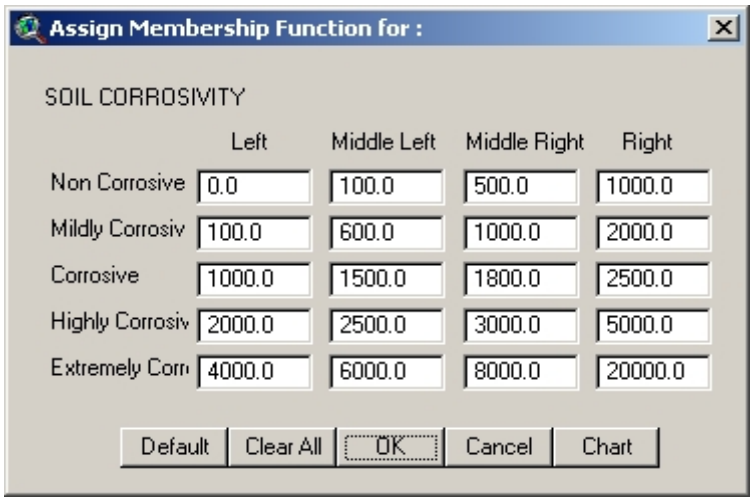


3. Pipe External Protection

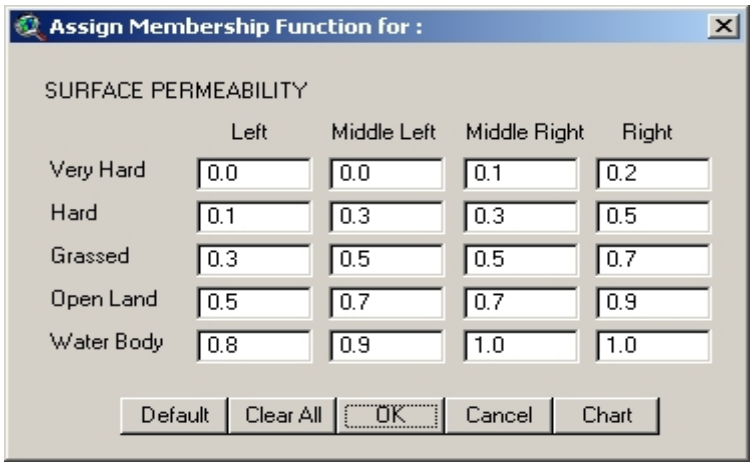


4. Soil Corrosivity

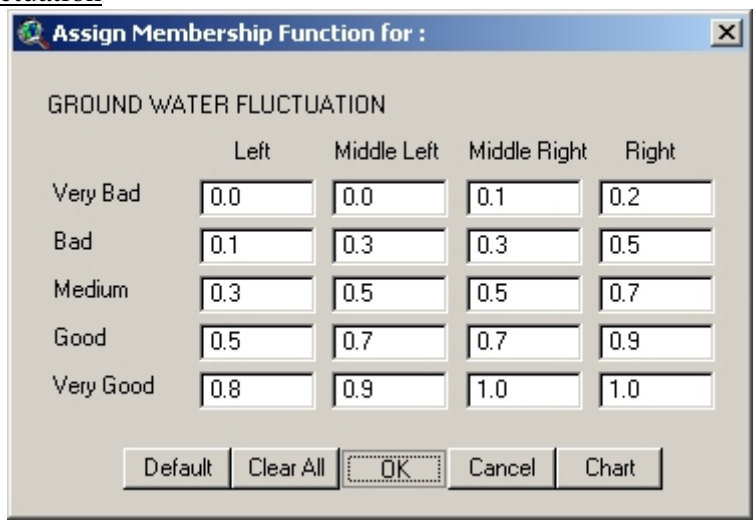
When defining the soil corrosivity membership function, the 'Soil Corrosivity' property is used.



5. Surface Type/Permeability

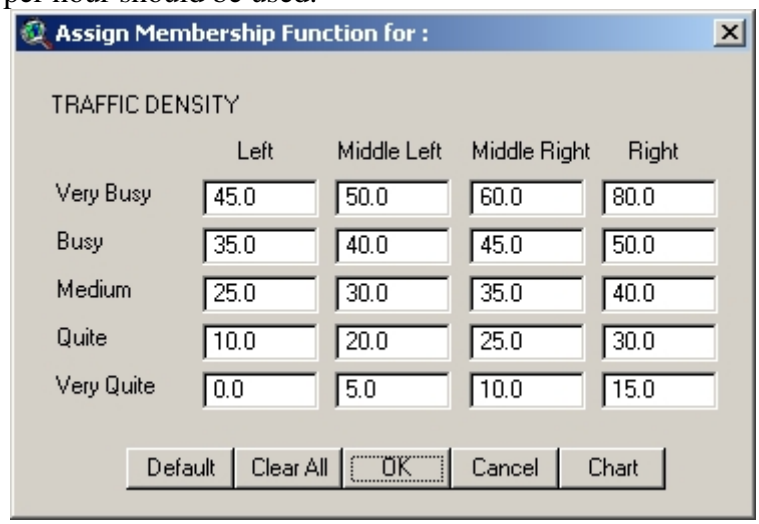


6. Ground Water Table Fluctuation



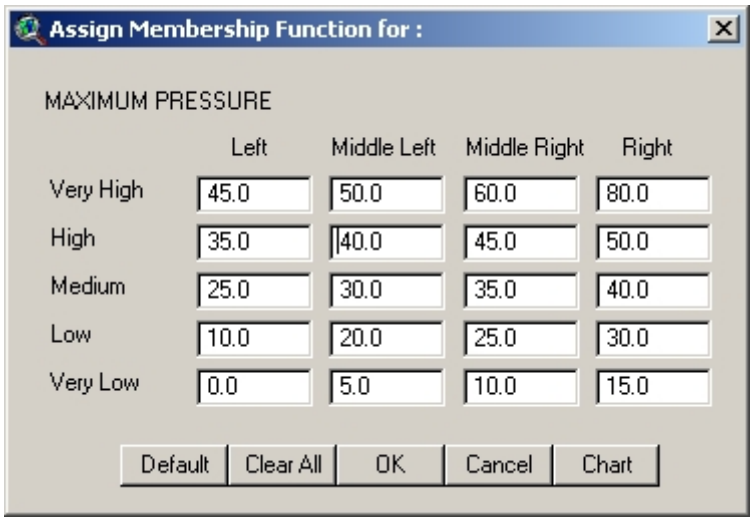
7. Traffic Density

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

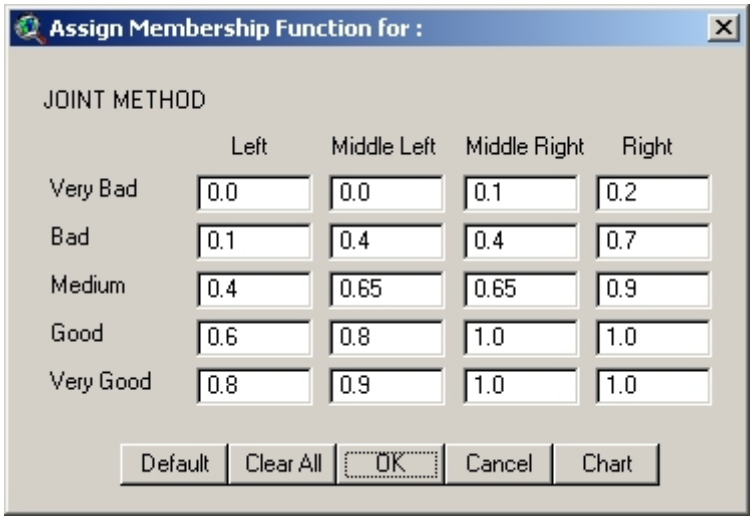


8. Maximum Pressure

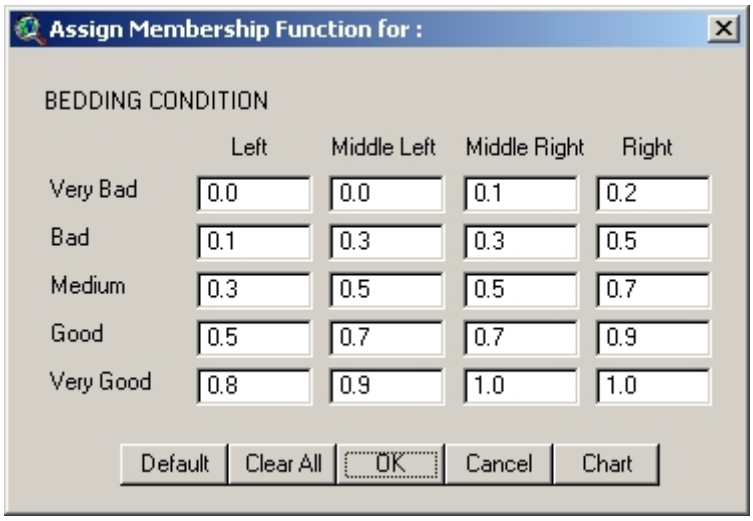
When defining the maximum pressure membership function, the values of pressure at the outlets should be used.



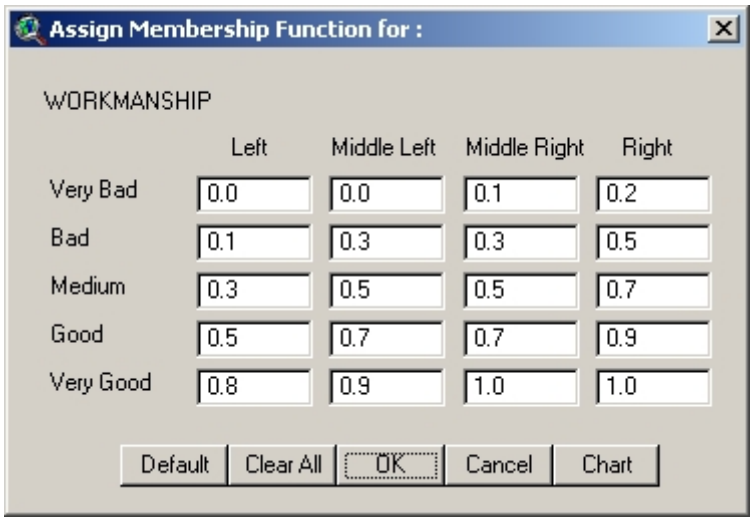
9. Joint Method



10. Bedding Condition



11. Workmanship

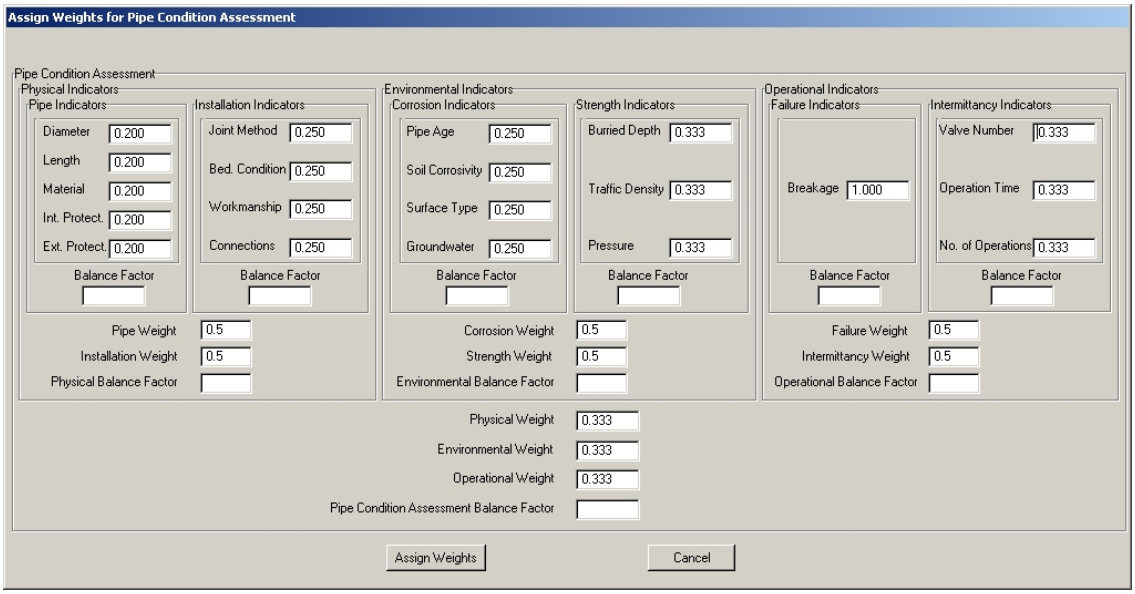


4.5.2 Weightage methods

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:

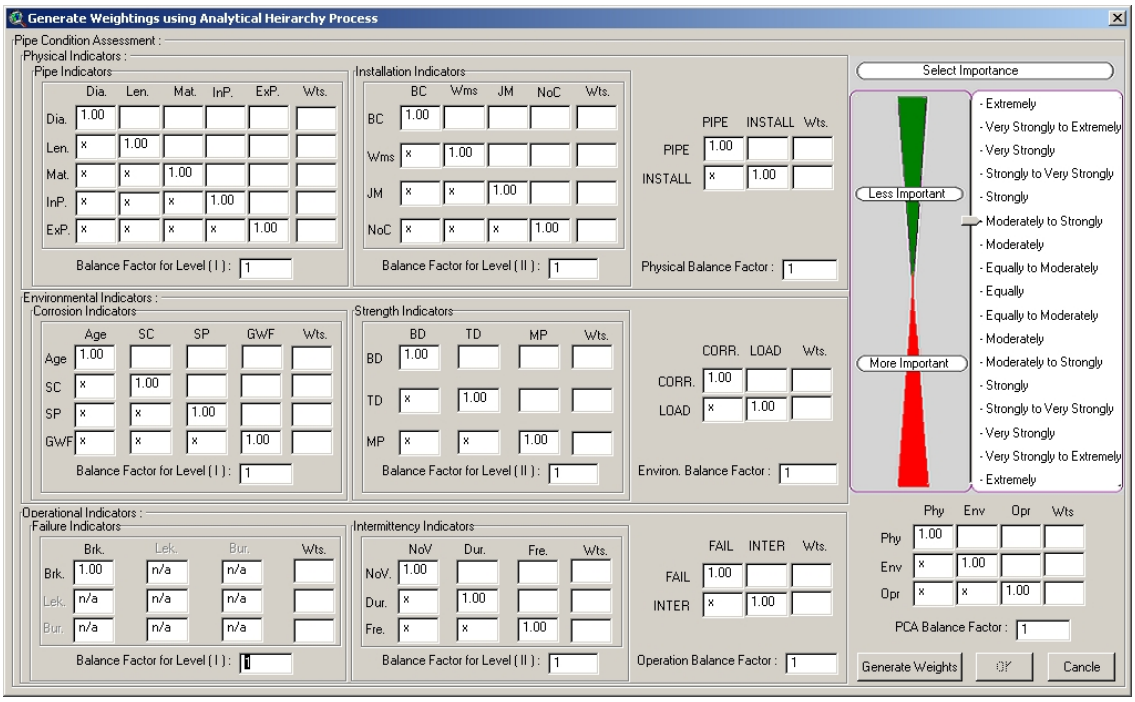
Equal Weights: With this method, equal weights are assigned to all the indicators of particular group. A balancing factor of 1 is assigned to all the groups.

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

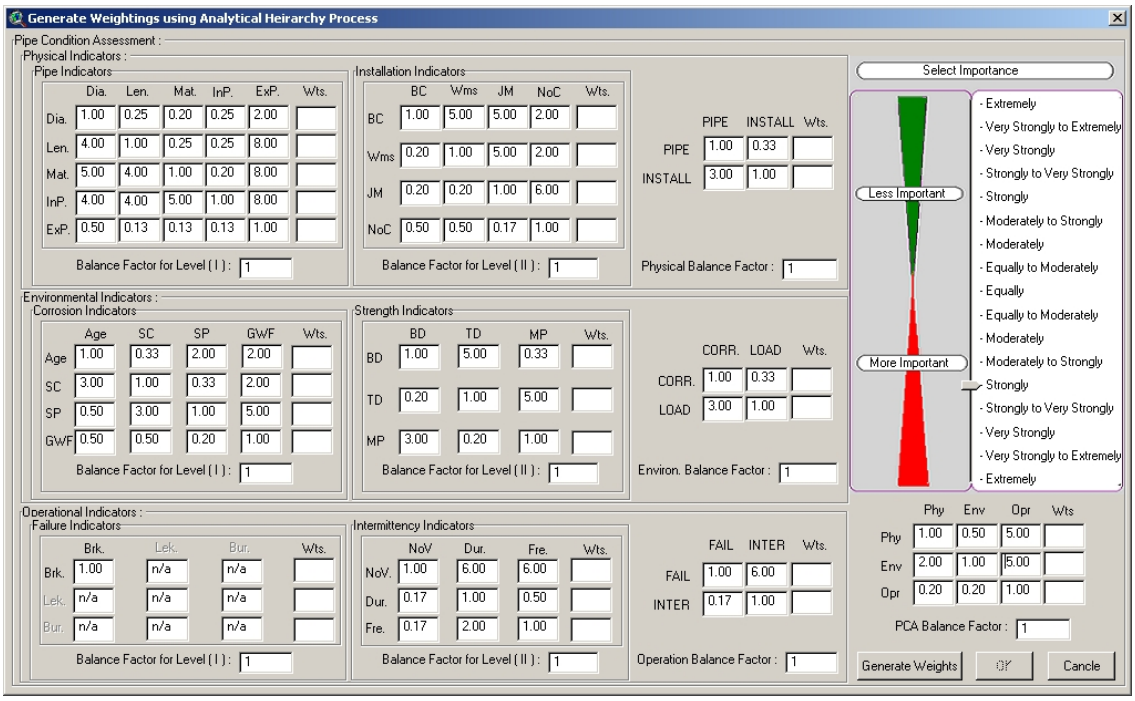


Depending on the number of indicators selected for the assessment, equal weights are assigned initially to all the indicators. The user can change the weights assigned to each indicator. However, it is necessary that the sum of the weights given in one group should be equal to 1 (see screen above). The 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.

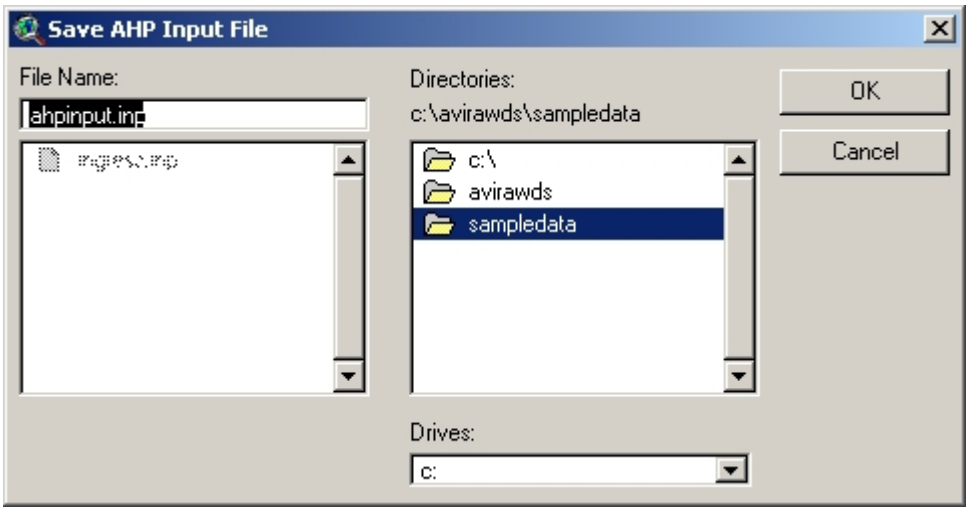
Generated by AHP: Weights can also be generated using the pair-wise comparison, that is, by Analytical Hierarchy Process (AHP). Clicking on 'Generate Weights' causes the following 'Generate Weights using Analytical Hierarchy Process' form to appear.



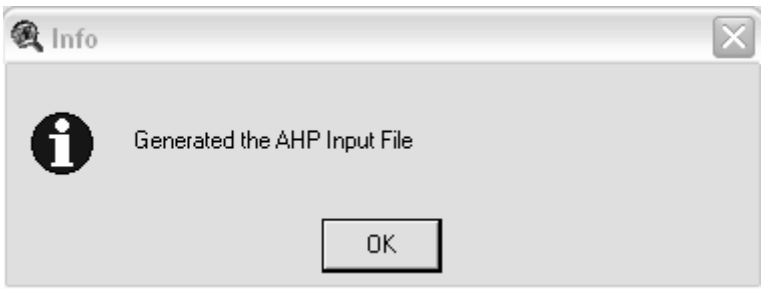
The matrix elements are enabled for those indicators that are selected in the 'Pipe Condition Assessment Input Form'. The slider on the right-hand side of the 'Generate Weightings using Analytical Hierarchy Process' form can be used to define the matrix element. The user needs to input values for the 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.



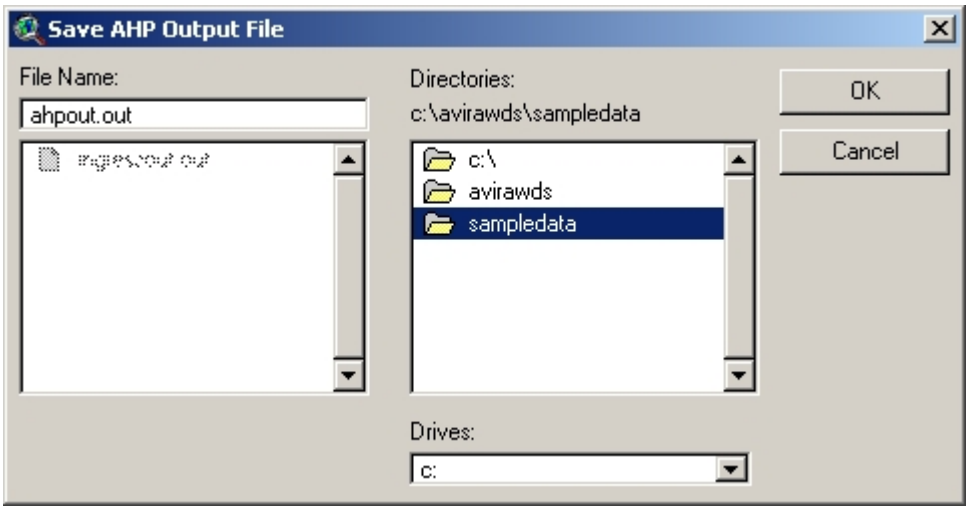
The user then clicks the 'Generate Weights' button, which opens the 'Save AHP Input File' dialogue box to save the AHP input matrix, as shown below:



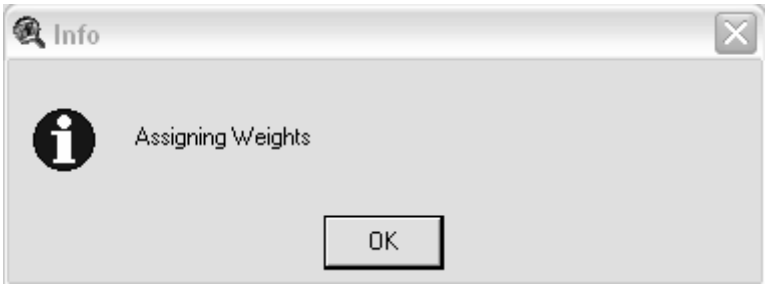
After selecting the input filename to save AHP input, the following dialogue box appears:



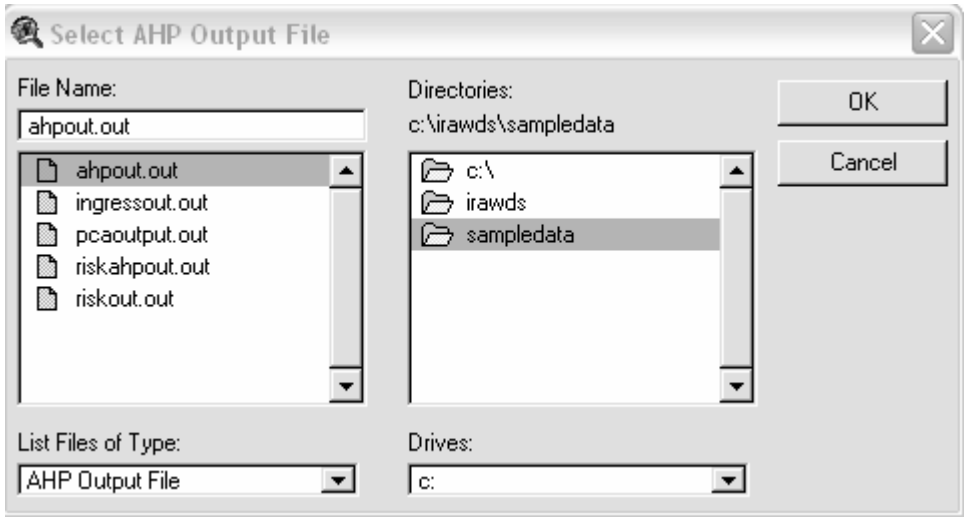
Confirming ‘OK’ on the ‘Generated the AHP Input File’ Info message box opens the ‘Save AHP Output File’ dialogue box and prompts the user about the filename to save the AHP output under, as shown below:



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

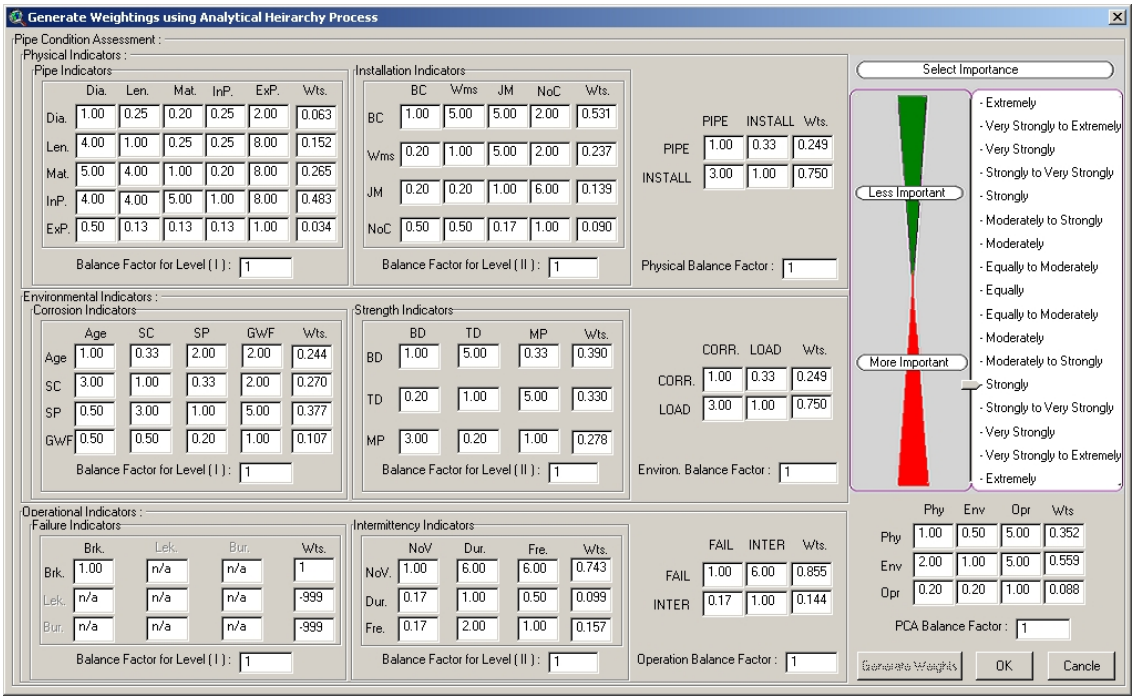


Clicking ‘OK’ executes the AHP model, which generates the weight for each parameter considered in the ‘Pipe Condition Assessment Input Form’ and then asks the name of AHP output file for viewing, as shown below:

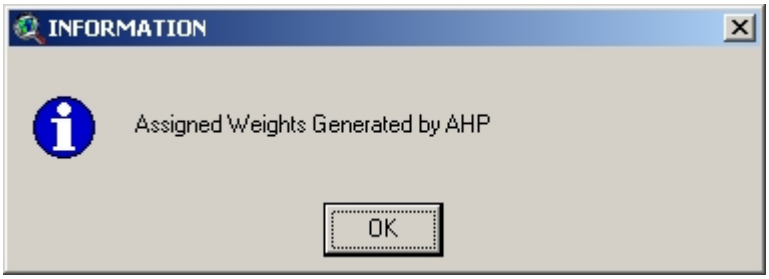


After the user gives the name of AHP output file, the following message appears:

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:



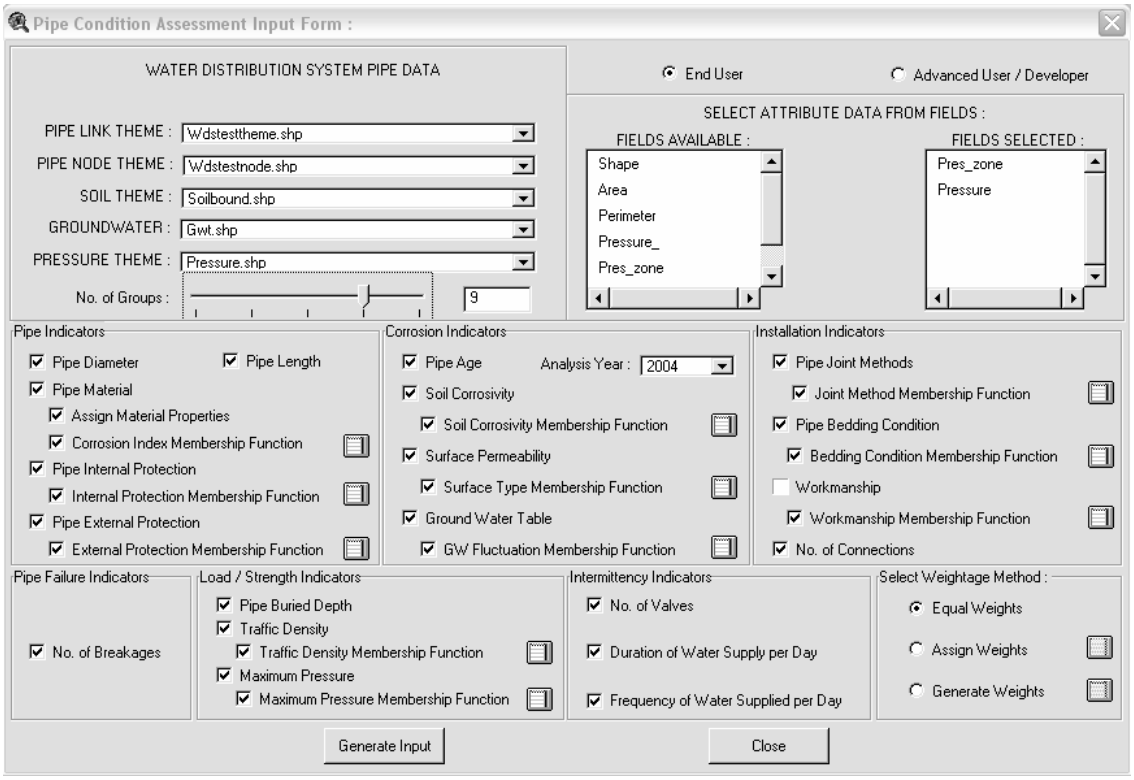
During this step the 'Generate Weights' button is disabled and 'OK' button is enabled. If the user clicks the 'OK' button, then the weights generated by AHP are assigned and a message is displayed as shown below:



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

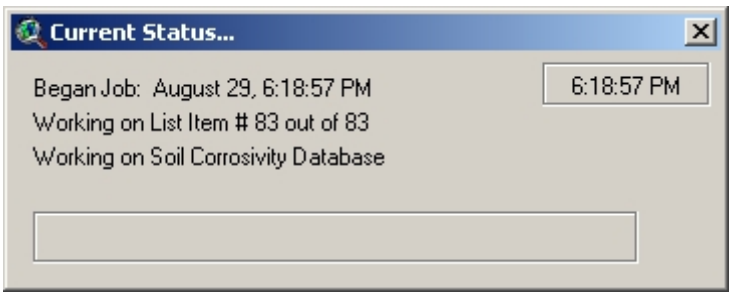
4.6 Number of groups

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:



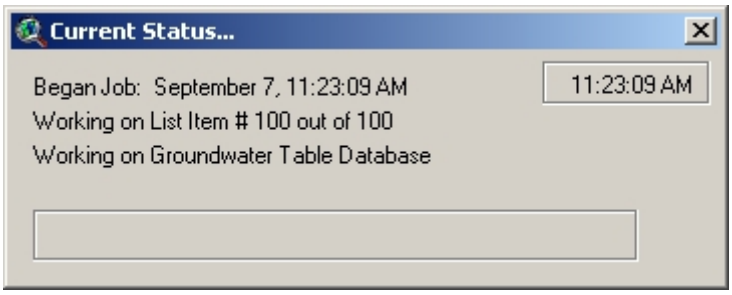
4.7 Generating the input file (PCA)

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.

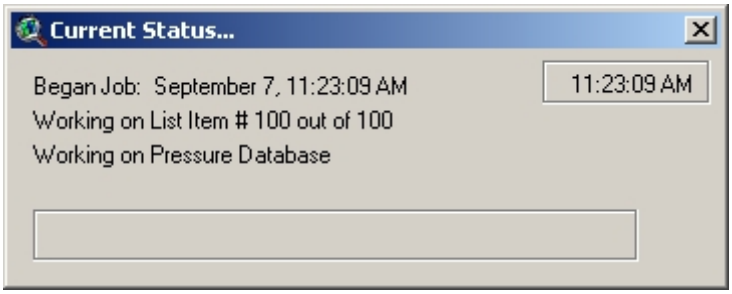


If the 'Ground Water Table' is selected, the interface finds the average groundwater table depth and groundwater fluctuation depth for each pipe. Then using the pipe

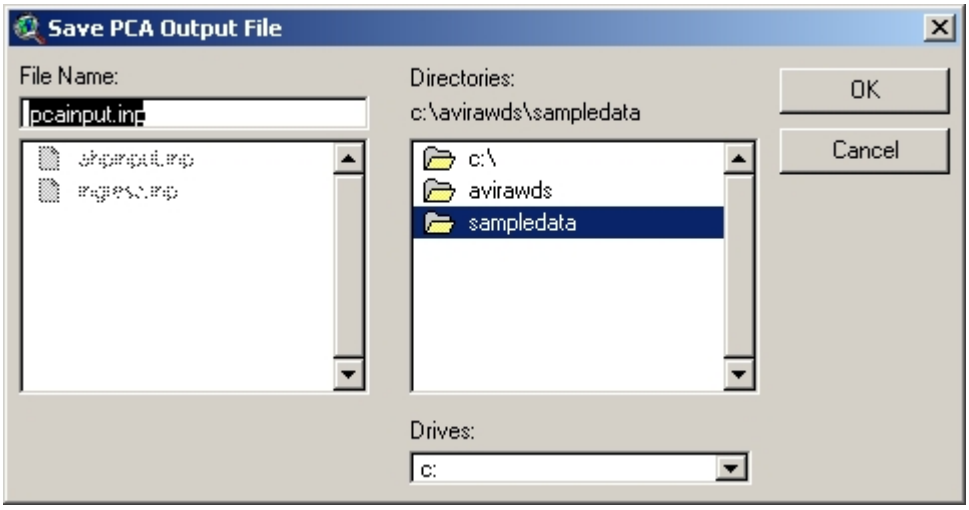
buried depth and the groundwater table data, it computes the groundwater category for each pipe and appends the water distribution pipe theme accordingly.



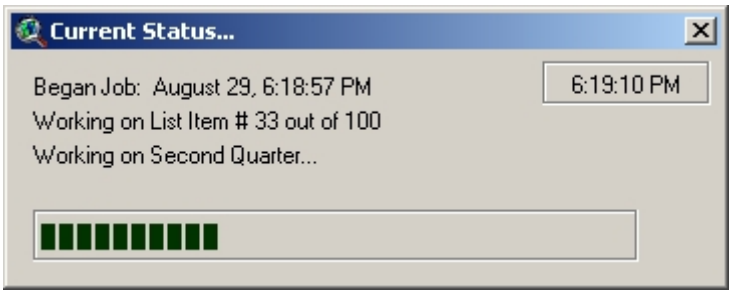
If the 'Maximum Pressure' is selected, the interface finds the pressure for each pipe and then appends the water distribution pipe theme according to the pressure category.



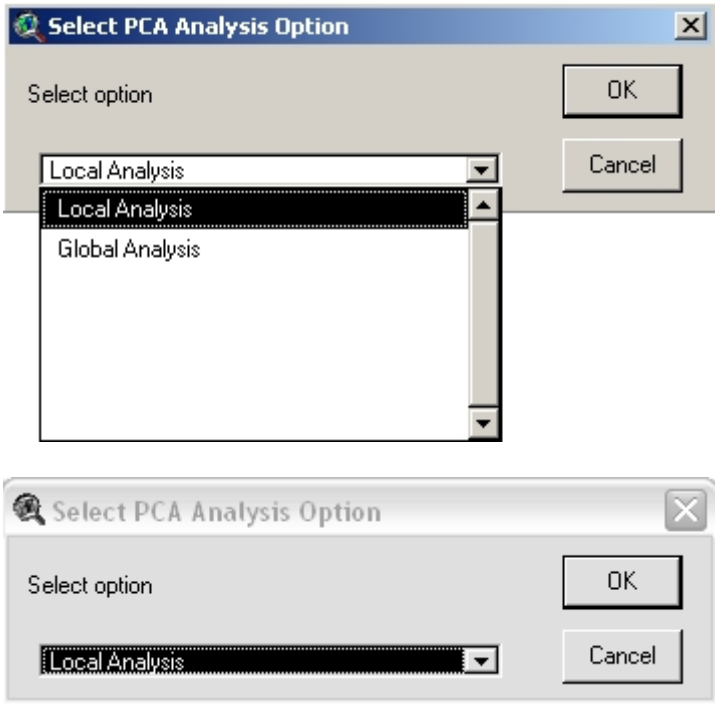
It then opens the 'File Save' dialogue box to save the file with the user-defined name.



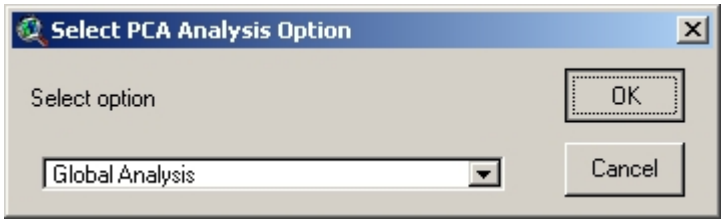
After the user writes/selects the input filename, the interface starts writing the input file. The data generation and writing progress is shown in the 'Current Status…' bar, as shown below:



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.

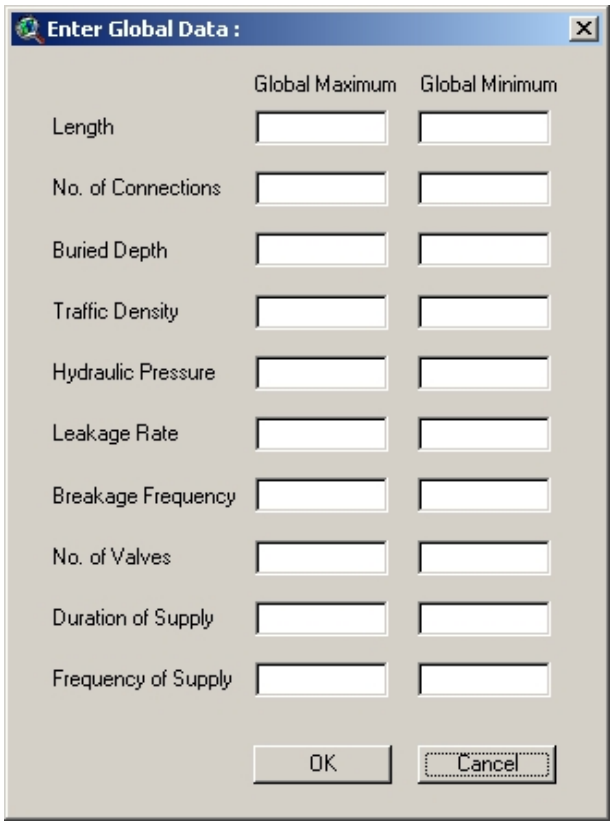


If user selects the 'Local Analysis' option, no more data input is required and the interface scans through the data input and finds the local maximum and minimum for the particular parameter required.

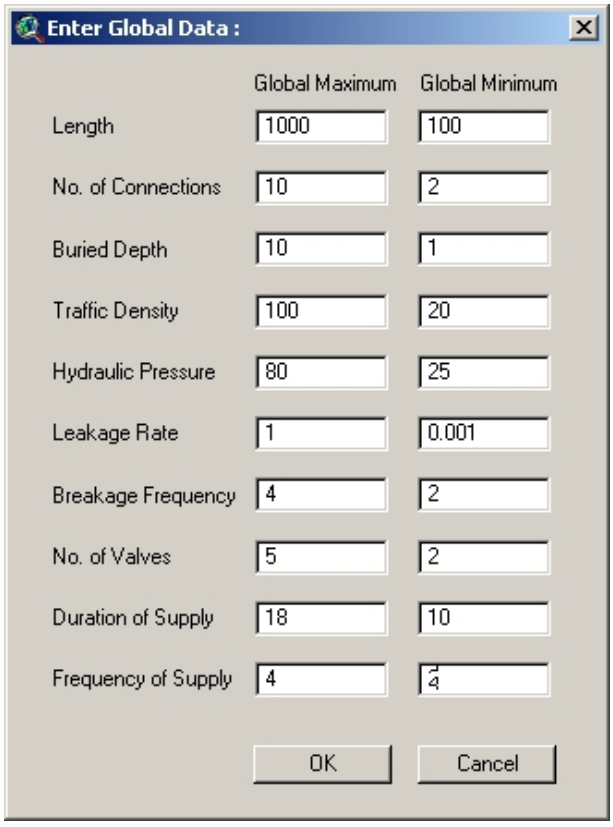


If the 'Global Analysis' option is selected, then one more input form is opened asking the user to fill in the maximum and minimum for certain parameters; these can then be

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



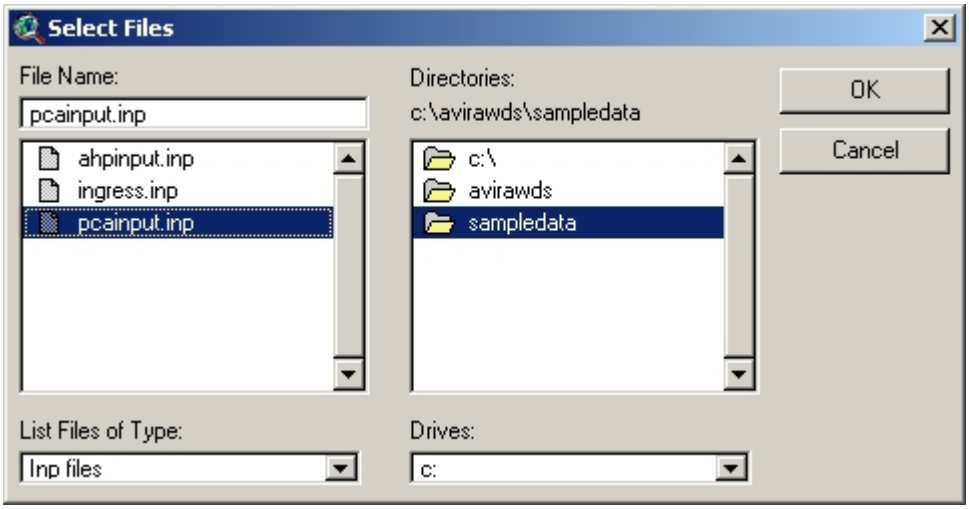
After the user has completed the data, the 'Global Data' input form looks as shown below:



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

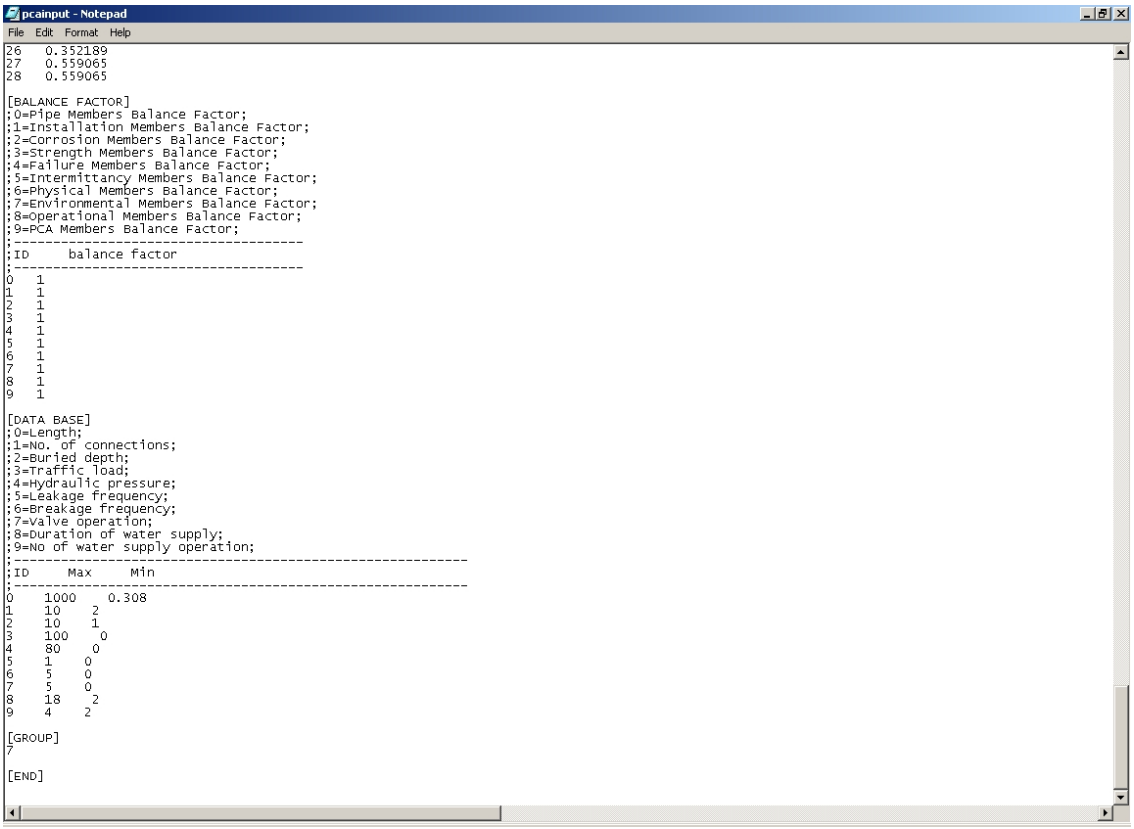
File Edit Format Help

```
;=====================================================================;
;       WATER PIPELINE Vulnerability Assessment Input
;=====================================================================;

[WATER PIPE]
;---------------------------------------------------------------------------------------------------------------------------------------------------
;ID     StNode  EndNode StJoint EndJoint        Material        Traffic SurfPerm        InProtect       ExProtect       BedCond Workship
;---------------------------------------------------------------------------------------------------------------------------------------------------

689     631     632     4       4       0       2       0       2       1       0       4       0       1       2       500     50 120  1.312
703     632     643     1       1       0       2       2       2       4       4       1       0       1       2       500     50 120  51.20
722     660     631     1       1       1       2       2       2       4       3       1       0       1       2       500     50 70   21.79
762     643     696     2       2       0       2       2       2       4       3       2       0       1       2       400     50 120  48.79
781     696     713     2       2       0       2       2       2       4       3       2       0       1       2       400     50 120  13.70
786     719     660     2       2       1       2       2       2       4       1       2       0       1       2       500     50 70   57.72
796     713     728     2       2       0       2       2       2       4       3       2       0       1       2       400     50 120  65.78
800     732     719     2       2       1       3       2       2       4       1       2       0       1       2       500     50 70   17.32
803     734     732     2       2       1       3       2       2       4       1       2       0       1       2       500     50 70   1.848
808     728     739     2       2       0       2       0       2       1       3       3       1       1       1       400     35 120  37.87
809     740     734     2       2       1       3       2       2       4       1       2       0       1       2       500     50 70   18.99
818     739     747     2       2       0       2       0       2       1       3       3       1       1       1       400     35 120  62.12
824     753     740     2       2       1       3       2       2       4       1       2       0       1       2       200     50 70   72.37
830     747     758     2       2       0       2       0       2       1       3       4       1       4       1       400     35 120  48.64
831     760     753     2       2       1       3       0       2       1       1       2       0       1       2       200     50 70   27.62
836     765     728     2       2       0       2       0       2       1       3       2       1       1       2       400     20 130  38.94
837     765     760     2       2       1       3       0       2       1       1       2       1       1       2       200     20 120  25.67
842     758     769     2       2       0       2       0       2       1       3       4       1       4       1       400     35 120  38.08
852     777     765     2       2       1       3       0       2       1       1       2       1       1       1       200     35 95   37.53
855     780     765     2       2       0       3       0       2       1       1       2       1       1       2       200     20 130  12.74
856     781     734     2       2       2       4       2       1       4       1       2       0       1       2       500     50 100  61.00
861     785     781     2       2       2       4       2       1       4       1       2       0       1       2       200     20 120  3.559
862     786     785     2       2       2       4       2       1       4       1       2       0       1       2       200     20 120  0.308
865     769     788     1       1       0       3       0       2       1       3       4       1       4       1       400     35 120  54.68
866     789     777     2       2       1       3       0       2       1       1       3       1       1       1       200     35 95   40.72
879     800     786     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  19.12
880     789     801     2       2       1       3       0       2       1       1       3       1       1       1       200     35 95   36.71
883     801     806     2       2       1       3       0       2       1       1       4       1       4       1       200     35 95   36.38
884     807     758     2       2       1       2       0       2       1       3       4       1       4       1       400     35 95   37.14
885     806     807     2       2       1       3       0       2       1       1       4       1       4       1       200     35 95   0.517
892     814     785     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  30.13
893     815     814     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  3.216
898     807     821     2       2       1       3       0       2       1       1       4       1       4       1       200     35 95   37.69
899     821     822     2       2       1       3       0       2       1       1       4       1       4       1       200     35 95   1.133
900     823     815     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  11.45
905     827     800     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  35.15
914     834     788     1       1       0       3       0       2       1       3       4       1       4       1       400     35 120  35.88
915     822     834     1       1       1       3       0       2       1       1       4       1       4       1       200     35 95   52.62
917     815     836     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  30.48
918     801     837     2       2       0       1       0       2       1       1       3       1       4       1       200     35 120  31.21
920     839     834     1       1       0       3       0       2       1       1       4       1       4       1       200     35 120  7.589
936     852     827     1       1       2       1       0       1       1       1       2       0       1       2       200     20 120  64.84
942     858     839     1       1       0       3       0       2       1       1       4       1       4       1       200     35 120  17.21
944     760     860     2       2       0       1       0       2       1       1       2       1       1       2       200     20 130  85.53
945     852     860     2       2       0       1       0       2       1       1       2       1       1       2       200     20 130  33.33
949     836     863     1       1       2       4       2       1       4       1       2       0       1       2       200     20 120  69.51
950     865     780     2       2       0       1       0       2       1       1       2       1       1       2       200     20 130  74.34
951     860     865     2       2       0       1       0       2       1       1       2       2       1       2       200     20 130  25.65
956     869     852     1       1       2       1       0       1       1       1       2       0       1       2       200     20 120  24.21
957     863     869     1       1       2       3       0       1       1       1       2       0       1       2       200     20 120  35.20
```

pcainput - Notepad

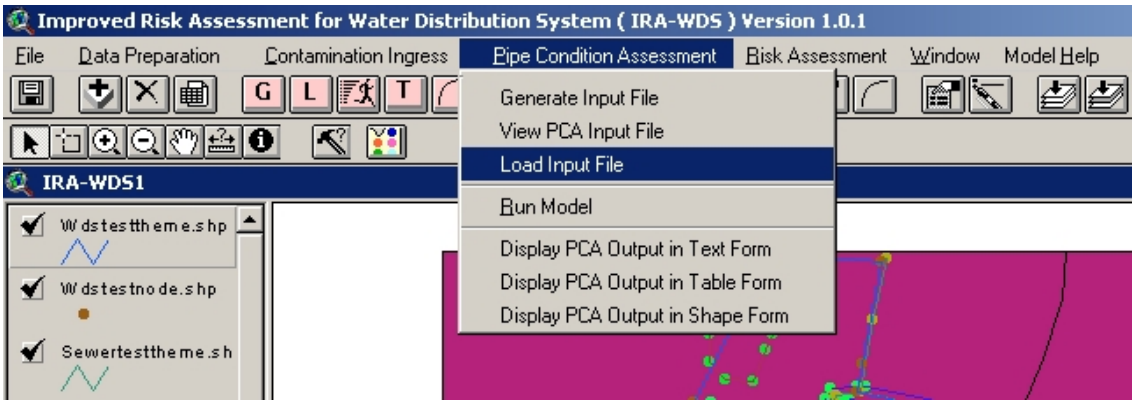
File Edit Format Help

```
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       2       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= U1
;3= PVC
;4= CI
;---------------------------------------------------------------------------------------------------------
;ID      CorrResis       MaxPres         MaxLoad         MaxDia          MinDia          MaxLife
;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
```

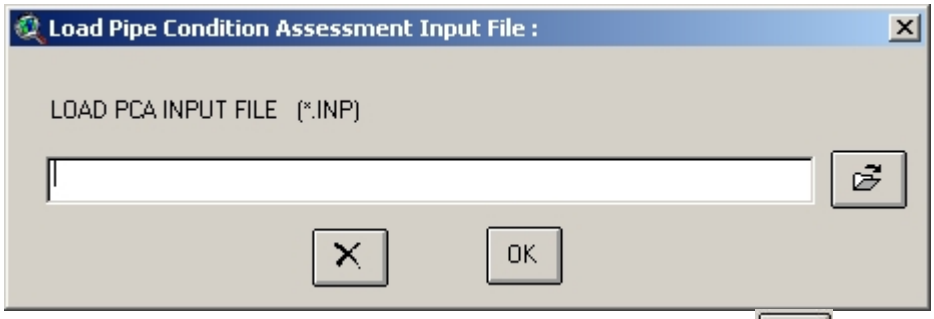


4.9 Loading the input file

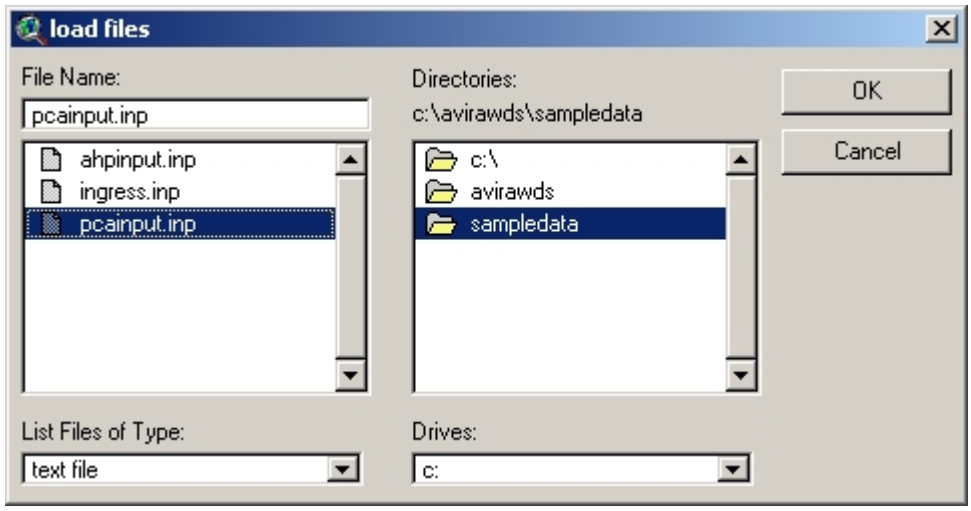
The input file to be used for running the Pipe Condition Assessment Model is loaded using the tool  , which is just below the 'Pipe Condition Assessment' menu or by clicking on the 'Pipe Condition Assessment' menu and then clicking on the submenu 'Load Input File', as shown in the screen below:



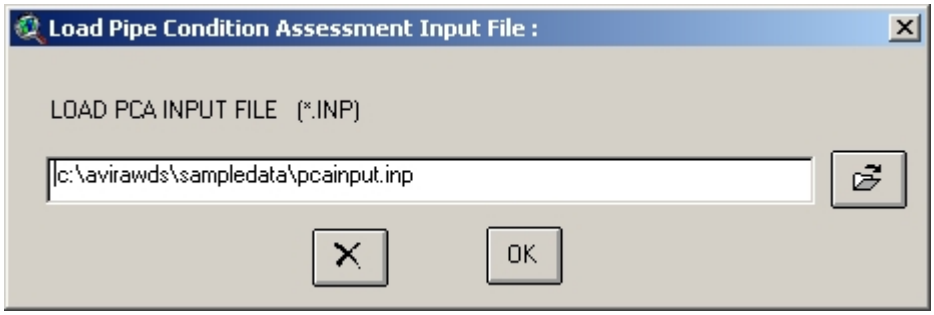
The ‘Load Pipe Condition Assessment Input File’ is shown below:



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:



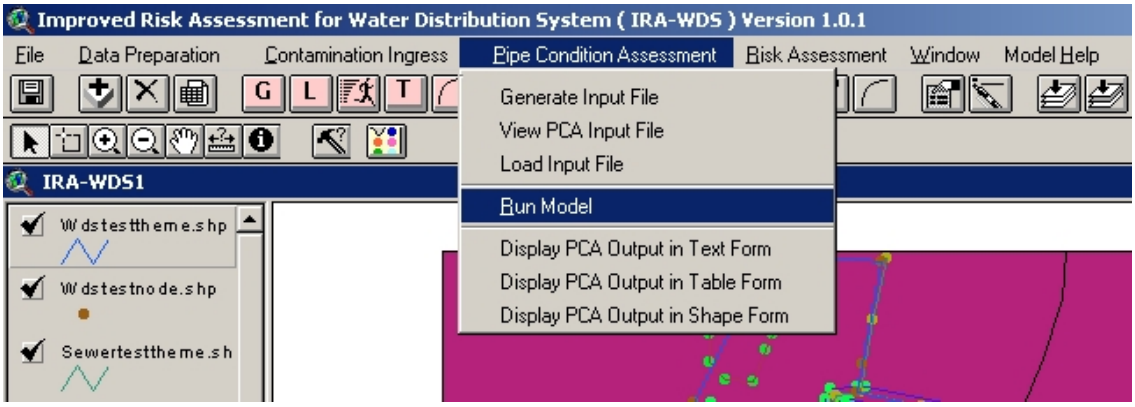
After the appropriate file has been selected and the user has pressed the ‘OK’ button on the filename, the filename appears in the ‘Load Pipe Condition Assessment Input File’ dialogue box.



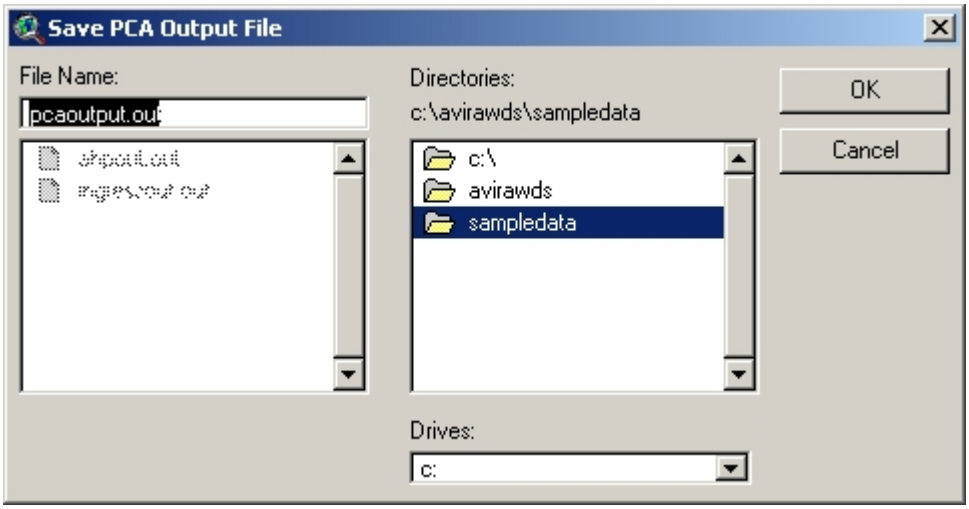
If the user wants to change the filename, he or she can do so by clicking the button  , which clears the filename from the ‘Load Pipe Condition Assessment Input File’ dialogue box. If user is sure of the input file selected, he or she can load it by clicking on the  button. This also closes ‘Load Pipe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

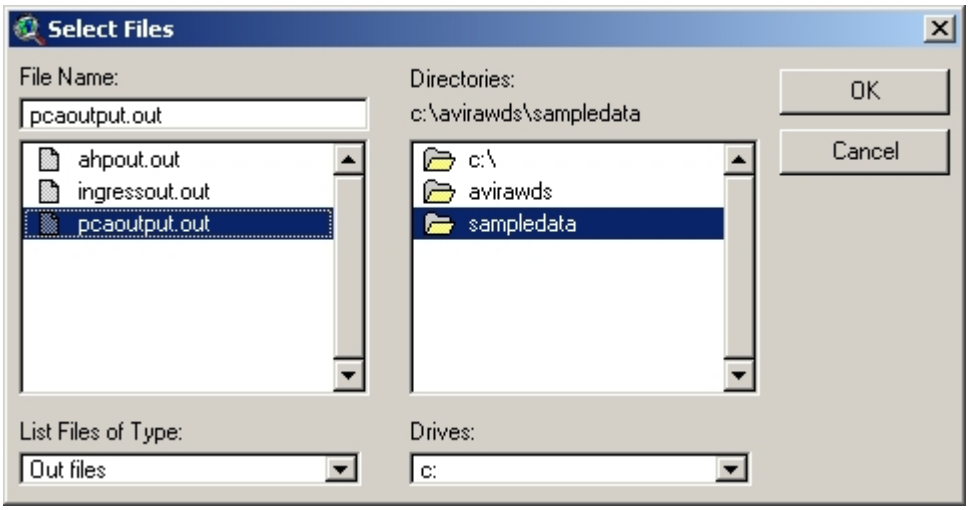
4.11 Displaying the output

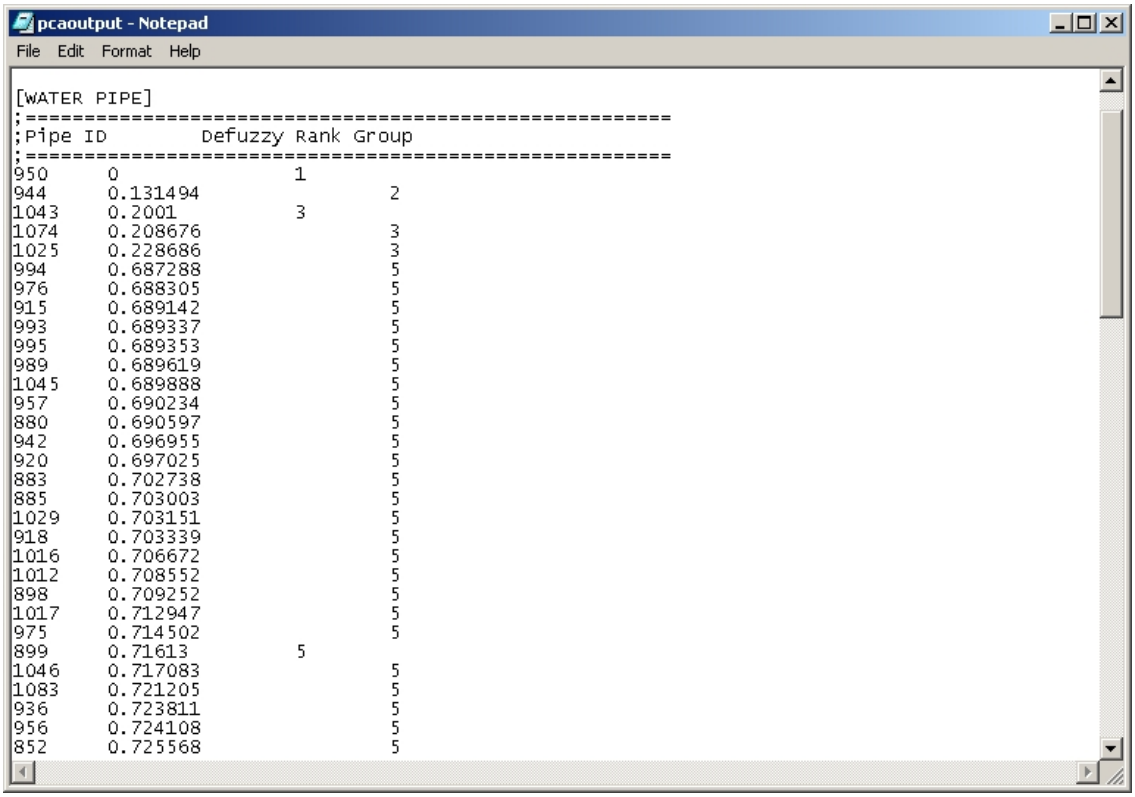
Output can be displayed in the following three forms:

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

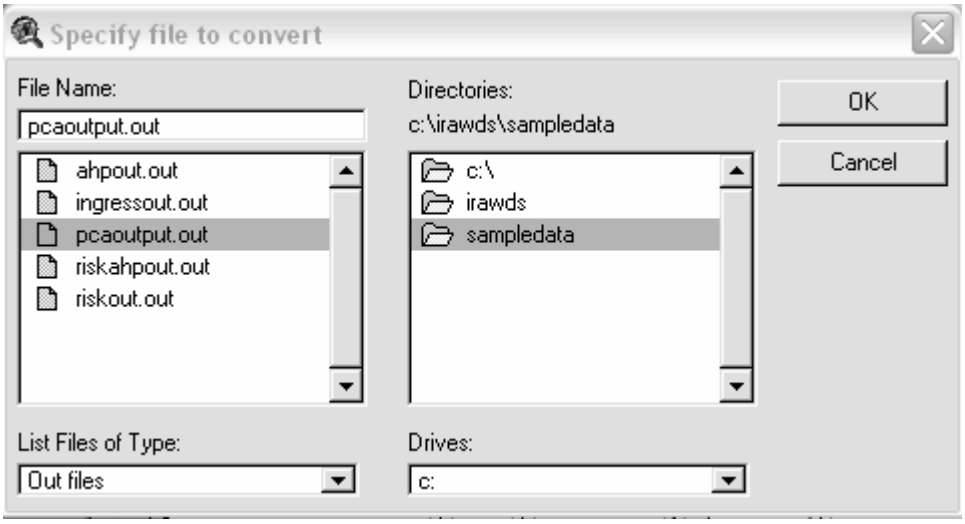
The user can view the output file in the text form in notepad by clicking on the  button or by selecting the 'Display PCA Output in Text Form' submenu from the 'Pipe Condition Assessment' menu and browsing the appropriate output file to view.





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:

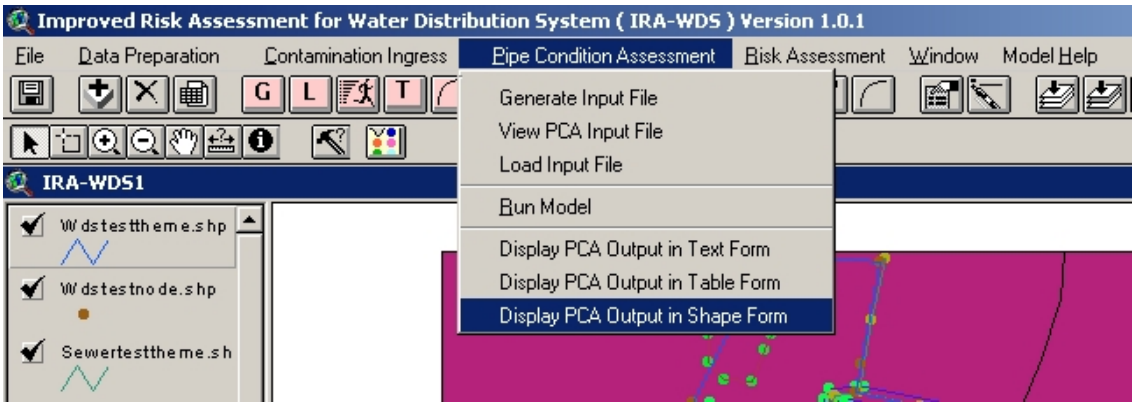


c:\irawds\sampledata\pcaoutput.dbf

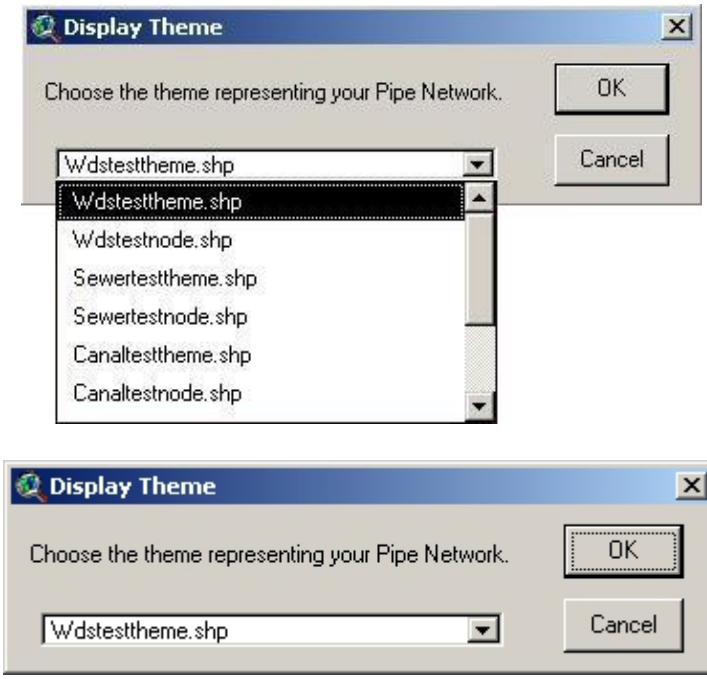
PipeID	DeFuzzy	Rank
950	0.000	1
944	0.283	3
1043	0.430	4
1074	0.448	4
1025	0.491	5
831	0.776	7
975	0.777	7
824	0.778	7
880	0.781	7
852	0.793	7
866	0.797	7
837	0.797	7
951	0.797	7
936	0.799	7
1083	0.799	7
957	0.800	8
809	0.802	8
989	0.804	8
883	0.805	8
994	0.805	8
945	0.806	8
956	0.806	8
915	0.808	8
786	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

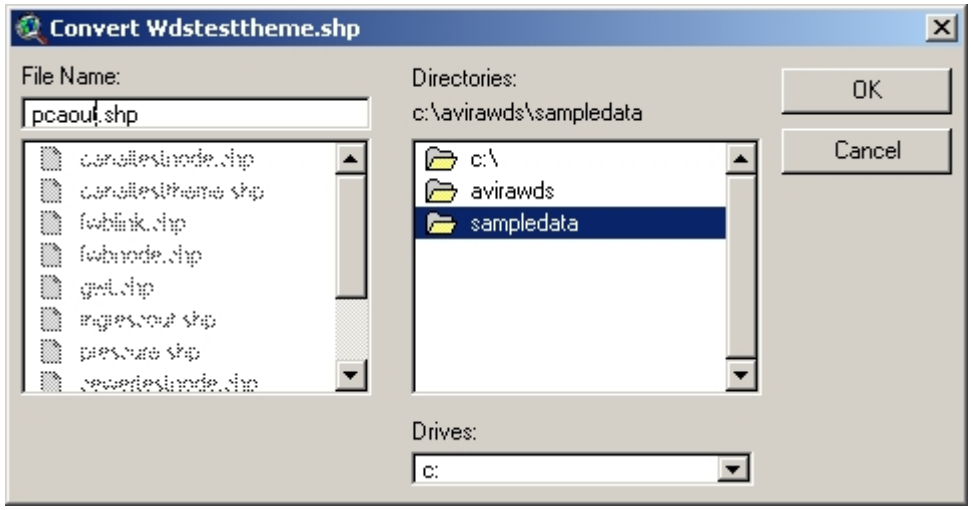
To view the Pipe Condition Assessment output in shape file form, the user should click on the  button, which is just below the 'Pipe Condition Assessment' menu or he or she can click on the 'Pipe Condition Assessment' menu and then click on the submenu 'Display Ingress Output in Shape Form', as shown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



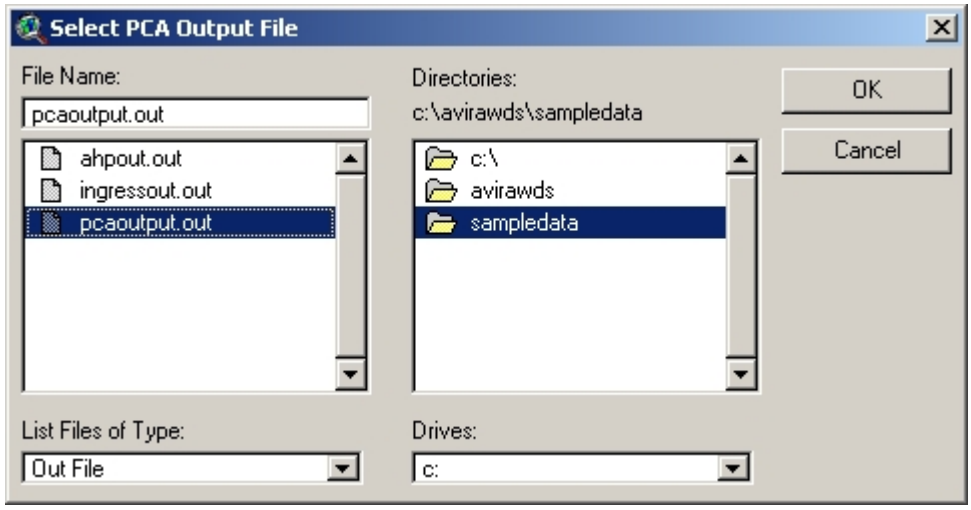
This opens the 'Display Theme' message box asking the user to specify which theme represents the water distribution system pipe theme, as shown below:



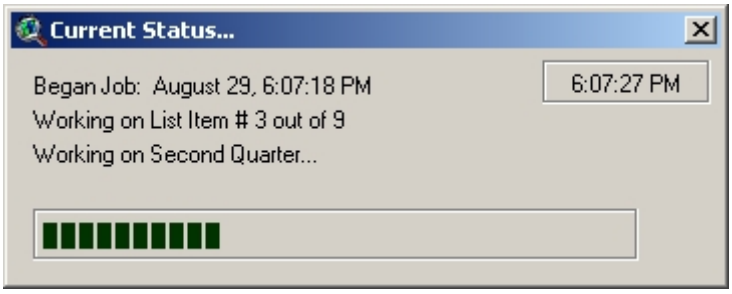
Once the user selects the appropriate theme representing the water distribution system pipe network and clicks on the 'OK' button, the 'Convert Theme' dialogue box appears on the screen and asks the user to give the name with which he or she wants to store/convert the selected theme, as shown on next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

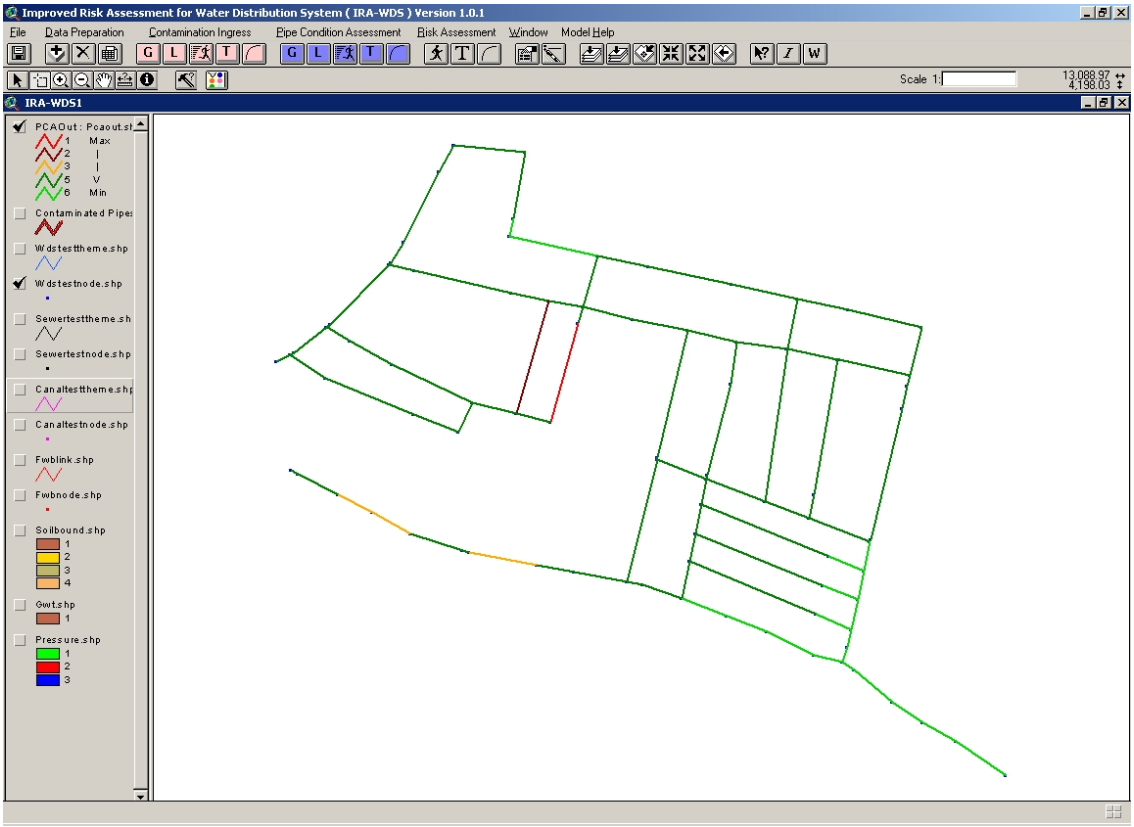


Once the user has selected the appropriate filename and clicked 'OK', the program shows the progress meter, as below:



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

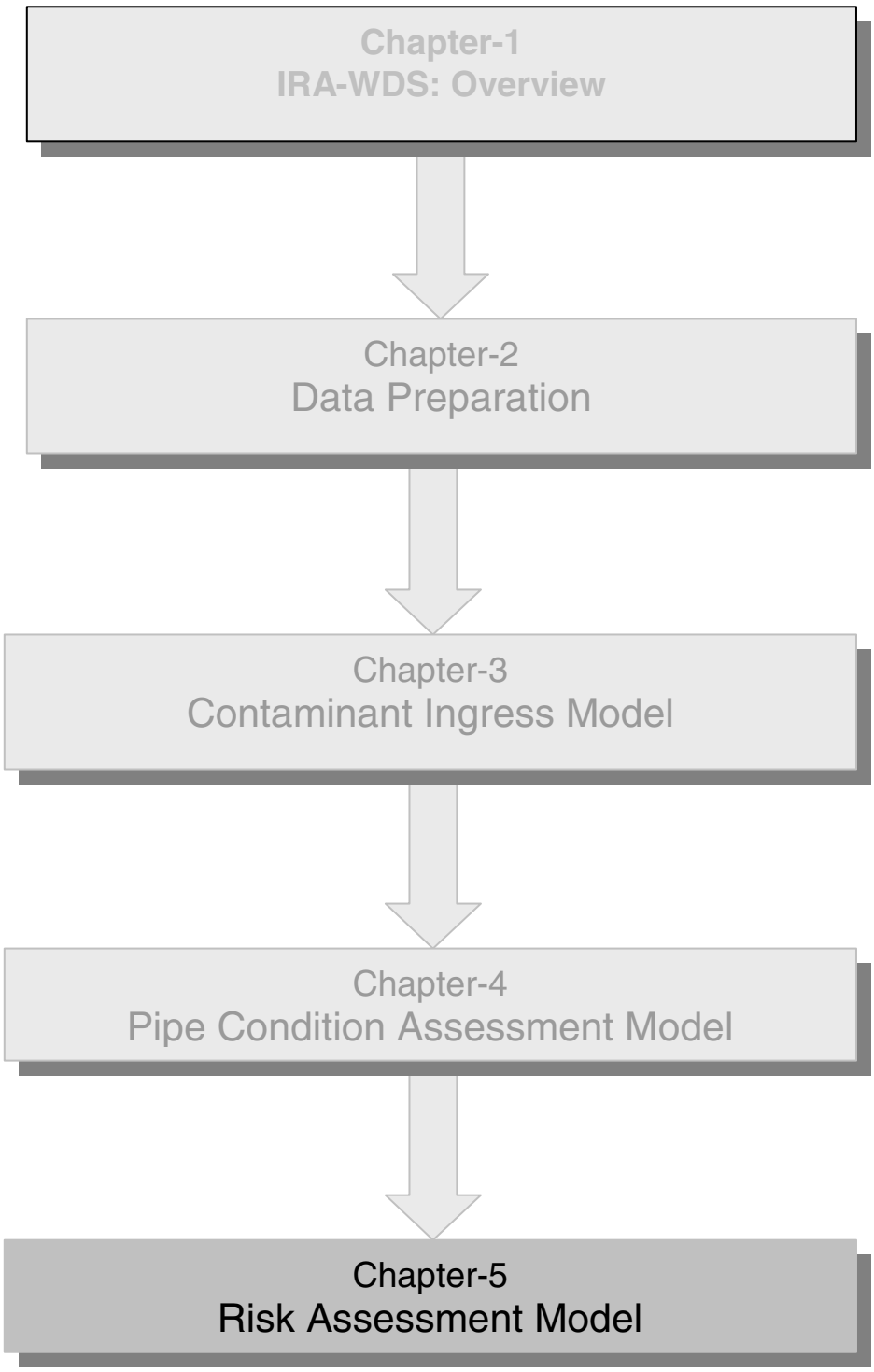
After clicking the ‘OK’ button on this message box, the new shape-file is added to the IRA-WDS data viewer. The ‘PCAOut’ theme legend needs to be changed by the user and instead of viewing the theme in a single colour, it can be viewed by unique values of ‘PCARank’, as shown below:



CHAPTER FIVE

Risk Assessment Model

Manual of Risk Assessment for Contaminant Intrusion into Water Distribution Systems



Chapter 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.

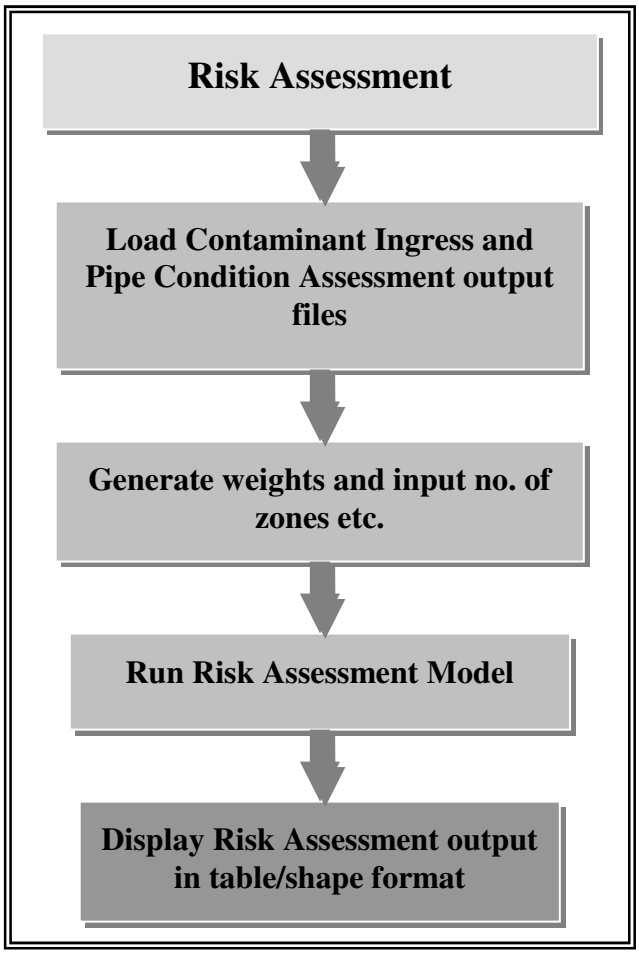


Figure 5.1. Overview of Risk Assessment Model of IRA-WDS

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

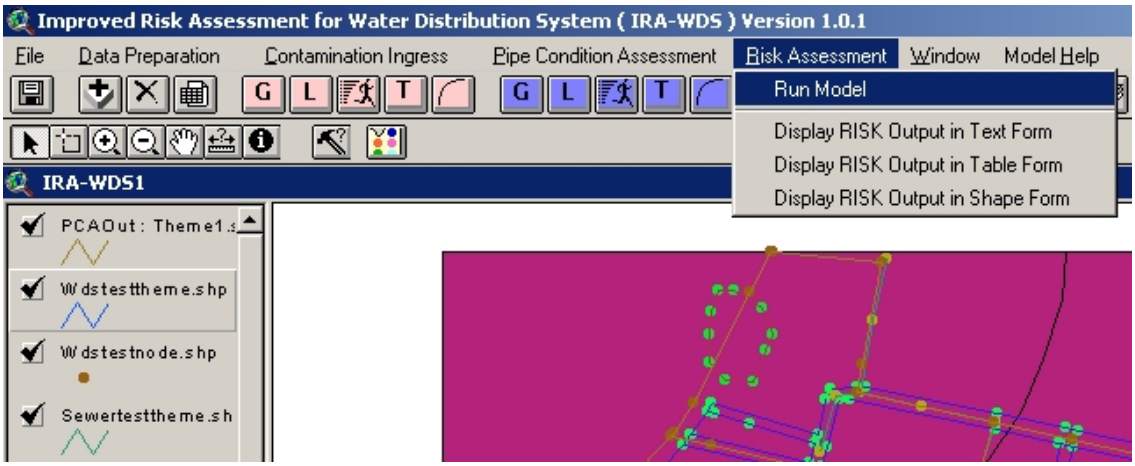
- Run Model
- Display output (optional)

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

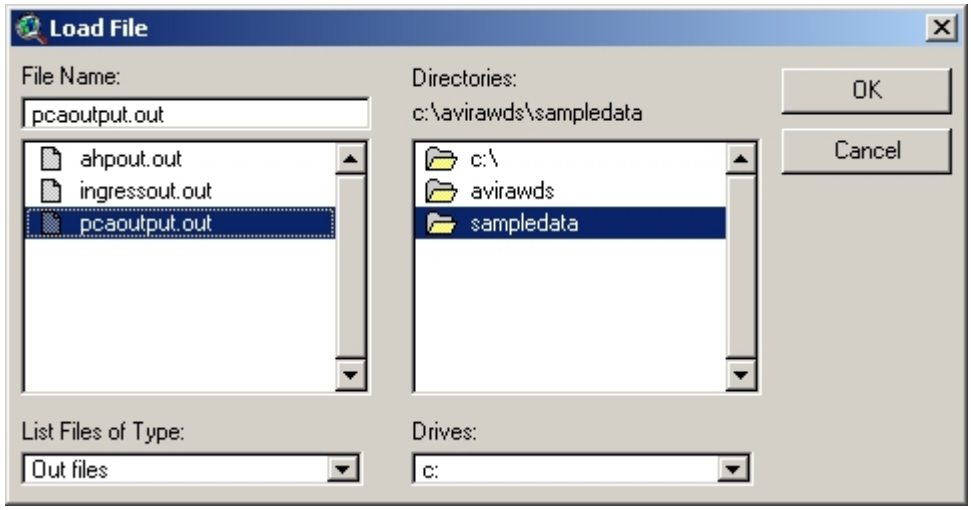
5.2 Running the Risk Assessment Model

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:



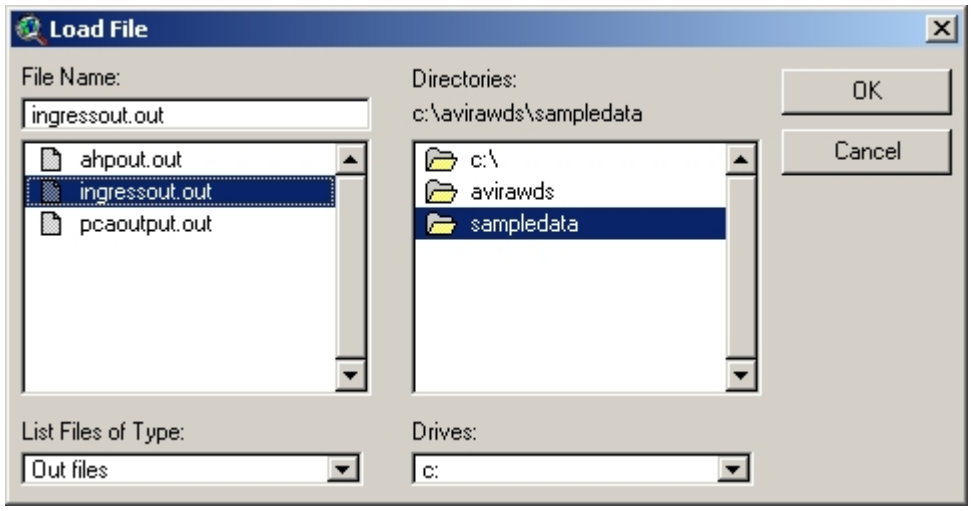
5.2.1 Loading the files

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.



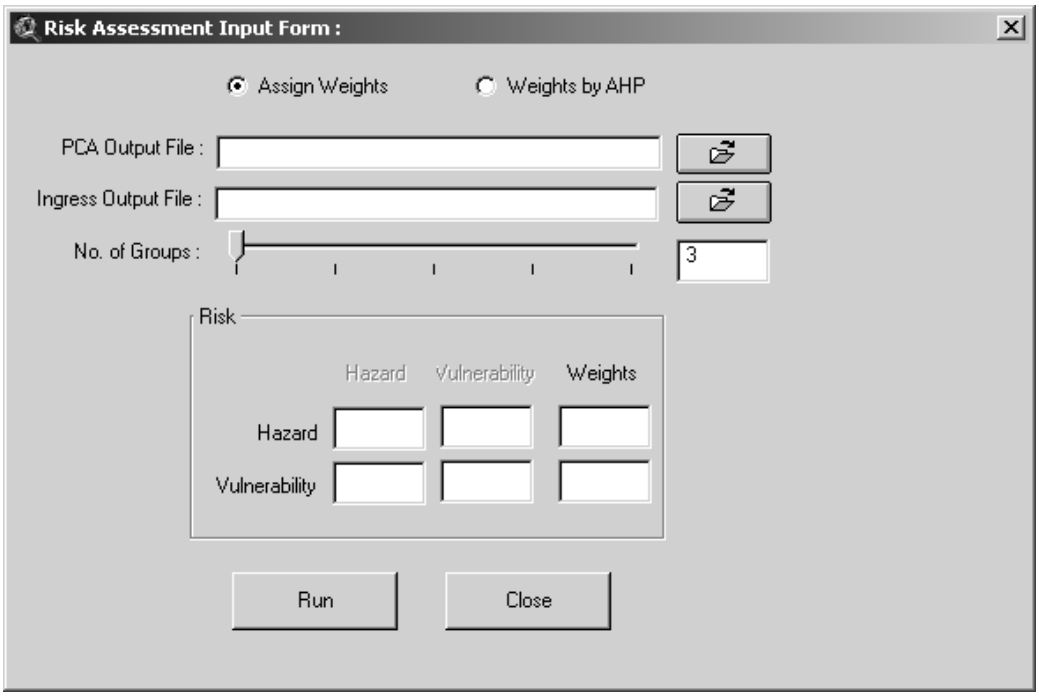
After selecting the appropriate file, the user should click on the 'OK' button; this will close the 'Load File' dialogue box and will write the name of the selected file in the 'PCA Output File' text box.

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.

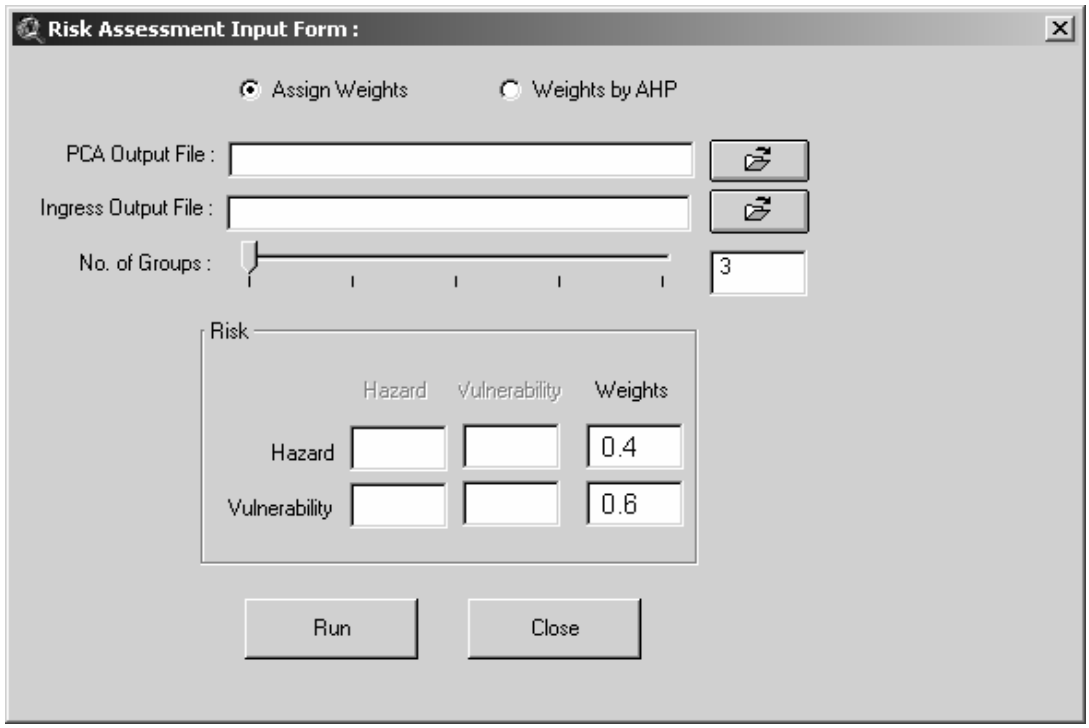


5.2.2 Weights

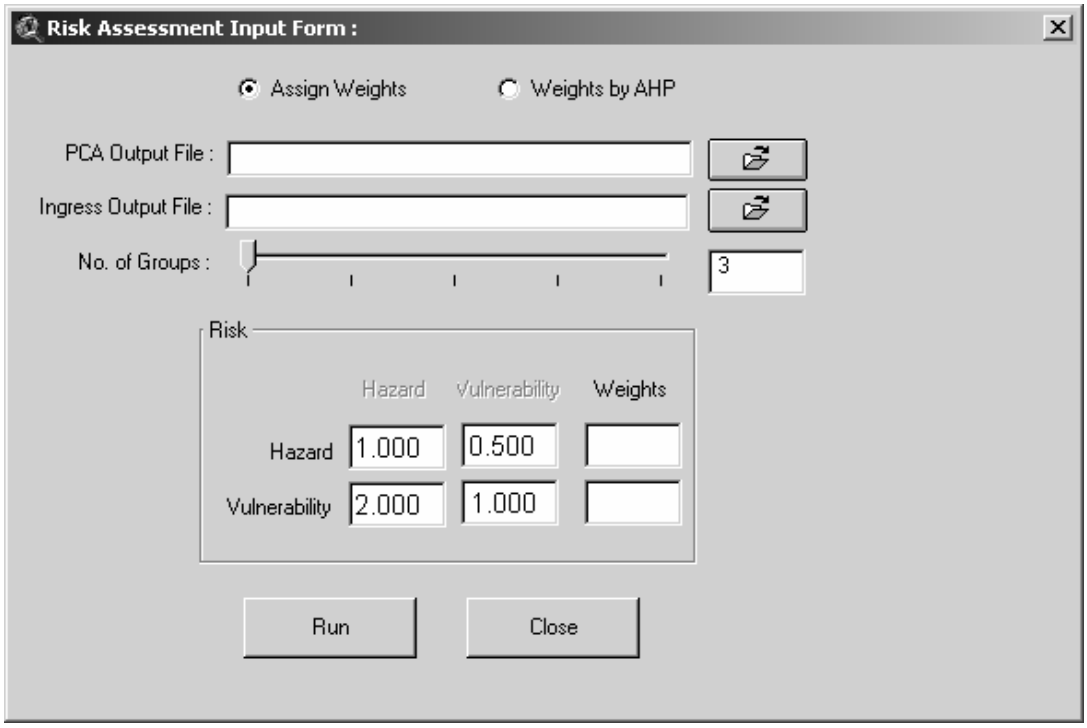
The 'Risk Assessment Input Form' has two options for giving importance to the Risk Assessment parameters ('Pipe Condition', 'Length of Contamination' and 'Concentration of Contamination'). These options are:

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:



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:

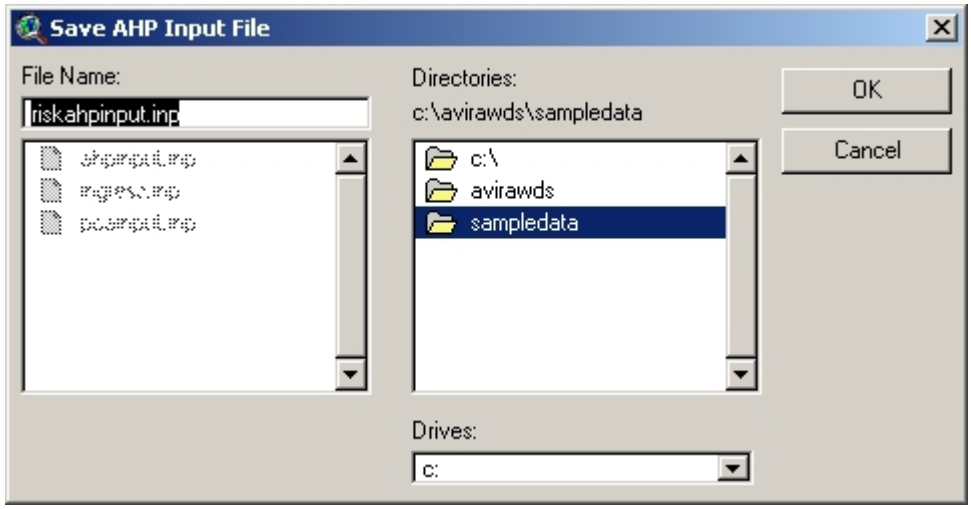


The interface also allows the user to select the number of groups in which the risk is to be categorized by sliding the bar in front of 'No. of Groups' on the 'Risk Assessment Input Form' or by entering the number of groups in the box provided, as shown above.

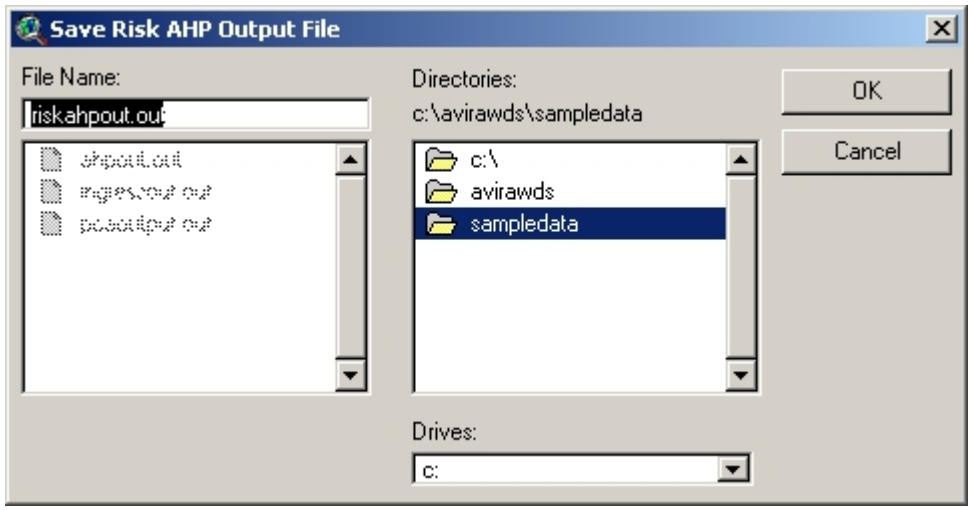
5.2.3 Running the Risk Model

To run the risk model, the user should click on the 

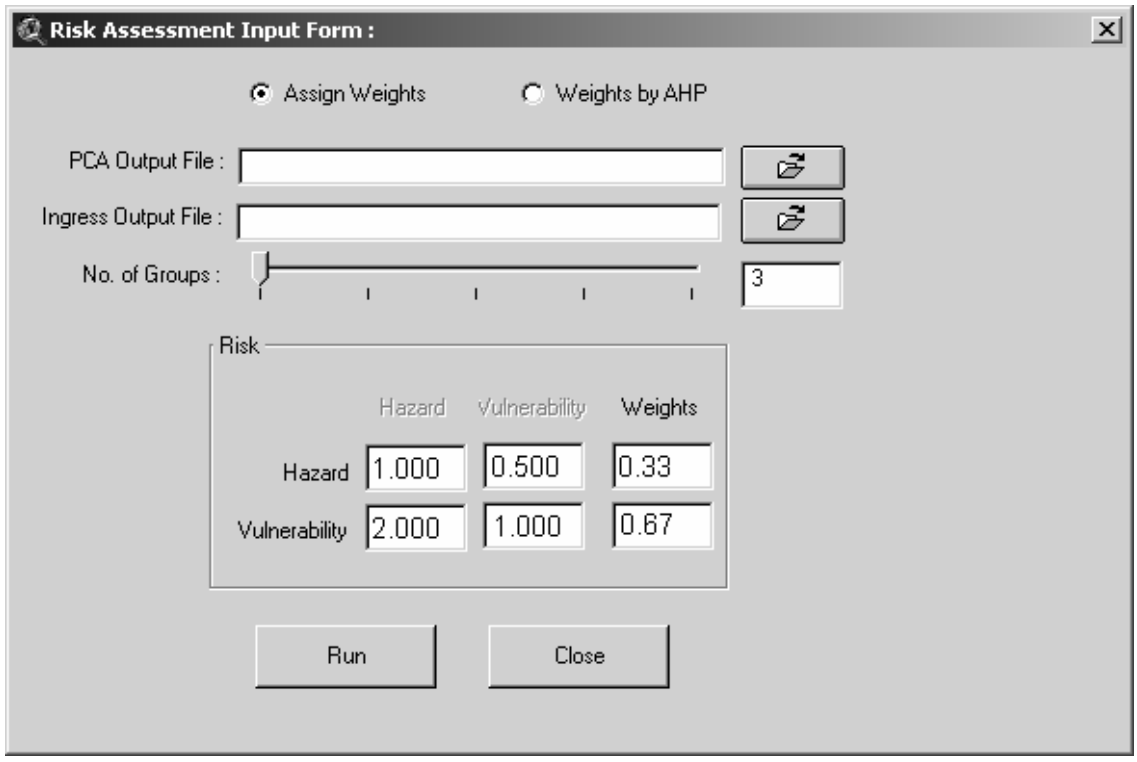
button on the 'Risk Assessment Input Form'. If 'Weights by AHP' has been selected, the model first writes the AHP input file for generating the weights. It then opens the 'Save AHP Input File' dialogue box to save the AHP input file generated, as shown below:



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:

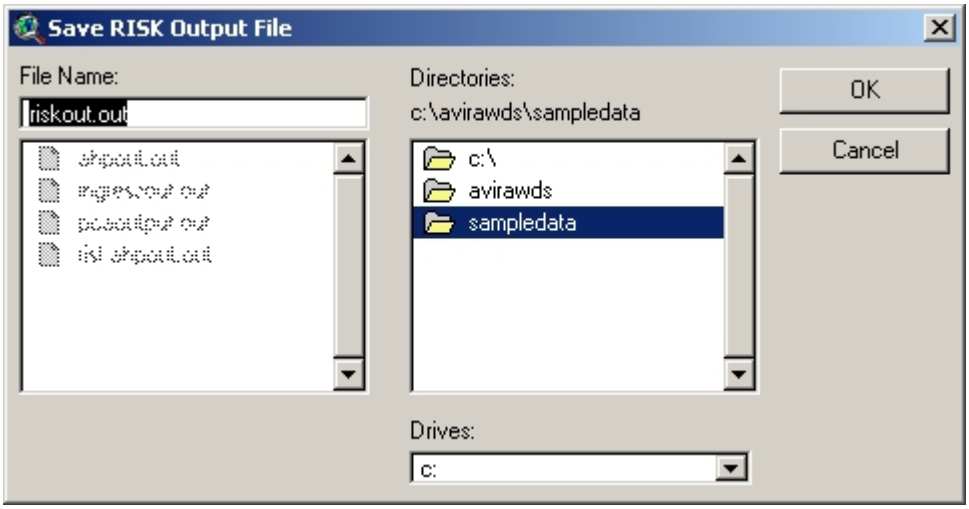


After choosing the output file to write, the weights are generated and generated weights are written in text box 'Weights' as shown below:



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.

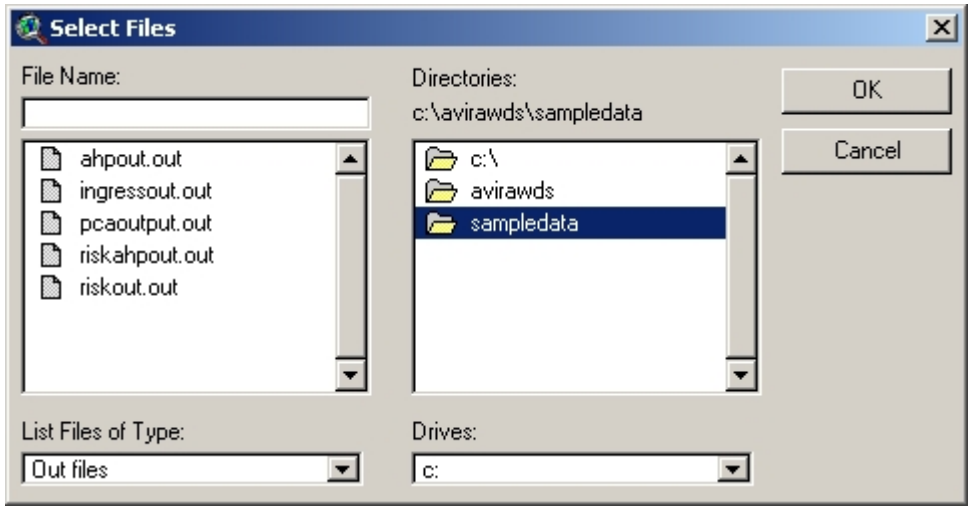
5.3 Displaying output

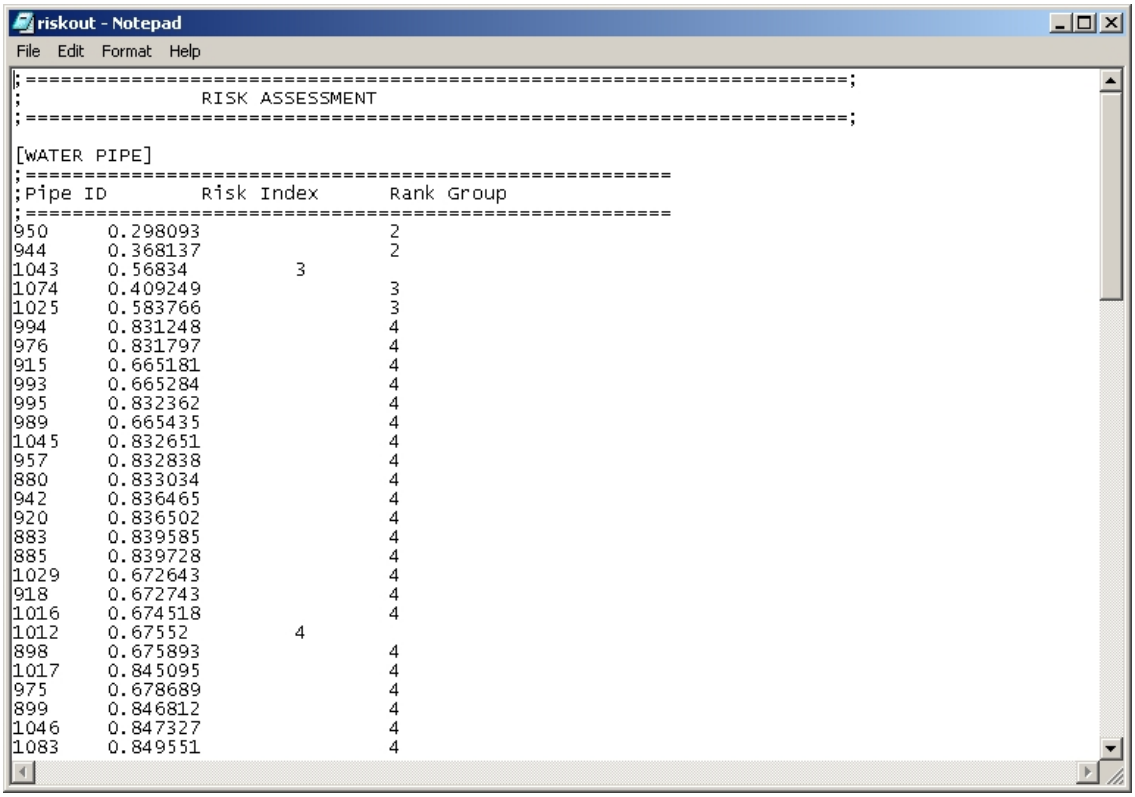
The output can be displayed in following three forms:

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

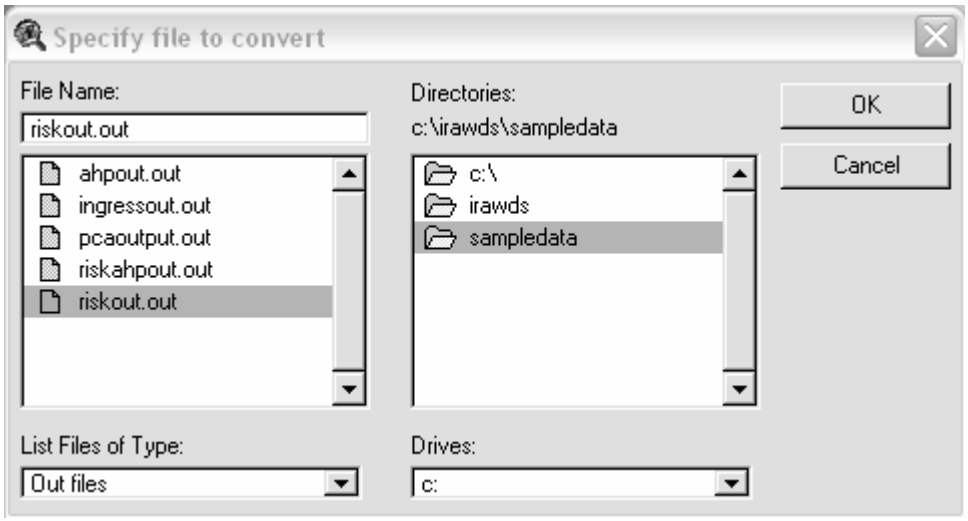
The user can view the output file in text form in notepad by clicking on the  button or by selecting the 'Display RISK Output in Text Form' submenu from the 'Risk Assessment' menu and browsing the appropriate output file to view.





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.

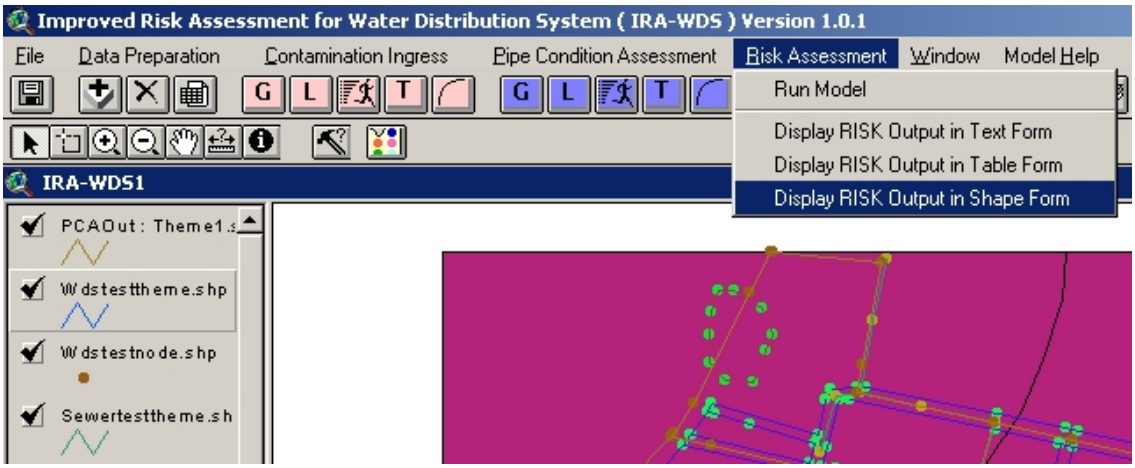


c:\irawds\sampledata\riskout.dbf

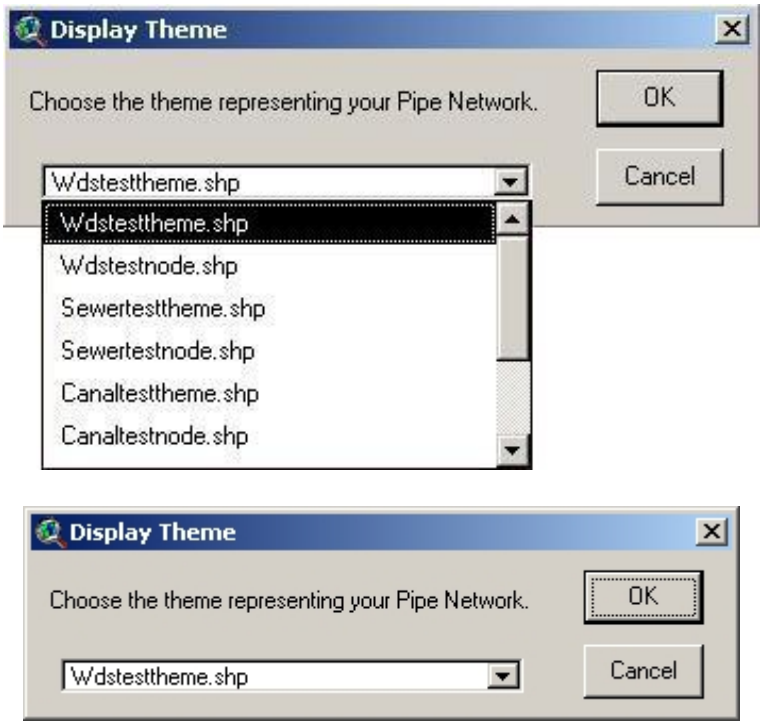
PipeID	RiskIndex	Rank
950	0.336	2
944	0.430	3
1043	0.810	4
1074	0.485	3
1025	0.830	4
831	0.925	5
975	0.594	3
824	0.926	5
880	0.927	5
852	0.931	5
866	0.932	5
837	0.932	5
951	0.932	5
936	0.602	4
1083	0.933	5
957	0.933	5
809	0.603	4
989	0.604	4
883	0.935	5
994	0.935	5
945	0.935	5
956	0.935	5
915	0.605	4
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

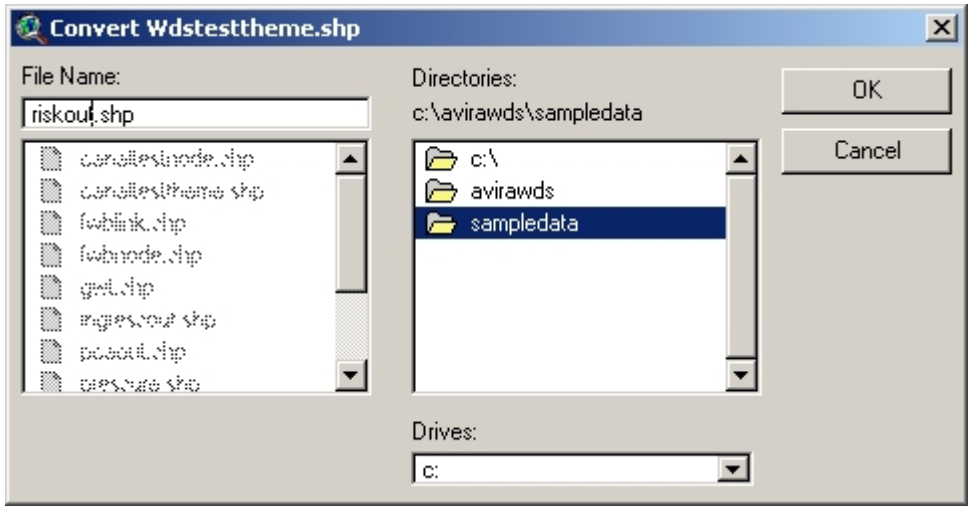
To view the Risk Assessment output in shape file form, the user should click on the  button, which is just below the 'Risk Assessment' menu or he or she should click on the 'Risk Assessment' menu and then click on the submenu 'Display RISK Output in Shape Form', as shown on the screen below:



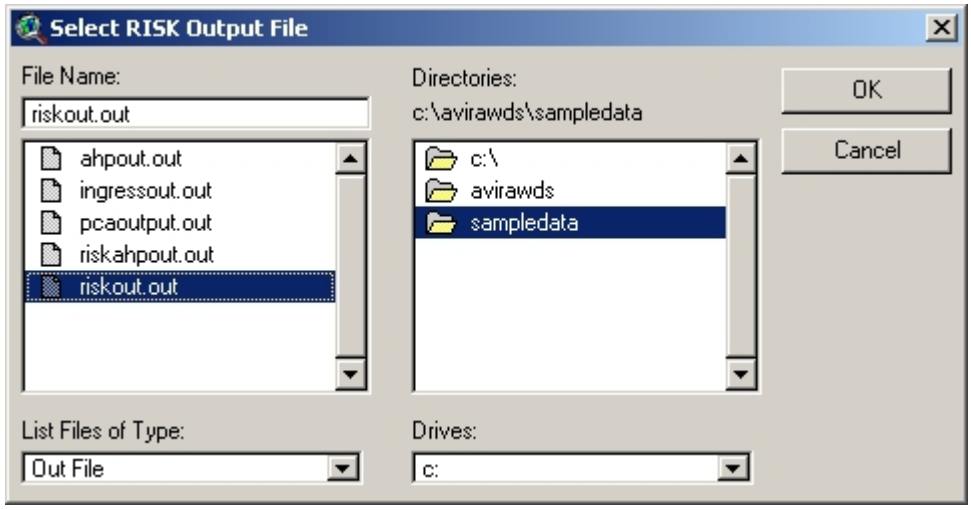
This opens the 'Display Theme' message box asking the user to specify which theme represents the water distribution system pipe theme, as shown below:



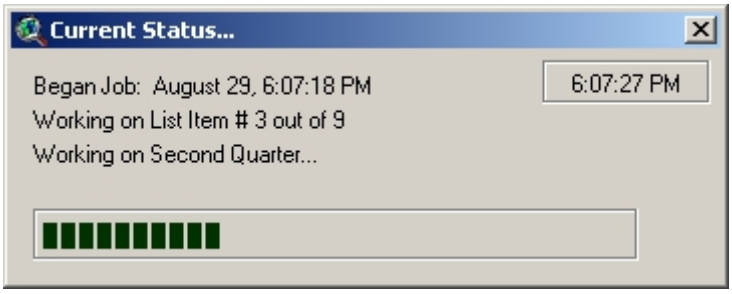
Once the user has selected the appropriate theme representing the water distribution system pipe network and has clicked on the 'OK' button, the 'Convert Theme' dialogue box appears on the screen; this asks the user to give the name with which he or she wants to store or convert the selected theme, as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

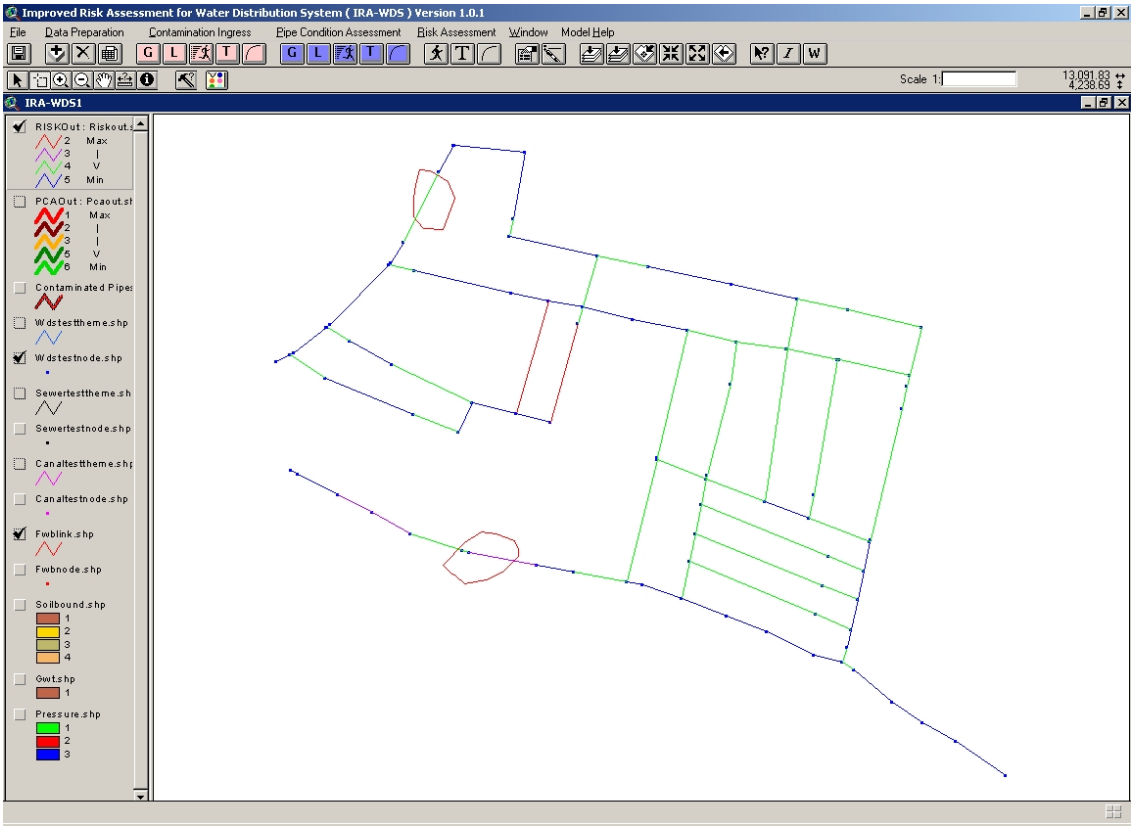


Once the user has selected the appropriate filename and clicked 'OK', the program shows the progress meter, as shown below:



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.

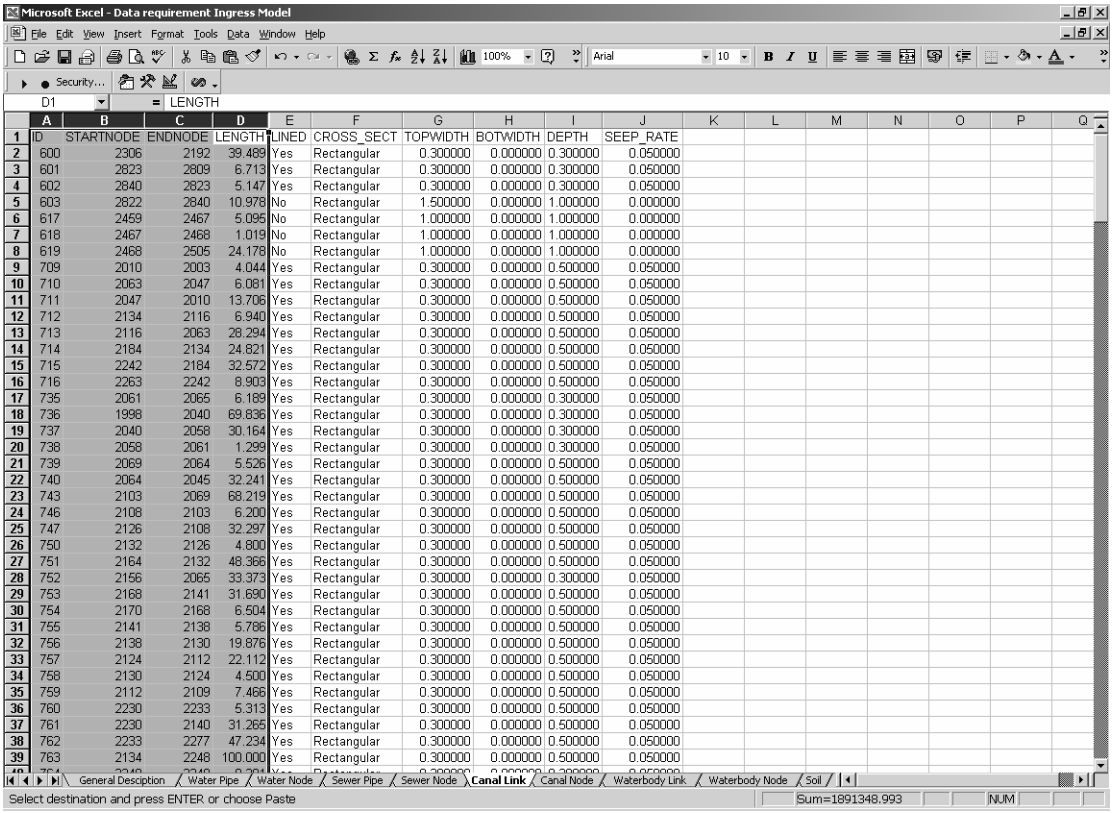
Table A.1. Canal link data for Contaminant Ingress Model			
Field name	**Unit**	**Description**	**Useful references**
LINED	*Yes/No*	Lined or unlined	N/A
CROSS_SECT		Type of cross section	Section 2.3.2.1 of Book 3
TOPWIDTH	*Metres*	Top width of cross section	
BOTWIDTH	*Metres*	Bottom width of cross section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

Table A.2. Canal node data for Contaminant Ingress Model			
Field name	**Unit**	**Description**	**Useful references**
ELEVATION	*Metres*	Elevation of the node	Section 2.3.2.1 of Book 3
WATER_DEPT	*Metres*	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	***Metres***	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

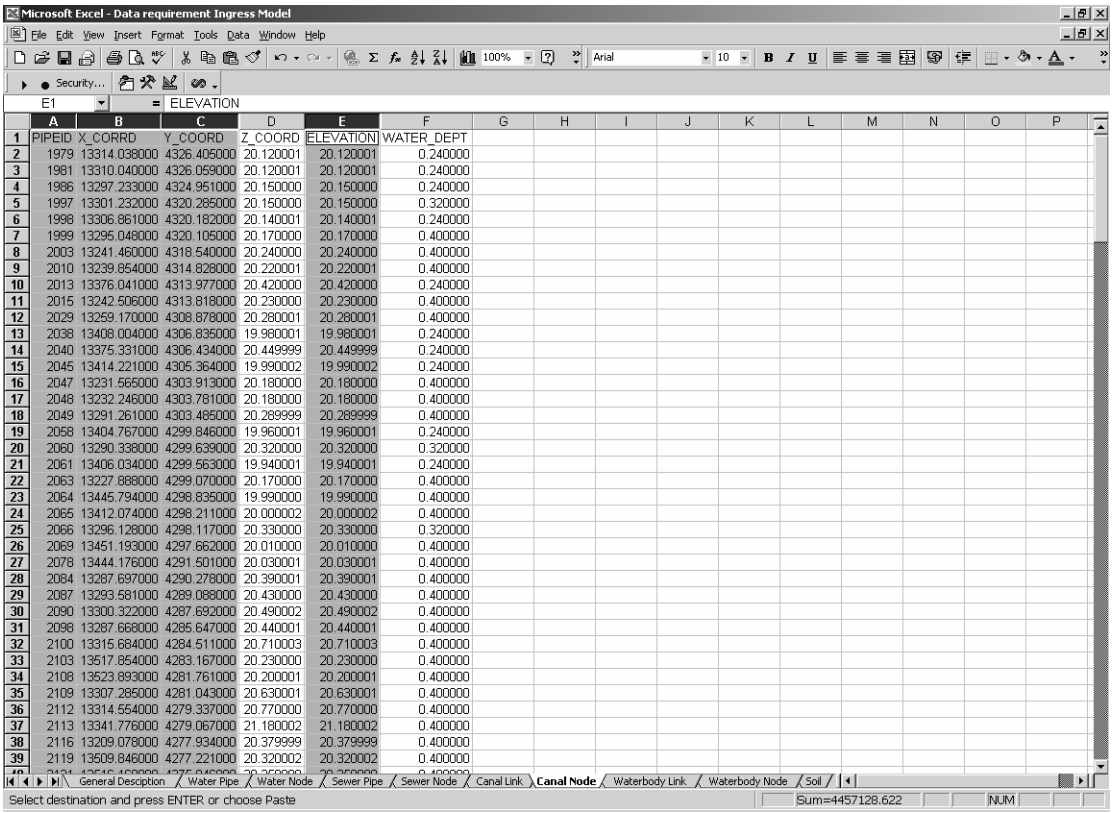
D1 = LENGTH

	A	B	C	D	E	F	G	H	I	J
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

Select destination and press ENTER or choose Paste | 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_CORRD	Y_COORD	Z_COORD	ELEVATION	WATER_DEPT										
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	13290.338000	4299.639000	20.320000	20.320000	0.320000										
21	2061	13406.034000	4299.563000	19.940001	19.940001	0.240000										
22	2063	13227.888000	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

Select destination and press ENTER or choose Paste | Sum=4457128.622 | NUM

Figure A.2. Node data entry for canals

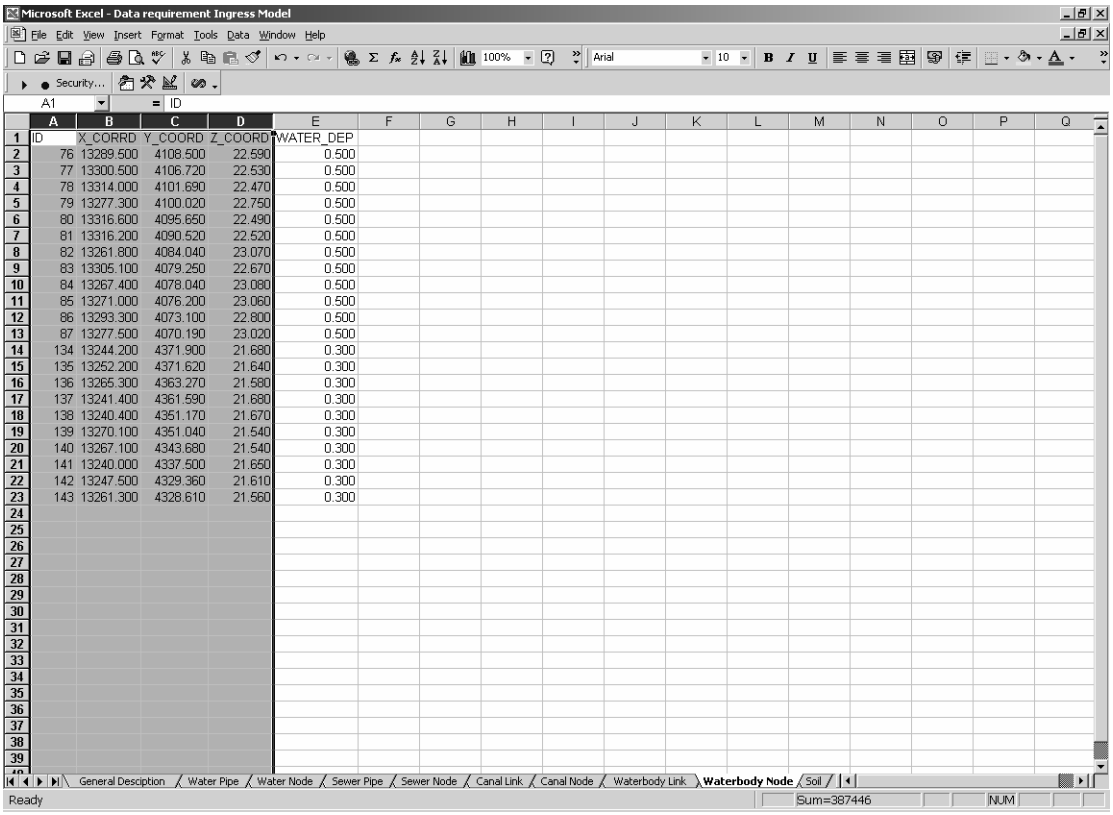


Figure A.3. Node data entry for foul water bodies

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:

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

where
S – sorptivity (L/T^2)
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.