



User Manual

ARC Ventilation Tool

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1. User Manual Overview

The purpose of this User Manual is to introduce the ARC Ventilation Tool and provide instructions on how to use it to perform calculations.

Tool set-up, execution and the generation of results are relatively straight-forward tasks, making the Tool useable for anyone with basic computer skills. It is however recommended that where a user is not familiar with sewer modelling/analyses, modelling should be overseen by someone who is experienced. This is important for all areas of Tool usage, from the beginning in generating data input values, through to interpreting results and onto “fine-tuning” the Tool inputs to facilitate “scenario-specific” analyses.

To complement the information contained within, worked examples illustrating the use of the Tool are provided in **Appendix B**.

2. ARC Ventilation Tool Overview

The ARC Ventilation Tool is a computer-based tool that has been developed to assist in estimating the effect of selected natural ventilation mechanisms and/or forced ventilation in gravity sewers under user-specified conditions. The Tool takes the form of a collection of formulae and reference data contained within a Microsoft Excel workbook file. Physical pipe details, ambient conditions and wastewater information for a sewer domain of interest is entered by the user and the Tool calculates the pressure and air flow distribution at each node within a serial network of gravity sewer components. The Tool outputs can then be used to identify and manage odour and corrosion issues in sewers.

The Tool is provided as two different versions – a *Manual* version and an *Automated* version. The former requires the user to drive the iterative calculations to convergence by entering the input ventilation rate for each iteration step – a total of 5 inputs. The user also specifies the direction of gassing (in or out) at nodes where it does or may occur. The Automated version of the Tool solves the iterations automatically, after the user supplies one initial input value, as well as predicting the gassing direction. These versions of the Tool are described further in **Section 4.4.2**.

2.1. Basis of the Tool

The Tool uses the principles of fluid mechanics and conservation of momentum to calculate headspace ventilation and static pressure in a sewer. The following mechanisms are accounted for in the Tool:

- Drag at the air/water interface
- Friction at the dry pipe walls
- Buoyancy effect due to a difference in density between ambient air and the sewer headspace
- Decreased pressure at sewer openings (such as stack/chimney vents) due to wind
- Mechanical ventilation from/into the sewer

The equations that define the above mechanisms are presented in **Appendix A**.



As part of the calculation “backbone”, the ARC Ventilation Tool additionally performs hydraulic calculations to determine the depth of the wastewater flow, the cross-sectional area of the wastewater flow, and the wastewater velocity. These are calculated using user-supplied information including pipe material characteristics, diameter, slope and wastewater flow rate.

2.2. Tool Applications

The Tool is a serial network model, meaning it can be applied to a network of pipes connected end-to-end. Sewer branches must be handled individually. Once set up and, if possible, field validated, the Tool can provide the following quantitative information for a given set of wastewater flow, ambient air state and fan-induced conditions:

- Sewer headspace air flow within each reach of the network
- Static pressure at each node (manhole) within the network
- Out-gassing or in-gassing flow rates at each opening to the network

This information has many uses including:

- Input data to sulphide fate models for the purpose of assessing odour and corrosion “hot-spots”
- Estimating the size and location of forced ventilation equipment
- Estimating out-gas flow rates
- Assessing ventilation rates within a sewer
- Sizing air jumpers and other sewer ventilation structures
- Sizing gas-phase odour control systems

3. Assessable Components

In its current form, the Tool is able to model ventilation in gravity-flow sewers and air jumpers. Surcharged pipes, such as siphons and rising mains cannot be modelled per se since they do not have an air phase. Rather they would represent a model domain boundary. Reaches between such bottle-necks would be modelled as separate domains, that is, each continuous headspace would be assessed in a separate modelling file. In the case of siphons with air jumpers, the sewer upstream and downstream of the siphon would form a continuous domain with the air jumper included in the domain.

Drop structures are not currently supported with respect to air/liquid drag. However, the buoyancy effect of drop structures is supported. Therefore, it is recommended that drop structures be handled in one of two ways:

- 1) Include the physical drop structure in the Tool at the node where the drop occurs. The Tool will account for buoyancy but ignore the drag effect of the drop. This case would represent the lower bound on the ventilation effect of a drop structure.
- 2) Include a “pseudo” gravity pipe with a steep slope (say 0.03 m/m) and vary the length to achieve a drag effect equivalent to a drop structure. This method could be used if pressure data are available for the drop structure i.e. measurements taken at the top and bottom of the drop structure. The length of the “pseudo” pipe would be varied to achieve the observed top-to-bottom pressure difference across the drop structure.

A detailed description of all parameters required for Tool setup, i.e. physical and wastewater characterisation data, is provided in **Section 4.3**.

4. Using the ARC Ventilation Tool

The purpose of this section is to provide an overview of how to input data and operate the Tool.

4.1. General Tool Functions

As a Microsoft Excel workbook, the Tool functions as per any other workbook. The name of the Tool file can be re-named to identify calculations of specific sewers or scenarios. When the Tool file is open, data is entered directly into input cells (light blue), with calculations updated immediately. Work may be saved throughout a session by clicking the “Save” button in the top toolbar. At the end of a session, the user clicks the “Save” button and closes the file.

Cells are colour-coded according to their significance for users. Light blue highlighting indicates input cells that users enter data into to define a sewer/scenario. These are generally the only cells that can be changed by a user. Orange/peach highlighting indicates outputs i.e. pressures and air flow rates.

Throughout the *Ventilation* sheet, some cells contain comments, denoted by red tabs, which help prompt what kind of input is required for the cell or column below it.

Figure 4-1 shows the colour-coded input and output cells of the *Ventilation* sheet as an example. Cells with red tabs indicating comments, along with a comment box, can also be seen.

The screenshot shows the SCORE Sewer Ventilation Tool Excel spreadsheet. The interface includes a menu bar (Home, Insert, Page Layout, Formulas, Data, Review, View, Developer, Get Started) and a formula bar. The spreadsheet is divided into several sections:

- Input Section (Rows 1-12):** Contains user input fields for Ambient Temp (14.00), Ambient RH (60.00), Ambient Pressure (101000), Fan Pressure (0), Fan Node (Downstream), Downstream Node, Ambient 10 m Wind Speed (0), and Ambient Stability Class (C).
- Comments (Rows 13-12):** Includes instructions for determining the fan operating point, iteration steps, and a note about picking a hole or vent pipe opening.
- Iterations Table (Rows 10-11):**

Iterations	Auto solve	1	2	3	4	5
Air Discharge (L/s)		-220.9	-220.7	-220.8	-220.8	-220.8
Air balance (L/s)		0	0	0	0	0
- Results Section (Rows 13-27):** Contains calculated output data for various pipe segments, including Node Absolute Static Pressure, Node Discharge Driving Force, Headspace Air Flow Rate, Headspace Air Velocity, and Outgas Flow Rate.

Figure 4-1 Ventilation sheet - input and output cells, and cells with comments



4.2. Organisation of the Tool

The Tool is composed of three spreadsheets, with tabs labelled (in order of appearance in the Tool):

- Ventilation
- Air
- Depth

The *Ventilation* sheet is where all inputs specific to a sewer under assessment are entered. It is also on this sheet that the computation of ventilation and pressure occurs.

The *Air* sheet contains tables of physical properties and constants related to air. These are used by the Ventilation sheet and users would not normally change them.

The *Depth* sheet contains a routine used for solving the Manning's Equation for water depth. Again, users would not normally make changes to this sheet.

4.3. Data Input

After opening the Tool workbook, the user should go to the *Ventilation* sheet. The cells that the user can alter to define a sewer/scenario are highlighted in light blue. These user-defined parameters are generally split into groups. The first group consists of ambient and sewer air conditions, fan specifications, and wind conditions. The second collection of variables comprises sewer characteristics, including diameter, invert elevation, and wastewater flow. **Table 4-1** lists the user-defined parameters, along with the sheet location, units, and notes of each. **Figure 4-2** shows the *Ventilation* sheet with the input groups outlined.



Table 4-1 Ventilation Tool User Inputs

Variable	Ventilation Sheet Location (Cells)	Units	Notes
Air Conditions			
Ambient pressure (barometric pressure)	F3	Pascals, Pa	Ground-level atmospheric pressure (absolute).
Ambient temperature	F4	degrees Celsius, °C	Ground-level atmospheric (ambient) temperature.
Headspace air temperature	G4	degrees Celsius, °C	Sewer headspace air temperature. If unknown, assume the same as wastewater temperature for natural ventilation. If unknown and the sewer features forced ventilation, assume the same as ground-level atmospheric (ambient) temperature.
Ambient relative humidity	F5	percent, %	Ground-level (ambient) relative humidity.
Headspace relative humidity	G5	percent, %	Sewer headspace air relative humidity. If unknown, assume 99% for natural ventilation. If unknown and the sewer features forced ventilation, assume the same as ground-level (ambient) relative humidity.
Fan			
Fan pressure	F7	Pascals, Pa	Fan pressure (selected from fan performance curve). See Section 4.3.2 for details on entering this parameter.
Fan node	F8	-	The name of the node of the sewer pipe where the fan/fan extraction point is located. See Section 4.3.2 for details on entering



Variable	Ventilation Sheet Location (Cells)	Units	Notes
			this parameter.
Wind Conditions			
10 m wind speed	F10	metres per second, m/s	Wind speed measured 10 m above ground level. See Section 4.3.3 for details on entering this parameter.
Ambient stability class	F11	-	Stability class is an indicator of atmospheric turbulence, commonly categorised into 6 classes – A, B, C, D, E, and F. The classes are defined according to wind speed and solar radiation for day time, and wind speed and cloud cover for night time. The <i>Air</i> spreadsheet displays the combinations of conditions for each class in Cells D19:I25.
Sewer Characteristics			
Reach name	B16 to end	-	The user-defined name of a pipe reach. This may be a text string or purely numerical, but a value must be entered for each pipe reach. When a node is named, the node's position is at the upstream end of the reach.
Pipe length	C16 to end	metres, m	Length of reach.
Pipe diameter	D16 to end	metres, m	Diameter of sewer pipe.
Pipe slope	E16 to end	metres per metre, m/m	Slope of the sewer pipe.
Manning's roughness coefficient	F16 to end	s/m ^{1/3}	The Manning's roughness coefficient (<i>n</i>) is used in gravity-flow sewer depth-of-flow calculations and depends on material of construction. Any standard fluid mechanics text (e.g. Massey

Variable	Ventilation Sheet Location (Cells)	Units	Notes
			1998) will list more information on typical n values to be used. For concrete sewers, a typical value of n is 0.014.
Dry absolute roughness	G16 to end	metres, m	The dry absolute roughness of the pipe material. Typical values for concrete are in the range of 3×10^{-4} to 3×10^{-3} m. Refer to a standard fluid mechanics text (e.g. Massey 1998) for values for other materials and conditions (e.g. degree of corrosion, etc.).
Node discharge area	H16 to end	square metres, m ²	The area of an opening in the pipe that allows air to enter or leave the sewer. For example, pick holes or vent stacks. Row 14 corresponds to the downstream node of the network. Row 16 corresponds to the upstream node. Either of these may be open to the atmosphere, in which case the node discharge area will be the cross-sectional area of the sewer headspace, which is calculated in Cell AJ14 or AJ16, respectively. Reference AJ to H where appropriate. Where there is no discharge, use a value of 0.0001 or less but not zero.
Discharge coefficient	I16 to end	dimensionless	The discharge coefficient for air across an orifice or fitting. Depending on the type of structure through which the air is discharging, it may be more convenient to use either a minor loss coefficient, K, or an orifice discharge coefficient. For pick holes or other sharp edged orifices, input the discharge coefficient. For a goose neck or vent stack, sum the minor loss coefficients and convert to a discharge coefficient using the formula in cell I13. If the node is sealed or the discharge coefficient is not known, use a value of 1.
Node discharge	J16 to end	metres, m	The elevation of a discharge point e.g. a vent pipe or stack. Note:



Variable	Ventilation Sheet Location (Cells)	Units	Notes
elevation			This is the elevation relative to sea level, not the height above ground level.
Ground elevation	K16 to end	metres, m	Ground elevation above sea level for the upstream end of reach.
Pipe rise	L16 to end	metres, m	This parameter is calculated from the pipe slope and is provided as a convenience for the user to calculate pipe invert elevation if the pipe slope is known and at least one invert elevation is known.
Pipe invert elevation	M16 to end	metres, m	Pipe invert elevation above the datum (sea level) for the upstream end of a reach.
Entering wastewater flow	N16 to end	cubic metres per second, m ³ /s	Flow of wastewater entering at each node. Normally wastewater enters at the upstream node, but side stream flows can enter at other nodes (e.g. rising main discharge).

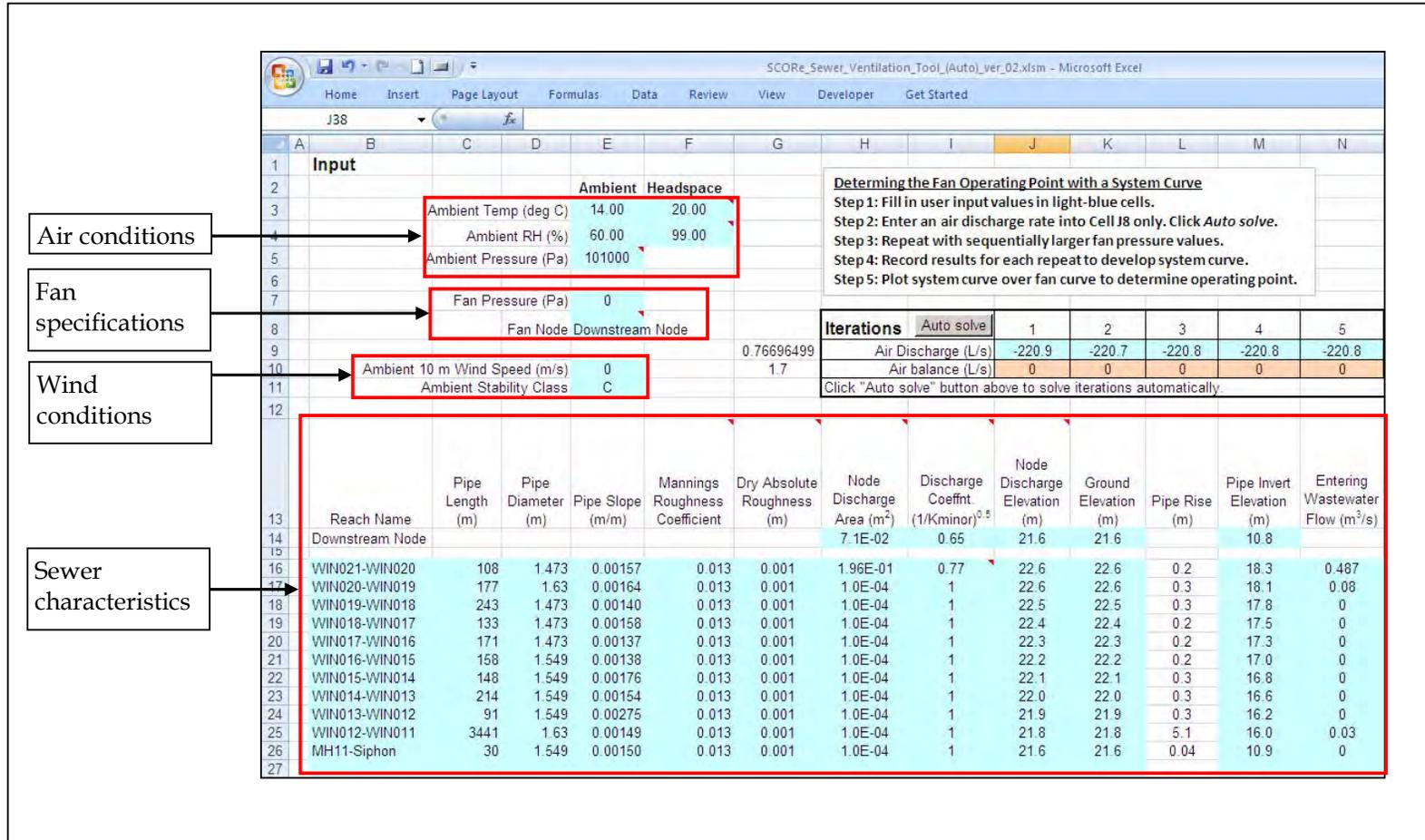


Figure 4-2 Input Groups on the Ventilation Sheet



4.3.1. Defining the Downstream Node

Row 14 corresponds to the downstream-most node in the network. This row includes values related to the last node but not the last pipe, as the pipe values are in the same row as the upstream node (i.e. the reach data in the row lowest down the sheet). To clarify with an example, if there are four consecutive reaches named A, B, C and D, then the inputs of Row 14 would apply to the downstream end of reach D. The parameters of the Row 14 cells have the same meaning and take the same inputs described in **Table 4-1** for corresponding columns.

4.3.2. Specifying Forced Ventilation

As shown in **Table 4-1**, forced ventilation is considered in the Tool by entering the fan pressure and node where the fan is located into Cells F7 and F8 respectively. If there are no fans associated with the sewer, the fan pressure cell is left blank.

Where fans are considered, the Tool assumes that the fan is withdrawing air from the sewer, not blowing air into the sewer. To specify fan pressure, select a point within the expected fan operating range and enter the pressure as a positive value. Multiple pressure values should be modelled to determine a “system curve” for the sewer.

If significant pressure losses are expected due to a long stack, media bed or other system elements, the curve pressure point is reduced by the expected minor losses. For example, if 500 Pa is a value to be considered from a fan performance curve, but appurtenances produce minor losses of 100 Pa, enter 400 Pa into the Tool.

Nodes are defined as the upstream end of a reach. In entering the name of the fan node, if the name does not match a name in Column B from Row 16 downwards, errors will appear in output cells. The easiest way to avoid this is to copy the name of the node from Column B and paste it into Cell F8.

4.3.3. Incorporating Wind Effects

The effects of wind speed are considered by setting the wind speed in Cell F10. The actual wind speed the Tool uses is that measured 10 metres above ground level, as the 10m wind speed is typically what is recorded at airports and other meteorological stations. These measurements are less affected by local vegetation and terrain features, which reduce the wind speed measured at the surface.

The Tool automatically recalculates the wind speed for each node discharge point based on the height of the point. Where a node discharge point is equal to ground-level, which is typical of many manholes, the wind speed will be zero as per its ground-level boundary condition.

If wind is not believed to have a significant influence on ventilation in the sewer, specifically out-gassing, then the wind speed can be set to 0 m/s in the Tool. This selection may also be made to evaluate the resultant ventilation in the absence of wind.

If a wind speed to be used has been measured at a height other than 10 metres, the wind speed can be converted for use in the Tool by using the following wind profile power equation:

$$U_z = U_r \left(\frac{Z}{Z_r} \right)^p$$



where U_z = the wind speed at a height Z , which is to be used in the Tool

U_r = the wind speed measured at a height Z_r

Z = the height for which the wind speed is to be calculated (10 m in the case of the Tool)

Z_r = the height at which the wind speed has been measured

p = wind profile exponent

The wind profile exponent varies from 0.15 for daytime, unstable conditions, to 0.30 for night-time, calm conditions in an urban environment. **Table 4-2** shows the exponents that correspond to each stability category, along with a short description of each category.

Table 4-2 Power Law Exponents

Stability Category	Urban Exponent	Category Conditions
A	0.15	Very unstable. Daytime only.
B	0.15	Unstable. Daytime only.
C	0.20	Slightly unstable. Daytime only.
D	0.25	Neutral. Day and night.
E	0.30	Stable. Night-time only.
F	0.30	Very stable. Night-time only.

4.4. Calculation Operations

4.4.1. Iterations

The primary purpose of the Tool is to provide calculations of sewer headspace ventilation and pressure. However, in order to calculate one of these parameters, the other parameter must be known. In order to calculate ventilation and pressure, where both are unknown, the Tool uses an iteration process where an initial estimate of the ventilation rate through the downstream node is made by the user. Subsequent iteration cycles refine the downstream node ventilation rate estimate, in which the user provides a new flow rate value in the cells in Row 14. For each iteration cycle, a set of calculations are performed to provide the static pressure and ventilation rate at nodes throughout the sewer. The process is repeated until the Tool converges.

Associated with each iteration cycle is an “air balance”. Simply put, this is where the Tool checks that the air entering the sewer is equal to the air leaving, based on calculations using the preceding estimate of the downstream node pressure. The final ventilation and pressure results are obtained when the air balance is zero, or approximately zero, signifying that conservation of mass has been satisfied.

There are two versions of the Tool, where the differences centre mainly on how the iterations are solved. These are described in the following section.

4.4.2. Ventilation Tool Versions

The Tool is provided in two versions – a “Manual” version and an “Automated” version. The Manual version, as its name suggests, requires the user to enter a new air flow value for each iteration step, while the Automated version requires no more than an initial air flow value,



with all iterations completed automatically. A description of these versions and how they are used follows below.

4.4.2.1. Manual Version

To use the Manual Version, the iterative process is initialised in the section of the spreadsheet under “Stagnant Condition” (i.e. assumption of no air movement), where the user adjusts/enters the first downstream node air flow in Cell BU14 (Figure 4-3), highlighted blue, until a value of zero is obtained in Cell BU11. This calculates results for the stagnant condition, which are also the inputs for the first iteration in the cells to the right. The user also specifies the direction of in-gassing or out-gassing for nodes that have openings to the surface. Once adjustments to the node gassing direction and first air flow input are complete, the outputs for the stagnant condition and the first iteration are immediately available.

Following the first air balance, the user scrolls across the sheet to the next iteration cycle. The Tool uses five iteration cycles in all to refine its calculations.

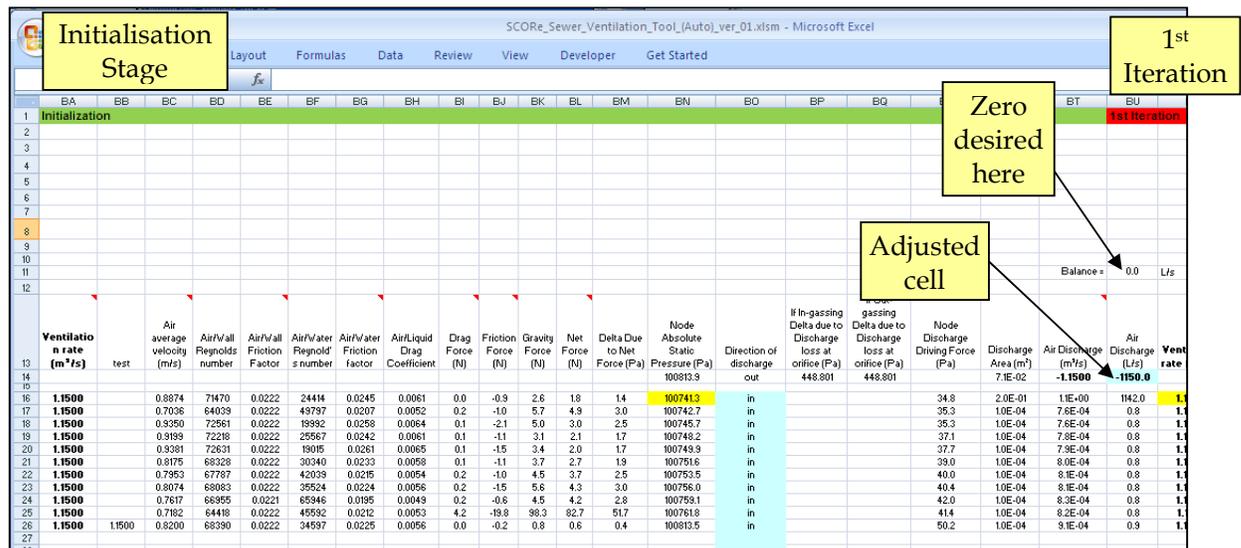


Figure 4-3 First iteration cycle adjustment

After the value in Cell BUT11 is near zero, the user scrolls across the sheet to the next iteration cycle. The Tool uses five iteration cycles to refine its calculations. The final iteration cell to change is Cell EW14, located in the Fifth Iteration section. The pressure results from the fourth iteration cycle and the ventilation results from the fifth iteration cycle are the final outputs from the Tool. These outputs are relayed to Columns P to T (highlighted orange/peach) at the beginning of the sheet, beside the input columns, for easy referencing.

Summarised instructions for the iteration process of the Tool are as follows:

1. Ensure all inputs listed in Section 4.3 have been entered.
2. Scroll to Column BO, labelled “Direction of Discharge” and specify the direction of gassing for each node in the blue highlighted cells.
3. Enter a ventilation rate for the downstream node in Cell BU14, under “1st Iteration”. Adjust this value until the air balance above in Cell BU11 is zero, or as close to zero as possible.

4. Scroll right to the next Direction of Discharge column, Column CI, and specify gassing directions.
5. Scroll right to the next downstream node ventilation cell, Cell CO14, Located under "2nd Iteration". Similar to Step 2, adjust this value until the air balance above in Cell CN11 is near zero.
6. Continue to scroll right, specifying gassing discharge directions and adjusting the downstream node ventilation rate to achieve a zero air balance. Changes in the entered node ventilation rate should decrease with each iteration, indicating convergence.
7. The pressure and ventilation outputs are available in Columns P to T for the user to copy and use elsewhere.

Note that for Step 2 (and Steps 4 and 7), all nodes must have a gassing direction of either "in" or "out", regardless of whether gassing would actually occur at the node. If gassing cannot occur for a specific node, the discharge area should be set to a low value in Column H. A gassing direction will still be required for the Direction of Discharge input columns, but the effect on calculations will be negligible.

As a note of caution, the stagnant condition (ventilation rate of zero) is a better initial estimate for a relatively sealed sewer network in which forces manifest as a pressure distribution with minimal flow. For networks with large openings, very slight differences in pressure result in large air flows. Therefore, the user will need to use care in selecting downstream node ventilation rates.

Notes are also provided on the *Ventilation* sheet to prompt the user on making the adjustments. **Figure 4-4** illustrates the steps above in the form of a flow diagram.

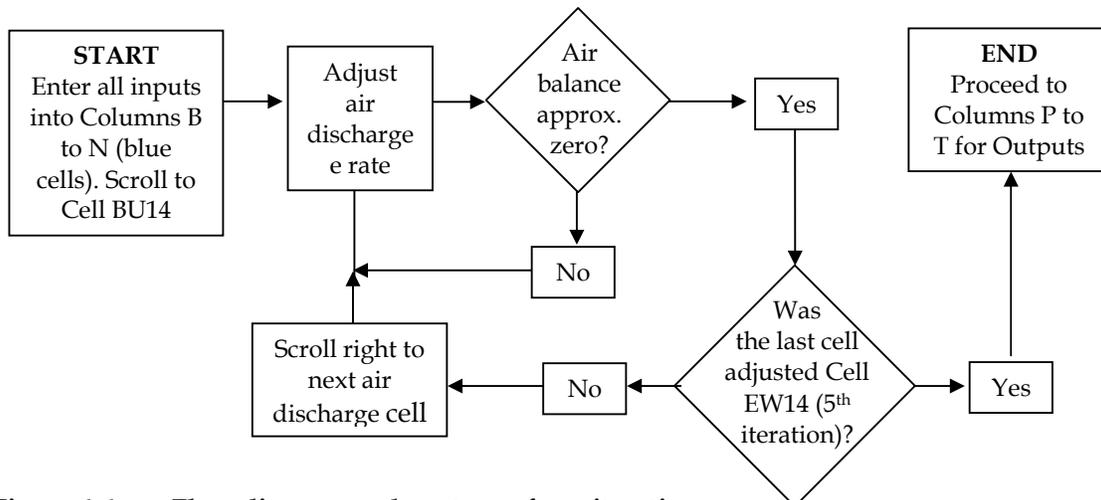


Figure 4-4 Flow diagram on how to perform iterations in the 1001

The air discharge rate from the downstream node and the air balance from each iteration are summarised at the start of the sheet, above the inputs, for convenience in allowing the user to quickly verify that the difference in these parameters has reduced with successive iterations.



4.4.2.2. Automated Version

The Automated Version differs from the Manual Version in the following ways:

- Iterations are performed by the Tool, and
- The Tool determines the gassing direction for each node.

Apart from these differences, the Tool functions in the same way as the Manual Version.

Upon opening the Tool, you may be asked if you accept or wish to enable Macros. This question may also appear at the top of the screen below the Excel toolbar. You should make the appropriate selection to enable Macros.

To activate the solving of the iterations, the user enters an air flow for the first iteration in Cell J9 in the *Iterations* block above the inputs. Generally any value apart from zero is acceptable, but the cell cannot be left blank. Clicking the “Auto solve” button completes the calculation process and results are available in the *Results* area of the Ventilation sheet.

As there are no user-entered inputs in the calculation areas of the Tool, there is little reason for users to scroll to these areas. Despite this, users are still encouraged to inspect the results of each iteration (e.g. node pressures, airflows, etc) and ensure that sensible values are being produced. As for any model or software application, blind use of the Tool without some level of scrutiny and understanding of its operation could have drastic consequences in the conclusions drawn about ventilation. In this sense, and in keeping with recommendations in **Section 1**, the Manual Version has the benefit of engaging the user to apply their ventilation experience as they scroll between iterations.

4.5. Tool Outputs

The outputs of the Tool are located in the orange/peach highlighted cells (**Figure 4-1**) in the *Ventilation* sheet in Columns P to T. **Table 4-3** describes the outputs.

Table 4-3 Ventilation Tool Outputs

Variable	Ventilation Sheet Location (Cells)	Units	Description
Node static pressure	P16 to end	Pascals, Pa	Static pressure at the upstream end of each reach.
Node Discharge Driving Force	Q16 to end	Pascals, Pa	The differential pressure between the atmosphere and the manhole (underside of the manhole cover).
Headspace air flow	R16 to end	litres per second, L/s	Headspace air flow rate. Positive values indicate downstream flow.
Headspace air velocity	S16 to end	metres per second, m/s	Headspace air velocity. Positive values indicate downstream flow.
Outgas flow	T16 to end	litres per second, L/s	Outgas flow rate. Positive values indicate in-gassing, negative values indicate out-gassing.

As was the case for the inputs, the values of the parameters at the downstream end of the last reach are displayed in Row 14 (i.e. Cells P14 and T14).

Column T also presents fan conditions in Cells T7 and T8. The fan pressure in Cell T7 is repeated from the input while the fan flow rate in Cell T8 indicates the flow produced by the fan. A negative flow corresponds to air extraction from the sewer while a positive flow indicates air injection.

4.6. Forced Ventilation Calculations

One of the key uses of the Tool is its ability to provide the data for a “system curve” at a point in a sewer network. In the design of sewer ventilation systems, the system curve is a plot of pressure and corresponding air flow response to a fan installed at a particular node in the sewer network. The system curve for a sewer would be influenced by the flowing wastewater, so a given system curve pertains to specific wastewater flow conditions.¹ The node where a fan is installed is often dependent on land usage and classification at surface level, such as whether there are residences nearby and the zoning of the area that the node falls inside.

The system curve can be used to find the operating point for a specific fan that may be under consideration for installation in the sewer. The operating point is the intersection of the model-determined system curve and the fan’s performance curve. When the Tool is run using the conditions that correspond to the operating point, the resulting pressure/flow distribution is what would be expected from that particular fan.

Figure 4-5 shows how the system curve (dark red line) and fan performance curve (blue line) are plotted to indicate the operating point.

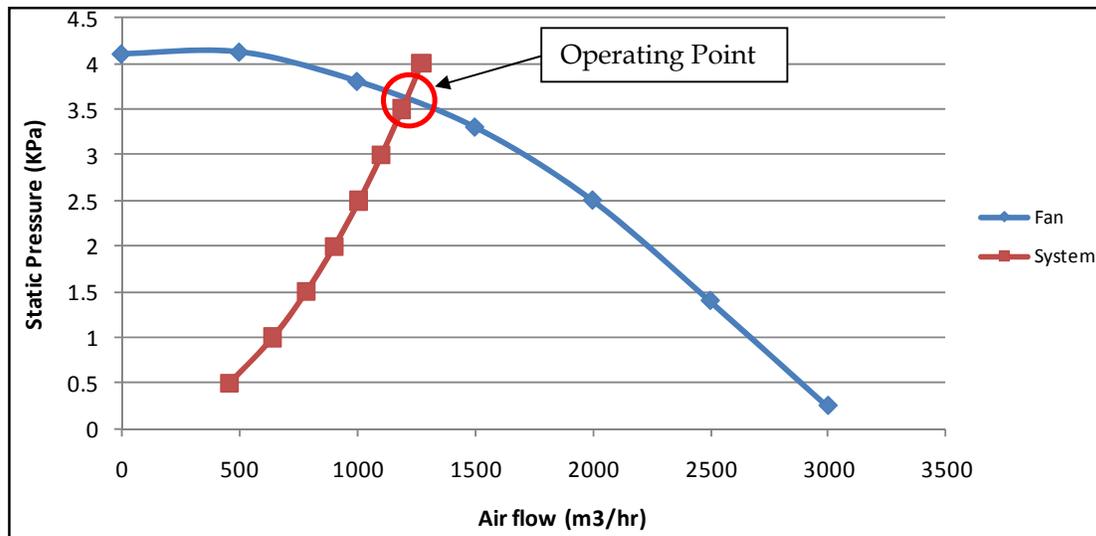


Figure 4-5 Determination of Fan Operating Point

¹ More information about system curves can be found in manuals and guides produced by the *American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)*, or the *American Conference of Governmental Industrial Hygienists (ACGIH)*.



To develop a system curve, the Tool should be run at multiple fan pressure inputs spanning the range of interest. The instructions for determining the operating point with the Tool are described in the *Ventilation* sheet of the Tool, above the inputs, and are also provided as follows.

- Step 1: Fill in user input values into light blue cells.
- Step 2: Enter an initial fan pressure and determine the air flow by:
 - a. Selecting downstream node ventilation rates for each iteration and adjust to balance air flow (Manual Version); or
 - b. Enter a ventilation rate into Cell J9 and click "*Auto solve*" (Automated Version).

Record fan pressure and resulting ventilation rate in a separate spreadsheet.

- Step 3: Repeat with sequentially larger fan pressure values.
- Step 4: Use results to develop a system curve (plot of pressure versus air flow).
- Step 5: Plot system curve over fan curve to determine the operating point.

Figure 4-6 repeats the steps above for producing a system curve in a graphical format. The second worked example in **Appendix B** further illustrates how the Tool is used to determine the operating point by developing a system curve.

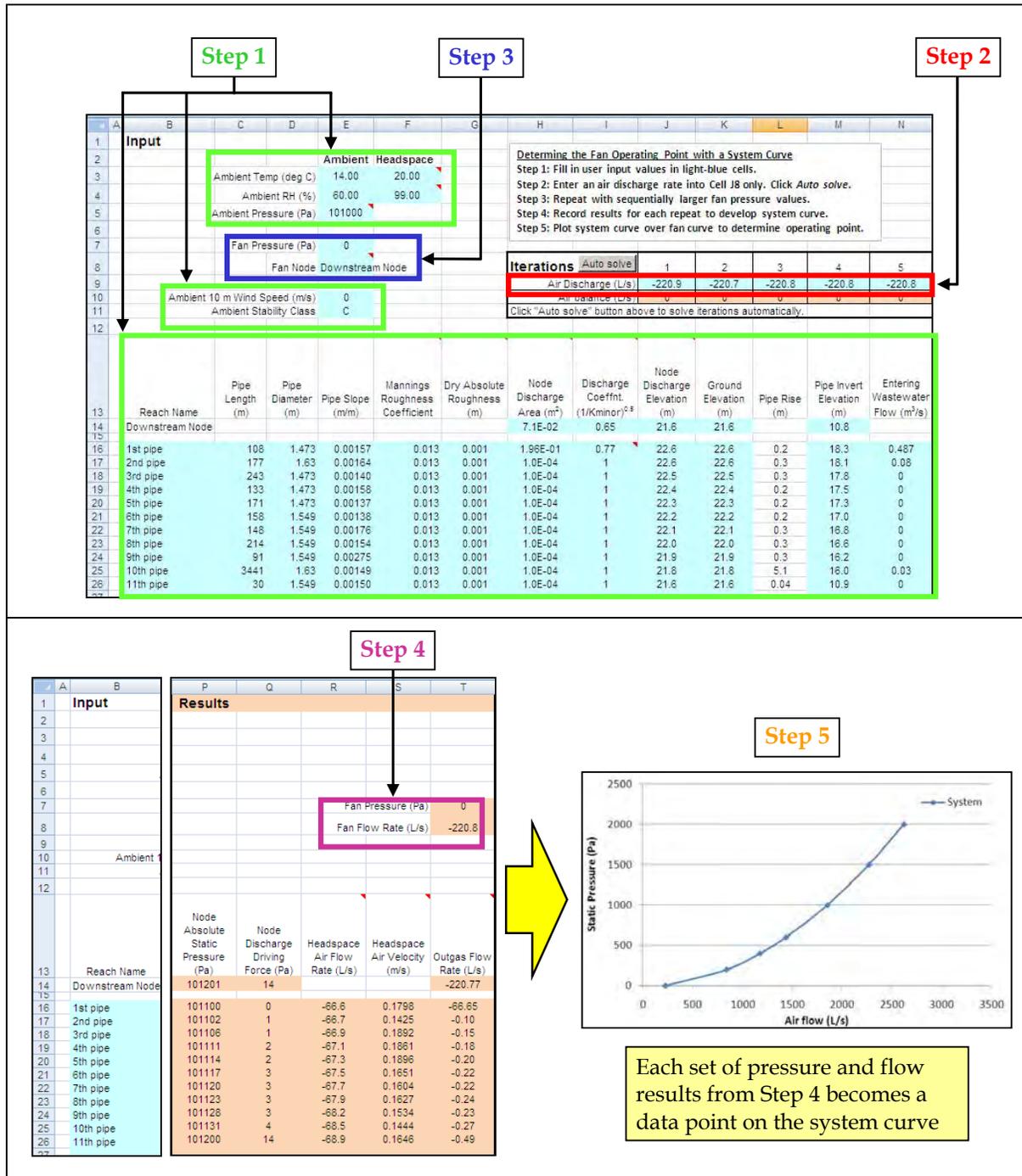


Figure 4-6 Production of a System Curve

5. Field Validation

5.1. The Purpose of Field Validation

Field validation can be used to confirm the Tool predictions or indicate where adjustments are required in the Tool configuration so that it can most accurately represent the physical domain of interest. By referencing previous data or undertaking new measurements at a few strategic locations, confidence can be gained in the Tool's predictions over the model domain for various simulated scenarios. This process provides an understanding of pressure/flow dynamics within a sewer network without the substantial costs of physically testing the entire system.

A validated pipe model can be a valuable tool for assessing the impact of changes in sewer conditions on system ventilation. Scenarios can be evaluated anytime with the Tool without the need to undertake extensive field testing each time a change occurs, or prior to actually making changes to a component.

The following section provides guidance in conducting field validation.

5.2. Field Measurements

5.2.1. Parameters of Interest

The data that should be collected in the field as part of a validation exercise generally consists of the following:

- Headspace Air
 - differential pressure
 - temperature
 - relative humidity
- Ambient Conditions
 - wind speed (if applicable)
 - temperature
 - relative humidity
- Wastewater
 - flow
 - temperature

Section 5.2.9 presents an example of sampling at a manhole for the above parameters.

5.2.2. Testing Locations

While project goals and available budget usually have some influence on the locations selected, field testing locations should preferably be selected based on a preliminary assessment of the conveyance system ventilation dynamics with the Tool. It is recommended that locations where the greatest discharge pressure driving forces are predicted are tested. The largest driving forces are the easiest to detect above background, and usually of the greatest interest with respect to out-gassing.



5.2.3. Apparatus and Equipment

Equipment should be constructed so that it is portable and can be used to test multiple locations with ease. Analytical equipment should also allow portability along with a sufficient response time, accuracy, and logging capability.

5.2.4. Testing Methods

The testing protocol presented here has been devised so that no entry to the sewer is required by personnel. The testing protocol is divided into the following aspects:

- Headspace air
- Ambient Conditions
- Wastewater

The following sections detail how each of the aspects can be tested, along with some advice on sampling in **Section 5.2.8**. **Section 5.2.9** presents an example of how sampling could be done using the protocol.

5.2.5. Headspace Air

The key property of interest of the headspace air is the driving force it creates relative to the atmosphere – the differential pressure. This can be measured by inserting a tube through a sealed opening down to the crown level of the pipe. At the surface, the tube is connected to a differential pressure meter with a resolution and range appropriate for characterising the differential pressure. Small diameter tube should be avoided to prevent condensation settling in the tube and distorting measurements. Note that it is important to ensure that the manhole is well sealed, with no gaps around the edges of the cover and all holes and gaps in the cover sealed.

Temperature and relative humidity can be measured by suspending a logging device(s) that measures these in the same manhole as the pressure tube.

5.2.6. Ambient Conditions

Ambient conditions can be measured using a portable weather station that measures wind speed (direction is not necessary), temperature, and relative humidity. Mount the wind speed meter at the height of the standpipe opening. Set the station to log parameters at short intervals e.g. once per minute.

It is recommended that testing is not conducted on windy days, as wind can be highly variable and is not useful for validation purposes. The measurement of wind speed is still necessary though to verify the conditions present during testing.

5.2.7. Wastewater

Wastewater flow and, where available, water temperature are required inputs for the Tool. These should be measured (or calculated) for the domain of interest.

5.2.8. Tips and Advice

Take care not to leave temperature logging instruments exposed to direct sunlight, so as to avoid distorted measurements.

Periodically check instruments to ensure that they are logging reasonable measurements. This will require downloading some instruments to view their log.



If any changes are made to sampling apparatus or testing conditions, note the details and time that they occurred and inspect measurements of any parameters that may have been affected later.

Record all relevant observations, such as weather, condition of the sewer, etc for later reference.

5.2.9. Validation Testing Example

An example of validation testing employing the protocol is shown in **Figure 5-1** where only a single manhole is needed to complete all of the testing and no entry to the sewer required.

In the example, a tube used for measure pressure just under the manhole cover has been inserted through a small hole in the cover. The tube is connected to a one port on a differential pressure meter, with the other port open to atmosphere.

A combined temperature/relative humidity logger has been suspended inside the manhole shaft to measure the state of sewer air.

Ambient conditions are logged by a small weather station that logs wind speed, temperature, and relative humidity. Note that if the effect of wind was under assessment, the height of the weather station would have to be measured and the wind speed input for the Tool would have to be re-calculated for a height of 10 metres per the method described in **Section 4.3.3**.

Wastewater flow can be determined from a depth sensor (not shown) positioned at the same manhole, or data logged by the network. Water temperature data can be obtained by measurement with a temperature sensor tethered at the top of the manhole (not shown), measurements by the network, or just assuming it.

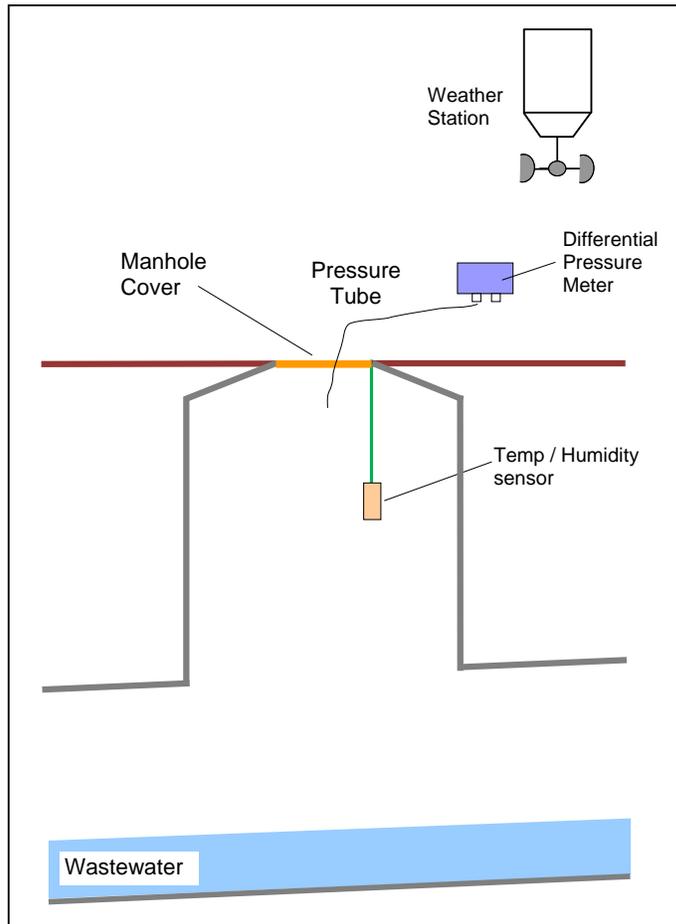


Figure 5-1 Testing at a Manhole

5.3. Tool Validation Adjustments

Should significant discrepancies be found between the Tool predictions and field measurements, the configuration of the sewer in the Tool should be reviewed to determine if any assumptions require adjustment. More than likely, assumptions will have been made about how well-sealed the boundaries are, and so focus should be drawn to these first.

An example of a common situation that may be encountered is accounting for side-sewers for which there is little information about. Since they can act to relieve pressure or deliver air to a sewer under negative pressure just like surface openings, side-sewers can be incorporated into the Tool and configured in the same way. An artificial node may need to be created to incorporate a side-sewer. Once entered, the user can adjust parameters, such as the node discharge area and discharge coefficient, to bring the Tool's predictions into alignment with testing data.

Of course side-sewers are not the only part of the modelling boundary that may require review, for example, nodes with openings to the surface may require similar treatment.

Having made all reasonable adjustments, should the differences between the Tool and test data still be considerable, the user should undertake checks to see if there is a pattern or common element in the differences. These include:



- Is one set of values (i.e. Tool outputs or test data) always greater than the other?
- Is the difference, or percentage difference, between predictions and measurements (approximately) the same?
- Do the discrepancies only occur for measurements taken at particular times of the day, or for particular dates?

Seeking an explanation may include going back to review the Tool input data, checking for errors, and ensuring that the sewer dimensions and characteristics used in the Tool are current. Another pitfall users should be aware of is confusing how a parameter is defined in the Tool (e.g. measuring pressure at a location different to the location that it is defined for in the Tool).

6. References

Apgar D., Co-principal investigator; Witherspoon J., co-principal investigator; Ward M., Research Engineer, 2009. Minimization of Odors and Corrosion in Wastewater Collection Systems, Phase II Collection System Ventilation Research Report, Water Environment Research Foundation.

Haaland S. E. 1983. Simple and Explicit Formulas for the Friction Factor in Turbulent Pipe Flow, J. Fluids Eng., 105, March.

Massey, B., "Mechanics of Fluids", Stanley Thomas Ltd. 7th edition, 1998.



Appendix A

Basis of the Tool



Basis of the Tool

The forces and ventilation phenomena that are considered in the Tool are listed **Section 2.1**. The equations used to define these ventilation mechanisms are presented in this Appendix.

Equation 1 is the core equation of the Tool, showing that the sum of all forces that acts on the air in a sewer component headspace equals the net change in momentum of the air through the component:

$$\frac{\Delta Mom}{\Delta t} = \Delta Force_{Pres} + Force_{Grav} + Force_{Drag} - Force_{Fric} \quad (1)$$

where $\Delta Mom/\Delta t$ (N) is the rate of change of momentum of air within a sewer headspace. This term will be effectively zero for a sewer component in which there is little change of mass flow (density of air entering is similar to density of air exiting) or velocity (pipe does not change direction or diameter) along a reach.

The force associated with differences in static pressure at the component boundaries ($\Delta Force_{Pres}$ (N)) is calculated by Equation 2:

$$\Delta Force_{Pres} = Area_{air} \times \left[(Pressure)_{Upstream} - (Pressure)_{Downstream} \right] \quad (2)$$

where $Area_{air}$ (m²) is the headspace cross-sectional area.

The force of gravity acting in the downstream direction ($Force_{Grav}$ (N)) is calculated as shown in Equation 3:

$$Force_{Grav} = Slope \times Density_{air} \times Area_{air} \times Length \quad (3)$$

in which $Slope$ (m/m) is the pipe slope, $Density_{air}$ (kg/m³) is the headspace air density, and $Length$ (m) is the pipe length.

The drag force at the air/water interface ($Force_{Drag}$ (N)) is determined by Equation 4:

$$Force_{Drag} = Density_{air} \left[\frac{1}{2} C_D (Velocity_{water} - Velocity_{air})^2 \times Width \times Length \right] \quad (4)$$

in which C_D (dimensionless) is a drag coefficient analogous to that of smooth flat plate drag, $Velocity_{water}$ (m/s) is the wastewater velocity, $Velocity_{air}$ (m/s) is the headspace air velocity, and $Width$ (m) is the water surface width.

The force of friction between the headspace air and pipe walls ($Force_{Fric}$ (N)) is calculated by Equation 5:

$$Force_{Fric} = Density_{air} \left[\frac{f}{8} Velocity_{air}^2 \times Perimeter_{air} \times Length \right] \quad (5)$$

in which f (dimensionless) is the Darcy friction factor and $Perimeter_{air}$ (m) is the headspace non-wetted perimeter. The value of f is calculated from the Haaland equation [Haaland 1983] using a headspace air diameter equivalent to a round duct with the same cross-sectional area as the headspace air.

Appendix B Worked Examples

Worked Examples

The first example is a simple problem for determining ventilation in a sewer under natural ventilation conditions (i.e. no fans present). The only openings from the sewer to the surface are an air inlet vent and a grate over the pump station where the pipe terminates.

The second example is a much more complicated problem involving more of the Tool's capabilities. The subject sewer has an air inlet from the surface and consideration is given to the options of adding a natural ventilation stack or air extraction system consisting of a fan and biofilter.

Worked Example 1 - Modelling Humpty Falls Main

The Problem:

In updating its corrosion management program, the local water utility in the town of Humpty Falls decides to incorporate the ARC Ventilation Tool to screen its network for pipes of potential concern. The Humpty Falls Main, a major collector pipe that runs through the town, is selected as the first sewer for assessment with the Tool.

Sewer Design and Data:

The Humpty Falls Main runs through an area where the presence of hills requires a siphon. The section of pipe to be modelled begins immediately after the siphon. The first manhole after the siphon is manhole 21 (HFM021), which features a small opening covered with a grate to allow air to be drawn into the sewer.

There are two side-streams that join the main in the section under consideration. These side-streams are rising mains and so do not have a route for air to pass through. The diameter of the pipe increases to accommodate the flow from the side-streams. At no point does the pipe surcharge.

Figure B-1 shows the modelling domain between the end of the siphon and the pump station. **Figure B-2** below shows a pipe elevation drawing of the pipe section to be modelled. Ground elevations and the entrances of side-streams are also indicated.

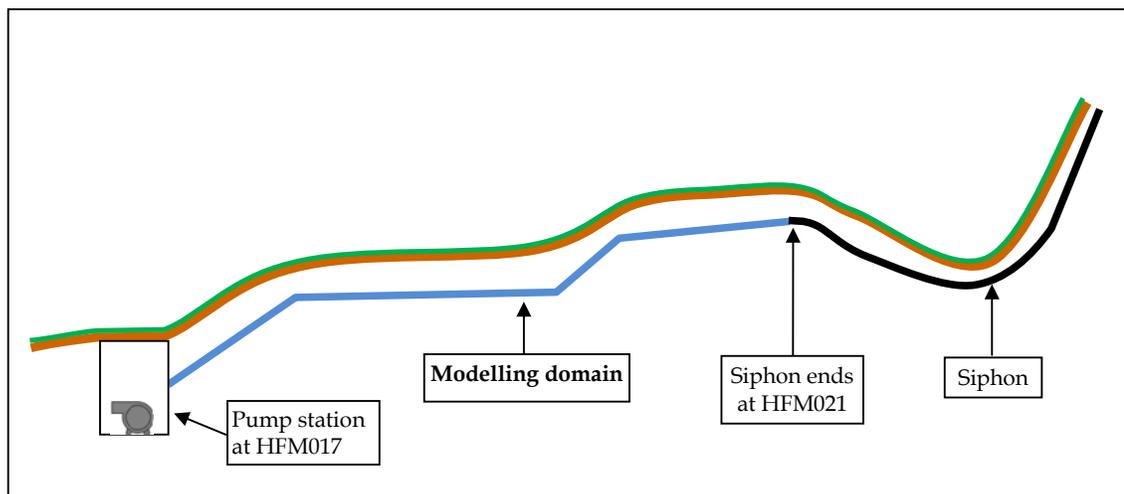


Figure B-1 Modelling Domain of Humpty Falls Main

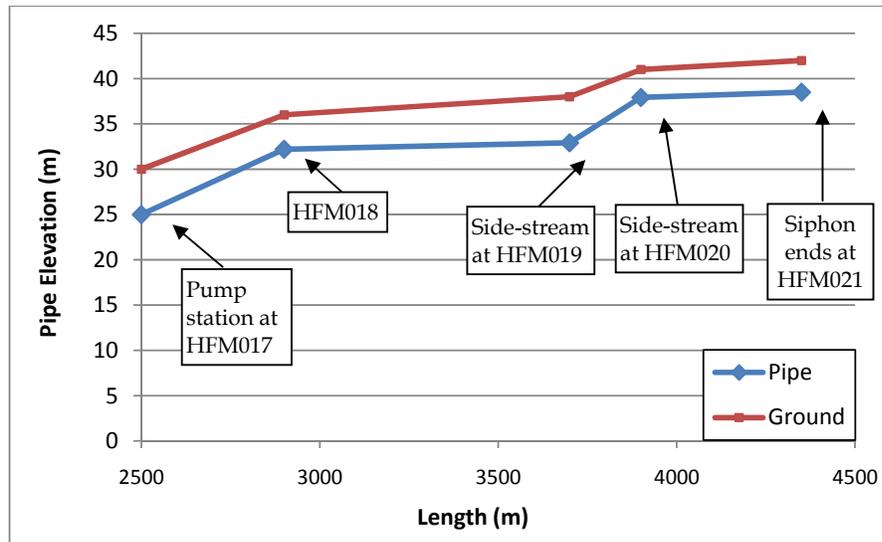


Figure B-2 Humpty Falls Main Pipe and Ground Elevations

The sewer design characteristics are provided below in **Table B-1**, with the Main split into its component reaches. Elevations are provided for the upstream manhole. The last column of **Table B-1** accounts for openings to the pipe by recording the elevation of discharge (or inlet) points. The openings at HFM021 and HFM017 are approximately at ground level.

Table B-1 Sewer Design Characteristics of Humpty Falls Main

Reach	Length (m)	Diameter (m)	Slope	Upstream Pipe Invert Elevation (m)	Upstream Ground Elevation (m)	Upstream Discharge Elevation (m) ^{Note 1}
HFM021-HFM020	450	0.6	0.0013	38.5	43.5	43.5 ^{Note 2}
HFM020-HFM019	200	0.6	0.0250	37.9	41.0	(41.0)
HFM019-HFM018	800	0.8	0.0009	32.9	38.0	(38.0)
HFM018-HFM017	400	1	0.0180	32.2	36.0	(36.0)
HFM017 (node)	-	-	-	25.0	30.0	30.0 ^{Note 2}

Notes:

- Discharge elevations of nodes that do not have openings are shown in parenthesis. Despite there being no opening at these locations, it is recommended that ground level is entered as a default.
- In this example, the discharge elevation is the same as ground elevation as the discharge node is a ground-level vent. However, the discharge elevation would be higher than ground-level if the vent was instead a stack.

It is decided that the average wastewater flows should be used to evaluate the Tool. **Table B-2**, below, shows the average flow from the siphon and two side-streams that enter at HFM020 and HFM019.

Table B-2 Average Wastewater Flows

Name	Entering Wastewater Flow (m ³ /s)
Siphon	0.15
HFM020	0.02
HFM019	0.06

The average ambient and sewer air state conditions to evaluate ventilation are shown in **Table B-3**.

Table B-3 Air State Conditions

Parameter	Ambient	Sewer Headspace
Temperature (deg C)	20.00	20.00
Relative Humidity (%)	50.00	99.00
Ambient Pressure (Pa)	101000	N/A

Modelling

To model the sewer, a few more inputs are required to define it. These are shown in **Table B-4**. The Manning's factor and dry absolute roughness are assumed to be the same for all sections of the sewer. A Manning's coefficient of 0.0145 is used to account for the roughness that would be associated with the aged condition of the pipe.

In the last two columns of **Table B-4**, the vents at the upstream and downstream ends of the pipe need to be considered. The parameters used to account for these have different values for the other pipes which do not have openings.

Each vent has a 0.20 m diameter opening with a grate. There is no rounding of the edges. Treating these openings as sharp-edged orifices, a discharge coefficient, incorporating entrance, pipe friction, and exit losses, of 0.67 is determined for each ($C_d = \{1 / (K_{ent} + K_{fric} + K_{ex})\}^{0.5} = \{1 / (0.5 + 0.74 + 1)\}^{0.5} = 0.67$).

As no other openings are assumed for this round of modelling, negligible area sizes are assigned to all other manholes.

Table B-4 Additional Tool Inputs

Reach	Manning's Factor	Dry Absolute Roughness (m)	Upstream Node Discharge Area (m ²)	Upstream Node Discharge Coefficient
HFM021-HFM020	0.0145	0.001	0.0031	0.67
HFM020-HFM019	0.0145	0.001	1.00E-06	1
HFM019-HFM018	0.0145	0.001	1.00E-06	1
HFM018-HFM017	0.0145	0.001	1.00E-06	1
HFM017 (node)	-	-	0.0031	0.67
Notes: Highlighted values indicate values used for openings from sewer headspace to the surface.				

The final inputs are wind speed and stability class. Wind is best treated as a special case, since it is variable and not always present. So as to provide conservative calculations, the wind speed is set to zero. With a zero wind speed, the stability class is of no consequence and so any class can be selected. It is worth noting that if a non-zero wind was set, it would still have no effect on the final results as all node discharge points are equal to ground level.

Figure B-3 below shows a screenshot from the Tool with inputs completed. No fan pressure (Cell E7) has been entered since natural ventilation conditions are considered. A fan node has still been specified (Cell E8) but this is to ensure that all calculations are executed correctly – any node could be specified for this.

O27													
A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Input												
2				Ambient	Headspace								
3			Ambient Temp (deg C)	20.00	20.00								
4			Ambient RH (%)	50.00	99.00								
5			Ambient Pressure (Pa)	101000									
6			Fan Pressure (Pa)	0									
7			Fan Node	HFM021-HFM020									
8			Ambient 10 m Wind Speed (m/s)	0									
9			Ambient Stability Class	C									
10													
11													
12													
13	Reach Name	Pipe Length (m)	Pipe Diameter (m)	Pipe Slope (m/m)	Mannings Roughness Coefficient	Dry Absolute Roughness (m)	Node Discharge Area (m ²)	Discharge Coeffnt. (1/Kminor) ^{0.5}	Node Discharge Elevation (m)	Ground Elevation (m)	Pipe Rise (m)	Pipe Invert Elevation (m)	Entering Wastewater Flow (m ³ /s)
14	Downstream Node						3.1E-02	0.67	30.0	30.0		25.0	
15													
16	HFM021-HFM020	450	0.6	0.0013	0.0145	0.001	3.1E-02	0.67	43.5	43.5	0.6	38.5	0.15
17	HFM020-HFM019	200	0.6	0.02500	0.0145	0.001	1.0E-06	1	41.0	41.0	5.0	37.9	0.02
18	HFM019-HFM018	800	0.8	0.00090	0.0145	0.001	1.0E-06	1	38.0	38.0	0.7	32.9	0.06
19	HFM018-HFM017	400	1	0.01800	0.0145	0.001	1.0E-06	1	36.0	36.0	7.2	32.2	0
20													

Determining the Fan Operating Point with a System Curve
 Step 1: Fill in user input values in light-blue cells.
 Step 2: Select gassing direction of nodes for each iteration.
 Step 3: Select downstream node ventilation rates for each iteration.
 Step 4: Repeat with sequentially larger fan pressure values.
 Step 5: Record results for each repeat to develop system curve.
 Step 6: Plot system curve over fan curve to determine operating point.

Iteration Summary	1	2	3	4	5
Air Discharge (L/s)	-47.4	-47.4	-47.5	-47.3	-47.7
Air balance (L/s)	0	0	0	0	0

Figure B-3 Inputs Specified for Humpty Falls Main

Results

The results from Columns P to T in the Tool are shown in **Figure B-4** and presented again with notes in **Table B-5**. It is apparent that under the conditions modelled, 47 L/s of air will be drawn into the sewer and carried through the sewer headspace, with the static pressure increasing along the way.

HOME		INSET				
E32		P	Q	R	S	T
1	A	Input				
2	B					
3						
4						
5						
6						
7						
8		Fan Pressure (Pa)				0
9		Fan Flow Rate (L/s)				47.4
10						
11						
12						
13	Reach Name	Node Absolute Static Pressure (Pa)	Node Discharge Driving Force (Pa)	Headspace Air Flow Rate (L/s)	Headspace Air Velocity (m/s)	Outgas Flow Rate (L/s)
14	Downstream Node	101033	3			-47.41
15						
16	HFM021-HFM020	100866	-3	47.4	0.5360	47.41
17	HFM020-HFM019	100868	-11	47.4	0.2242	0.00
18	HFM019-HFM018	100933	-1	47.4	0.2407	0.00
19	HFM018-HFM017	100943	-2	47.4	0.0696	0.00
20						
21						

Figure B-4 Results for Humpty Falls Main in the Ventilation Tool

Table B-5 Results from the Ventilation Tool for Humpty Falls Main

Reach	Node Static Pressure ¹ (Pa)	Node Discharge Driving Force (Pa)	Headspace Air Flow Rate ² (L/s)	Headspace Air Velocity ² (m/s)	Outgas Flow Rate ³ (L/s)
HFM021-HFM020	100866	-3	47.4	0.5360	47.41
HFM020-HFM019	100868	-11	47.4	0.2242	0.00
HFM019-HFM018	100933	-1	47.4	0.2407	0.00
HFM018-HFM017	100943	-2	47.4	0.0696	0.00
HFM017 (node)	101033	+3	-	-	-47.41

Notes:

1. Static pressure at upstream end of reach.
2. Positive values indicate ventilation moving downstream.
3. Positive values indicate in-gassing.

Further Exercises

Further evaluation can be done with the Tool to determine the influence of different assumptions and ventilation configurations. Some alterations that could be modelled are:

- Assess the effect of adding vents at different manholes, and alter which vents have in-gassing or out-gassing (Manual Version of Tool).
- Assess ventilation for different wastewater flow rates (e.g. minimum, maximum) and air conditions (i.e. humidity and temperature).
- Combine with a sulphide fate model to see the influence that different ventilation rates have on H₂S in the headspace.
- Add a fan somewhere in the sewer and determine the operating point by developing a system curve.

Worked Example 2 - Modelling ACME City One

The Problem:

ACME City One (AC1) is a major interceptor pipe that runs beneath ACME City. It starts at a pump station where several sewers converge, and runs to the city's major wastewater treatment plant (WWTP), ACME City WWTP. The entire length of AC1 is gravity pipe.

As the city has built up over time and the volume handled by AC1 grown, so have the complaints about odours in areas along the length of AC1 increased. It is suspected that AC1 is responsible. To confirm this, an investigation into the operation of the system is to be undertaken.

Sensing that some form of improvement will be necessary, the facility's operator has already drafted some options, including installing a dispersion stack or installing an odour control system with a stack.

As part of the investigation, the operating point of a ventilation fan nominated in the draft control options will be determined. The technical feasibility of adding an odour control system will also be assessed. The ARC Ventilation Tool will be used to assist with this task.

Sewer Design and Data:

Figure B-5 below shows a pipe elevation drawing of the pipe section to be modelled. Ground elevations and the entrances of side-streams are also indicated. The side-streams are rising mains and so do not offer a route for air.

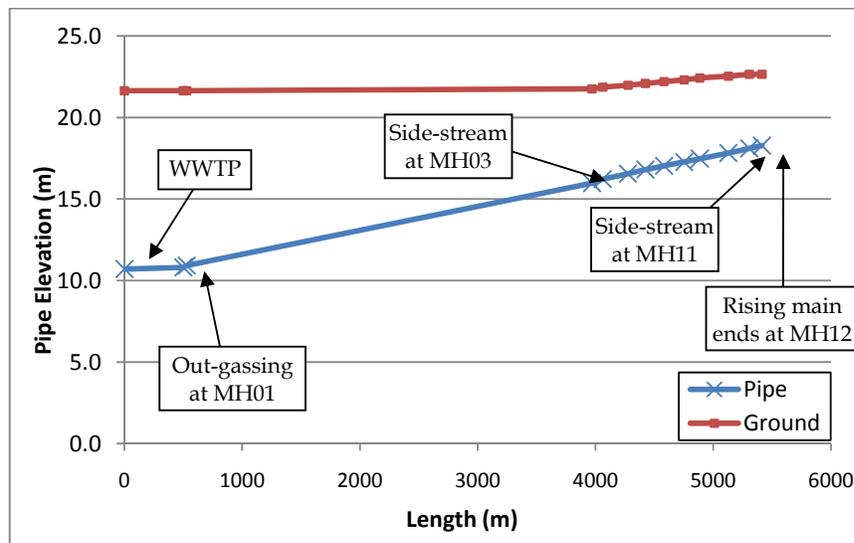


Figure B-5 ACME City One Pipe and Ground Elevations

Downstream of the pumping station, the rising main ends and the pipe becomes a gravity sewer at a location designated MH12. At MH12 there is a 0.5 m diameter pipe to the sewer, covered with a grate, which allows air to be drawn into the sewer.

As the interceptor nears ACME City WWTP, the pipe becomes surcharged. This happens between MH01 and the plant. MH01 currently features a vent with a grate also. The

diameter of the pipe to the sewer is 0.3 m. **Figure B-6** shows the air inlet and outlet vents at MH12 and MH01, respectively.

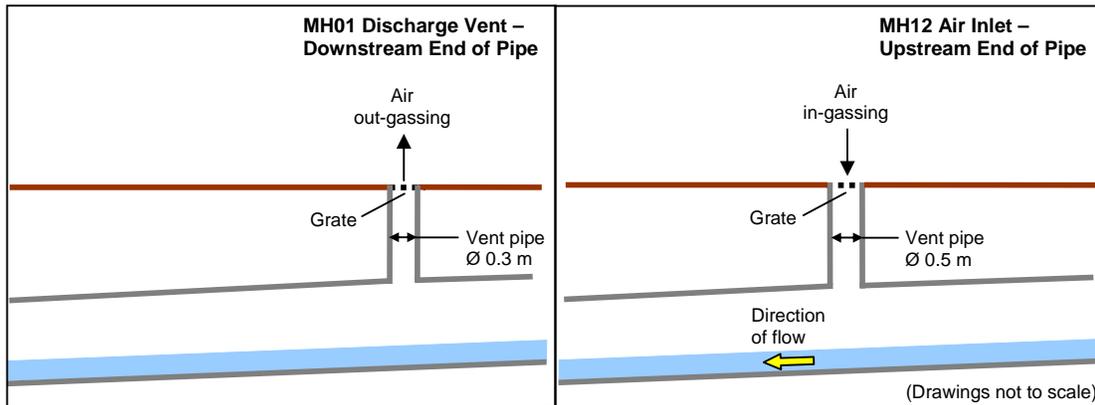


Figure B-6 Air Inlet and Discharge Points on ACME City One

The sewer design characteristics are provided below in **Table B-6**, with the interceptor split into its component reaches. Elevations are indicated for the upstream manhole. The last reach, MH01–WWTP, is excluded from the Tool since it becomes surcharged.

Table B-6 Sewer Design Characteristics of ACME City One

Reach	Length (m)	Diameter (m)	Slope	Upstream Pipe Invert Elevation (m)	Upstream Ground Elevation (m)	Upstream Discharge Elevation (m) ^{Note 1}
MH12 - MH11	108	1.473	0.00157	18.3	22.6	22.6 ^{Note 2}
MH11 - MH10	177	1.63	0.00164	18.1	22.6	(22.6)
MH10 - MH09	243	1.473	0.0014	17.8	22.5	(22.5)
MH09 - MH08	133	1.473	0.00158	17.5	22.4	(22.4)
MH08 - MH07	171	1.473	0.00137	17.3	22.3	(22.3)
MH07 - MH06	158	1.549	0.00138	17.0	22.2	(22.2)
MH06 - MH05	148	1.549	0.00176	16.8	22.1	(22.1)
MH05 - MH04	214	1.549	0.00154	16.6	22.0	(22.0)
MH04 - MH03	91	1.549	0.00275	16.2	21.9	(21.9)
MH03 - MH02	3441	1.63	0.00149	16.0	21.8	(21.8)
MH02 - MH01	30	1.549	0.0014993	10.9	21.6	(21.6)
MH01 (node)	-	-	-	10.8	21.6	21.6 ^{Note 2}

Notes:

- Discharge elevations of nodes that do not have openings are shown in parenthesis. Despite there being no opening at these locations, it is recommended that ground level is entered as a default.
- In this example, the discharge elevation is the same as ground elevation as the discharge node is a ground-level vent. However, the discharge elevation would be higher than ground-level if the vent was instead a stack.

The last column of **Table B-6** is the elevation of discharge (or inlet) points. The openings at MH12 and MH01 are approximately at ground level, and so assumed to be ground level. Note that whilst there are no other openings to the sewer, elevations for other nodes should still be entered into the Tool. In this case the discharge elevations are also set equal to the ground elevation.

It is decided that the average wastewater flows should initially be used for the purpose of the investigation. **Table B-7**, below, shows the flow from the pump station and two side-streams that enter at MH11 and MH03.

Table B-7 Average Wastewater Flows

Name	Entering Wastewater Flow (m ³ /s)
Pump station	0.487
MH11	0.08
MH03	0.03

The average ambient and sewer air state conditions are shown in **Table B-8**. For the case of forced ventilation, the temperature and relative humidity of the sewer headspace are set equal to ambient based on the assumption that the fan will force a lot more ambient air into the sewer than under natural ventilation conditions, and so the headspace will be closer to ambient than typical sewer conditions.

Table B-8 Air State Conditions

Parameter	Natural Ventilation		Forced Ventilation	
	Ambient	Sewer Headspace	Ambient	Sewer Headspace
Temperature (deg C)	14.00	20.00	14.00	14.00
Relative Humidity (%)	60.00	99.00	60.00	60.00
Ambient Pressure (Pa)	101000	N/A	101000	N/A

The performance curve of the proposed fan is converted into **Table B-9**.

Table B-9 Fan Performance Curve Data

Static Pressure (Pa)	Flow rate (L/s)
1050	3100
1200	2900
1400	2500
1600	2050
2000	900
2150	150

Modelling

To model the interceptor, a few more inputs are required to define the pipe. These are shown in **Table B-10**. The Manning's coefficient and dry absolute roughness are assumed to be the same for all sections of the sewer. In the last two columns, the air inlet opening and extraction point need to be considered. The parameters used to account for them are highlighted.

The air inlet at MH12 is a 0.50 m diameter pipe, covered with a grate, running down to the interceptor. There is no rounding of the edges where the pipe joins the crown of the interceptor, or where the pipe interfaces with the surface. A discharge coefficient of 0.77 is determined ($C_d = 1/(0.5+0.2+1.0)^{0.5} = 0.77$). This calculation includes the entrance ($K=0.5$), friction (K estimated at 0.2) and exit ($K=1$) losses associated with the vent pipe. The frictional losses are estimated by using an assumed air flow through the vent, which can be refined later if the ventilation rate calculated by the Tool would significantly change the discharge coefficient.

The vent pipe from the sewer at MH01 is 0.30 m in diameter. Again, the interface of the duct with the crown of the interceptor is flush with no rounding. A discharge coefficient of 0.65 is calculated.

As there are no other openings from the sewer, negligible area sizes are assigned to all other manholes.

Table B-10 Additional Tool Inputs

Reach	Manning's Coefficient	Dry Absolute Roughness (m)	Upstream Node Discharge Area (m ²)	Upstream Node Discharge Coefficient
MH12 - MH11	0.013	0.001	0.196	0.77
MH11 - MH10	0.013	0.001	1.00E-04	1
MH10 - MH09	0.013	0.001	1.00E-04	1
MH09 - MH08	0.013	0.001	1.00E-04	1
MH08 - MH07	0.013	0.001	1.00E-04	1
MH07 - MH06	0.013	0.001	1.00E-04	1
MH06 - MH05	0.013	0.001	1.00E-04	1
MH05 - MH04	0.013	0.001	1.00E-04	1
MH04 - MH03	0.013	0.001	1.00E-04	1
MH03 - MH02	0.013	0.001	1.00E-04	1
MH02 - MH01	0.013	0.001	7.07E-02	0.65
MH01 - WWTP	-	-	1.00E-04	1
Notes: Highlighted values indicate values used for openings from sewer headspace to the surface.				

The final inputs are wind speed and stability class. As in Example 1, a calm condition is recommended in keeping with a conservative approach. Of course, with all vents at ground level in the current configuration, wind would have no influence if it was to be included.

Figure B-7 below shows a screenshot from the Tool with inputs completed.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Input													
2					Ambient	Headspace								
3	Ambient Temp (deg C)				14.00	20.00								
4	Ambient RH (%)				60.00	99.00								
5	Ambient Pressure (Pa)				101000									
6	Fan Pressure (Pa)				0									
7	Fan Node				Downstream Node									
8														
9	Ambient 10 m Wind Speed (m/s)				0									
10	Ambient Stability Class				C									
11														
12														
13	Reach Name		Pipe Length (m)	Pipe Diameter (m)	Pipe Slope (m/m)	Mannings Roughness Coefficient	Dry Absolute Roughness (m)	Node Discharge Area (m ²)	Discharge Coeffnt. (1/Kminor) ^{2.5}	Node Discharge Elevation (m)	Ground Elevation (m)	Pipe Rise (m)	Pipe Invert Elevation (m)	Entering Wastewater Flow (m ³ /s)
14	Downstream Node							7.1E-02	0.65	21.6	21.6		10.8	
15														
16	MH12-MH11		108	1.473	0.00157	0.013	0.001	1.9E-01	0.77	22.6	22.6	0.2	18.3	0.487
17	MH11-MH10		177	1.63	0.00164	0.013	0.001	1.0E-04	1	22.6	22.6	0.3	18.1	0.08
18	MH10-MH09		243	1.473	0.00140	0.013	0.001	1.0E-04	1	22.5	22.5	0.3	17.8	0
19	MH09-MH08		133	1.473	0.00158	0.013	0.001	1.0E-04	1	22.4	22.4	0.2	17.5	0
20	MH08-MH07		171	1.473	0.00137	0.013	0.001	1.0E-04	1	22.3	22.3	0.2	17.3	0
21	MH07-MH06		158	1.549	0.00138	0.013	0.001	1.0E-04	1	22.2	22.2	0.2	17.0	0
22	MH06-MH05		148	1.549	0.00176	0.013	0.001	1.0E-04	1	22.1	22.1	0.3	16.8	0
23	MH05-MH04		214	1.549	0.00154	0.013	0.001	1.0E-04	1	22.0	22.0	0.3	16.6	0
24	MH04-MH03		91	1.549	0.00275	0.013	0.001	1.0E-04	1	21.9	21.9	0.3	16.2	0
25	MH03-MH02		3441	1.63	0.00149	0.013	0.001	1.0E-04	1	21.8	21.8	5.1	16.0	0.03
26	MH02-MH01		30	1.549	0.00150	0.013	0.001	1.0E-04	1	21.6	21.6	0.04	10.9	0

Figure B-7 Inputs Specified for ACME City One

By entering a fan pressure into the Tool and completing the subsequent air balance iterations, the Tool provides a corresponding fan flow rate. A range of static pressures are evaluated in the Tool to determine the flow rate and generate a system curve.

Results

Current Configuration – Natural Ventilation

Evaluating the natural ventilation condition firstly, using the corresponding air state inputs from **Table B-8** and setting the fan pressure to zero, a ventilation rate of 220.8 L/s is determined.

Addition of a Fan – Forced Ventilation

The pressure inputs and corresponding flow results for the forced ventilation condition are presented in **Table B-11**. The air state inputs for forced ventilation in **Table B-8** were used in calculating these flows. Discharge coefficients were assumed to be unchanged from the natural ventilation condition, though this could be refined later if necessary.

Table B-11 AC1 System Curve Data

Static Pressure (Pa)	Flow rate ¹ (L/s)
0	-215.5
200	-791.1
400	-1105.5
600	-1350.2
1000	-1741.2
1500	-2132.4
2000	-2461.8

Notes:
 1. Negative flow rates indicate that air is extracted from the sewer.

By plotting the data from **Table B-9** and **Table B-11** together (with absolute airflows used), an operating point is able to be determined, as shown in **Figure B-8**. The operating point is approximately 2,180 L/s (7,884 m³/hr) at 1,550 Pa.

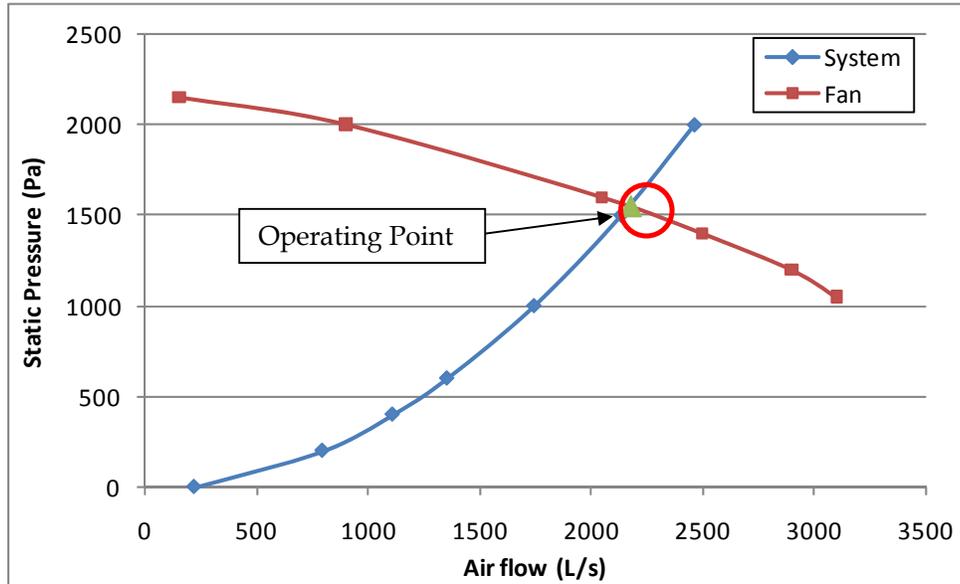


Figure B-8 Determination of Fan Operating Point

The discharge driving forces for nodes along the length of the interceptor for both natural and forced ventilation are shown in **Table B-12**. The results indicate that the potential exists for out-gassing to occur after the first reach for natural ventilation, even without the influence of wind, though it does not become considerable until MH03 and MH02. Adding a fan changes conditions substantially, placing the pipe under negative pressures that would be more than sufficient to prevent fugitive emissions.

Table B-12 Node Discharge Driving Forces

Node	Node Discharge Driving Force (Pa)	
	Natural Ventilation	Forced Ventilation ^{Note 1}
MH12	-1	-127
MH11	0	-129
MH10	+1	-131
MH09	+2	-137
MH08	+2	-139
MH07	+3	-144
MH06	+3	-147
MH05	+3	-149
MH04	+3	-153
MH03	+4	-154
MH02	+14	-195
MH01 ^{Note 1}	+14	+1356

Notes:

1. Determined by running the Tool with the operating point pressure of 1,550 Pa.

Modelling Conclusion

The conclusion from this round of modelling is that a fan would improve the ventilation of the sewer and insure against fugitive emissions. Considering **Figure B-8**, it appears that there is some opportunity to add an odour treatment unit or other alteration that would create a back-pressure at the gassing manhole, but any proposal would have to be carefully reviewed to avoid significant loss of flow.

Field verification should be conducted on the sewer in its current natural ventilation state to check that the sewer is accurately represented by the Tool. After modifications have been made to improve ventilation, the performance testing results should be compared with the Tool's calculations for forced ventilation.

Extension

Dispersion Stacks and Temperature Differentials – Natural Ventilation

Before venturing into modifications to install fans and other equipment that could be costly, it is worth assessing the effect of adding a single stack to the downstream manhole under natural ventilation conditions. Adding an 8 m stack to MH01 increases the node discharge elevation from 21.6 to 29.6 m. With the opening no longer at ground level, this means that the Tool could consider the effect of wind, though for the purpose of this example it will be disregarded.

The coefficient of the inlet vent at MH12 remains unchanged at 0.77, however the coefficient for the air discharge vent at MH01 changes to 0.70 due to the incorporation of frictional losses in the stack. This is based on a stack diameter of 0.3 m (the same as the vent shaft), and the natural ventilation rate of 220.8 L/s determined earlier.

Figure B-9 shows the ventilation from MH01 for the conditions of no stack and installing the 8 m stack, compared with ambient temperature. The sewer temperature remains fixed at 20°C for all data points. With increasing ambient temperature, it is seen that the ventilation rate decreases, though the decline is more pronounced for the condition including the stack.

For the lowest ambient temperature, and thus the greatest temperature differential, adding a stack increases the sewer ventilation by 30 L/s, or 13% compared to the sewer with no stack. At an ambient temperature 26°C (6°C above the sewer) the ventilation rate for the sewer with a stack is equal to that without a stack. Beyond this point, the ventilation rate for a sewer with a stack falls below that of the sewer without a stack.

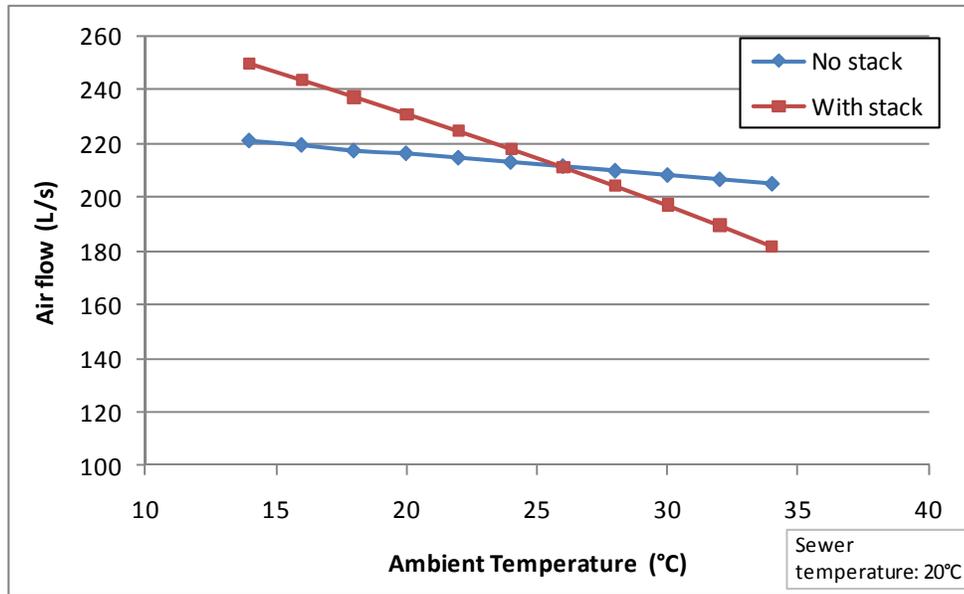


Figure B-9 Influence of Ambient Temperature on Sewer Ventilation

Effect of Adding a Biofilter – Forced Ventilation

If the dispersion stack fails to achieve suitable reduction in odour, the plant operator is considering installing a biofilter. A particular design of biofilter that has been proposed has a total pressure loss of 1,110 Pa, including losses from duct bends from the sewer to the biofilter. The overall effect in this case is that the fan curve is reduced by the pressure drop over the biofilter, as shown in **Figure B-10**. The operating point is now 1,540 L/s (5,544 m³/hr) at 700 Pa.

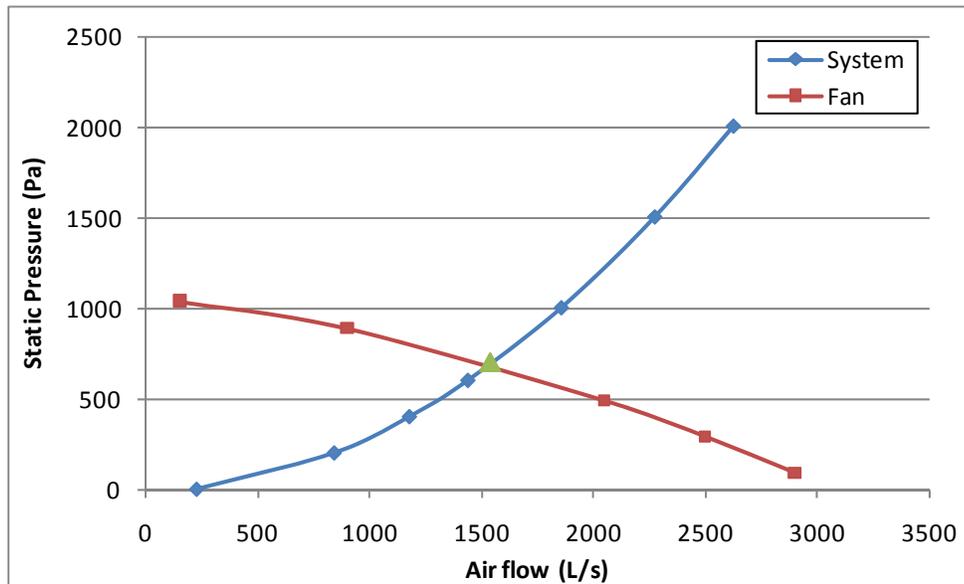


Figure B-10 Operating Point for Fan with a Biofilter and Stack at MH01

To summarise, the results of assessing AC1 with the Ventilation Tool are as follows:

Table B-13 Summary of Different Operating Points

Scenario	Static Pressure (Pa)	Flow rate (L/s)
Fan only	1,550	2,180
Fan, 8m stack, and biofilter	700	1,540

Notes: Operating points in this table are for the conditions of ambient RH: 60%, sewer RH: 99%, ambient temperature: 14°C, sewer temperature: 20°C.

Further Exercises

Further evaluation can be done with the Tool to determine the influence of different assumptions and ventilation configurations. Some alterations that could be modelled are:

- Select a fan with a different fan curve.
- Assess the effect of adding vents at different manholes, and whether in-gassing or out-gassing occurs.
- Determine the effect of moving the air extraction point further upstream.
- Assess ventilation for different wastewater flow rates (e.g. minimum, maximum) and air conditions.
- Combine with sulphide fate model to see the influence of new ventilation rates on H₂S in the headspace.