APPENDIX A - Composition of the program

An overview of the relationship between the programs and files in ALEID2000 is given in Figure 1. The program consists of the calculation part (the DOS-program, ALCALC) and the ALEID2000-input and presentation shell, in Windows. The names around the blocks indicate files or file groups involved.
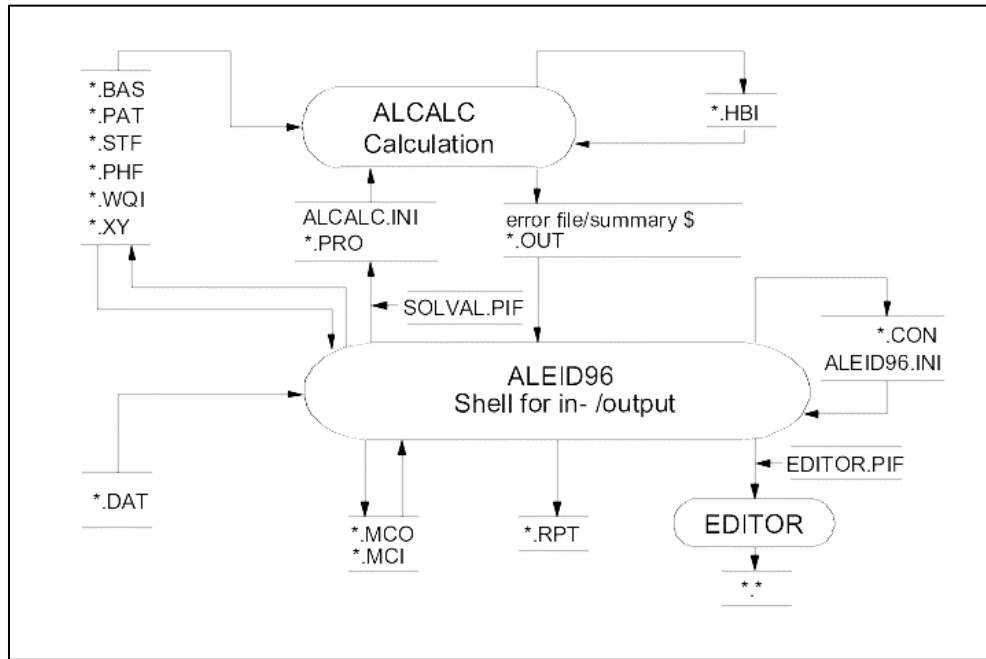

Figure 1 Relation between the programs and files in Aleid96/ALEID2000

The following relationships can be seen in the figure:

- Running the calculation program from the shell needs the installation file ALCALC.INI together with a project file (*.PRO). The names of the model input files (*.BAT, *.PAT, etc.) are indicated in this project file. All these files have also to be present. The ALCALC.INI file is generated by the program whereas the input files have to be created by user (via an editor or the ALEID2000 menu in the shell).
- After a successful calculation has been done, a (binary) output file (*.OUT) is created, together with the error-/status report file, $. The .OUT-file contains all calculated information about the network. This information can be used for presentation of the results in the shell or in an ASCII-report file (*.RPT).

- The model input files (*.BAS, *.PAT, etc.) can also be modified from the shell.
- The shell makes use of a number of support files (ALEID2000.INI and the .MCI- and .MCO macro files) and additional input data (*.DAT: units file and *.CON: geographical contours).
- An independent editor can be run from the shell (see sections 3.3.2 and 5.5.1)
- An additional binary output file, *.HBI, containing hydraulic results is also created after a calculation. This can be used later for running water quality calculations.
- Communication between the ALEID2000-shell and the DOS-programs (ALCALC and the editor) takes place via PIF-files.

APPENDIX B - Error messages

Error messages in the calculation program, ALCALC

*** ERROR 10: cannot open hydraulics scratch file
A temporary hydraulic file is created for use in water quality calculations when a specific .HBI-file is not requested. The message appears if the temporary file cannot be created. Possible causes: insufficient space on the hard-disk or memory problems.

*** ERROR 11: cannot open hydraulics file
The same as error 10, but here for the specified .HBI-file name.

*** ERROR 12: hydraulics file does not match network data
The specified .HBI-file refers to another network configuration than the one currently used for analysis.

*** ERROR 13: cannot read hydraulics file
The specified .HBI-file is incomplete or damaged.

*** ERROR 14: cannot save results to file
A general message when a file with results has to be created, and this is not possible. Possible causes: insufficient space on the hard-disk or memory problems.

*** ERROR 101: not enough memory to store network data
*** ERROR 102: not enough memory for hydraulic analysis
*** ERROR 103: not enough memory for water quality analysis
*** ERROR 104: not enough memory to write output report
The network model is too large for available memory of the calculation program, ALCALC.

*** ERROR 200: one or more errors in the input file
One or more errors are detected during the data reading procedure.

*** ERROR 201: syntax error
*** ERROR 202: duplicate node
The node names in the sections [CONSUMPTION] and [TANKS] should always differ.

*** ERROR 203: duplicate link
The link names in the sections [PIPES], [PUMPS], [HYDRANTS] and [VALVES] should always differ.

*** ERROR 204: undefined node
*** ERROR 205: undefined link
*** ERROR 206: illegal pump/hydrant/reservoir curve
*** ERROR 207: illegal time pattern index
*** ERROR 208: illegal parameter value

*** ERROR 209: illegal pipe data
The link data are incomplete, or impossible values are specified for some parameters (e.g. negative diameter)

*** ERROR 210: tank levels mis-specified
Specified surface levels are not in agreement (e.g. minimum is greater than maximum)

*** ERROR 211: no tanks or reservoirs in network
A network has to consist of minimum one fixed head node being boundary condition for the pressure.

*** ERROR 212: control valve connected to a tank
This is not allowed.

*** ERROR 215: not enough nodes in network
The network model should consist of minimum one reservoir/fixed head node, one ordinary node and a pipe connecting these two.

*** ERROR 216: illegal status setting for link

*** ERROR 217: report start time greater than simulation duration
The report will obviously not be created.

*** ERROR 218: line exceeds 200 characters

*** ERROR 300: cannot solve network hydraulic equations
The maximum (specified) number of iterations has been reached without satisfying the requested calculation accuracy. Possible causes: inconsistent control settings initiating unstable operation, e.g. conflicting pump curves, valve operation, etc.

*** ERROR 301: The following nodes isolated from the network at time:...
A group of nodes create "an isolated island". Possible causes: the connecting link is accidentally omitted during the model building procedure, or becomes closed at certain moment (valve) without providing a feed from another side.

*** ERROR 500: for one or more nodes the elevation is missing
The nodal elevation has to be specified in the co-ordinates file

*** ERROR 600: calculation duration less then zero

*** ERROR 901: attempt to change to project drive failed
*** ERROR 902: attempt to change to project directory failed
*** ERROR 903: Path of project directory too complicated
*** ERROR 904: attempt to remove older version of file failed
*** ERROR 905: attempt to rename file failed

Different messages that appear if the ALCALC program cannot detect the input files.

APPENDIX C

Files in the program and working directories

Program directory
AL2000.EXE
ALCALC.EXE
COLEBR.EXE
COLE{UK}.TXT
EQUIVA.EXE
SOLVAL.BAT

Working directory
*.PRO   -   project files
*.BAS   -   basic files
*.XY   -   coordinate/ground elevation file
*.STF   -   control settings files
*.PHF   -   pump/hydrant/reservoir curve library
*.CON -   contour file
*.WQI   -   water quality files
*.MCO -   macro files in output mode
*.MCI   -   macro files in input mode
*.OUT   -   binary output files
*.HBI   -   binary hydraulic files
*.RPT   -   ASCII-report files
*.DAT   -   data files (for graph presentation setting)
ALCALC.INI   -   initialization file for the ALCALC program
$.   -   ASCII report on computing process
*.INI   -   INI file for relevant project
*.BAK -   backup files

APPENDIX D

Files created in ALEID2000

D.1 Overview of the ALEID2000 files

ALEID2000 creates a number of files: to support its own execution, or to obtain (keep) information required by the user. A distinction can be made between modified input files, support files and output files. Some of these files are readable (in ASCII-format), others can be accessed only through the ALEID2000 shell (binary format).

D.1.1 Modified input files

All relevant input information can be modified via the option "Edit - Modify input". Done in this way, the modifications remain temporary (in the program memory) unless the "File - Save input" option is used. The original input is overwritten after that, if not saved under another file name. Moreover, parts of the input file that cannot be changed through the "Edit - Modify input" option, such as empty rows or/and separate comments (created by editor) will be removed from the file.

D.1.2 Support files

Support files keep the current settings needed for the program execution. These are files with variable content modified through the main ALEID2000 menu:

.MCI/.MCO* - are macro files which contain arbitrary screen settings for input/output presentations. These (binary) files are entirely manipulated (saved, loaded, renamed or removed) by the user.

.INI - are project files which contain initialisation settings.

ALCALC.INI - contains calculation run parameters such as start, end, time step, accuracy, etc. The file becomes re-created (i.e. the original content overwritten) every time the menu option "Run - Standard" is used.

D.1.3 Output files

Other files created by ALEID2000 result from model simulation runs, and serve general purpose of helping analyse calculation results. These are the following binary files:

- file with hydraulic solution (*.HBI);
- file with full output information (*.OUT);

and readable (ASCII-format) files:

- output report files (*.RPT);
- error-/status report file $.

The indicated files are automatically overwritten with every new calculation, the user decides either the old version should be removed, or renamed beforehand.

D.2 Binary output files

ALEID2000 creates three types of binary files used for model presentations in the shell: macro files, file with hydraulic solution and file with full output information.

D.2.1 Macro files

Macro files, *.MCI/*.MCO, serve exclusively for saving the preferred combination of screen settings for graph presentations. The files are created via the "Create Macro" main menu option and can be loaded by the "Call Macro" option. For more details see sections 5.7.6 and 5.7.7.

D.2.2 File with hydraulic solution

This file (*.HBI) is created and later used by the ALCALC calculation program. It contains the output of hydraulic calculations relevant as an input for various water quality calculations. The file name should be specified within the dialog box accessed via the "Run - Standard" menu option, in the "Hydraulic solution" input cell. It can also be done by editing the ALCALC.INI file, under section [SOLUTION] - HY-DRAULICS SAVE or USE depending on the purpose.

D.2.3 File with full output information

The binary output (*.OUT) is created by the ALCALC calculation program for general presentation of the results. It contains full information (hydraulic and water quality) for all selected times. The file name should be specified within the dialog box accessed via the "Run - Standard" menu option, in the "Binary report" input cell. It can also be done by editing the ALCALC.INI file, under section [REPORT] - BFILE.

NOTE: Part of the same output information is presented in both above files, for practical reasons. Having a different format than the .OUT-file, the .HBI-file is meant only as an interim step towards the water quality calculation. Therefore is its content not readable by the shell.

D.3 Calculation summary: error-/status report file, $

The status file, $, offers information about the calculation run. Before the calculation will be executed, the user may choose the level of detail presented in the file. This is done via the "Run - Standard" option, in the "Status info" menu, or directly in the ALCALC.INI file under section [REPORT] - STATUS (NO, YES, FULL). The file content is overwritten with every new calculation, unless renamed beforehand. The file content appears automatically on the screen each time the calculation is successfully completed. It can also be inspected at any moment via the "Report - Output summary" menu option. Three different file formats are possible:

Status: none (NO)

This option offers a list with main calculation parameters only. A sample layout looks as follows:

```
ALEID2000 network calculations

   with pump instead of fixed head node

      Calculation run on............. Wednesday 21 August 1996
      Project file...................... SIMPLE1.PRO
      Basic configuration file.......... simple.bas
      Demand pattern library............ simple.pat
      Control settings file............. simple.stf
      Water quality file................ simple.wqi
      Coordinates file.................. simple.xy
      Pump/hydrant/reservoir library..... simple.phf
      File with hydraulic solution....... SIMPLE1.HBI
      File with full output information.. SIMPLE1.OUT


      Total nodes........................ 10
      Total pipes........................ 8
      Total reservoirs................... 1
      Total pumps........................ 2
      Total hydrants..................... 0
      Total valves....................... 0

      Units of measure................... SI
      Head-loss formula.................. Darcy-Weisbach (iter.)
      Maximum number of iterations....... 40
      Calculation year................... 1996
      Start time......................... 0.00  hours
      Total duration..................... 24.00 hours
      Hydraulic time step................ 1.00  hour
      Specific Gravity .................. 1.00
      Kinematic viscosity................ 1.02e-006 m2/sec
      Absolute accuracy for pressures.... 0.001000 m
      Relative accuracy for flows........ 0.001000
      Diffusion.......................... 1.21e-009 m2/sec
      Total nodal (average) demand....... 263.75 m3/h
      Pressure related demand calculation Yes

      Water quality calculation......... Travel time
      Minimum residence time............. 6.00 min
      Maximum No. of segments per pipe... 100
```

Status: limited (YES)

Besides the indicated information above, this option includes a short status report on each consecutive steady-state calculation, namely:
- Balance/imbalance and the total number of iterations. Balance means that the flow continuity is reached in general for the whole system. If imbalance is indicated, it reflects problems with continuity equations in some nodes (not necessary large). This can be checked in the output report for each node (table column "Balance error"). The number of iterations shows if the requested calculation accuracy has been reached within the maximum number of iterations.
- Total demand (incl. leakage)
- Mode of operation for main components: inflow/outflow for reservoirs, settings for pumps and valves.

For example:

```
Hydraulic status at time  0:00:
-----------------------------------------------------------
Balance OK           6 iterations
Flow accuracy        0.000061
Pressure accuracy    0.000024
Total demand         421.00 m3/h
Reservoir gp         Outflow  (Fixed head)
Pump 11              Open   (1.00 setting)
Pump 22              Open   (1.00 setting)
-----------------------------------------------------------
```

Furthermore, if a water quality calculation was carried out, a short water quality status report will be given for each time, indicating the water quality step and the number of pipes where more segments (than specified) are required to obtain an accurate calculation. Example:

```
Water quality status:
------------------------------------
   Time    Time step  # pipes above
   hour          min  segment Limit
------------------------------------
   0:00         6.00           0
   1:00         6.00           0
   2:00         6.00           0
   3:00         6.08           0
------------------------------------
```

Status: complete (FULL)

Besides the information given by the YES-status, the accuracy of the hydraulic calculation will be illustrated by listing the accuracy for each iteration, under this option. In addition, a list is given of links, which due to critical reservoir levels have to be closed/opened.

D.4   Report files

D.4.1   General

The output report files (*.RPT) are created via the "Report - ASCII output" menu option, from the information stored in the binary output file (*.OUT). Depending on the choices from the dialog box, the data will be sorted in tables for different times/time series. The following parameters can be selected:

Node data:
- Node name (compulsory);
- Ground elevation;
- Pressure threshold;
- Node pressure;
- Piezometric head;
- Up to five demand categories;
- Total demand (nominal);
- Total demand (actual, calculated in pressure related mode);
- Percentage actual/nominal demand;
- Water quality.

Link data:
- Link name (compulsory);
- Node name - begin link;
- Node name - end link;
- Diameter (not for pumps);
- Length (not for pumps);
- Wall roughness (not for pumps);
- Flow rate;
- Pressure drop (not for closed pipes);
- Pressure gradient (not for closed pipes);
- Velocity (not for closed pipes)
- Pump power;
- Link status;
- Link type;
- Specified wall reaction coefficient;
- Specified volume reaction coefficient.

D.4.2 Snapshot report files

Calculation results for all specified times are given in this file. The file consists of:
- Header with general information;
- The node and/or link table(s) for each specified time and combination of the above mentioned parameters.

The header has the following format:

```
*********************************************************************
*                                                                   *
*      ALEID2000                                                    *
*      Output based on : XXXXXXXX.PRO en XXXXXXXX.OUT       *
*      Date:   00-00-0000                                           *
*      Time:   00:00:00                                             *
*                                                                   *
*********************************************************************
```

The following indications related to the node- or pipe type can be given in the last table column:

- Reservoir   :   Reservoir
- Pump   :   Pump
- Hydrant   :   Hydrant
- Check valve   :   CV
- Pressure reducing valve   :   PRV
- Pressure sustaining valve   :   PSV
- Flow controlled valve   :   FCV
- Pressure breaking valve   :   PBV
- Throttle valve (general)   :   TCV

This column remains empty for ordinary nodes and pipes

D.4.3 Time series report files

Building tables for the time series report files is done in the same way as for the snapshot reports. The table title consists of the node- or link name. The combination of the parameters is given for the times indicated in the first column.

APPENDIX E

Theoretical background of the calculation

E.1 General

ALEID2000 performs calculations for a distribution network model. In such a model, the network will be schematized to a system of nodes and links where a node represents a supply, storage or demand, while the link between two nodes defines a pipe, pump or valve.

Different components of the network model are described in this chapter, as well as the background of the calculation features of ALEID2000. This is more a theoretical description of the possibilities in the program. Practical information about the layout of the input files and the program commands are to be found in Chapter 4 and 5, respectively. Where necessary, the reference to the related sections in these chapters will be given here.

E.2 Components of the network model

E.3 Nodes

E.3.1 General

A node marks a change in a pipe property. This situation arises from a change in:

- pipe diameter;
- pipe material (change of k-value);
- pipe flow as a result of:
    * pipe intersection;
    * pipe branching;
    * pipe merging;
    * major consumer connected;
    * jointly modelled demand;
    * supply (feeding) point.

In this way, extra nodes can be introduced providing additional information about the network, e.g. so called "configuration"-nodes used to fit the network lay-out in graphical presentations to the real one.

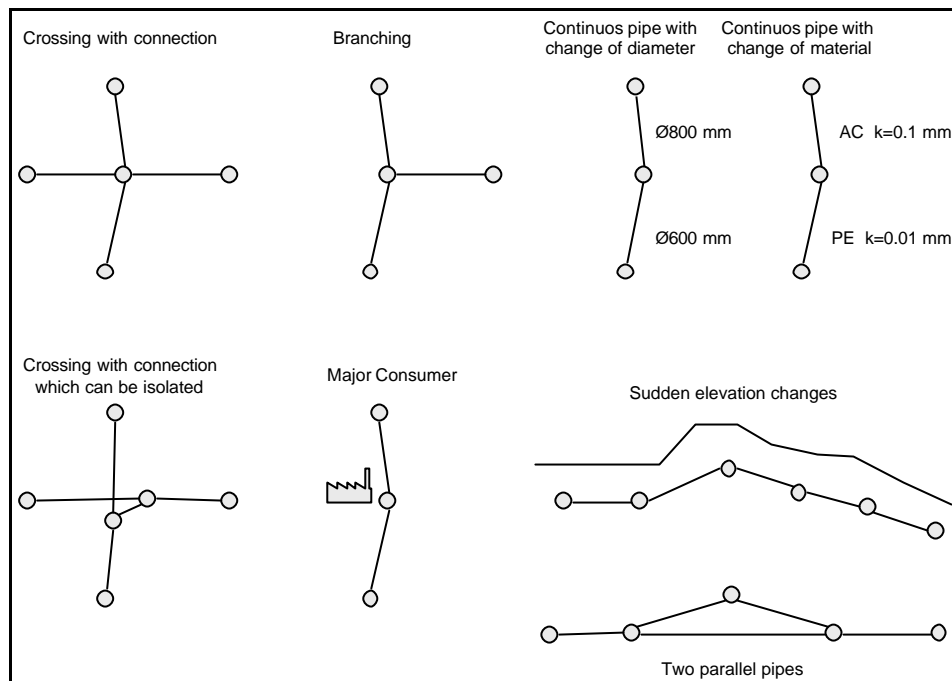Various possibilities are given in Figure 2.

Figure 2 Possible node types in network models

The following information is required for each node:

- node name;
- node type;
- ground elevation;
- co-ordinates;
- for demand nodes: demand in categories;
- for reservoirs: initial or fixed head value;
- pressure threshold;
- for concentration calculation: initial concentration;
- for the source of concentration calculation: incoming concentration + reference to related pattern.

E.3.2   Node data

Specific aspects about the node information are discussed in the summary below. Details about the input in ALEID2000 are to be found in 4.

Node names
Each node must have a unique name. The name consists of maximum 7 alphanumeric characters. ALEID2000 makes no difference between upper- and lower-case letters. Thus, "NODE1" is the same as "Node1".

To preserve clarity within a model, the nodes can get a name that incorporates the topography. The advantage of topographic indication is that the user can easily detect the exact location of the node based on its name.

For example, a node name can be formed as "XX000AA" where:

"XX"   gives a global indication of the area (e.g. municipal code);
"000"   represents the serial number within the chosen area;
"AA"   can be used if additional nodes have to be created in the neighbourhood of
        an already existing node whose code should stay unchanged.

With consistent notation between different models, it is relatively easy to combine them into a new bigger model.

Node type
Unlike in ALEID 7.1(L) where a node type had to be specified for each node, ALEID2000 distinguishes only between ordinary demand nodes and supply (reservoir) nodes. The first have to be defined in the basic file (*.BAS) under the section [CONSUMPTION], the second under the section [TANKS] (see section 4.7, Basic file).

Node elevation and co-ordinates
The nodal elevation has to be specified so that the program can make a difference between piezometric head (i.e. pressure against reference level) and actual pressure (against ground level). The other two plain co-ordinates (X and Y) are used exclusively for graph presentation purposes. These three data are needed for each node collected in the co-ordinates file (see section 4.11).

Node demand
The demand at nodes is formulated from an average demand, which can be corrected by appropriate factors and percentages for simulation of demand (and leakage) patterns throughout a certain period. For explanations about related factors and percentages see Appendix E section F.3.3.

Pressure threshold
This is the pressure below which the demand starts to be dependent on the pressure (see Appendix e section E.3.4).

Reservoir water level
The head estimation has to be given only for reservoirs: depending on the type of reservoir either as a fixed head (water surface elevation), or as an initial value for the iteration. No head estimation is required for ordinary nodes.

Initial concentration
This is the concentration in the node at the beginning of the simulation. This parameter is only required if a concentration calculation is performed.

Source concentration
The source concentration is an incoming concentration specified through a pattern, for a node. The principle is the same as to the consumption pattern: the corresponding factor multiplies the basic concentration after each time step.

E.3.3 Demand modelling

The demand is modelled at the nodes. In each node, the total demand is built from a maximum of five demand categories, DC_i, which – with their own peak factors – influence five average (basic) demands, $Q_{avg,i}$. The peak factors are grouped per category in ALEID 7.1(L), whereas in ALEID2000 each node recognises its own categories with accompanying peak factor values.

The basic demand can be multiplied by the following factors and percentages:
- hourly factor, pf_h
  Average demand multiplied by the hourly factor represents a demand at a particular moment. In this way the demand can be followed over one or more days if the corresponding pattern is given. The pattern time step is arbitrary, several factors can be specified per hour (e.g. each 15 minutes).
- day factor, pf_d,
  The day factor represents the ratio between a peak demand per day, and the average daily demand within a week. A maximum of seven day factors (one week) can be specified.
- leakage percentage, L_i,
  The leakage percentage is related to the incoming volume of water. The basic demand will be multiplied by:

$$\frac{100}{100 - L_i} \quad \textbf{(1)}$$

The leakage percentage effectively represents a percentage divided between a known physical leakage and other unknown factors causing a difference between inflow and outflow (e.g. administrative errors).
- correction factor, C_i,
  The basic demand is multiplied by this factor, in order to close the water balance.
- growth percentage, $G_{i,j}$, where index "j" represents a certain prognosis period. A linear growth model is followed here. For each period, a separate growth factor can be given. There can be at most five periods specified. Thus, the concept of seasonal length from ALEID 7.1(L) has disappeared here.

The outcome of n(n=1,...,5) basic demands and m(m=1,...,5) prognosis periods with $k_{i,j}$ calculated years for period "j" yields for the total nodal demand, Q, the following formula:

$$Q = \sum_{i=1}^{n} Q_{tot,i} = \sum_{i=1}^{n} pf_{d,i} * pf_{h,i} * \left(\frac{100}{100 - L_i}\right) * C_i * \left(1 + \sum_{j=1}^{m} k_{i,j} * \frac{G_{i,j}}{100}\right) * Q_{avg,i} \quad \textbf{(2)}$$

Example

Suppose the demand of node A003 has to be calculated for hour 10 of the day 3 in year 1996. The following will be specified in the basic file (*.BAS):

```
[CONSUMPTION]
   A003   3
        28  01    02    02    02    01
```

```
          20  03    03    01    03    01
                    10    05    03    00    00    00
```

and in the demand pattern library (*.PAT):

```
[PATTERNS]
01  1.00  1.10  1.41  1.576 ......
02  0.67  0.56  0.89  1.301 .....
03  0.50  0.56  0.89  1.301 .....
05  1.00  1.00  1.00  1.00  .....

[DAYFACTORS]
01  1.0  1.2  1.4  ...
02     1.0. 1.1  1.4
03     1.2  1.0  1.0

[LEAKAGE]
01  9.11
02  6.46

[CORRECTION]
01  1.1
02  1.04
03  1.0

[RELATIVE GROWTH]
01  1990  1995  2000
01     3.0  2.0   0
```

The calculation goes as follows:

Node: A003

The first demand category:
Basic demand $Q_{avg,1}$ = 28 m3/h
hour factor pattern 01 $pf_{h,1}$ = 1.576
day factor pattern 02 $pf_{d,1}$ = 1.4
leakage percentage 02 L_1 = 6.46 %
correction factor 02 C_1 = 1.04
Growth percentage 03:
- period '90-'95 $G_{1,1}$ = 3 %
- period '95-2000 $G_{1,2}$ = 2 %
Year 1996 $k_{1,1}$ = 5 and $k_{1,2}$ = 2

The total demand of category 1 will be:
$Q_{tot,1}$ = 1.4 * 1.567 * (100/(100-6.46)) * 1.04 * (1+ 5 * 0.03 + 2 * 0.02) * 28
$Q_{tot,1}$ = 81.26 m^3/h

The second demand category:
Basic demand $Q_{avg,2}$ = 20 m3/h
hour factor pattern 03 $pf_{h,2}$ = 1.301
day factor pattern 03 $pf_{d,2}$ = 1.0 (not given)
leakage percentage 01 L_2 = 9.11 %
correction factor 03 C_2 = 1.0 (not given)
Growth percentage 03:
- period '90-'95 $G_{2,1}$ = 3 %

- period '95-2000 $G_{2,2} = 2\%$

Year 1996 $k_{2,1} = 5$ and $k_{2,2} = 2$

The total demand of category 2 will be:

$Q_{tot,2} = 1.0*1.301*(100/(100-9.11))*1.0*(1+5*0.03 + 2*0.02)* 20$

$Q_{tot,2} = 34.07 \text{ m}^3/\text{h}$

The third demand category:

Basic demand $Q_{avg,3} = 10 \text{ m3/h}$

hour factor pattern 05 $pf_{h,3} = 1$

day factor pattern 03 $pf_{d,3} = 1.0$ (pattern not given)

leakage percentage 00 $L_3 = 0\%$ (default setting)

correction factor 00 $C_3 = 1.0$ (default setting)

Growth percentage 00

- period '90-'95 $G_{3,1} = 0\%$ (default setting)

- period '95-2000 $G_{3,2} = 0\%$ (default setting)

Year 1996 $k_{3,1} = 5$ and $k_{3,2} = 2$

The total demand of category 3 will be:

$Q_{tot,2} = 1 * 1 * (100/(100 - 0))* 1.0 * (1+ 5 * 0.0 + 2* 0.0) * 10$

$Q_{tot,2} = 10 \text{ m}^3/\text{h}$

Finally, the total demand for node A003 will be in this moment:

$Q_{tot} = Q_{tot,1} + Q_{tot,2} + Q_{tot,3} = 81.26 + 34.07 + 10 = 125.33 \text{ m}^3/\text{h}$

E.3.4   Pressure related demand

In some situations, the calculated (actual) demand becomes smaller than the nominal (modelled) demand, due to hydraulic conditions that occur in the network. This is particularly a case in extreme situations, e.g. when a pipe bursts or if the demand grows so high that it cannot be delivered by the network. In such cases, the demand can be more realistically described by being made dependent on the calculated pressure. The outcome is that under a certain, user-specified pressure threshold, P_{cr}, the demand drops proportionally with the pressure (see Figure 3).
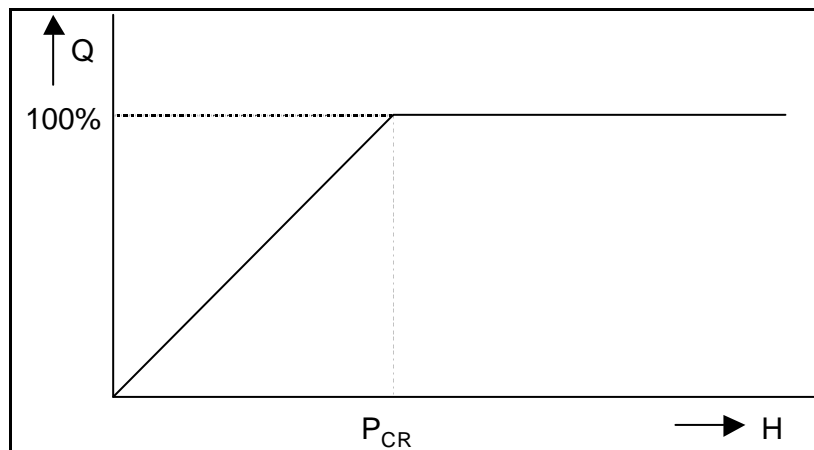
Figure 3   Pressure related demand

Hence, the pressure threshold is defined as a critical pressure i.e. a (piezometric) head against ground elevation. Different thresholds can be specified for different nodes.

Pressure related demand calculation is commonly used in calculations of system reliability. More information about this is given in Appendix F, section F.7.

E.3.5   Reservoirs

Three types of special nodes can represent a storage or supplying point in ALEID2000:

1. Fixed head node
    The head in the node will keep the specified value during the iteration process. In theory, a suction node for a pump can be modelled in this way, or a large storage with more or less stable surface water level. It is possible to change the fixed head value during the calculation by changing the control settings of the model.
2. Variable reservoir (cylindrical)
    The following model is given in ALEID2000, for a cylindrical reservoir of variable level (e.g. water tower):

$$\Delta H \; = \; \frac{Q}{A} \Delta t \qquad\qquad (3)$$

where:
ΔH - change in the water level (m)
Q - the flow in (+) or out (-) the reservoir (m³/sec)
A - cross section area (m²)
Δt - time step (sec)

Moreover, the minimum and maximum levels have to be specified.

3. Variable reservoir (general)
    The above relation is not valid for non-cylindrical reservoirs. The relation between the volume in the reservoir and the elevation of the water surface can be specified explicitly by the help of a so called V,H-relation. The user defines pairs of points for volume and water elevation. The values in-between are linearly interpolated (see Figure 4). The lowest and highest given values will be considered respectively as the min./max. volume of the reservoir.
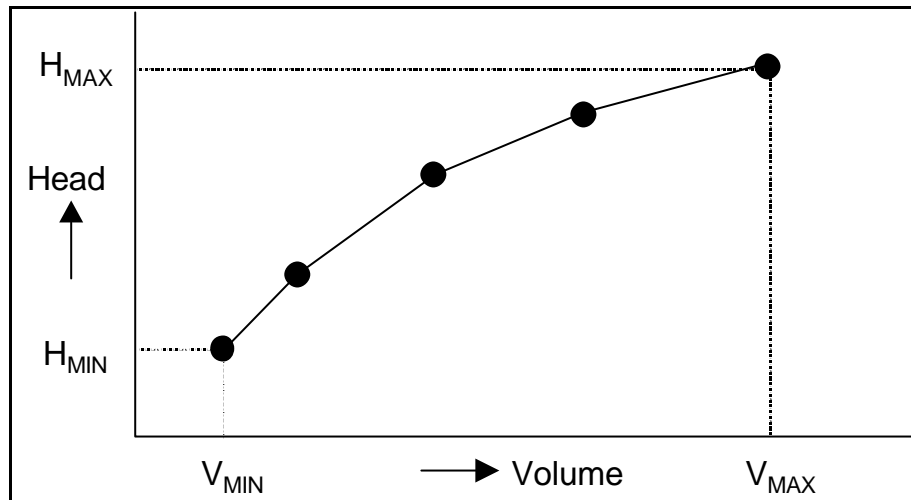
Figure 4   Volume-Height relation of a reservoir

E.4   Links

E.4.1   General

Links between the nodes are formed by pipes, valves, pumps or hydrants. Each of these elements has its own characteristics, which are described, in the sections below. The required data differ from one to another type of element, however a link name, begin and end node names have to be given in each case. Different types of links are distinguished in different sections of the input (basic) file:

- section [PIPES] contains information about ordinary pipes and check valves;
- section [VALVES] contains information about all other valves;
- section [PUMPS] contains information about pumps;
- section [HYDRANTS] contains information about hydrants/fire taps.

E.4.2   Pipes

Links between nodes are in most cases ordinary pipes. Flow direction in a pipe emerges from the node with the higher head to the node with the lower head. If the higher head node coincides with the first (left) specified node in the input information for the pipe, the pipe flow takes positive value. If the second (right) specified node has the higher head, the pipe flow will be negative.

The pressure drop in a pipe , associated with a flow can be written in general as:

$$\Delta H \; = \; a * Q^{b-1} |Q| \qquad \qquad \textbf{(4)}$$

where ?H is the pressure drop in metres head, Q the flow in m^3/sec, "a" a coefficient describing the pipe resistance and "b" a flow exponent.

ALEID2000 uses three forms of equation 4:

Table 1 Head-loss formulas in ALEID2000

Formula	Resistance coeff. (a)	Exponent (b)
Darcy-Weisbach	$\lambda \cdot \dfrac{8.L}{\pi^2.g.D^5}$	2
Hazen-Williams	$\dfrac{2,79.10^{-6}.L}{C^{1,85}.D^{4,87}}$	1.85
Chézy-Manning	$\dfrac{7,97.10^{7}.n^2.L}{D^{5,33}}$	2

The pipe diameter, D, in above equations is expressed as m.
The friction factor, λ, in the Darcy-Weisbach formula can be calculated from the Colebrook equation:

$$\lambda = \frac{0,25}{\log^2\left[\dfrac{1}{0,4\,\mathrm{Re}\,\sqrt{\lambda}}+\dfrac{k}{3,71D}\right]} \qquad \textbf{(5)}$$

This formula needs iterative calculation. An alternative expression can be used instead for direct calculation of λ:

$$\lambda = \frac{0,25}{\log^2\left[\dfrac{5,74}{\mathrm{Re}^{0,9}}+\dfrac{k}{3,71D}\right]} \qquad \textbf{(6)}$$

The parameter symbols in the equations in Table 1, 5 and 6 mean:

D - pipe diameter (m)
g - gravity (m^2/sec)
Re - Reynolds number
L - pipe length (m)
k - pipe k-value (m)
λ - friction factor of Colebrook
C - Hazen-Williams friction factor
n - Manning friction factor

Formulas 5 and 6 are valid for turbulent flow conditions only (Reynolds number > 2300). For laminar flow (Re < 2300) the friction factor will be calculated as:

$$\mathbf{\lambda} \;=\; \frac{64}{\text{Re}} \qquad\qquad (7)$$

In ALEID2000, the following information is requested for pipes:

- pipe name;
- begin node;
- end node;
- internal diameter;
- length;
- wall roughness coefficient (depending on head loss formula used);
- local loss coefficient;
- for concentration calculation: wall reaction coefficient;
- for concentration calculation: volume reaction coefficient;

Specific points for attention are described in the following paragraphs.

Pipe name
The same is valid for the pipe names as for the node names. The pipe names have to be unique and should not create a problem when merging different models.

Begin- and end node names
These nodes should be given already in the list of nodes (i.e. have to be present there). The order of the node names is important only if check valves are modelled (input section [PIPES]).

Diameter
The pipe diameter is known from the maps or a pipe information system. Depending on the pipe material, the actual internal diameter will deviate from the nominal diameter. Furthermore, the internal diameter may change due to corrosion processes, e.g. by CI pipes. The model is very sensitive to changes in diameter, because of a high exponent in the head-loss formulas (Table 1). In problem cases, a combination of diameter and wall roughness can be determined by tests.

Length
The same source of information as for diameters can be used for determination of the pipe length. In the ALEID2000 model, the length related to a pipe does not necessarily correspond to the length calculated from accompanying node co-ordinates. The co-ordinates in the model are primarily intended for visual presentation of the network and describe its schematized layout in most cases.

Wall roughness coefficient

The type of wall roughness coefficient is dependent on the chosen head-loss formula. The most accurate calculations are provided by applying the Darcy-Weisbach formula i.e. the roughness factor, k. The values from table 2 can be used as a first approximation.

Table 2   k-values for various materials

Material	k-value(mm)	source
CI <= 200 mm	5	E/L
CI > 200 mm	2	E/L
CI cement lined on site	0.5	E
CI cement lined in factory	0.2	M
Asbestos-cement	0.2	M
Concrete	0.5	E/L
PE	0.05	M
PVC	0.05	M
Steel bitumen coated	1.5	L
Steel cement lined	0.2	M

Sources of information in the table are:
M - value of the manufacturer;
L - value from the literature;
E - empirical figure.

Local loss coefficient

Besides the friction losses, where the loss factor depends on the flow rate, an additional, local loss can be modelled for e.g. bends, opened valves, diameter changes, etc. Hence, the total pressure drop along one pipe will be:

$$\Delta H \ = \ \Delta H_{friction} + \Delta H_{local} \qquad \textbf{(8)}$$

where $\Delta H_{friction}$ is described by formula 4. The additional loss, ΔH_{local} is defined by:

$$\Delta H_{local} \ = \ x \frac{8}{p\,g} \frac{Q|Q|}{D^4} \qquad \textbf{(9)}$$

where x is a loss factor specific for a given locality (e.g. bend). The value of x usually ranges between 0 and 2. Information about exact values of x for particular structures can be found in hydraulic textbooks, or in manufacturer catalogues (e.g. for valves).

Wall- and volume reaction coefficients
These are reaction coefficients used in the reaction model for non-conservative materials. For further information see Appendix E, section E.8.2.

E.4.3 Gate valves

Gate valves are treated in the model as ordinary pipes that can be temporarily or permanently closed, by the control setting (see Appendix E, section E.6.5). A cross will be put on the closed pipe in the graphic presentation, during the corresponding time interval.

E.4.4 Check valves (CV)

A check valve (non-return valve) functions in the model as an ordinary pipe with a given boundary condition. The positive flow direction in the pipe is defined as the direction from the firstly specified (begin) node (1) to the second (end) node (2). The head, H_1, is greater than H_2, in this case.

A check valve will close when H_1 becomes smaller than H_2, and thus, the return flow takes place. This means (see Figure 5):

If $H_1 > H_2$: normal flow
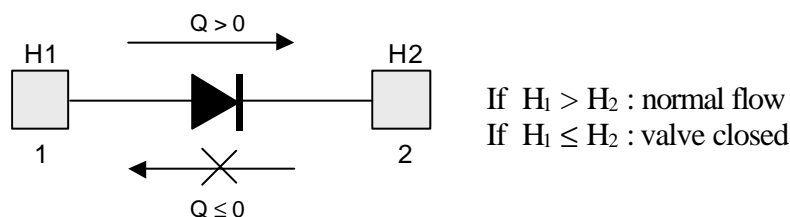If $H_1 \leq H_2$: valve closed

Figure 5   Check valve

In the basic input file, a check valve is specified under the section [PIPES] on an ordinary pipe with a code, CV.

The opening and closing of a check valve is dependent only on flow direction. Control of this type of valve is not possible. It is however possible to simulate a failure by setting the pipe diameter to 1 mm.

E.4.5 Pressure reducing valve (PRV)
A pressure reducing valve limits the head at the downstream node, (2), to the given value, H_{red}, if the head attempts to rise above that value. When the head at the downstream node drops below H_{red}, the flow through the valve will not be obstructed. If the head at the downstream side becomes greater than at the upstream side, the valve will be closed to prevent return flow. This means (see Figure 6):

If $H_1 > H_2$ and $H_2 < H_{red}$: normal flow
If $H_1 > H_2$ and $H_2 = H_{red}$: H_2 becomes H_{red}, adjusted flow
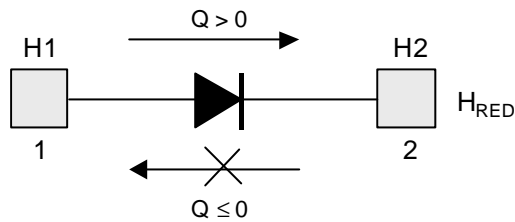If $H_1 \leq H_2$: valve closed

Figure 6   Pressure reducer

A pressure reducing valve is defined in the basic input file under section [VALVES], with pipe name, begin- and end-node, diameter, valve code (PRV), the reduction head, H_{red}, and optionally with the local loss factor when the valve is fully opened. The length of the pipe is neglected in the calculation and no friction losses are considered.

Pressure reducing valves can be open or closed through the control settings. In addition, the value of the reduction head can be adjusted, too.

E.4.6   Pressure sustaining valve (PSV)
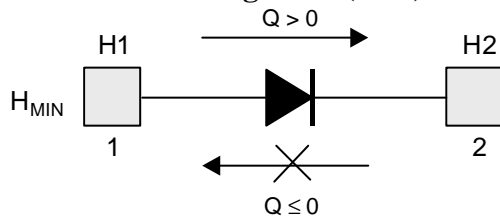

Figure 7   Pressure sustaining valve

A pressure sustaining valve keeps a minimum head, H_{min}, at the upstream node, (1), if the head attempts to drop below that value. When the head at the upstream node rises above H_{min}, the flow through the valve will not be obstructed. If the head at the downstream node becomes higher than the head at the upstream node, the valve will be shut off to prevent return flow. This means (see Figure 7):

If $H_1 > H_2$ and $H_1 = H_{min}$: normal flow
If $H_1 > H_2$ and $H_1 < H_{min}$: H_2 becomes adjusted to H_{min}
If $H_1 = H_2$: valve closed

A pressure sustaining valve is defined in the basic input file under section [VALVES], with pipe name, begin- and end-node, diameter, valve code
(PSV), the minimum head, H_{min} and optionally with the local loss factor when the valve is fully opened. The length of the pipe is neglected in the calculation and no friction losses are considered.

Pressure sustaining valves can be opened or closed through the control settings. In addition, the value of the reduction head can be adjusted, too.

E.4.7 Pressure breaking valve (PBV)

Pressure breaking valve forces specified fixed pressure drop, $?H_v = H_2 - H_1$ at the valve (see Figure 8). The flow is allowed in both directions.
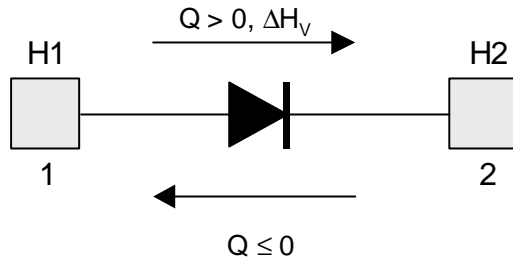

Figure 8   Pressure breaking valve

Pressure breaking valve is defined in the basic input file under section [VALVES], with pipe name, begin- and end-node, diameter, valve code (PBV), the specified pressure drop, $?H_v$ and, optionally, with the local loss factor when the valve is fully opened. The length of the pipe is neglected in the calculation and no friction losses are considered.

Pressure breaking valves can be opened or closed through the control settings. In addition, the value of the reduction head can be adjusted, too.

E.4.8 Flow control valve (FCV)

Flow control valve limits the flow to the specified rate, Q_{FCV}. The program gives a warning if this flow rate cannot be reached without imposing additional pressure drop. This means (see Figure 9):
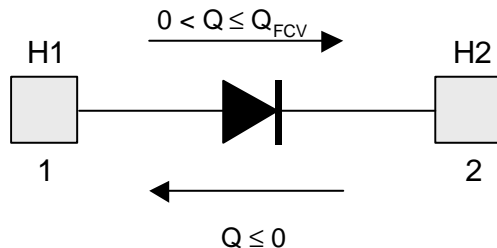

Figure 9   Flow control valve

- if $Q = Q_{FCV}$ than $Q = Q_{FCV}$
- if $Q < Q_{FCV}$ than $Q = Q$ incl. warning

A flow control valve is defined in the basic input file under section [VALVES], with pipe name, begin- and end-node, diameter, valve code (FCV), the specified flow, Q_{FCV}, and, optionally, with the local loss factor when the valve is fully opened. The length of the pipe is neglected in the calculation and no friction losses are considered.

Flow control valves can be open or closed through the control settings. In addition, the value of the reduction head can be adjusted, too.

E.4.9   Throttle control valves (TCV)

Throttled valves simulate a partly closed valve by adjusting the local loss coefficient of the valve causing a pressure drop dependent also on the flow rate and direction (see formula 9 and Figure 10). This type of valve allows for change in flow direction.
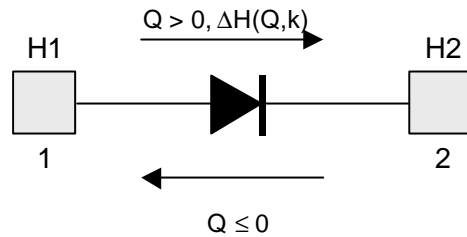

Figure 10   Throttle control valve

The relation between the opening level of the valve and resulting pressure drop is usually available from the manufacturer (valve characteristics).

Throttle control valve is defined in the input section meant for valves [VALVES] with pipe name, begin and end node, diameter, valve code (TCV), the loss factor, ?, and optionally with the local loss factor when the valve is fully opened. The length of the pipe is neglected in the calculation and no friction losses are considered.

Throttle control valves can be opened or closed through a control regime. The loss coefficient, ?, can also be adjusted in operation control.

E.4.10   Pumps

Pumps are modelled as links where the head increases. This increase can be described in the model through a quadratic relation between pumping head and flow, or by a series of points with linear interpolation. The pump characteristics can be further varied by making them dependent of the pump speed. The following relations are valid:

Quadratic curves
The method of description in ALEID 7.1(L) is extended here with a variable speed feature. The characteristics of each pump can be compiled from different quadratic parts valid for a certain flow range. A general formula for each part of the curve can be written:

$$H_p \;=\; a*Q^2 + b*\boldsymbol{h}*Q + c*\boldsymbol{h}^2 \tag{10}$$

where:
H_p : head increase due to pumping (pumping head)

Q   : pumped flow
a, b, c   : factors of the quadratic relation
?   : rotational pump speed (default value ?=1)

If a = 0, the formula describes a straight line.

In pump characteristics generally the pump head drops with increasing flow (the curve drops).
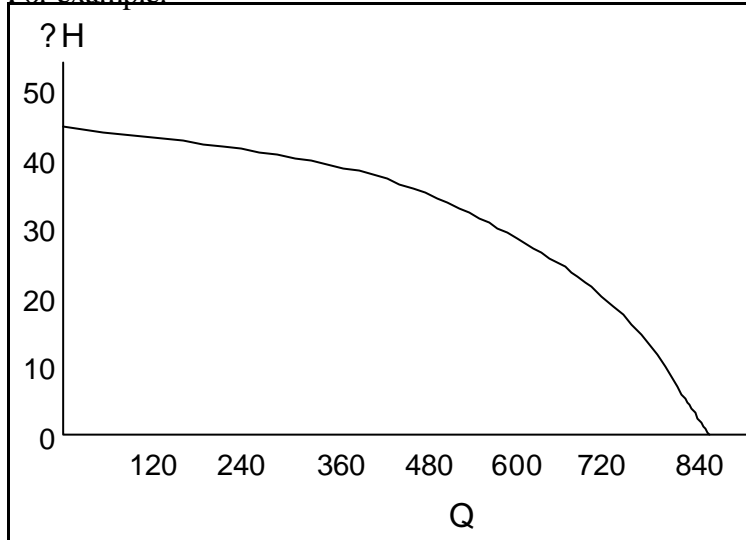
For example:

Figure 11   Quadratic curve

The pump curve of the pump, P, is supplied by the manufacturer. The working point lays around $(Q,H_p) = (200,40)$. The quadratic formula can be determined by reading three points from the graph: the working point and one point left and right. Three equations with three unknowns (a, b, c) can be formed and calculated in this way.

For a pump efficiency ? = 1, the pump curve can be written as a quadratic formula:

$$H_p = -0.0006944*Q^2 + 0.11104*Q + 45.468$$

This curve has a maximum for $Q = 80$ m^3/h. This means that the part of the curve for $Q < 80$ m^3/h cannot be used. According to the equation, $H_p = 0$ for $Q = 348,28$ m^3/h.

The part of the curve for $0 = Q < 80$ can be simplified by a straight line specified between the points $(Q,H_p) = (80,50)$ and $(Q,H_p) = (0,52)$, whereby 52 mwc is the maximum head.

Thus, (see also Figure 11):

$0 = Q < 80$? $H_p = -0,025*Q + 52,00$
$80 = Q < 348,28$? $H_p = -0,0006944*Q^2 + 0,11104*Q + 45,468$

Linear interpolation of points

Because some calculation work is necessary in order to derive the above mentioned quadratic equations, an option to define pump curves with a number of Q,H-points has been added to ALEID2000. The program then assumes a straight line between the specified points. These describe the curve for a standard pump speed with $? = 1$. The expression for each straight line of the curve then becomes:

$$H_p = b * \mathbf{h} * Q + c * \mathbf{h}^2 \tag{11}$$

where:

Hp	:	pumping head
Q	:	pumped flow
b,c	:	by the program calculated coefficients of the straight line
?	:	pump speed

Where the pump curve is defined by a set of Q,H-points, the values for Q, sorted in ascending order, should be coupled with the values for H, sorted in descending order (the curve drops).

For example:

6 Q,H-relation

Q (m³/h)	H_p (mwc)
0	52.00
80	50.00
100	49.73
125	48.60
150	46.60
175	43.73
200	40.00
225	35.40
250	29.93
275	23.59
300	16.38

Suppose the pump from the previous example has to be modelled by Q,H-points. A number of points have to be read from the graph in this case. These are given in table 6 representing the above quadratic relation (see also Figure 12):
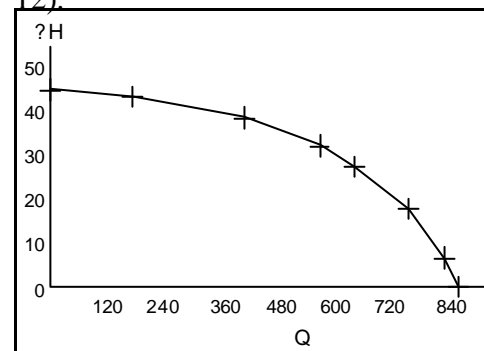

Figure 12   Interpolated curve

Switching the pumps on and off (for both types) is specified by control settings. They can be operated according to a certain plan (time), pressure and flow rate. Also the pump speed can be set to different operation modes.

The program declares error messages if the calculated Q,H-values fall beyond the specified curve range, e.g. return flow appears, or if Q becomes larger than the maximum specified value.

E.4.11   Hydrants

Hydrants (fire taps, reservoir filling) are modelled in the same way as pumps. The given relations (hydrant curves) however describe the remaining pressure over the hydrant against the delivered flow.
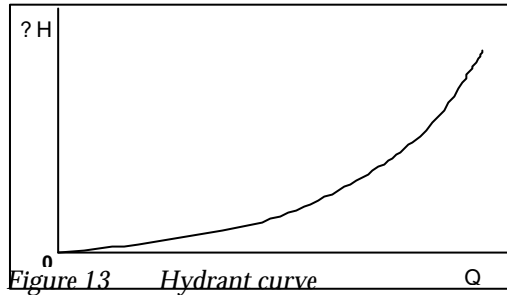
Obviously, the hydrant curve is rising: the more pressure is available, the larger the flow will be (see Figure 13). This trend should be strictly followed where the pump curve is defined by a set of Q,H-points.

Figure 13   Hydrant curve

The operation of hydrants is regulated in control mode, depending on time, pressure and flow. The program declares error messages if calculated Q,H-values fall beyond the specified curve range, e.g. return flow appears, or if Q becomes larger than the maximum specified value.

E.5   Operation

E.5.1   Operation of shutters, valves, pumps and hydrants
In each moment, it has to be clear which pipes/shutters and valves are open or (partly) closed, which pump is "on" and at what speed, and which hydrant stays open. This is regulated in the program through control and operation settings. A link (shutter, valve, pump or hydrant) can be operated with respect to a certain plan (time), pressure in a reservoir, arbitrary point in the system or a flow in a pipe.

NOTE: The operations are neither checked nor optimised by the program. If they conflict, problems may occur in the calculation. The program simply performs the indicated operation.

E.5.2   Operation of fixed head nodes (reservoirs)
It may be reasonable for model simulation over a period, to adjust the fixed head during the calculation. This operation is specified with respect to a certain plan (time).

E.6   Hydraulic calculation

When all required hydraulic model elements are defined in the input, a calculation can be performed. The basic results of the calculation are nodal heads and link flows in the network. The program will also determine the values derived from these, such as pressures, pressure gradients and velocities.

The program makes calculations for given times. Boundary conditions have to be known for each time. These are:
-    reservoir levels;
-    pump operation (on/off, pump speed);
-    valve operation (open/closed, specific setting);
-    given demand;
-    relation between the demand and pressure.

The boundary conditions are defined by means of initial settings (e.g. for reservoirs), operation modes (pumps), and patterns of demand modelling.

The calculation starts from the defined start time, when only the reservoir levels have to be specified by the user. For two consecutive steady state calculations, the program uses, as much as possible, the values of the previous calculation as boundary conditions for the next one. Here also, the values at reservoirs are predominantly important. If these however, are to be specified by the user, the calculations at different times would become independent of each other. When the course of the reservoir levels becomes determined by the program, it is a result of a

number of steady state calculations for consecutive times, i.e. so called "quasi-dynamic" simulation (see Appendix E, section E.3.5).

E.7 Reliability assessment

E.7.1 Background

Assessment of network reliability can be done through a series of hydraulic calculations. This is done when the effects of subsequent component failures are analysed by closing them in the model, one at a time. If the pressure related demand calculation is carried out, this will result in more or less severe reduction of the water delivery, as can be shown by ALEID2000.

The objective here is to perform meaningful calculations i.e. to recognise which system elements have disastrous effects on the distribution when out of operation. Obviously, a transmission pipe of larger diameter will create bigger pressure losses if it bursts, than a small peripheral distribution pipe. In The Netherlands, the following recommendation given by the Dutch water works association, VEWIN, is taken as a guideline:

With the failure of one main element of a distribution network, a daily demand of at least 75 % of the demand on the maximum demand day should still be satisfied in the calamity area (approx. for each 2000 connections).

More discussion of this regulation is offered in the VEWIN-report: "System Reliability", committee[4]).

E.7.2 Calculation method

To allow the above recommendation to be translated into practice, the method for calculating system reliability is developed in the following steps (see Figure 14).

1. Production units within the system have to be identified first (e.g. a clear water reservoir where all pumps are connected can be considered an integral production unit). Each production unit should further be divided into possible segments. A segment is considered as a feeding element of the network model. Failure of one segment is considered a calamity. Calamities in the rest of the supply system (extraction, raw water transport and treatment) are translated as failures of production units or pipes.
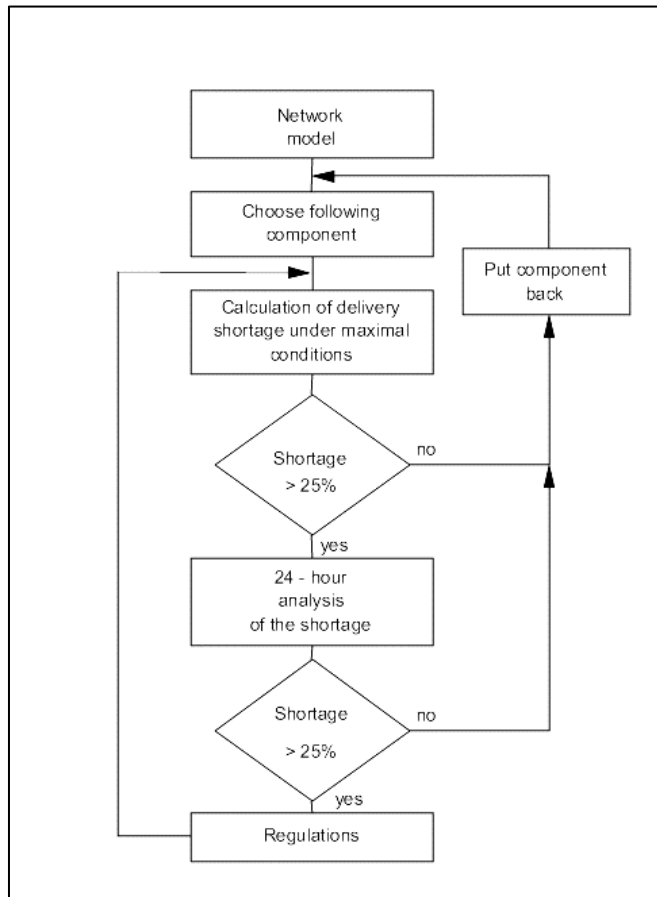
Figure 14   Flow chart of reliability assessment procedure

The following steps have to be repeated by each component in the network model:

2. Take the chosen component out of the model. This can be done by control and operation settings, where this component can be closed.
3. Perform the network calculation for the maximum hour of maximum consumption day, and possibly in hours of maximum demands for major demand categories. These calculations should be executed in pressure related demand mode. The nature of the pressure related demand is assumed to be as presented in Figure 15 (see also Appendix E, section E.3.4). Above a certain pressure, which for normal domestic demand is set to 20 mwc, the demand becomes independent of the pressure.

    When the pressure drops below 20 mwc, the required demand cannot be entirely delivered. This means that higher elevated taps will not get water. As it is assumed that the relation between pressure and demand is linear in the range 0 mwc - threshold of 20 mwc, for pressure of 15 mwc only 75 % of the original demand can be delivered or a shortage of 25 % is encountered. That shortage is a level with which the reliability should be compared. In the program, pressure thresholds have to be specified by the user. Different nodes can have different values.
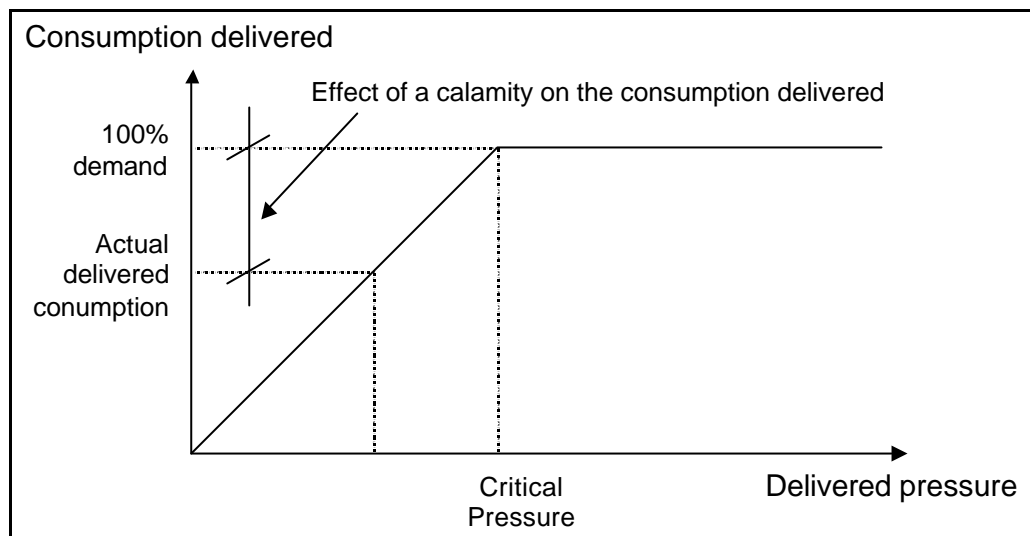
Figure 15   Pressure related demand

4. Analyse, in the calculation results, whether less than 75% of the demand at maximum hour/maximum day is delivered in some nodes. If there are no such nodes, it can be concluded that at any other moment of the maximum day, a minimum 75% of the demand will be delivered. If however, the delivery in number of nodes drops below 75 % of the demand, the next steps should follow.

5. For elements/units identified under step 3 as causing the delivery below 75%, run 24-hour simulations (pressure related), assuming that the component is out of operation during the entire period. Possible implications on operation of production units and clear water storage can be analysed in this way. Adjustment of their operation can be investigated.

6. Check whether with modified system operation, nodes with delivery below 75% still exist. If not, a new mode of operation may be recommended.

Execution of steps 1-6 delivers calculations under regular supply conditions, so called "zero calculation". Furthermore, a "zero+ calculation" can be done for developing of the supply strategy in irregular situations:

7. For these nodes which do not satisfy the conditions, inventorize possible modification of operation under calamity. Possible measures could be: valve manipulation, altered pumping regime or inclusion of pipe connections, etc. The effect of these measures can be tested by the above-described procedure.

8. If after "zero+ calculations" the system still remains unreliable, improvements should be introduced (i.e. new investments are necessary). The effect of the improvements should be analysed again.

Steps 3 and 4 form a "filter" which serve as a simple control in order to prevent unnecessary calculations. In case of quick 24-hour simulations (quick computers, small-scale models) these steps can be omitted from the procedure.

There is no special reliability assessment feature in ALEID2000. 24-hour simulations in pressure related demand mode and results presentation through the menu option **Graph, Demand** are meant for such analyses.

E.7.3   Remarks about the network model

The following aspects require particular attention, during modelling for purposes of network reliability assessment:

Pumps
Pumping stations have to be presented in the model as clusters of pump units. Each pump unit plays an independent role in reliability assessment and its potential failure has to be separately included in the analysis.

Reservoirs
A difference should be made between periods of a day when reservoirs deliver water and periods when their volume is recovered. To do this, a reservoir can be substituted by an "hydraulically equivalent" combination of a node and pumping station. Refilling pattern of the reservoir will be described by the nodal demand pattern, while the pumping station simulates periods of reservoir discharge. For both, the node and the pump, the demand/operation will be set to zero/off during the reservoir operation in the opposite flow direction.

NOTE: Modelling of supply points as nodes with "negative demand", is not recommended during reliability assessment calculations and for pressure related demand calculations, in general. As negative demands are not corrected in the calculation based on pressure dependence, the results of the simulation may not reflect the reality ("forced inflow"). Fixed head nodes or pumps should be used instead.

Demand patterns
As a 24-hour calculation has to be performed, it is crucial that the demand patterns for *all* categories are defined for the maximum consumption day, and in the entire simulation period.

E.8 Water quality calculation

E.8.1 Water quality algorithm

The water quality algorithm is developed for the purpose of monitoring a dissolved substance in the network. The algorithm uses the flows from the (ordinary) hydraulic calculation to solve a system of equations that describe the mass balance. For each pipe between the nodes "i" and "j", it can be written:

$$\frac{\partial c_{ij}}{\partial t} = \frac{Q_{ij}}{A_{ij}} \frac{\partial c_{ij}}{\partial x_{ij}} + q(c_{ij}) \qquad (12)$$

where:

c_{ij}	:	concentration of the substance in pipe "i,j" as function of the distance and the time (i.e. $c_{ij} = c_{ij}(x_{ij}, t)$), in mass units per m^3;
x_{ij}	:	the distance in pipe "i,j", in m;
Q_{ij}	:	the flow in pipe "i,j" at time "t", in m^3/h;
A_{ij}	:	cross-section area of pipe "i,j", in m^2;
$2(c_{ij})$	:	reaction speed of the substance in pipe "i,j" , in mass units per m^3 per day.

Equation 12 has to be solved with known initial boundary conditions: for begin time, t = 0, and at the pipe node where $x_{ij} = 0$:

$$c_{ij}(0, t) = \frac{\sum_k Q_{ki} c_{ki}(L_{ki}, t) + M_i}{\sum_k Q_{ki} + Q_{si}} \qquad (13)$$

The sums are made for all pipes "k,i" connected to pipe "i,j" and with the flow direction towards node "i". Here L_{ki} is the length of pipe "k,i", M_i the additional mass which can be introduced by an external source at node "i", and Q_{si} the flow rate of that source.

ALEID2000 solves these equations according to a numerical scheme called "The Discrete Volume Element Method" (DVEM). This is a method developed by the US EPA (for details, see Rossman[2]). Its implementation in ALEID2000 is based on the EPA-computer program, EPANET.

Where the flows are constant, DVEM calculates within each hydraulic time step, a shorter water quality time step and splits the pipe into a number of volume units in which complete mixing is assumed. The following steps are performed within each water quality time step, afterwards (see also
Figure 16):
- the material becomes transported from each pipe segment in the direction of the downstream boundary segment. If a node is located at the up-stream border of the segment, the concentration and flow from other incoming pipes will be added to it (transport step).

- The mixing concentration in each node will be calculated and transported to the initial segment of the next pipe while the nodal flow will be deducted.
- Possibly given reaction in the pipe is executed.

The above steps are repeated until a new hydraulic condition appears. The network will be segmented again and the calculations carried out again. The longest possible water quality time steps will be chosen by this method. The pipe flow however, may not be greater than the actual pipe volume, otherwise the time step mass becomes transported without being mixed in the passing node. Thus, the water quality time step, dt_{wk}, cannot be longer than the shortest residence time in any pipe in the network, i.e.:
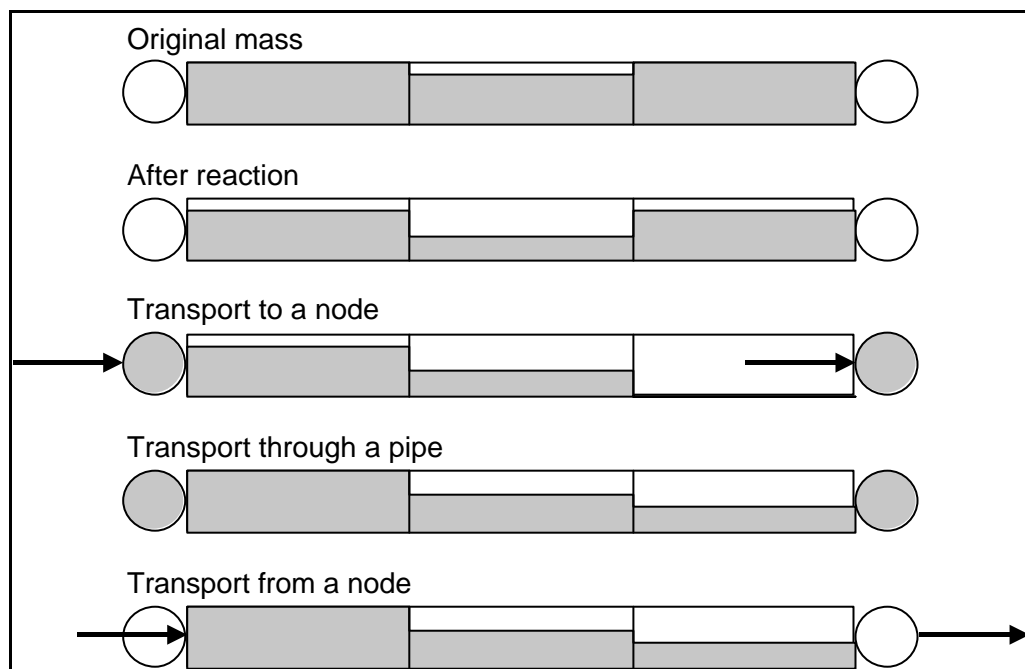
Original mass

After reaction

Transport to a node

Transport through a pipe

Transport from a node

Figure 16   Steps of the water quality algorithm

$$dt_{wk} = \text{Min} \frac{V_{ij}}{Q_{ij}} \text{ for all pipes i, j} \qquad \textbf{(14)}$$

where V_{ij} is the volume of pipe "i,j" and Q_{ij}, the flow in that pipe. Pumps, hydrants and valves will not be taken into consideration. These elements have no specified length in the model, and therefore transport through such an element is assumed to be instant.

With a known water quality time step, the number of volume segments, n_{ij}, in each pipe is given by:

$$n_{ij} = E[\frac{V_{ij}}{Q_{ij} dt_{wk}}] \qquad \textbf{(15)}$$

where E[x] is the largest rounded value smaller or equal to "x".

To prevent calculation times becoming too long and the number of segments too large, ALEID2000 limits the water quality time step, dt_{wk}, to a value that is not smaller than one of the specified values. This value is calculated by the program as being 1/10 of the length of the hydraulic time step, but it can also be specified by the user. The user can also define a maximum number of volume segments into which a pipe is divided. The default setting here is 100.

E.8.2   Reaction model

Equation 12 of the water quality model offers a mechanism for considering the reactive reduction (or growth) of a substance which spreads throughout the network. The reaction can take place in the water flow (volume- or bulk reaction) as well as with the pipe wall (wall reaction). ALEID2000 can model both types of reactions. The first order reaction model is described further. In that model, a substance concentration decreases in the water according to the following formula:

$$\boldsymbol{q}(c) \; = \; -k_b c - \frac{k_f}{R_f}(c - c_w) \qquad\qquad \textbf{(16)}$$

where:

k_b : the first order bulk reaction coefficient, per sec.
c : substance concentration in the water, mass units per m^3
k_f : mass transfer coefficient between water and pipe wall, m/sec.
R_H : hydraulic radius of the pipe (D/4), m
c_w : substance concentration at the pipe wall, mass units per m^3

The first term in the equation models the reaction in the water (bulk reaction), while the second term, with the unknown concentration, c_w, indicates where the substance mass will be transported, to the pipe wall or in the water flow.

If we assume that the wall reaction can also be modelled as a first order reaction with regard to c_w, and at the same reaction speed as in water, the following mass balance can be written:

$$k_f(c - c_w) \; = \; k_w c_w \qquad\qquad \textbf{(17)}$$

where k_w id the wall reaction coefficient in m/sec. Solving this equation for c_w and substituting it in equation 16, the following expression can be written:

$$\boldsymbol{q}(c) \; = \; -Kc \qquad\qquad \textbf{(18)}$$

where K is a global first order reaction constant, described as:

$$K = k_b + \frac{k_w k_f}{R_H(k_w + k_f)} \qquad\qquad \textbf{(19)}$$

The above formulas describe the substance reduction with mass transport from the water to the pipe wall. When the negative sign for K is removed from equation 18, the equation will indicate the substance growth, with mass transport from the pipe wall to the water (increase in concentration, see also Figure 17).
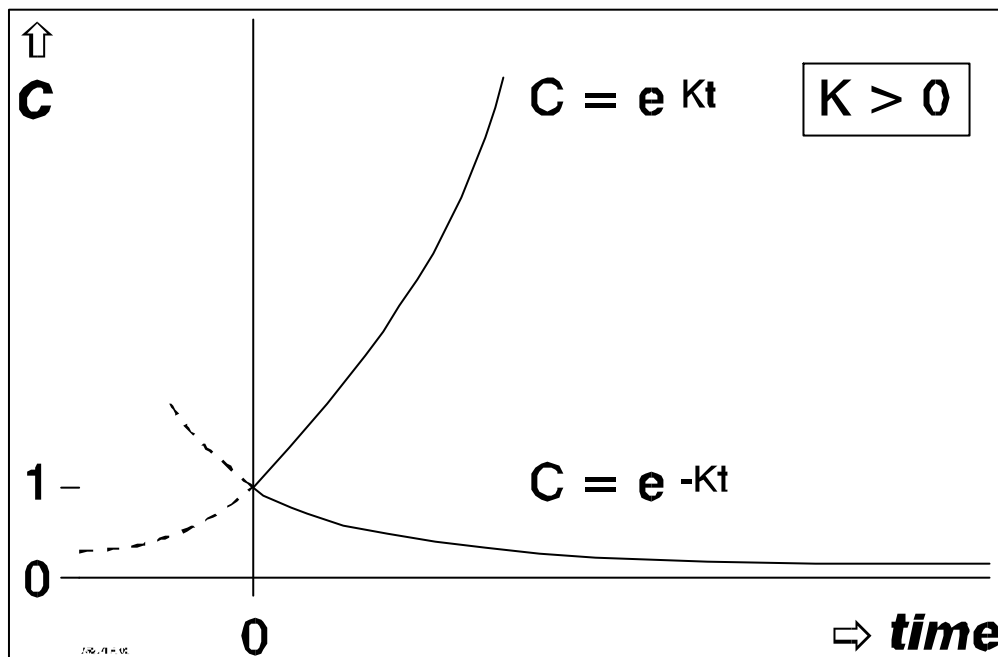

Figure 17   ***Growth/reduction by first order reaction model***

Thus, there are three coefficients that describe the reactions in a pipe. The bulk reaction coefficient, k_b, and the wall reaction coefficient, k_w, have to be determined from the field being required as the model input information. The mass transfer coefficient, k_f, will be calculated by the program whereby the dimensionless Sherwood number is used (see Edwards e.a.[3]):

$$Sh = 0,0023\,Re^{0,83}\,Sc^{0,333} \quad voor\ Re \geq 2300 \qquad\qquad \textbf{(21)}$$

$$k_f = \frac{Sh.DF}{D} \qquad\qquad \textbf{(20)}$$

$$Sh = 3,65 + \frac{0,0668(D/L) ReSc}{1 + 0,04[(D/L) ReSc]^{0,67}} \quad \text{voor } Re < 2300 \qquad \textbf{(22)}$$

where:

k_f	:	mass transfer coefficient, m/sec.
Sh	:	Sherwood number
Re	:	Reynolds number (Q*D/A/?)
Sc	:	Schmidt number (? /DF)
D	:	pipe diameter, m.
L	:	pipe length, m.
Q	:	flow rate, m^3/ sec
A	:	pipe cross-section area, m^2
DF	:	substance molecular diffusion in liquid, m^2/sec.
?	:	kinematic viscosity of the liquid, m^2/sec.

Formula 21 is applicable for turbulent flows, where the mass transfer coefficient is independent of the position along the pipe. For laminar flow, formula 22 gives an average value for the mass transfer coefficient along the pipe.

E.8.3 Limiting potential

A limited growth of e.g. trihalomethanes can be modelled in the program. Here, a maximum concentration, so called limiting potential, C_{lim} will be specified. The concentration is in this case defined as:

$$\frac{dC}{dt} = K(C_{lim} - C) \qquad \textbf{(23)}$$

or:

$$C(t) = -e^{-Kt} + C_{lim} \qquad \textbf{(24)}$$

This is a somewhat different growth function than $C(t) = e^{Kt}$ with $K > 0$. In the function with C_{lim}, the growth becomes proportional to the difference between C_{lim} and current concentration. With a negative reaction coefficient, C_{lim} can be used as a minimum concentration value. This is possible in the current program version only when all nodes have an initial concentration higher than C_{lim}. Smaller concentrations (0 also) will be directly set to the C_{lim} value. See also Figure 18.

E.8.4   Average travel time and water propagation

Average travel time can also be calculated in ALEID2000, with the model described in Appendix F, section F.8.1. To be able to do this, the program makes the following adjustments:

-   the variable, c, in formula 12 is interpreted as the average travel time of the water.
-   the reaction term, ?(c), in formula 12 takes a constant value of 1.0.
-   new water coming from reservoirs or supply nodes, enters the network at travel time = 0.

Average travel time is a simple tool for determination of the global water quality.

The water propagation from a node can also be monitored in a similar way. The following assumptions should be made in formula 12:

-   the variable, c, in formula 12 will be interpreted as the percentage of the flow coming out of the specified node.
-   the reaction term, ? (c), in formula 12 takes a constant value of 0.
-   the c-value of the source node will be kept to 100% during the simulation.
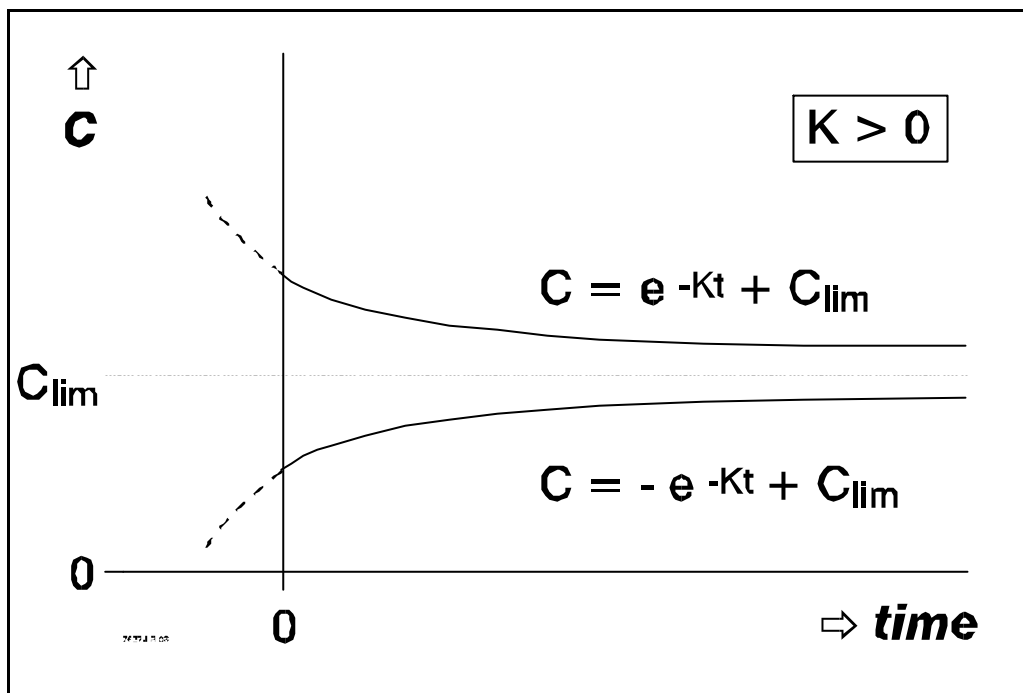

Figure 18   Growth/reduction by use of limiting potential

Any node in the network can be the source node, including reservoir nodes. Monitoring the water propagation from a certain node can be useful for system operation where water mixing takes place. This can give an impression of the contribution of various sources to the nodal demands, and how the geographical spread of mixing varies with time.

E.8.5 Possibilities and limitations of water quality calculations

Calculation of the water quality parameters is an average calculation. This means that if water of one particular source reaches a node through different routes (i.e. with different travel times and consequently quality), the calculation proceeds from that node with the average quality of all streams joined in it. In the example in Figure 19, there are three routes between nodes A and B: AB, ACDB and ACEDB. The water (quality) delivered by the pumping station, P, passes all these routes and the flows, having different travel times, fractions and water quality, become ultimately mixed in node B. For calculations further downstream, the water quality in pipes AB and DB is averaged for node B, weighted in proportion to the flows in these pipes.
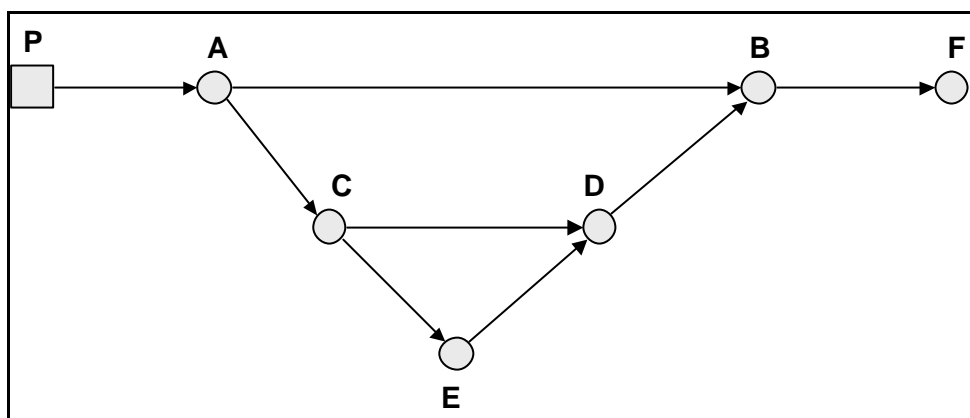

Figure 19   Various routes for water quality calculations

It is possible in theory to keep the streams separated even after node B, but this principle is not supported by ALEID2000.

Initial concentrations in each node can be specified in the water quality input file (*.WQI), section [QUALITY], together with the incoming concentrations and their patterns under sections [SOURCES] and [QPATTERNS]. Other details about the format of input are explained in section 4.10. The incoming concentrations can be specified for all nodes, regardless of their function as a real (water) supply source or an ordinary node somewhere in the middle of the route. In calculations of percentages (option TRACE) a source (of concentration) node has to be specified from which the water flow will be followed. This node has to be a real water source (e.g. reservoir). One source only can be followed per calculation.

In calculations of average travel times, there is no distinction made between water from different sources.

APPENDIX F

Troubleshooting

1. On some occasions the original Windows dialog boxes are used in the program, e.g. for printer settings or choice of (project) directories. The language in these boxes will be as used in the Windows program, thus not necessarily English. This may confuse rather than create a real problem.

2. ALEID2000 makes use of English notation for numbers, i.e. with a decimal point (e.g. 1,234.56). The setting can be adjusted via Windows commands. It is recommended to adjust the country settings in such a way that a country is selected that uses the decimal point notation by default. Decimal point notation is required for calculating!

APPENDIX G

Overview of units in ALEID2000

Parameter	SI-units
Ground elevation	meter
Demand	m^3/hour
Reservoir bottom level	meter above reference
Reservoir water level	meter above reservoir bottom
Reservoir diameter	meter
Reservoir volume	m^3
Water quality at nodes / reservoirs - Concentration - Travel time - Source tracing	 mg/l (or determined by user) hour percent
Pipe length	meter
Pipe diameter	millimetre
Pipe roughness - Darcy-Weisbach - Hazen-Williams - Chézy-Manning	 millimetre none none
Local loss	none
Pumping head	meter
Pumping flow	m^3 / hour
Pump speed	none
Valve diameter	millimetre
Valve pressure setting	meter above reference
Valve flow setting	m^3 / hour
Bulk reaction coefficient	day^{-1}
Wall reaction coefficient	meters/day
Specific gravity	none
Viscosity	m^2/sec
Diffusity	m^2/sec

APPENDIX H

Overview of data in ALEID2000

Node
    Name
    Ground elevation
    X-coordinate
    Y-coordinate
    number of average demands
    average demands (0 - 5)
    5 identification numbers of demand patterns (0 - 5)
    pressure threshold
    initial concentration
    initial age
    initial fraction
    added basic concentration
    identification number of concentration pattern
    nominal total demand (original)
    actual total demand (calculated)
    % demand reduction compared to the nominal demand
    calculated demand per category (0 - 5)
    pressure
    (piezometric) head
    calculated added concentration
    calculated concentration
    calculated fraction
    calculated age
    comment

Reservoir
    Name
    Ground elevation
    X-coordinate
    Y-coordinate
    initial concentration
    initial age
    initial fraction
    added basic concentration
    identification number of concentration pattern
    pressure threshold
    bulk reaction coefficient
    initial water level (+ reference datum)
    choice from:
        min   or   identification of V,H-relation or --
        max
        diameter
    head
    pressure

outflow / inflow
calculated added concentration
calculated concentration
comment

Pipe
    Name
    Name begin node
    Name end node
    Diameter
    Length
    C-/k-value
    local loss coefficient (optional)
    type (- or CV)
    bulk reaction coefficient
    wall reaction coefficient
    opening status (open / closed)
    (dependent from
        - initial controls
        - operation controls)
    pressure drop
    flow
    velocity
    pressure gradient
    comment

Pump
    Name
    Name suction node
    Name pressure node
    Identification number of the pump curve
    Speed
    (dependent on
        - initial controls
        - operation controls)
    opening status (open / closed)
    (dependent on
        - initial controls
        - operation controls)
    bulk reaction coefficient
    wall reaction coefficient
    pressure drop
    flow
    velocity
    pressure gradient
    power
    comment

Hydrant
    Name

Name downstream node
Name upstream node
Identification number of the hydrant curve
Opening status (open / closed)
(dependent on
- initial controls
- operation controls)
bulk reaction coefficient
wall reaction coefficient
pressure drop
flow
velocity
pressure gradient
comment

Valve
Name
Name downstream node
Name upstream node
Type (PRV,PBV, PSV, FCV, TCV)
Diameter
Setting (on pressure, flow or loss)
(dependent on
- initial controls
- operation controls)
local loss coefficient (optional)
bulk reaction coefficient
wall reaction coefficient
opening status (dependent on
- initial controls
- operation controls)
pressure drop
flow
velocity
pressure gradient
comment

Initial control pipe / hydrant
- pipe- / hydrant name
- status (open / closed)

Initial control pump
- pump name
- status (on / off)
or
- speed

Initial control valve
- valve name

- status (open / closed)

or

- valve setting

Operation control pipe / hydrant
- pipe- / hydrant name
- status (open / closed)
- operating criterion:
  AT TIME ...
  IF NODE .. BELOW ... (head)
  IF NODE .. ABOVE ... (head)

Operation control pump
- pump name
- status (on / off)

or

- speed
- operation criterion:
  AT TIME ...
  IF NODE .. BELOW ... (head)
  IF NODE .. ABOVE ... (head)

Operation control valve
- valve name
- status (open / closed)

or

- valve setting
- operation criterion:
  AT TIME ...
  IF NODE .. BELOW ... (head)
  IF NODE .. ABOVE ... (head)

Operation control reservoir
- reservoir name
- reservoir water level
- operation criterion: AT TIME

Demand factors
- pattern time step
- hourly factors
- day factors
- leakage percentage
- correction factor
- identification numbers per row

Growth model
- begin and end year per period
- growth percentage per period

Concentration pattern
- parallel to hourly factors

Pump/hydrant curve
 Identification number
 Type curve
 number of curve segments
 For each segment:
  Qmin (lower boundary)
  Qmax (higher boundary)
  a,b,c-coefficients of quadratic equation
 or:
  Q,H-points

Reservoir level curve
- number of curve segments
- V,H-points

Model title
 maximum 9 rows of maximum 80 characters

General options
 Units
 Head-loss formula
 Viscosity
 Mass density

Options water quality
 Global pressure threshold
 Global bulk reaction coefficient
 Global wall reaction coefficient
 Limiting potential
 Diffusion coefficient

Hydraulic calculation run parameters (ALCALC.INI)
 Start time
 End time
 Calculated year
 Number of iterations
 Calculation accuracy
 File name with hydraulic solution
 Name binary report file
 Name ASCII-output file
 Report start time ASCII/output-file
 Report time step ASCII/output-file
 Page length

Calculation run parameters for water quality (ALCALC.INI)

quality time step
minimum travel time
segments

Contour
- X-coordinate
- Y-coordinate
or
- asterisk character, "*"

APPENDIX I

Supporting programs COLEBROOK and EQUIVALENT

I.1 General

The DOS-programs: COLEBROOK and EQUIVALENT, are separate programs supporting ALEID2000. The programs are transported in the original version from ALEID 7.1(L) where they were located under the main menu options "K" and "L", respectively. In the installation procedure of ALEID2000, COLEBROOK and EQUIVALENT will be located in the ALEID2000-group, together with the main program. They can be started by double clicking on the relevant icon or from DOS by typing COLEBROOK or EQUIVALENT followed by <Enter>.

I.2 Program COLEBROOK

This program enables static calculation of a single pipe by using the Colebrook formula for determining the friction factor. The main menu options can be selected with the function keys, <F1> to <F4>, or the mouse.

The three calculation options make use of the same formulas existing in the main ALEID2000 program, namely the Darcy-Weissbach head-loss equation:

$$\Delta H = \mathbf{\lambda} * \frac{8L}{\mathbf{\rho}^2 g} * \frac{Q^2}{D^5}$$

with the Colebrook formula used in the following form:

$$\mathbf{\lambda} = \frac{0.25}{\log^2 [\frac{1}{0.4Re\sqrt{\mathbf{\lambda}}} + \frac{k}{3.71D}]}$$

where:
- D : pipe diameter
- ?H : head loss along the pipe
- Q : pipe flow
- g : gravity
- Re : Reynolds number
- L : pipe length
- ? : friction coefficient of Colebrook
- k : absolute roughness

SI-units must be applied in both formulas.

Through menu options <F1> to <F3>, a number of input data must be specified. This is done in the sub-menu by typing the data into the input cells. Moving through the cells is done with the help of the cursor pad. The following data must be specified:

<F1> - the water temperature, absolute roughness (k-value), pipe length, diameter and flow rate. The program will determine the pressure drop.

\<F2\> - the water temperature, absolute roughness (k-value), pipe length, diameter and pressure drop. The program will determine the flow rate (pipe capacity).

\<F3\> - the water temperature, absolute roughness (k-value), pipe length, flow and pressure drop. The program will determine the diameter.

The calculation starts by pressing **\<F10\>**. After it has been completed, the results will be presented in the next menu which allows for printing or repetition of the calculation. If no other calculation is requested, the program ends.

Exiting from the main menu is done by pressing **\<F4\>**.

I.3   Calculation of equivalent pipe: EQUIVALENT

This program calculates equivalent pipe diameter for pipes in parallel or in series. These can be considered with the same or with different k-values.

The calculation makes use of the Darcy-Weissbach head loss equation and the Colebrook formula for determination of the friction coefficient.

After the choice 1,2,3 or 4, has been made, the total number of pipes under consideration must be indicated. Length and diameter must be specified for each pipe. The k-value must also be specified per pipe unless assumed constant.

Furthermore, a choice must be made to calculate an equivalent diameter for a given pipe length, or an equivalent length for a given pipe diameter.

The results of the calculation appear on the screen and will be stored in the file EQUIVALENT.LIS. The program allows for printing or repetition of the calculation. If no other calculation is requested, the program ends.