Technical University of Denmark

Wind Atlas Analysis and Application Program: WAsP 7 Help Facility

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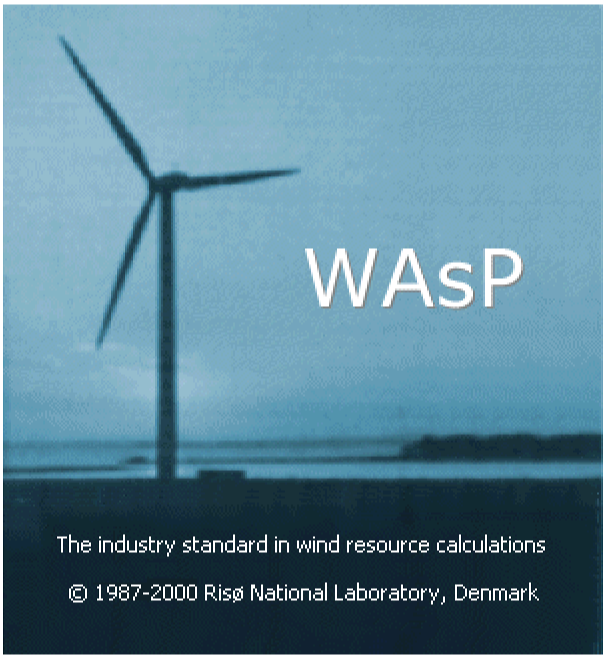


WAsP 7 Help Facility

12 September 2001

Welcome

In 1987 the Wind Energy and Atmospheric Physics Department at Risø National Laboratory introduced WAsP – a powerful tool for wind data analysis, wind atlas generation, wind climate estimation and siting of wind turbines. Over the years, the program has become the industry standard for wind resource assessment and siting of wind turbines and wind farms and it has been employed in more than 70 countries all over the world.

A new release of this indispensable tool for everybody working with wind energy is now available – WAsP for Windows 95, 98, NT 4 and 2000. The program has been developed by the same team who worked out the Danish Windatlas, the European Wind Atlas and previous versions of the WAsP programs.

The algorithms at the heart of the WAsP software have been tested and applied for more than 15 years in many different parts of the world. As time has passed, most of our efforts have been devoted to refining the WAsP algorithms and supporting the existing software. Meanwhile, user interface design standards have moved on. Many users (and prospective users) have indicated their desire for a new, modern, user interface. WAsP 7 is intended to meet these demands.

WAsP is 100% 32-bit Windows software, which runs under Windows 95, Windows 98, Windows NT 4.0 and Windows 2000. It conforms to standard windows software user-interface conventions, making it easy to learn and easy to use.

We recommend that you work through the Quick Start Tutorial – to see for yourself what WAsP 7 is all about. If you're already using the existing DOS versions of WAsP, you might read on here before entering the tutorial.

With the release of WAsP 7, we also plan to handle feedback and support in a much more systematic and dynamic way than before. The main focal point for these efforts will be the WAsP home page. Among other things, we plan to maintain a list of Frequently Asked Questions (FAQ), a list of Known Issues, a list of User Requested Features as well as information on our own ideas for the future development of WAsP. Last, but not least, there will be a Download Page where you can download the latest version of the software and help file. Users who do not have access to the Internet may receive free updates on disk.

As it says in the License Agreement and Copyright Statement, the WAsP software is provided 'as is' and 'does not represent a commitment on the part of Risø National Laboratory' etc. However, we are of course aware that the programs may contain errors, programming bugs and inconsistencies – especially with the introduction of this major upgrade. Therefore, we guarantee that we will do our best to check, maintain and correct the programs in the WAsP package, and that we'll make available or distribute corrected versions to registered users of the software.

We wish you the best of luck with your wind projects and hope WAsP 7 can help you reach your goals.

The WAsP team at Risø

What is WAsP?

WAsP is a PC-program for the vertical and horizontal extrapolation of wind climate statistics. It contains several models to describe the wind flow over different terrains and close to sheltering obstacles. WAsP consists of five main calculation blocks:

Analysis of raw data. This option enables an analysis of any time-series of wind measurements to provide a statistical summary of the observed, site-specific wind climate. This part is implemented in a separate tool, the Observed Wind Climate (OWC) Wizard.

Generation of wind atlas data. Analyzed wind data can be converted into wind atlas data sets. In a wind atlas data set the wind observations have been 'cleaned' with respect to site-specific conditions. The wind atlas data sets are site-independent and the wind distributions have been reduced to some standard conditions.

Wind climate estimation. Using a wind atlas data set calculated by WAsP or one obtained from another source – e.g. the European Wind Atlas – the program can estimate the wind climate at any specific point by performing the inverse calculation as is used to generate a wind atlas. By introducing descriptions of the terrain around the predicted site, the models can predict the actual, expected wind climate at this site.

Estimation of wind power potential. The total energy content of the mean wind is also calculated by WAsP. Furthermore, an estimate of the actual, annual mean energy production of a wind turbine can be obtained by providing WAsP with the power curve of the wind turbine in question.

Calculation of wind farm production. Given the thrust coefficient curve of the wind turbine and the wind farm layout, WAsP can finally estimate the wake losses for each turbine in the farm and thereby the net annual energy production of each wind turbine and of the entire farm, i.e. the gross production minus the wake losses.

The program thus contains analysis and application parts, which may be summarised as follows:

Analysis

time-series of wind speed and direction —> wind statistics

wind statistics + site description —> wind atlas data sets

Application

wind atlas data sets + site description —> estimated wind climate

estimated wind climate + power curve —> estimated power production

Wind farm production

estimated power productions + wind turbine / farm characteristics —> gross and net annual energy production of each turbine and of entire wind farm

The WAsP models and the wind atlas methodology are described in more detail in the European Wind Atlas.

WAsP 7 installation

This brief guide describes the installation procedure for WAsP, version 7.2. Great care has been taken to ensure that the installation will run successfully, but as with all Windows software installations, there is a risk that running it could upset the normal functioning of your system. It is strongly recommended that you exercise some caution in choosing when to run the installation program. Please contact the WAsP team at Risø before installing if you need any specific advice.

To use the full range of features in a software product from Risø, you must have a valid product licence. The installation is therefore divided into two separate steps:

1. Installing the WAsP software
2. Installing the WAsP licence

The installation disk

The WAsP installation files are shipped on a CD-ROM, which contains the following software packages:

- WAsP 7 for Windows 95/98/ME/NT4/2000
- WAsP 4 (16-bit) and 5 (32-bit) for DOS
- Adobe Acrobat Reader 5.0
- Internet Explorer 5.5 (SP2)
- www.WINDPOWER.org, version 3.0
- Golden Software demos of Didger, Surfer, Grapher and MapViewer

The WAsP software package

This package is described further in the following topics and in this help facility. The package contains all the programs and data needed to run WAsP, including the complete User's Guide, Quick Start Tutorial, Technical Reference, etc.

The WAsP for DOS packages

Also included on the WAsP installation CD are the latest releases of the 16- and 32-bit versions of WAsP for DOS. Read the readme.txt and wasp42.txt to learn how to install the WAsP 4 package; read the readme.txt and wasp52.txt to learn how to install the WAsP 5 package. No part of these packages is required to run WAsP for Windows; they are shipped only for the convenience of WAsP users who wish to be able to exploit the characteristics of this DOS software in existing projects and analyses.

www.WINDPOWER.org

For general information about wind power, as well as links to other web sites related to wind power, a good place to start is the award-winning home page of the Danish Wind Turbine Manufacturers

Association. A recent download of this entire home page is provided for your perusal on the WAsP distribution disk, in the folder \Windpower. The pages exist in English, German, French, Spanish and Danish, and may be read with Internet Explorer 4 or Netscape 4, or later. To start reading, **Open** the file index.htm in either of the five folders English, Deutsch, Francais, Espanol or Dansk. The actual home page can of course also be accessed over the Internet.

This comprehensive source of information is brought to you by courtesy of the Danish Wind Turbine Manufacturers Association. Please observe the copyright statements and other conditions for use given in the pages.

Software requirements

Before installing WAsP, you should check the following points carefully.

Windows 95 version

If you're running Windows 95, check the Windows version. Invoke **Settings** in the **Start** menu, then **Control Panel** and in the control panel choose 'System'. In the General page under the heading 'System', you will find the actual version of Windows 95. The version number, e.g. 4.00.950, should be followed by an 'A' or a 'B', meaning that Service Pack 1 or 2 has been installed.

If this is not the case, you should get Windows 95 Service Pack 1 from the Microsoft Download Center. The download is free of charge. Be sure to get the right International Language Update if you are not using the standard English version of Windows 95.

Internet Explorer version

If you're running Windows 95 or NT 4.0, make sure that you have Internet Explorer 4 or later installed. If not, you may install an English version from the WAsP CD: Run Ie5setup.exe in the directory \IE5 (or Ie4setup.exe in the directory \IE4) and follow the instructions. A 'minimal' installation is sufficient and we further recommend not to install the Active Desktop.

If you have an International Language version of Windows 95 and Internet Explorer, you should get the corresponding update at Microsofts Download Center and not install it from the WAsP CD. Internet Explorer 4 or 5 may update some of your system files and is required for full functionality of the WAsP licence manager and help facility.

If you're running Windows 98 you don't need to install Internet Explorer.

Minimum software requirements

The minimum requirements for installing and running WAsP successfully are thus Windows 95A and Internet Explorer 4.

You should also read the 'License Agreement for the use of WAsP' before installing the program.

Installing the WAsP software

First, close all active programs on the PC. Then, if you're upgrading from an earlier WAsP version:

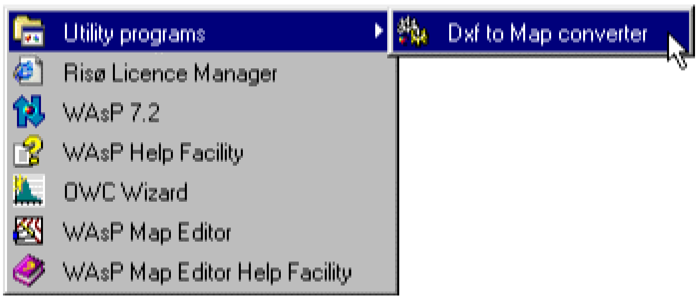
1. Un-install WAsP using the Control Panel un-install facility
2. Install the WAsP 7 programs from this CD

If you're installing WAsP 7 onto a computer with no previous version of WAsP:

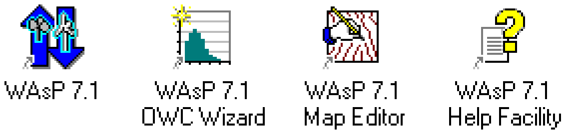
1. Except for Windows 98, ensure IE is installed (at least version 4.0)
2. Install the WAsP 7 programs from this CD

WAsP can be installed from the CD by invoking Wasp7Setup.exe and MapEditorInstall.exe. Invoke these files using **Run** in the **Start** menu. And, as with any other power tool: 'read, understand and follow the instructions' – in this case those given by the installation programs. Agree to the default values and folders suggested by the installation programs unless you are absolutely confident with what you are doing.

WAsP, some utility programs and sample data files will be installed in the folder \Program Files\Wasp and several sub-folders. They will also appear in the **Start** menu, in a 'WAsP' folder under the **Programs** menu item. This folder should contain seven installed items:



For fast and easy access to the WAsP software, you can also make short-cuts to the programs on your Windows desktop, e.g.



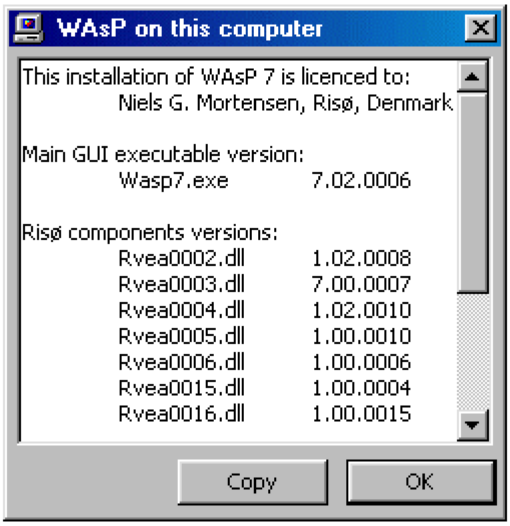
Obtaining and installing the licence

The Risø Licence Manager is invoked from the **Start** / **Programs** / **WAsP** menu. This program will guide you through the three-stage process of installing the licence:

1. You apply for a product licence unlock code by sending us your machine ID number.
2. We send you your product licence unlock code.
3. You enter the product licence unlock code to install the licence.

The unlock code and user name information is sent to you by Risø and must be entered exactly as it is written by Risø; including spaces, special characters and punctuation marks – use copy and paste to transfer this information. When the user name and license unlock code have been entered correctly, WAsP can be executed.

The User Name can be displayed any time in the WAsP **Help** menu under the menu point **WAsP on this computer...**



This information window further contains the version numbers of the installed components.

Running WAsP

We suggest you start by reading through the 'Introduction' section of the WAsP help facility. If you are already using the existing DOS versions of WAsP, you might read on in the 'Notes for users of previous versions' section. Next, we recommend that you work through the Quick Start Tutorial – to see for yourself what WAsP is all about.

The documentation and User's Guide to the WAsP program are contained in the WAsP help facility. Here you should be able to find most of the information required to run WAsP.

If you have problems using the WAsP software please send an e-mail to the WAsP support staff. If you do not have e-mail, you may send a fax to the number given here.

You should also check the list of known issues at the WAsP home page and/or the list of Frequently Asked Questions, which will be introduced and maintained at the same Web address.

Keeping your installation up to date

The latest version of the WAsP program may be downloaded from the WAsP download page in the form of an update file to the main installation on the CD-ROM. Note, that it will only run on the PC computer where the original WAsP installation was made. Updates of other WAsP files and programs may be available as well (WAsP Help Facility, RIX etc.).

Great care is taken to ensure that WAsP installations and updates will run successfully, but as with all Windows software installations, there is a risk that running it could upset the normal functioning of your system. It is recommended that you exercise some caution in choosing when to update your WAsP installation. Please contact the WAsP team before updating if you need any specific advice.

The latest version of Internet Explorer is available from Microsoft's Download Center. You may also visit Microsoft's Windows Update site to download and install the latest Windows updates for your computer.

What's new in WAsP 7?

WAsP 7 is not just another update of WAsP 6; it contains new functionality, an improved user interface, a much improved help facility and several new or updated auxiliary software packages. Some of the major changes and additions compared to previous versions are:

- Wake loss and wind farm efficiency calculations implemented
- New wind farm windows and wind farm file support
- New power curve window and wind turbine file support
- WAsP help facility updated and expanded significantly
- Power curve library updated and expanded
- www.WINDPOWER.org updated to version 3.0
- WAsP 5.2 (32-bit, DOS) now included
- WAsP 4.2 (16-bit, DOS) now included
- An Air Density Calculator included
- The DXF-file Translator included
- Internet Explorer 5.5 included
- Adobe Acrobat 5.0 included

A more detailed list of fixes and changes in WAsP 7.2 (relative to version 7.0 released in Feb 2000) is given below (last update 2001-08-21):

Licencing

- Licensing system is much less sensitive to machine configuration changes
- Added executable binary version of Licence Manager (in case of problems with HTML version)
- Licence manager HTML pages now run OK under Internet Explorer 4 as well as under IE5.

General

- Can run the application without a licence installed now, but no calculations ... (!!)
- Fixes toolbar problem under Win2K
- Cosmetic changes to labels and so on
- More changes to displayed units (yellow labels)
- Added updated and expanded sample data and workspaces
- Various bugs in the graphic user interface have been fixed

Embedded Help

- Added an updated and expanded help file
- Changed path settings for the help file
- Added help link for new windows in OWC wizard

Hierarchy

- Workspace hierarchy tree can now be collapsed to project level
- Workspace hierarchy tree members can now appear without type names

OWC-Wizard

- Default discretization bin width's set to 1/1000 of the raw data units
- Fixed erroneous rounding by the OWC wizard of some values to integers (min and max speed)
- OWC Window display now deals correctly with bin width not equal to one
- Alert raised in OWC wizard if more than 50 bins
- OWC Wizard deals more elegantly if number of valid selected entries is zero

Roughness description

- DOS-WAsP Roughness description files correctly written if no change lines in a sector
- Bad problem with reading roughness rose files from DOS WAsP now fixed
- Roughness descriptions using the "comma and gaps for missing data" format now read in correctly

Wind farm object

- Various enhancements to list views in wind farm window
- Cut and paste from wind farm window lists now has correct tabbing
- Correct import of DOS-WAsP random rsf files to make wind farm
- Can import wind farm from a text file list of position pairs (such as could be produced from Excel easily)
- Correct naming of new or imported site locations for wind farms from rsf- and text-files
- Correct import of locations list in text field to make wind farm
- Air density setting facility withdrawn from the wind farm wake modeling. In case of an old wind farm file containing a non-standard air density specification, this specification is cancelled and the user is informed that this option is not supported. The effect of non-standard air density must be taken into account by using an air-density specific turbine power curve.
- Wake modeling calculation now has progress monitor and can be interrupted
- Wind farm now correctly saves specific height setting and restores it.
- An algorithmic inaccuracy occurring for wind distributions with high Weibull A-parameters, sometimes resulting in small negative wake losses, has been fixed.
- The wake effect module algorithm has been revised to give full consistency with the WAsP kernel. Two different methods can be used to calculate the all-directions AEP :
    - a) by all-directions Weibull distribution (used in the WAsP kernel); and
    - b) by sum of sectorial contributions (used internally in the wake effect calculation).
- In the wake effect module the difference between these methods has been dealt with by "harmonizing" the latter, and no warning nor error message is issued in case the difference is "large". In a later version of WAsP a switch will be introduced to enable the user to choose between the two options for the WAsP kernel (wake-effect-free production) and the wake effect calculation in common.

Other objects

- Fixes export problem with so-far-unsaved resource grids
- All problems with blank extra lines in trb and pow files now fixed
- Obstacles are now inserted to the bottom of the list, not the top
- Added some new Vestas turbines to the library

- Corrected the Vestas V47 turbine *.pow and *.trb files

Computational/algorithmic core

- Fixes the 'Cairo' bug: A wind atlas can now be produced without a specified map, i.e. a flat terrain with a constant (default) roughness length of 0.03 m is assumed.
- Fixes the 'Fulla' bug (no more mysterious DOS windows popping up!)
- Model radius lower limit lowered to 5000 m
- Fixed misc. bugs in error handling
- Azimuthal resolution can now be set to 1, 2, 3, 4, 5, 6, 9, 10, 12, or 15
- Fixed bugs regarding memory allocation in connection with non-default azimuthal resolutions.
- Better bounds checking of azimuthal resolution
- Increased working memory sizes to fix 'Too large map file' errors
- In the AEP (Annual Energy Production) calculation algorithm, a minor inaccuracy, resulting in a slight overestimation in case of very "high" Weibull distributions, has been fixed.
- WAsP 7.2 may now treat very detailed orography description in a map, i.e. densely spaced height contour lines within the calculational domain around a site being treated. Such conditions have in previous versions caused the calculation to break down when analyzing an observed wind climate (i.e. creating a regional wind climate *.lib), or when calculating wind resources at a site (in connection with single turbines, wind farms or wind resource grids). Fortunately, this annoying limitation has now been removed.

Known issues

With the release of WAsP 7, the Park model has been included in the WAsP program through the wind farm member. In some respects, the wind farm model acts as a separate model and it also has its own settings and dump file.

It is important to note the following:

- WAsP uses an air density of 1.225 kgm^{-3} when calculating power density. Similarly, power production is calculated for this standard air density if one of the sample power curves is used.
- Only if the power curve is specified for the actual site air density, or an existing power curve has been scaled to the site air density (this is only recommended for some turbines though), will the wind turbine power production calculated by WAsP correspond to this air density.
- When invoking **Edit in map editor** from the map's right-click menu, any changes to the map are not automatically used in WAsP; the map must be saved from the map editor and reloaded into WAsP for the changes to take place.

You should also check the list of known issues at the WAsP home page.

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Acknowledgements

The WAsP program was originally developed, designed and implemented by Ib Troen, Niels G. Mortensen and Erik L. Petersen from Risø National Laboratory, with financial support from the Commission of the European Communities (DGXII).

The present Windows-version was developed by a team consisting of Lars Landberg, Niels G. Mortensen and Ole Rathmann from the Wind Energy Department at Risø, Sofus S. Mortensen from Lambda Soft (DK) and Duncan N. Heathfield from World in a Box Limited (UK).

The ruggedness index concept was developed and tested by Anthony J. Bowen from the University of Canterbury, New Zealand.

Artistic drawings by Søren Rasmussen.

The WAsP help facility

This help facility should eventually become the complete, on-line User's Guide and Technical Reference for the WAsP program. The main characteristics of the WAsP Help Facility are:

- **Based on Microsoft HTML help**
  - Requires Internet Explorer 4.0 or later for full functionality
- **Complete on-line documentation**
  - Text, tables and images
  - Table of contents, index and keywords
  - Books and topics can be printed
- **Fast and easy to use**
  - Context-sensitive help (**F1-**help)
  - Full-text search facility
- **Hyperlinks to topics, URL's and e-mail addresses**
- **Easy to update and distribute**

The help facility can be invoked and used in two different ways: as context-sensitive help or as a stand-alone application/document.

The help facility is far from static, but is being developed continuously. New versions will be made available at the WAsP home page and you'll receive a notification when this happens – if you have informed us about your e-mail address.

Context-sensitive help

Pressing the **F1-**key on your keyboard invokes context-sensitive help for the active window or dialog. This works in the WAsP program as well as for the Observed Wind Climate Wizard. The WAsP map editor has its own help facility.

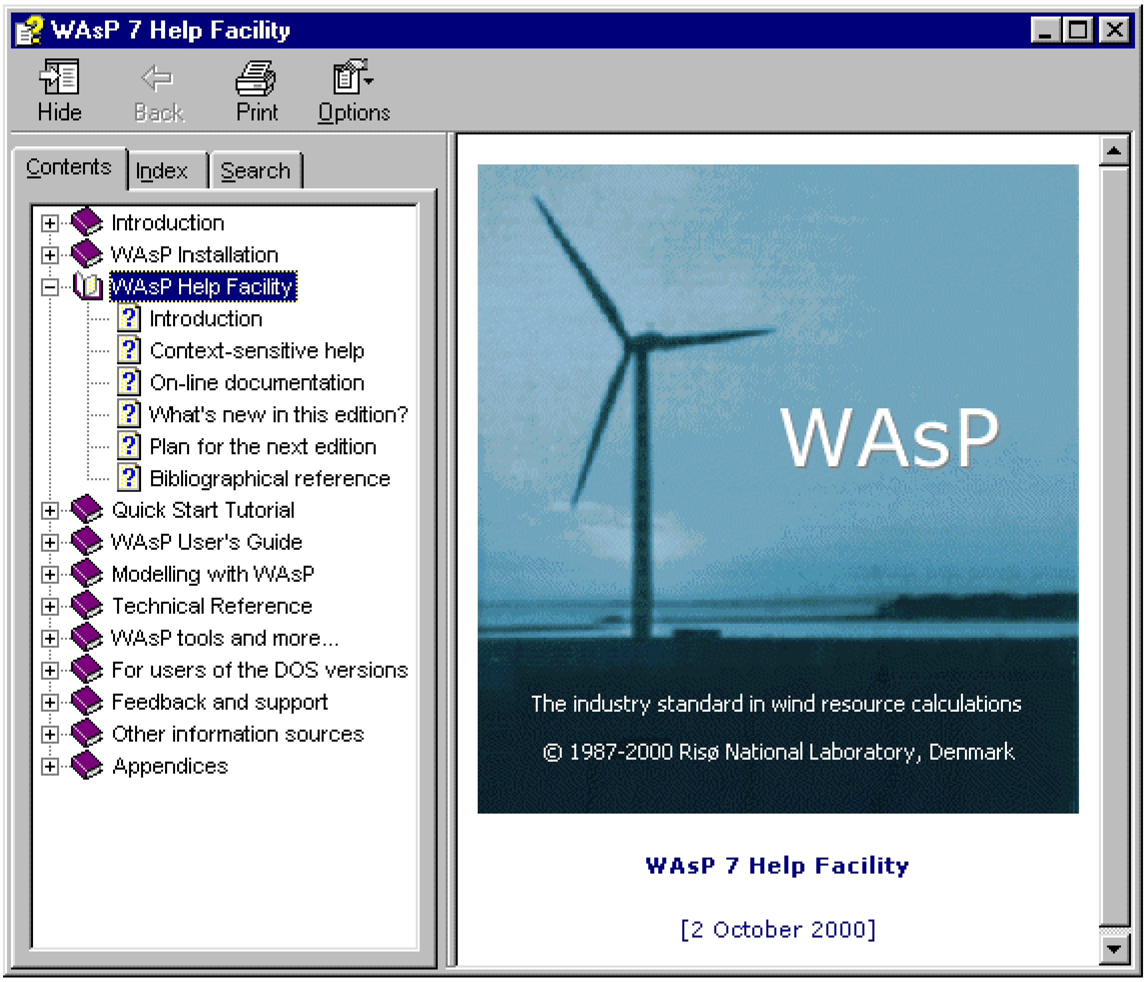
From the WAsP program you are guided directly to the User's Guide of the help facility; to a point from which you should be able to find the answer you're looking for. Use the **Contents** tab to navigate the help facility via the table of contents, or use the related topics controls present on most **F1**-help entry pages.

As an example, the obstacle window entry page has the following two controls:

You can also use the **Index** tab to navigate via the keywords of the index or you can use the full-text search facility by choosing **Search**.

Complete on-line documentation

The help facility is the complete on-line User's Guide and Technical Reference for the WAsP program package. It can be invoked from the main menu of WAsP by choosing the **Contents and Index** menu item from the **Help** menu. Or, it can be invoked from the **Start** / **Programs** / **WAsP** menu in Windows. The opening screen looks like this:



The help facility can be browsed in several ways: you may use the **Contents** tab to navigate the help facility via the table of contents, or you may use the **Index** tab to navigate via the keywords of the index. Finally, you may use the full-text search facility by choosing **Search**.

In the different topics of the help facility you may find links to other topics and to Web pages; these can be invoked directly with the left-hand button of the mouse. Links to e-mail addresses will start your e-mail application when invoked.

Topics and entire books can be printed when choosing the **Print** menu point.

What's new in this edition?

The WAsP help facility is continuously under development, so changes and additions to its structure and contents should be expected. Major changes compared to the second general release (WAsP 6.0, June 1999) are:

- A *WAsP Installation* book has been added.
- A *Modelling with WAsP* book has been added. This describes the topographical concepts used in WAsP modelling, as well as the different models of WAsP: the roughness model, the flow model, the shelter model and the wake model.
- A *WAsP Tools and more...* book has been added. In this, we have collected information on the OWC Wizard, the MapEdit utility, the Air Density Calculator, the RIX program and the DXF translator, as well as lists of other software and hardware that may be useful when working with WAsP in practice.
- The *Park program* section does not exist anymore since the functionality of the Park program is now included in WAsP.
- Some sample WAsP forms are now described in the *Appendices* section.
- A description of the wind-climatological fingerprint has been added to the *Appendices* section.

Note also, that the terminology used in WAsP has been changed slightly: we have tried to avoid any sloppy uses of the terms 'energy' and 'power' as well as some related terms.

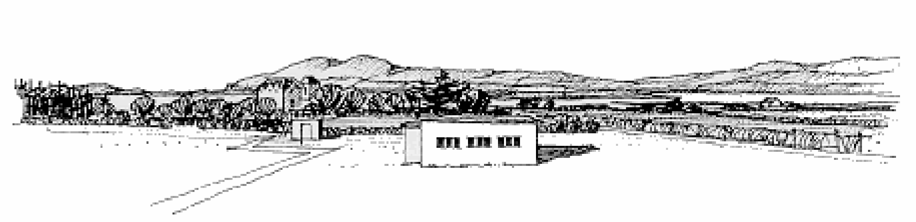
Major changes in the second release (June 1999) compared to the first general release (March 1999) are described here.

Plan for the next edition

The contents of the next edition will to some extent depend on the user response to the present version. However, we do plan to add more information on the following subjects:

- Wind power meteorology in general
- Site calibration and customisation
- Limitations of the wind atlas methodology
- Wind resource assessment in specific situations: offshore, near-shore, complex terrain and wind resource mapping.

We also aim at providing more sample data and example projects with the WAsP package.



Bibliographical reference

Title: Wind Atlas Analysis and Application Program: WAsP 7 Help Facility

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Date: September 2001

Topics: 291

Tables: 11

Illustrations: 229

References: 26

Abstract: The Wind Atlas Analysis and Application Program (WAsP) is a PC-program for horizontal and vertical extrapolation of wind data. The program contains a complete set of models to calculate the effects on the wind of sheltering obstacles, surface roughness changes and terrain height variations. The analysis part consists of a transformation of an observed wind climate (speed and direction distributions) to a wind atlas data set. The wind atlas data set can subsequently be applied for estimation of the wind climate and wind power potential, as well as for siting of specific wind turbines. The WAsP 7 Help Facility includes a Quick Start Tutorial, a User's Guide and a Technical Reference. It further includes descriptions of the Observed Wind Climate Wizard, the WAsP map editor tool, the Air Density Calculator, the RIX program for calculating the ruggedness index of a site in complex terrain and the DXF Translator.

Descriptors (INIS/EDB): COMPUTER PROGRAM DOCUMENTATION; DATA ANALYSIS; MAPS; RESOURCE ASSESSMENT; SITE CHARACTERIZATION; W CODES; WIND; WIND POWER.

Please refer to: Mortensen, N.G., D.N. Heathfield, L. Landberg, O. Rathmann, I. Troen and E.L. Petersen (2001). *Wind Atlas Analysis and Application Program: WAsP 7 Help Facility*. Risø National Laboratory, Roskilde, Denmark. 291 topics. ISBN 87-550-2941-8.

Introduction

This section of the WAsP help facility is intended to provide a very brief introduction to the essential features and uses of WAsP.

A concise explanation of the most basic techniques is followed by a simple step-by-step example.

New users will get an idea of what WAsP is for and how to use it. Existing users of older versions of WAsP will be introduced to the new ways of working.

The Quick Start Tutorial starts here.

Just the basics...

This section is not intended to be a complete guide to using WAsP. Instead, you are introduced to just enough of the basics to let you work through the simple step-by-step example.

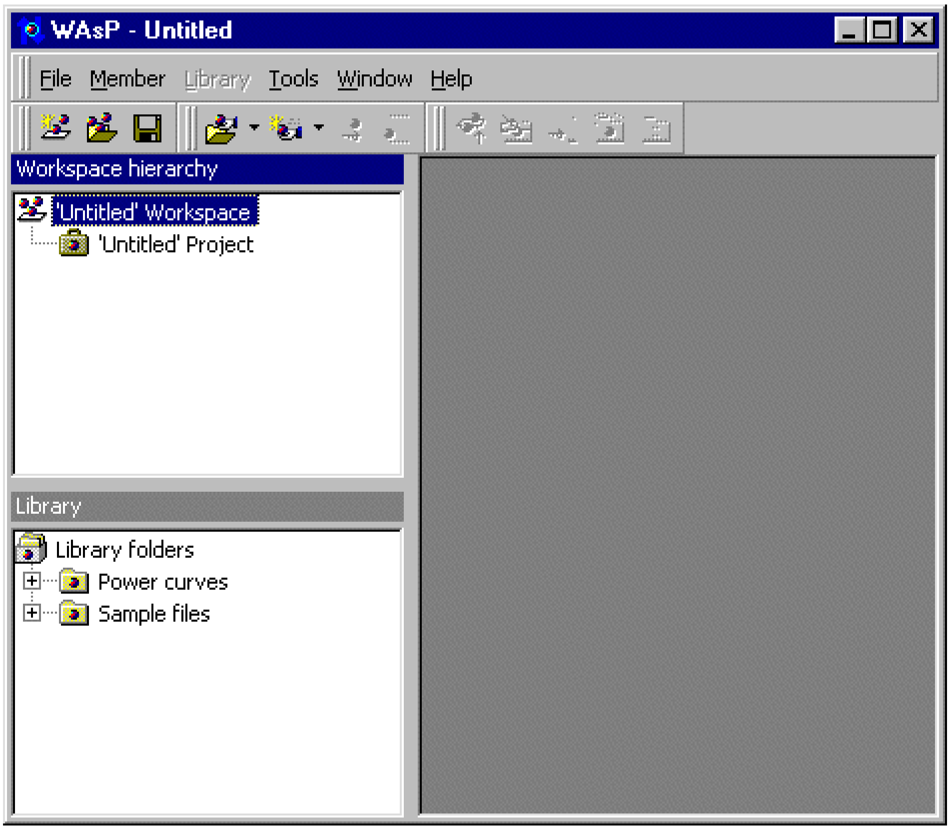
Read through the following sections in order

1. WAsP workspaces
2. Working with the workspace hierarchy
3. Saving the workspace members

This brief introduction is followed by the step-by-step example.

Opening a new WAsP workspace

When you first open WAsP, you are presented with an empty window. To start work, you need to open a workspace. In WAsP, all work is performed within the context of a workspace. Workspaces can be created, saved and re-opened. To open a new workspace, select **New workspace** from the **File** menu.



Two white window 'panes' have appeared on the left-hand side of the main window: the workspace hierarchy and the library. The library pane simply makes it faster to find files. It is explained elsewhere in the documentation. For now, ignore the library pane and concentrate on the workspace hierarchy, which is the most important area of the program.

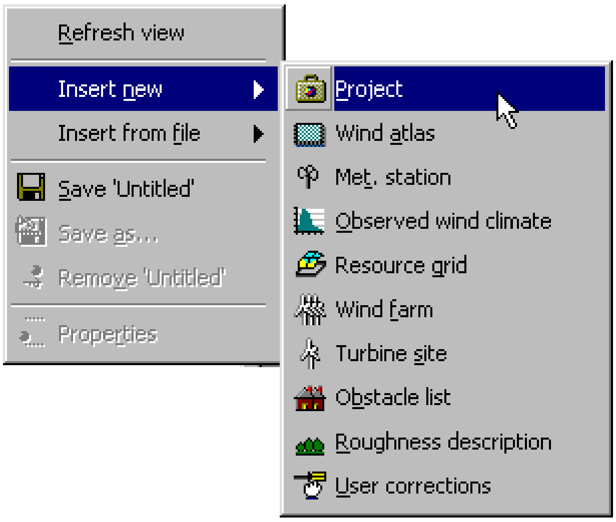
Now read about Working with the workspace hierarchy.

Working with the workspace hierarchy

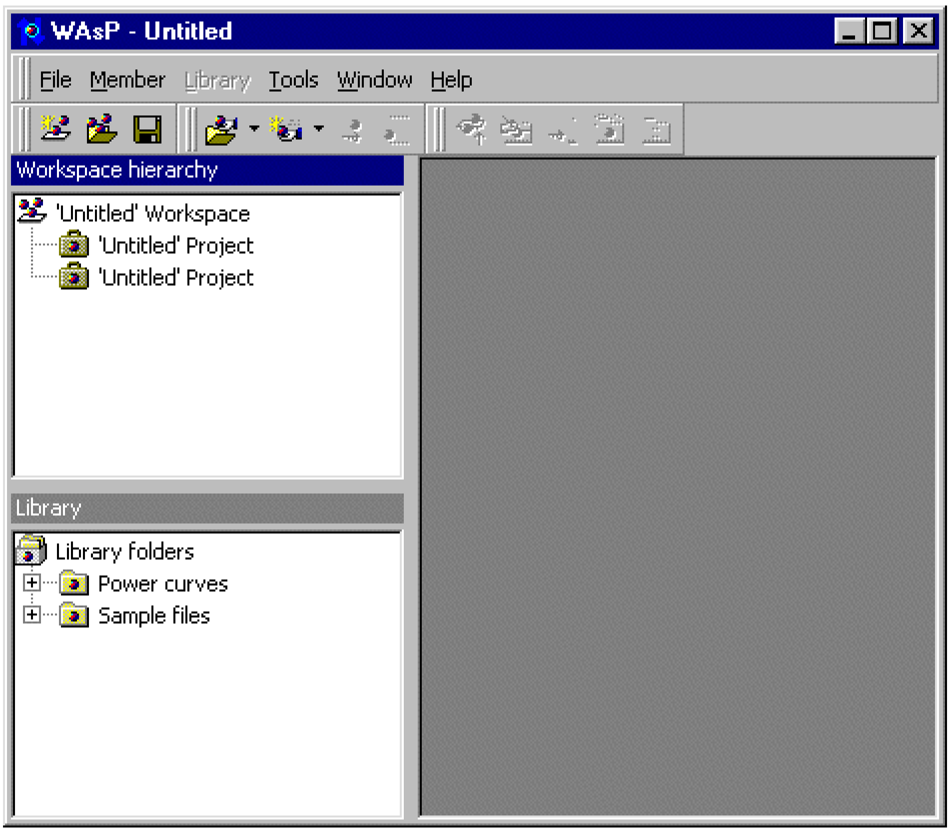
The workspace hierarchy contains one single icon, representing the 'root' of the workspace. This workspace further contains one 'Untitled' project. To work with WAsP, you need to add new items to the workspace. These items are arranged in a hierarchy and are called hierarchy members or just 'members', for short. The workspace root is always at the very top of the hierarchy. All of the members of the workspace are children of the workspace root.

To insert a new member to the hierarchy, do the following:

- Click with the right hand mouse button on the workspace icon.
- A small 'pop-up' menu appears. Select **Insert new**.
- Another menu appears. Select **Project**.



A project hierarchy member is inserted as a child of the workspace root.



Every member of the hierarchy has a right-click menu. Most members' right-click menus include insertion sub-menus.

To insert another member to the hierarchy:

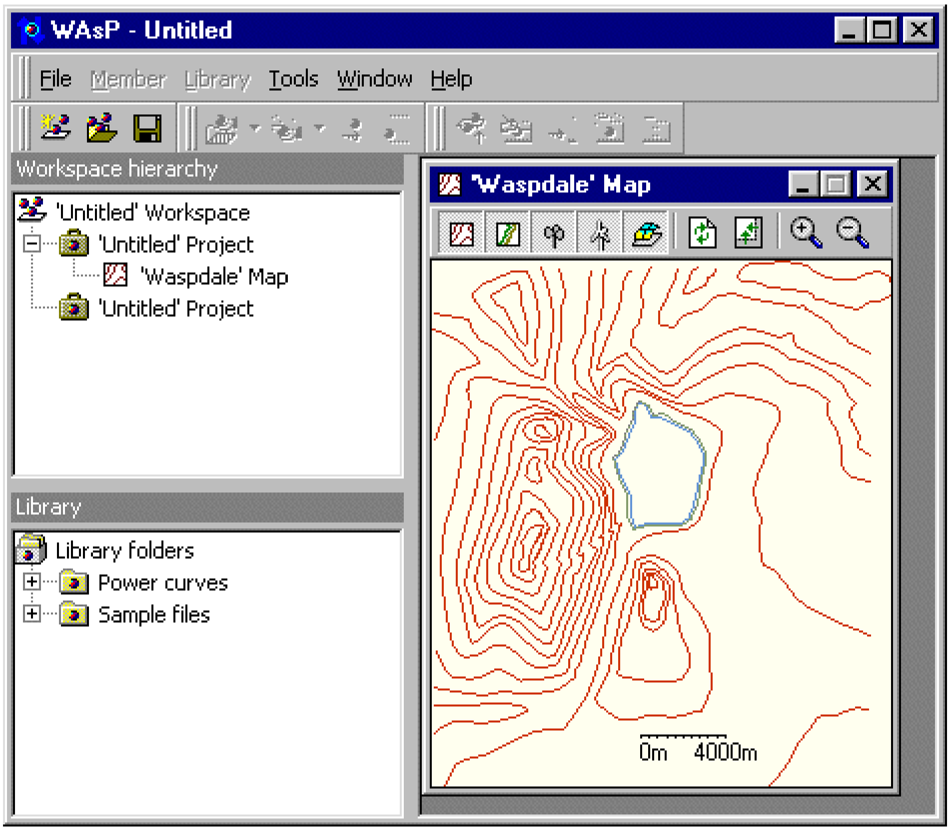
- Select **Insert from file** from the first projects pop-up menu
- Select **Map** from the insertion sub-menu
- A file-choice dialog box appears. Select the file called 'Waspdale.map'

You may have to navigate to the folder containing the sample data, which was created when you installed WAsP. The map is now a member of the hierarchy, as a child of the first project.

To view the map:

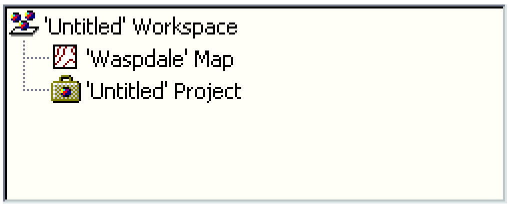
- Select **View** from the map icon's right-click menu.

The map window appears in the right-hand side of the main window.



Most members in the hierarchy have an associated window in addition to the simple icon, which is displayed in the hierarchy itself.

All members of the hierarchy (except the hierarchy root) can be inserted, moved around or deleted. You can re-organise the existing hierarchy members by dragging them around with the mouse. To move the map so that it is a child of the workspace root, simply drag the map icon onto the workspace icon.



The map and the project are now both children of the workspace root. There are constraints on where different types of hierarchy member can be placed in the hierarchy, but most types of member (including maps) are allowed to be children of the workspace root.

You have already learned the most important techniques for working with WAsP!

It is largely a matter of manipulating the members of the workspace hierarchy using the mouse. Learning to use WAsP is now simply a question of getting to know the various members of the workspace hierarchy and understanding how to use them.

Now read about Saving the workspace and members.

Saving the workspace and members

Each member of the workspace has an associated data file. When you work with a hierarchy member in WAsP, you are dealing with a copy of the data and you can make changes to anything. The changes to the data are not written to the file unless you save them.

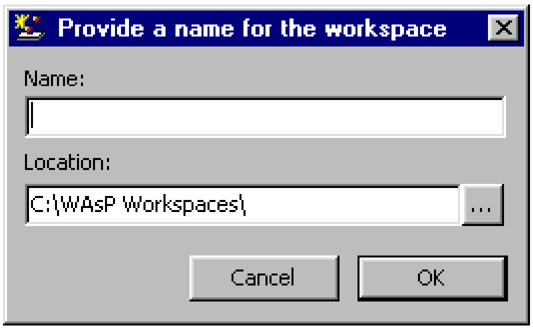
You can save changes to most individual hierarchy members by using their right-click menu:

- Select **Save** from the member icon's right-click menu.

To save a copy of a member:

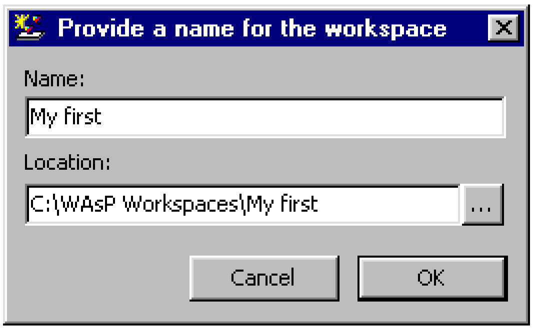
- Select **Save** as... from the member icon's right-click menu.
- Provide a name and path for the file in the file dialog box, which appears.

Every WAsP workspace and every WAsP project is stored in its own folder on your computer. So, when you first save a project or workspace you need to provide the name of a new folder rather than a file name. A special dialog box appears to help you do this:



To save the workspace:

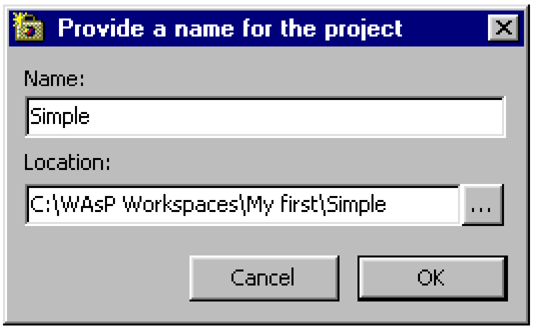
- Select **Save** from the workspace icon's right-click menu.
- Type a name in the box, which appears.
- Notice that the new folder name is being added automatically to the location.



When you press OK, a new folder with that name is automatically created, and a new workspace file with the same name is placed into the folder. You are now invited to save the project too.

To save the project:

- Type a name in the box, which appears.
- Notice that the project folder is being created as a sub-folder of the workspace folder.



You can save whole branches of the workspace hierarchy in a single operation. For example, if you save a project, any changes to any of the children of the project are automatically saved too. (That's why, in the example above, you were invited to save the project, even though you had only asked to save the workspace.

At any time, you can save the whole workspace by clicking on the **Save workspace** icon in the main toolbar. Any new files, which you create in the context of a project or a workspace, are (by default) saved to the project or workspace folder.

Now you should be ready for a step-by-step example...

Introduction

The example works through a complete wind turbine siting operation, starting with some measured wind data and ending up with a prediction of the power yield from erecting a turbine at a specific site.

You can find the data used for the example in the folder containing the sample data, which was created when you installed WAsP, e.g. '\WAsP Workspaces\Samples\Sample data'.

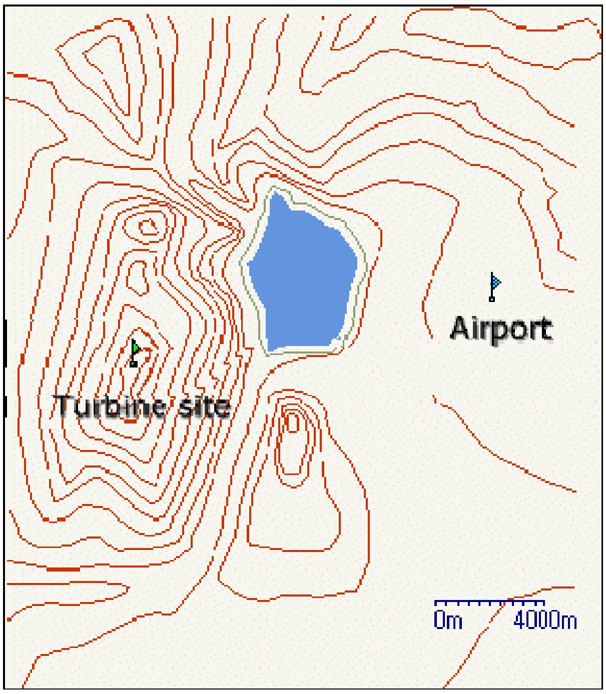
At the bottom of each page is a Proceed... link, which will take you to the next page in the example.

Proceed...

The situation

The company *Friends of Wind Energy, Waspdale Ltd.* has asked you to provide a prediction of the power yield from locating a wind turbine in Waspdale. They propose to erect a single 600-kW wind turbine at the summit of Waspdale hill (they have modest energy requirements).

No wind measurements have been taken at the turbine site itself, but data have been collected from a meteorological station at nearby Waspdale airport. A map of Waspdale is shown below.



You are equipped with:

- a contour map of the area
- the wind data from the airport
- a simple description of the land use in the area
- an annotated sketch of the airport buildings near the met. station
- a description of the power-generating characteristics of the turbine

These have been converted into digital files, as follows:

- a digital map of topography and roughness
- a data file containing wind data
- a data file describing the buildings at the airport
- a data file containing a power production curve for the turbine

Proceed...

Working with WAsP to provide a prediction

From engineering data, you know how much power will be generated by the turbine at a given wind speed. If the plan was to erect the turbine at exactly the same place where the meteorological data had been collected, then it would be a really simple task to work out how much power to expect.

However, just from looking at the map it is obvious that the proposed turbine site is completely different from the meteorological station at the airport: the properties of the meteorological station itself will affect the wind data recorded there. In addition, the properties of the turbine site will have an effect on the way that the wind behaves near the turbine. It is also unlikely that the hub height of the turbine would be the same as the height of the anemometer.

What you need is a way to take the wind climate recorded at the meteorological station, and use it to predict the wind climate at the turbine site. That's what WAsP does.

Using WAsP, you can analyze the recorded data, correcting for the recording site effects to produce a site-independent characterisation of the local wind climate. This site-independent characterisation of the local wind climate is called a wind atlas or *regional wind climate*. You can also use WAsP to apply site effects to wind atlas data to produce a site-specific interpretation of the local wind climate.

Providing a prediction in the Waspdale case will therefore be a two-stage process. First, the data from the meteorological station need to be analysed to produce a wind atlas, and then the resulting wind atlas needs to be applied to the proposed turbine site to estimate the wind power.

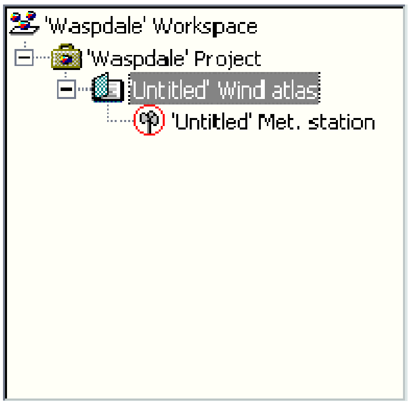
Proceed...

Setting up a met. station

To begin, you need to open a new workspace in WAsP. A new, 'Untitled' project is automatically inserted in this workspace. Save the workspace and project, calling them both 'Waspdale'. Return to the GUI essentials if you don't know how to do this.

Now insert a new wind atlas as a child of the project. The wind atlas will be generated from a meteorological station. Insert a new met. station hierarchy member as a child of the wind atlas.

The workspace should now look like this:



Provide names for the wind atlas and met. station by saving them. To do this, simply save the whole workspace: you will be prompted for the file names for the newly created hierarchy members. Call the wind atlas 'Waspdale' and call the met. station 'Airport'.

WAsP now requires:

- a description of the data-recording site
- a summary of the wind data recorded at the site

Proceed...

Adding wind observations

You now need to insert some wind data to the hierarchy.

Select the met. station and use **Insert from file** to insert an **Observed wind climate** member. You will be asked to provide the name of a file to use. Navigate to the folder containing the sample data, which was created when you installed WAsP, and select the file called 'Waspdale.tab'.

You can read more about how to create observed wind climate files from raw data measurements elsewhere in the documentation.

The workspace should now look like this:

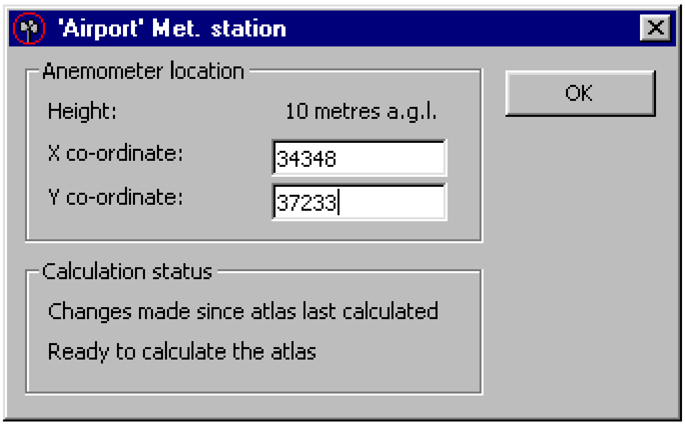
Proceed...

Describing the site

Now WAsP needs to know about the site where the data were collected. First, introduce a map as a child of the project. You should use the project's **Insert from file** method and select the file called 'Waspdale.map'. Now you need to locate the met. station in the map.

To locate the met. station:

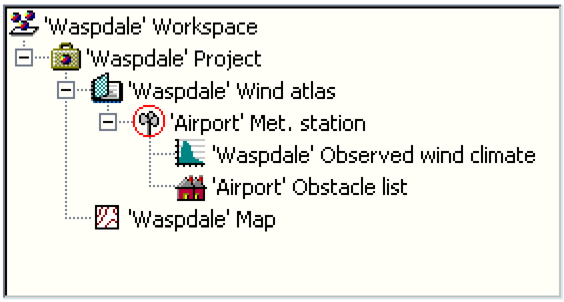
- From the met. station's right-click menu, select **Edit location**.
- When a dialog appears, set the location to (34348,37233).
- Press OK.



At the met. station site, several buildings and shelterbelts of trees were found in the vicinity of the anemometer mast. WAsP needs to know about these.

Insert a list describing the obstacles, use the **Insert from file** method of the met. station to add an **Obstacle list**. When the choose file dialog box appears, select the file 'Airport.obs'.

The workspace hierarchy should now look something like this:



Proceed...

The atlas calculation

WAsP is now ready to calculate the wind atlas for Waspdale, but before proceeding, pause to examine the members of the hierarchy which are contributing to the analysis. The map, the observed wind climate and the obstacle list all contain data and can be viewed. Each has a command called **View** on its right-click menu, which will open the window associated with the member. Open each one and have a look. To see where the met. station is in the map, select the **Highlight location in map** command from the met. station's right-click menu, or click on the little anemometer icon in the map's toolbar.

Now get WAsP to generate the wind atlas. From the met. station's right-click menu, select the **Calculate atlas** command. When the calculation is finished, the small red ring which surrounded the met. station icon has gone. This indicates that the calculations for the met. station are up to date.

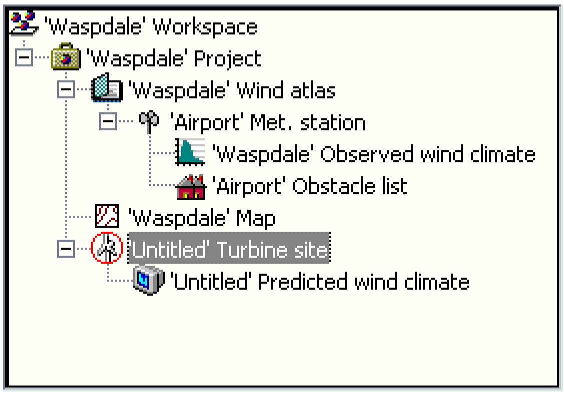
To see the results of the calculation, select the **View** command from the Wind atlas' right-click menu. The wind atlas is displayed. This is a site-independent characterization of the wind climate for the Waspdale area; you may also think of it as the *regional wind climate* of Waspdale.

Proceed...

Setting up a turbine site

Now that the project contains a wind atlas with site-independent wind climate data, we can apply those data to the proposed turbine site. WAsP will adjust the data for the situation found at the turbine site, and will produce a prediction of the wind climate for the site itself.

You need to add a turbine site hierarchy member to the workspace. Insert a new turbine site as a child of the project. The workspace now looks like this:



WAsP has automatically added a new hierarchy member called a predicted wind climate as a child of the turbine site. This member will be used to contain all of the predictions, which WAsP generates for the turbine site. It cannot be separated from its turbine site parent.

Save the workspace. You will be prompted to provide a name for the turbine site. Call it 'Hilltop', since the plan is to erect the turbine on a hill.

WAsP now requires:

- the location of the site in the map
- a description of the type of wind turbine that you propose to use.

There are no obstacles near the hilltop, so there is no need to add an obstacle list to this site.

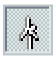
Proceed...

Locating the turbine site

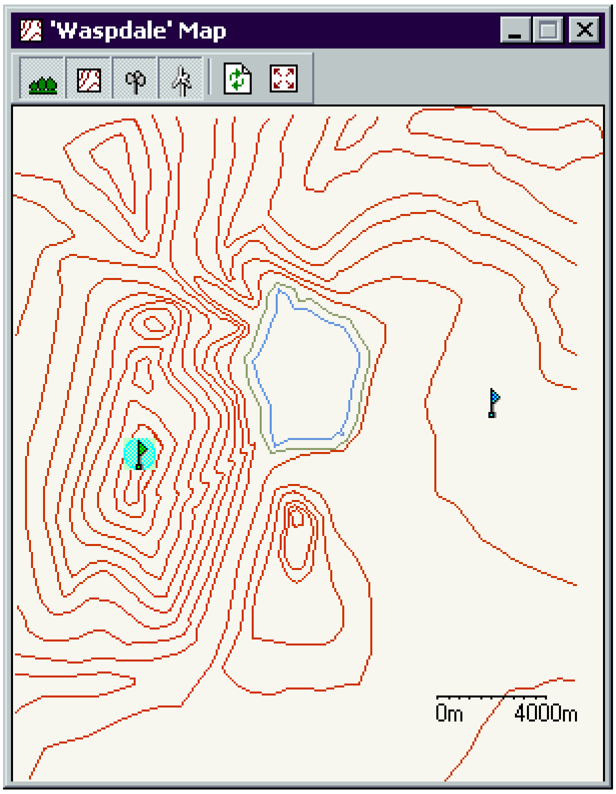
First, locate the turbine site in the map. Because the map and the turbine site are in the same project, WAsP automatically knows that the site lies in the area covered by the map. All that you need to do is provide the co-ordinates.

This could be done by following the same procedure as used for siting the met. station (type the co-ordinates into the site dialog box). However, since the location of the turbine site has not been exactly decided, we do not need to be so precise at this stage. We can use a different method.

From the turbine site's right-click menu, select **Locate in map**. The map window will appear, and the turbine site will be highlighted in the middle of the map area. If the turbine site disappears as you are working with it, check that the turbine site button in the toolbar is in the down position, like this:



It is now possible to drag the turbine site in the map to the location you want. Put it on top of the hill in the west of the area, like this:



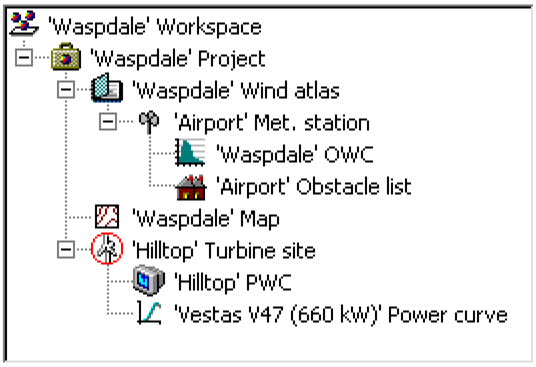
If you want to adjust the location of the site to an exactly specified position, then use the site dialog box, which can be reached at any time from the right-click menu of the turbine site icon in the workspace hierarchy. You can also call up the dialog box by right-clicking on the flag icon in the map.

Proceed...

Assigning the power curve

In order to predict how much power will be produced by the turbine, WAsP needs to know the power production characteristics of the turbine. You provide this information to WAsP by associating a power curve hierarchy member with the turbine site. From the turbine site's right-click menu, select **Insert from file**, and then choose 'Vestas V47 (660 kW).pow' when prompted.

The hierarchy should now look like this:



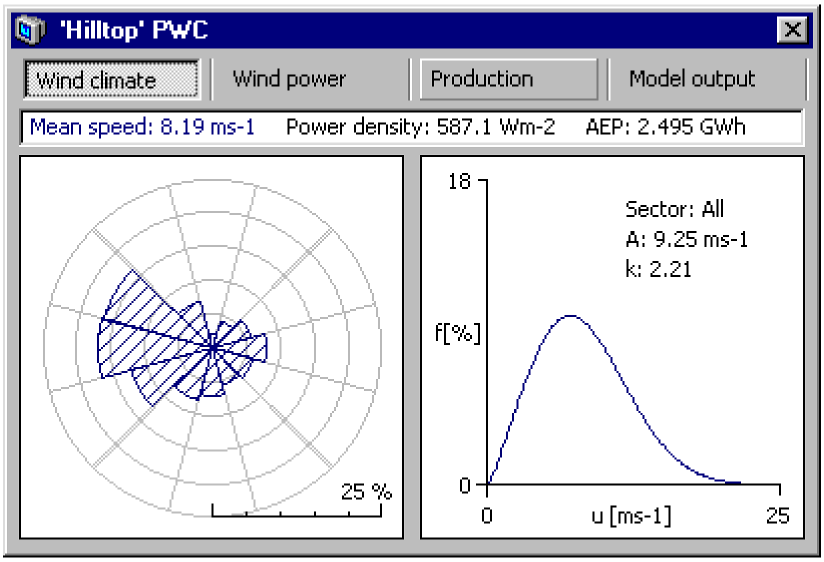
It is not yet possible to view the predicted wind climate, but you can open the power curve window and view the generating characteristics of the turbine.

Proceed...

Predicting the wind climate

WAsP is now ready to predict the wind climate for the turbine site. From the turbine site's right-click menu, select **Calculate wind climate**. As with the met. station, the small red ring surrounding the turbine site icon disappears as soon as the calculation is performed.

You can now open the predicted wind climate window to view the results:



The numbers shown above might differ slightly from those returned to you, because the location of the sites might not be exactly the same. WAsP has estimated that about 2.5 GWh per year would be generated by erecting a turbine on the hilltop. This number is referred to as the Annual Energy Production (AEP) in the predicted wind climate (PWC) window.

You can now return to the *Friends of Wind Energy, Waspdale Ltd.* and make your report!

Proceed...

There's a lot more to learn...

There's still a lot more to learn about the user interface of WAsP, but as you have seen, you don't need to know about that in order to get work done. For first-time WAsP users, it's important to understand more about what WAsP is actually doing behind the scenes. WAsP results are not useful unless the models' limitations are understood. Before using WAsP for any real world applications, it's important to study the material, which explains WAsP modelling in more detail.

The Modelling with WAsP book of this help facility offers brief explanations to many aspects of the wind atlas methodology. For more comprehensive descriptions you should consult the Risø readings on wind power meteorology, in particular the European Wind Atlas. Details on specific topics may also be found in the publications in the References section.

Some practical information for the novel WAsP user may be found in these related topics:

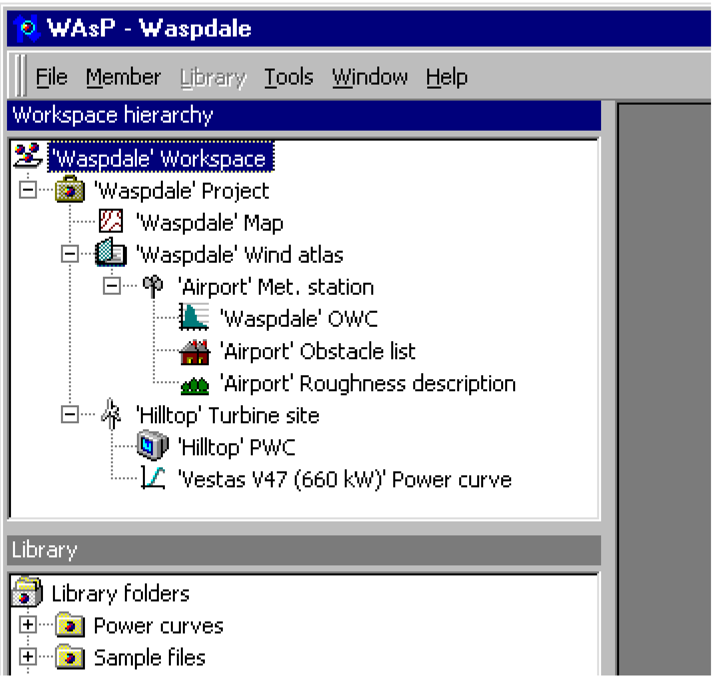
Sample data and workspaces

In addition to the sample data used for the Quick Start Tutorial, three sample workspaces are installed in the folder '\WAsP Workspaces\Samples' during the installation: 'WAsPdale', 'Wind farmer' and 'Resource grid'. You may **Open** any of these workspaces and study how typical WAsP applications are set up in the workspace hierarchy.

A collection of sample wind turbine power curves are installed in the folder '\Program Files\WAsP\Power curves'. These are also available directly from the WAsP Library.

Sample workspace #1: WAsPdale

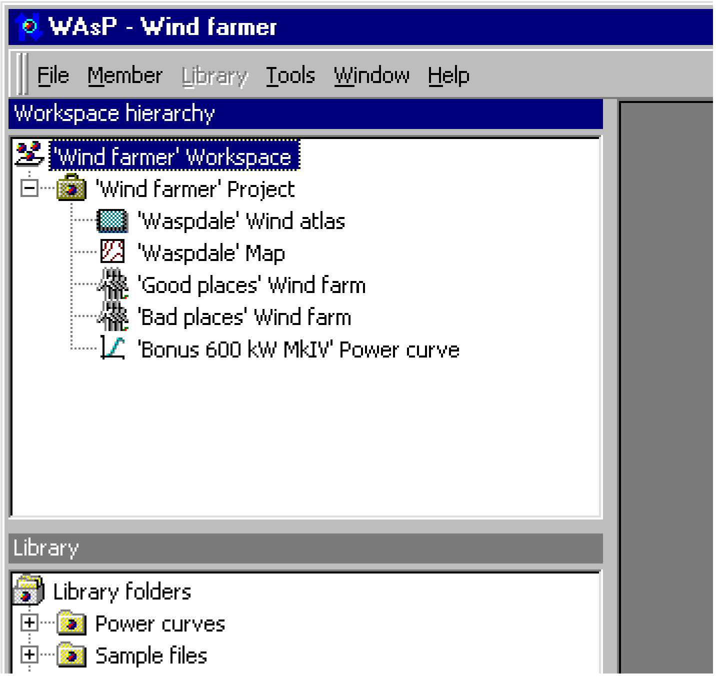
The 'WAsPdale' workspace is an example of the classic WAsP session: analysing the wind data from a met. station to obtain the regional wind climate (wind atlas) and then using the same wind atlas data set to predict the wind climate and power production at a nearby turbine site:



Note, that both the met. station and the turbine site are located in the same map; this is typical, but not necessary. The regional wind climate is assumed to be the same at both sites.

Sample wokspace #2: Wind farmer

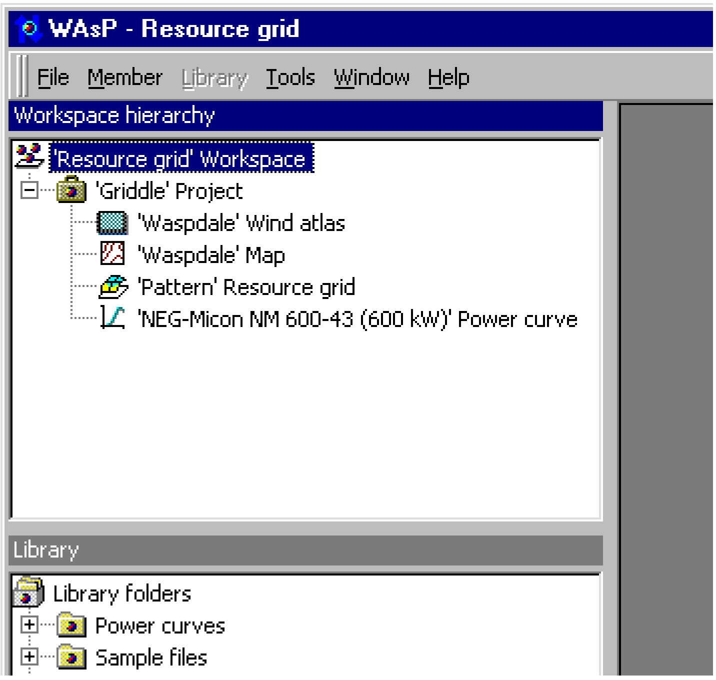
The 'Wind farmer' workspace is an example of another typical application: an existing wind atlas data set is used to predict the power production of several wind farms (or different layouts) in a given area:



Note, that the wind atlas, map and power curve are common to both wind farms.

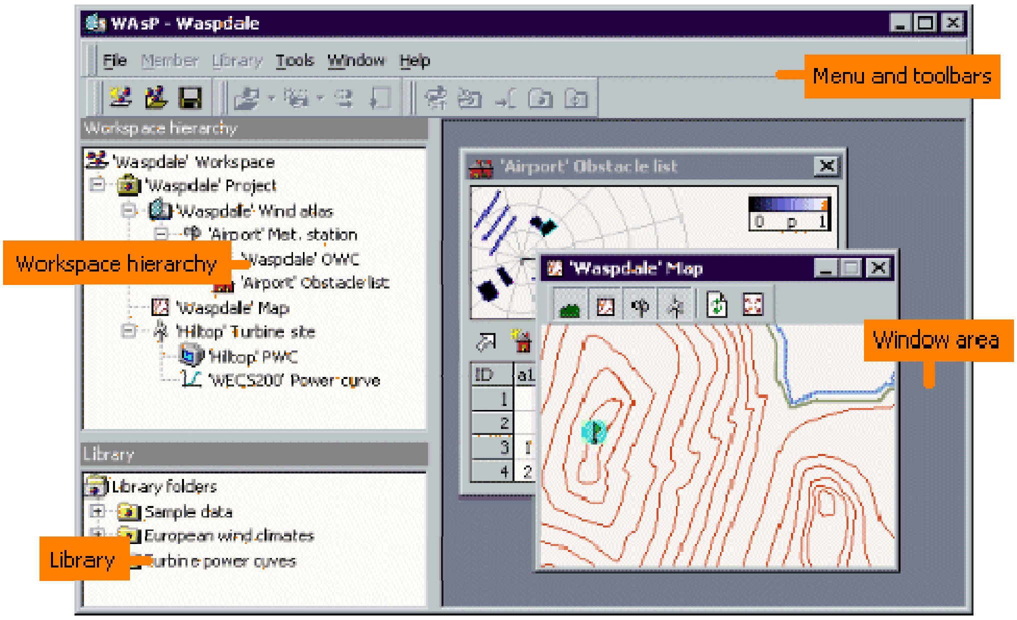
Sample workspace #3: Resource grid

The 'Resource grid' workspace is an example of how to investigate the variation in the wind resource over an area: an existing wind atlas data set is used to predict the wind climate and power production of several wind turbine sites in a given area:



Again, the wind atlas, map and power curve are common to all the modelled wind turbine sites. The turbine sites are arranged in a regular grid and the resource grid can be used to establish a wind speed or power production map of the area – suitable for micro-siting of the actual turbine sites in a wind farm.

Overview of the WAsP user interface



The main window of WAsP has four work areas.

At the top of the main window lies the application menu and toolbars. These can be moved to new positions.

On the left hand side of the main window are two panes: the workspace hierarchy pane and the library pane. These cannot be moved or closed, but they can be re-sized. The workspace hierarchy pane and the library pane are only visible when a workspace is currently open in WAsP.

The remaining space in the main window is the window area. This space is used to display windows, which can be opened, moved, resized and closed while working with the program.

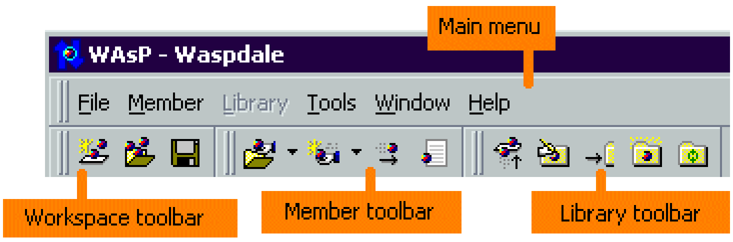
Use the right-hand mouse button!

Working with menus and the keyboard is not the quickest way to get things done in WAsP. Whatever you are doing, try clicking with the right-hand mouse button and see what happens. Often there is a handy context-sensitive pop-up menu, which will contain the very command you need.

So if you want to view a map, don't go to the main menu and look for a nested sub-menu called 'Display' with a massive list of all the things that could ever be done or displayed. Instead, click on the map's icon with the mouse and then hit the right-hand mouse button.

Menu and toolbars

WAsP has a main menu and three toolbars:



The main menu

The main menu contains the following sub-menus:

File. Lets you open, save and close workspaces.

Member. A context-sensitive menu, which lets you call the methods of the currently selected hierarchy member.

Library. A context-sensitive menu which lets you call perform operations on the library.

Tools. A list of launchable utility programs and some user options.

Window. A menu to help you manage the windows which are currently open.

Help. Information about WAsP.

The Member and Library sub-menus are sometimes disabled, depending on the what part of the program you are using.

The toolbars

Each toolbar contains buttons, which correspond to the most frequently-used items accessible from the sub-menus of the main menu.

Click on one of the items below to read more about using the toolbars.

- The workspace toolbar
- The member toolbar
- The library toolbar

The toolbars can be moved around or closed. WAsP will remember the way that you organise the toolbars between runs.

WAsP workspaces

In WAsP, all work is performed within the context of a workspace. Workspaces can be created, saved and re-opened. When you start WAsP, you need to re-open or create a workspace before you can do any work.

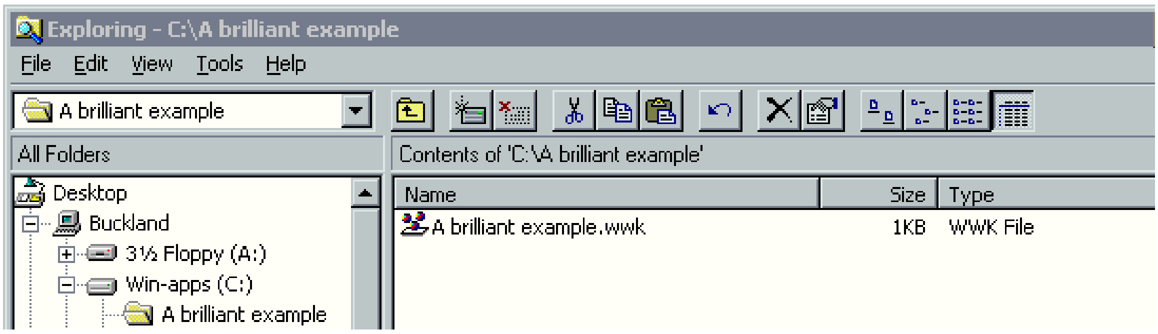
A workspace contains one or more projects and may contain members (data files) that are common to several projects or members that are not used in any project.

Workspace files and workspace folders

Workspaces are saved as files, which have the extension 'wwk'. Workspaces files do not contain any actual data of their own, but are used simply to record the relationships between other data files.

When a new WAsP workspace is first saved to file, it is saved into a newly-created folder with the same name as the workspace itself. This makes it easier to organise any newly-created files, which will be included in the workspace.

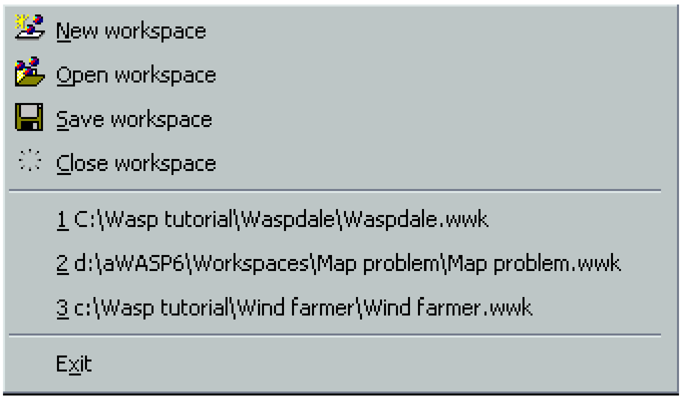
For example, if you create and save a new workspace called 'A brilliant example' at the root of drive 'C' on your computer, the resulting arrangement will look like this in Windows Explorer:



It's not possible to rename a workspace using a 'Save as...' operation. Once a workspace has been created, it can only be saved using the original name.

Working with workspaces

The **File** menu can be used to create, open, save and close workspaces:



The menu also includes a list of the most recently used workspaces.

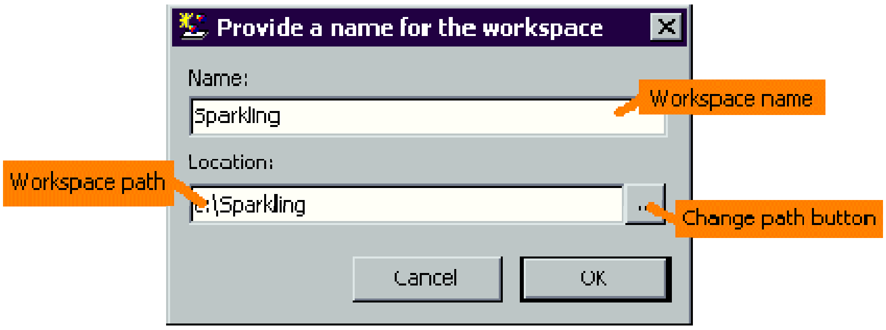
There is a workspace toolbar, which offers the main workspace functions:

Saving an existing workspace

Use **Save workspace** from the **File** menu. The workspace and all its contents will be saved to file.

Saving a newly-created workspace

The first time that a newly-created workspace is saved, it needs to be given a name. Because a new folder is created on the computer's file system to hold the new workspace file, a special dialog box is used.



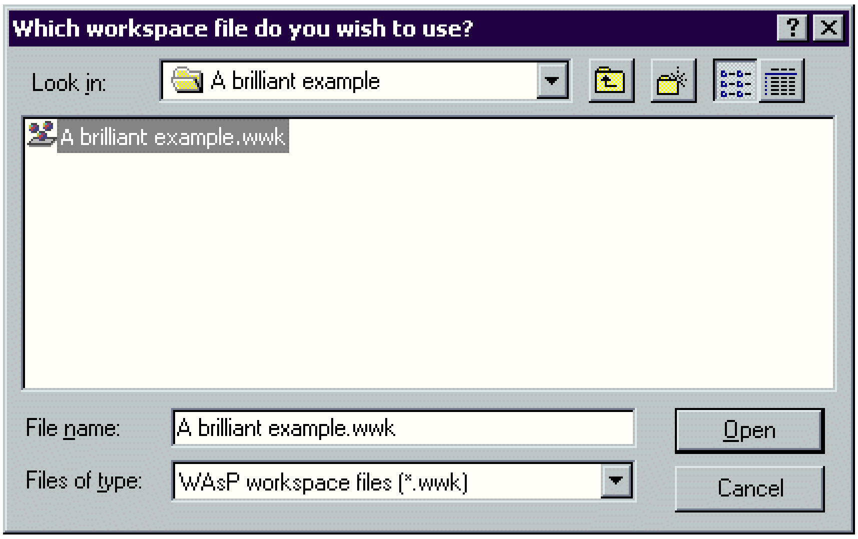
The name in the workspace name box automatically appears at the end of the location shown in the workspace path box because a new folder will be created to contain the new file.

First, check that the path is correct. You can change the path by clicking on the change path button and selecting a directory. In the example above, the root of drive 'C' has been selected as the location for the new workspace.

Next, provide a name for the workspace. The workspace location will be automatically synchronised with the name of the workspace. In the example above, a new folder called 'Sparkling' will be created in the root of drive 'C' and a new workspace file called 'Sparkling.wwk' will be inserted into the folder.

Opening an existing workspace

To open a workspace, simply use **Open workspace** from the **File** menu and select the workspace file (*.wwk) itself using the standard file dialog box. Remember that the workspace file will be found in a folder with the same name.

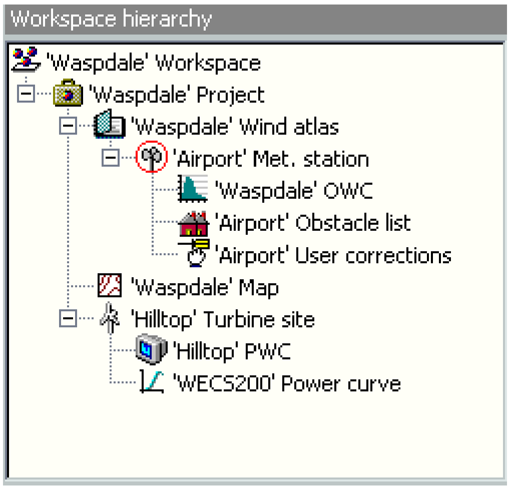


About the workspace hierarchy

When a workspace is open in WAsP, the contents of the workspace are organised into a hierarchy. The items in the hierarchy are called hierarchy members, or just members if the context is clear. The generic symbol for a hierarchy member is a small coloured ball .

The hierarchy is visually represented in a hierarchical tree, rather similar to the one used in Windows Explorer. Each member is represented by an icon and some text. The tree is called the workspace hierarchy, or just hierarchy if the context is clear.

Here's an example.



At the top of the hierarchy is the workspace root. Members can be parents and children of one another. Two members which share the same parent are called siblings, or peers. The workspace root cannot have a parent, but all other members always have a parent.

The organisation of the members in the hierarchy forms associations between the members. The members and their associations together represent a description of the situation, which is being modelled. Work in WAsP is done by adding, removing, moving and manipulating hierarchy members to change the modelled situation.

The hierarchy enforces rules governing the possible parent-child associations between different types of hierarchy member. Some types of member can never be children of some other types of member, and some types of member cannot have children at all.

Workspaces and projects

When working in Wasp, all significant modelling tasks should be done in a project, not a workspace. A project is a modelling environment. The workspace area is a scratch area, or a way of working with several projects at the same time. Workspaces are not designed to be portable between machines, but projects are especially designed with that in mind. If you want to share a project file with a colleague, or move it to another computer, then you should use the project's Export facility. This will create a new folder, copy all of the required data into that folder and all of the project's members will then point to files within the new folder. This folder can be copied, e-mailed, zipped or whatever, and then re-opening the project WPR file contained in that folder will open the project successfully on the other computer.

What is a hierarchy member?

Members and their files

The WAsP models need data files for input and output. Each hierarchy member represents a WAsP data file on the computer's file system. Members can be thought of as 'pointers' to files, and the hierarchy's purpose it to represent modelling relationships between the files. The organisation of members in the hierarchy is not related to the arrangement of their corresponding files on the computer's file system.

Members can be:

- inserted into the hierarchy as new
- inserted into the hierarchy from file
- saved to file
- saved to a file with a different name
- removed from the hierarchy

When WAsP works with hierarchy members, nothing is written to the members' original file contents until the changes are explicitly saved. This is because WAsP works with copies of the data files or, for some hierarchy members, simply holds all the information in memory.

When a member is removed from the hierarchy, the corresponding file is not deleted from the file system. If you move or delete a file referenced by a workspace between WAsP sessions, then it will be missing when you next open the workspace.

Different members, different rôles

Some members preserve information about the arrangement of their children. When these members are re-opened, they automatically re-open all of their children into the workspace too. The workspace root itself is one such member, so when a workspace is re-opened, all of the members which were in the workspace the last time it was saved will be re-opened and their relationships restored. Projects, met. stations and turbine sites also preserve information about their children between runs.

Other members are largely responsible for holding data, and do not preserve information about the organisation of the hierarchy. These hierarchy members have windows which can be opened in the right hand side of the main window, allowing their data to be viewed and, in some cases, manipulated.

Introducing the hierarchy members

There are several types of hierarchy member, which can appear in the workspace. The list below provides a brief introduction to them. They are explained in more detail elsewhere.

Workspace root

There is always one (and only one) root in each workspace. It sits at the top of the hierarchy and has no parent. The workspace root can have members of any type as its children. When a previously saved workspace is opened, all of the children of the workspace are also re-opened.

Project

Projects are used to manage related groups of hierarchy members. Projects offer several facilities, which make it easy to perform operations that are relevant to all of the members of the project. Projects are always children of the workspace root. When a previously saved project is opened, all of the children of the project are also re-opened, so entire projects can be saved and used in other workspaces.

Map

WAsP uses maps to get information about the orography and roughness characteristics of the landscape in which the modelling is being done. Maps can appear in various places in the workspace hierarchy, but typically each project will have one map.

, Wind atlas

Wind atlases are the central items in the hierarchy. A WAsP wind atlas contains data describing a site-independent characterisation of the wind climate for an area. The WAsP models are devoted to analysing wind data collected from met. stations to produce wind atlases and applying the atlas to estimate the wind climate (and power production) for turbine sites.

A wind atlas is illustrated using a closed book icon if the atlas is simply a static data file. An open book icon is used if the wind atlas is associated with a met. station which might re-calculate the atlas.

Met. station

A meteorological station (met. station for short) is used to calculate a wind atlas. It represents a data collection site located somewhere in an associated map. A met. station does not have any data except its location in the map. It is associated with a wind climate which has been observed at the station. It may be associated with a list of obstacles surrounding the station and a description of the roughness lengths of the surrounding area.

When a met. station is re-opened, all of the children of the met. station are also re-opened. This makes it possible to save a met. station and its associated child members as a complete branch of the hierarchy and re-use it in other workspaces or projects.

Observed wind climate

A summary of the wind data recorded at a met. station is called an observed wind climate (or OWC for short).

Turbine site

A turbine site is used to estimate the power production which would result from locating a turbine somewhere in an associated map. Every turbine site always has a predicted wind climate. A turbine site does not have any data except its location in the map and the hub height of the turbine. A turbine site may be associated with a list of obstacles surrounding the station and a description of the roughness lengths of the surrounding area.

When a turbine site is re-opened, all of the children of the turbine site are also re-opened. This makes it possible to save a turbine site and its associated child members as a complete branch of the hierarchy and re-use it in other workspaces or projects.

Predicted wind climate

A predicted wind climate contains output calculated by a turbine site. It corresponds to an observed wind climate in that it is a site-specific description of the wind climate, but also contains extra information about power density and annual energy production.

Wind farm

Wind farms are collections of 'lightweight' turbine sites which are calculated in a batch. The output is less detailed than a turbine site, and they are less flexible, but they offer a convenient way to work with several sites together.

Resource grid

Resource grids are also collections of 'light-weight' turbine sites calculated in a batch, but here the sites are arranged in a regular grid covering an area. The extension of the grid and the grid cell size may be chosen to map the wind climate or wind resource anywhere in the map – and with as much detail as is required.

Power curve

A power curve describes the way that a turbine's power output changes with wind speed. It can be associated with one or many turbine sites or wind farms.

Obstacle list

Met. stations and (less commonly) turbine sites can have obstacles in their surroundings. An obstacle list is a description of some sheltering obstacles which can be associated with a site.

Roughness description

An alternative to providing roughness information in a map is to provide a site-specific description. Turbine sites and met. stations can both be associated with roughness descriptions.

User corrections

A set of user corrections can be associated with a met. station or turbine site. It provides a way of informing WAsP about some site-specific adjustments which cannot be described using the other hierarchy members.

Modelling with the hierarchy members

WAsP modelling involves:

- analysing observed wind data to calculate wind atlases and
- applying wind atlases to particular turbine sites to calculate an estimate of the wind climate and power.

In the workspace hierarchy, these calculation jobs are performed by met. stations, turbine sites, wind farms and resource grids.

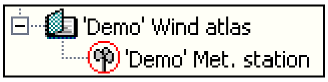
Met. stations are used to calculate wind atlases

A wind atlas is calculated by adjusting a summary of recorded wind data to remove the influencing effects of the collection site itself. To calculate a wind atlas, a met. station uses the following hierarchy members:

- an observed wind climate
- the map in which the met. station is located
- (optionally) a list of the obstacles surrounding the data collection site
- (optionally) a description of the surface roughness for the area surrounding the site
- (optionally) a set of user corrections to apply to the summary data

In summary, uses + + + + to produce

Met. stations are always children of the atlases which they are calculating, and so the output is 'moved up' the hierarchy into the parent atlas, thus:



Turbine sites are used to calculate predicted wind climates

A predicted wind climate is calculated by adjusting the data from a wind atlas for the influencing effects of the turbine site itself. To calculate a predicted wind climate, a turbine site uses the following hierarchy members:

- a wind atlas
- the map in which the turbine site is located
- (optionally) a power curve describing the turbine's generating characteristics
- (optionally) a list of the obstacles surrounding the turbine site
- (optionally) a description of the surface roughness for the area surrounding the site
- (optionally and rarely) a set of user corrections to apply to the wind atlas

If no power curve is used, then the output will be simply a predicted wind climate which describes wind directions, speed and energy.

In summary, uses + + + + to produce

Turbine sites are always parents of the predicted wind climates which they are calculating, and so the output is 'moved down' the hierarchy into the child predicted wind climate, thus:

Wind farms are used to calculate power production for several sites

Wind farms calculate summary wind climate data for each of several turbine sites by adjusting the data from a wind atlas for the influencing effects of the turbine sites itself. To calculate the summary data, a wind farm uses the following hierarchy members:

- a wind atlas
- the map in which the wind farm sites are located
- a power curve describing the generating characteristics of all of the turbines

In summary, uses + + to produce summary data displayed by

Resource grids are used to calculate power production for a grid of sites

Resource grids calculate summary wind climate data for each of several sites by adjusting the data from a wind atlas for the influencing effects of the sites itself. To calculate the summary data, a resource grid uses the following hierarchy members:

- a wind atlas
- the map in which the resource grid is located
- a power curve describing the generating characteristics for the resource grid

In summary, uses + + to produce summary data displayed by

Wind farms and resource grids appear less often in the help

It is obvious that (in terms of the hierarchy interactions) the wind farm and resource grid calculations are a simpler subset of the turbine site calculations. To simplify the documentation, they are often ignored when explaining general modelling issues. The explanations focus on the met. stations and the turbine sites. It's generally safe to assume that wind farms and resource grids can be treated as turbine sites which have no children in the hierarchy.

Patterns of association

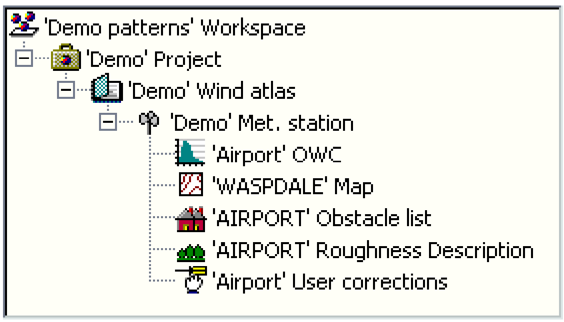
The organisation of the members in the hierarchy forms associations between the members.

The associations are only important to members that perform calculations: met. stations, turbine sites and wind farms. In order to perform their calculations, these members need to work out which other members to use. The calculating members seek to assemble a correct set of other members.

Simple associations

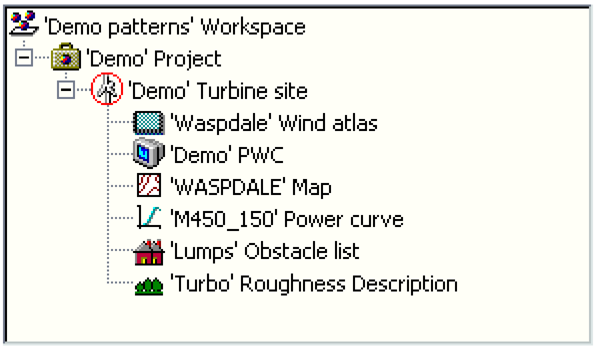
The simplest kind of association is the parent-child association. A calculating member can simply have all of the necessary members as its children.

For a met. station's calculation, the associated members could be organised thus:

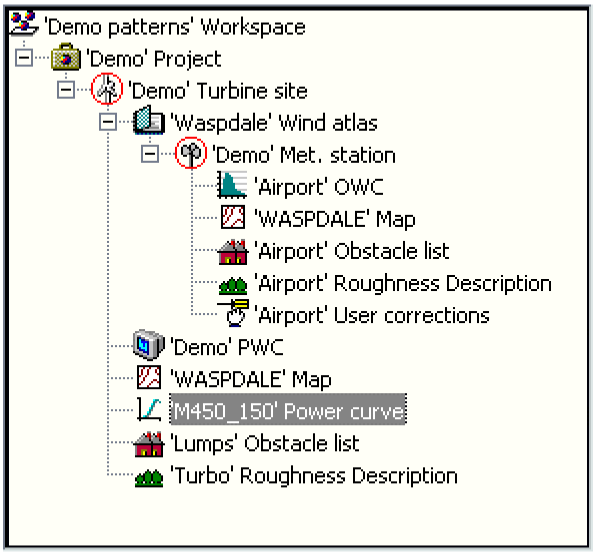


Note, that the met. station is a child of the wind atlas which it is calculating. This is always the case, since output from met. stations 'moves up' the hierarchy.

For a turbine site's calculations, the associated members could be organised thus:



Note, that the turbine site is a parent of the predicted wind climate which it is calculating. This is always the case, since output from turbine sites 'moves down' the hierarchy. Notice also that the wind atlas being used is just a static data file (the closed book icon is displayed). If the wind atlas was dynamically calculated from a turbine site, the workspace could look like this:

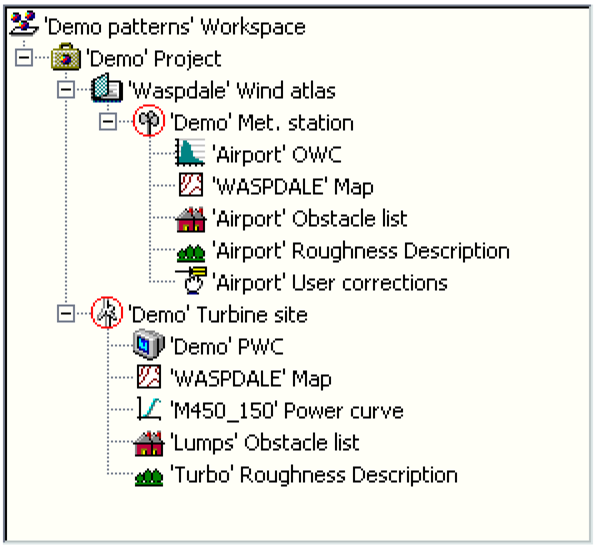


The arrangement illustrated above would work perfectly well, but it is rather inelegant. The same map appears twice in the project. If a new turbine site was added to the project, then the wind atlas would need to be added to that turbine site too. It's possible to take advantage of more complex associations to simplify the hierarchy and to make it easier to add new sites to the project.

More complex associations

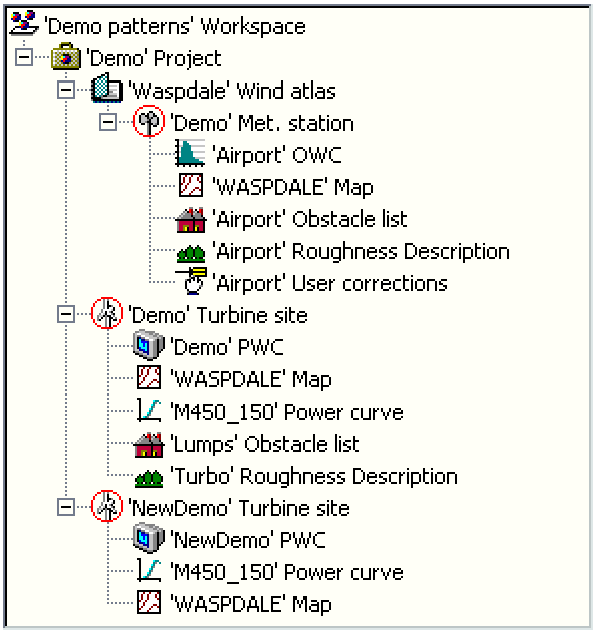
Members are associated if they have a parent-child association, but members can also explore further up the hierarchy in search of associations. Any ancestor (parent's parent, *etc.*) can be treated as associated, as can peers of any ancestor. This system allows a modelling situation with many relationships to be expressed concisely.

Working with the example given above, the hierarchy could be re-organised so that the wind atlas and the turbine site are peers, like this:

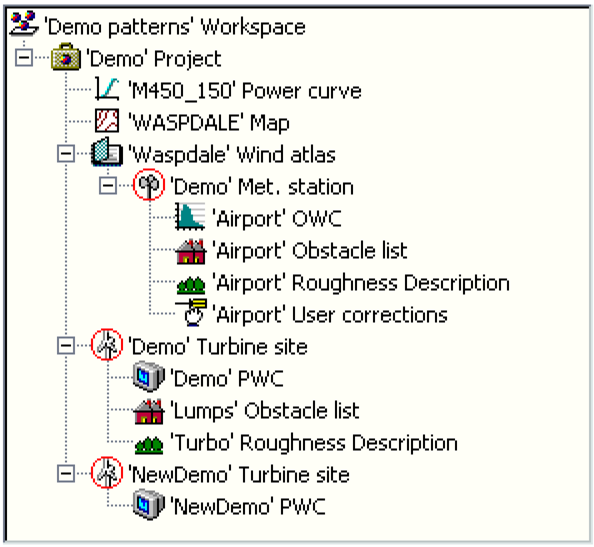


Modelling output is moving up the hierarchy because the met. station is writing results to the atlas, along the hierarchy because the atlas and the turbine site are peers, and down the hierarchy because the turbine site is writing results to the predicted wind climate, thus:

This pattern allows more turbine sites to be added to the project without needing to replicate the atlas, as follows:

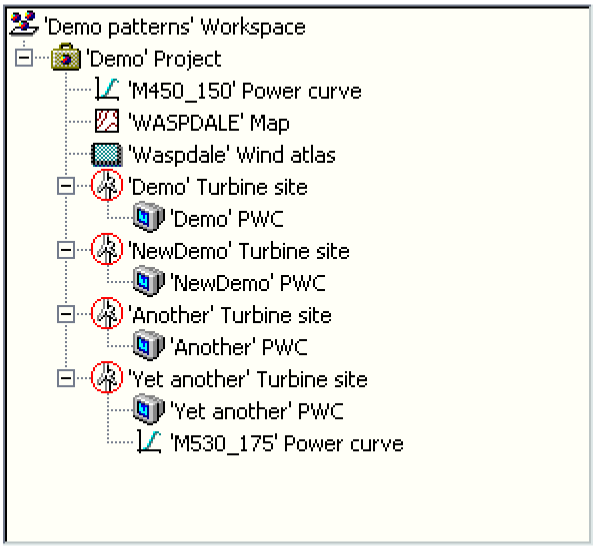


In the hierarchy illustrated above, the same map appears in three places. By making the map a peer of the turbine sites and wind atlas, it can be shared by the turbine sites and the met. station. The same power curve also appears twice. It, too, can be made a peer of the two turbine sites and can then be used by both of them, thus:



It is not possible for sites to share site-specific information, such as obstacle lists and observed wind climates which by definition are unique to the site itself.

If a member is associated with more than one member of the same type, then the nearest relative is the one used. This allows a group of peers to use the same member, but one or more of them can use a different member. For example, several turbine sites could be using the same power curve but one of them could use a different type, as shown in the hierarchy illustrated below:



The first three turbine sites will all use the 'M450_150' power curve, but the 'Yet another' turbine site will use the 'M350_175' power curve.

Legitimate parent-child associations

The table below specifies the how parent-child associations can be formed between different types of hierarchy members. There's no need to remember or refer to this table when using the software, because the hierarchy members themselves automatically enforce these rules.

Object type	Valid parents	Valid children (and number)
Workspace root	None	Any (0..n)

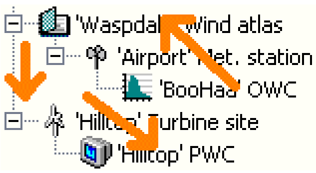
Project	Workspace	Atlas (0..n) Wind farm (0..n) Resource grid (0..n) Turbine site (0..n) Map (0..1) Atlas (0..1) Power curve (0..1)
Wind farm	Workspace Project	Map (0..1) Atlas (0..1) Power curve (0..1)
Resource grid	Workspace Project	Turbine site (0..n) Map (0..1) Atlas (0..1) Power curve (0..1)
Turbine site	Workspace Project Wind farm	Predicted wind climate (1) Roughness description (0..1) Obstacle list (0..1) User corrections (0..1) Map (0..1) Atlas (0..1) Power curve (0..1)
Map	Workspace Project Wind farm Resource grid Turbine site Met. station	None
Atlas	Workspace Project Wind farm Resource grid Turbine site	Met. station (0..1)
Met. station	Workspace Atlas	Observed wind climate (0..1) Roughness description (0..1) Obstacle list (0..1) User corrections (0..1) Map (0..1)
Observed wind climate	Workspace Met. station	None
Predicted wind climate	Workspace Turbine site	None

User corrections	Workspace Turbine site Met. station	None
Roughness description	Workspace Turbine site Met. station	None
Obstacle list	Workspace Turbine site Met. station	None
Power curve	Workspace Project Wind farm Resource grid Turbine site	None

Associated members have the same number of sectors

The WAsP models represent the world in sectors. The number of sectors used for modelling is not fixed but data structured with 8 sectors is of course incompatible data structured with 12 sectors. So, all associated hierarchy members which are being used together for modelling must have the same number of sectors.

The number of sectors used is determined by the structure of the observed wind climate, since this feeds directly into the wind atlas and then on through the turbine sites to determine the structure of the predicted wind climates.



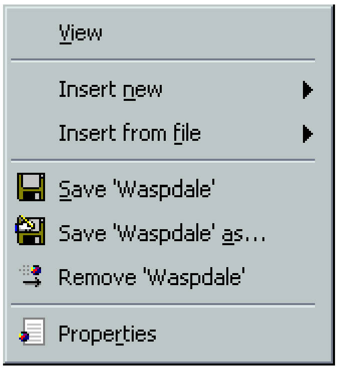
The number of sectors in an observed wind climate is determined when it is first generated from raw data using the OWC Wizard.

Hierarchy members' methods

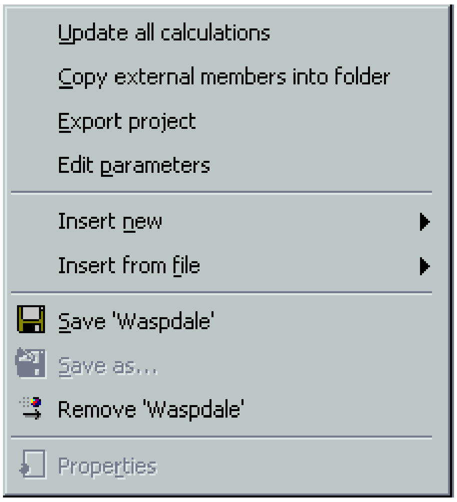
The member's menus

Each hierarchy member has menu of commands, or methods. This menu is headed **'Member'** and appears as a sub-menu of the main menu. It further appears as a pop-up menu if a member is clicked with the right mouse button, or when the **F2** key is pressed while one of the hierarchy members is selected.

This menu is the most important tool for working with WAsP. Depending on which hierarchy member is selected, the contents of the menu presented will be different. Some members do not offer all of these methods, and some offer extra methods in addition to those shown. The illustration below shows a basic member's menu (for a wind atlas) and a more complex one (for a project).



Wind atlas member's menu



Project member's menu

The members' toolbar

There is also a hierarchy member toolbar which offers buttons for some of the most common hierarchy member methods:

The buttons (from left to right) correspond to the menu items **Insert from file**, **Insert new**, **Remove** and **Properties**.

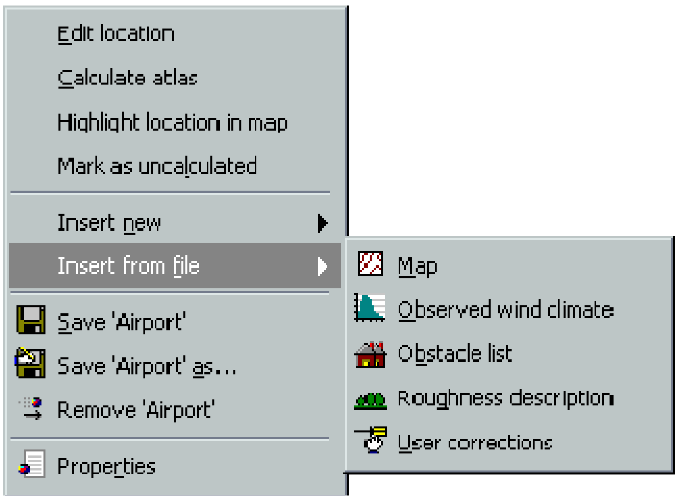
Viewing a member's interface window

Any member which has its own user interface window will have a method called **V**iew at the top of its menu. Clicking this will bring up the window in the window area on the right-hand side of the main window. It's possible to have several windows open at once and to leave them open while doing other work.

Inserting members

To insert a member to the workspace hierarchy

- Select the hierarchy member which will be the parent of the member to be inserted
- From the parent member's menu, select either **Insert from file** or **Insert new**. A secondary menu will appear, listing the types of hierarchy member which are legitimate children of the parent member. The 'from file' insertion menu looks like this (for a met. station).



- Select the type of member to insert. If the **Insert from file** menu was used, then a file selection dialog box will appear. Select the file you wish to use to create the hierarchy

member. If the **Insert new** menu was used, then the new member will be created immediately.
- The new member will be added to the hierarchy as a child of the parent member.

The member-specific insertion menus

Depending on the type of parent member, the insertion sub-menus will contain different types of insertable member. Some members cannot be inserted as new members, and can only be inserted from file, so sometimes the **Insert from file** or **Insert new** sub-menus contain different lists.

User corrections and maps cannot be created or edited from within the WAsP application, so these types of member never appear on the **Insert new** sub-menu.

Although WAsP cannot create and edit observed wind climates directly, observed wind climates do appear on the 'insert new' menu for met. stations. When an observed wind climate hierarchy member is inserted as new, the OWC Wizard is automatically launched to guide you through the process of creating a new observed wind climate file.

Inserting from the member methods toolbar

Clicking on one of the two insertion buttons on the member methods toolbar also causes the a list of insertable member types to be displayed as a drop-down list.

Inserting from the library

An alternative way to insert members from file is to open them from the library.

Moving members

Moving members from one place in the hierarchy to another is a simple matter of dragging with the mouse.

As the dragged hierarchy member is moved over potential 'target' parent members, the mouse pointer changes. If it would be impossible for the dragged member to be a child of the target, a 'no drop' icon is displayed, otherwise, the mouse pointer is the same as the hierarchy member being dragged.

This is what the 'no-drop' icon looks like.

If a member is dropped onto a parent which cannot accept it, a message is displayed and the move operation is not completed.

It is not possible to copy members by dragging them around the workspace: members can only be inserted, moved and removed.

Removing members

To remove a member from the hierarchy, simply select it and from its hierarchy member menu, choose **Remove**.

If the member has unsaved changes, you will be asked whether you wish to save the changes before removing the member.

Removing a member from the workspace hierarchy does not cause the corresponding file to be deleted from the file system.

Saving members

All hierarchy members can be saved. If the member has children, then all the children (and the children's children) as also saved at the same time. So, when the workspace root is saved, every member in the whole workspace is saved.

Simple save

To save a member's data, simply select it and from its hierarchy member menu, choose **Save**. If the member has not been saved before, you will be asked to provide a name for the file.

Save as...

If the file has been saved before and you wish to save it with a new name, you can use the **Save as** method. You will be asked to provide a new name for the file. This method is not available for workspaces and projects.

The old file will not be deleted from the file system, but remember that if you make changes to or delete other members which are referenced by the old file, then WAsP may be unable to re-open the old file again successfully.

What happens when a member is saved?

For members whose files contain mostly data (like an obstacle list), the original source file is replaced with the working copy that WAsP has been using since the member was last saved.

For members whose files mostly contain information about the organisation of other members in the hierarchy (such as project files), the original file is overwritten with data describing the current arrangement of members in the hierarchy. When those members are re-opened in the hierarchy, their children will also be re-opened, so inserting a met. station member from file might also insert an obstacle list and an observed wind climate.

Members' properties

Many hierarchy members have a **Properties** method.

If this method is invoked, a dialog is displayed which shows some of the properties of the member, particularly relating to how it relates to the underlying file system. Here is an example for a wind atlas hierarchy member.

There's no information here which you actually need in order to do WAsP modelling, but it can sometimes be useful if the relationship between the hierarchy member and the files on the system is confused.

If the name of the saving file name or the working temporary file name is longer than can be displayed in the label provided, then the whole name will appear as a pop-up 'tip' if the mouse pointer is allowed to linger over the label for a moment.

Refreshing the workspace hierarchy display

If a problem is encountered, then it's possible to force WAsP to refresh the workspace hierarchy display. To do this, select the workspace hierarchy and press the **F5** key on the keyboard. Alternatively, select the **Refresh view** method of the workspace root hierarchy member.

Function keys

A few keyboard function keys and key combinations are recognised by WAsP:

F1 invokes context-sensitive help for the active window.

F2 invokes and displays the members' methods menu.

F5 refreshes the workspace hierarchy and library displays.

F11 is equivalent to **Ctrl-C** and copies the contents of the active window to the Windows clipboard.

Other keys and key combinations

Del pressing this key deletes the highlighted item.

Space bar pressing this key scrolls the selection of a highlighted item, e.g. through the sectors in the OWC or PWC displays.

Ctrl-C copies the contents of the active window to the Windows clipboard.

About the workspace root

The workspace root has no modelling role in WAsP. It simply represents the workspace itself in the workspace hierarchy display. The workspace has no data and simply maintains a list of its children.

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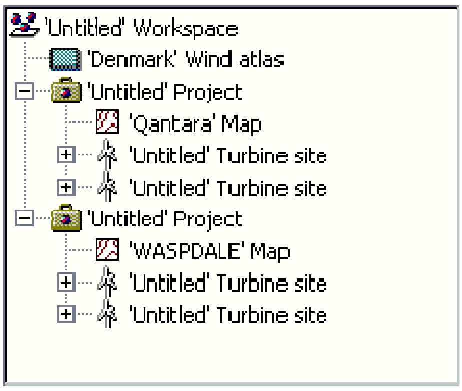
Children of the workspace root

Usually, the workspace root is a parent of one or more projects (within which modelling work can be done), but the root can also be a parent of any other type of hierarchy member. What is more, it can have any number of any type of children. The rules about member's associations are completely relaxed for the workspace root. This makes it possible to use the workspace root as a 'scratch' area in which to hold hierarchy members when they are not being used in modelling work.

Very occasionally, it might be useful to involve the workspace root's children in modelling. If there is a member which for some reason needs to be shared between several projects, then placing it as a child of the workspace root means that it will be available for any calculations performed in any project. For example, a workspace could contain several projects, each with a different map and several turbine sites. It could be convenient to have all of the projects use the same wind atlas, in which case the wind atlas could be made a peer of all the projects, as shown below.



This might indeed be the best arrangement, but projects have some extra facilities not offered by workspaces and in consequence it's often best simply to include all of the members involved in a piece of modelling work within projects.

About projects

Projects provide a structure to work with related hierarchy members. Projects are used to contain any modelling work which describes the same place or the same basic situation. As a general guide, a project should be used to group together things which would all be described in the same report.

Unlike workspaces, which can have jumbled collections of unrelated child hierarchy members, hierarchy members organised into projects must be arranged according to the rules governing parent-child associations. All of the children of a project share the same model parameter values. Projects also offer useful methods for performing operations on all of the project's children and managing their files.

Like workspaces, project files do not contain any actual data of their own, but are used simply to record the relationships between other data files.

About projects

Projects provide a structure to work with related hierarchy members. Projects are used to contain any modelling work which describes the same place or the same basic situation. As a general guide, a project should be used to group together things which would all be described in the same report.

Unlike workspaces, which can have jumbled collections of unrelated child hierarchy members, hierarchy members organised into projects must be arranged according to the rules governing parent-child associations. All of the children of a project share the same model parameter values. Projects also offer useful methods for performing operations on all of the project's children and managing their files.

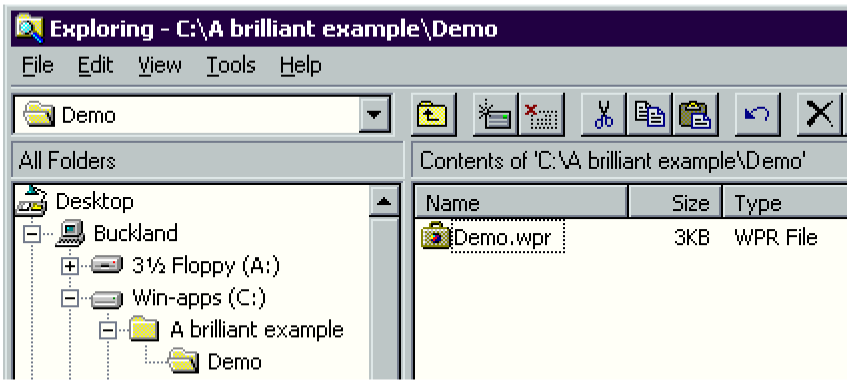
Like workspaces, project files do not contain any actual data of their own, but are used simply to record the relationships between other data files.

Project files and project folders

Projects are saved as files, which have the extension 'wpr'. Projects files are used to record the relationships between other data files and to preserve the values of modelling parameters. They contain no other data and simply 'point to' other files on the file system.

When a new WAsP project is first saved to file, it is saved into a newly-created folder with the same name as the project itself. This makes it easier to organise any newly-created files which will be included in the project. The idea is the same as for workspaces, so that if you create a new workspace, insert a new project and save them both, two new folders will be created on the computer's file system. The project's folder will be a sub-folder of the workspace.

For example, if you create and save a new workspace called 'A brilliant example' at the root of drive 'C' on your computer, add a new project to the workspace and save it as 'Demo', the resulting arrangement will look like this in Windows Explorer:



Although the project's folder is located as a sub-folder of the workspace's folder, the project is entirely independent of the workspace. The project can be opened into other workspaces, or moved around on the file system. You can even merge the contents of the project and workspace folders.

The workspace does, of course, have a pointer to the project, so moving or deleting the project from the file system will make it impossible for it to be automatically re-opened in the workspace. This dependency is one-way: the project has no pointer to its parent workspace.

It is not possible to rename a project using a 'Save as...' operation, but WAsP does provide a project export method to help you copy and share projects.

Updating all calculations in a project

It's possible for a project to contain a large number of turbine sites and (in rare cases) quite a few met. stations. If a simple change is made to some aspect of the project (such as editing a parameter value or adjusting a shared map), then all of the output from all of the sites should be re-calculated.

To make this easier, each project's method list contains a method called **Update all calculations**. This method can be invoked whenever there is at least one member of the project which can be calculated. The project simply works through all of those members and prompts them to be recalculated automatically.

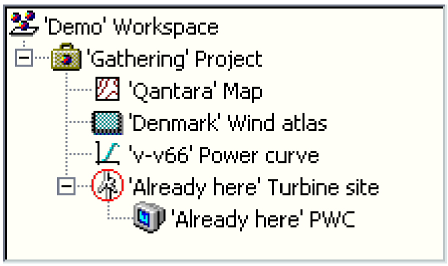
Because modelling output flows from met. stations, through wind atlases and on to turbine sites, the project first makes all of the met. stations recalculate their wind atlases, and then works through again, dealing with the turbine sites.

Gathering project members' files

A project file, like a workspace file, contains only pointers to other files, not a copy of the data in those files. It's possible, therefore, that the members gathered into a project have files scattered all over the file system. That's fine, and is often a convenient way to work, but sometimes it is useful to be able to gather all of those scattered files into one place. It can get a bit confusing...

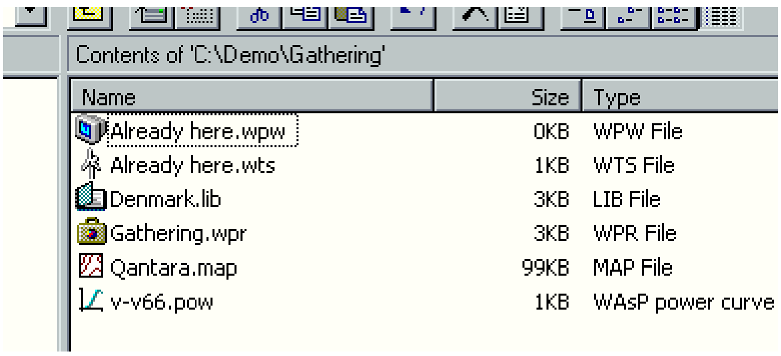
Projects' method lists include a method called **Copy external members into folder**, which does exactly what it says. Each project has its own folder in which the project file is saved. This method works through all of the members of a project and places a copy of each member's file into the project's own folder. The original files are not moved, but copies are made. The pointers in the project's file are changed to point to the files which are now to be found in the same folder.

For example, the illustration below shows a project which has just been assembled. The map, atlas and power curve have all been opened from file from existing folders elsewhere on the file system. Only the turbine site and its ever-faithful friend the predicted wind climate are newly-created members.



The project's folder on the file system looks like this (in Windows Explorer):

After invoking the **Copy external members into folder** method on the 'Gathering' project, the file system view looks like this:



Exporting complete projects

Project files preserve a list of pointers to the files of the members contained in the project. The files can actually be scattered around all over the computer file system. This makes it difficult to take a copy of everything in a project for back up, or to share files between computers or people.

Projects' method lists include a method called **Export project** to make it easier. Using this method is a bit like using a **Save as**... method on a normal file. You need to provide a name for a new project, just as if you were saving a project for the first time. However, instead of simply creating a new folder and making a copy of the project file, the method also makes copies of all of the files referenced by the project and placed these copies into the new folder too. The pointers in the new project's file are changed to point to the copied files which are now in the new project folder.

These pointers are now simple relative file names, not absolute path file names. That's to say that they no longer contain information about the path on the computer's file system, but just contain the names of the files. That means that the project can be read on any computer, regardless of its file system configuration.

About project parameters

The behaviour of the WAsP models can be adjusted by making alterations to model parameters. The parameters are used whenever a calculation is performed, such as when a met. station calculates a wind atlas.

A unique parameter set is associated with each WAsP project. All members which are children of the project will make use of the same parameters. It's possible to have a workspace which contains two projects (say, for example, one from Iran and another from Europe) and for the calculations performed within each project to use completely different parameter values.

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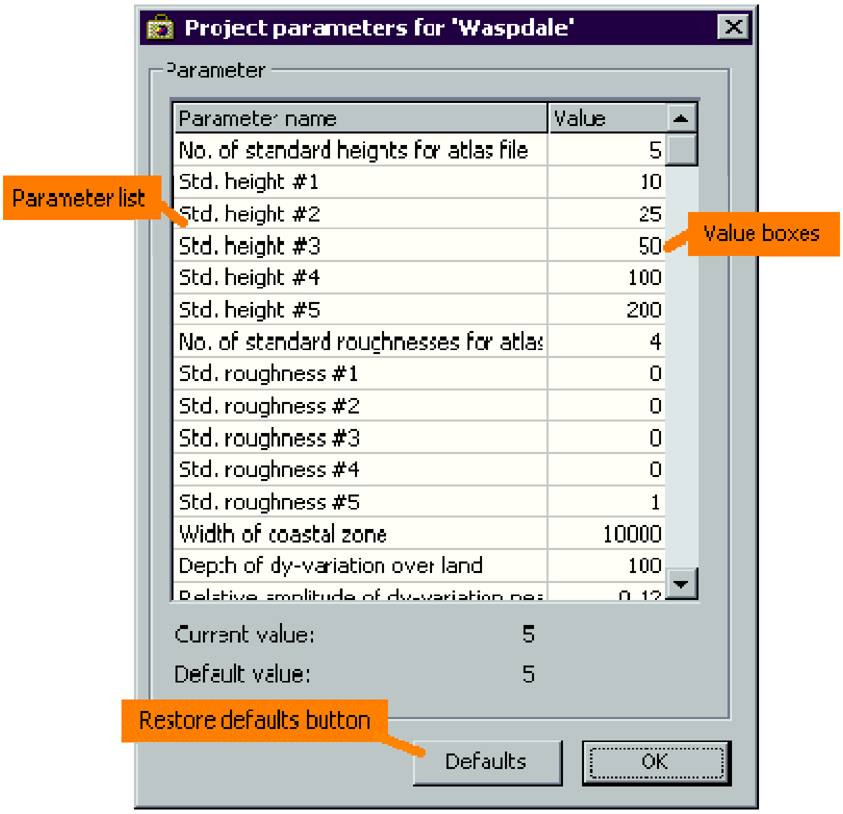
Editing project parameters

To edit a project's parameters, select the **Edit parameters** method from the project's methods. The parameter editor dialog box will appear.



To change a parameter value, select the parameter from the list and either double-click on it, or press the **Enter** key. A small box will appear, allowing you to enter a new value.

Do not edit a parameter without first checking that you understand what it means, and reading the documentation describing the values which can be legitimately used. If an invalid value is submitted, it will be rejected but the message which appears might not be very helpful. WAsP will try to restore the previous or default value.

To restore all of the parameters to their default values, click on the restore defaults button.

About wind atlases

Wind atlases contain the site-independent or regional wind climate, derived from the wind measurements at a meteorological station through the wind atlas analysis. The observed wind climate has thereby been reduced to certain standard conditions, i.e. wind roses and wind speed distributions for five standard heights and four roughness classes in a number of sectors (usually 12).

To calculate a wind atlas, use a met. station hierarchy member. The format of the corresponding wind atlas file is described in the Technical Reference section.

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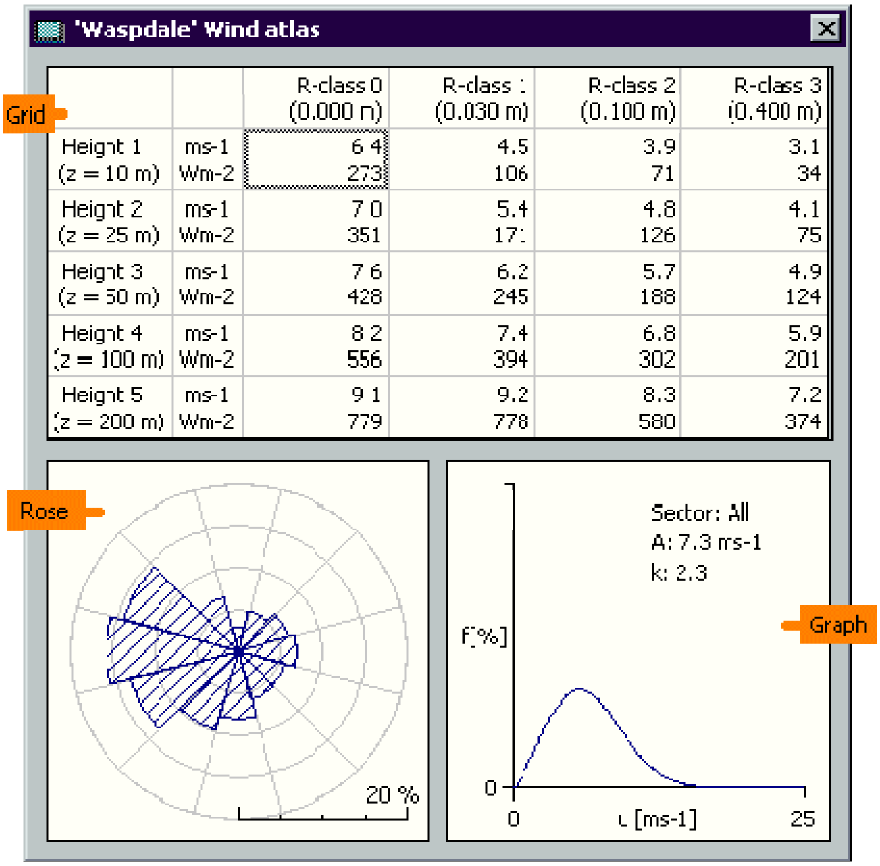
The wind atlas window

The wind atlas window provides a graphical representation of the data in the wind atlas. There are more data contained in an atlas than can be displayed at one time in the window, but it is possible to see all of the data by interacting with the atlas display.



The window has three data display areas: the grid, the rose and the graph.

The grid shows the mean wind speed and mean power density of the wind for the different roughness lengths and standard heights. The rose displays the sector-wise frequencies of wind direction. The graph shows the frequency distribution of wind speeds, and the Weibull-*A* and Weibull-*k* parameters for the sector.

For each combination of a roughness length and a standard height, there is a wind rose. For each sector in each rose, there is a wind speed distribution graph.

To display the rose for a particular combination of roughness length and standard height, click on the corresponding cell in the grid. It is also possible to navigate around in the grid using the direction keys on the keyboard.

To read numbers from the rose, allow the mouse pointer to linger for a moment over one of the sectors. A label will appear, giving the directional frequency for that sector.

When first displayed, the graph shows the curve for all sectors (non-directional). To display the graph for one sector only, click with the mouse on one of the sectors in the rose. The rose sector will be highlighted and the graph will be adjusted to display the data for that sector. Hitting the spacebar on the keyboard will move the selection around the rose. To return to the non-directional display, click on the rose anywhere outside the area marked with rings.

To read off a particular value from the graph, move the mouse pointer over the graph area. A 'read-off' line will appear, labelled with the precise frequency for the wind speed.

Exporting output

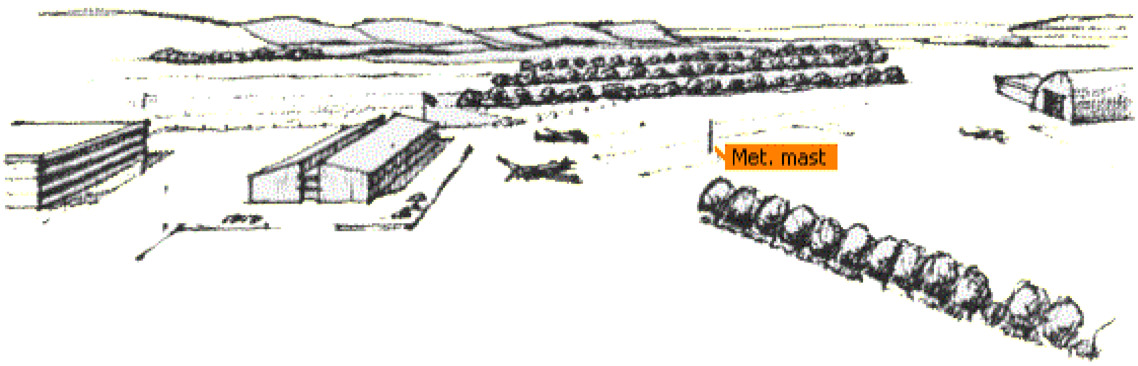
It is not possible to print the wind atlas contents directly, but the rose and graph graphics and the grid's contents can be copied to the Windows system clipboard. They can then be pasted into other Windows applications and printed.

To copy the rose or graph, click on one with the mouse and then use **Ctrl-C** or press the **F11** key on the keyboard. To copy the grid contents, click on the grid and then press the **F11** key on the keyboard.

About met. stations

Meteorological stations (met. stations) are used to calculate wind atlases. A met. station has no data of its own except the co-ordinates of its location in the map and a list of its children.

The illustration below shows the area surrounding the met. mast at the imaginary 'Waspdale' airport. It's clear that the data collected at the mast will be influenced by the buildings, hills and trees. Fortunately, such influences are systematic and (thanks to WAsP) predictable.



Met. stations calculate a wind atlas by adjusting the data found in an observed wind climate to remove the influencing effects of the collection site itself. The site effects are represented by a map, and (optionally) by an obstacle list, a site-specific roughness description and some user corrections to the wind data collection.

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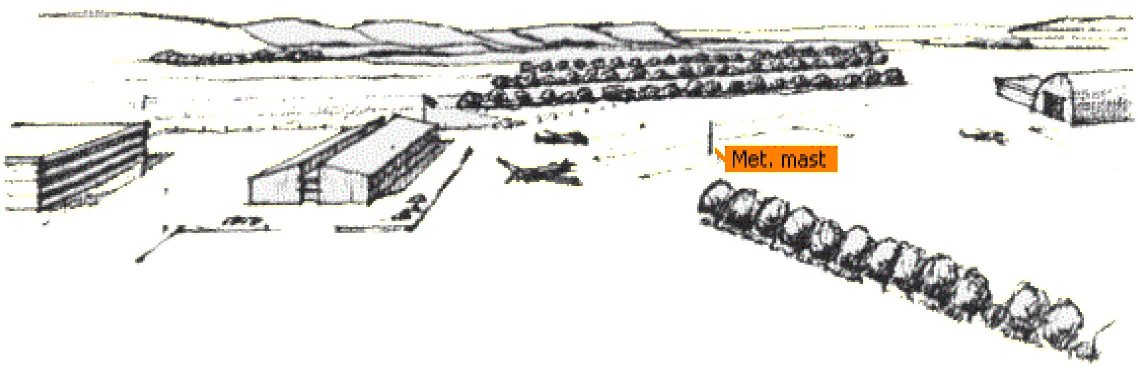

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Calculation status

Four types of hierarchy member can perform calculations: met. stations, turbine sites, resource grids and wind farms. These calculating members are sensitive to changes in the hierarchy which affect them. They also search up and down the hierarchy to look for the other members with which they collaborate to do modelling work.

Ready to calculate?

Calculating members have a method called **Calculate** which is only available if the hierarchy is correctly set up to allow the calculation to proceed. If a calculating member is not ready to be calculated, then a different method is available, called **Explain why cannot be calculated**. If this method is invoked, then a brief explanation of what more needs to be done is presented.

Detection of changes in influencing information

If a calculating member detects a change to an associated influencing member or to the arrangement of its associated influencing members, then it 'realises' that the results data ought to be recalculated to reflect the new situation being modelled in the hierarchy.

When this happens, the calculating member's icon changes to display a red ring marker . When calculating members are recalculated, their icon returns to normal.

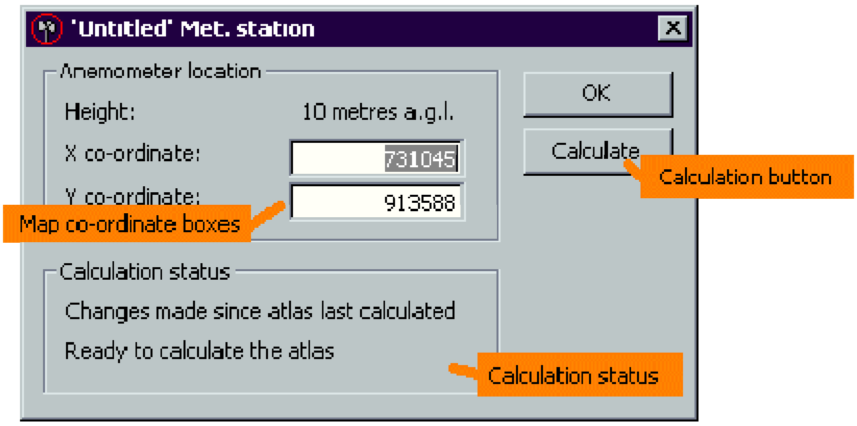
Overriding change detection

It's possible to tell a calculating member whether its wind atlas is due for recalculation. If the member 'thinks' that it ought to do a recalculation, then it has a method called **Mark as calculated** which will override its status. Conversely, if it thinks that it is up-to-date, then a method called **Mark as uncalculated** is available.

The met. station control dialog

The met. station has a control dialog which can be used to specify the precise co-ordinates of the met. station in an associated map and to force a re-calculation of the associated wind atlas.

The dialog is displayed if a met. station's **Edit location** method is invoked, or if the met. station's icon in the map is clicked with the right-hand mouse button.



Editing the met. station co-ordinates

The *x* and *y* co-ordinates of the met. station can be typed in, allowing more precise positioning than by dragging in the map.

The calculation button is not visible if the met. station is not ready to perform a calculation. The calculation status display shows information which can be deduced.

Met. stations in the map window

If a met. station is associated with a map hierarchy member, and has valid co-ordinates, then it can be displayed in the map, where it is indicated by an icon marker.

Hide or show the locations of met. stations in the map display by clicking on the toolbar button marked with the met. station icon.

To select and identify a met. station, click on the marker in the map with the left mouse button. The name of the site and the exact ground co-ordinates are shown in a pop-up label.

Dragging the met. station into position on the map

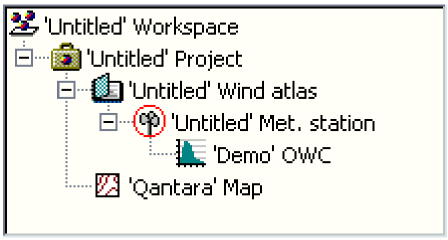
To display the met. station in the map, select the met. station's **Highlight location in map** method. If the map is not showing, it will be opened. The met. station's icon will be highlighted. If the met. station has never been located in the map, the select the method called **Locate in map**. The map window is opened and the met. station is automatically positioned at the centre of the mapped area.

It's now possible to change the location of the met. station by dragging it in the map using the left-hand mouse button. A label appears giving the exact co-ordinates as you drag the met. station. Depending on the zoom level, it might be difficult to position the met. station precisely. If this is a problem, simply right-click on the icon in the map and the met. station control dialog will appear, allowing you to edit the co-ordinates.

Preparing to calculate an atlas

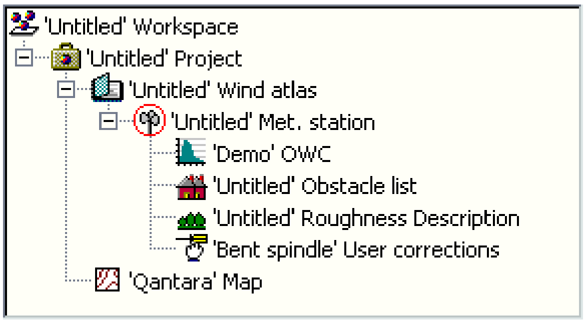
To calculate a wind atlas, a met. station must:

- Have a wind atlas hierarchy member as its parent
- Be located in an associated map
- Have an observed wind climate as one of its children
- Be a member of a project



Optionally, a met. station can:

- Have an obstacle list as one of its children
- Have a roughness description as one of its children
- Have a set of user corrections as one of its children



Starting from scratch, here's how to prepare to calculate a wind atlas with a met. station.

1. Create a new workspace
2. To the workspace, insert a new project
3. To the project, insert a new wind atlas
4. To the wind atlas, insert a new met. station
5. To the project, insert a map from file
6. To the met. station insert an observed wind climate from file
7. Locate the met. station in the map

Setting the location of a met. station

There are two ways to set the location of a met. station in the map.

- [Editing the co-ordinates in a dialog box]
- [Dragging the met. station into position on the map]

Calculating a wind atlas

If the met. station is ready to calculate its wind atlas, then the calculation performed by either

- Selecting the met. station's **Calculate atlas** method
- Hitting the calculate button on the met. station's control dialog
- Instructing the met. station's project to update all calculations

After a wind atlas is calculated,

- if the wind atlas window is open, the data display will be immediately refreshed to display the new data
- the met. station icon will change to indicate that the wind atlas is not due for re-calculation
- any turbine sites associated with the newly-recalculated wind atlas will change status to indicate that their predicted wind climates are due for recalculation

About observed wind climates

Observed wind climates (OWC) contain a time-independent summary of wind data which are needed to calculate a wind atlas. The format of the corresponding observed wind climate file is described in the Technical Reference section.

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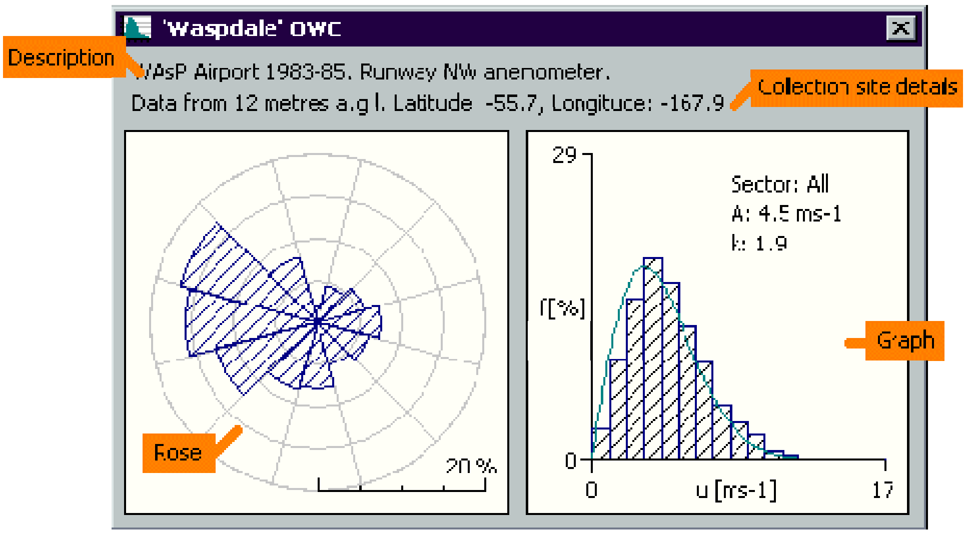
The observed wind climate window

The OWC window provides a graphical representation of the data in the OWC.



On the left is a wind rose, showing the relative frequencies of wind direction for each sector. The graph to the right shows a histogram of the frequencies of wind speeds at the collection site. The Weibull-*A* and Weibull-*k* parameters for the distribution are pre-calculated and displayed. The derived Weibull curve is overlaid onto the histogram.

When first displayed, the graph shows a histogram of wind speed frequencies for all sectors (non-directional). To display the graph for one sector only, click with the mouse on one of the sectors in the rose. The rose sector will be highlighted and the graph will be adjusted to display the data for that sector. Hitting the spacebar on the keyboard will move the selection around the rose. To return to the non-directional display, click on the rose anywhere outside the area marked with rings.

Exporting output

It is not possible to print the observed wind climate contents directly, but the rose and graph graphics can be copied to the Windows system clipboard. They can then be pasted into other Windows applications and printed.

To copy the rose or graph, click on one with the mouse and then use **Ctrl-C** or press the **F11** key on the keyboard.

About maps

Maps are used to describe the orography and surface roughness of the area surrounding sites (turbine sites and met. stations).

WAsP uses vector maps, in which terrain surface elevation is represented by height contours and roughness lengths by roughness change lines. The format of the corresponding map file is described in the Technical Reference section.

It is not possible to create and edit maps from within the WAsP program; this must be done with the map editor which can be invoked from the **Tools** menu.

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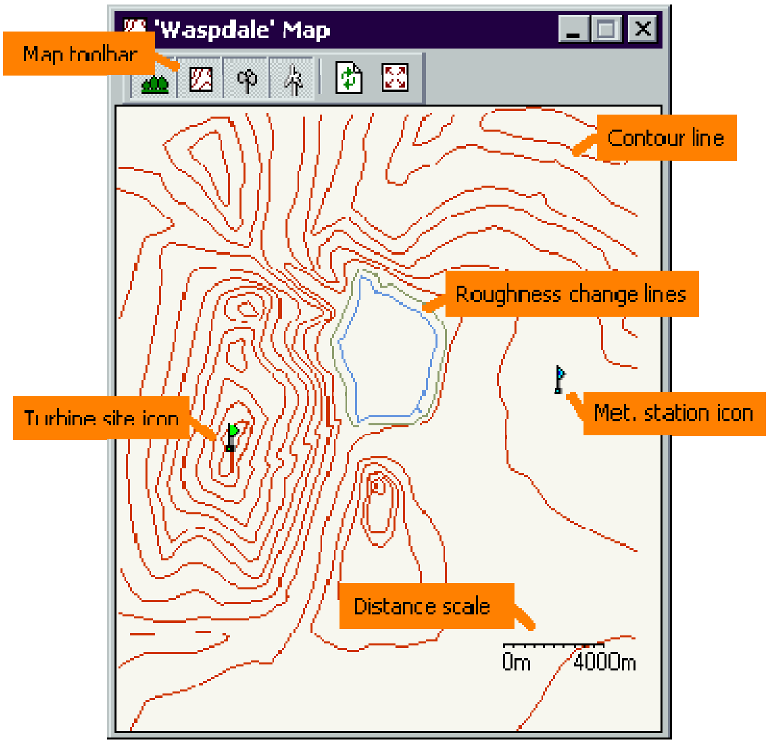
The map window

The map window shows elevation contour lines, roughness change lines and the locations of any turbine sites or met. stations which are associated with the map in the workspace hierarchy



You can explore the map and change the map display using the mouse and the toolbar.

Navigating around the map

The map image can be dragged around inside the display window using the mouse. Click and hold down the left mouse button. The mouse pointer icon changes to a paper-sliding hand. By moving the mouse around, the map is moved just as a piece of paper on a desk would be moved.

It's possible to zoom the map display. To zoom in, double-click on the map with the left mouse button. The mouse pointer position will be at the centre of the new display. After a zoom, only part of the total map may be visible in the display window. The whole map has actually been drawn, though, so it can still be navigated by dragging around as described above. It is not a good idea to zoom in too many times, because a zoomed map requires a great deal of memory. Depending on your computer's configuration, you will notice the map re-draw takes much longer after 4 or 5 zooms.

To zoom out, double-click on the map with the right mouse button. If you zoom out so that the map is smaller than the display window, you may wish to make the window smaller. Click on the toolbar button marked to shrink the window to the map.

To restore the map to the original view, click on the toolbar button marked .

Changing the map display

Hide or show the roughness change lines and elevation lines by clicking on the toolbar buttons marked and . Hide or show the locations of met. stations and turbine sites by clicking on the toolbar buttons marked and .

The colours used for drawing the map can be adjusted from the main options window.

Getting precise spatial information from the map

The map displays a ground scale to give a general idea of the map's meaning. If the scale appears in an inconvenient place, it can be dragged around in the map by using the left mouse button.

To see the current co-ordinates of the mouse pointer in terms of the map co-ordinate system, simply press or hold down the right mouse button.

Working with sites in maps

If a turbine site or met. station is associated with a map hierarchy member, and has valid co-ordinates, then it can be displayed in the map.

The turbine sites and met stations displayed in a map are more than just illustrations. It is possible to interact with the sites by working within the map itself.

To select and identify a site, click on the marker in the map with the left mouse button. The name of the site and the exact ground co-ordinates are shown in a pop-up label.

A site can be moved by dragging it in the map using the left mouse button. As you drag, the drop co-ordinates are displayed in a pop-up label. After dropping the site to its new location, you can make very fine adjustments to the exact position by editing the data in the site's control dialog window.

To display a site's control dialog window, select the site in the map and then click on it with the right mouse button. This dialog is the same as that which appears when the **Edit location** method of the site is invoked from the workspace hierarchy.

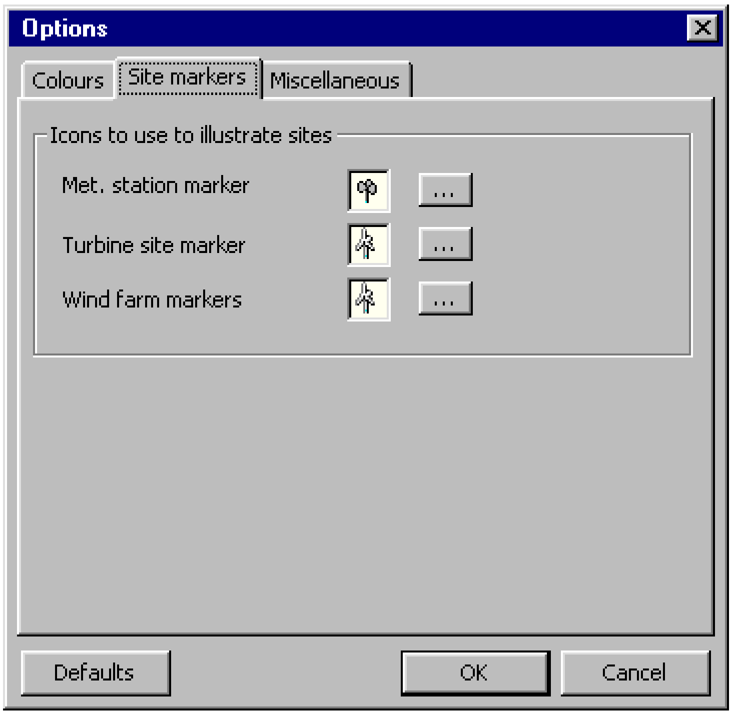
Exporting map displays

The map cannot be printed directly, but the map graphic can be copied to the Windows system clipboard. It can then be pasted into other Windows applications and printed.

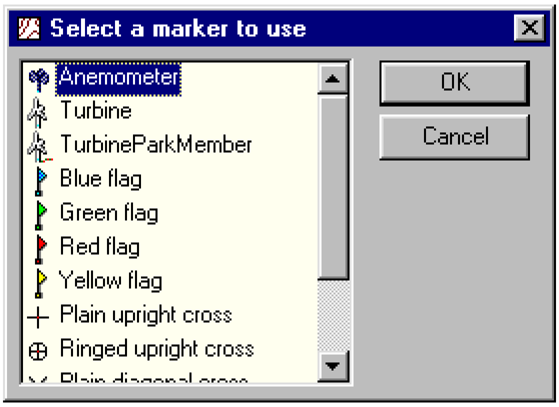
To copy the map graphic, use either **Ctrl-C** or press the **F11** key on the keyboard while the map is selected. The whole map is placed in the clipboard, even if the display window only shows a small part of the map itself. The map graphic is exported at whatever zoom level is currently being used, so the image might take up a lot of memory!

Changing map markers

Here you can choose which marker WAsP should use when indicating the location of met. stations, turbine sites and wind farm sites in the map.



To choose a marker, press the button marked with three dots next to the one you wish to change. Another dialog will appear, displaying a list of markers.



Select a marker from the list.

Preparing map files for use in WAsP

It is not possible to create or edit map files from within this version of WAsP. To alleviate this restriction, we have provided three possible 'workarounds':

1. WAsP will accept map files in BNA format, which is output from Golden Software's DIDGER program, a cheap and simple digitising package.
2. WAsP is supplied with a utility program called MapEdit, which is a lightweight map editor program. The MapEdit tool will accept vector maps in several formats and provides extensive tools for adjusting, checking, digitising and maintaining map files. Scanned maps (*.bmp) can be digitised from within the map editor.

3. WAsP also includes an earlier version of WAsP for DOS, which includes facilities for digitising and editing map files. The map file format has not changed between the versions, so it is possible to use the old program as a map creator and editor tool.

We may provide a more satisfactory solution to this issue in a later release. What we provide will be largely determined by user feedback, so please do send an e-mail explaining your preferences.

Using existing map data

Digital map data may already exist for the site or region in question. If such data exist, they must be converted or transformed into a map format that WAsP can use, i.e. digital height contours where the elevations and coordinates are in metres in a Cartesian coordinate system.

4. WAsP includes a DXF Translator which can extract a WAsP map-file from an AutoCAD DXF-file. This Drawing eXchange Format has become a common format for exchange of line drawings between different programs, and several suppliers of digital maps use DXF-files as a means of storing and exchanging map data. Also, the height contours of a map can be exported to a DXF-file if AutoCAD is used to digitise the map.
5. Digital elevation models cannot be used directly by WAsP, but must be transformed to height contour or vector maps. A digital elevation model (DEM) consists of the spot heights of nodes in a (usually) regular grid and some commercial programs can perform this transformation. The exported output may be a 3-D dxf-file (Surfer) which must be converted to a WAsP map file. The GRD2MAP program, which is part of the WAsP Utility Programs, can transform a Surfer *.grd file (DEM) directly to a WAsP *.map file.

About obstacle lists

Obstacle lists are used to describe objects in the vicinity of a site (met. station or turbine site) which might affect the behaviour of the wind at the site. Examples of sheltering obstacles include buildings, shelterbelts and groups of trees.

Data in WAsP obstacle lists describe the obstacles using a site-relative coordinate system and obstacles are represented as 3-dimensional boxes with a rectangular footprint and cross-section. A maximum of 50 obstacles can be specified in one list.

Obstacles, shelter and the shelter model of WAsP are described in more detail here.

The format of the obstacle list file is described in the Technical Reference section.

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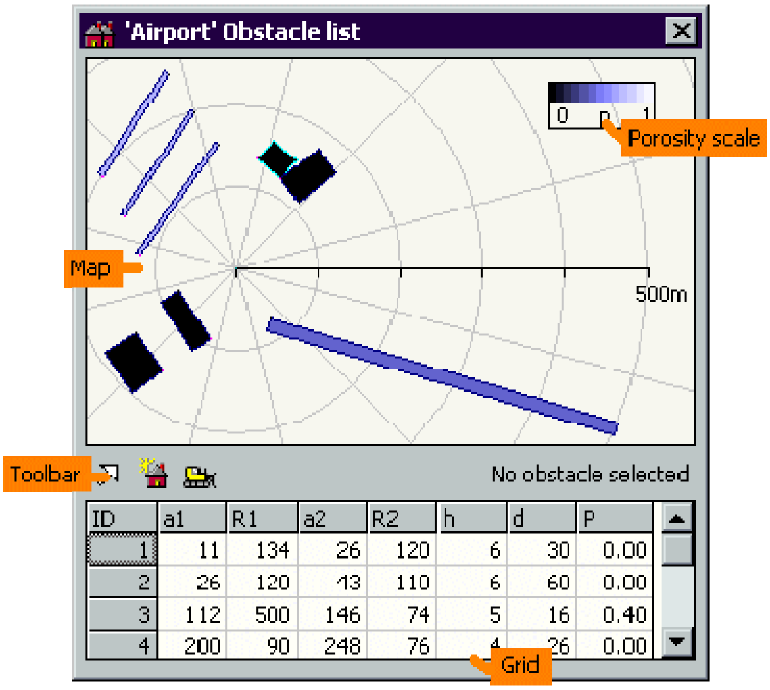
The obstacle list window

The obstacle list window provides a plan view of the obstacles described in the obstacle list.



The layout of the obstacles is illustrated in a map, with obstacles coloured according to their porosity. There is a key to the porosity colour scale and a ground distance scale.

If the mouse pointer is moved slowly over an obstacle, then a label will appear, displaying the ID number, height and porosity of that obstacle. Moving the mouse pointer slowly over another part of the map will reveal the ground co-ordinates of the mouse pointer position.

The actual data describing the obstacles are displayed in an editable grid in which each row contains the data describing one obstacle. Clicking on a row in the grid will cause the corresponding obstacle to be highlighted in the map. The grid's column titles are very abbreviated. Allowing the mouse pointer to linger over the grid will cause a label to appear, revealing the full title of the column.

Adjusting the layout

The window can be re-sized. If the area illustrated by the map is tall and narrow, it may be more convenient to display the grid to the right of the map. It's possible to move the grid by clicking on the **Move the grid** button on the toolbar. Clicking again on the same button moves the grid back.

If the porosity scale appears in an inappropriate place, it can be dragged to a new location using the right mouse button. The ground distance scale cannot be dragged from its original position.

Working with obstacle lists

It's possible to add, edit and remove obstacles by working with the grid.

Adding a new obstacle to the list

Click the **Add new obstacle** button on the toolbar. A new obstacle is added to the top of the list with ID number 1. The new obstacle is created with made-up data which ensure that the new obstacle is at further away than existing obstacles. A row is added to the top of the grid. Edit the grid to set the data describing the new obstacle.

Removing an obstacle from the list

Select the obstacle to be removed by clicking on the obstacle in the map or by selecting the row in the grid containing data for that obstacle. Remove the selected obstacle by clicking on the **Remove currently selected obstacle** button on the toolbar, or by pressing the **Delete** key on the keyboard.

Editing obstacle data

Select the grid cell containing the datum to be edited and either press the **Enter** key on the keyboard or double-click on the cell with the mouse. A box appears on the grid which allows the number to be edited.

ID	a1	R1	a2	R2	h	d	P
1	26	120	43	110	6	60	0.00
2	112	500	146	74	5	16	0.40
3	200	90	248	[illegible]	4	26	0.00
4	215	154	237	144	6	46	0.00

Type the new value into the box and either press **Enter** or click elsewhere on the window to close the editor box. The map view of the obstacles is immediately redrawn to reflect the changes.

Exporting output

It is not possible to print the obstacle list directly, but the map graphic and the grid's contents can be copied to the Windows system clipboard. They can then be pasted into other Windows applications and printed.

To copy the sketch map, click on it with the mouse and then press the **F11** key on the keyboard. To copy the grid contents, click on the grid and then press the **F11** key on the keyboard.

Preparing an obstacle list

Sheltering obstacles may be identified and their characteristics obtained from a detailed map, aerial photograph and/or during a site visit. If the site is a met. station, only obstacles which were present at the time of the wind data collection should be described.

The obstacle information may be compiled on a separate sheet like the Obstacle Description Form, which is then used to establish the obstacle list file. The format of the obstacle list file is described in the Technical Reference section.

In the field

The bearings from the site to two corners of an obstacle are taken using a compass. The distances to the same corners are estimated by 'walking' the distances or using an odometer or range-finder. The dimensions and porosity of the obstacle must be estimated; a measuring tape may come in handy at this stage. Photographs are taken from the site for every 30º of azimuth, starting from north (0º).

In office

If a detailed map or aerial photograph is available, the obstacle information may be obtained or checked in the office. The obstacle list for the site is generated by entering the information in the grid of the obstacle list window or by generating an obstacle list file (*.obs, ASCII text file) using a text editor – any 'old' obstacle list file may be used as template.

About roughness descriptions

When calculating a wind atlas from met. station data, or to predict the wind climate at a turbine site, WAsP can make adjustments for the roughness lengths of the terrain around the site. Of course, WAsP requires information about the roughness environment to do this.

If the map associated with a site contains roughness change lines, then WAsP can derive information about the roughness environment automatically. There is no need to provide any other information.

However, if the map contains only elevation data, then an alternative way to provide a WAsP with information about the roughness environment for a site is to associate a roughness description with the site, by inserting one as a child member of the site in the workspace hierarchy.

A roughness description divides the area surrounding the site into sectors. Each sector is in turn divided into 'bands' of different roughness length.

There are two formats for roughness description files.

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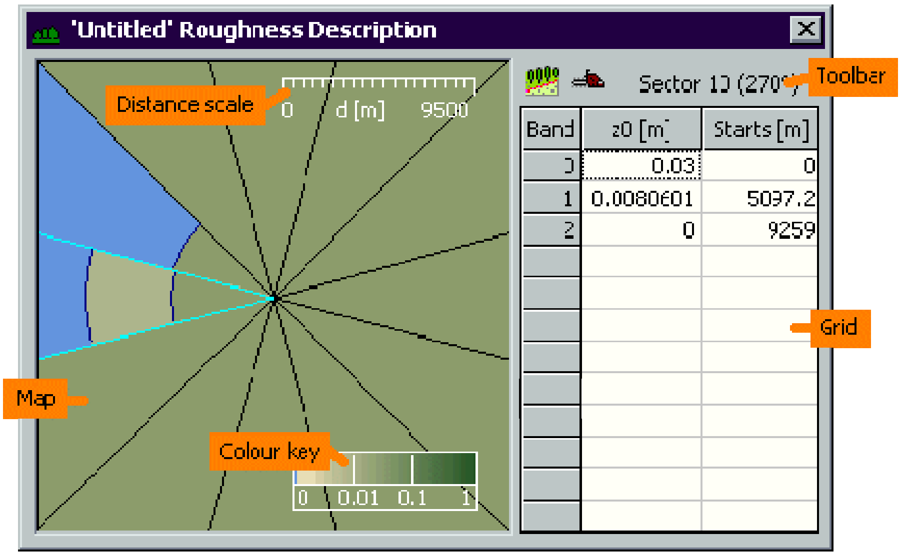
There are two formats for roughness description files.

The roughness description window

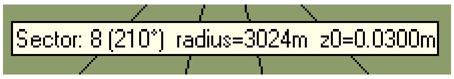
The roughness description window illustrates the roughness of the terrain surrounding a turbine site or met. station.

The sketch map displays the area surrounding the site. The area is divided into sectors and each sector can be divided into bands with different roughness lengths. The bands are separated by roughness change lines and are coloured according to a logarithmic scale which starts at blue (which is reserved for areas with a roughness length of exactly zero) and runs from light brown to dark green.



A roughness colour key and a distance scale are displayed on the map. They can be dragged around using the left mouse button if in an inconvenient position. It is possible to display the roughness map using a logarithmic ground scale (where changes close to the site are greatly emphasised in the display). To switch the display to logarithmic mode, right-click on the distance scale and select from the small pop-up menu which appears.

To discover the exact value for an area, move the mouse pointer slowly over the sketch map. A label will appear which indicates which sector is selected, the centre bearing of that sector, the distance (radius) from the site of the current mouse position, and the roughness length in the area under the mouse pointer:



To select a sector, click on it in the map. The data for the selected zone are shown in the grid to the right of the map. Each row in the grid contains the band index, the roughness length of the band and the distance from the site to the start of the band.

Generating a roughness description from a map

If a met. station or turbine site is located in a map which contains roughness information (roughness change lines), then there is no need to use a roughness description member for that site. Still, it's sometimes useful or interesting to get an insight into how WAsP is interpreting the map data for that site. It's possible to get WAsP to generate a roughness description for the site from the map roughness information.

To do this,

1. Check that the site is correctly located in an associated map
2. Insert a new roughness description hierarchy member as a child of the site
3. From the roughness description's methods, select **Obtain description from map**
4. The roughness description's interface window will be opened, to show the derived description

The resulting description can be examined, edited and saved.

Working with roughness descriptions

It's possible to add, edit and remove sector bands by working with the grid. The number of sectors in a roughness description is determined when it is first created, and cannot be edited.

Adding a roughness band to a sector

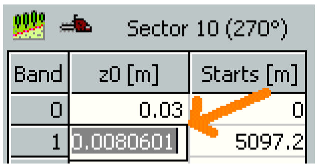
- Select the sector to be edited by clicking on it in the map area. The sector will be highlighted in the map, and the grid's contents will be changed to contain the bands for that sector.
- Click on the **Add roughness band** button on the grid's toolbar . A new band is added to the sector.

Removing a roughness band from a sector

- Select the sector to be edited by clicking on it in the map area. The sector will be highlighted in the map, and the grid's contents will be changed to contain the bands for that sector.
- Select the band to be removed by clicking on the corresponding row in the grid.
- Either click on the **Remove roughness band** button on the grid's toolbar, or press the **Delete** key on the keyboard. The selected band will be removed.

Editing a roughness band

Select the grid cell containing the datum to be edited and either press the **Enter** key on the keyboard or double-click on the cell with the mouse. A box appears on the grid which allows the number to be edited.



Type the new value into the box and either press **Enter** or click elsewhere on the window to close the editor box. The map view is immediately redrawn to reflect the changes.

Exporting output

It is not possible to print the roughness description contents directly, but the map graphic and the grid's contents can be copied to the Windows system clipboard. They can then be pasted into other Windows applications and printed.

To copy the map, click on it with the mouse and then press the **F11** key on the keyboard. To copy the grid contents, click on the grid and then press the **F11** key on the keyboard.

Preparing a roughness description from field data

Preparing a site-specific roughness description from field data and observations is described here.

Roughness description and user correction files

Roughness descriptions are stored in *.rrd files and user corrections are stored in *.ucf files. Earlier DOS versions of WAsP stored both data sets together in a single file with the extension *.rds.

WAsP provides backward-compatibility by allowing you to open *.rds files as roughness descriptions or user corrections, and allowing you to work with roughness descriptions as *.rrd files with no user corrections information.

When creating a roughness description hierarchy member from file, you can choose to open an *.rds file. The roughness data will be read in from the file, but any user corrections data will not be used. Similarly, you can choose to open an *.rds file when creating a user corrections hierarchy member from file, and any roughness data found in the file will be ignored. It follows that if you want to use an *.rds file containing both user corrections data and roughness description data, then you need to open the same file twice: once when creating a user corrections member from file, and once when creating a roughness description from file.

If you create a new roughness description you can still use it with an earlier version of WAsP. The roughness description's menu contains a method called **Save in DOS WAsP format (*.rds)**. If you select this method, then an *.rds file will be generated from the roughness description. It will be saved to the same path as the existing *.rrd file and have the same filename: only the *.rds extension will be different. No user corrections data will be written to the file.

The workspace will now point to this *.rds file, so if you make changes to the roughness description and save them, then they will be saved to the *.rds file and will still be there when you next open the workspace. The *.rrd file which you converted will remain unaltered and unused, unless you wish to revert to using *.rrd format. To do this, select the method called **Save in WAsP 6 format (*.rrd)**. This will swap the two files around again, and any changes will now be written to the *.rrd file.

About user corrections

User corrections are used when some source of site-specific, systematic error is known, but cannot be included in the obstacle list or roughness description. They can be applied to sites (met. stations and turbine sites).

For example, the shadowing effect of a wind vane mounted close to an anemometer used at a met. station might be known to reduce the measured speed in a certain sector by 5%. It would (of course) be inappropriate to represent the vane as an obstacle; instead WAsP can adjust the calculations for the affected site using data provided in user corrections.

User corrections include an wind speed factor adjustment and a direction turning adjustment. The turning adjustment is very rarely used, because such adjustments are usually applied to all observations and directions: they can be applied when summarising the raw data from the instrument (see the OWC Wizard).

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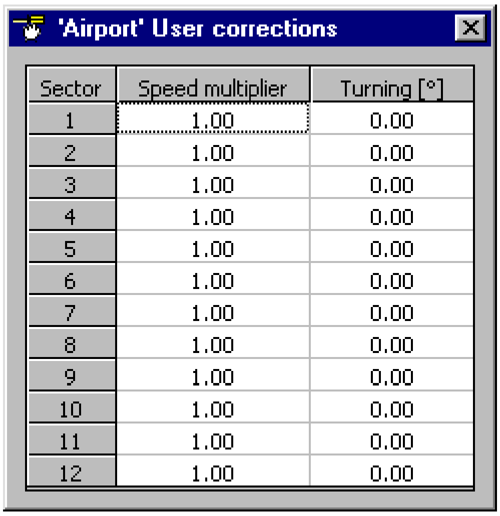
The user corrections window

The user corrections window displays the corrections for a site in a three-column grid. The picture below shows a set of user corrections which are completely neutral – these corrections would have no effect on the calculations performed.


'Airport' User corrections

Sector	Speed multiplier	Turning [°]
1	1.00	0.00
2	1.00	0.00
3	1.00	0.00
4	1.00	0.00
5	1.00	0.00
6	1.00	0.00
7	1.00	0.00
8	1.00	0.00
9	1.00	0.00
10	1.00	0.00
11	1.00	0.00
12	1.00	0.00

Editing user correction data

Select the grid cell containing the datum to be edited and either press the **Enter**- key on the keyboard or double-click on the cell with the mouse. A box appears on the grid which allows the number to be edited. Type the new value into the box and either press **Enter** or click elsewhere on the window to close the editor box.

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About turbine sites

Turbine sites are used to calculate a predicted wind climate for a particular point. A turbine site has no data of its own except the co-ordinates of its location and a list of its children.

A turbine site calculates a predicted wind climate by taking a wind atlas which describes the general wind climate of an area and applying it to a particular location, adjusting for the effects of the features of the site itself. The site has an (*x*, *y*)-location in space and two *z* locations: the elevation of the site and the height above ground level for which the prediction is generated.

Each power curve has a default height. That's the usual height for the type of turbine which is described by the power curve. It's not necessary to use this height: a predicted wind climate can be generated for any height over 1 metre, regardless of which power curve is being used.

It's possible to calculate a predicted wind climate for a point without specifying a particular turbine power curve. That's the equivalent of erecting a turbine mast but not fitting a turbine to it. The predicted wind climate in that case will of course not contain any predictions describing the likely power yield of the turbine, but a prediction containing data for the wind directions, frequencies, speeds and energy will be produced.

In fact, it's quite appropriate to think of a turbine site as simply a point in 3-D space where a turbine could be erected. WAsP can calculate a prediction of the wind climate for that point. You can take things further by specifying a particular turbine type (by choosing a power curve to use). WAsP will then generate a prediction of the power yield for the combination of the point and the turbine type in addition the basic data in the predicted wind climate.

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Calculation status

Four types of hierarchy member can perform calculations: met. stations, turbine sites, resource grids and wind farms. These calculating members are sensitive to changes in the hierarchy which affect them. They also search up and down the hierarchy to look for the other members with which they collaborate to do modelling work.

Ready to calculate?

Calculating members have a method called **Calculate** which is only available if the hierarchy is correctly set up to allow the calculation to proceed. If a calculating member is not ready to be calculated, then a different method is available, called **Explain why cannot be calculated**. If this method is invoked, then a brief explanation of what more needs to be done is presented.

Detection of changes in influencing information

If a calculating member detects a change to an associated influencing member or to the arrangement of its associated influencing members, then it 'realises' that the results data ought to be recalculated to reflect the new situation being modelled in the hierarchy.

When this happens, the calculating member's icon changes to display a red ring marker . When calculating members are recalculated, their icon returns to normal.

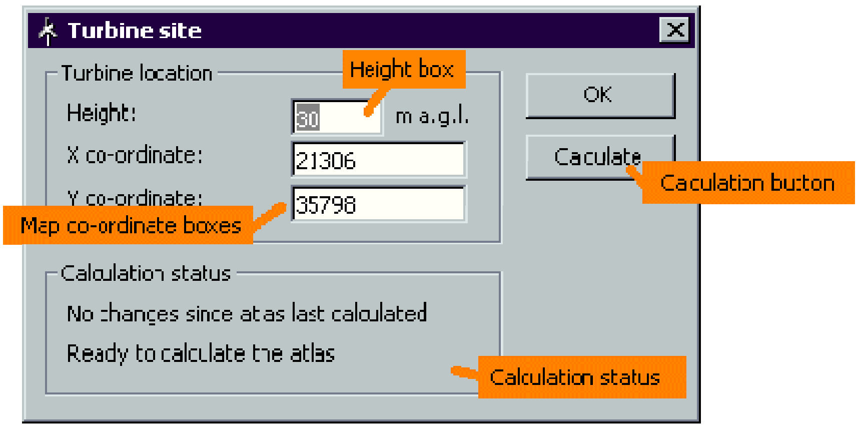
Overriding change detection

It's possible to tell a calculating member whether its wind atlas is due for recalculation. If the member 'thinks' that it ought to do a recalculation, then it has a method called **Mark as calculated** which will override its status. Conversely, if it thinks that it is up-to-date, then a method called **Mark as uncalculated** is available.

The turbine site control dialog

The turbine site has a control dialog which can be used to specify the precise location of the site and to force a re-calculation of the associated predicted wind climate.

The dialog is displayed if a turbine site's **Edit location** method is invoked, or if the turbine site's icon in the map is clicked with the right-hand mouse button.



Editing the turbine site co-ordinates

The *x* and *y* co-ordinates of the turbine site can be typed in, allowing more precise positioning than by dragging in the map. The height of the calculation can also be entered. If you type a value here, it will immediately override any default value which has been used because a power curve has been associated with the site.

The calculation button is not visible if the turbine site is not ready to perform a calculation.

Turbine sites in the map window

If a turbine site is associated with a map hierarchy member, and has valid co-ordinates, then it can be displayed in the map, where it is indicated an icon marker.

Hide or show the locations of turbine site in the map display by clicking on the toolbar button marked with the turbine site icon.

To select and identify a turbine site, click on the marker in the map with the left mouse button. The name of the site and the exact ground co-ordinates are shown in a pop-up label.

Dragging the turbine site into position on the map

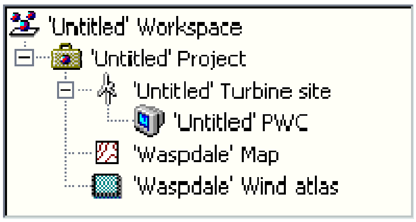
To display the turbine site in the map, select the turbine site's **Highlight location in map** method. If the map is not showing, it will be opened. The turbine site's icon will be highlighted. If the turbine site has never been located in the map, then select the method called **Locate in map**. The map window is opened and the turbine site is automatically positioned at the centre of the mapped area.

It's now possible to change the location of the turbine site by dragging it in the map using the left-hand mouse button. A label appears giving the co-ordinates as you drag the turbine site. Depending on the zoom level, it might be difficult to position the turbine site precisely. If this is a problem, simply right-click on the icon in the map and the turbine site control dialog will appear, allowing you to edit the co-ordinates.

Preparing to calculate a predicted wind climate

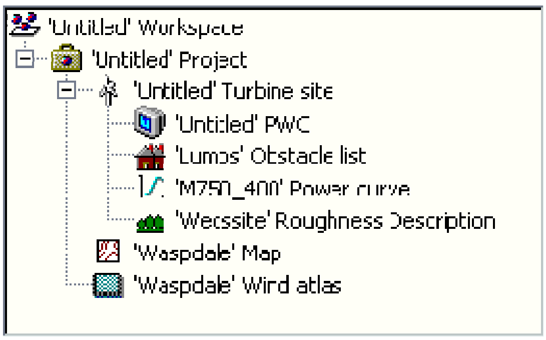
To calculate a predicted wind climate, a turbine site must:

- Be associated with a wind atlas
- Be located in an associated map
- Have an observed wind climate as one of its children
- Be a member of a project



Optionally, a turbine site can:

- Be associated with a power curve
- Have an obstacle list as one of its children
- Have a roughness description as one of its children
- Have a set of user corrections as one of its children



Starting from scratch, here's how to prepare to calculate a predicted wind climate with a turbine site.

1. Create a new workspace

2. To the workspace, insert a new project
3. To the project, insert a new turbine site
4. To the project, insert a wind atlas from file
5. To the project, insert a map from file
6. Locate the turbine site in the map
7. Specify a height for the turbine site

Setting the location of a turbine site

There are two ways to set the location of a turbine site in the map.

- Editing the co-ordinates in a dialog box
- Dragging the turbine site into position on the map

Calculating a predicted wind climate

If the turbine site is ready to calculate its associated predicted wind climate, then the calculation can be performed by either

- Selecting the turbine site's **Calculate** method
- Hitting the calculate button on the turbine site's control dialog
- Instructing the turbine site's project to update all calculations

After a predicted wind climate is calculated,

- if the predicted wind climate window is open, the data display will be immediately refreshed to display the new data,
- the turbine site icon will change to indicate that the predicted wind climate is not due for re-calculation.

About predicted wind climates

Predicted wind climates (PWC) contain the results of the WAsP application, i.e. the estimated wind climate and power production for an application (turbine) site. The results are calculated by the WAsP models and based on a previously calculated wind atlas.

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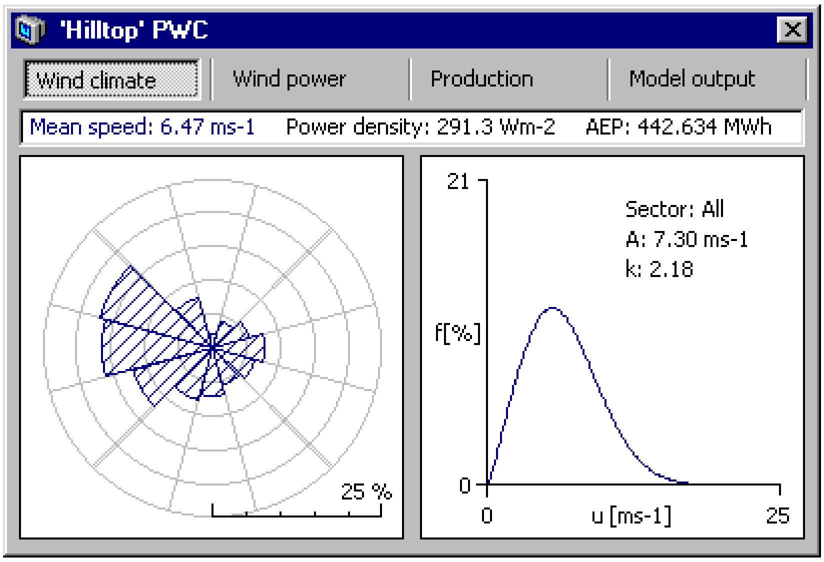
The predicted wind climate window

The predicted wind climate window displays the results for a turbine site calculation. The summary results box displays the mean wind speed, the total mean power density and the total mean power production (AEP). Note, that these values are calculated from the Weibull *A* and *k* parameters of the total wind speed distribution.



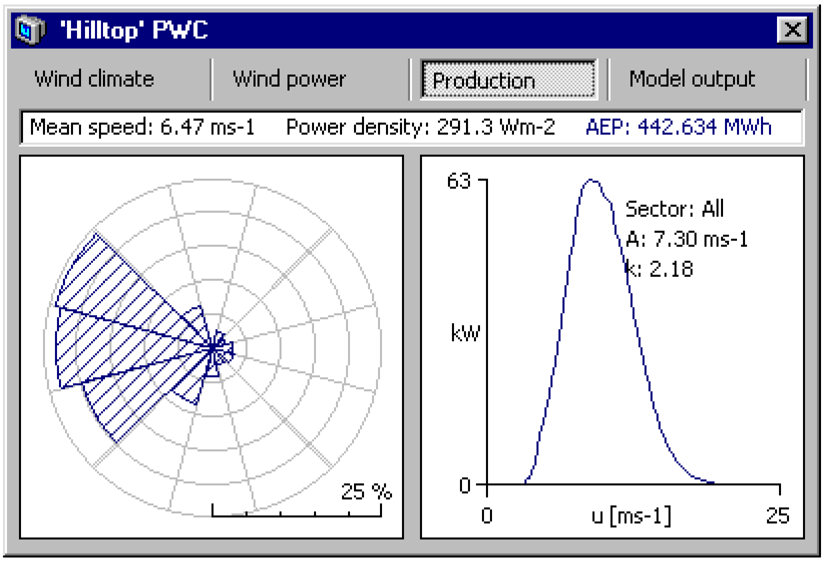
There are four data displays.

- Rose and graph for the predicted wind climate
- Rose and graph for power density
- Rose and graph for power production (AEP)
- Grid showing detailed model output data

Select a data display by clicking the appropriate button on the display control bar.

Using the 'rose and graph' displays

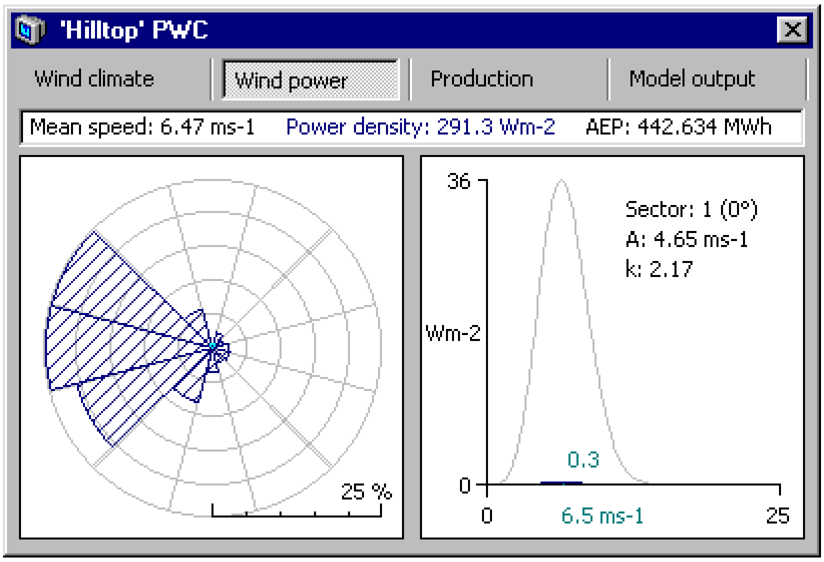
The three rose and graph displays are functionally similar, although they of course display different data.



To see the actual values used to construct the rose, move the mouse pointer slowly over a rose sector.

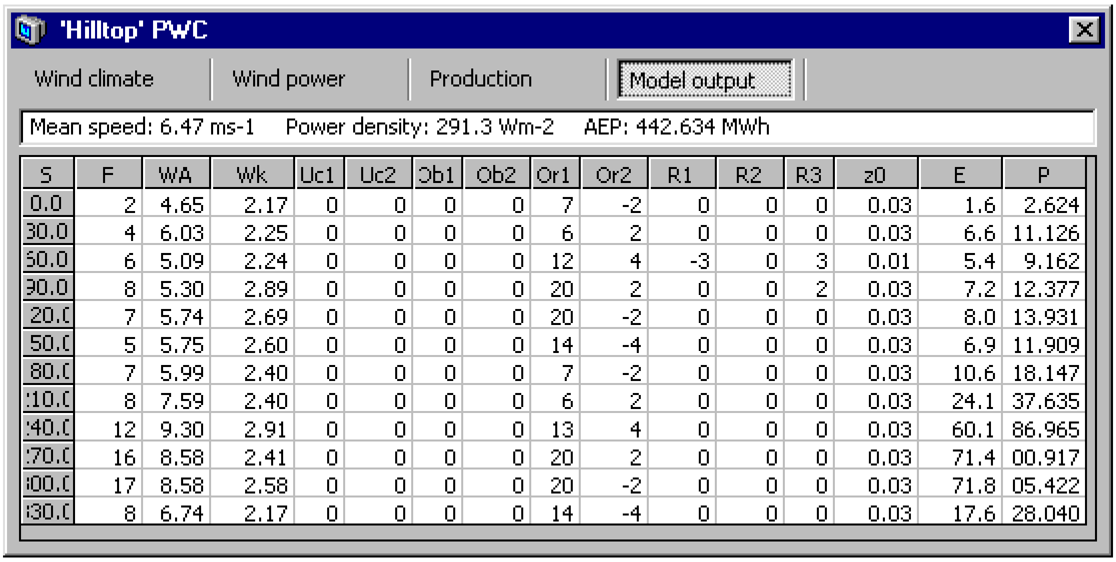
Each sector has a corresponding curve, and there is also a curve for all sectors (non-directional). To select a sector, click on it in the rose display. Hitting the spacebar on the keyboard will move the selection around the rose. To select all sectors, click on the rose anywhere outside the area marked with rings.

When a sector is selected, the graph will be changed to reflect the data for that sector. Moving the mouse pointer over the graph will reveal a 'read-off' line, labelled with the precise frequency/value datum for the point on the curve. The graph area is also used to display the Weibull *A* and *k* parameters for the sector. The sector graphs further show a greyed curve which is the actual curve scaled (arbitrarily) to the *y*-axis maximum.



Using the grid display

The grid display shows the details of the model's output. Various output data values are given for each sector.



S	F	WA	Wk	Uc1	Uc2	Ob1	Ob2	Or1	Or2	R1	R2	R3	z0	E	P
0.0	2	4.65	2.17	0	0	0	0	7	-2	0	0	0	0.03	1.6	2.624
30.0	4	6.03	2.25	0	0	0	0	6	2	0	0	0	0.03	6.6	11.126
50.0	6	5.09	2.24	0	0	0	0	12	4	-3	0	3	0.01	5.4	9.162
90.0	8	5.30	2.89	0	0	0	0	20	2	0	0	2	0.03	7.2	12.377
20.(	7	5.74	2.69	0	0	0	0	20	-2	0	0	0	0.03	8.0	13.931
50.(	5	5.75	2.60	0	0	0	0	14	-4	0	0	0	0.03	6.9	11.909
80.(	7	5.99	2.40	0	0	0	0	7	-2	0	0	0	0.03	10.6	18.147
:10.(	8	7.59	2.40	0	0	0	0	6	2	0	0	0	0.03	24.1	37.635
:40.(	12	9.30	2.91	0	0	0	0	13	4	0	0	0	0.03	60.1	86.965
:70.(	16	8.58	2.41	0	0	0	0	20	2	0	0	0	0.03	71.4	00.917
:00.(	17	8.58	2.58	0	0	0	0	20	-2	0	0	0	0.03	71.8	05.422
:30.(	8	6.74	2.17	0	0	0	0	14	-4	0	0	0	0.03	17.6	28.040

To see less abbreviated column titles, move the mouse pointer slowly over the grid. A label will appear, showing the fill title of the column. The window can be resized to allow more room to display the grid.

The last two columns of the grid show the sector-wise contributions to the total energy and the total power production, i.e. taking the frequency of occurrence of the wind into account. The power production given in the summary results box above the grid is calculated from the Weibull *A*- and *k*-parameters of the total wind distribution. Therefore, the sum of the sector-wise productions may not be exactly the same as the total; however, in most cases the difference should be small.

You can use the **Ctrl-C** key combination to copy the list of model results to the system clipboard.

Exporting output

It is not possible to print the predicted wind climate contents directly, but the summary results box, the rose and graph graphics and the grid's contents can be copied to the Windows system clipboard. They can then be pasted into other Windows applications and printed.

To copy the summary results box, simply click on it. All three summary data will be automatically selected. Use either **CTRL-C** or press the **F11-**key on the keyboard to copy these data to the clipboard.

To copy the rose or graph, click on one with the mouse and then press the **F11-**key on the keyboard. To copy the grid contents, click on the grid and then press the **F11**-key on the keyboard. When the grid contents are copied, the contents of the summary data are also placed in the clipboard.

About power curves

Power curves are used to describe wind turbines. They can be associated with turbine sites, wind farms and resource grids. WAsP can also read wind turbine data in the Park format.

Power curves contain information about how turbines transform wind energy into electrical power, and the hub height usual for the turbine when deployed. The power curve file may also contain the rotor diameter and values of the thrust coefficient, *C*t.

The formats of the power curve and other wind turbine data files are described in the Technical Reference section.

Power curves and power production estimation is described in more detail here.

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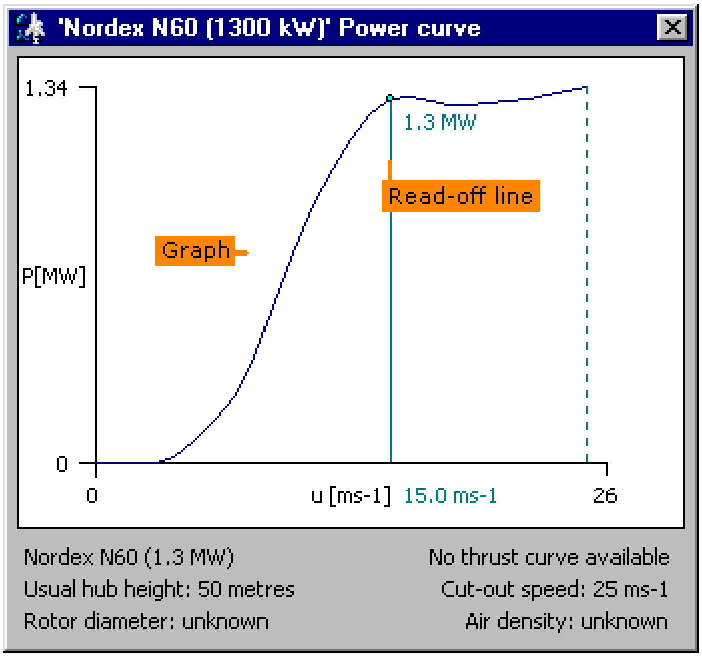
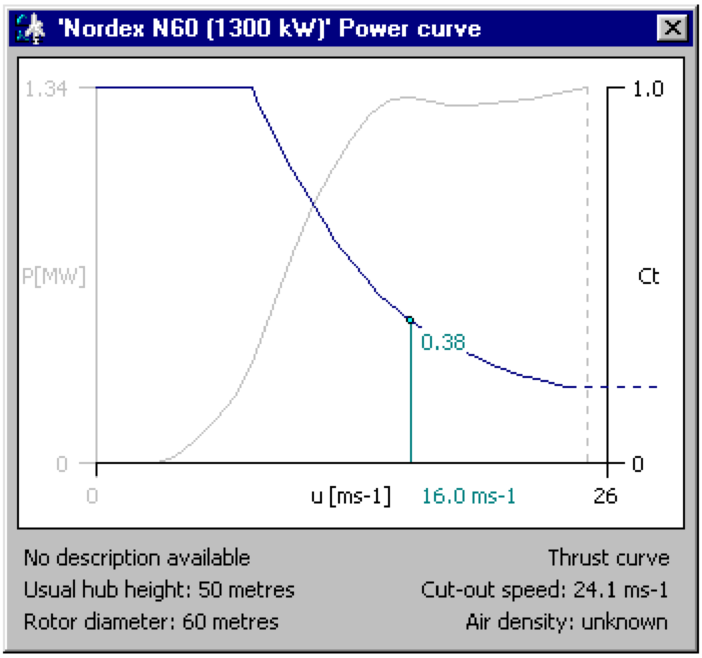
The power curve window

The power curve window shows at least the turbine description, the typical hub height and a graph of the power output against wind speed.



To obtain a precise data reading, move the mouse over the graph. A read-off line appears and follows the mouse position. If the wind speed for the current mouse pointer position is one of the original data points from the file, a small ball appears where the curve and the read-off line meet.

In addition, the power curve window may show the rotor diameter and a graph of the thrust coefficient against wind speed, if this information is available.



The power curve or thrust coefficient graphs are selected by clicking on the left-hand or right-hand *y*-axis, respectively. Precise data readings of thrust coefficient values are obtained by moving the mouse over the graph, as described above.

About wind farms

Wind farms provide a convenient way to calculate power yield predictions for several turbine sites simultaneously.

A wind farm consists of a set of turbine sites which differ from each other only in their map location. They must all lie within the same map, but can be arranged in any pattern. You can also set the wind farm to model the reduction in power yield for each turbine caused by interference from its neighbours; these reductions are called the wake losses.

Each site in a wind farm is like a simpler version of a normal turbine site. All the sites have the same height above ground. If a power curve is associated with the wind farm, then that curve is used for all of the sites in the farm. A wind farm site cannot have an associated obstacle list, nor a site-specific roughness description. A site does not have an associated predicted wind climate hierarchy member, but instead just a few key summary data are generated for each site. If you need a lot of detail about each site, then you need actually to have several turbine sites in the same project.

Wind farm sites are simpler than turbine sites, but are also easier to manage as a group. A wind farm presents data about the total power or energy yield for a set of sites. You can also adjust the calculation height for all of the sites in a wind farm simultaneously. You need to create each site in the wind farm individually, but this is still much quicker than creating several normal turbine sites. Wake losses can only be modelled using a wind farm: if you set up several separate turbine sites, then there is no way to model interference between them, no matter how close they are.

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Calculation status

Four types of hierarchy member can perform calculations: met. stations, turbine sites, resource grids and wind farms. These calculating members are sensitive to changes in the hierarchy which affect them. They also search up and down the hierarchy to look for the other members with which they collaborate to do modelling work.

Ready to calculate?

Calculating members have a method called **Calculate** which is only available if the hierarchy is correctly set up to allow the calculation to proceed. If a calculating member is not ready to be calculated, then a different method is available, called **Explain why cannot be calculated**. If this method is invoked, then a brief explanation of what more needs to be done is presented.

Detection of changes in influencing information

If a calculating member detects a change to an associated influencing member or to the arrangement of its associated influencing members, then it 'realises' that the results data ought to be recalculated to reflect the new situation being modelled in the hierarchy.

When this happens, the calculating member's icon changes to display a red ring marker . When calculating members are recalculated, their icon returns to normal.

Overriding change detection

It's possible to tell a calculating member whether its wind atlas is due for recalculation. If the member 'thinks' that it ought to do a recalculation, then it has a method called **Mark as calculated** which will override its status. Conversely, if it thinks that it is up-to-date, then a method called **Mark as uncalculated** is available.

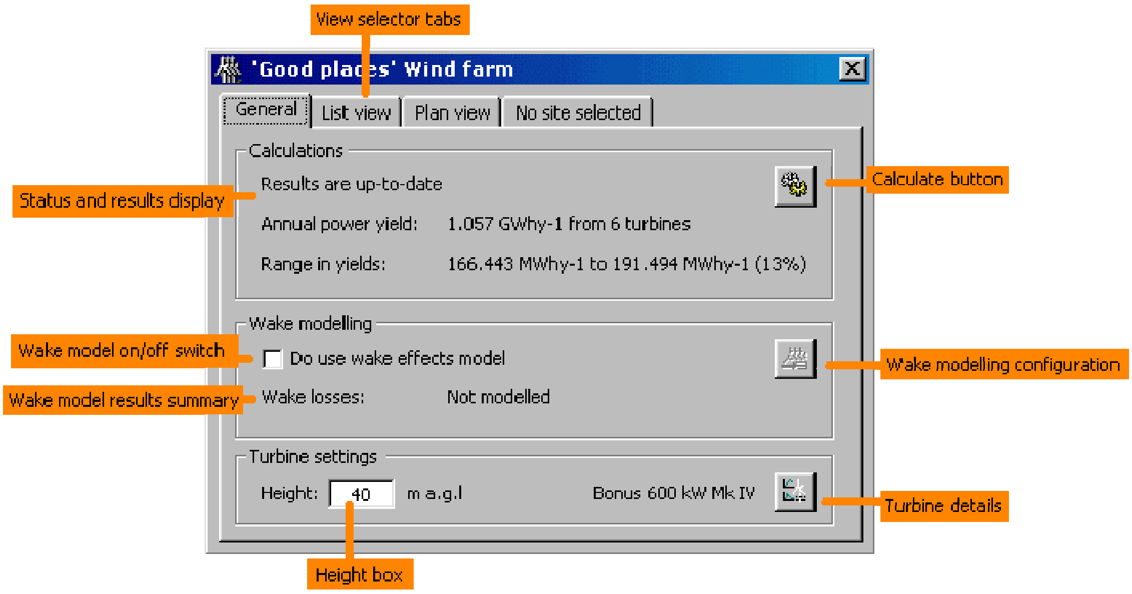
The wind farm window

The wind farm window is a tabbed dialog box with four views:

- General & summary information about the farm as a whole
- A list of all the sites in the farm, with summary information about each
- A plan view of positions of the turbines in the farm with overlay roses showing results
- Detailed, sector-wise information about one selected site

The first view - general & summary information

The first view displays general & summary information about the wind farm.



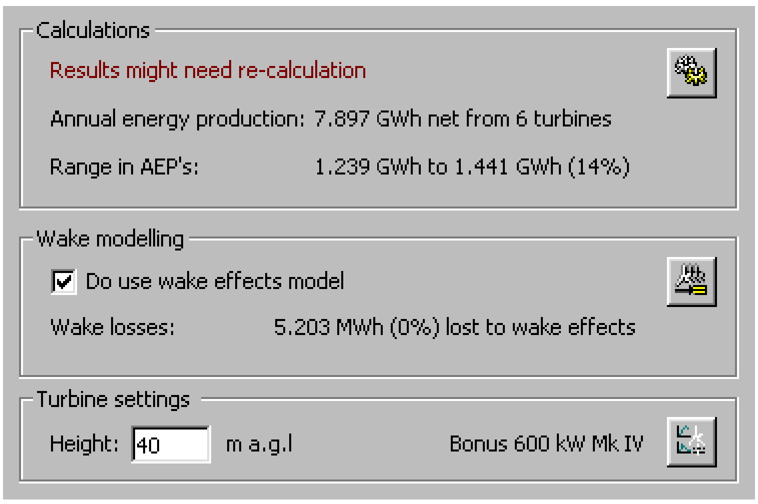
The status of the calculation is indicated. If you have made a change to the configuration of the wind farm, or changed something else which might affect the results, the status display will change to indicate that the results may need to be recalculated. Press the calculate button to recalculate the wind farm results.

The results summary shows the annual energy production (AEP) of the farm. If wake losses are modelled, then this figure will be the total of all sites after wake loss adjustments have been made to the turbine yields. The line below shows the range in yields between individual turbines in the wind farm. These two data are gross figures: if wake losses are modelled, the losses are not applied to these data displaying the range.

The wake modelling section allows you to switch on or off the wake effects model. If wake effects modelling is switched on, then an extra line of results information is available, showing the sum of all wake losses for all the turbine sites in the wind farm. Pressing the wake modelling configuration button will bring up the wake model settings dialog window. This box lets you control how the wake modelling is performed.

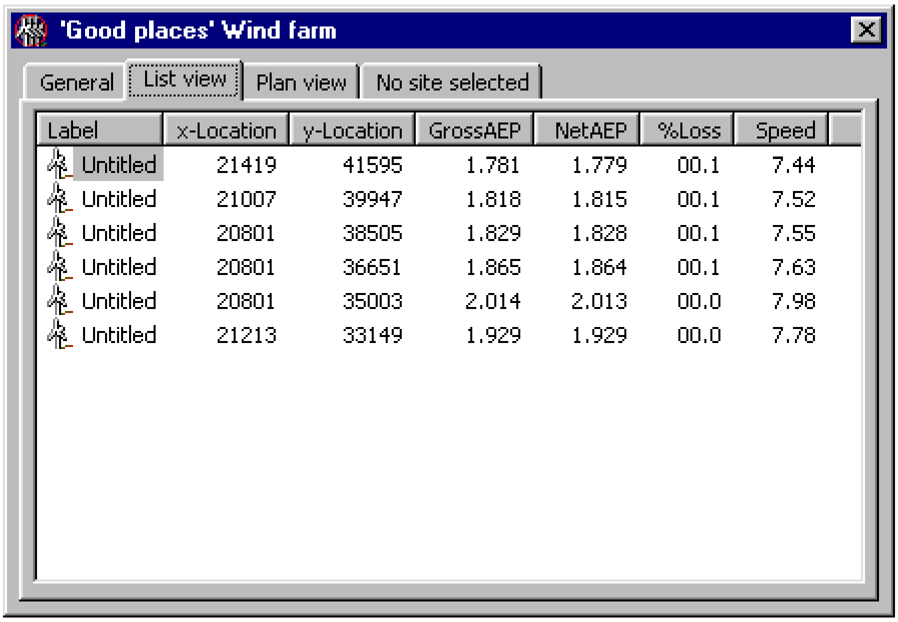
The turbine settings section shows the height at which the calculations are performed (the hub height for all of the sites in the farm). The height can be changed by adjusting the number shown. It is not possible for different sites to have different heights. This section also indicates which turbine type is being used in the modelling. Pressing the turbine details button will simply launch the power curve window for the associated hierarchy member. Note, that a thrust coefficient curve must be specified in order for WAsP to calculate the wake effects.

The picture below illustrates some of the points discussed.



The second view – a list of the sites in the farm

The second view provided by the window simply shows a list of all the sites in the wind farm, with some summary information about each one: site label, *x*-and *y*-coordinates of the site, gross power yield, net power yield, wake loss and mean wind speed. If the wake loss model is used, then the wake losses are shown as a percentage of the gross power yield.



The sites can be sorted according to their label, coordinates, gross AEP, net AEP, wake loss or mean wind speed by clicking on the corresponding column heading button.

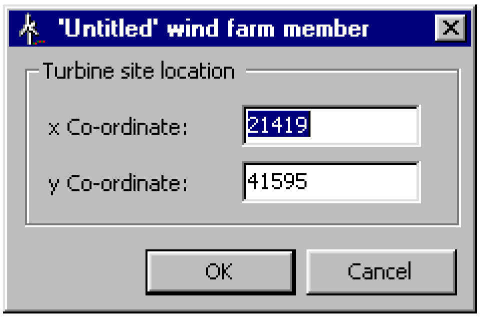
If a site in the list is selected, then right-clicking on it will bring up a menu of possible actions. This menu allows you to rename sites, remove existing sites and insert new sites:

Clicking 'Show site details' will make the window change views to the site details view, with the currently selected site details displayed.

Clicking 'Show site in plan' will make the window change views to the plan view, with the currently selected site highlighted.

If a map is associated with the wind farm, then clicking on 'Show site in map' will open the map's window and show the currently selected site in the map.

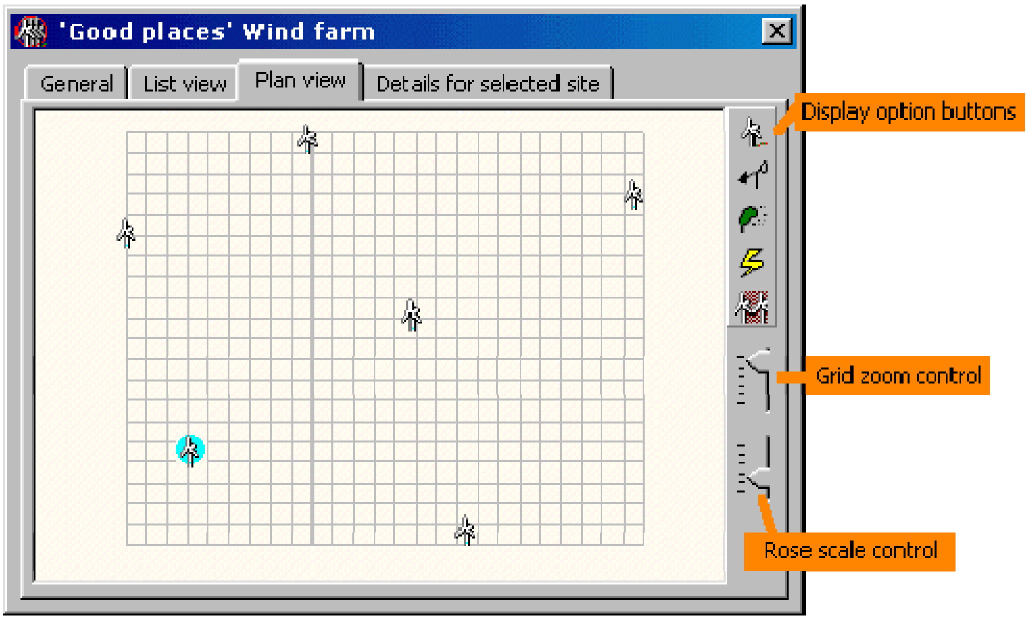
Clicking on 'Edit site location' will present another small dialog which lets you edit the turbine site's co-ordinates:



You can use the **Ctrl-C** key combination to copy the list of site results (with a header of summary data) to the system clipboard.

The third view – a plan view of the sites in the farm

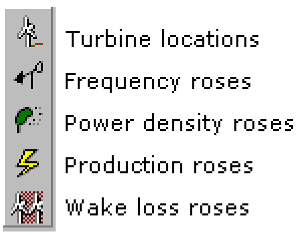
The third view shows a plan of the layout of the turbines in the wind farm.



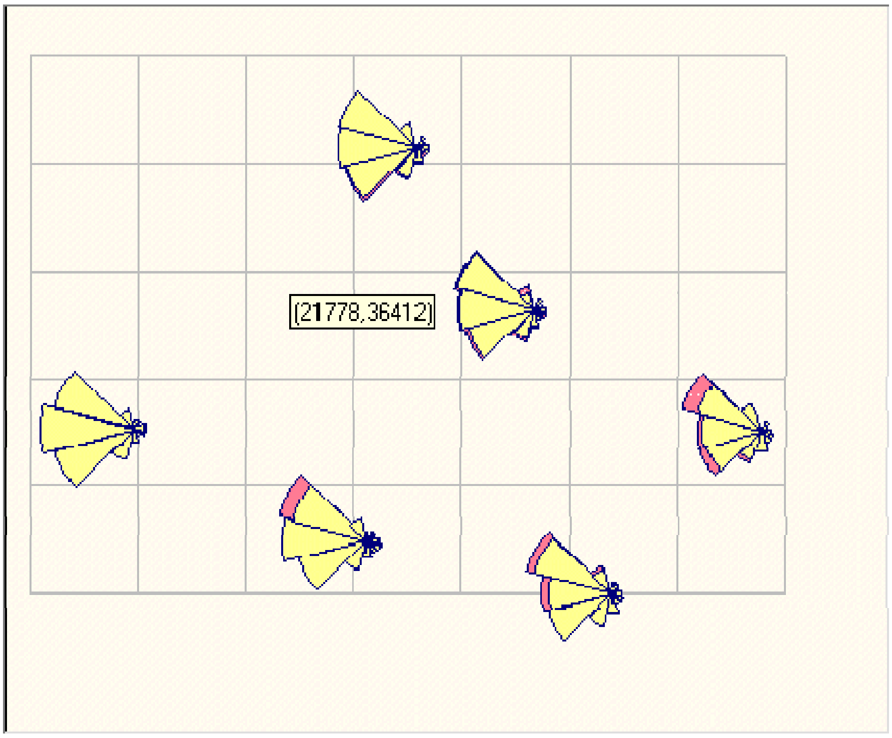
By default, a simple icon is used to show the location of each site. The layout grid – against which the sites are displayed – has a resolution of 500 metres and is aligned with the map reference system. If you move the mouse slowly over the grid, the current position co-ordinates will appear. You can select a different icon to use for wind farm sites by changing the setting in the options window. Use the grid zoom control to change the size of the displayed area.

If you click on a turbine site icon, it will become the currently selected site (click near the bottom of the icon, since this is the actual site location, not the hub). When a site is selected, you can move it by dragging. If you hold down the **Ctrl** key while doing this, the site is copied instead of moved so a new turbine site is inserted into the farm. If you right-click on a selected site, then a menu appears which is similar to that accessible from the list view.

If results have been calculated, then it is possible to change the display to show roses describing the data. To do this, use the display option buttons.



The picture below shows the wake loss roses, which is the most complicated view. You can change the size of the roses using the rose scale control. You can change the colours used to display the roses in the options window.

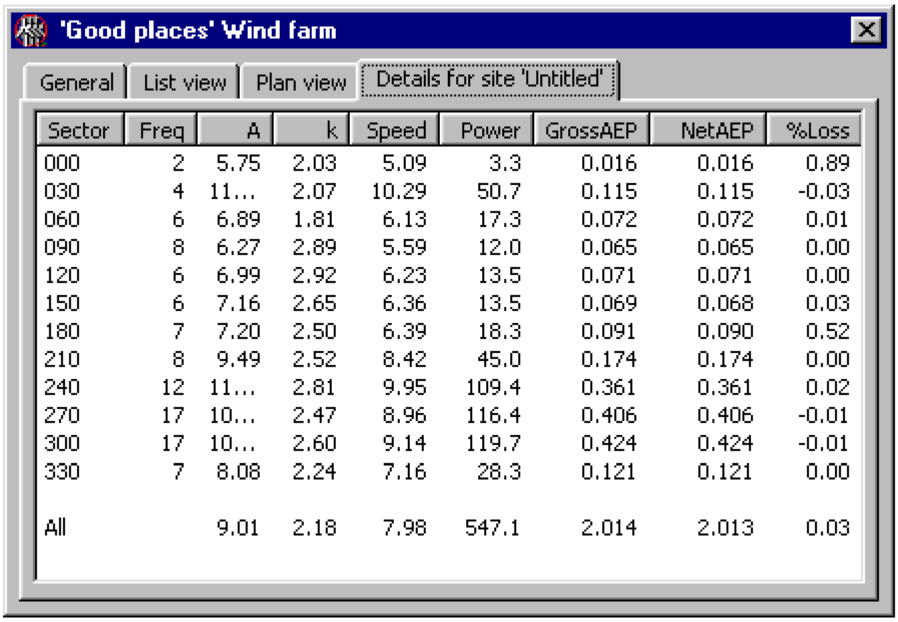


The yellow segments show the net power production, and the red segments show the power production lost to wake interference. The total shape of the segment illustrates the gross power and is indeed exactly what is shown if you select the power production roses button.

You can use the **Ctrl**-**C** key combination to copy a picture of the plan view display to the system clipboard.

The fourth view – detailed results for a single site

If a site is selected, either in the plan view or the list view, then it is possible to use the fourth tab to display detailed results for a single site.



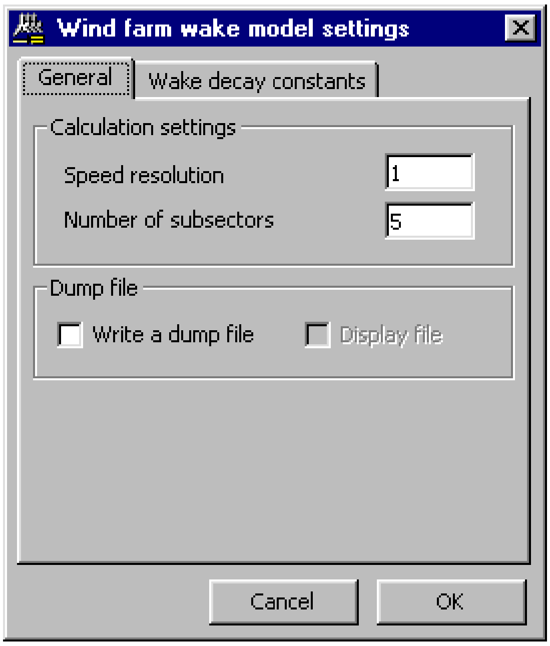
Sector	Freq	A	k	Speed	Power	GrossAEP	NetAEP	%Loss
000	2	5.75	2.03	5.09	3.3	0.016	0.016	0.89
030	4	11...	2.07	10.29	50.7	0.115	0.115	-0.03
060	6	6.89	1.81	6.13	17.3	0.072	0.072	0.01
090	8	6.27	2.89	5.59	12.0	0.065	0.065	0.00
120	6	6.99	2.92	6.23	13.5	0.071	0.071	0.00
150	6	7.16	2.65	6.36	13.5	0.069	0.068	0.03
180	7	7.20	2.50	6.39	18.3	0.091	0.090	0.52
210	8	9.49	2.52	8.42	45.0	0.174	0.174	0.00
240	12	11...	2.81	9.95	109.4	0.361	0.361	0.02
270	17	10...	2.47	8.96	116.4	0.406	0.406	-0.01
300	17	10...	2.60	9.14	119.7	0.424	0.424	-0.01
330	7	8.08	2.24	7.16	28.3	0.121	0.121	0.00
All		9.01	2.18	7.98	547.1	2.014	2.013	0.03

The display shows the results sector-by-sector and some sector-independent data too. If you want to investigate the predictions more closely (e.g. by exploring the corrections used), then you should create a separate turbine site hierarchy member and use that.

You can use the **Ctrl-C** key combination to copy these data to the system clipboard.

Wake modelling configuration

Pressing the wake modelling configuration button in the wind farm window will bring up the wake model settings dialog window. This box lets you control how the wake modelling is performed.



Calculation settings

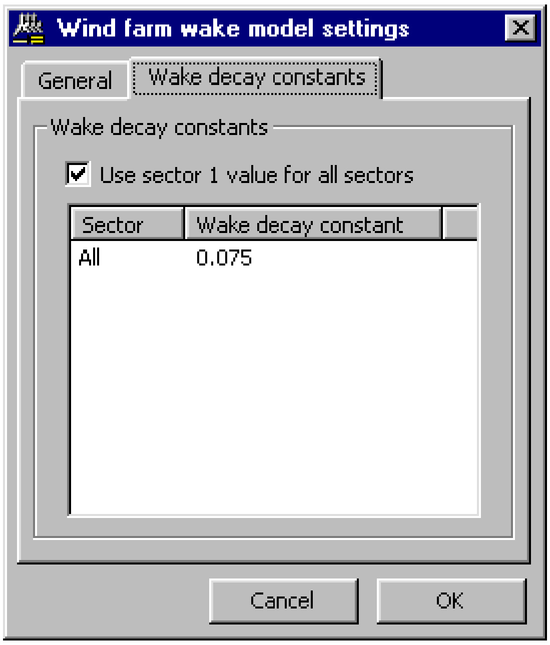
The number of steps per sector defines how many degrees the program steps between each wake calculation. It should be chosen such that the direction step becomes lower than about 5-8 degrees; the default value is five sub-sectors, corresponding to a step of 6º.

Wake model dump file

The dump file is a text file where the wind farm results are listed in some detail for each sector and for all sectors: Weibull *A* and *k*, frequency of occurrence, gross and net power production and efficiency of the turbines. It also gives the wind farm efficiency in per cent for all wind speeds and directions as well as the overall 'wind farm power curve', i.e. the power production of the entire farm as a function of the wind speed.

Wake decay constants

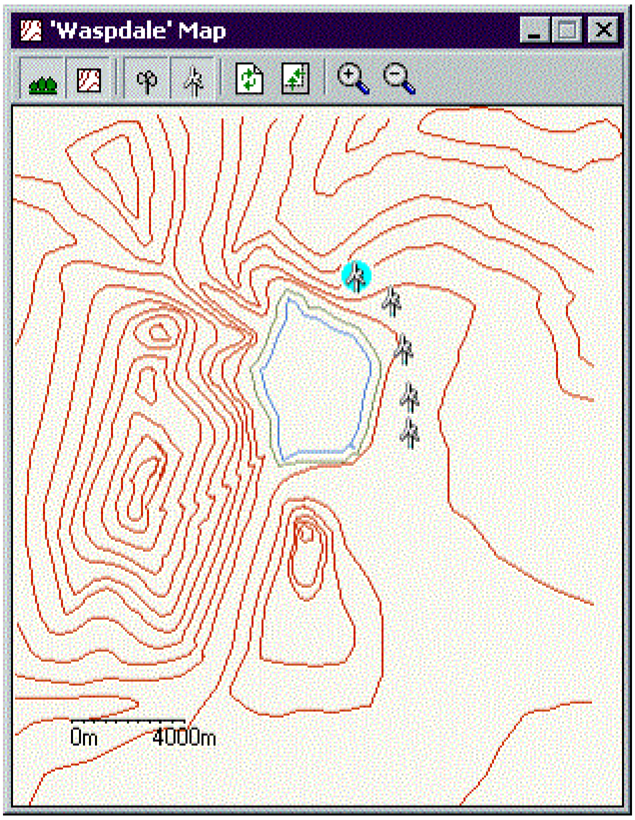
You can also specify which wake decay constant(s) to use in the wake modelling:



The default value is 0.075 used in all sectors.

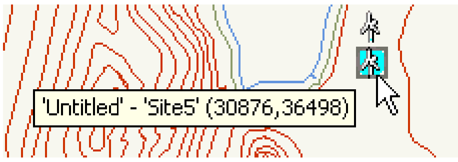
Wind farms in the map window

The sites in wind farm can be displayed in an associated map.



The same button on the map toolbar is used to control the display of normal turbine sites and wind farm sites. By default, the same icon is used as a wind farm site marker as a turbine site marker, but you can change the marker which is used. In the map display, there is no indication that the sites are members of the same wind farm.

To select a wind farm site, click on it with the left mouse button. It will be high-lighted and if you wait a moment, then a label will appear which displays the name of the wind farm, the name of the site and the exact co-ordinates of the site.



When selected, the site can be moved by dragging it with the left mouse button held down. It is also possible to copy the site by pressing and holding down the **Ctrl**-key and then dragging the highlighted site with the left mouse button. When you drop the site into a new location, a new site is automatically created and added to the wind farm. The original site remains unmoved. Doing this several times is a really quick way to set up a wind farm.

If a site is highlighted, then clicking on it with the right mouse button will cause the wind farm window to be displayed, with the highlighted site selected.

Preparing to calculate a wind farm

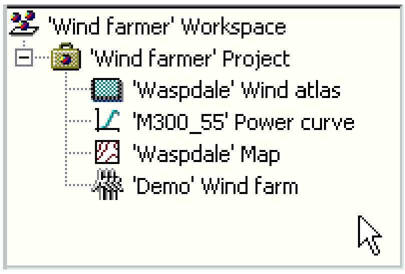
To be calculated, a wind farm must at least

- Be associated with a wind atlas
- Have all of its sites located within an associated map
- Be a member of a project

Optionally, a wind farm can:

- Be associated with a power curve
- Be associated with a thrust coefficient curve

The power curve must be specified in order to calculate power production, the thrust coefficient curve must be specified in order to calculate wind farm wake effects and wind farm efficiency. Here's what a typical work space would look like:



Starting from scratch, here's how to prepare to calculate a wind farm:

1. Create a new workspace
2. To the workspace, insert a new project
3. To the project, insert a wind atlas from file
4. To the project, insert a map from file
5. To the project, insert a power curve from file
6. To the project, insert a new wind farm

The actual wind farm layout can now be done from scratch, in the map or from file.

Setting up a wind farm from scratch

Starting from scratch, here's how to set up the turbines in a wind farm:

1. Right-click on the wind farm and choose to **View** the wind farm window
2. Right-click in the blank area of the 'List view' window to invoke the menu
3. Choose **Insert turbine site** to create the first site
4. In the 'List view' window, right-click the newly-created site
5. Choose either **Show site in map** or **Edit site location**
6. In the map window, drag the highlighted site to a likely location, or
7. Enter the turbine site coordinates in the 'Turbine site location' window
8. Add more wind turbine sites following points 8-12

It should now be possible to calculate the farm by pressing the 'Calculate all sites' button in the 'General' view of the wind farm window.

Wind farms can be set up in the map or the layout can be imported from a list of wind turbine coordinates.

Setting up a wind farm from the map

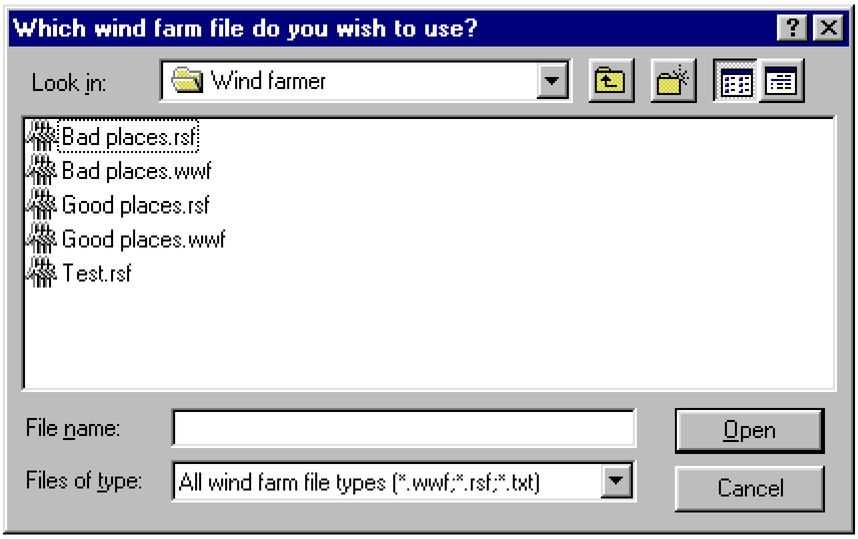
If a wind farm includes at least one site, then you can quickly and easily add more by working in the map. How to set up the first turbine is explained here.

1. Highlight one of the existing sites in the map by clicking on the marker with the left mouse button.
2. Press and hold down the **Ctrl-**key on the keyboard.
3. Click on the highlighted site with the left mouse button and drag the highlighted marker to a new location.
4. Drop the marker.
5. A new site is added immediately to the wind farm.

Sites can be moved by dragging the highlighted site to a new position in the map, or by right-clicking a highlighted site and entering the new map coordinates of the site.

Setting up a wind farm from file

If the layout of the wind farm is already given by the coordinates of the wind turbine positions, this layout can be imported directly from file:



Three different file types are recognised by WAsP:

1. WAsP wind farm files (*.wwf)
2. DOS-WAsP random resource files (*.rsf)
3. Free-format coordinate pairs files (*.txt)

When imported, sites can be moved by dragging the highlighted site to a new position in the map, or by right-clicking a highlighted site and entering the new map coordinates of the site.

Calculating a wind farm

If the wind farm is ready to be calculated, then the calculation can be performed by either

- Selecting the wind farm's **Calculate** method
- Pressing the calculate button on the wind farm's window
- Instructing the wind farm's project to update all calculations

After a wind farm is calculated,

- if the wind farm window is open, then the data grid will be immediately refreshed to display the new data,
- the wind farm icon will change to indicate that it is not due for re-calculation.

About resource grids

Resource grids let you manage a rectangular set of points for which summary predicted wind climate data are calculated. The points are regularly spaced and are arranged into rows and columns. This lets you see a pattern of wind climate or wind resources for an area. You don't need to create each point in the grid individually. Instead you just specify the location of the grid, the number of rows and columns and the distance between the points.

Each point in the grid is like a simpler version of a normal turbine site. All the points have the same height a.g.l. If a power curve is associated with the grid, then that curve is used for all of the points in the grid.

A point cannot have an associated obstacle list, or a site-specific roughness description (roughness rose); the roughness must be specified in the map as roughness change lines. A point does not have an associated predicted wind climate hierarchy member, instead just a few key summary data are generated for each point. If you want to generate a more detailed prediction for a point, then you need to create a normal turbine site.

For each point, WAsP calculates the following data:

- the elevation
- the mean wind speed
- the mean power density
- the annual energy production (if a power curve is associated)
- the Weibull-*A* value
- the Weibull-*k* value

When a resource grid is saved, not all of the calculated data are saved to file. Mean wind speed data are never saved. If power data were calculated, then energy data are not saved. If power data were not calculated, then they are not saved.

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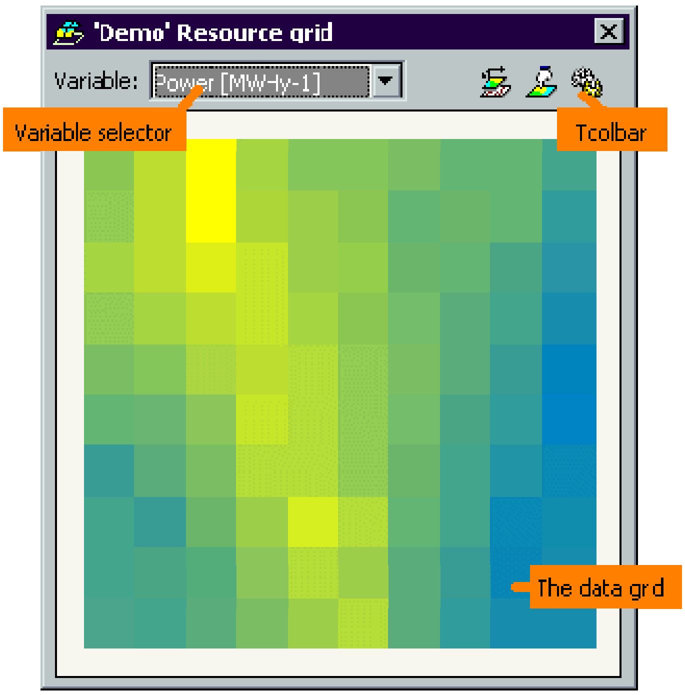
The resource grid window

The resource grid window displays the calculated data for the points in the grid, and provides a toolbar to let you work with the grid.



If the grid has data to display, then you can choose which data to view by selecting a variable from the variable selector. The data grid will be updated to show the data for the selected variable. If no variable is selected or if no data are available, then a simple array of points markers is shown to illustrate the structure of the grid.

There is no scale, but if you allow the mouse pointer to linger for a moment over the coloured grid, then a label will appear which provides details of the current location and the data value for that point.

Whichever variable is selected, and whatever the data values are, the data are always displayed using a simple linear colour scale in which the range of colours is scaled from the minimum value found to the maximum value found. The WAsP options window allows you to change the colours used.

The toolbar has three buttons.

 If the resource grid is located within the area covered by an associated map, then pressing this button will show the map with the resource grid displayed as a colour underlay.

 This button lets you configure the grid. Pressing this button displays the resource grid configuration dialog.

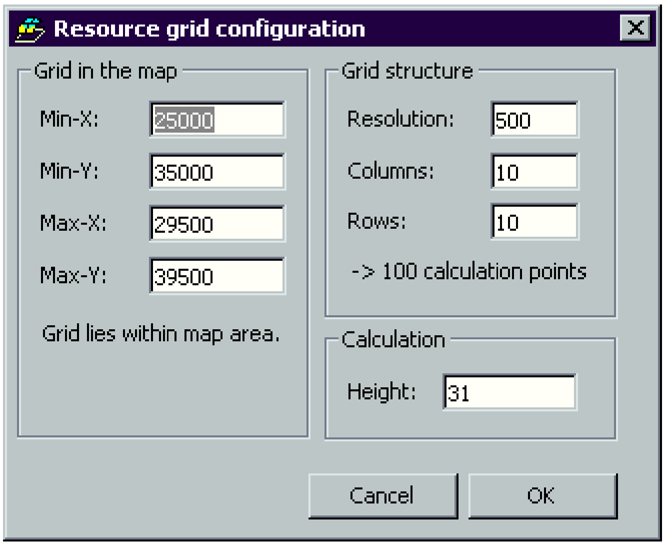
 This is the calculate button. Pressing it will cause the whole grid to be recalculated.

 If the grid cannot be calculated then the calculate button icon is changed to this. Pressing the button will cause a message to be displayed which explains why the resource grid cannot be calculated.

The buttons on the toolbar correspond to methods of the resource grid's menu.

Configuring a resource grid

To configure the resource grid, either press the configure button on the toolbar of the resource grid window, or choose to configure from the menu of methods. A window like the one shown below will appear.



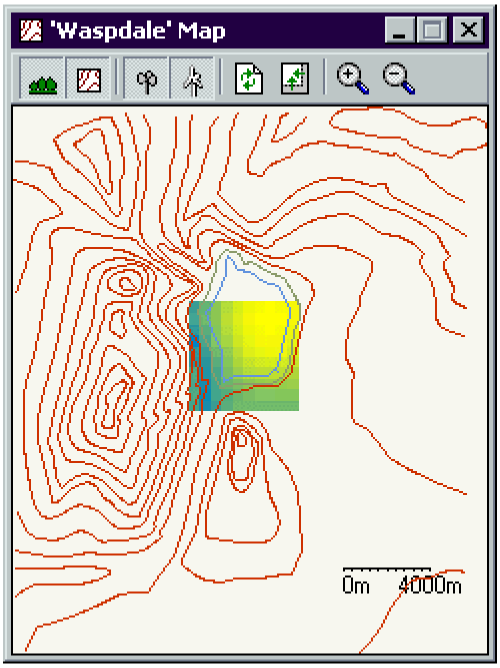
The grid is configured by providing several data values. The four data on the left are used to locate the grid in the map and the three on the right are used to define the structure of the grid. Since these data are inter-dependent, WAsP automatically completes the values for some of the data as you work. For example, if you simply provide values for Min-*X* and Min-*Y* and then go directly on to specify the resolution and rows and columns, then WAsP will calculate the Max-*X* and Max-*Y*.

WAsP immediately determines whether the grid lies completely within the area of any associated map and displays the number of calculation points contained in the grid which you have specified.

This dialog can also be used to set the height for the calculation. If a power curve is associated with the grid, then the default height for that power curve is used automatically. You can simply override such a value by editing the box shown here. If you subsequently rearrange the hierarchy so as to associate a different power curve with the resource grid, then WAsP will ask whether you want to use the current height or replace it with the default height for the newly-associated power curve.

Resource grids in the map window

To display the resource grid in the map window, press the display in map button on the resource grid window toolbar, or select the appropriate method from the menu of methods. The map will be shown and the resource grid will be illustrated as an 'underlay' to the contour and roughness change lines.



The grid shown is the same as the variable which has been selected in the resource grid window variable selector. If no variable has been selected, then the outline of the grid is shown instead. If you change the selected variable in the resource grid window, the grid in the map will not be automatically updated: you need to force the grid to redisplay itself in the map.

Unlike met. stations, turbine sites and wind farm sites, the resource grid cannot display continuously with the map. If you resize or redraw the map, then the grid will disappear, and you need to force it to redisplay to see it again.

It is not possible to move or resize the grid from the map window: you need to use the resource grid configuration dialog.

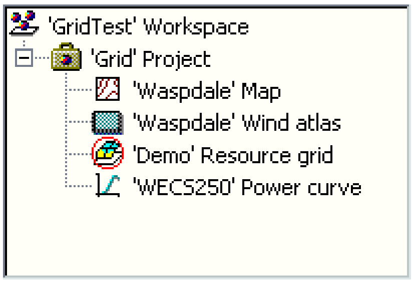
Preparing to calculate a resource grid

To be calculated, a resource grid must

- Be associated with a wind atlas
- Be entirely located in an associated map
- Be a member of a project

Optionally, a resource grid can:

- Be associated with a power curve



Starting from scratch, here's how to prepare to calculate a resource grid:

1. Create a new workspace
2. To the workspace, insert a new project
3. To the project, insert a new resource grid
4. To the project, insert a wind atlas from file
5. To the project, insert a map from file
6. In the resource grid configuration dialog, specify the location of the grid in the map

7. In the resource grid configuration dialog, specify the size and resolution of the grid
8. Specify a height for the resource grid calculations

Calculating a resource grid

If the resource grid is ready to be calculated, then the calculation can be performed by either

- Selecting the resource grid's **Calculate** method
- Hitting the calculate button on the resource grid's window
- Instructing the resource grid's project to update all calculations

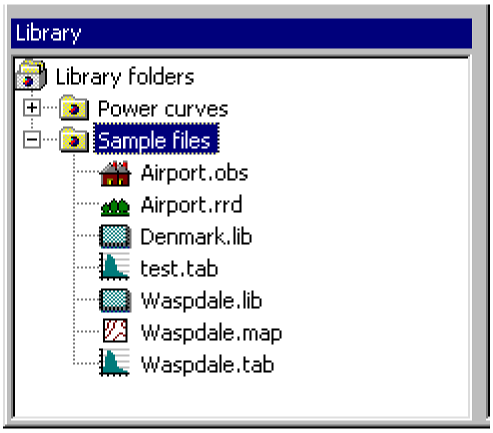
After a resource grid is calculated,

- if the resource grid window is open and a variable is selected for display, the data grid will be immediately refreshed to display the new data,
- the resource grid icon will change to indicate that it is not due for re-calculation.

An example of the results of a resource grid calculation is given here.

About the library

The library makes it faster to open files in WAsP. The library contains library folders. Each library folder contains a list of files which can be opened directly into the WAsP workspace hierarchy, thereby avoiding the need to use the file selection dialog. In other words, each library folder is a mapped to one or more folders on the file system, and presents a list of the files found, filtered by type. The library can be easily re-configured to suit the way you store your files.



The library is arranged as a simple hierarchy, with only three levels:

- the library root
- the library folders
- the library folder contents: , , , *etc.*

Library folders cannot contain other library folders.

Each library folder contains a list of files. Only files which can be opened in the WAsP workspace hierarchy are shown. Each file is shown with the icon of the type of hierarchy member which corresponds to the file type. The files' extensions are also shown.

Each library folder is associated with one or more folders on the computer's file system and presents a list of files that are found in that file system folder(s). Library folders can list all of the WAsP files found, can list only one type of WAsP file or can list several WAsP files. They do not list files found in sub-folders on the file system folder.

The library is not visible unless a workspace is open.

Opening files from the library

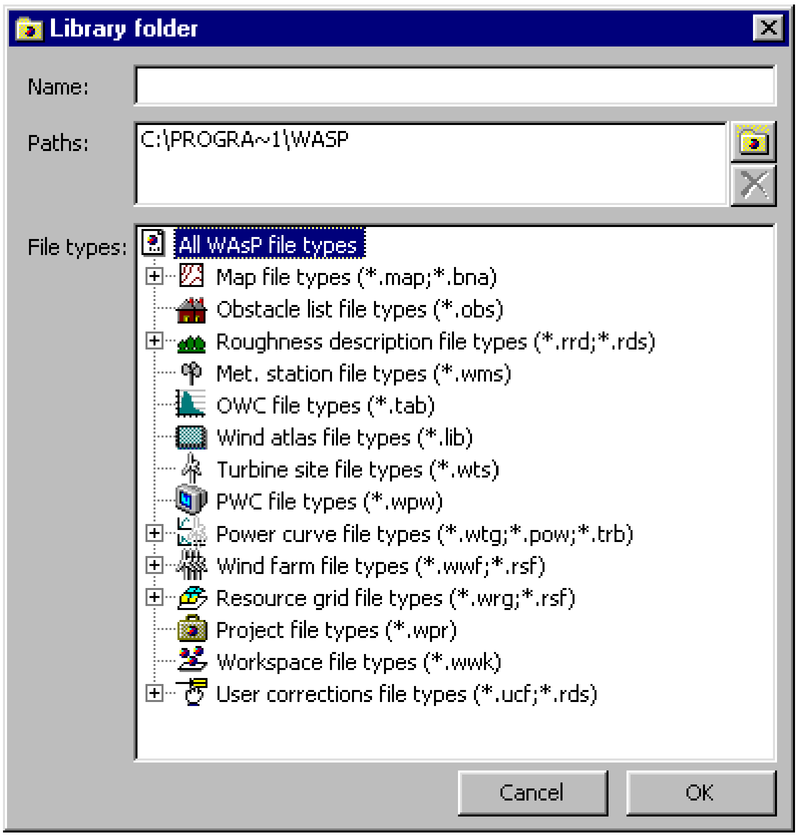
Files from the library can be opened into the workspace in three ways:

1. Files can be dragged from the library to become children of an existing member in the workspace hierarchy.
2. Files can be opened into the root of the workspace by double-clicking on them in the library.
3. Files can be opened into the root of the workspace by selecting **Open member in workspace** from the file's right-click popup menu.

Adding and removing library folders

To add a new library folder

1. Select the library root
2. From root's the right-click menu, select **Add new folder**
3. A dialog appears, allowing you to set the properties of the new library folder:



1. Type a **Name** for the library folder. This is only used to identify the folder in the library pane.
2. Select one or more **Path**'s to a folder on the computer's file system. The library folder will list the files from this/these file system folder/s.
3. From the **File types** pane, select one or more types of files to be listed in the library folder. You can set the library folder to list all types of WAsP files, just one type or several types. The type is chosen by left-clicking on them; if choosing more than one you must hold down the **Ctrl**-key.

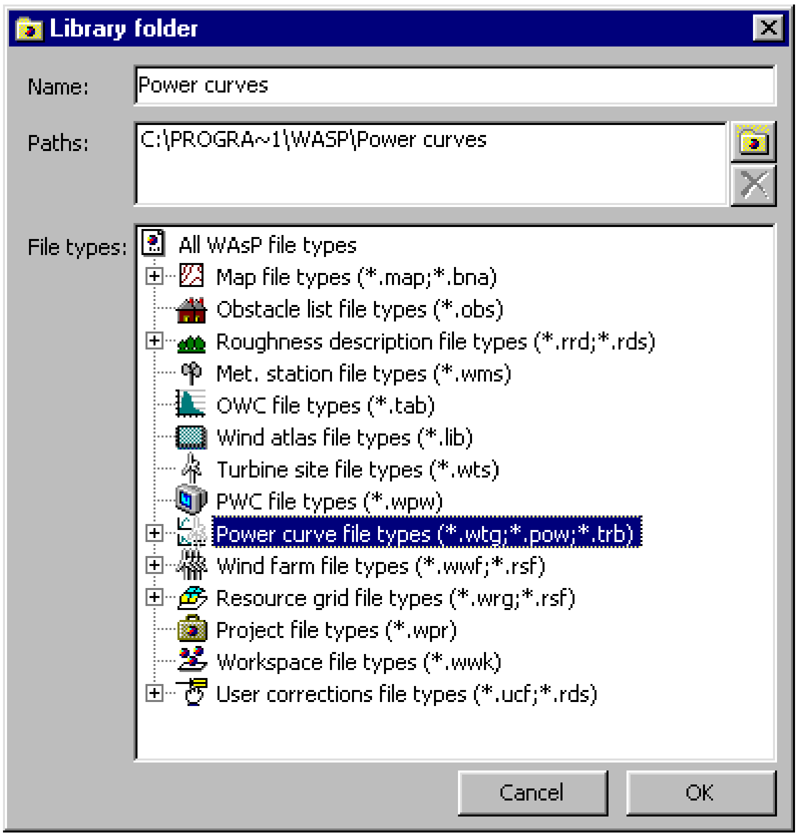
To remove an existing folder

1. Select the library folder to be deleted
2. From library folder's the right-click menu, select **Remove folder**

Editing library folder properties

It's easy to change the properties of a library folder:

1. Select the library folder to be edited
2. From the folder's right-click menu, select **Edit folder properties**
3. A dialog appears, allowing you to change the properties of the new library folder:



1. Change the **Name** for the library folder.
2. Change or select one or more **Path**'s to a folder on the computer's file system. The library folder will list the files from this/these file system folder/s.
3. From the **File types** pane, select one or more types of files to be listed in the library folder. You can set the library folder to list all types of WAsP files, just one type or several types. The type is chosen by left-clicking on them; if choosing more than one you must hold down the **Ctrl**-key.

Refreshing the library contents

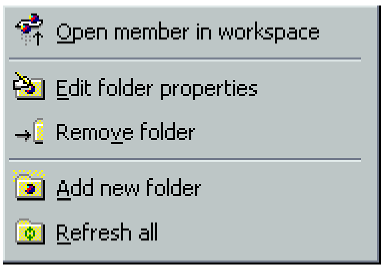
The library's folders' contents are automatically refreshed whenever a folder is added, removed or edited. Sometimes, it is useful to force the library to refresh the file list. For example, if you have moved or deleted a file using the Windows Explorer and want the change to be reflected in the library.

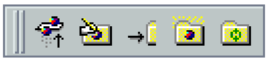
There are two ways to refresh the library's contents.

1. Select the library root  and from the root's the right-click menu, select **Refresh all** 
2. Click anywhere on the library and press the **F5** key.

The library menu and toolbar

The main window has a toolbar and a menu which can be used to work with the library. The menu and toolbar buttons are the same as the library's right-click pop-up menu.





If the library is not currently selected, then both the toolbar and the menu will be disabled. Different menu options and toolbar buttons become enabled and disabled depending on whether the library root, a library folder or a file is selected.

About GUI options

You can change the way that the WAsP user interface behaves by setting options in the options window. These options do not affect the way calculations are performed, but are limited to the display and file management.

The options window can be displayed by selecting **Options** from the **Tools** menu of the main window.

With the options window, you can:

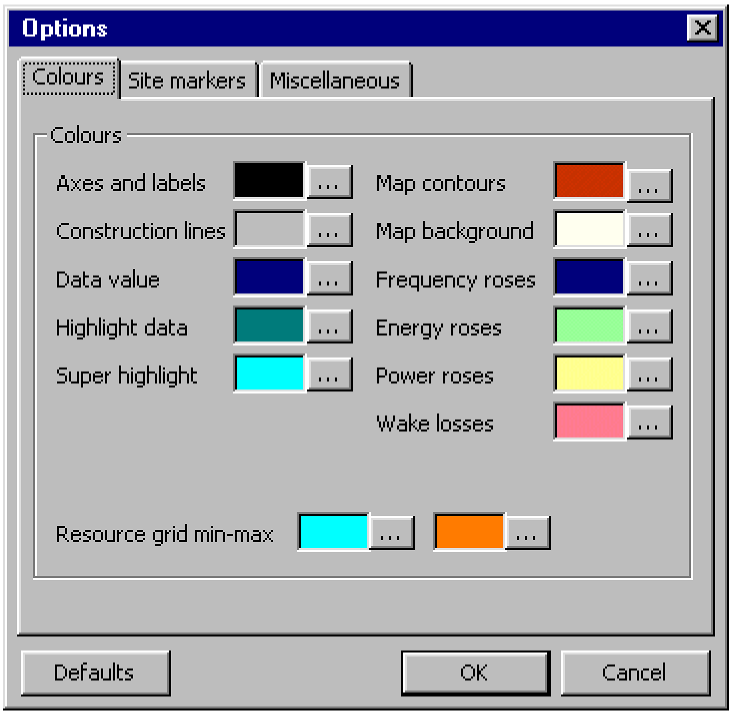
1. Change the display colours
2. Change the markers used in the map
3. Change miscellaneous options

There is a button marked **Defaults**, which is always available. Pressing this button will return *all* settings to their default values.

Setting display colours

Here you can choose which colours WAsP should use when preparing graphical displays.

To change a colour, click on the button next to it marked with three dots.



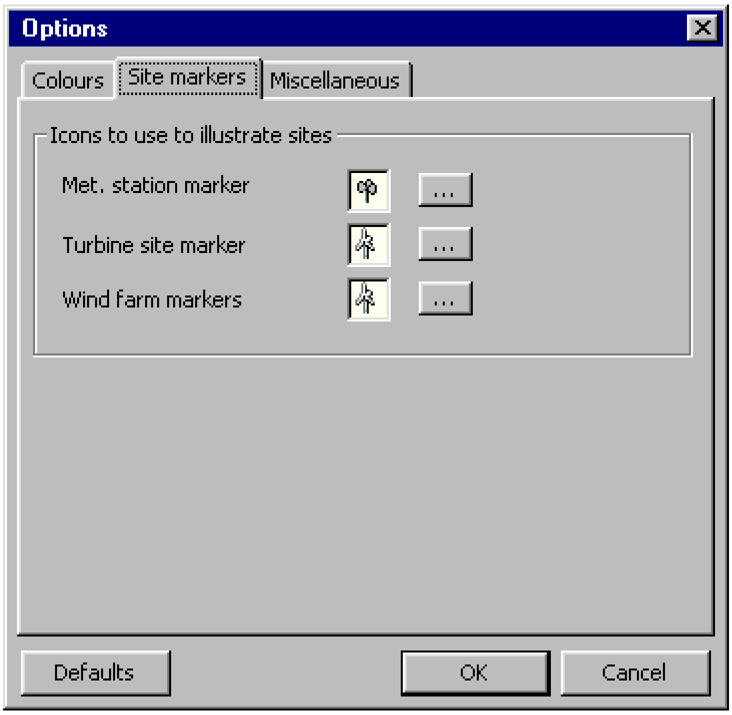
When displaying resource grids, WAsP interpolates between the min and max colours which you select.

If you change a colour, the affected displays will not be immediately adjusted. The next time that they are redrawn, the new colour will be used.

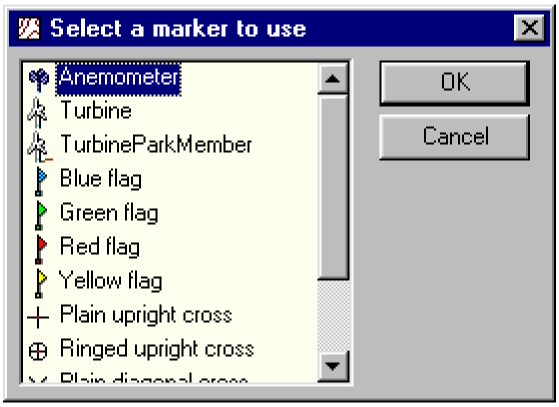
The roughness description colour scale is not editable.

Changing map markers

Here you can choose which marker WAsP should use when indicating the location of met. stations, turbine sites and wind farm sites in the map.



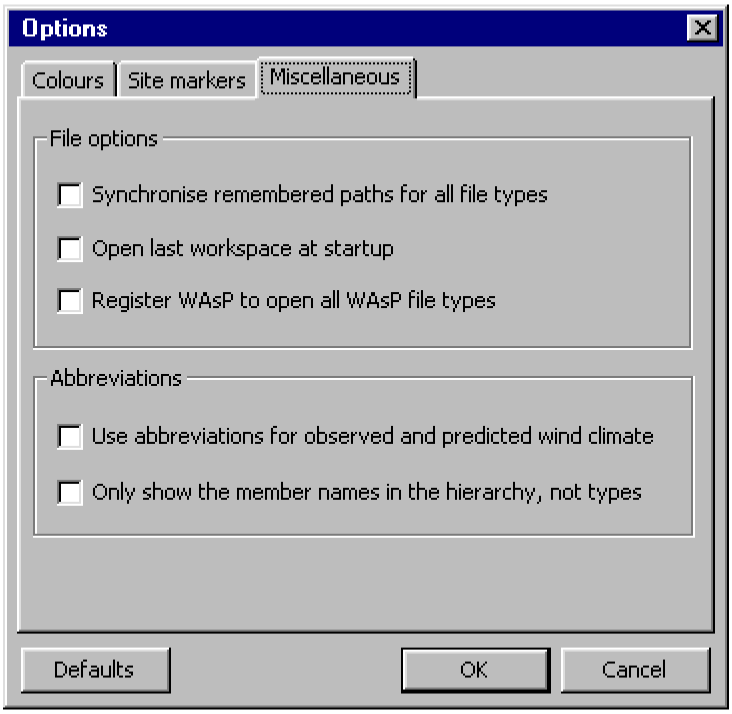
To choose a marker, press the button marked with three dots next to the one you wish to change. Another dialog will appear, displaying a list of markers.



Select a marker from the list.

Miscellaneous options

You can use this part of the options window to change some miscellaneous options.



1. When you open or save a file, WAsP remembers where you found or placed it. Next time you open or save a file of the same type, WAsP will automatically offer you the same directory as you last used. By default, WAsP remembers a separate directory for each type of file, but you can tell WAsP to remember the same directory for all file types. Which setting is best will depend on the way that you work and the way that you organise your files.
2. When WAsP starts, no workspace is open. If you wish, you can tell WAsP to open the workspace which you were last using.
3. When you first run WAsP, the program is associated with several different types of files, so that Windows knows to use WAsP to work with files of those types. It's possible that these settings can be disrupted. Check this box to restore the WAsP file associations. The associations will be restored the next time that you start the WAsP program.
4. The names 'observed wind climate' and 'predicted wind climate' are rather long, and tend to make it difficult to see things in the workspace hierarchy. If you tell WAsP to use abbreviations instead, then 'OWC' and 'PWC' will be used when identifying hierarchy members. This setting will only be effected when you next start WAsP.
5. If you still think the workspace hierarchy is 'too wide', you can tell WAsP to show only icons and member names in the hierarchy tree.

WAsP tools

The **Tools** menu is used to launch utility programs from within WAsP. The following tools are available:

- The OWC Wizard
- The WAsP map editor
- The Air Density Calculator

In addition, the following DOS utility programs are included on the CD-ROM and installed in the main WAsP directory:

- The RIX Calculator
- The DXF Translator

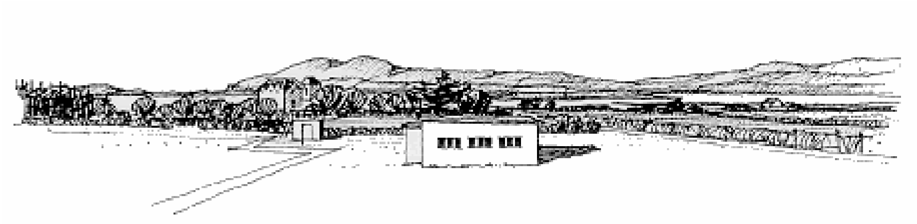
Other software and hardware may also be useful in working with WAsP.

Introduction

This section of the help facility describes the topographical concepts used in WAsP modelling, as well as the different models of WAsP: the roughness model, the flow model, the shelter model and the wind farm model.

In general terms, accurate predictions using the WAsP program may be obtained (Bowen and Mortensen, 1996) provided:

- the reference site (meteorological station) and predicted site (wind turbine site or met. station) are subject to the same overall weather regime,
- the prevailing weather conditions are close to being neutrally stable,
- the reference wind data are reliable,
- the surrounding terrain (of both sites) is sufficiently gentle and smooth to ensure mostly attached flows, and
- the topographical model inputs are adequate and reliable.



Introduction

Time-series of wind data or climatological (statistical) summaries may be obtained from synoptic stations, from stations established for the collection of climatic data or from other sources. In the selection of wind data a number of goals should be aimed at which can be summarised as follows:

- Sufficient time period. At least one year, but preferably several years.
- Well exposed anemometer, far from buildings and other obstacles. This requirement is often the most difficult to satisfy.
- Accurate description of anemometric conditions and data of 10-min or hourly averages collected for e.g. each 3-hour period throughout the 24-hour day.

Using raw data as the initial data source is generally preferable, since this allows detection of errors in the data which may be undetectable in data summaries. The raw data must be processed by the OWC Wizard in order to obtain a statistical summary table that can be employed by WAsP.

The data characteristics that are important for the processing of a time-series of wind speed and direction can conveniently be collected by filling in a WAsP Data Description Form. Ask the data supplier to fill in this form if you do not collect the data yourself.

Inspection and quality control

Data should be carefully inspected even though they are assumed to be quality-controlled by the supplying organisation. The most important checks after receipt of the data are: visual inspection of the time series of wind speed and direction and inspection of the frequency table (histogram). By inspection, it is possible to detect data deficiencies such as:

- Abnormally high wind speeds.
- An abnormal number of observations in certain wind speed classes and/or wind direction sectors.
- Certain patterns in the table caused by the transformation of data originally reported in Beaufort, knots, miles per hour etc. to metres per second. The transformation of data measured in for example 16 sectors to 12 sectors may also cause a pattern in the table.
- Stations with a systematic lack of observations, e.g. no night-time observations.

The cure for these data deficiencies is often quite simple (European Wind Atlas, 1989). The abnormally high wind speeds can be removed manually. Abnormal occurrences of wind speeds and directions should be checked against known climatology. The patterns caused by data discretisation can be eliminated by WAsP, given the discretisation bin widths.

In general, there is no simple procedure for filling in missing data.

Data discretisation

An important consideration is the question of whether the wind data have already been truncated severely. If, for example, a 'raw' data set is given in integral ms^{-1} due to prior processing (which is common practice for some meteorological stations) use of the OWC Wizard with the default setting for the wind speed bins of 1 ms^{-1} will cause errors, since the speed value $u = n$ (n integer) will add to the nth bin, which is subsequently represented by its midpoint value $um = n + 0.5$.

To avoid this shifting of the wind speed and direction distributions, it is possible to specify the discretisation bin widthsapparent in the raw data. WAsP will then automatically correct for this effect when calculating the distributions. Note, that discretisation errors will be apparent in the 'OWC Wizard - Finished' window.

If a table/histogram has already been compiled on the basis of a discretised time-series and the series is not readily available for re-processing, the bin limits of the TAB-file could be adjusted using a text editor. The corrected file is subsequently used as input to WAsP.

Example 1

If wind speeds are given in integral metres per second (1, 2, 3, ...) and wind directions in 36 classes (10, 20, 30, ..., 360) the discretisation bin widths are 1.0 ms^{-1} and 10º, i.e. 1.0 and 10.0. Note, that scaling of the raw data is not required.

Example 2

If wind speeds are given in integral knots (1, 2, 3, ...) and wind directions in 32 classes or points (1, 2, 3, ..., 32) the discretisation bin widths are 1.0 knot and 1 point, i.e. 1.0 and 1.0. Note, that in this case the wind speeds would also have to be multiplied by 0.5144 [ms^{-1}/knot] and wind directions by 11.25 [º/point]; since WAsP accepts SI-units only.

Anemometric conditions

Most wind speed measurements are made using cup anemometers. The accuracy and reliability of such wind data are influenced by the factors and conditions listed below.

- **Tower shadow**
- **Boom and clamp effects**
- **Anemometer design**
    - distance constant (l_0)
    - mech. and elec. construction
- **Turbulent biases**
    - *u*-bias, proportional to $(sU/U)^2$ (overspeeding)
    - *v*-bias, proportional to $(sV/U)^2$ (DP-error)
    - *w*-bias, proportional to $(sW/U)^2$ (angular response)
    - stress-bias, proportional to $<uw>/U^2$
- **Calibration procedure**
    - wind tunnel calibration
    - atmospheric (in-situ)
- **Anemometer condition**
    - long-term stability of output
    - maintenance schedule
- **Environmental conditions**
    - sea spray, salt, dust, insects, ...
    - icing of instrument
- **Anemometer siting**

A standard WAsP analysis is concerned mainly with the siting of the anemometer through the descriptions and modelling of the surrounding topography. However, all of the factors listed above should be evaluated to obtain the highest accuracy in the wind speed and direction data – and thereby in the production estimates.

Introduction

Estimation of the wind resource ranges from overall estimates of the mean energy content of the wind over a large area – called *regional assessment* – to the prediction of the average yearly energy production of a specific wind turbine at a specific location – called *siting*. The information necessary for siting generally needs to be much more detailed than in the case of regional assessment. However, both applications make use of the general concepts of topography analysis and regional wind climatologies.

In order for WAsP to calculate the effects of topography on the wind at a given place ("the site") it is necessary to describe systematically the characteristics of the surroundings. The site may be a projected wind turbine site or a met. station or wind mast.

For a given situation, there are three main effects of topography on the wind: roughness, orographic and shelter effects. In nature these effects are not entirely independent. The program takes this into account, but allows the user to specify the close-by sheltering obstacles, the roughness of the surrounding terrain, and the orography independently. How these terrain characteristics are obtained and entered to WAsP is explained in the following.

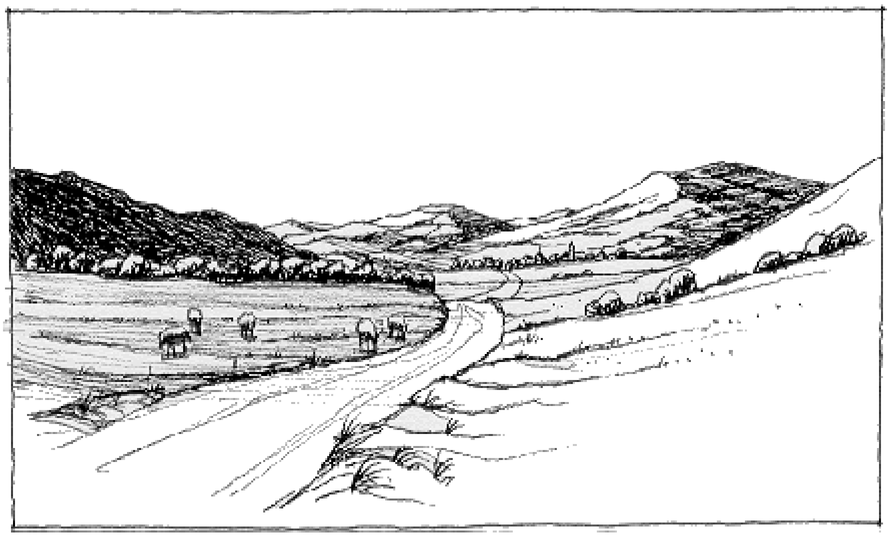
For a given site, there may not be any near-by obstacles present and therefore no shelter effects. Similarly, the site may be situated in entirely flat terrain in which case there will be no effects of the orography. However, the surface will **always** influence the wind through the roughness of the terrain. So, even for the simplest of sites you must evaluate and specify the terrain surface roughness. If you do not specify the roughness explicitly, WAsP will assume a default roughness length of 0.03 m.

Roughness

The collective effect of the terrain surface and obstacles, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain. However, not all the topographical elements contribute to the roughness. Vegetation and houses are examples of roughness elements, whereas long smooth hills, for example, are not, because they do not themselves cause an increase in the turbulence of the flow.

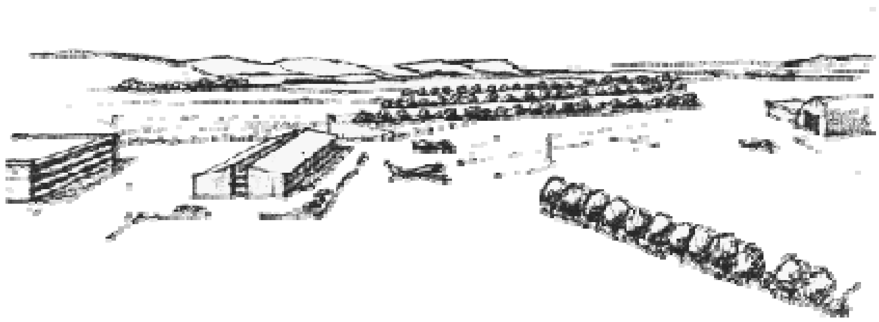
Orography

Orographic elements such as hills, valleys, cliffs, escarpments and ridges exert an additional influence on the wind. Near the summit or crest of these features the wind will accelerate while near the foot and in valleys it will decelerate.



Obstacles

Close to an obstacle such as a building the wind is strongly influenced by the presence of the obstacle. The effect extends vertically to approximately three times the height of the obstacle, and downstream to 30 to 40 times the height. If the point of interest is inside this zone, it is necessary to take the sheltering effects into account, whereas if the point is outside the zone the building should be treated as a roughness element.



The buildings and rows of trees shelter the met. mast in the center of the drawing.

Practical considerations

When it comes to describing a site in practice it is recommended that the following material is available:

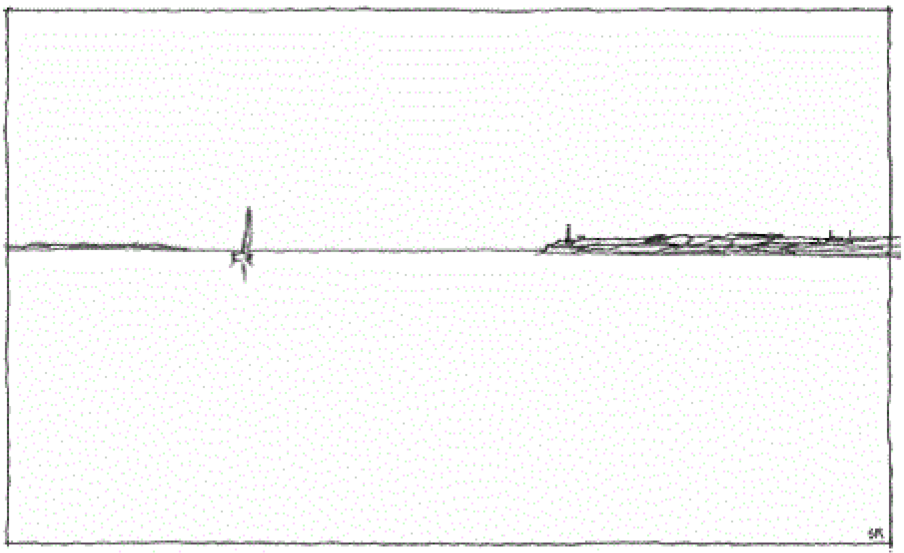
- a recently revised topographical map on a scale of 1:25,000 or 1:50,000 with height contour lines.
- a topographical map or sketch showing the distribution of areas with different roughness, e.g. forests, shelter belts (windbreaks), lakes, oceans, towns etc. If this is not at hand, a roughness rose (i.e. a sector-wise description of the roughness in e.g. 12 sectors) should be constructed.
- a map or sketch showing sheltering obstacles close to the point of interest.

Photographs of the surroundings of the site and/or aerial photographs may come in handy if a visit to the site(s) is not feasible. In general, however, a visit to the site(s) is strongly recommended.

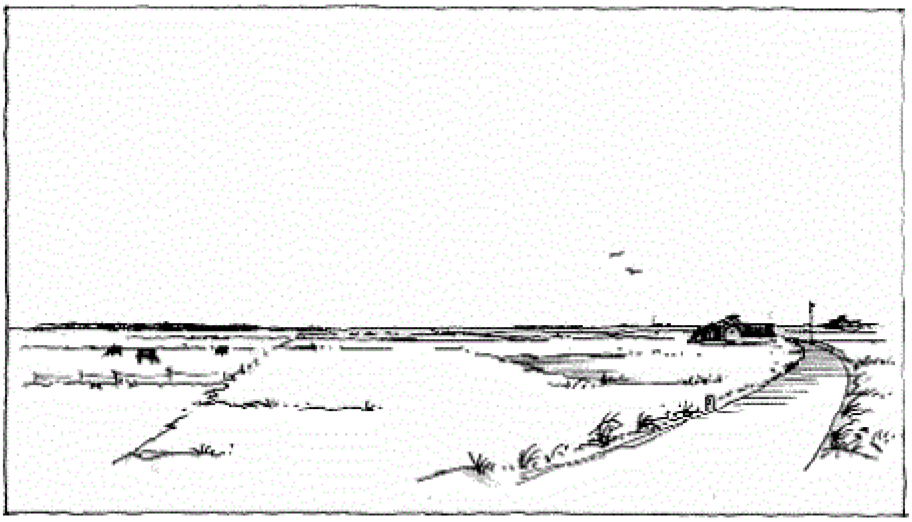
A list of tools you might find useful for site visits is given here. A number of WAsP forms have also been developed as an aid in collecting the relevant data and site information.

The roughness of a terrain

The roughness of a particular surface area is determined by the size and distribution of the roughness elements it contains; for land surfaces these are typically vegetation, built-up areas and the soil surface. In the European Wind Atlas (Troen and Petersen, 1989) the different terrains have been divided into four types, each characterised by its roughness elements. Each terrain type is referred to as a *roughness class*. A description and illustration of these four roughness classes is given in the figures below which furthermore give the relation between roughness length and roughness class, the former being the commonly used length scale to characterise the roughness of a terrain.



Example of terrain corresponding to roughness class 0: water areas. This class comprises the sea, fjords, and lakes. The roughness length is z_0 = 0.0002 m.



Example of terrain corresponding to roughness class 1: open areas with few windbreaks. The terrain appears to be very open and is flat or gently undulating. Single farms and stands of trees and bushes can be found. The roughness length is z_0 = 0.03 m.

Example of terrain corresponding to roughness class 2: farm land with wind-breaks, the mean separation of which exceeds 1000 m, and some scattered built-up areas. The terrain is characterised by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or undulating. There are many trees and buildings. The roughness length is z_0 = 0.10 m.

Example of terrain corresponding to roughness class 3: urban districts, forests, and farm land with many windbreaks. The farm land is characterised by the many closely spaced windbreaks, the average separation being a few hundred metres. Forest and urban areas also belong to this class. The roughness length is z_0 = 0.40 m.

The roughness length

The roughness of a terrain is commonly parameterised by a length scale called the roughness length, z_0. Formally, z_0 is the height where the mean wind speed becomes zero, if the wind profile has a logarithmic variation with height. This usually occurs during moderate and strong wind conditions.

A simple empirical relation between the roughness elements and the roughness length has been given by Lettau (1969). A roughness element is characterised by its height *h* and the cross-section facing the wind *S*. Further, for a number of roughness elements distributed evenly over an area, the density can be described by the average horizontal area, A_H, available to each element. Then

$$z_0 = 0.5\ (h \cdot S)\ /\ A_H$$

This relation gives reasonable estimates of z_0 when A_H is much larger than *S*. It tends to overestimate z_0 when A_H is of the order of *S*; this is because, when the roughness elements are close together, the flow is 'lifted' over them. Then only a fraction of *S* and *h* contributes to the roughness. Furthermore, the lifting of the flow requires measuring the height above ground from somewhere between the top of the roughness elements and half the height of the elements. This height is referred to as a *displacement length*. The displacement length must often be taken into account on sites with forests, cities, and tall vegetation. Finally, the equation assumes that the porosity is approximately zero, i.e. the roughness elements are solid. For porous roughness elements, z_0 from the equation above must be reduced by a fraction equal to the porosity. An example of the use of this equation is given here.

Table of roughness lengths

The table below indicates the relation between roughness length, terrain surface characteristics and roughness class given in the European Wind Atlas. The table may serve as a guideline for assigning roughness length values.

***z*0 [m]**	**Terrain surface characteristics**	**Roughness Class**
1.00	city	
0.80	forest	
0.50	suburbs	

0.40		**3** (0.40 m)
0.30	shelter belts	
0.20	many trees and/or bushes	
0.10	farmland with closed appearance	**2** (0.10 m)
0.05	farmland with open appearance	
0.03	farmland with very few buildings/trees	**1** (0.03 m)
0.02	airport areas with buildings and trees	
0.01	airport runway areas	
0.008	mown grass	
0.005	bare soil (smooth)	
0.001	snow surfaces (smooth)	
0.0003	sand surfaces (smooth)	
0.0002		**0** (0.0002 m)
0.0001	water areas (lakes, fjords, open sea)	

It should be noted that in general the roughness length as applied in WAsP has to be considered as a climatological parameter because the roughness of an area changes with foliation, vegetation, snow cover and so on. The energy production of a wind turbine must be determined on the basis of climatology, primarily because of the variations of the weather; however, the seasonal variations in the local terrain characteristics can also have a profound influence.

Roughness of water

The roughness length of surfaces covered by vegetation may vary with the wind speed. For example, the bending of stalks by the wind can change the form of the surface. A similar phenomenon occurs for water waves where both the height and form of the waves are dependent on wind speed. From dimensional arguments, the following equation can be obtained for the roughness over water when viscous effects and the surface tension of the water are neglected (Charnock, 1955):

$$z_0 = b \cdot u_*^2/g$$

where b is a constant (approx. equal to 0.014), g the gravitational acceleration, and u_* the friction velocity.

During the development of WAsP it was attempted to use both the equation above and a fixed value for the roughness of water areas, roughness class 0. It turned out that a fixed value of 0.0002 m gave results as good as the Charnock equation for the moderate to high wind speeds of interest to wind energy applications, hence all calculations in WAsP are obtained with this value.

Note, however, that on input the roughness of water must be given as 0 (zero), in order for WAsP to distinguish between water areas and very smooth land surfaces.

Specifying terrain roughness

There are two different ways of describing the roughness characteristics of the terrain surrounding a site:

- in the form of a digital map of roughness-change lines, i.e. lines separating areas of equal roughness (length). The roughness map describes the distribution of areas of equal roughness length from which WAsP is able to interpret the roughness conditions at any site within the map
- in the form of a site-specific roughness description, also referred to as a roughness rose. In this case the roughness conditions at one site are described sector by sector as seen from the site, i.e. the description contains the distance to and magnitude of the roughness changes that occur in each sector.

In the first case, WAsP calculates its own roughness rose from the roughness map, in the second case WAsP uses the rose specified by the user directly. The input to the model accounting for roughness is thus in both cases a roughness rose.

The roughness map offers the greatest flexibility, because the site can be chosen at random within the area covered by the map. The roughness rose, on the other hand, generally offers higher accuracy in the roughness description of single sites.

The surface will **always** influence the wind through the roughness of the terrain. Even for the simplest of sites you must evaluate and specify the terrain surface roughness. If you do not specify the roughness explicitly, WAsP will assume a default roughness length of 0.03 m in all sectors.

Introduction

Areas of different roughness are apparent on most topographical maps. Examples are: water areas (the sea, fjords, lakes), sand surfaces, bare soil, moor, open farmland, farmland with many shelter belts, forests, villages, and cities.

The landscape can be classified into areas of similar roughness on basis of the information contained in the map, as well as any other information available, e.g. aerial photographs. This classification may be thought of as dividing the landscape into a number of terrain types or roughness classes – often in more detail than the classes mentioned above. When the classification has been done, a roughness length z_0 can be assigned to each class; one possible relation between roughness class and roughness length was given here.

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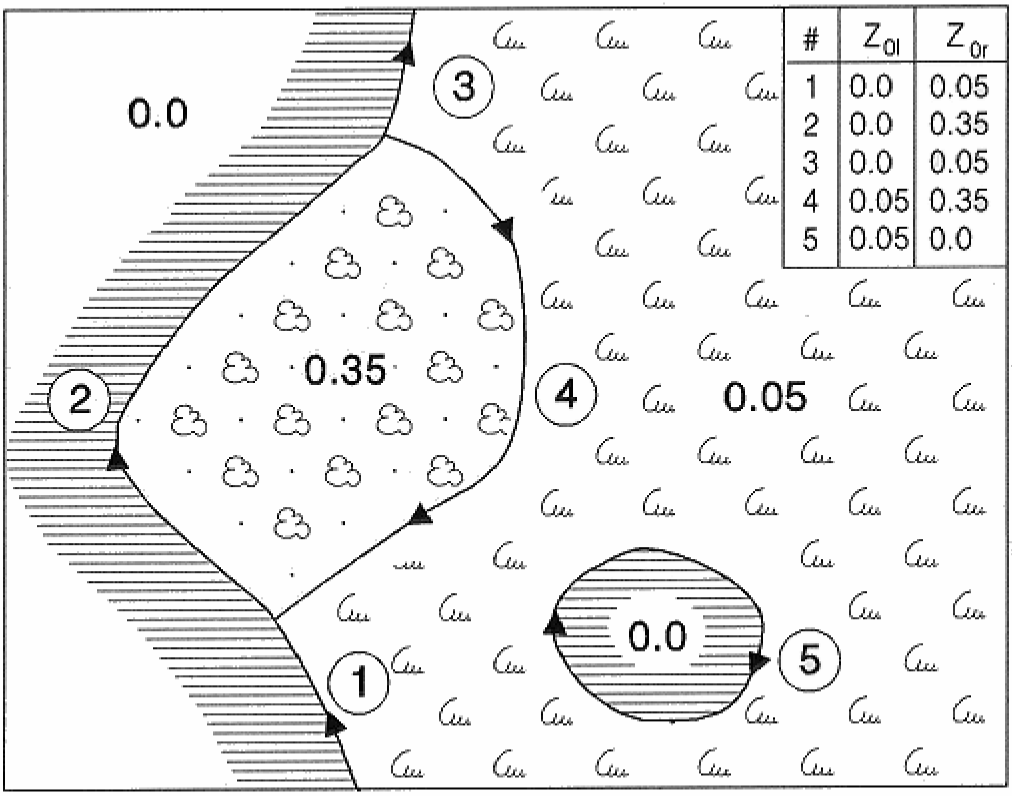
Roughness-change lines

The lines separating areas of different roughness are referred to as roughness-change lines. Whereas the familiar height contour lines are assigned one value only, i.e. the elevation above mean sea level, roughness-change lines are assigned two values: the roughness lengths z_{01} and z_{02} found on either side of the line.

Furthermore, the starting point and end point of each roughness-change line must be specified. Tracing the line from the starting point to the end point, the left- and right-hand sides of the line are unambiguously defined and the roughness lengths can be referred to as the *left-hand* z_{0l} and *right-hand* z_{0r} roughness lengths, respectively.

The characteristics of roughness-change lines are apparent from this sketch map:



Each line has a starting point and an end point, and two roughness length values are assigned to it. Water surfaces must be assigned a roughness length of 0 m (zero metres).

Roughness map characteristics

Great care must be exercised when drawing and digitising the roughness-change lines, in order to ensure a consistent roughness map. As with height contours, roughness-change lines should never cross each other; if they do, ambiguity in the roughness lengths will result, thereby creating wrong results.

Like height contour data, the roughness data are stored in a map file, containing the values and coordinates of the roughness lines. The order of the coordinates in the file defines the start and end points of the lines. Height contour lines and roughness-change lines may be present in the same map file or may be stored in different files. Evidently, the coordinate systems must be the same in both cases.

Certain features in the landscape, first of all coast lines, represent both a height contour and a roughness-change line. Consequently, three types of lines may be present in the map file:

1. Contour line only, i.e. a line through points that are at the same height above sea level. The elevation *(z)* is given in metres.
2. Roughness line only, i.e. a line separating areas of different roughness lengths. This type of line is described by two parameters: the roughness length on the left-hand side z_{0l} and the roughness length on the right-hand side z_{0r} of the line. The roughness lengths are given in metres.
3. Combined roughness and contour line, i.e. a line that is both a contour line and roughness line (e.g. a coastline). These lines have three parameters: the roughness length on the left-hand side z_{0l}, the roughness length on the right-hand side z_{0r}, and the elevation of the line z – all of which are given in metres.

Preparing a roughness map

Maps can be digitised in at least three different ways: using a digitising tablet with a paper map, using the PC and mouse with a scanned map, or transforming existing digital data to the WAsP map format; see here for more details.

The roughness classification and digitisation should preferably extend to at least 5 km from any site likely to be investigated. If extensive water surfaces occur in the area, it may even be extended to 10 km or more. Topographical maps on scales of 1:25,000 or 1:50,000 are well suited for the roughness length classification and preparation of the roughness map.

The roughness-change line descriptions close (within a km or so) to the prospected site(s) should be as detailed and accurate as possible. Conversely, both the detail and accuracy may be relaxed somewhat far away from the site(s).

It is very important that the roughness map provides a coherent and consistent picture of the different roughness areas. The digitisation should be done carefully and the roughness map should be checked thoroughly with the WAsP Map Editor.

Accuracy and detail of the map

The roughness classification should preferably extend to at least 5 km from any site likely to be investigated. If extensive water surfaces occur in the area, it may even be extended to 10 km or more. Topographical maps on scales of 1:25,000 or 1:50,000 are well suited for roughness length classification and preparation of the roughness map.

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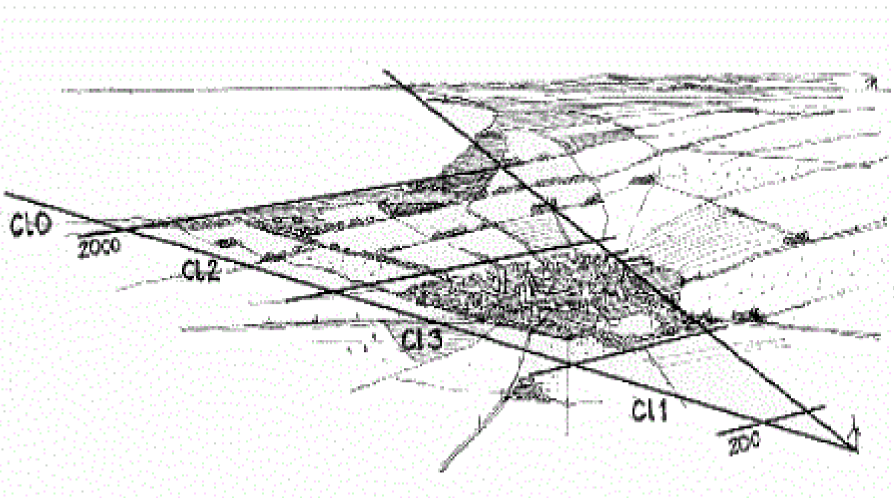
Introduction

In general, the roughness roses for the sites are conveniently calculated by WAsP using the roughness map as input. However, sometimes, either due to the lack of a proper topographical map or because only one (simple) site description is needed, the roughness rose may be entered directly.

The specification of a roughness rose for a given site is – like the roughness map – a matter of assigning proper roughness lengths to the various surface types around the site. The classification is done sector by sector like this:



The roughness classification may be compiled on a separate sheet like the Roughness Classification Form' provided here.

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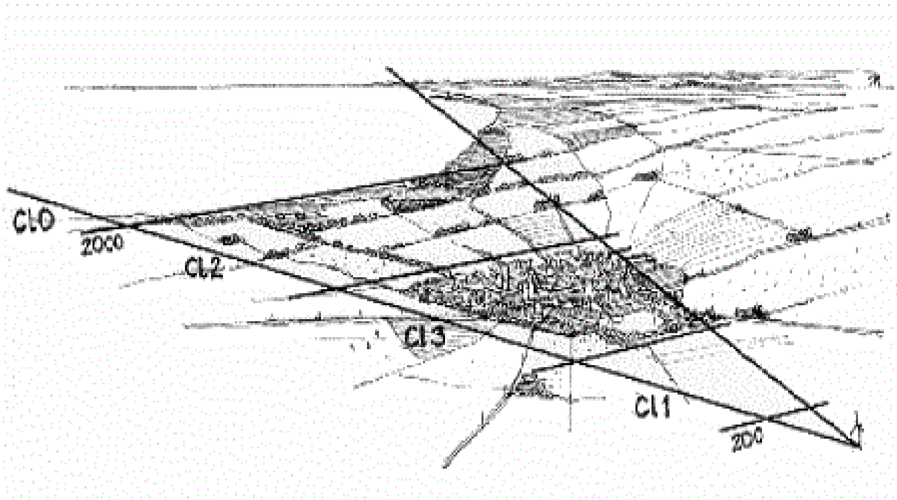


The roughness classification may be compiled on a separate sheet like the Roughness Classification Form' provided here.

Preparing a roughness rose

Dividing the horizon in e.g. twelve 30-degree sectors, the classification is done sector by sector after the following principles:

• The classification shall extend to at least 5 km from the site. If there are extensive water surfaces (z_0 = 0) further away it may even be extended to 10 km or more.

• In case there are several roughness changes in one sector, the following rule may be applied: Let X_1 be the distance from the site to the first change of roughness, X_2 the distance from the site to the next, and X_n the distance to roughness change number *n*. Then,

$X_n >= 2\ X_{n-1}$ for n = 2,3,... and n =< 10

This guideline should be adhered to in order to avoid an abundance of roughness changes, but it may be deviated from in cases where clear roughness boundaries are found, e.g. at a coastline. A maximum of ten roughness changes can be specified in each sector.

• In case the terrain between two lines of roughness change is not uniform a resulting roughness, z_0^R, must be estimated. Dividing the sector segment into quarters of approximately equal roughness, this table gives the overall roughness length of the segment as a function of the number of quarters of each roughness class in the segment.

This division has to be done keeping in mind that areas close to the site will exert the strongest influence on the wind speed at the site. By using the principle of this figure, high weights are assigned to close-by areas when each of the areas I, II, III and IV are given the same weight. Hence, if area I, II, III and IV are of class 0, 1, 2 and 3, respectively, the resulting roughness derived from this table is ~ 0.04 m.

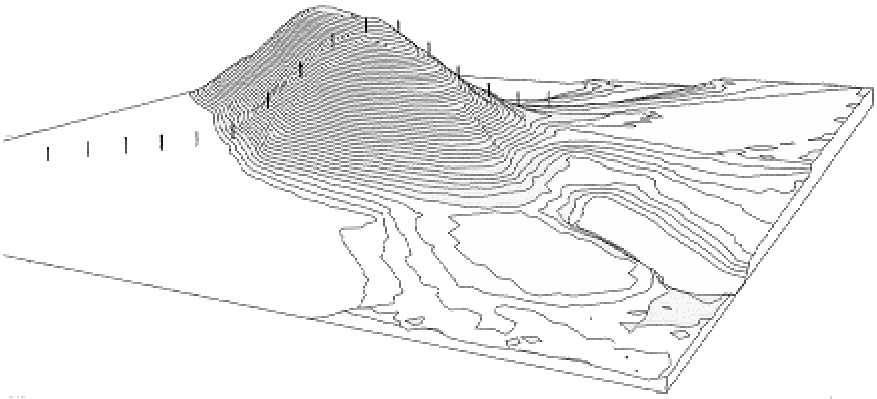
The roughness classification may be compiled on a separate sheet like the Roughness Classification Form' provided here.

Limitations of the roughness model

The roughness model can handle up to 10 changes of roughness in each of up to 36 sectors. The default value is seven roughness changes in each sector.

Effect of terrain orography

The effects of height variations in the terrain on the wind profile can most clearly be demonstrated by the results from the international field experiments at the Askervein hill on the Isle of South Uist in the Hebrides (Taylor and Teunissen, 1987; Salmon et al., 1987). The figure below shows a perspective plot of the Askervein hill. The line along which measurements of wind speed and direction were recorded is indicated by the meteorological towers.

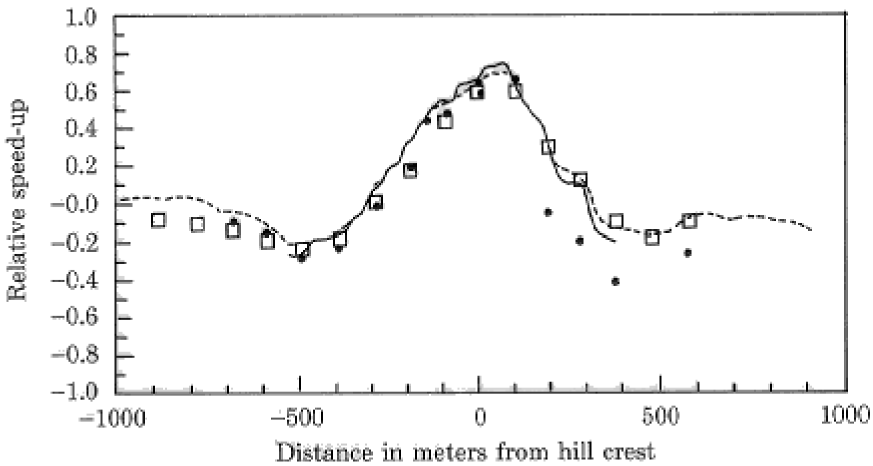


Horizontal speed-up profile

The experimental data are shown below with the relative speed-up at 10 m a.g.l. plotted against the distance from the crest. The relative speed-up is defined as:

relative speed-up = $(u_2 - u_1) / u_1$

where u_2 and u_1 are the wind speeds at the same height above ground level at the top of the hill and over the terrain upstream of the hill, respectively.



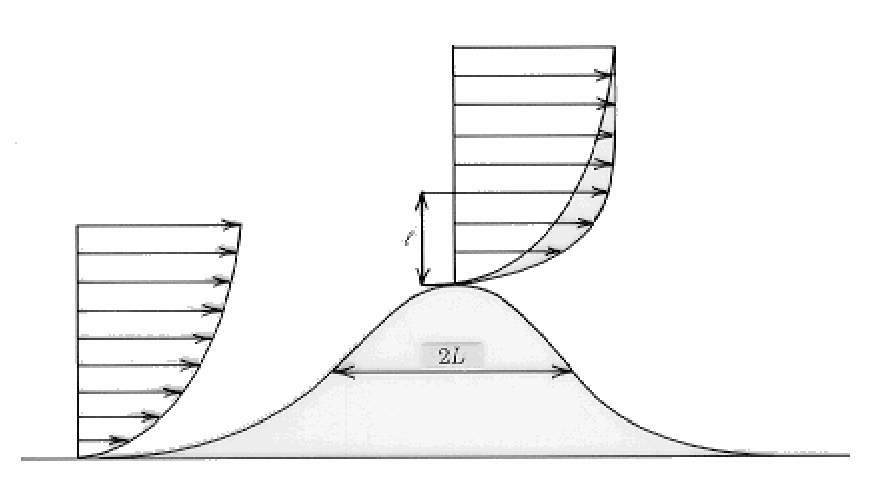
Relative speed-up ratios for flow over the Askervein hill at 10 m above ground level. Measurements are indicated by dots and results from the orographic model by squares. Results from two other numerical models are shown by a full and dashed line, respectively.

The data in the figure are obtained for a wind direction almost perpendicular to the orientation of the ridge. Also shown are the results from three numerical models: the BZ-model (Troen, 1990) used in WAsP and two other models (Beljaars et al., 1987). Some noteworthy characteristics from the figure are:

- the speed-up at the crest is 80 per cent as compared with the undisturbed upstream mean wind speed
- the negative speed-up (speed-down) in the front and lee of the hill is 20 to 40 per cent as compared with the undisturbed upstream mean wind speed

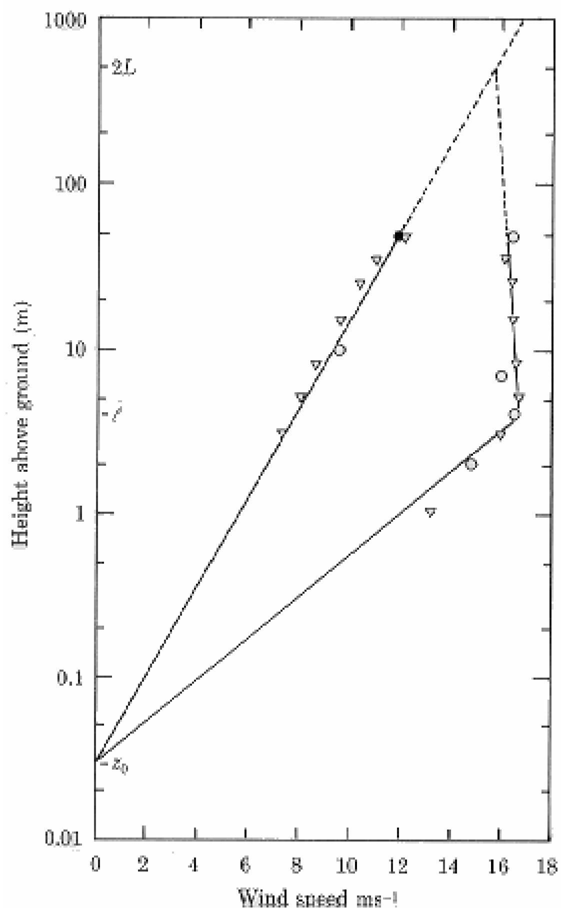
Vertical speed-up profile

The flow over an idealised hill, with upstream and hill-top wind profiles, is shown in the figure below. Two length scales characterising the flow are indicated: *L* is a characteristic length of the hill, here – following traditional nomenclature – the half width at the middle of the hill; *l* is the height of maximum relative speed-up.



It is evident that hills exert a profound influence on the flow, and this has to be taken into account as carefully as possible. But one should be aware that all the height changes in the terrain influence the flow: a 5% height increase can have a 5% impact on the mean wind speed – possibly at hub height – resulting in a 15% increase of the available power.

The figure below shows wind profiles recorded simultaneously upstream and on top of the Askervein hill. Note that the upstream profile is logarithmic with height whereas the hill-top profile has a knee at the height l, the height of maximum relative speed-up. The profile is almost constant with height above the knee until it matches with the upstream profile at the height 2*L* where *L* is a characteristic length of the hill, typically the half-width as shown above.



Wind speed profiles recorded simultaneously upstream and on top of the Askervein hill (Jensen et al., 1984).

The symbols indicate wind speed measurements.

Upstream wind profile is the straight line to the left; hill-top profile is the line to the right.

The two length scales *L* and *l* are defined above.

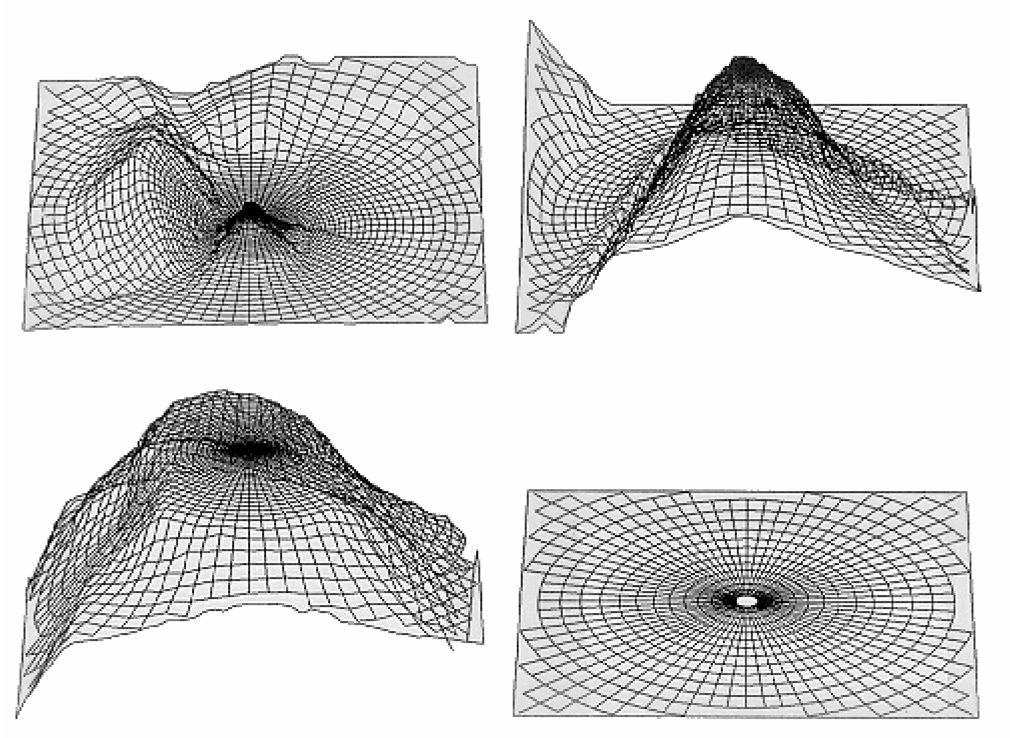
The flow model of WAsP

WAsP utilises the 'BZ-model' of Troen (1990) to calculate the wind velocity perturbations induced by orographic features such as single hills or more complex terrain. The BZ-model belongs to a family of models related to the Jackson and Hunt theory for flow over hills (Jackson and Hunt, 1975; Taylor et al., 1983). The model was developed with the specific purpose of detailed wind energy siting in mind and has the following general features:

- It employs a high-resolution, zooming, polar grid. This is coupled with a map analysis routine in order to calculate the potential flow perturbation profile at the central point of the model.
- It integrates the roughness conditions of the terrain surface into the spectral or scale decomposition. The 'inner-layer' structure is calculated using a balance condition between surface stress, advection and the pressure gradient.
- It uses an atmospheric boundary layer thickness of approx. 1 km to force the large scale (say, more than a few kilometres) flow around high-elevation areas.

The zooming grid

The zooming grid of the BZ-model is illustrated in the figure below. A 25 by 25 sq. km section of Waspdale is shown in the upper left-hand corner of the figure. The grid is centered at the WECS site on Beeverly Hill and has a radius of about 27 km. The BZ-model examines all the grid points shown when estimating the wind conditions at the hill site. In the upper right-hand corner a closer view of the same site and grid is shown, covering an area of 5 by 5 sq. km.



Still closer, the drawing in the lower left-hand corner covers an area of about 1 sq. km. Finally, the centre of the grid is shown in the lower right-hand corner of the figure; this covers approximately 200 by 200 sq. m. The grid resolution at the centre of the model is 4 m.

Specifying orography

In general, it is necessary to take the effect on the flow from the height variations around the site into account. In principle, the necessary input to the model is the height of the terrain at each grid point, but a much more convenient representation of the terrain heights is the contour lines (lines representing equal elevation) given on standard topographical maps. The model was designed, therefore, to directly accept arbitrarily chosen contour lines as input and it integrates the estimation of grid-point values and the numerical integrations into one process.

The zooming grid consists of 100 radial stations and the resulting resolution near the centre is approximately 2 m for a model with *R* = 10 km, and approximately 10 m for *R* = 50 km, etc. Therefore, resolution is limited in practice only by the accuracy and density of the contour data from the topographical maps.

Preparing an orographic map

Maps can be digitised in at least three different ways: using a digitising tablet with a paper map, using the PC and mouse with a scanned map image, or transforming existing digital data to the WAsP map format; see here for more details.

When planning for the provision of the digital height contour map one should take the following points into consideration:

- WAsP employs a zooming polar grid where resolution is very high close to the centre of the model (the site) and gets progressively lower towards the edge of the model.

- The grid of the model is also 'zooming' in the sense that the scale of the grid is adjusted so it contains the entire domain described in the digital map.

The relation between domain size – defined here as the distance from the model centre to the point farthest away in the map – and the grid cell size at the centre of the model is illustrated in the table below. The radial grid size is enlarged by 6 per cent from one cell to the next.

Domain size (radius) [km]	5	10	20	50	100
Grid size (center) [m]	1.3	2.7	5.3	13.3	26.6

The zooming polar grid inherent in the BZ-model, indicates that the contour line description close (within a km or so) to the prospected site(s) should be as detailed and accurate as possible, and – conversely – that detail and accuracy may be relaxed somewhat far away from the site(s). The map should preferably extend to at least 10 km from any (calculation) site.

Accuracy and detail of the map

The zooming grid inherent in the BZ-model indicates that the height contour line descriptions close to the prospected site(s) should be as detailed and accurate as possible and – conversely – that both detail and accuracy may be relaxed somewhat far away from the site(s).

Special attention must be given to the site itself – especially if this is right on top of a hill or a ridge. Preferably, the 'closest' contour line should enclose the very site and in this way define the hilltop precisely. If this is not the case, one should supplement the map contours with a height contour just enclosing the site and with the same elevation as this.

An adequate height contour map should cover an area of at least 10 by 10 km, with a height contour interval of less than about 20 m. The extreme points of the terrain, hill tops and crests, should be specified as well. Contours may be 'thinned' to obtain a manageable map/map file (Mortensen and Petersen, 1997).

Limitations of the flow model

In general, accurate predictions using the WAsP BZ flow model may be obtained (Bowen and Mortensen, 1996) provided:

- the met. station and wind turbine site are subject to the same overall weather regime, i.e. that meso-scale effects are not significant,
- the prevailing weather conditions are close to being neutrally stable, and
- the surrounding terrain (of both sites) is sufficiently gentle and smooth to ensure mostly attached flows.

The latter requirement in particular has a significant impact on the accuracy of WAsP predictions in complex terrain.

The ruggedness index of a site

One objective measure of the steepness or ruggedness of the terrain around a site is the so-called *ruggedness index* or RIX, defined as the percentage fraction of the terrain steeper than some critical slope, say 0.3 (Wood, 1995). This index was proposed as a coarse measure of the extent of flow separation and thereby the extent to which the terrain violates the requirements of linearized flow models such as the BZ-model. The recommended operational envelope of the WAsP flow model thus corresponds to small (~ 0%) RIX values.

Based on the limited experience available, landscapes may be characterised by the following RIX values: flat and hilly 0%, more complex about 10% or less, mountainous from about 10 to 50% or more. The RIX values of a specific met. station, turbine site or wind farm in complex or mountainous terrain can (and should) be calculated using the RIX calculator.

An orographic performance indicator

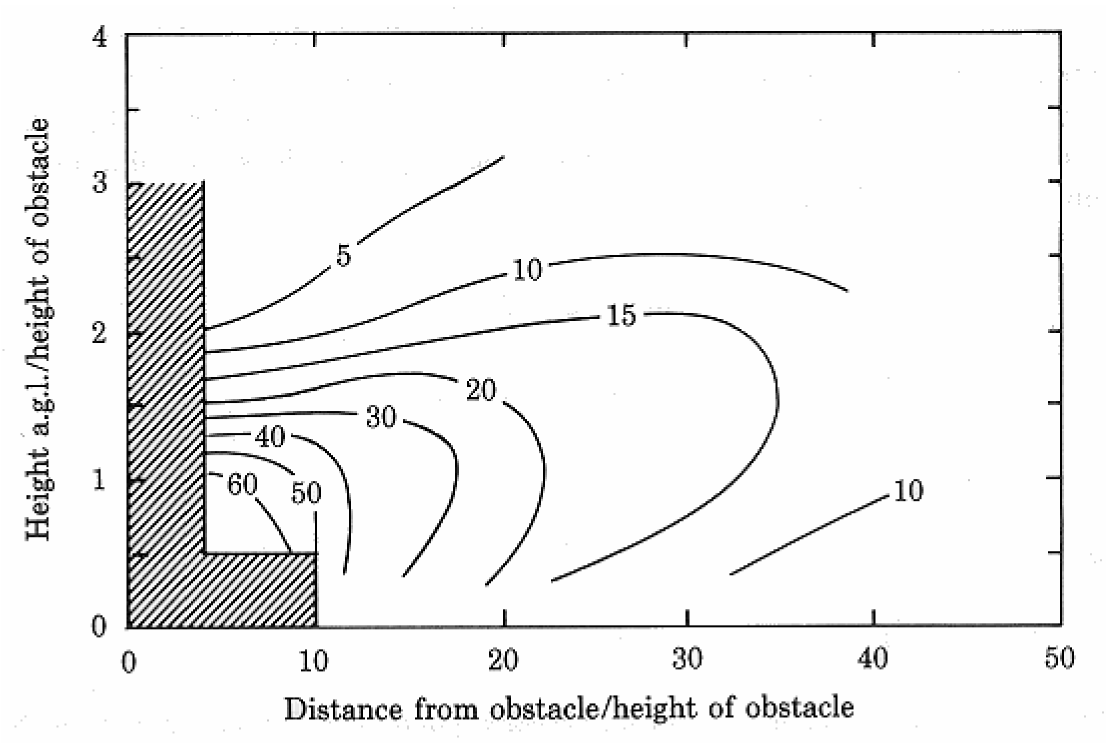
The ruggedness index has also been used to develop an orographic *performance indicator* for WAsP-predictions in complex terrain (Bowen and Mortensen, 1996; Mortensen and Petersen, 1997) – where the indicator is defined as the difference in the percentage fractions between the predicted and the reference site. This indicator may provide the sign and approximate magnitude of the prediction error for situations where one or both of the sites are situated in terrain well outside the recommended operational envelope. The use of this performance indicator is described in more detail here.

Shelter behind obstacles

Shelter is defined as the relative decrease in wind speed caused by an obstacle in the terrain. Whether an obstacle provides shelter at the specific site depends upon:

- the distance from the obstacle to the site (*x*)
- the height of the obstacle (*h*)
- the height of the point of interest at the site (*H*)
- the length of the obstacle (*L*)
- the porosity of the obstacle (*P*)

The reduction of wind speed due to shelter from an infinitely long two-dimensional obstacle of zero porosity is shown below. The figure is based on the expressions given by Perera (1981).



The shelter decreases with diminishing length and increasing porosity of the obstacle. In the shaded area the sheltering is very dependent on the detailed geometry of the obstacle. In addition, wind speed is usually increased close to and above the obstacle – similar to the speed-up effects over hills.

Porosity of obstacles

As a general rule, the porosity can be set equal to zero for buildings and ~ 0.5 for trees. A row of similar buildings with a separation between them of one third the length of a building will have a porosity of about 0.33. For windbreaks the characteristics listed in the table below may be applied. The porosity of trees changes with foliation, i.e. the time of year and like the roughness length, the porosity should be considered a climatological parameter.

Windbreak appearance	Porosity *P*
Solid (wall)	0
Very dense	< 0.35
Dense	0.35 - 0.50
Open	> 0.50

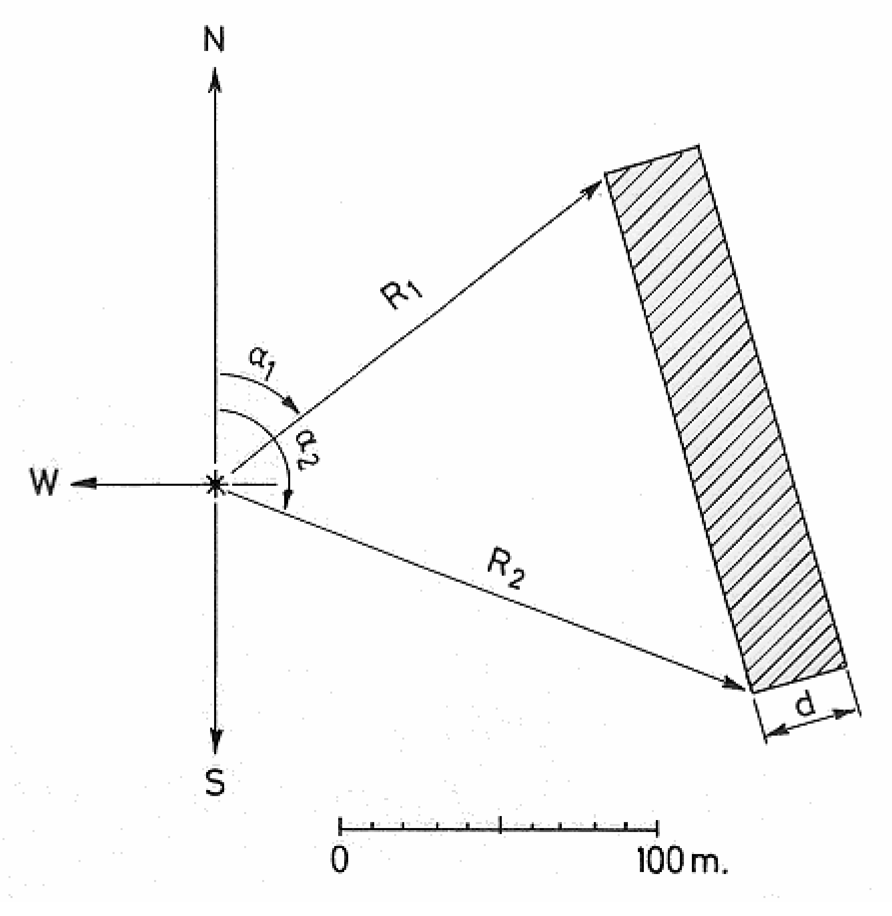
The porosity is the ratio, expressed in the table above as a fraction, of the area of the windbreaks 'pores', to its total area.

'Shelter' from wind turbines

The wind turbines in a wind farm also 'shelter' each other, leading to a reduction in the overall power production. The shelter model should **never** be used to model the 'shelter' or wake effects from a wind turbine or wind farm.

Specifying obstacles

Obstacles are considered by WAsP as 'boxes' with a rectangular cross-section and footprint. Each obstacle must be specified by its position relative to the site, its dimensions and must be assigned a porosity. The figure below defines the quantities that specify a single obstacle and that must be input to WAsP; the '*' marks the position of the site.



Obstacles are thus specified relative to a specific site and are not linked directly to the topographic map.

α_1 angle from N to first corner [º]

R_1 radial distance to first corner [m]

α_2 angle from N to second corner [º]

R_2 radial distance to second corner [m]

h height of obstacle [m]

d depth of obstacle [m]

P estimated porosity (fraction 0-1)

Angles are measured from 0º (north) to 360º clockwise, corresponding to bearings taken with a compass. Distances are measured in metres.

Preparing an obstacle list

Sheltering obstacles may be identified and their characteristics obtained from a detailed map, aerial photograph and/or during a site visit. If the site is a met. station, only obstacles which were present at the time of the wind data collection should be described.

The obstacle information may be compiled on a separate sheet like the Obstacle Description Form, which is then used to establish the obstacle list file. The format of the obstacle list file is described in the Technical Reference section.

In the field

The bearings from the site to two corners of an obstacle are taken using a compass. The distances to the same corners are estimated by 'walking' the distances or using an odometer or range-finder. The dimensions and porosity of the obstacle must be estimated; a measuring tape may come in handy at this stage. Photographs are taken from the site for every 30º of azimuth, starting from north (0º).

In office

If a detailed map or aerial photograph is available, the obstacle information may be obtained or checked in the office. The obstacle list for the site is generated by entering the information in the grid of the obstacle list window or by generating an obstacle list file (*.obs, ASCII text file) using a text editor – any 'old' obstacle list file may be used as template.

Obstacle or roughness element?

The figure shown here may serve as a guideline when deciding whether to include obstacles in the terrain as sheltering obstacles or as roughness elements:

- if the point of interest (anemometer or wind turbine hub) is closer than about 50 obstacle heights to the obstacle and closer than about three obstacle heights to the ground, the object should probably be included as an obstacle. In this case the obstacle should not at the same time be considered as a roughness element.
- if the point of interest is further away than about 50 obstacle heights or higher than about three obstacle height, the object should most likely be included in the roughness description.

Since most anemometers are mounted at a standard height of 10 m a.g.l. and often quite close to buildings, the shelter effect is potentially very serious in the analysis of wind data. On the other hand, a wind turbine with a hub height of 30-50 m a.g.l. and sited well away from buildings will rarely experience shelter effects at all.

Limitations of the shelter model

WAsP's shelter model can handle up to 50 obstacles at the same time only, so a maximum of 50 obstacles can be specified in one obstacle list.

Very close to an obstacle, corresponding to the hatched area in this figure, the obstacle model will not yield realistic results. Furthermore, investigations by Taylor and Salmon (1993) indicate that the shelter model of WAsP probably overestimates the shelter provided by 3-dimensional obstacles – in some cases by as much as a factor of 2 – whereas the shelter calculated for 2-dimensional fences seem to be very similar to the model results and experimental data reported.

The shelter model should **never** be used to model the 'shelter' or wake effects from a wind turbine or wind farm.

Introduction

The question of primary interest in wind power applications is of course: "What power production can be expected from a given wind turbine at a given site?" To answer this, it is necessary to know the power curve of the wind turbine as well as the probability density function of the wind speed at hub height. The product of these two functions gives the power density curve, the integral of which is the mean power production (European Wind Atlas, 1989). This integral is evaluated by WAsP in terms of the Weibull distribution parameters and approximating the power curve with a piecewise linear function.

The probability density function or distribution function gives the frequency of occurrence of a given wind speed. Estimating the relevant probability density function or Weibull distribution is the very purpose of the wind atlas methodology.

Hence, to calculate the power production of a wind turbine, you need the predicted wind climate for the site and the following turbine characteristics:

- The wind turbine hub height [m]
- The power curve [ms^{-1} and kW]

This information is given in a wind turbine data file; a number of sample power curves are included in the 'Power curves' folder of the main WAsP directory.

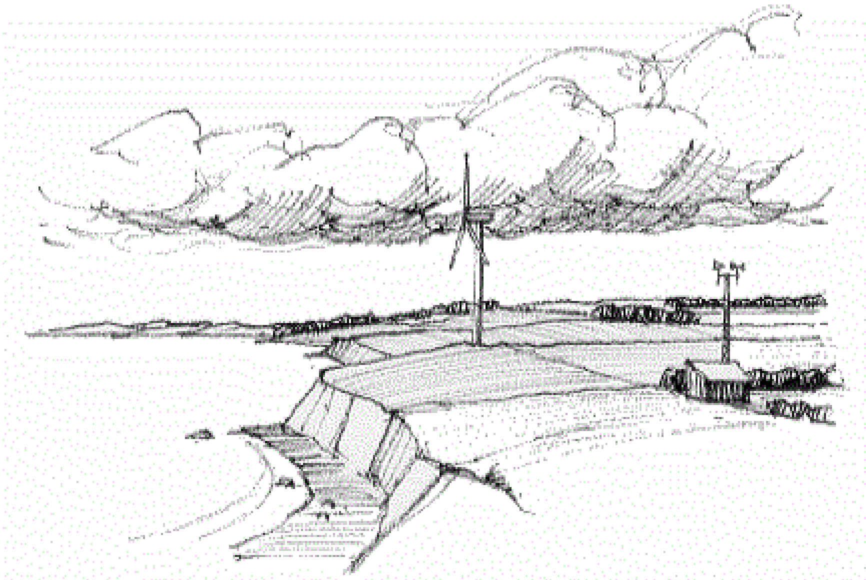
The hub height

Given the change of wind speed with height above ground level, the hub height of the wind turbine in question must be known accurately. This height is usually set automatically by inserting a power curve member to WAsP, but it can also bet set or changed in the turbine site control dialog.

In general, the hub height is simply the nominal hub height given by the wind turbine manufacturer. This is the height provided in the wind turbine data files.

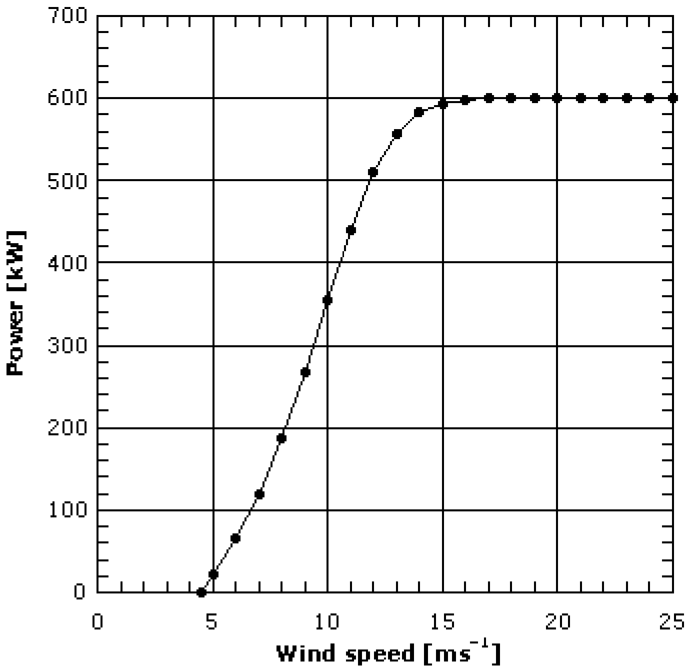
However, in certain situations the precise meaning of "height above the ground'' is not evident. As an example, consider a wind turbine on a low hill: if the height of the hill is very small compared to the hub height and the sides slope steeply, the hill can be considered as a foundation for the turbine which adds to the hub height. But if the lateral and vertical dimensions of the hill are increased, the situation changes and the relevant height becomes the height above the hill top.

Another example is shown below where a wind turbine is erected close to an escarpment. For winds coming from the sea one might be tempted to use the height from the water surface to the hub. But this is quite wrong because the wind has been influenced by the cliff long before it hits land, and the relevant height is therefore the height above ground.



The power curve

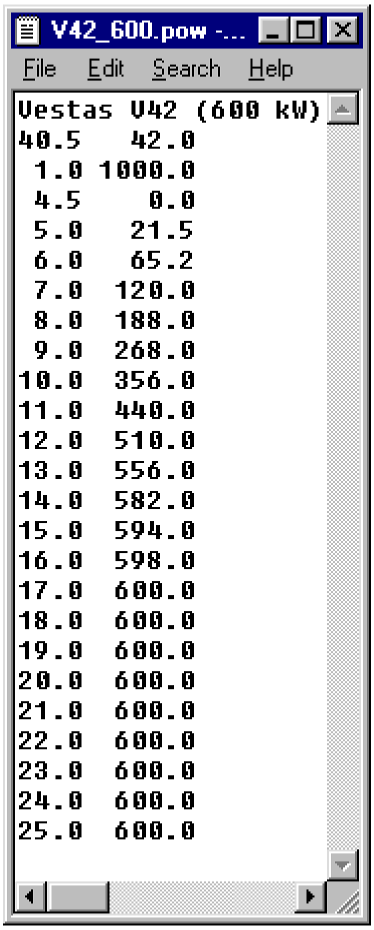
The power production by a wind turbine varies with the wind that strikes the rotor. It is common practice to use the wind speed at hub height as a reference for the power response of the wind turbine. The power produced as function of the wind speed at hub height is conventionally called the *power curve*. The figure below shows a sample power curve, plotted as a piecewise linear curve with nodes for every metre per second.



When the wind speed is less than the *cut-in* wind speed, the turbine will not be able to produce power. When the wind speed exceeds the cut-in speed, the power output $P(u)$ increases with increasing wind speed to a maximum value, the *rated power*; thereafter the output is almost constant. At wind speeds higher than the *cut-out* speed the wind turbine is stopped to prevent structural failures.

Preparing a power curve

Before inserting a power curve in the hierarchy, a file containing the power curve data of the wind turbine in question should be prepared. The file corresponding to the sample power curve shown here is shown below.




```
Vestas V42 (600 kW)
40.5    42.0
 1.0 1000.0
 4.5     0.0
 5.0    21.5
 6.0    65.2
 7.0   120.0
 8.0   188.0
 9.0   268.0
10.0   356.0
11.0   440.0
12.0   510.0
13.0   556.0
14.0   582.0
15.0   594.0
16.0   598.0
17.0   600.0
18.0   600.0
19.0   600.0
20.0   600.0
21.0   600.0
22.0   600.0
23.0   600.0
24.0   600.0
25.0   600.0
```

The file contains the following information:

Line 1 is a text string identifying the contents of the file.

Line 2 states the actual or projected hub height of the wind turbine and (optionally) the rotor diameter.

Line 3 gives two scaling factors for wind speed and power output, respectively. These scaling factors are simply the conversion factors from the units of speed and power used in the file to ms^{-1} and W, respectively.

Line 4 and onwards gives the corresponding values of wind speed and power output, here ms^{-1} and kW.

Note, that the power production will be calculated for the interval of wind speed between the cut-in and the cut-out speeds – as specified in the file.

The power curve (*.pow) may be described by a maximum of 100 points.

WAsP can read different wind turbine data files; the formats of these are described in the Technical Reference section. An old power curve file may serve as a template when making a new one.

Power curve and thrust coefficient data may be obtained from the manufacturer of the wind turbine. A number of sample power curves are included on the WAsP CD.

Estimating mean power

The procedures and equations used by WAsP for calculating the mean power production of a wind turbine are given here:

Once the power curve $P(u)$ is measured for a wind turbine, the mean power production can be estimated provided the probability density function of the wind speed at hub height is determined either by measurements or a siting procedure:

$$P = \int_0^\infty \Pr(u)P(u)du \qquad (1)$$

If the probability density function $\Pr(u)$ has been determined through the siting procedure, it is given as a Weibull function in which case the expression of the mean power production becomes:

$$P = \int_0^\infty \left(\frac{k}{A}\right)\left(\frac{u}{A}\right)^{k-1} \exp\left(-\left(\frac{u}{A}\right)^k\right) P(u)du \qquad (2)$$

As a general rule, this integral cannot be computed analytically and numerical methods must be used.

Actual power curves are rather smooth and can be well approximated by a piece-wise linear function with a few nodes. Using this approximation, the power can be written as:

$$P(u) = \frac{P_{i+1} - P_i}{u_{i+1} - u_i}\left(u - u_i\right) + P_i \qquad (3)$$

which allows for an analytical solution of Eq. (2) (Petersen et al., 1981), viz.

$$P = \sum_i \frac{P_{i+1} - P_i}{\alpha_{i+1} - \alpha_i}\left(G_k(\alpha_{i+1}) - G_k(\alpha_i)\right) \qquad (4)$$

where $\alpha_i = u_i/A$. The function $G_k(\alpha)$ is $1/k$ times the incomplete gamma function of the two arguments $1/k$ and α^k.

In some situations a discontinuity can be found in the power curve. In case of a jump in power from P_i to P_{i+1} at $u_i = u_{i+1}$, the contribution to the sum from this interval becomes:

$$\left(P_{i+1} - P_i\right)\exp\left(-\alpha_i^k\right) \qquad (5)$$

By using Eqs. (4) and (5) the mean power can be theoretically calculated for any power curve simply by dividing it into a sufficient number of linear sections. In practice, the method will only be useful if the power curve can be approximated by a small number of linear sections.

Influence of air density

The power curve for any given wind turbine depends on air density, which changes with temperature and air pressure (elevation). The power curve is usually referred to a standard air density of 1.225 kg m^{-3}, corresponding to conditions of standard sea level pressure of 1013.25 hPa and an air temperature of 15ºC. This is also the fixed air density value used in this version of WAsP when calculating the power density.

A power curve applied to a site where the average air density is different from the standard value is commonly assumed to be proportional to the ratio of the site air density to the standard value. This may be acceptable in some cases due to the rather limited range of air densities encountered. However, for wind turbines where the power output is used for control, as is the case for most pitch-regulated turbines, the correct calculation of mean power output is more involved. The correct solution in this case is to obtain a power curve from the manufacturer which has been calculated for the site-specific air density.

A table of air density as a function of elevation and mean temperature at the same elevation is given here. An Air Density Calculator is further provided in the **Tools** menu.

Sample power curves

A number of sample power curves are included in the 'Power curves' folder of the main WAsP directory; these were supplied by the manufacturers of the turbines.

These power curves are usually referenced to standard atmospheric conditions, i.e. an air pressure of 1013.25 hPa and an air temperature of 15ºC.

Note, that any given wind turbine model may have more than one power curve; for example the turbine may be optimised for some specific requirements of a project or some specific characteristics of the site; in particular it may be given for the site-specific air density. It is therefore advisable to contact the manufacturer directly before doing the final calculations of a project.

Introduction

To calculate the power production of a wind farm, taking the turbine wake losses into account, you need the predicted wind climates for the sites and the following turbine characteristics:

- The wind turbine hub height [m] and rotor diameter [m]
- The power curve [ms^{-1} and kW]
- The thrust coefficient curve [ms^{-1} and dimensionless]

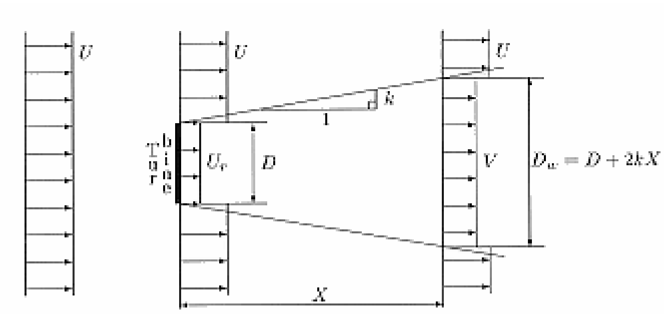
This information is given in a wind turbine data file; a number of sample power curves are included in the 'Power curves' folder of the main WAsP directory.

The wind farm model

The wind farm model is based on a mathematical model of the wake behind a wind turbine, developed by N.O. Jensen (1984). This model uses momentum-deficit theory to predict the flow field in a very simple way: the wake is assumed to expand linearly behind the rotor. Thus the only variables are the initial velocity deficit at the start of the wake and the wake decay constant, which is the rate of expansion (break-down) of the wake.

Because the model is two-dimensional, only turbines of the same hub height can be calculated, and the terrain must be relatively homogeneous in order to prevent large speed-up effects etc.

The flow field used by the model to calculate wind turbine output is shown below.



The reduced wind speed is calculated using the following equation

$$V = U\left[1 - \left(1 - \sqrt{1 - C_t}\right)\left(\frac{D}{D + 2kX}\right)^2\right]$$

where $(1-C_t) = (U_r/U)^2$, V is the wind speed in the wake, U is the undisturbed wind speed, C_t the thrust coefficient, D the rotor diameter, X the axial (downwind) distance from the rotor to the point of calculation, and k is the wake decay constant.

The thrust coefficient

The thrust coefficient curve may be difficult to find in standard technical data; we have tried to supply it with as many sample wind turbine data files as possible. It can be computed by a rotor simulation program, estimated from data for similar wind turbines, or measured directly as tower bending moment. The thrust coefficient C_t is defined as:

$$C_t = \frac{2F_T}{\rho \pi R^2 U^2}$$

where F_T is the thrust force, rho is the density of the air, R is the radius of the rotor, and U is the undisturbed wind speed.

Limitations of the wake model

The distance between neighbouring turbines in the farm should be larger than about four diameters.

For very large arrays (the model can handle several 100's of turbines) there might be a larger reduction in power production than computed, due to the influence of the turbines on the general roughness description for the site.

The model is not able to properly handle speed-up and slow-down effects, which may be important for wind farms in complex and mountainous terrain. The wakes are supposed to follow the terrain surface of the landscape.

User-specified corrections

In addition to the wind speed and direction corrections calculated by the WAsP models it is further possible for the user to specify sector-wise corrections to the wind speed and direction. Such user-specified corrections can be applied to met. stations and turbine sites.

Using other models

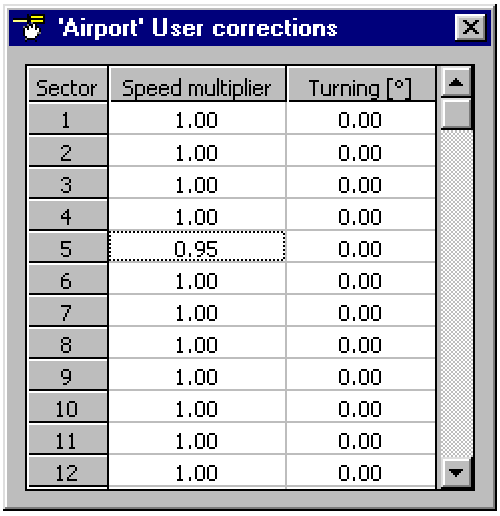
The corrections might come from e.g. wind tunnel measurements of the shelter effects, from another shelter model or from another complex terrain flow model. In this way, it is possible to use wind atlas modelling and the WAsP hierarchy together with your own experimental or modelling results.

In this case, it may not be convenient to enter the corrections sector by sector in the user corrections window; your model or application could also write a user corrections file directly. The format of this file is described here.

Local effects

It is also possible to enter strictly 'local' influences on the wind measurements in the user corrections window. The word local is used here to characterise effects that cannot easily be classed with either roughness, shelter or orography. Such effects may be known to the user by experience or experiment.

If, for example, the shadowing effect of a wind vane mounted close to the anemometer is known to reduce the measured wind speed in a certain sector by about 5%, this amount of reduction can be specified in a 'User corrections' member to this met. station as


'Airport' User corrections

Sector	Speed multiplier	Turning [°]
1	1.00	0.00
2	1.00	0.00
3	1.00	0.00
4	1.00	0.00
5	0.95	0.00
6	1.00	0.00
7	1.00	0.00
8	1.00	0.00
9	1.00	0.00
10	1.00	0.00
11	1.00	0.00
12	1.00	0.00

Note the magnitude of the correction factor: 0.95 because the measured speed is 5% too low. In principle, the wind direction can be corrected in a similar way; however, since direction corrections are often applied to all directions/wind observations, this correction is most often applied directly to the meteorological data when summarising the raw data from the instrument (see the OWC Wizard).

Digital elevation models

A digital elevation model (DEM) consists of the spot heights of nodes in a (usually) regular grid. Digital elevation models cannot be used directly by WAsP, but must be transformed to height contour or vector maps. Some commercial programs, e.g. Surfer, can perform this transformation. The exported output is a 3-D dxf-file which must be converted to a WAsP map file. The GRD2MAP program, which is part of the WAsP Utility Programs, can transform a Surfer *.grd file (DEM) directly to a WAsP *.map file.

Investigations in the mountains of Northern Portugal (Mortensen and Petersen, 1997) indicate that the prediction errors are large when maps are based on grids with large grid cell sizes (> 75 m), and decrease with decreasing grid cell size for the finer grids (< 75 m). With a grid cell size of about 50 m or less the prediction errors were found to be identical to the errors obtained with an original, 20-m contour, digitised map. A combination of a 2 by 2 km hand-digitised map around the site with any of the nine maps used (based on DEM's of 10, 25, 50, 75, 100, 125, 150, 200 and 250 m grid size) gave results that were as accurate as using the original digitised map. Thus, if a digital elevation model is available only, the grid size should be less than about 50 m. Furthermore, the grid cell size seems not to be critical if the terrain within 1 km of the site is digitised in detail.

Irregular spaced spot heights

If irregularly-spaced spot heights are available only, these may be transformed into a regular grid using Surfer and then to a contour map using Surfer or GRD2MAP. The representativity of the resulting height contour map depends critically on the distribution and density of the original data points, so great care must be exercised in the WAsP analyses.

Physical units

WAsP uses metric units according to the International System of Units. Examples of fundamental and derived physical units used in WAsP are:

Physical variable	Units	Symbols
Time	hours, minutes, seconds	h, min, s
Distance, height, depth	metres	m
Roughness length, elevation	metres	m
Coordinate (metric)	metres	m
Coordinate (geographical)	degrees (decimal)	º (360º-system)
Direction, bearing	degrees (decimal)	º (360º-system)
Speed, Weibull *A*-parameter	metres per second	ms^{-1}
Power (output)	watts	W
Power density	watts per square metre	Wm^{-2}
Power production	watt-hours per year	Why^{-1}
Annual energy production	watt-hours	Wh

The following prefixes may be used with some of the units above:

Prefix	Symbol	Value	Example
hecto	h	10^2	hPa
kilo	k	10^3	kW

mega	M	10^6	MWh
giga	G	10^9	$GWhy^{-1}$

The WAsP file descriptions contain information about the units used in each file.

Coordinate systems

Three different coordinate systems are used when working with WAsP: geographical coordinates, map coordinates and site-specific coordinates.

Geographical coordinates

Geographical coordinates consist of latitude and longitude and are measured in degrees. Latitude North and longitude East are considered positive, latitude South and longitude West negative. The latitude is used to tell WAsP 'where on earth' the wind measurements were taken so the program can take the earth's rotation into account when generating the wind atlas data set. Consequently, the latitude and longitude are used only in the observed wind climate file and when processing a time-series of wind data using the Observed Wind Climate Wizard.

Cartesian map coordinates

Map coordinates consist of *x*- and *y*-values in a Cartesian coordinate system and must be given in metres. Any system can be used as long as it is Cartesian and given in metres – the Universal Transverse Mercator (UTM) system printed on many maps is an excellent choice. Note though, that this system changes from one UTM zone to the next, so the entire map should be specified in coordinates corresponding to one UTM zone only. The elevation of height contour lines must also be given in metres, usually above mean sea level [m a.s.l.]. If the map coordinates or elevations are not given in metres these must be transformed to metres. A transformation based on two fixed points and a linear height transformation can be specified directly in the header of the map file. The WAsP map editor also contains several options for transforming maps.

Site-specific polar coordinates

Site-specific coordinates are used only when specifying obstacles relative to the site. The position of an obstacle is specified by two angles (measured from North through 360º clockwise) and two distances, see the obstacle list file. Distances are measured in metres.

About project parameters

The behaviour of the WAsP models can be adjusted by making alterations to model parameters. The parameters are used whenever a calculation is performed, such as when a met. station calculates a wind atlas.

A unique parameter set is associated with each WAsP project. All members which are children of the project will make use of the same parameters. It's possible to have a workspace which contains two projects (say, for example, one from Iran and another from Europe) and for the calculations performed within each project to use completely different parameter values.

WAsP parameters

The project-specific parameters can be viewed and edited in the WAsP Project's methods by invoking **Edit parameters**. The default value and allowable range for each parameter are given below.

Standard conditions for wind atlas data sets

Parameters #1-12 determine the 'standard conditions' used when calculating and storing wind atlas data sets (*.lib files): the number of standard heights and their values, the number of standard roughnesses (or 'roughness classes') and their values. Parameters #2-6 and #8-12 must increase progressively.

#	Description	Default	Range	Old #
1	Number of standard heights for *.lib files	5	2-5	12

2	Standard height #1	10	5-200	13
3	Standard height #2	25	5-200	14
4	Standard height #3	50	5-200	15
5	Standard height #4	100	5-200	16
6	Standard height #5	200	5-200	17
7	Number of roughness classes for *.lib file	4	2-5	18
8	Standard roughness length #1	0.00	0-2.0	19
9	Standard roughness length #2	0.03	0-2.0	20
10	Standard roughness length #3	0.10	0-2.0	21
11	Standard roughness length #4	0.40	0-2.0	22
12	Standard roughness length #5	1.00	0-2.0	23

A height lower than 10 is recommended if you wish to predict wind conditions at heights lower than 10 m a.g.l. Likewise, a roughness between 0 and 0.03 m is recommended if large parts of the terrain have a roughness length of, say, 0.003 m.

Other parameters and constants

Parameters #13-30 determine various other constants and parameters used in the WAsP modelling; click on the parameter number in the table below to obtain a brief description. The 'Old #' column gives the parameter number in the old WAsP 4/5 for DOS, i.e. in the text file wasp.par.

#	Description	Default	Range	Old #
13	Width of coastal zone	10000	0-20000	2
14	Depth of daily variation over land	100	50-300	3
15	Rel. amplitude of daily variation near ground	0.12	0.01-0.25	4
16	Avg. offset over land from neutral at $z=P_2$	0.11	0.01-0.25	5
17	Height of inversion in BZ model	1000	100-5000	6
18	Softness of inversion in BZ model	1	0-1	7
19	Decay-length for roughness area size	10^4	10^3-10^6	31

20 True upwind direction in BZ model	false	false/true	34
21 Azimuth resolution in BZ model	5	1-15	42
22 Depth of daily variation over water	50	25-300	51
23 Factor in height of min. stab. induced var.	$2 \cdot 10^{-3}$	$0\text{-}5 \cdot 10^{-3}$	54
24 Rms heat flux over land	100	0-200	56
25 Rms heat flux over water	30	0-200	57
26 Offset heat flux over land	-40	-200-200	58
27 Offset heat flux over water	15	-200-200	59
28 Sub-sectors in roughness map analysis	6	1-9	65
29 Max. number of roughness changes/sector	7	1-10	67
30 Max. interpolation radius in BZ model	$2 \cdot 10^4$	$5 \cdot 10^3\text{-}5 \cdot 10^4$	75

External parameters

Parameter #13 (formerly #2)

Width of the coastal zone. During onshore winds this is the zone where the transition in thermal stability from over-sea to over-land conditions takes place. Default value is 10,000 m.

Parameter #14 (formerly #3)

The height above ground where differences between stable and unstable profiles are smallest, usually identified as the height where the daily variation of wind speed changes from a maximum during daytime to night-time maxima (for $z >= P_{14}$). Default is 100 m. This parameter is not used if $P_{23} > 0$ (default).

Parameter #15 (formerly #4)

The rms-value of stability-induced relative amplitude of wind speed near the ground, usually close to the rms-value of the daily course of the wind speed near ground (at 10 m say). Default value is 0.12. This parameter is not used if $P_{23} > 0$ (default).

Parameter #16 (formerly #5)

The relative increase of the wind speed at $z = P_{14}$ due to stability effects – relative to a logarithmic profile. Default is 0.11. This parameter is not used if $P_{23} > 0$ (default).

Parameter #17 (formerly #6)

Height of inversion in BZ flow model. Default is 1000 m. See note 1.

Parameter #18 (formerly #7)

Softness of inversion in BZ model. Can take values between 0 and 1. Default is 1.0. See note 1.

Parameter #19 (formerly #31)

Decay length for roughness area size. Default is 10,000 m.

Parameter #20 (formerly #34)

True up-wind direction (BZ-model): 1. No: 0. Default is 0 (turned off).

Parameter #21 (formerly #42)

Azimuthal resolution in BZ flow-model. May be set to 1, 2, 3, 4, 5, 6, 9, 10, 12 or 15 degrees. Default is 5 degrees.

Parameter #22 (formerly #51)

Depth of daily variation over water. Default is 50 m. This parameter is not used if P_{23} > 0 (default).

Parameter #23 (formerly #54)

Factor in height of minimum stability induced variance. Default is 2.0E-3. See note 2.

Parameter #24 (formerly #56)

Rms heat flux over land. Default is 100 [Wm^{-2}]. See note 2.

Parameter #25 (formerly #57)

Rms heat flux over water. Default is 30 [Wm^{-2}]. See note 2.

Parameter #26 (formerly #58)

Offset heat flux over land. Default is -40 [Wm^{-2}]. See note 2.

Parameter #27 (formerly #59)

Offset heat flux over water. Default is 15 [Wm^{-2}]. See note 2.

Parameter #28 (formerly #65)

Number of sub-sectors per sector in roughness map analysis. Default is 6.

Parameter #29 (formerly #67)

Maximum number of roughness changes per sector. Maximum is 10, default is 7.

Parameter #30 (formerly #75)

Maximum interpolation radius for the complex terrain model, in metres. Default value is 20,000 meters. The fraction of the flow model radius added to the radius when modelling is 0.5.

Note 1

The BZ model in WAsP is based on neutral stratification. The purpose of including an inversion height (parameter #17) and a strength parameter (#18) is to enable an (admittedly extremely simple) modelling of the climatological effect of the stably stratified atmosphere above the boundary layer. Horizontal scales larger than the inversion height are "squeezed"' to make the calculated velocity perturbations more horizontal and attenuate vertical motion. The softness parameter (#18) governs the strength of this effect from maximum squeezing (= 0) to minimum (= 1) where the inversion has no effect at all.

Note 2

The background for these parameters is explained in more detail in Chapter 8 of the European Wind Atlas (Troen and Petersen, 1989).

WAsP file formats

WAsP uses several different types of disk files that you should be aware of, or even familiar with. These files are used to store information required by WAsP during execution. Some of the files are generated by storing the information entered during a session, while others must be prepared beforehand.

Each member of the hierarchy has an associated file; to avoid confusion and enhance systematics WAsP assumes a default file name extension for each of these files:

Hierarchy member	extension	also	future...
WAsP workspace	wwk		
WAsP project	wpr		
Meteorological station	wms		
Observed wind climate	tab		owc
Terrain map	map	bna	
Obstacle list	obs		
Roughness description	rrd	rds	
User corrections	ucf		
Wind atlas	lib		rwc
Wind turbine site	wts		
Predicted wind climate	wpw		pwc
Wind turbine	pow	trb, wtg	
Wind farm	wwf	rsf, txt	
Resource grid	wrg	rsf	

With these default file name extensions, the files will be recognised by e.g. Windows Explorer as WAsP files. However, you may also specify the name completely and thereby override the default choice. Short descriptions of these files and their formats are given in the following.

All WAsP files are ASCII text files so they can in principle be edited, viewed, changed, printed and saved using any ASCII text editor, e.g. Notepad or WordPad.

The WAsP workspace file

The WAsP workspace file contains information on (pointers to) the hierarchy members associated with a WAsP workspace.

Data are stored in an ASCII (text) file with the default file name extension 'wwk'. This file is created and maintained entirely by the WAsP program and the format is therefore not of interest here.

The WAsP project file

The WAsP project file contains information on (pointers to) the hierarchy members associated with a WAsP project.

Data are stored in an ASCII (text) file with the default file name extension 'wpr'. This file is created and maintained entirely by the WAsP program and the format is therefore not of interest here.

The wind atlas file

The wind atlas file contains the sector-wise frequency of occurrence of the wind (the wind rose) as well as the wind speed frequency distributions in the same sectors (as Weibull *A*- and *k*-parameters). The wind climates are specified for a number of reference roughnesses (roughness classes) and heights above ground level.

Data are stored in an ASCII (text) file with the default file name extension 'lib'. The lib-file is created by WAsP from an observed wind climate, transforming the local (site-specific) wind climate into regional (site-independent) descriptions of the wind climate.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the wind atlas file
2	Number of roughness classes, heights and sectors in data set
	Default values are: 4, 5 and 12
3	Reference roughness lengths [m]
	Default values are: 0.0, 0.03, 0.10 and 0.40 m
4	Reference heights above ground level [m]
	Default values are: 10, 25, 50, 100 and 200 m a.g.l.
5	Frequencies of occurrence for **reference roughness #1** (0 m)
6	Weibull *A*-parameters for reference height #1 (10 m) in [ms^{-1}]
7	Weibull *k*-parameters for reference height #1 (10 m)
8-9	Weibull *A*- and *k*-parameters for reference height #2 (25 m)
10-11	Weibull *A*- and *k*-parameters for reference height #3 (50 m)
12-13	Weibull *A*- and *k*-parameters for reference height #4 (100 m)
14-15	Weibull *A*- and *k*-parameters for reference height #5 (200 m)

16-26 As lines 5-15, but for **reference roughness #2** (0.03 m)

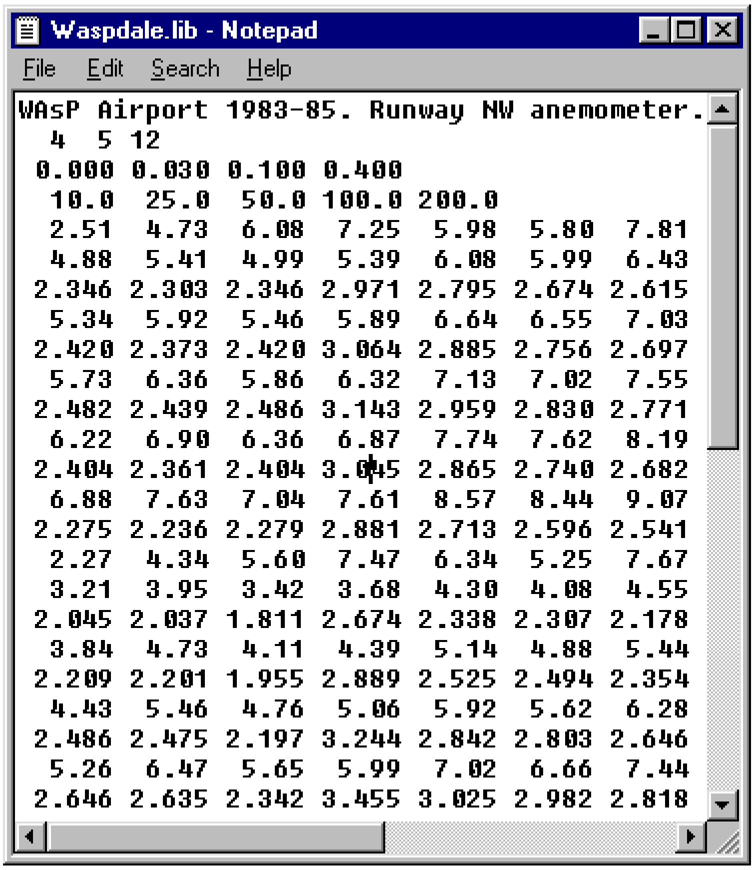
27-37 As lines 5-15, but for **reference roughness #3** (0.10 m)

38-48 As lines 5-15, but for **reference roughness #4** (0.40 m)

The wind speed and direction distributions may be given for a maximum of 5 reference roughnesses (roughness classes), 5 heights and 36 sectors.

Example

The following window shows part of a wind atlas file, opened in the Notepad text editor. Only the first seven sectors are shown.




```
WAsP Airport 1983-85. Runway NW anemometer.
  4  5 12
 0.000 0.030 0.100 0.400
  10.0  25.0  50.0 100.0 200.0
  2.51  4.73  6.08  7.25  5.98  5.80  7.81
  4.88  5.41  4.99  5.39  6.08  5.99  6.43
 2.346 2.303 2.346 2.971 2.795 2.674 2.615
  5.34  5.92  5.46  5.89  6.64  6.55  7.03
 2.420 2.373 2.420 3.064 2.885 2.756 2.697
  5.73  6.36  5.86  6.32  7.13  7.02  7.55
 2.482 2.439 2.486 3.143 2.959 2.830 2.771
  6.22  6.90  6.36  6.87  7.74  7.62  8.19
 2.404 2.361 2.404 3.045 2.865 2.740 2.682
  6.88  7.63  7.04  7.61  8.57  8.44  9.07
 2.275 2.236 2.279 2.881 2.713 2.596 2.541
  2.27  4.34  5.60  7.47  6.34  5.25  7.67
  3.21  3.95  3.42  3.68  4.30  4.08  4.55
 2.045 2.037 1.811 2.674 2.338 2.307 2.178
  3.84  4.73  4.11  4.39  5.14  4.88  5.44
 2.209 2.201 1.955 2.889 2.525 2.494 2.354
  4.43  5.46  4.76  5.06  5.92  5.62  6.28
 2.486 2.475 2.197 3.244 2.842 2.803 2.646
  5.26  6.47  5.65  5.99  7.02  6.66  7.44
 2.646 2.635 2.342 3.455 3.025 2.982 2.818
```

The meteorological station file

The meteorological station file contains the map coordinates of the wind mast as well as information on (pointers to) the observed wind climate and other hierarchy members associated with the meteorological station.

Data are stored in an ASCII (text) file with the default file name extension 'wms'. This file is created and maintained entirely by the WAsP program and the format is therefore not of interest here.

The observed wind climate file

The observed wind climate file contains the frequencies of occurrence of the wind in a number of sectors (the wind rose) and wind speed bins. It further contains the height of observation above ground level and the geographical coordinates (latitude and longitude) of the wind mast.

Data are stored in an ASCII (text) file with the default file name extension 'tab'. The tab-file can be generated by the Observed Wind Climate Wizard or may be prepared from a climatological table using a text editor.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the observed wind climate/anemometer
2	Latitude [°], Longitude [°] and height a.g.l. of anemometer [m]
3	Number of sectors, speed factor *au* and direction offset *bd* [º]
	wind speed bin limits [ms^{-1}] = *au* · {column 1}
	wind rose rotated by b_d
4	Sector-wise frequencies of occurrence [%]
5	Upper limit for speed class 1, sector-wise frequencies [‰] in class 1
6	Upper limit for speed class 2, sector-wise frequencies [‰] in class 2
7–*n*	Same as line 5 and 6, but for speed class 3–*n*

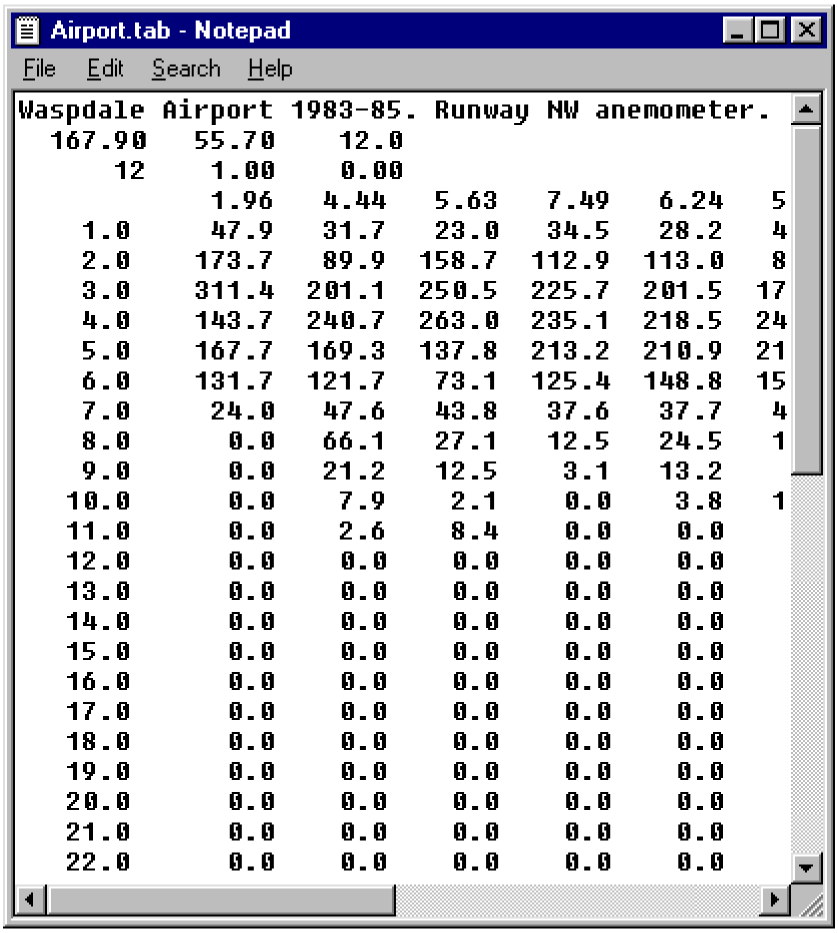
The speed distributions may be described by a maximum of 50 wind speed bins and 36 sectors. The wind speed bins need not have the same width; however, the sectors are considered of equal angular width. Note, that the frequencies of occurrence of wind speed are given in per mille [‰], i.e. they will add up to 1000 for each sector.

Special considerations

The location/position of the observed wind climate must be given in geographical coordinates, i.e. as latitude and longitude in decimal degrees. Conventionally, latitude N and longitude E are considered positive; latitude S and longitude W negative. Latitude can thus take values between -90º and +90º and longitude values between -180º and +180º.

Example

The following window shows part of an observed wind climate file, opened in the Notepad text editor.



```
Airport.tab - Notepad
File  Edit  Search  Help
Waspdale Airport 1983-85. Runway NW anemometer.
  167.90    55.70    12.0
      12     1.00    0.00
             1.96    4.44    5.63    7.49    6.24   5
     1.0     47.9    31.7    23.0    34.5    28.2   4
     2.0    173.7    89.9   158.7   112.9   113.0   8
     3.0    311.4   201.1   250.5   225.7   201.5  17
     4.0    143.7   240.7   263.0   235.1   218.5  24
     5.0    167.7   169.3   137.8   213.2   210.9  21
     6.0    131.7   121.7    73.1   125.4   148.8  15
     7.0     24.0    47.6    43.8    37.6    37.7   4
     8.0      0.0    66.1    27.1    12.5    24.5   1
     9.0      0.0    21.2    12.5     3.1    13.2
    10.0      0.0     7.9     2.1     0.0     3.8   1
    11.0      0.0     2.6     8.4     0.0     0.0
    12.0      0.0     0.0     0.0     0.0     0.0
    13.0      0.0     0.0     0.0     0.0     0.0
    14.0      0.0     0.0     0.0     0.0     0.0
    15.0      0.0     0.0     0.0     0.0     0.0
    16.0      0.0     0.0     0.0     0.0     0.0
    17.0      0.0     0.0     0.0     0.0     0.0
    18.0      0.0     0.0     0.0     0.0     0.0
    19.0      0.0     0.0     0.0     0.0     0.0
    20.0      0.0     0.0     0.0     0.0     0.0
    21.0      0.0     0.0     0.0     0.0     0.0
    22.0      0.0     0.0     0.0     0.0     0.0
```

Introduction

In general, terrain map files contain digital height contour lines and/or roughness change lines. Three types of lines are recognised by WAsP:

1. Height contours, characterised by their elevation [m a.g.l.]
2. Roughness change lines, characterised by the roughness lengths on either side of the line. The two roughness lengths are given in [m].
3. Combined height contours/roughness change lines. A coast line, for example, is characterised by its elevation (usually 0 m a.g.l.) and also marks the roughness change between water and land.

The map file must be provided in either of the following two formats:

1. WAsP terrain map file (*.map). This is the format used by all previous versions of WAsP and the format you obtain if you use WAsP 4 for digitising the information of paper map sheets. The output of the DXF translator is also written in this format.
2. Atlas terrain map file (*.bna). This is a format recognised by several GIS and other programs and the format you obtain if you use Didger for digitisation.

The WAsP terrain map file

Data are stored in an ASCII (text) file with the default file name extension 'map'. The map-file can be established by digitisation of lines from a map sheet or may be prepared by reformatting existing digital map information.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the terrain map: + ...

2 Fixed point #1 in user and metric [m] coordinates:

X_1(user) Y_1(user) X_1(metric) Y_1(metric)

3 Fixed point #2 in user and metric [m] coordinates:

X_2(user) Y_2(user) X_2(metric) Y_2(metric)

4 Scaling factor and offset for height scale (*Z*):

Z_{metric} = {scaling factor}(Z_{user} + {offset})

5a Height contour: elevation (*Z*) and number of points (*n*) in line:

Z n

5b Roughness change line: roughness lengths to the left (z_{0l}) and right (z_{0r}) side of the line, respectively, and number of points:

$z_{0l} z_{0r} n$

5c Roughness and contour line: roughness lengths to the left and right of the line, respectively, elevation and number of points:

$z_{0l} z_{0r}$ *Z n*

6– Cartesian coordinates (*X, Y*) of line described in 5a, 5b or 5c:

X_1*Y*1 [... *Xn Yn*]

Xn_{+1}*Yn*+1

... where [] embrace optional numbers and *n* is > 0

The pattern given in line 5 (a, b **or** c) and 6 is repeated as many times as there are height contours/roughness change lines in the file. Each line in the map must be described by a minimum of two points.

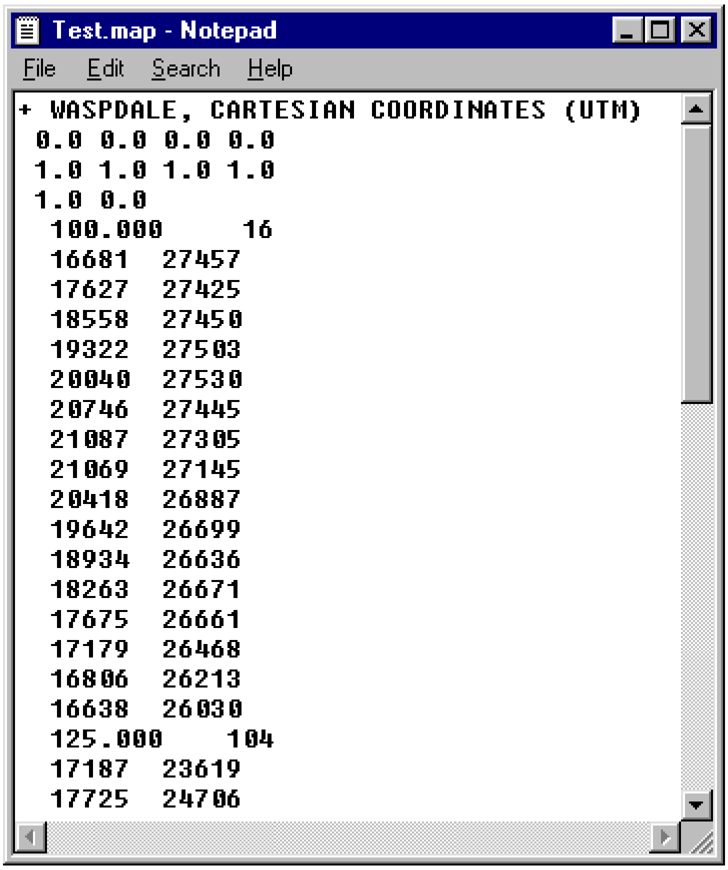
Coordinates and transformation

The '+'-sign in column one of the first line of the file indicates that coordinates in the file are Cartesian. Earlier versions of WAsP (4.X and 5.X) can also read maps given in polar coordinates.

Line 2 and 3 specify a simple coordinate transformation from user coordinates (the numbers given in the file, from line 6 and onwards) to metric coordinates. If the user coordinates given in the file are metric and absolute (like the UTM system provided on many maps), line 2-3 may be replaced by a single line containing non-numeric input.

Example

The following window shows part of a map file, opened in the Notepad text editor. In this case there is no transformation of coordinates (line 2-3) or the elevation values (line 4): the coordinates and elevations are given in [m].




```
+ WASPDALE, CARTESIAN COORDINATES (UTM)
 0.0 0.0 0.0 0.0
 1.0 1.0 1.0 1.0
 1.0 0.0
  100.000      16
  16681  27457
  17627  27425
  18558  27450
  19322  27503
  20040  27530
  20746  27445
  21087  27305
  21069  27145
  20418  26887
  19642  26699
  18934  26636
  18263  26671
  17675  26661
  17179  26468
  16806  26213
  16638  26030
  125.000     104
  17187  23619
  17725  24706
```

The Atlas terrain map file

The Atlas terrain map is an ASCII (text) file with the default file name extension 'bna'. The map information is stored as points, polygons and polylines, and the map coordinates must be in metres. A bna-file can be established by digitisation from a map sheet or may be prepared by reformatting digital map information. The bna-format is one of the export formats recognised by Golden Software's Didger program, a digitising program designed to run under Windows 95 or NT.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	"Primary ID","Secondary ID",{type/length}
2	X_1,Y_1
3	X_2,Y_2
	...
n+1	X_n,Y_n

n+2	"Primary ID","Secondary ID",{type/length}
n+3	X_1,Y_1
n+4	X_2,Y_2
	...
n+*m*+2	X_m,Y_m
...	...

The pattern given in line 1 to *n*+1 is thus repeated as many times as there are height contours and/or roughness change lines in the file. For WAsP to make use of the bna-file, it is important to adhere to the following conventions regarding the Primary and Secondary ID's:

The **Primary ID** must contain the elevation of the line, e.g. "125.0". If the line has no elevation, an empty string "" must be present.

The **Secondary ID** must contain the roughnesses of the line, e.g. "0.0 0.03", where the first value corresponds to the left-hand roughness length and the second value to the right-hand roughness length. The roughness length values must be separated by a comma. If the line is not a roughness change line, an empty string "" must be present.

The **type/length** must be a signed integer. The absolute value of this indicates the number of coordinate pairs (points) to follow, the sign indicates the type of line: an area/polygon (positive integer), a curve/polyline (negative integer) or a point (the value 1).

Following the {type/length} are the actual (*X, Y*)-coordinates that specify the object. These can be integers or real numbers and are stored one pair per line, separated by a comma.

Coordinates

The coordinates in the bna-file must be in metres and must be specified relative to a Cartesian coordinate system. The elevation and roughness length values must also be in metres.

Sample header lines

• Single elevation point (spot height), 47 m a.s.l.:

"47","",1

• Height contour only, 125-m above sea level, containing 245 coordinate pairs in a polygon:

"125.0","",245

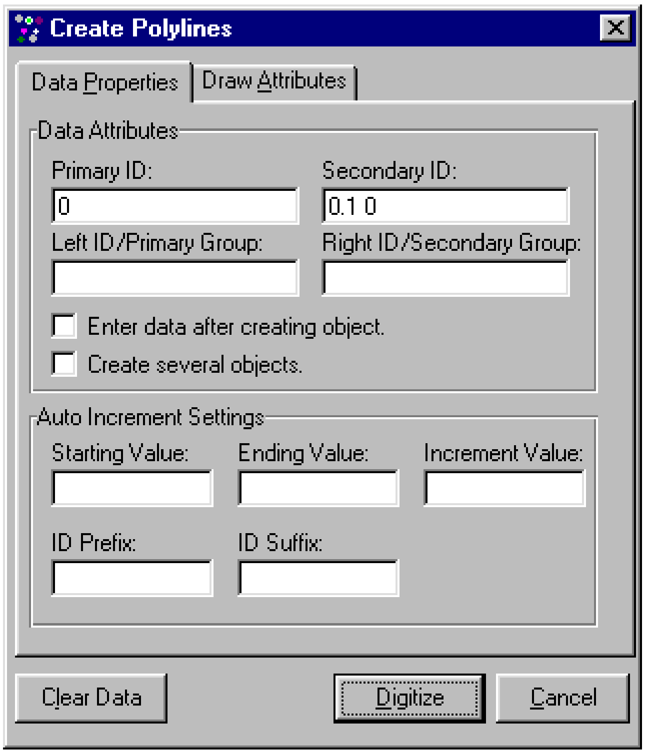
• Roughness change line only, left-hand roughness length 0 m (water) and right-hand roughness length 0.03 m, containing 709 coordinate pairs in a polyline:

"","0.0 0.03",-709

• Combined height contour and roughness change line (coastline), containing 134 coordinate pairs in a polyline:

"0","0.1 0",-134

As an example, this line is specified in Didger's **Create Polylines** dialog box in the following way:



The number of points (134) and the type (- for polyline) are automatically added by Didger. The dialog boxes for creating points and polygons are identical to the one shown above.

The obstacle list file

The obstacle list file contains the position, size and porosity of any sheltering obstacles close to the site.

Data are stored in an ASCII (text) file with the default file name extension 'obs'. The obs-file can be established by entering the information in a WAsP session and subsequently storing the file – or it can be prepared using a text editor.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the obstacle list
2	A_1 [º] R_1 [m] A_2 [º] R_2 [m] h [m] D [m] P [0-1]
	Characteristics of obstacle #1: Angle (A_1) and distance (R_1) to first corner of obstacle, angle (A_2) and distance (R_2) to second corner, height (h), depth (D) and porosity (P) of obstacle.
3	Characteristics of obstacle #2, format like line 2
n	Characteristics of obstacle #(n-1), n < 52

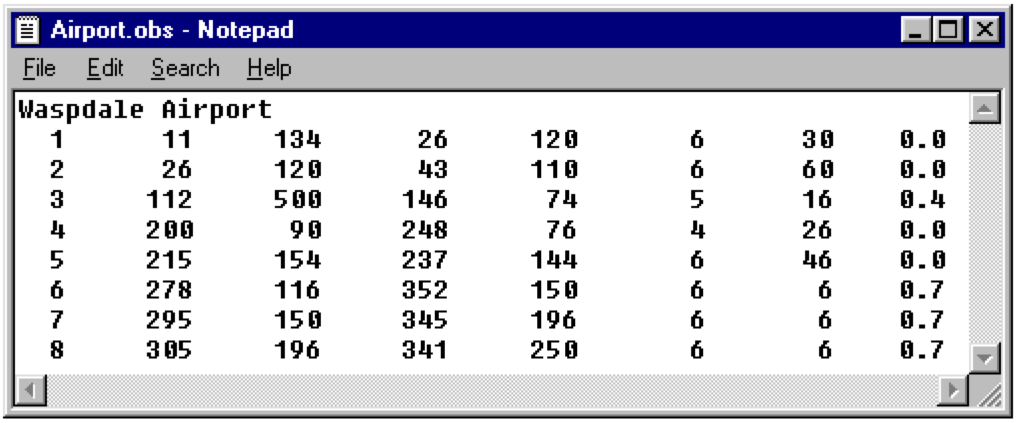
The pattern given in line 2 is repeated as many times as there are obstacles in the file. The obstacle list may contain a maximum of 50 obstacle specifications.

Coordinates

The position of an obstacle is specified in a local, polar coordinate system. Angles (bearings measured with a compass) are given clockwise from north, distance is the length of the radial from the site to the corner of the obstacle (measured with a measuring tape or a range finder). Obstacles are thus specified relative to the specific site and are not linked directly to the terrain map.

Example

The following window shows an obstacle list file, opened with the Notepad text editor. Eight obstacles are specified in the file airport.obs.




```
Waspdale Airport
  1     11    134     26    120      6     30    0.0
  2     26    120     43    110      6     60    0.0
  3    112    500    146     74      5     16    0.4
  4    200     90    248     76      4     26    0.0
  5    215    154    237    144      6     46    0.0
  6    278    116    352    150      6      6    0.7
  7    295    150    345    196      6      6    0.7
  8    305    196    341    250      6      6    0.7
```

The roughness description file

The roughness description file contains the roughness rose for a site, i.e. sector-wise specifications of the roughness lengths and roughness changes.

Data are stored in an ASCII (text) file with the default file name extension 'rrd'. The rrd-file can be obtained from the roughness description given in a WAsP map or from an existing DOS-WAsP roughness description file (*.rds).

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Version indication text, e.g. 'WASP 6.0 RRD'
2	Text string identifying the roughness rose description
3	Number of sectors in roughness rose description
4	Numbers of roughness changes in each sector
5	Roughness lengths next to the site [m] in sectors 1-*n*
6	Distances [m] to first roughness change in sectors 1-*n*
7	Roughness lengths beyond first roughness change
even	... more roughness change distances [m]
odd	... more roughness lengths [m]

Distances and roughness lengths written in a similar way as in lines 6-7 are repeated as many times as the number of roughness changes specified in line 4. With no roughness changes in any sector, line 5 would be the last line of the file. A maximum of 10 roughness changes in each sector is allowed.

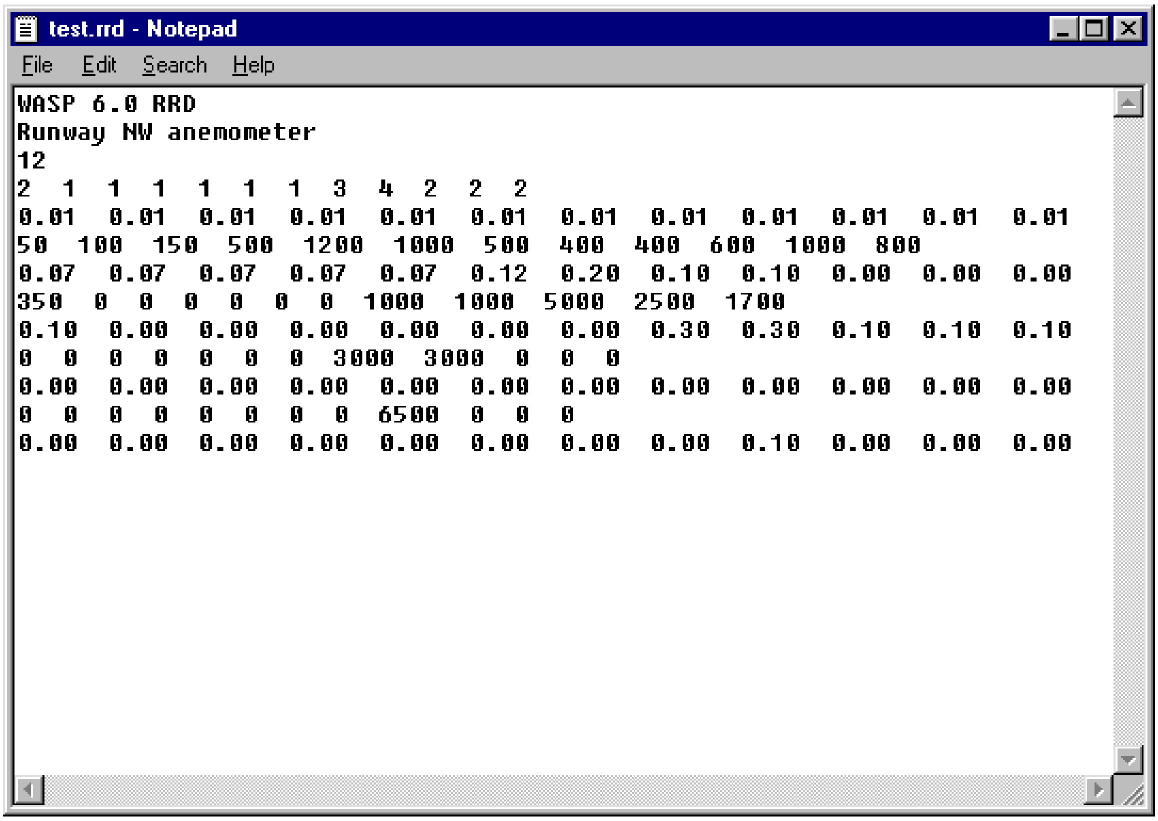
The development of the RRD-file is described in more detail here.

Special considerations

The roughness rose can be displayed and edited from within WAsP. Changes to the roughnesses and roughness change distances can also be entered directly in the file using a text editor.

Example

The following window shows part of a roughness description file, opened in the Notepad text editor.



test.rrd - Notepad

File Edit Search Help

```
WASP 6.0 RRD
Runway NW anemometer
12
2  1  1  1  1  1  1  3  4  2  2  2
0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01
50  100  150  500  1200  1000  500  400  400  600  1000  800
0.07  0.07  0.07  0.07  0.07  0.12  0.20  0.10  0.10  0.00  0.00  0.00
350  0  0  0  0  0  0  1000  1000  5000  2500  1700
0.10  0.00  0.00  0.00  0.00  0.00  0.00  0.30  0.30  0.10  0.10  0.10
0  0  0  0  0  0  0  3000  3000  0  0  0
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0  0  0  0  0  0  0  0  6500  0  0  0
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.10  0.00  0.00  0.00
```

The user corrections file

The user corrections file contains user-specified correction factors for wind speed and user-specified correction angles for wind direction for each sector.

Data are stored in an ASCII (text) file with the default file name extension 'ucf'. The corrections can be displayed and edited in the 'User corrections' window. The ucf-file may also be established using a text editor or written directly by other applications.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

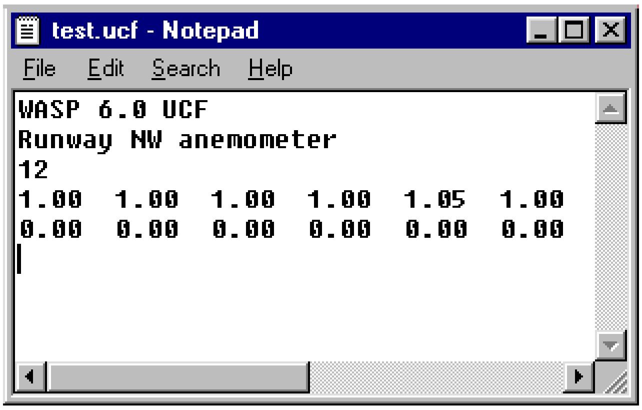
Line	Contents
1	Version indication text, e.g. 'WASP 6.0 UCF'
2	Text string identifying the user-specified corrections
3	Number of sectors

4	Sector-wise correction factors for wind speed
5	Sector-wise correction angles for wind direction [°]

The development of the ucf-file is described in more detail here.

Example

The following window shows part of a user corrections file, opened in the Notepad text editor. Only corrections for the first six sectors are shown.



The wind turbine site file

The wind turbine site file contains the map coordinates of the wind turbine site and the height above ground level [m a.g.l.] for which the calculations are carried out. It further contains information on (pointers to) the predicted wind climate and other hierarchy members associated with the turbine site.

Data are stored in an ASCII (text) file with the default file name extension 'wts'. This file is created and maintained entirely by the WAsP program and the format is therefore not of interest here.

The predicted wind climate file

The predicted wind climate file contains the estimated overall wind climate, power density and power production for a wind turbine site. Furthermore, it contains detailed results on the wind climate, power density, power production and modelling corrections for each of the sectors.

Data are stored in an ASCII (text) file with the default file name extension 'wpw'. The wpw-file is generated by saving the results of a wind turbine calculation. The general format of the file is shown below.

Line	Contents
1	Version indication text, e.g. 'WASP 6.0 SITE DMP'
2	The sector-independent results for the site
3	Results for sector #1
4	Results for sector #2
	...
n	Results for sector #*m*

The format of each line in the file is shown below. Numbers in the same line of the file are/must be separated by blank space(s) or a comma.

Column			**Contents of line 2**
1	A	Height above ground level [m a.g.l.]	
2	B	Weibull *A***-**parameter for total distribution [ms^{-1}]	
3	C	Weibull *k***-**parameter for total distribution	
4	D	Total mean wind speed [ms^{-1}]	
5	E	Total power density [Wm^{-2}]	
6	F	Total power production [Why^{-1}]	
7	G	Number of sectors	
8	H	Site elevation [m a.s.l.]	

Column			**Contents of line 3-*n***
1	A	Centre angle of the sector	
2	B	Frequency of occurrence [%]	
3	C	Weibull *A***-**parameter for the sector [ms^{-1}]	
4	D	Weibull *k***-**parameter for the sector	
5	E	User-specified correction factor for the sector	
6	F	User-specified correction angle for the sector	
7	G	Obstacle model correction for wind speed	
8	H	Obstacle model correction for wind direction	
9	I	Orographic model correction for wind speed	
10	J	Orographic model correction for wind direction	

11 K Roughness model correction for wind speed

12 L Roughness model correction for wind direction

13 M Number of roughness changes in sector

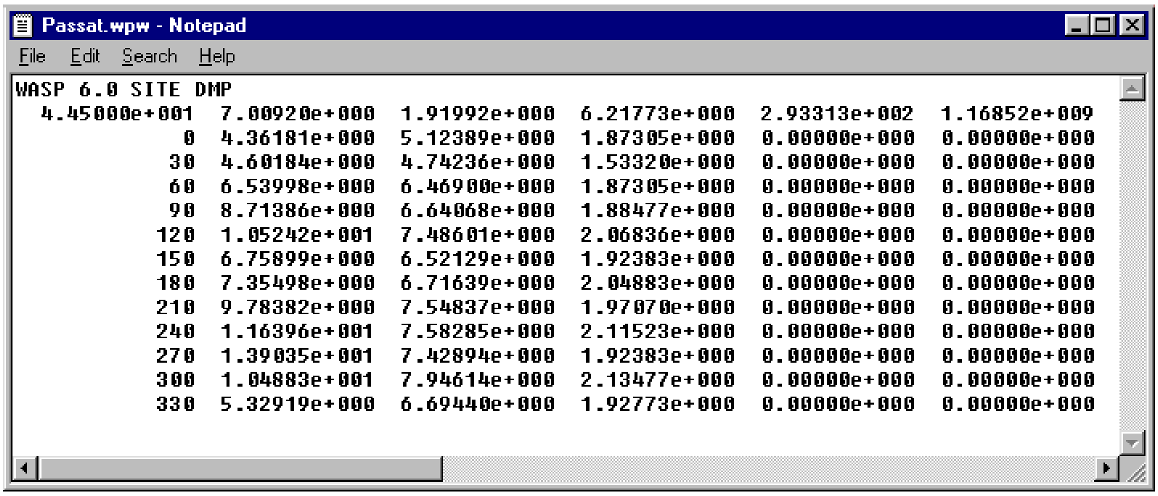
14 N Meso-scale roughness length of sector

15 O Power density [Wm^{-2}]

16 P Power production [Why^{-1}]

Example

The following window shows part of a predicted wind climate file, opened in the Notepad text editor. Only the first 6 columns of numbers in each line are shown.




```
WASP 6.0 SITE DMP
  4.45000e+001  7.00920e+000  1.91992e+000  6.21773e+000  2.93313e+002  1.16852e+009
             0  4.36181e+000  5.12389e+000  1.87305e+000  0.00000e+000  0.00000e+000
            30  4.60184e+000  4.74236e+000  1.53320e+000  0.00000e+000  0.00000e+000
            60  6.53998e+000  6.46900e+000  1.87305e+000  0.00000e+000  0.00000e+000
            90  8.71386e+000  6.64068e+000  1.88477e+000  0.00000e+000  0.00000e+000
           120  1.05242e+001  7.48601e+000  2.06836e+000  0.00000e+000  0.00000e+000
           150  6.75899e+000  6.52129e+000  1.92383e+000  0.00000e+000  0.00000e+000
           180  7.35498e+000  6.71639e+000  2.04883e+000  0.00000e+000  0.00000e+000
           210  9.78382e+000  7.54837e+000  1.97070e+000  0.00000e+000  0.00000e+000
           240  1.16396e+001  7.58285e+000  2.11523e+000  0.00000e+000  0.00000e+000
           270  1.39035e+001  7.42894e+000  1.92383e+000  0.00000e+000  0.00000e+000
           300  1.04883e+001  7.94614e+000  2.13477e+000  0.00000e+000  0.00000e+000
           330  5.32919e+000  6.69440e+000  1.92773e+000  0.00000e+000  0.00000e+000
```

Introduction

Wind turbine data files contain those characteristics of a wind turbine that are used to calculate the power production and, possibly, the park effects in a wind farm:

- The wind turbine hub height [m] and rotor diameter [m]
- The power curve [ms^{-1} and kW]
- The thrust coefficient curve [ms^{-1} and dimensionless]

The wind turbine data must be provided in either of the two following formats:

1. WAsP power curve file (*.pow). This is the format used by all previous versions of WAsP.
2. Park wind turbine data file (*.trb). This is the format used by all previous versions of Park.

For historical reasons, these two formats use slightly different conventions, see the topics below. A new and more flexible wind turbine data file format will be introduced gradually (*.wtg).

The power curve file

The power curve file contains the wind turbine power output and, optionally, the thrust coefficient as a function of hub-height wind speed.

Data are stored in an ASCII (text) file with the default file name extension 'pow'. The power curve file must be prepared using a text editor. The WAsP package contains a number of power curves obtained from the Danish manufacturers.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the wind turbine power curve
2	Wind turbine hub height [m] and rotor diameter [m]
3	Conversion factors for wind speed f_u and power f_p:
	wind speed [ms^{-1}] = $f_u \cdot$ {column 1}
	power output [W] = $f_p \cdot$ {column 2}
4–	wind speed, power output, thrust coefficient (optional)

The power curve may be described by a maximum of 100 points and power production is calculated for the entire interval of wind speeds given in the file.

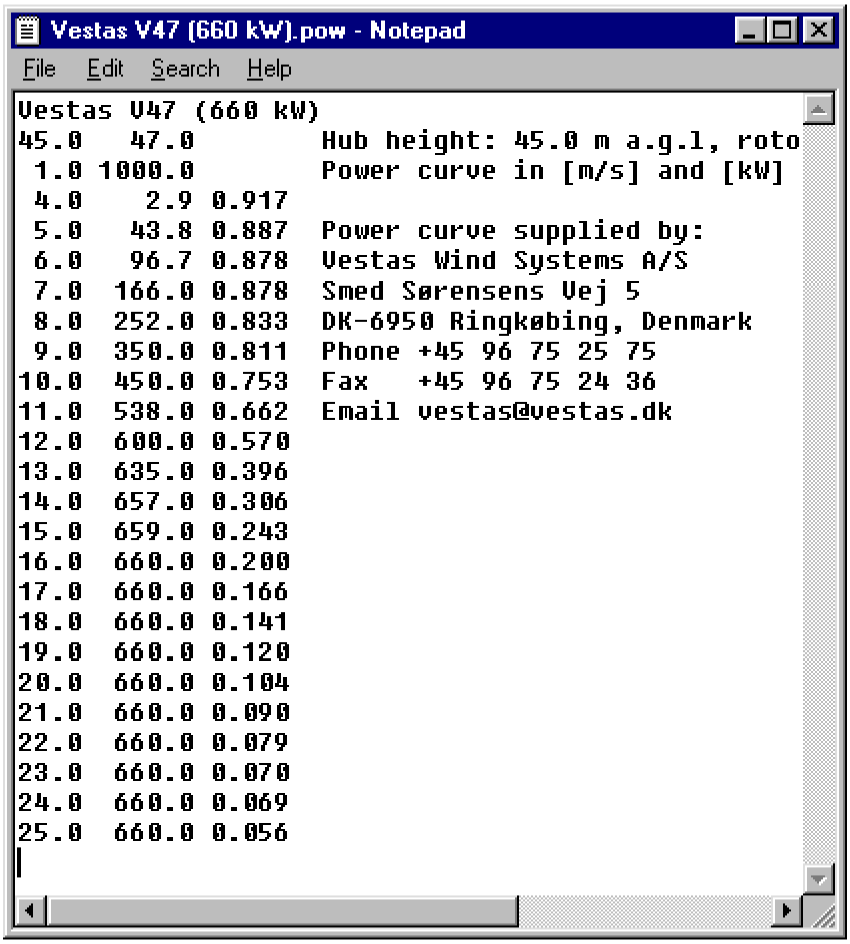
Special considerations

The two numbers given in line 3 are simply the conversion factors from the units of wind speed and power output used in the file to [ms^{-1}] and [W], respectively. Thus, if power output is given in [kW], the factor for power should be 1000.

The factor for power output can in some cases be used to estimate power production at an air density different from the standard value (1.225 kgm^{-3} at 1013.25 hPa and 288 K) by multiplying this factor with the ratio of the two air densities. If the average air temperature is 20°C and the site elevation is 400 m above sea level (and power output is given in kW at standard conditions) the factor could be changed to 938.8. In general, however, it is advisable to obtain a site-specific power curve from the wind turbine manufacturer.

Example

The following window shows the power curve file for a Vestas V47 660-kW wind turbine, opened in the Notepad text editor.



Vestas V47 (660 kW).pow - Notepad

File Edit Search Help

```
Vestas V47 (660 kW)
45.0   47.0        Hub height: 45.0 m a.g.l, roto
 1.0 1000.0        Power curve in [m/s] and [kW]
 4.0    2.9 0.917
 5.0   43.8 0.887  Power curve supplied by:
 6.0   96.7 0.878  Vestas Wind Systems A/S
 7.0  166.0 0.878  Smed Sørensens Vej 5
 8.0  252.0 0.833  DK-6950 Ringkøbing, Denmark
 9.0  350.0 0.811  Phone +45 96 75 25 75
10.0  450.0 0.753  Fax   +45 96 75 24 36
11.0  538.0 0.662  Email vestas@vestas.dk
12.0  600.0 0.570
13.0  635.0 0.396
14.0  657.0 0.306
15.0  659.0 0.243
16.0  660.0 0.200
17.0  660.0 0.166
18.0  660.0 0.141
19.0  660.0 0.120
20.0  660.0 0.104
21.0  660.0 0.090
22.0  660.0 0.079
23.0  660.0 0.070
24.0  660.0 0.069
25.0  660.0 0.056
```

Park wind turbine data file

The Park wind turbine data file contains the wind turbine power output and the thrust coefficient as a function of hub-height wind speed.

Data are stored in an ASCII (text) file with the default file name extension 'trb'. The Park wind turbine data file may be prepared using a text editor. The WAsP package contains a number of power curves in this format, obtained from the Danish manufacturers.

The general format of the file is shown below. Numbers in the same line of the file must be separated by one or more blank characters (spaces).

Line	Contents
1	Rotor radius [m] and wind turbine hub height [m]
2	Number of points, *n*, in power curve data set
3	Wind speed [ms^{-1}] and power output [kW], first point
n+2	Wind speed [ms^{-1}] and power output [kW], *n*th point
n+3	Number of points, *m*, in thrust coefficient data set
n+4	Wind speed [ms^{-1}] and thrust coefficient, first point

n+*m*+3 Wind speed [ms^{-1}] and thrust coefficient, *m*th point

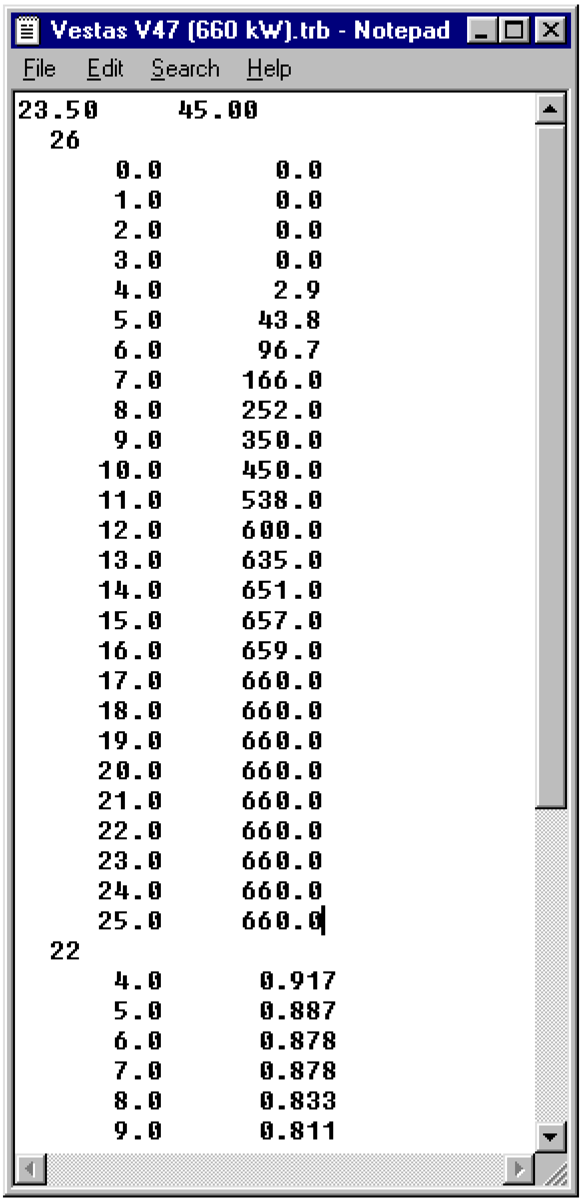
The power and thrust coefficient curves may be described by a maximum of 100 points each and power production is calculated for the entire interval of wind speeds given in the file.

Special considerations

Note, that the rotor is characterised by its *radius*, not its diameter. Also, the power output values must be given in kW and the first point must specify a power output of 0 kW, see below. The thrust coefficient should not exceed 1, if it does it will be truncated to 1.

Example

The following window shows part of the Park wind turbine data file for a Vestas V47 660-kW wind turbine, opened in the Notepad text editor. Note, that there must be at least one value of 0 kW in the beginning of the power curve.




```
23.50      45.00
  26
       0.0        0.0
       1.0        0.0
       2.0        0.0
       3.0        0.0
       4.0        2.9
       5.0       43.8
       6.0       96.7
       7.0      166.0
       8.0      252.0
       9.0      350.0
      10.0      450.0
      11.0      538.0
      12.0      600.0
      13.0      635.0
      14.0      651.0
      15.0      657.0
      16.0      659.0
      17.0      660.0
      18.0      660.0
      19.0      660.0
      20.0      660.0
      21.0      660.0
      22.0      660.0
      23.0      660.0
      24.0      660.0
      25.0      660.0
  22
       4.0       0.917
       5.0       0.887
       6.0       0.878
       7.0       0.878
       8.0       0.833
       9.0       0.811
```

The wind turbine data file

A new file format for wind turbine data is being implemented and will be introduced gradually. This format relies on the Extensible Mark-up Language (XML) for a more general and flexible file structure.

Introduction

Wind farm files contain the coordinates, height above ground level, estimated overall wind climate and estimated power density or power production for each of a number of sites in a wind farm. They further contain the wind rose and sector-wise wind speed distributions for each site. One format also contains information on the status of the wind farm calculations and the settings and constants chosen by the user for the wake modelling.

The wind farm data must be provided in either of the two following formats:

1. WAsP wind farm file (*.wwf). This is the format used by the present version of WAsP.
2. WAsP random resource file (*.rsf). This is the format used by all previous versions of WAsP.

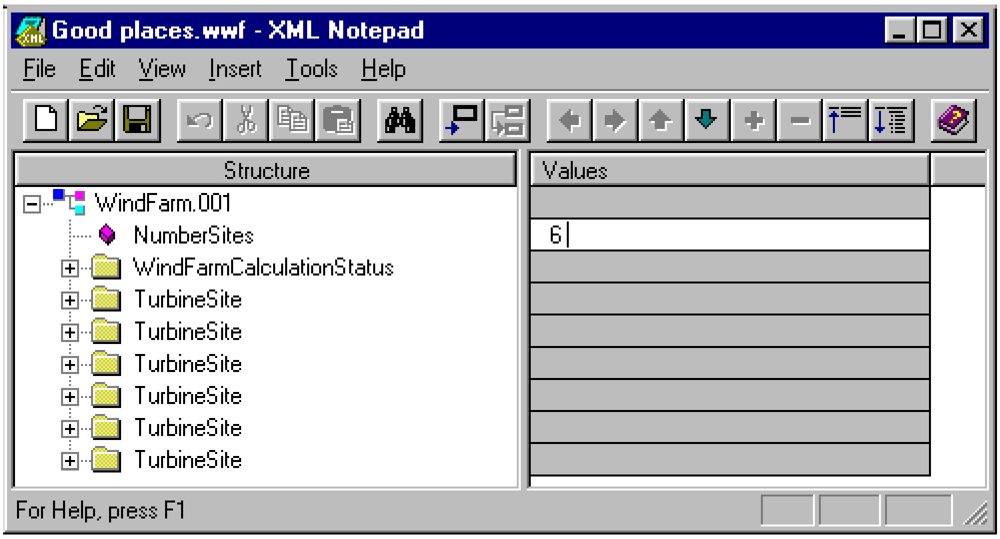
The present version of WAsP will use the wind farm file format as the default file format, but it is possible to export a random resource file as well.

Importing the wind farm layout from other programs

If the layout of the wind farm is already given as site coordinates (*x, y*) in a document or spreadsheet, you can import the positions as a free-format coordinate pairs file. However, once the wind farm results have been calculated, they must be stored in one of the two formats described above.

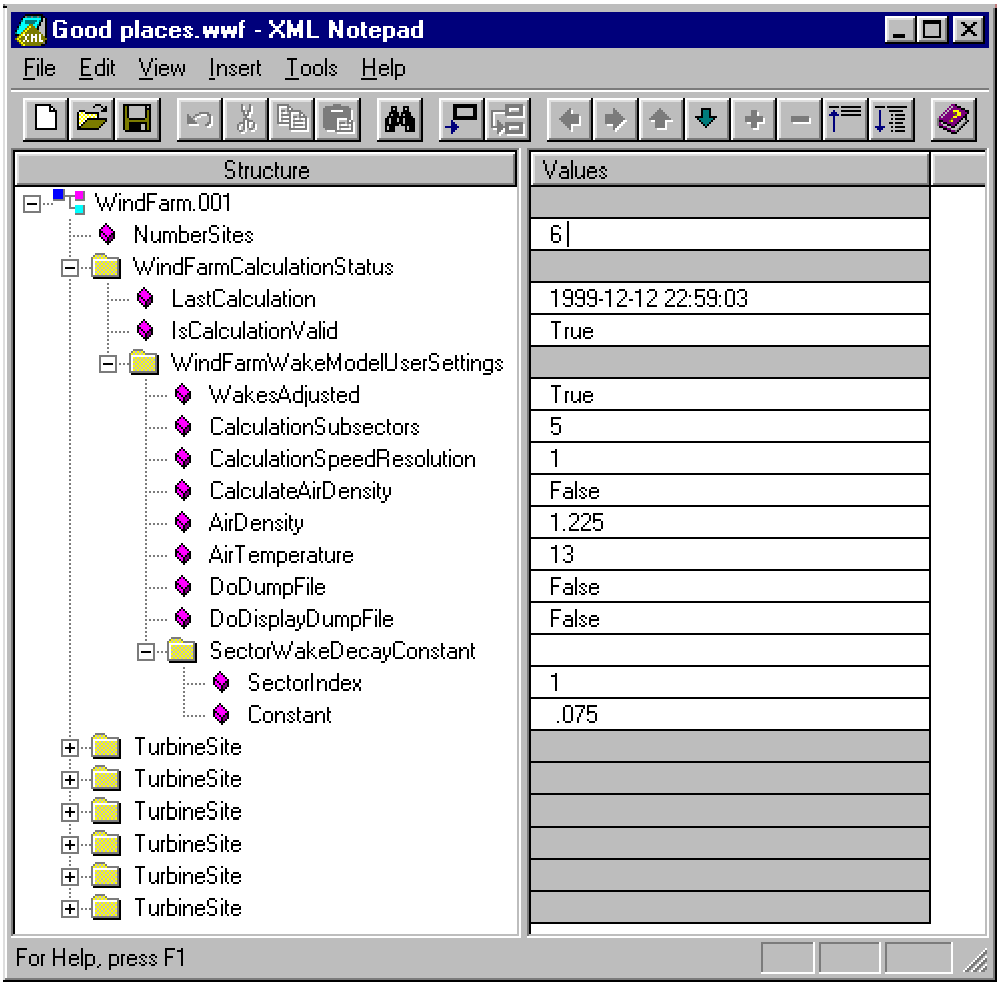
The wind farm file

This file format relies on the Extensible Mark-up Language (XML) for a general and flexible file structure. Data are stored in an ASCII (text) file with the default file name extension 'wwf'. The wwf-file may be generated by saving the results of a wind farm calculation. The general structure and contents of a wind farm data file is illustrated below, by showing one such file opened in the XML Notepad.



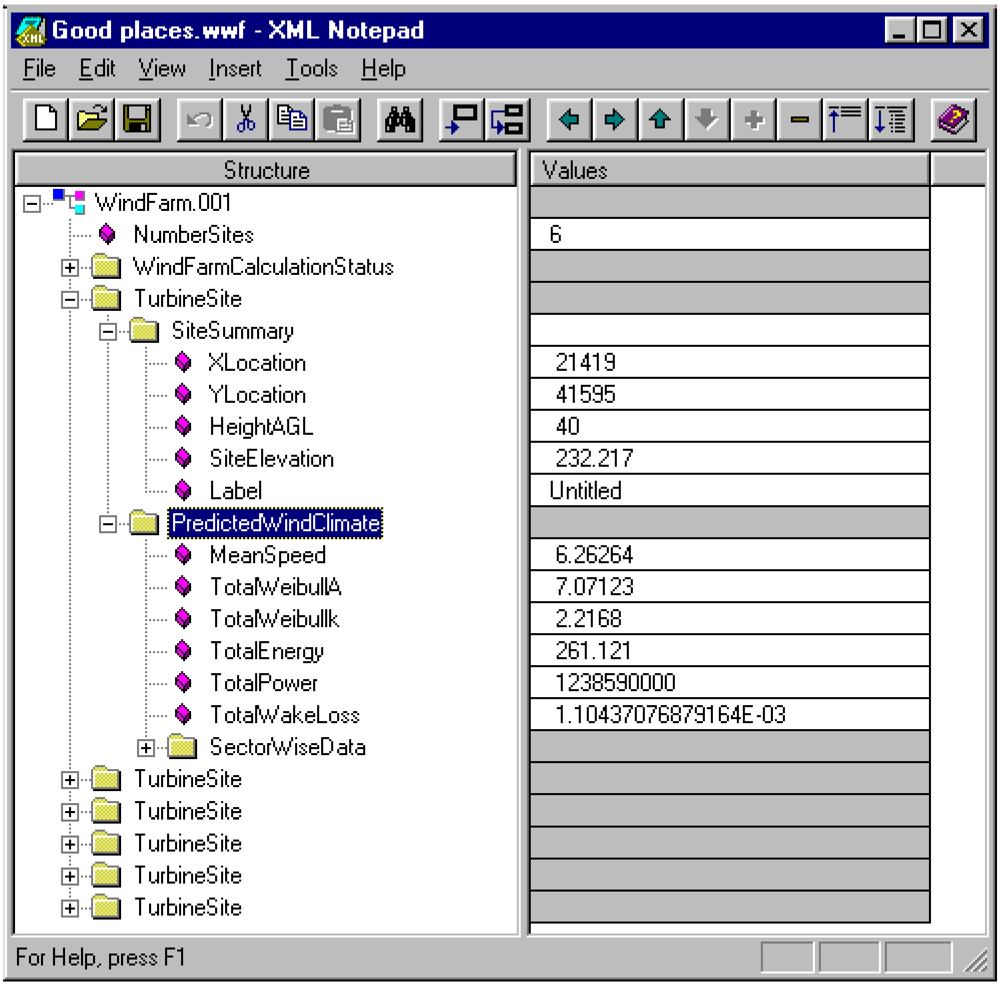
Calculation status

The wwf-file contains information on the status of the wind farm calculations and the settings and constants chosen by the user for the wake modelling. Both the structure and the actual values are shown in the example below.



Turbine site results

Each site is documented by a site summary as well as the predicted wind climate and estimated power production for the site. Wind climate estimates are further given for each of a number of sectors.



The random resource file

Data are stored in an ASCII (text) file with the default file name extension 'rsf'. The rsf-file may be generated by saving the results of a wind farm calculation. The wind farm layout (the labels and *X*- and *Y*-coordinates) can be entered in a new wind farm view, imported as an existing rsf-file or may be prepared with a text editor. The general format of the file is shown below.

Line	Contents
1	Results for site #1
2	Results for site #2
	...
n	Results for site #*n*

The format of each line in the file is shown below. Note, that the format is fixed in the sense that each number will occur within the fields (columns) specified.

Column	Contents
1-10	Text string (10 characters) identifying the site/WT

11-20 *X*-coordinate (easting) of the site [m]

21-30 *Y*-coordinate (northing) of the site [m]

31-38 *Z*-coordinate (elevation) of the site [m]

39-43 Height above ground level [m a.g.l.]

44-48 Weibull *A*-parameter for the total distribution [ms^{-1}]

49-54 Weibull *k*-parameter for the total distribution

55-69 Power density [Wm^{-2}] or power production [Why^{-1}]

70-72 Number of sectors

73-76 Frequency of occurrence for sector #1 [%·10]

77-80 Weibull *A*-parameter for sector #1 [ms^{-1}·10]

81-85 Weibull *k*-parameter for sector #1 [·100]

86-98 As columns 73-85, but for sector #2

... ...

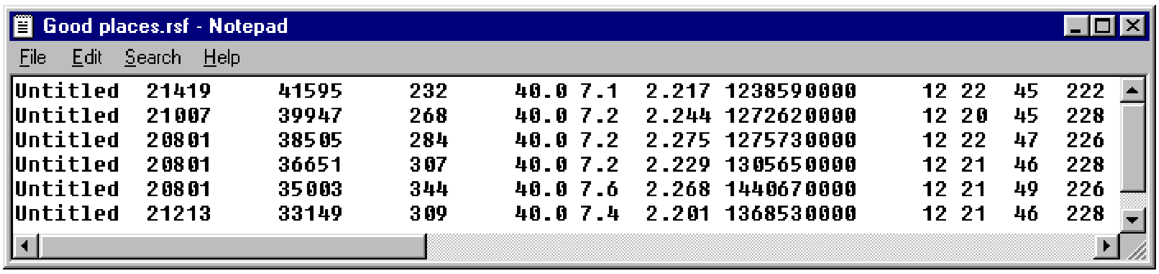
216-228 As columns 73-85, but for sector #12

Special considerations

Existing wind farm layouts can be employed by inserting an existing random resource file to your project.

Example

The window below shows part of a random resource file, opened in the Notepad text editor. Only the first 12 columns of site ID's and numbers in each line are shown.




```
Untitled  21419  41595  232  40.0 7.1  2.217 1238590000  12 22  45  222
Untitled  21007  39947  268  40.0 7.2  2.244 1272620000  12 20  45  228
Untitled  20801  38505  284  40.0 7.2  2.275 1275730000  12 22  47  226
Untitled  20801  36651  307  40.0 7.2  2.229 1305650000  12 21  46  228
Untitled  20801  35003  344  40.0 7.6  2.268 1440670000  12 21  49  226
Untitled  21213  33149  309  40.0 7.4  2.201 1368530000  12 21  46  228
```

Free-format coordinates

Data are stored in an ASCII (text) file with the default file name extension 'txt'. The txt-file may be generated using a text editor, spreadsheet, or other software. The file simply specifies the wind farm layout by the *x*- and *y*-coordinates of the wind turbine sites and contains no information on the wind climate or power production. The general format of the file is shown below.

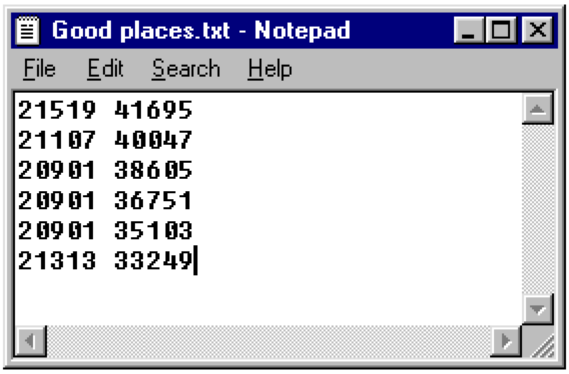
Line	Contents
1	*x*- and *y*-coordinates for site #1
2	*x*- and *y*-coordinates for site #2
	...
n	*x*- and *y*-coordinates for site #*n*

Special considerations

This file contains only the coordinates of the turbines and not any results. If the layout is imported via a *.txt-file, the wind farm should subsequently be saved as a *.wwf file.

Example

The window below shows part of a free-format coordinate pairs file, opened in the Notepad text editor. The coordinates are separated by space(s).



The resource grid file

The resource grid file contains the coordinates, height above ground level, the estimated overall wind climate and estimated power density or power production for each of a number of sites in a resource grid; which is simply a regular grid of sites. It further contains the wind rose and sector-wise wind speed distributions for each node point in the grid.

Data are stored in an ASCII (text) file with the default file name extension 'wrg'. The wrg-file is generated by saving the results of a resource grid calculation.

The general format of the file is shown below.

Line	Contents
1	N_x N_y $X_{min}$$Y_{min}$ {*cell size*}
	$N_x$is the number of grid points in the *X*-direction
	$N_y$is the number of grid points in the *Y*-direction

	X_{min} is the *X*-coordinate of the lower left corner of the grid [m]
	Y_{min} is the *Y*-coordinate of the lower left corner of the grid [m]
	{*cell size*} is the regular resource grid cell size [m]
2	Results for site #1
3	Results for site #2
	...
n+1	Results for site #*n*

The format of each line in the file is shown below. Note, that the format is fixed in the sense that each number will occur within the fields specified.

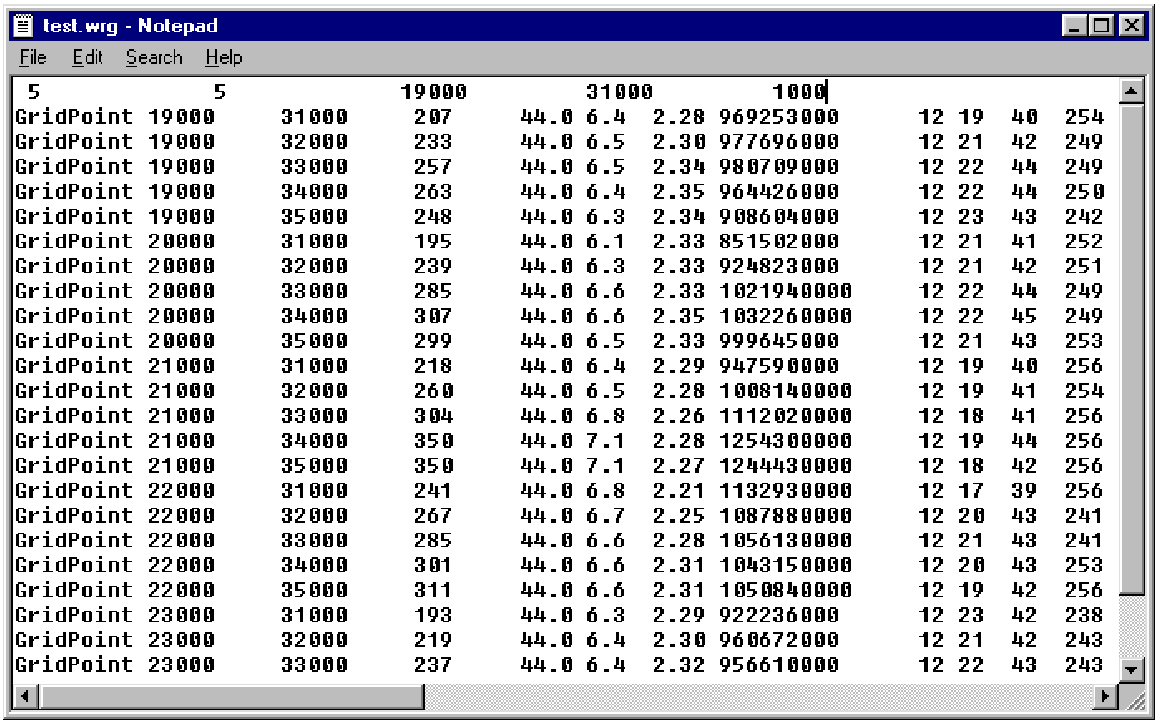
Column	Contents
1-10	Text string (10 characters) identifying the site/grid point
11-20	*X*-coordinate (easting) of the site [m]
21-30	*Y*-coordinate (northing) of the site [m]
31-38	*Z*-coordinate (elevation) of the site [m]
39-43	Height above ground level [m a.g.l.]
44-48	Weibull *A*-parameter for the total distribution [ms^{-1}]
49-54	Weibull *k*-parameter for the total distribution
55-69	Power density [Wm^{-2}] or power production [Why^{-1}]
70-72	Number of sectors
73-76	Frequency of occurrence for sector #1 [%·10]
77-80	Weibull *A*-parameter for sector #1 [ms^{-1}·10]
81-85	Weibull *k*-parameter for sector #1 [·100]
86-98	As columns 73-85, but for sector #2

… …

216-228 As columns 73-85, but for sector #12

Example

The following window shows part of a resource grid file, opened in the Notepad text editor. Only the first 12 columns of numbers in each line are shown.



```
test.wrg - Notepad
File  Edit  Search  Help
 5             5            19000          31000          1000
GridPoint 19000    31000    207    44.0 6.4  2.28 969253000    12 19   40   254
GridPoint 19000    32000    233    44.0 6.5  2.30 977696000    12 21   42   249
GridPoint 19000    33000    257    44.0 6.5  2.34 980709000    12 22   44   249
GridPoint 19000    34000    263    44.0 6.4  2.35 964426000    12 22   44   250
GridPoint 19000    35000    248    44.0 6.3  2.34 908604000    12 23   43   242
GridPoint 20000    31000    195    44.0 6.1  2.33 851502000    12 21   41   252
GridPoint 20000    32000    239    44.0 6.3  2.33 924823000    12 21   42   251
GridPoint 20000    33000    285    44.0 6.6  2.33 1021940000   12 22   44   249
GridPoint 20000    34000    307    44.0 6.6  2.35 1032260000   12 22   45   249
GridPoint 20000    35000    299    44.0 6.5  2.33 999645000    12 21   43   253
GridPoint 21000    31000    218    44.0 6.4  2.29 947590000    12 19   40   256
GridPoint 21000    32000    260    44.0 6.5  2.28 1008140000   12 19   41   254
GridPoint 21000    33000    304    44.0 6.8  2.26 1112020000   12 18   41   256
GridPoint 21000    34000    350    44.0 7.1  2.28 1254300000   12 19   44   256
GridPoint 21000    35000    350    44.0 7.1  2.27 1244430000   12 18   42   256
GridPoint 22000    31000    241    44.0 6.8  2.21 1132930000   12 17   39   256
GridPoint 22000    32000    267    44.0 6.7  2.25 1087880000   12 20   43   241
GridPoint 22000    33000    285    44.0 6.6  2.28 1056130000   12 21   43   241
GridPoint 22000    34000    301    44.0 6.6  2.31 1043150000   12 20   43   253
GridPoint 22000    35000    311    44.0 6.6  2.31 1050840000   12 19   42   256
GridPoint 23000    31000    193    44.0 6.3  2.29 922236000    12 23   42   238
GridPoint 23000    32000    219    44.0 6.4  2.30 960672000    12 21   42   243
GridPoint 23000    33000    237    44.0 6.4  2.32 956610000    12 22   43   243
```

WAsP 4 roughness description

The site-specific roughness description file contains the roughness rose for a site, i.e. sector-wise specifications of the roughness lengths and roughness changes, as well as user-specified correction factors for wind speed and correction angles for wind direction for each sector. The file format is used with previous versions of WAsP, but has now been implemented in two separate files: the RRD file and the UCF file. WAsP can open and save all of these files; however, the use of the two new formats are strongly recommended.

Data are stored in an ASCII (text) file with the default file name extension 'rds'.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the site-specific description
2	Height of WAsP calculations [m]
3	Sector-wise correction factors for wind speed
4	Sector-wise correction angles for wind direction [°]

5	Numbers of roughness changes in each sector
6	Roughness lengths next to the site [m] in sectors 1-*n*
7	Distances [m] to first roughness change in sectors 1-*n*
8	Roughness lengths beyond first roughness change
odd	... more roughness change distances [m]
even	... more roughness lengths [m]

Distances and roughness lengths written in a similar way as in lines 7-8 are repeated as many times as the number of roughness changes specified in line 5. With no roughness changes in any sector, line 6 would be the last line of the file. A maximum of 10 roughness changes in each sector can be specified.

The development of the new rrd- and ucf-files is described in more detail here.

Introducing the OWC Wizard

When calculating a wind atlas from site data, WAsP does not use the time-series of meteorological data. Instead, WAsP needs a tabular summary of the frequency of occurrence of wind speed versus wind direction. This tabular summary is contained in an observed wind climate file (OWC or *.tab file).

The OWC Wizard is a utility program which produces OWC files from raw wind speed and direction measurements. The time-series of wind speed and direction data are transformed into a table which describes a time-independent summary of the conditions found at the measuring site.

Data adjustments

As well as simply summarising the time-series data, the Wizard also makes it possible to adjust the raw data before compiling the summary. You can specify which of the raw data to omit from the summary, you can apply linear adjustments to the data values and you can specify the discretisation bin widths apparent in the raw data.

Multiple files, different formats

The OWC summary can be generated from one or more raw data files. Each raw data file which is included can have a different format, and can be collected with a different instrument.

Using the Wizard

The Wizard has been designed to be a quick but flexible way of producing OWC files from raw data. The process consists of navigating forward through a series of dialog boxes which sequentially collect the information required before producing the OWC file and saving it.

If the raw data are quite straightforward, then it's only necessary to make one or a few selections: the rest of the time the default values can be immediately accepted.

The dialogs contain some instructions, and there is help available for each dialog (pressing the **F1** key). The places where some input is required or possible are highlighted in white boxes.

If you tick one or more of the little boxes to the right of the white boxes where you enter the values, the present value(s) will be used as the default value(s) for subsequent OWC Wizard sessions.

The raw meteorological data

The raw meteorological data must be provided as files which contain readings for wind speed and wind direction. The observed wind climate can be produced from one or more raw data files. The data files can contain readings other than speed and direction, but they will of course be ignored when reading the file. If more than one data file is used, then each can have a different format.

The accuracy and reliability of your wind atlas data sets and wind resource assessments strongly depend on the quality of the raw meteorological data! Read more about wind data analysis here.

Legitimate formats

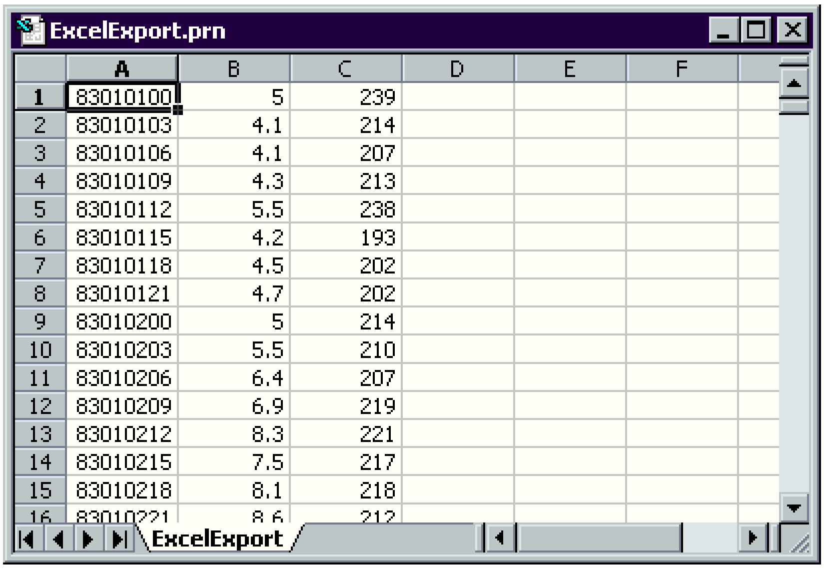
The current version of the Wizard does not read binary files, but providing that your files are not binary, the Wizard can read a variety of different data configurations.

- The data must be regularly arranged within the file.
- There should be no gaps or blank lines in the data arrangement.
- The data contained within the files must be separated from one another.
- Data can be separated by spaces or tabs or end of line markers.
- There can be several header lines at the top of the file.

It is recommended to use 'dummy values' for missing observations, e.g. '99.99' for wind speed and '999' for wind direction.

Example – Importing data from Excel

The picture below shows the standard sample file RawData.dat when viewed in Excel.

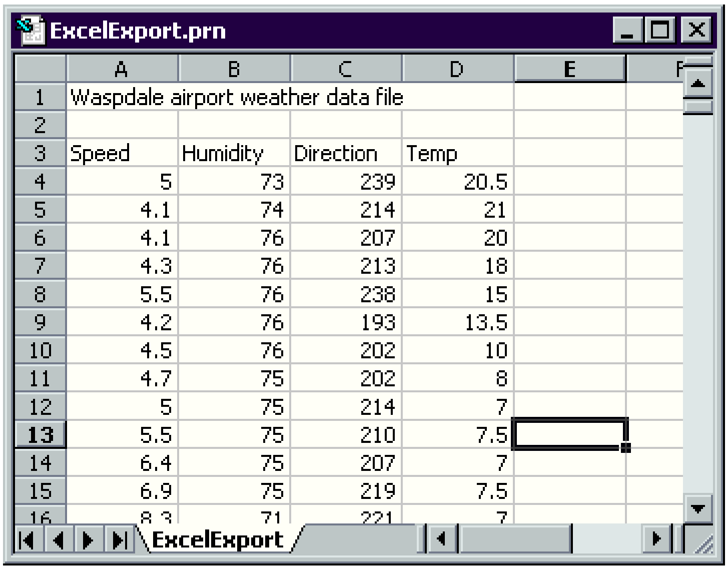


	A	B	C	D	E	F
1	83010100	5	239			
2	83010103	4.1	214			
3	83010106	4.1	207			
4	83010109	4.3	213			
5	83010112	5.5	238			
6	83010115	4.2	193			
7	83010118	4.5	202			
8	83010121	4.7	202			
9	83010200	5	214			
10	83010203	5.5	210			
11	83010206	6.4	207			
12	83010209	6.9	219			
13	83010212	8.3	221			
14	83010215	7.5	217			
15	83010218	8.1	218			
16	83010221	8.6	212			

If the raw data can be viewed like this in Excel, then the OWC Wizard can read them.

Each row contains a reading. The first column contains the date/time of the reading and the second and third columns contain the wind speed and direction respectively.

Other data arrangements are possible. The first column is not needed, and other columns could be included containing other data. The file could have a header section too, as shown in the picture below.



	A	B	C	D	E
1	Waspdale airport weather data file				
2					
3	Speed	Humidity	Direction	Temp	
4	5	73	239	20.5	
5	4.1	74	214	21	
6	4.1	76	207	20	
7	4.3	76	213	18	
8	5.5	76	238	15	
9	4.2	76	193	13.5	
10	4.5	76	202	10	
11	4.7	75	202	8	
12	5	75	214	7	
13	5.5	75	210	7.5	
14	6.4	75	207	7	
15	6.9	75	219	7.5	
16	8.3	71	221	7	

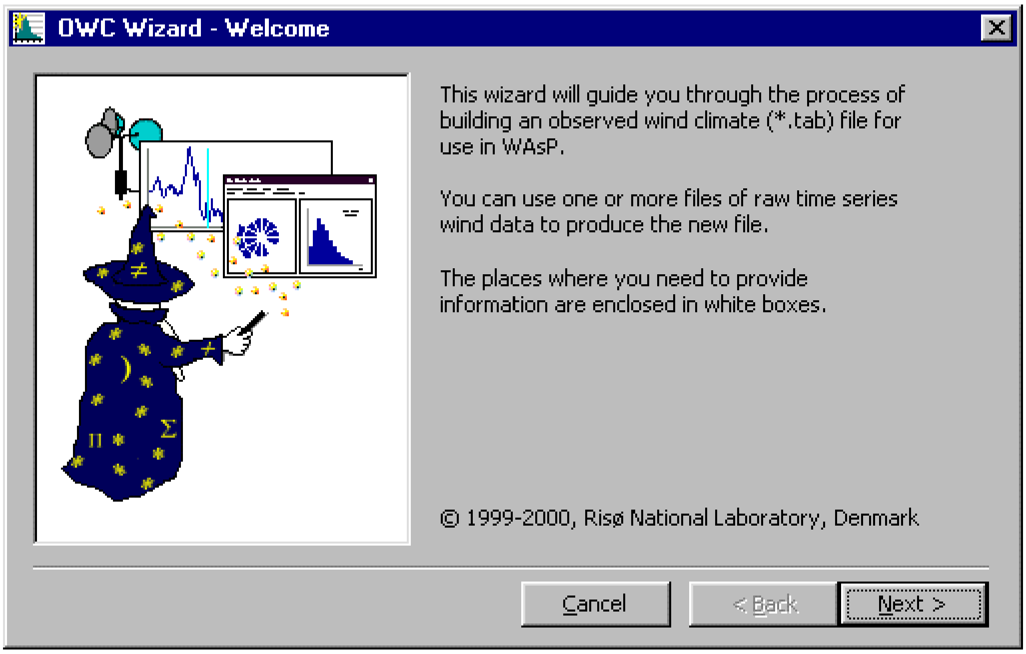
The OWC Wizard can read data like these too.

The best format in which to save data from Excel is **Formatted text (Space delimited)**. Alternatively, you could use **Text (Tab delimited)**. The OWC Wizard will be able to understand either.

Starting the OWC Wizard

There are three ways to start the OWC Wizard

1. From the Windows **Start** menu or Windows Explorer.
2. From the **Tools** menu of the main WAsP program.
3. By inserting a new observed wind climate file into the workspace hierarchy.



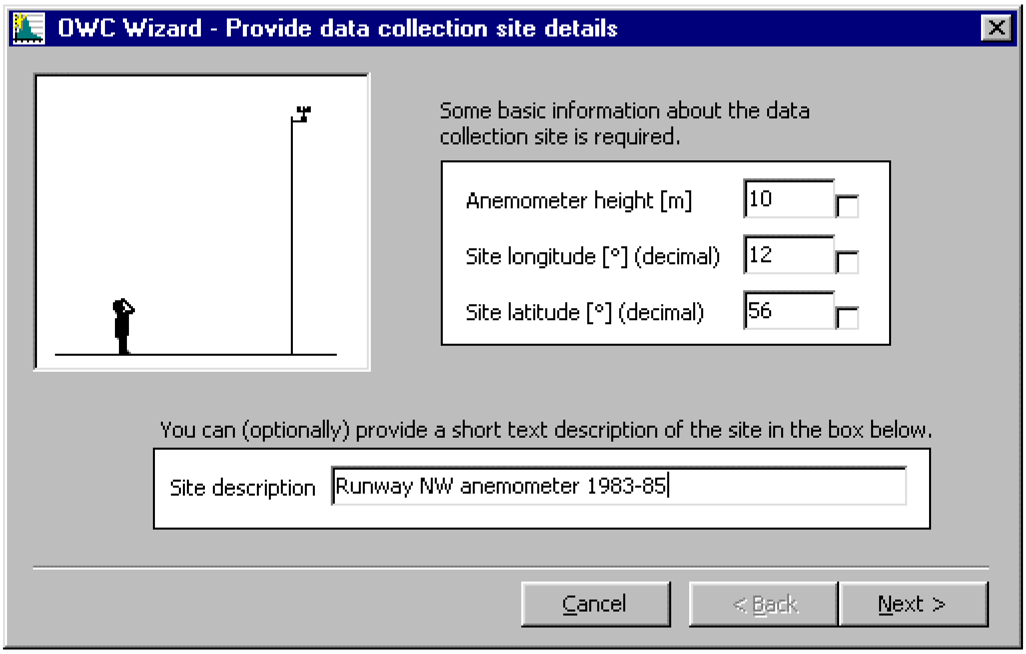
The dialog sequence

The Wizard consists of a series of dialogs which guide you through the process of creating an OWC file from one or more raw data files. The sequence of dialogs is as follows:

1. Welcome to the Wizard
2. Provide details of the site
3. Add a data set. For each data set, the following sequence of dialogs is displayed:
    1. Select data file
    2. Explain data structure
    3. Specify which rows to use
    4. Define adjustments to the data
    5. Define the speed and direction limits
    6. Review the data set
4. Choose the output settings
5. Save the file
6. Review the mean values of speed and power density and the difference between calculated and (Weibull) fitted values.

Providing site details

Before any data can be accepted, the Wizard needs some basic information about the site where the data were collected.



The anemometer height is the height of the anemometer *above ground level*; it's usually abbreviated m a.g.l. Entering a correct anemometer height is essential to make the subsequent WAsP calculations meaningful. If at all possible, check (or measure directly)the actual anemometer height during a site visit.

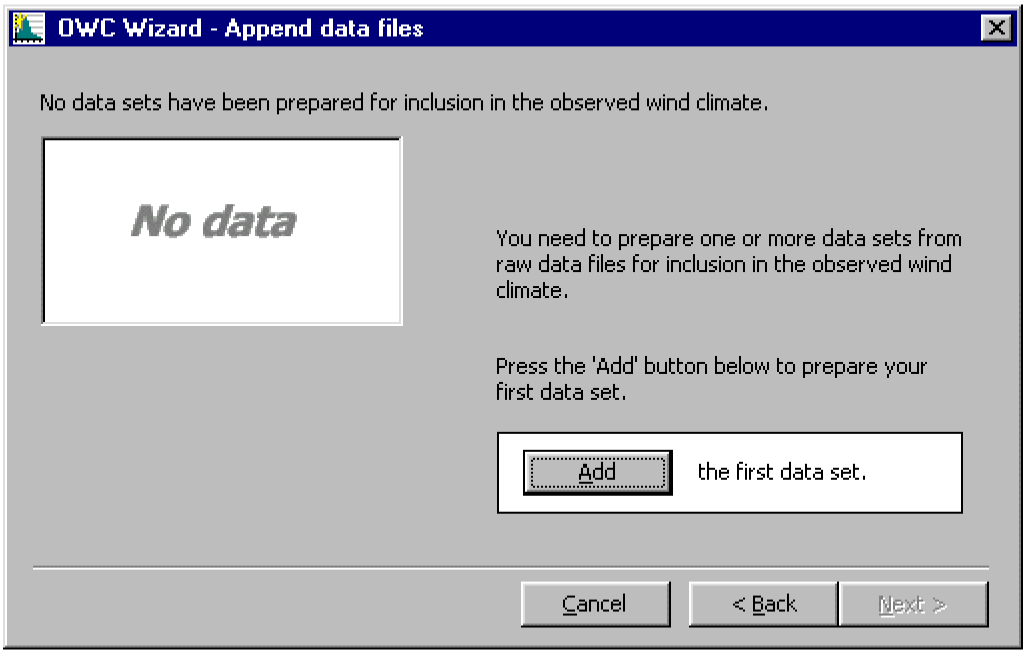
The site longitude and latitude cannot be left as zero since the site latitude is used by the WAsP models. Also, this information is included in the output file and may be very helpful to others working with the file later.

Note, that the location of the anemometer site must be provided here as its geographical coordinates, i.e. as the latitude and longitude in decimal degrees. Conventionally, latitude N and longitude E are considered positive; latitude S and longitude W negative. Latitude can thus take values between -90º and +90º and longitude values between -180º and +180º.

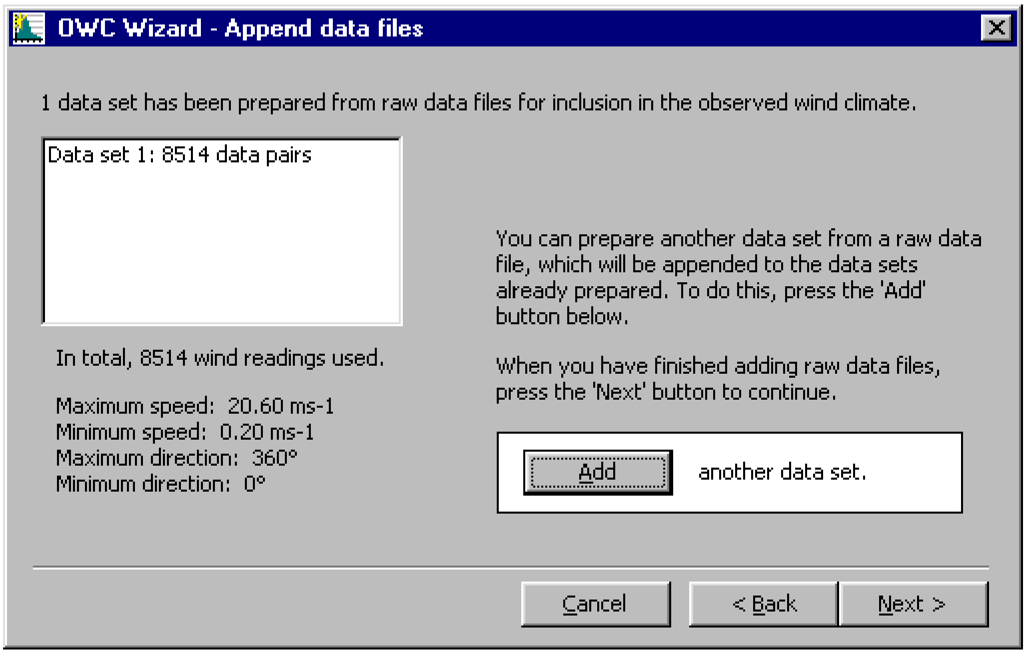
The site description will be displayed when the OWC is imported and displayed in the main WAsP program hierarchy.

Managing the data sets

The Wizard can accept one or more data files to use when generating the OWC summary file. If no data files have been added, then it is impossible to proceed from this dialog.



Clicking the Add button will launch a series of dialogs which manage the addition of one data file. When the data file has been added, this dialog will re-appear. While waiting for the next input, the Wizard shows a list of the data sets prepared so far and a brief summary of these data files.



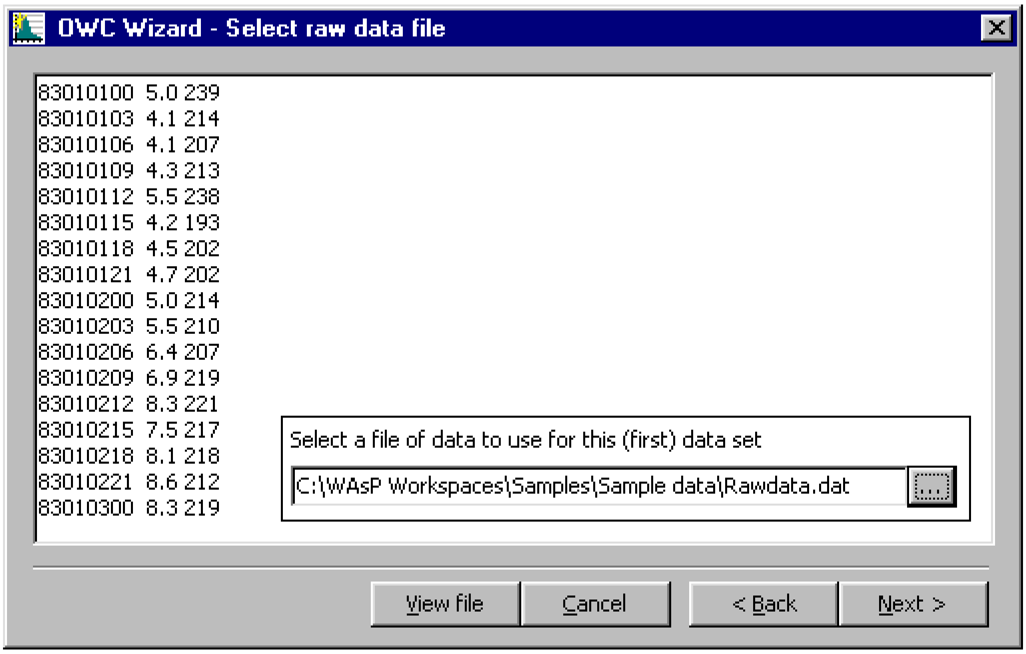
Now that some data have been added, it is possible to

- add another file, or
- go back to change the site details, or
- proceed to the next stage, or
- cancel the current OWCW session.

If you choose to **Cancel**, then all of the data sets which have been added will be lost. If you choose to proceed to the next stage, then it is possible to return back to this dialog and add another data set later.

Selecting the data file

Click the button marked '...' to select the raw data file.



When a file is selected, the Wizard displays the first few lines of the file contents in the background. If you choose **View file**, the file will be opened by NotePad or WordPad.

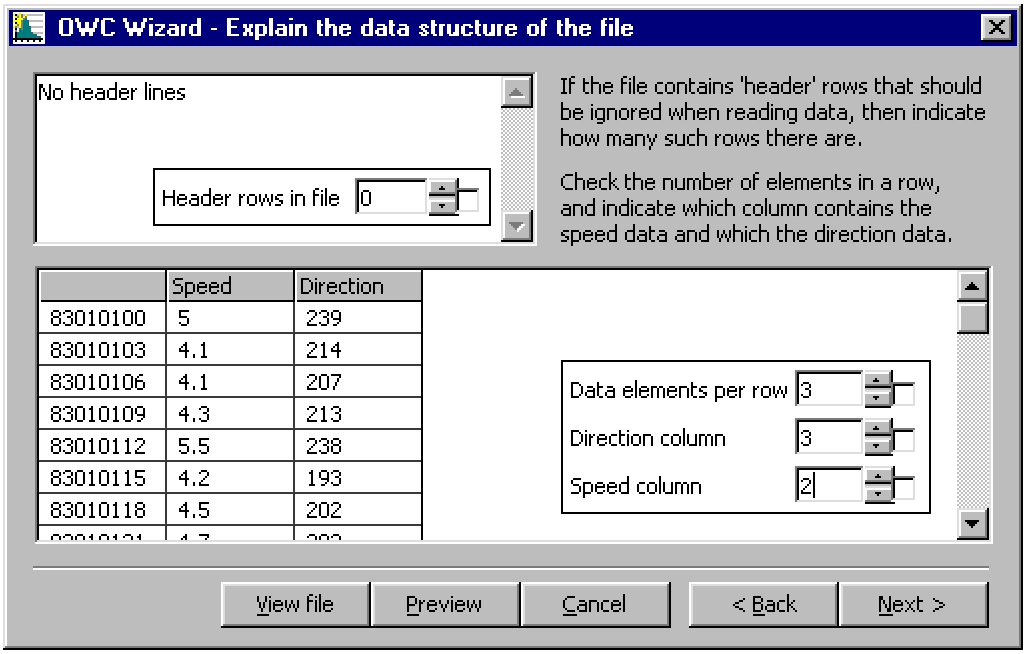
You can read more about the raw meteorological data file format.

Explaining the data structure

The Wizard needs to know how to interpret the contents of the file which is being added. The grid shown in the bottom half of the dialog provides a preview of how the data will be interpreted. The text area in the top left of the dialog shows the header information which is found in the file (and will of course be discarded for the analysis).

The Wizard makes an estimate of the number of header rows in the file and the number of data elements in each row. If a file has already been imported, then the Wizard simply applies the same explanation as was used for the last set. If the imported file is tab-delimited, then the Wizard's own estimate may be unsuccessful. The data preview areas will show the right numbers, but in completely the wrong arrangement.

The Wizard's estimate can be corrected by adjusting the figures for **Header rows in file** and **Data elements per row**.



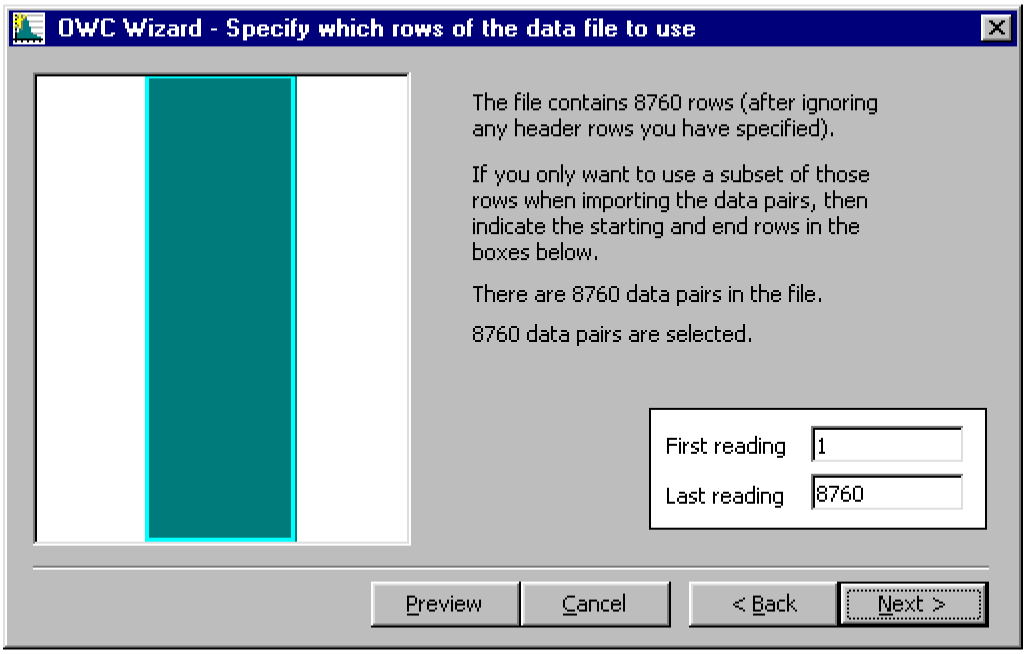
Adjust the figures in the boxes for **Direction column** and **Speed column** until the preview grid displays a correct interpretation of the data file (as in the picture above).

If you choose **View file**, the file will be opened by the NotePad or WordPad text editor.

If you choose **Preview**, the data will be shown in several graphs: the time traces of wind direction and wind speed, and as a polar scatter plot of the observations.

Specifying which rows to use

It may be that the data file contains data from a period which should be excluded from the analysis for some reason. It is possible to specify a subset of the entire data set to be imported. By default, the Wizard assumes that all of the data should be included, but by changing the values for First reading and Last reading, a subset can be defined.

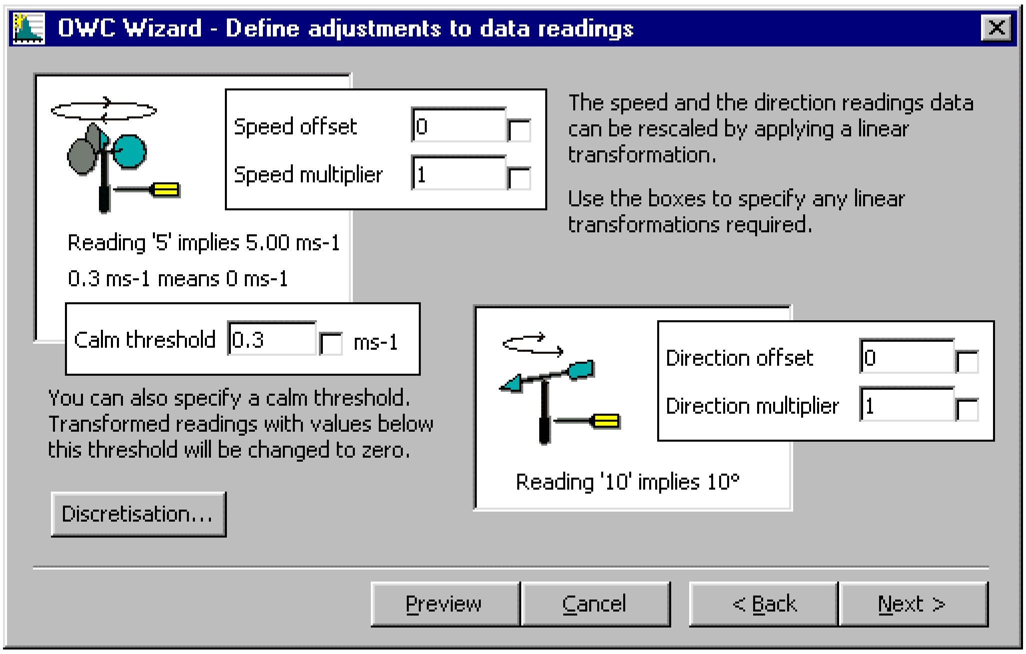


In the picture above, the first 8760 readings in the file have been excluded. The illustration on the left simply provides a quick visual check of the subset relative to the whole data set.

If you choose **Preview**, the data will be shown in several graphs: the time traces of wind direction and wind speed, and as a polar scatter plot of the observations.

Define adjustments to data readings

The contents of each data set are affected by the device used to collect the data. It's also possible that the wind speed and direction data are not recorded in standard SI units in the data file. The Wizard allows corrections to be made to all data values in the file.



In the window above, we have set the calm threshold to 0.3 ms^{-1} rather than 0 (zero).

Wind speed correction

A linear correction to the wind speed data can be made by adjusting the figures for **Speed offset** and **Speed multiplier** in the boxes provided. The correction is made according to the usual form $y = ax + b$, where the offset value is b and the multiplier value is a. The result of the correction is previewed as a line of text which calculates how a reading with a value of '5' would be interpreted.

This feature can be used to convert other units of wind speed to metres per second, e.g.:

From	to	multiplier (a)	offset (b)
km/hour	ms^{-1}	0.2778	0.0
miles/hour	ms^{-1}	0.4470	0.0
knots	ms^{-1}	0.5144	0.0

Calm indication and interpretation

It is also possible to provide a calm threshold. Any reading with a wind speed equal to or below this threshold value will be treated as zero (calm).

Wind direction correction

A linear correction to the wind direction data can be made by adjusting the figures for **Direction offset** and **Direction multiplier** in the boxes provided. The result of the correction is previewed as a line of text which calculates how a reading with a value of '10' would be interpreted.

Data discretisation

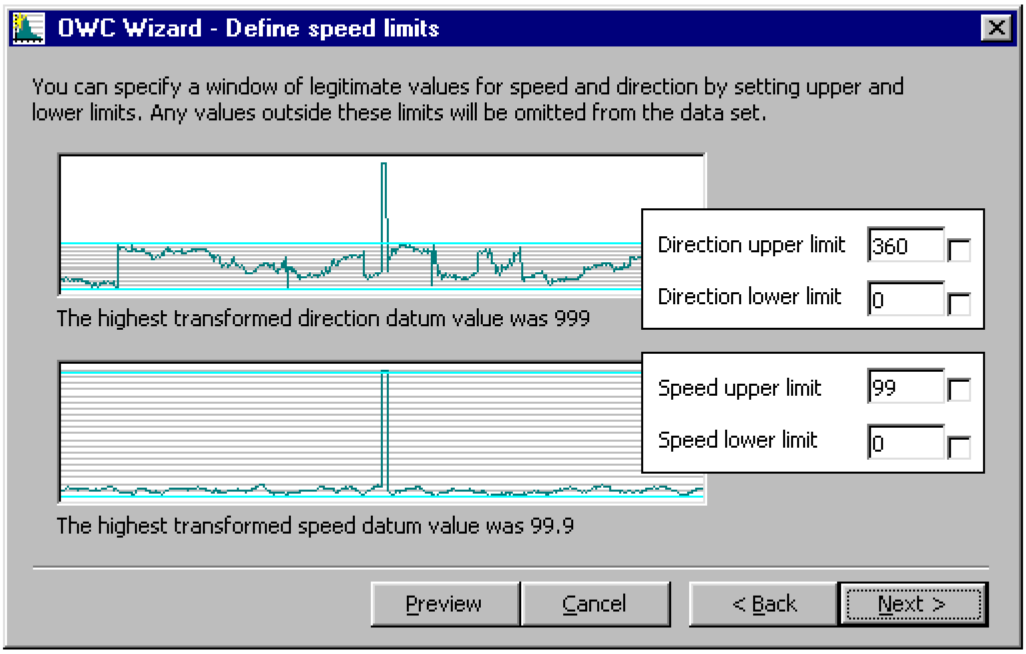
Pressing the **Discretisation...** button allows information about the discretisation in the raw data to be provided to the Wizard. All wind data are inherently discretised (even though the discretisation bin widths may be small) and it is recommended to enter the actual bin widths (data resolution) apparent in the data.

If you choose **Preview**, the data will be shown in several graphs: the time traces of wind direction and wind speed, and as a polar scatter plot of the observations. If the data have been severely discretised, you will see clear 'patterns' in the preview graphs.

Defining the wind data limits

Some data files contain readings with out-of-range values which indicate an error condition in the reading apparatus or is used as a flag for missing observations. This dialog allows upper and lower limits to be set for wind speed and direction data. Any data values outside these ranges will not be included in the OWC summary.

The picture below shows a data set with occasional very high readings. These readings have been excluded by the (default) value for the upper direction limit of 360 degrees and the (default) value for the upper speed limit of 90 ms^{-1}. Note, that the data window is given in engineering units.



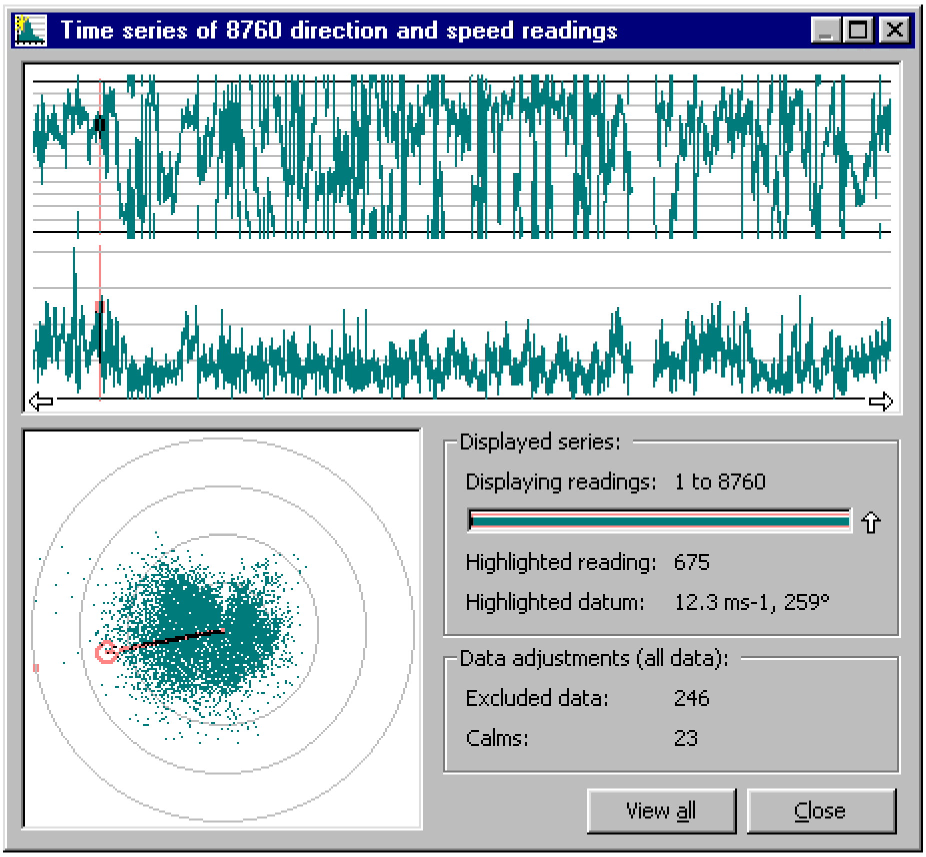
Hint: if the graph does not look right, then go back to the dialog where the speed and direction columns were selected and check that the right columns have been used.

The wind speed and direction limits are shown in the graphs above by coloured, horizontal lines.

If you choose **Preview**, the data will be shown in several graphs: the time traces of wind direction and wind speed, and as a polar scatter plot of the observations.

Displaying the data set

If you choose **Preview** in any of the OWC Wizard windows, the wind data will be shown in several graphs: the time traces of wind direction and wind speed, and as a polar scatter plot of the observations.

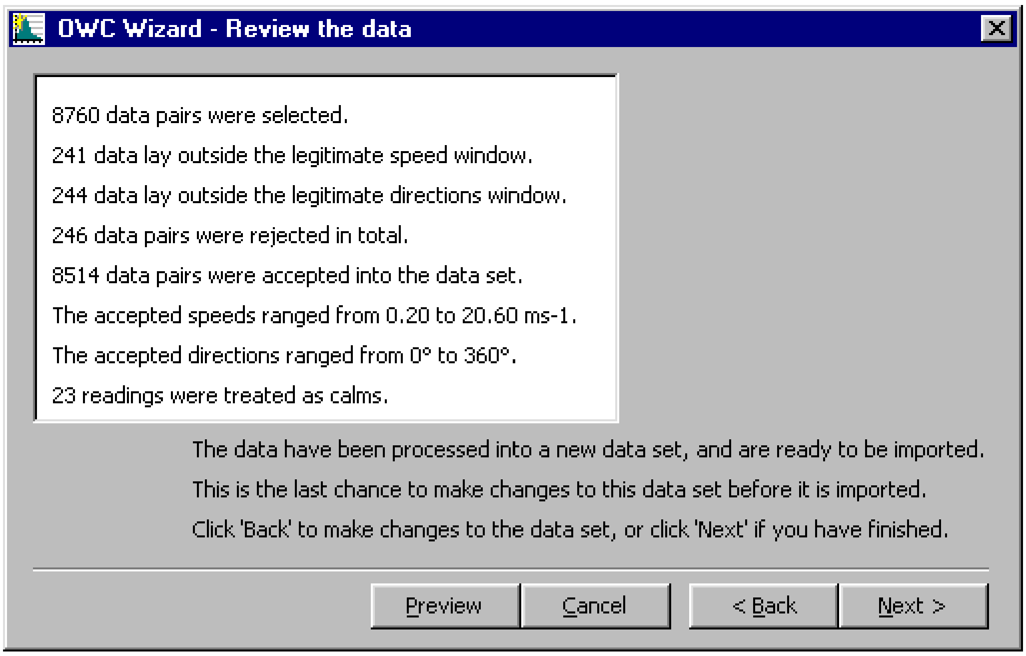


By moving the cursor over the time series display it is possible to read off the values of wind speed and direction. The display window can be shifted in time (Pan backwards and Pan forwards) by pressing the arrows in the bottom of the time series display.

You can zoom in on part of the displayed time series by pressing the left-hand button on the mouse and drag the pointer to select a new window. To zoom out one level press the arrow in the **Displayed series** area. By choosing **View all** in the bottom of the window the entire time series is shown.

Reviewing the data set

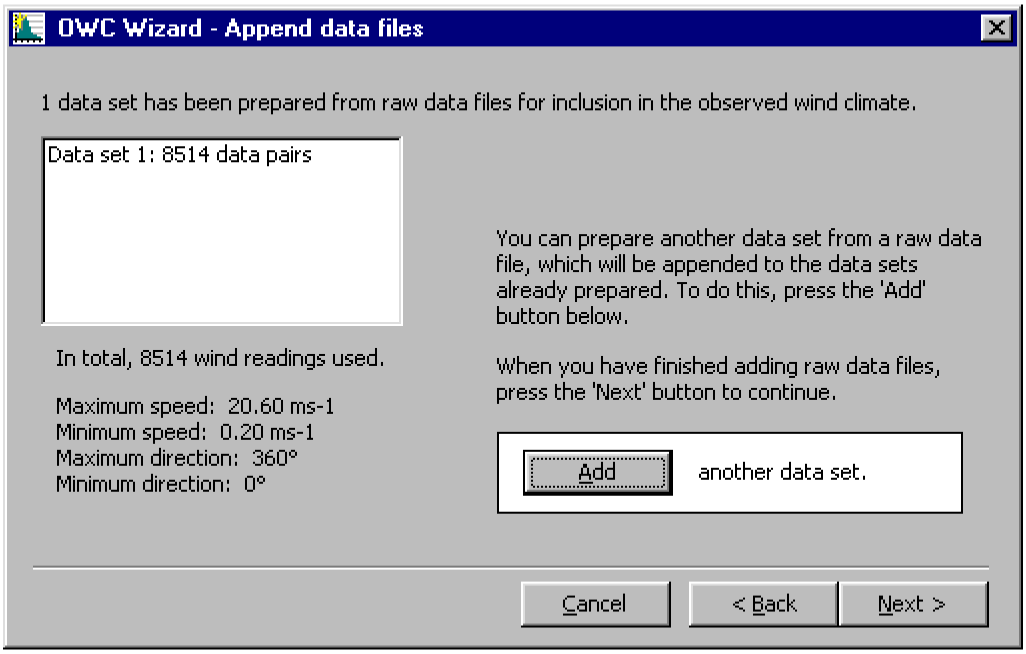
When the Wizard has gathered all of the information about the data set, it presents a summary review of the data.



This is the last opportunity to make changes to the settings for this data set before it is added to the OWC summary data. Pressing the **Next** button will import the data set and it will be impossible to remove it without clearing all of the data so far imported to the OWC.

Appending data files

Clicking the **Add** button will launch a series of dialogs which manage the addition of one more data file. When the data file has been added, this dialog will re-appear. While waiting for the next input, the Wizard shows a list of the data sets prepared so far and a brief summary of these data files.



Now that some data have been added, it is possible to

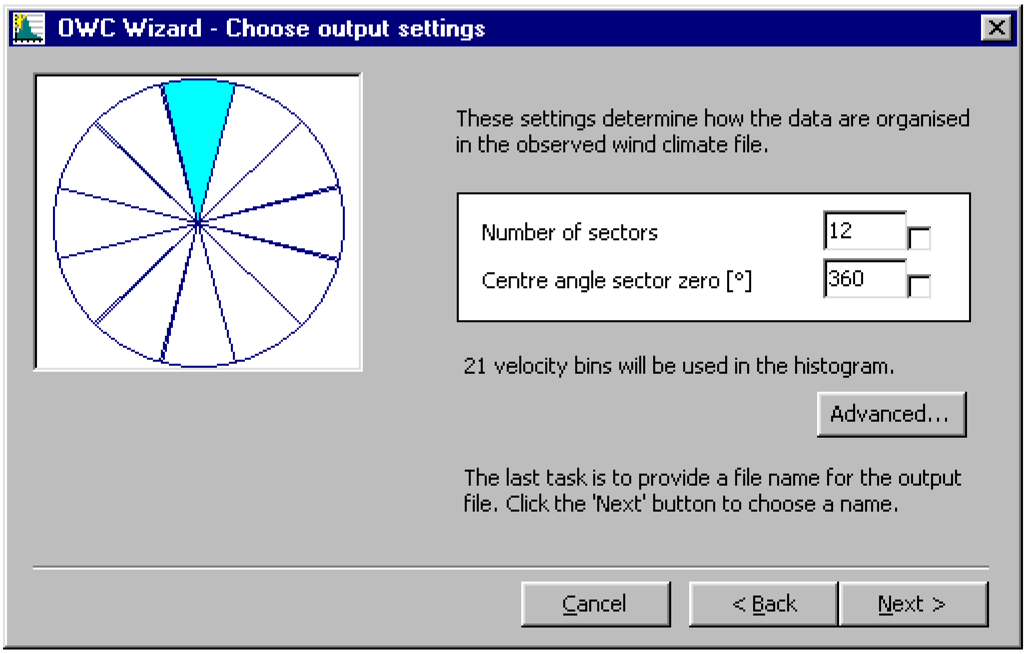
- add another file, or
- go back to change the site details, or
- proceed to the next stage, or
- cancel the current OWCW session.

If you choose to **Cancel**, then all of the data sets which have been added will be lost. If you choose to proceed to the next stage, then it is possible to return back to this dialog and add another data set later.

Choosing the output settings

When you have finished adding data sets, the Wizard is almost ready to write the summary to the OWC (TAB) file. Two more settings are required:

- the number of sectors in the analysis (default value is 12, max. is 36)
- the centre angle of the first sector (default value is 0° / 360°)

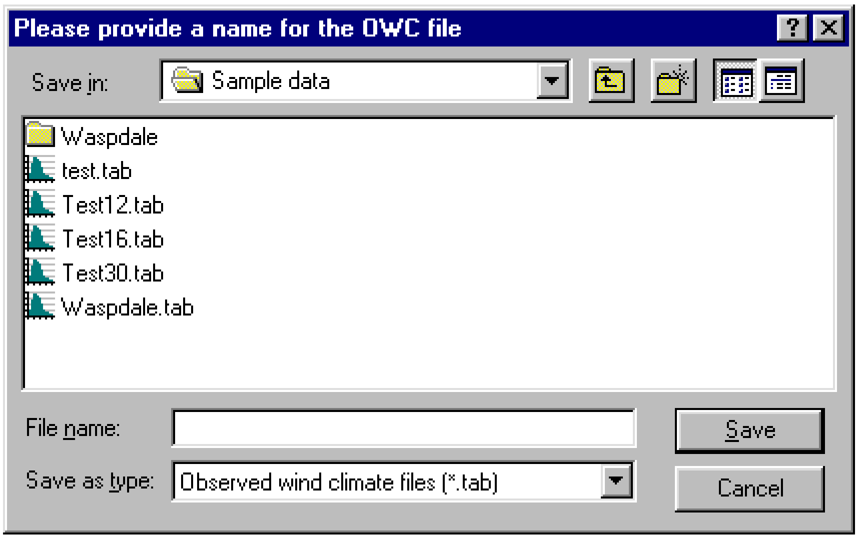


By checking the boxes to the right of the fields where you enter the values, it is possible to save the values currently showing, so that in the future they will be automatically used as default values by the Wizard. Pressing the **Advanced** button brings up the Advanced settings dialog.

All that remains is to save the output file.

Saving the OWC file

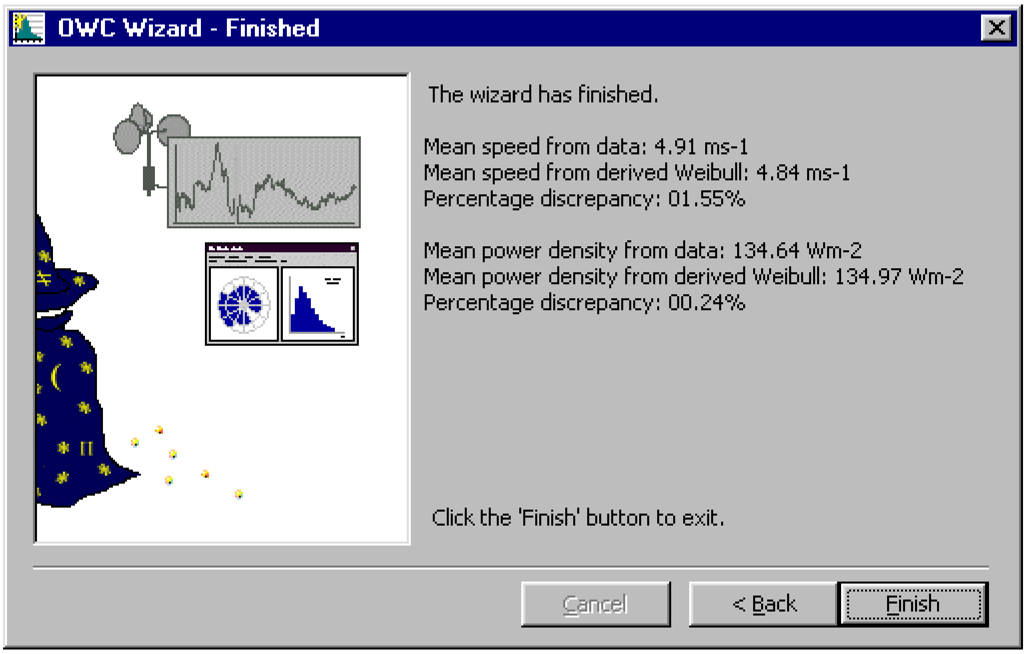
The last piece of information required by the Wizard is the name of the output file to which to save the data:



When the file is saved, the Wizard has finished its job. But...

Stop – don't Finish the wizard yet!

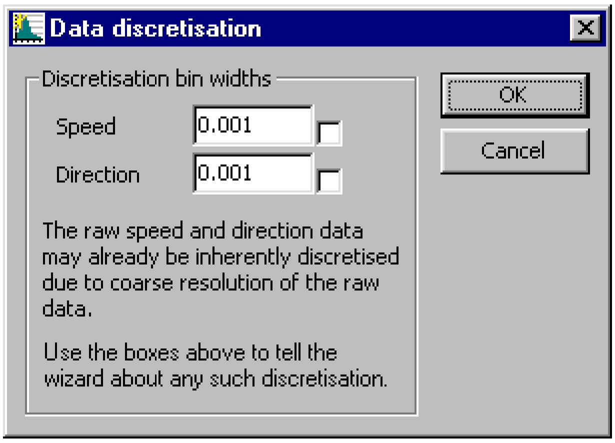
Before you **Finish** the Wizard, check carefully the displayed mean values of wind speed and power density. The differences between the means calculated directly from the data series and the means calculated from the fitted Weibull distributions should be small (say, a few per cent). If this is not the case, the fitted Weibull distributions are not accurate representations of your data and you must process the time series all over again. The most likely cause for large discrepancies is if you have not specified the discretisation values of the data.



If you started the Wizard from within the main WAsP program by choosing to insert a new OWC in the hierarchy, then WAsP will insert the newly created OWC at the place you have requested. The name of the file will of course be used as the description of the new OWC member. You can open the OWC window immediately to see the what the Wizard has produced.

Data discretisation

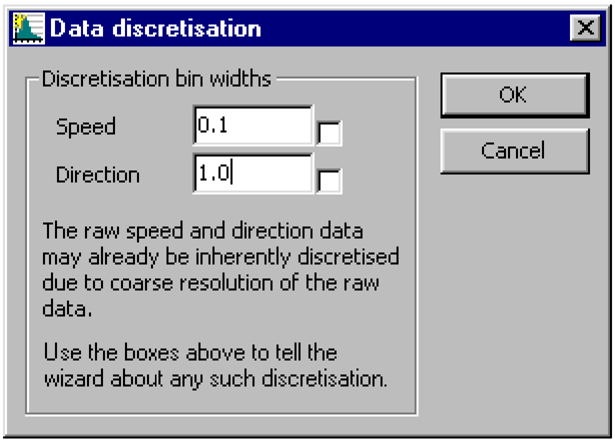
Pressing the **Discretisation...** button from the Define adjustments to data readings window causes the Data discretisation dialog to be displayed.



Using this dialog, it is possible to specify the discretisation bins apparent in the raw data. The Wizard will then automatically correct for the effect of such bins when fitting the Weibull distribution and calculating the data summary.

The discretisation bin widths must be given in raw data units and the default values are 1/1000'th of the raw data units. A value of exactly 0 (zero) is not allowed – since wind data are always given as discrete numbers. Data discretisation is described in more detail here.

In most cases – as is also the case in our sample data – the wind speed discretisation bin width is 0.1 ms^{-1} and the wind direction discretisation bin width is 1 degree:



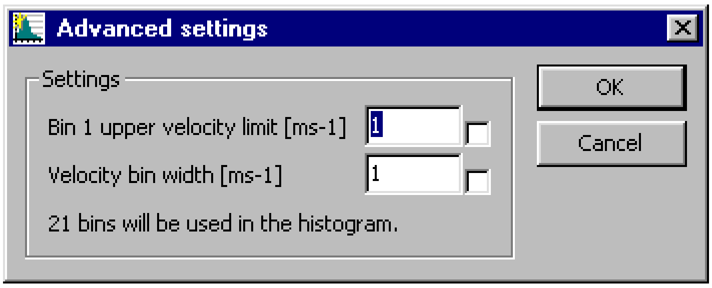
It is advisable to always enter the actual discretisation bin widths apparent in the data, even though the default values in this case would lead to the same end result as using the actual values.

Advanced settings for the OWC

Pressing the Advanced button from the Output data settings dialog brings up the advanced settings dialog.

This dialog is used to set

- the upper speed limit for the first speed bin (default value is 1 ms^{-1})
- the speed bin width for the summary table (default value is 1 ms^{-1})



A maximum of 50 wind speed bins in each sector will be used for the wind speed distributions.

The WAsP map editor

With the WAsP map editor utility you can retrieve, edit, check, reformat, transform and store WAsP map files. It is also possible to digitise scanned maps on screen using the mouse. This utility has taken over many of the tasks that were previously carried out in the EDIT mode of the MAPDATA menu in WAsP 4 and 5.

A brief description of the things you can do with the map editor is given below. More information is available in the help facility of the MapEdit program, see below.

Map file input and import

- input of WAsP map files (ASCII and binary formats)
- import of *.bna, *.ntf, *.xyz and other formats

Map data analysis and check

- overlay of scanned map and vector map
- visual inspection and zoom
- summaries of map information
- consistency check of roughness line node points
- joining of roughness lines and height contours

Map transformations

- changing map units
- transformations based on 1/2/3 fixed points

Editing of map contents

- view roughness lines, contours or both
- change colours of roughness lines and contours
- move, delete and insert point or line
- close, split and join line(s)
- change line properties
- join several roughness lines in node point

Digitisation of scanned maps

- input of bitmap background images (*.bmp)
- scaling of scanned map
- on-screen digitisation using the mouse

You can browse the MapEdit help facility right now by pressing this button:

The WAsP air density calculator

The air density calculator calculates air density [kg/m^3] as a function of altitude (elevation) Z [m a.s.l.] and mean air temperature at the same altitude. A lapse rate of 6.5 K/km and a sea level pressure of 1013.25 hPa are assumed. Air densities at regular intervals of altitude and temperature are given in tabular form here.

The estimate is based on a so-called standard atmosphere; if you have information on the long-term barometric pressure and air temperature at the site, you should calculate the air density directly.

The ruggedness of a terrain

The somewhat indeterminate term 'complex terrain' is often used in connection with the orographic characteristics of a landscape; primarily for hilly and mountainous terrain consisting of a 'complex' mixture of several (steep) hills or mountains. While most people have an idea of the general meaning of this term – albeit somewhat biased because of differences in experience – there exist no widely accepted measure of terrain complexity to which we can all refer, like e.g. terrain height (measured in m a.s.l.) or the steepness of a winding, mountain road (measured in per cent).

Even in the field of wind-flow modelling, it is not always clear what 'complex' means. One well-known measure of terrain complexity (or steepness) is relative relief, i.e. the difference between the highest and lowest level within unit areas of e.g. 100 square km (Rutkis, 1971; William-Olsson, 1974). This was used as a means for judging the influence of the mountains and thereby the degree of reliability of the results presented in the European Wind Atlas (Troen and Petersen, 1989). However, maps of relative relief generally do not show the effects of local topography.

One objective measure of the steepness or ruggedness of the terrain around a site is the so-called ruggedness index or RIX (Bowen and Mortensen, 1996), defined as the percentage fraction of the terrain within a certain distance from a specific site which is steeper than some critical slope, say 0.3 (Wood, 1995). This index was proposed as a coarse measure of the extent of flow separation and thereby the extent to which the terrain violates the requirements of linearized flow models.

The ruggedness index has also been used to develop an orographic performance indicator for WAsP-predictions in complex terrain (Bowen and Mortensen, 1996; Mortensen and Petersen, 1997) – where the indicator is defined as the difference in the percentage fractions between the predicted and the reference site. This indicator may provide the sign and approximate magnitude of the prediction error for situations where one or both of the sites are situated in terrain well outside the recommended operational envelope.

The ruggedness index

In practice, the ruggedness index is calculated for each of a number of radii originating at the site (met. station or wind turbine). A flat site will then have a RIX of 0%, a very complex (steep) site an index of, say, 30% – meaning that about one third of the terrain is steeper than our critical slope.

The value of the index defined above will of course depend on the size of the area we are looking at (the radius) and the threshold slope; however, the study indicates that these should be chosen within fairly narrow limits, see below. Given these values, the index is easy to calculate, providing a site-specific measure of terrain ruggedness, and seems to show rather well the effects of local topography on the accuracy of WAsP predictions (Bowen and Mortensen, 1996 and 1997).

The RIX program

The purpose of the RIX program is to calculate the ruggedness index of a specific site. In addition to the overall index, the program also calculates indices for each of a number of user-specified sectors.

The program is a DOS utility and must be invoked in an MS-DOS Prompt window, by typing its name at the prompt with the name of a WAsP map file and the site coordinates as arguments:

RIX *mapfile* X_{site} Y_{site} [*options*]

where *mapfile* = [*drive*][*path*]*filename*[.*ext*] specifies the WAsP map file, which must be in ASCII (text) format. The default *ext* is MAP and the site coordinates must be given in metres. A summary of command line arguments is shown if the program is started with a question mark 'RIX -?'.

Ruggedness indices for each of a number of sites in a wind farm can be calculated by specifying the WAsP resource file which contains the site coordinates:

RIX *mapfile rsffile* [*options*]

where *rsffile* = [*drive*][*path*]*filename*[.*ext*] specifies an existing WAsP resource file; the default *ext* of which is RSF.

The RIX program will be incorporated into the WAsP program in a later version.

Sample command lines

For a single site (e.g. a meteorological station or wind turbine) the command line could look like this:

```
RIX \wasp\project\mymap.asc 317070 6176091
```

where the results would then be shown directly on the screen. Calculating RIX for several sites (e.g. the wind turbine positions in a wind farm) the command line could look like this:

```
RIX \wasp\project\mymap.asc \wasp\project\park.rsf -Opark.rix
```

where the results would then be calculated for the positions specified in PARK.RSF and written to the file PARK.RIX.

Configuring the RIX program

The default configuration of the program is given in the text file RIX.CFG:

```
%
% rix configuration file
% sets up default values
%
radius = 3500
threshold = 0.3
sectors = 12
subsectors = 6
verbose = no
```

display_sectors = yes

skip_flat_center = yes

With this configuration, the program then takes the terrain within 3500 m of the site into account, the threshold slope is 0.3, and indices are calculated for 12 sectors based on six profiles in each sector. The number of sectors and azimuthal resolution correspond to the default values used by WAsP in calculating the orographic corrections. The radius 3500 m and threshold slope 0.3 are the values used by Bowen and Mortensen (1996, 1997).

Command-line options

The program can be invoked with one or more options in the command line:

-r#	sets the size (radius) of the terrain for which the RIX is calculated. The default value is 3500 m.
-t#	sets the threshold slope for calculation of the RIX value. The default value is 0.3.
-s#	sets the number of sectors for which the RIX values are calculated and displayed. The default value is 12.
-u#	sets the number of subsectors (terrain profiles) used for the RIX calculations. The default value is 6.
-o*file*	specifies an output (text) file containing the results. Results are shown on screen as default.
-v	verbose mode. Default is 'no' (-nv).
-d	display sector-wise RIX values. Default is 'yes'.
-skip	skip flat centre of map. Default is 'yes'.

Options which do not take an argument can be negated by putting an 'n' between the hyphen and the option letter(s).

Using the RIX program

The ruggedness index is described in some detail by Bowen and Mortensen (1996, 1997) and Mortensen and Petersen (1997). The main conclusions of these studies are:

If the RIX is ~0% the slopes of the terrain are less steep than 0.3 and the flow is likely to be attached, i.e. follow the terrain surface. This situation is generally within the performance envelope of WAsP.

If the RIX is >0% parts of the terrain are steeper than 0.3 and flow separation may occur in some sectors. This situation is generally outside the performance envelope of WAsP and prediction errors may be expected. Large RIX values will lead to large errors in the flow modelling. The accuracy of prediction, however, will depend on the relation between the two sites:

- If the predictor (meteorological station) and predicted (wind turbine) sites are equally rugged, i.e. have approximately the same RIX value, the modelling errors are significant but similar in magnitude. The overall prediction should still be accurate as the two errors would tend to cancel each other out. Such a situation obviously occurs for the self prediction at any category of site. However, it may also occur for two neighbouring sites in rugged terrain which have similar orography and orientation. This represents an important application involving the prediction of the wind speeds and energy at adjacent sites along a steep ridge in a wind farm.

- If the predictor site is rugged and the predicted site less rugged, i.e. the RIX value of the reference site is larger than that of the predicted site, the modelling errors are significant and unequal. The overall prediction will be underestimated with a significant negative error.
- If the predictor site is smooth or less rugged than the complex predicted site, i.e. the RIX value of the reference site is smaller than that of the predicted site, the modelling errors are significant and unequal. The overall prediction will be overestimated with a significant positive error.

The references given in the text above may be found in the References section.

Introduction

AutoCAD's DXF-file format (Drawing eXchange Format) has become a common format for exchange of line drawings between different programs, and several suppliers of digital maps use DXF-files as a means of storing and exchanging map data. Also, the height contours of a map can be exported to a DXF-file if AutoCAD is used to digitise the map.

WAsP 4 and 5 are already capable of importing and exporting map files in the ASCII DXF-format by simply specifying DXF as the file name extension. However, WAsP 4/5 can only process a subset of this format and the number of points and curves are limited. Therefore, an improved DXF- to MAP-file translator has been added to the WAsP Utility Programs and to WAsP for Windows.

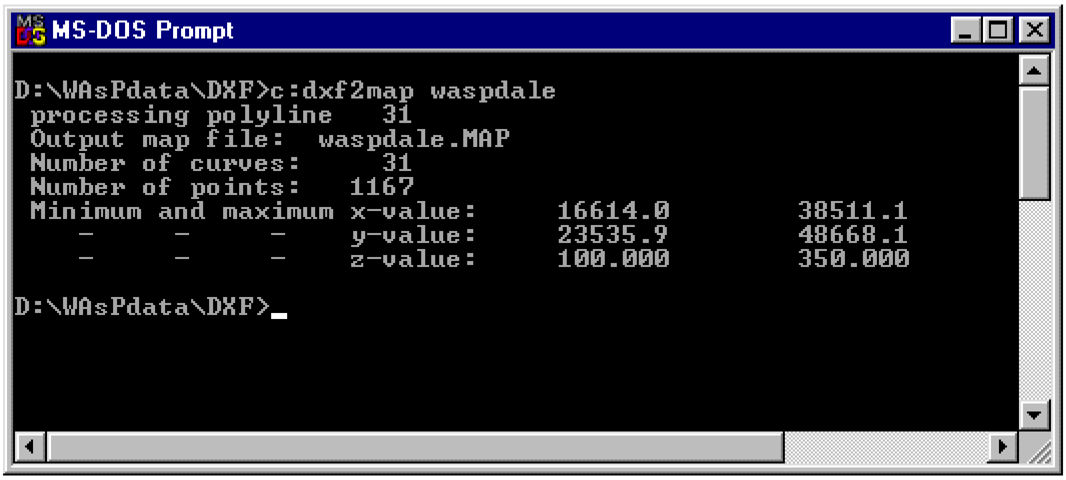
The DXF2MAP program

The program transforms an ASCII DXF-file into a WAsP map file that can be imported directly by WAsP. The program is a DOS utility and must be invoked in an MS-DOS Prompt window, by typing its name at the prompt, with the name of the DXF-file as command line argument:

DXF2MAP *filespec* [*options*]

where *filespec* = [*drive*] [*path*] *filename*[.*ext*] specifies the DXF-file. The default *ext* is dxf. If neither *filespec* nor *options* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark 'DXF2MAP -?'.

The output file is a WAsP map file in ASCII format – with the same *filespec* as the input file, but with the extension MAP. Existing files with the same specification(s) will be overwritten. Finally, the program displays a brief summary of the map file just established:



Command-line options

The program can be invoked with one or more options in the command line:

-d#	number of digits after a decimal sign, e.g. if coordinates are in degrees
-f	convert the contour line heights from feet to metres, i.e. the contour line values of the DXF-file are multiplied by 0.3048 to get a metric map file.

-l	elevation or height contour value stored in 'layer name' rather than 'primary *z*-coordinate' or 'height of object', which are the defaults.
-i#	vertical contour line interval in metres, i.e. only contours which are multiples of the specified interval value are extracted.
-r#1,#2	elevation range for extracted contours, i.e. only contours with height values between #1 and #2 are extracted to the map file.
-p	contours defined by pairs of coordinated points, i.e. with the AutoCAD LINE command.

Software

WAsP is a complete software package for wind data analysis, map editing, wind atlas generation, wind resource assessment and siting of wind turbines. Working with wind resource assessment and WAsP in practice, however, requires other software as well. In addition to a general-purpose office package containing a word-processor, a spreadsheet and a database, the software mentioned below may come in handy if you use WAsP on a regular basis.

Text editor

In order to create, view and edit the contents of text files you need a text editor. You can use **Notepad** to create or edit text files that do not require formatting and are smaller than 64K. Notepad opens and saves text in ASCII (text-only) format only. To create or edit files that require formatting or are larger than 64K, use **WordPad**. Both of these text editors are part of your Windows distribution.

File compression software

Some data and WAsP files – in particular the time-series wind data, the terrain map and the resource grid files – can get rather large in size. Software for file compression and archiving is therefore important, especially if you transfer the files over the Internet or mail them on floppy disks. The **WinZip** package runs on Windows 95/98/NT4; an evaluation version is available from www.winzip.com.

Digitising software

The creation of a new map by digitisation of paper maps is not possible any more from within the WAsP program. Three possible workarounds are described here. We recommend the **Didger** program from Golden Software for digitisation of maps. The BNA output format from this simple and cheap digitising package can be imported directly by WAsP and the new map editor utility. More information about this program is available from Golden Software. A demo version of the software is available here.

Graphics and plotting software (2D)

The graphic displays of WAsP data, e.g. of the wind rose, speed distributions or the power curve, can be copied to the Windows clipboard and pasted into your printouts and reports. For even better quality graphics and publication-ready figures, however, you will need dedicated plotting and graphics software: the plotting routines of a spreadsheet program or, better yet, a scientific graphics software package like **Grapher** from Golden Software. A demo version of this software is available here.

Graphics and plotting software (3D)

Many WAsP input data and results are *spatial* data: the contour and roughness maps, the wind farm layout and the wind resources over an area are important examples. It is of vital importance to be able to display these data and results in the best possible way, so it may be worthwhile to consider a plotting and graphics package specifically designed to illustrate spatial data. The **Surfer** package from Golden Software can make both 2D maps and 3D renderings of your WAsP data. A demo version of the software is available here.

WAsP Utility Programs

The WAsP **Utility Programs** is a collection of DOS (16/32-bit) and Windows (W95/98/NT4) programs to calculate, analyze, convert, transform, translate, plot, and print WAsP-related data. A brief description of the main features of each utility program is given here. Note, that a few utilities have been included in the present WAsP package.

Hardware

Site visits to met. stations and wind turbine / wind farm sites are a valuable, and often absolutely necessary, part of wind resource assessment and siting work. For this, you need a 'real' toolbox...

In the field

For site visits you will at least need the following:

- **Topographical maps** (1:25,000 to 1:100,000). Maps should preferably show the topography at the time of the collection of the met. data, or be as new as possible if you explore the wind resource for wind turbine site assessments. The contour line interval should be 20 m or smaller.
- **Compass** (360-degree). A good-quality, hand-held compass where the divisions are to the nearest degree. A sighting-type model is preferred for taking accurate bearings to nearby obstacles.
- **GPS receiver** (Global Positioning System). A battery-operated, hand-help GPS receiver should be preferred. Remember to use the datum setting corresponding to the map datum.
- **Camera** for taking photographs of the surroundings of the met. station and/or WTG position(s). Take sector-wise photographs from the site for each of twelve 30-degree sectors, as well as of the mast set-up and instruments.
- **Measuring tape**. A measuring tape of about 25 m or more, to measure the distances to nearby obstacles and, preferably, the actual height of the wind measuring equipment (however, never enter a mast or tower without the proper safety equipment!)
- **Summaries of wind measurements**. Summaries of the wind speed and direction data from the met. station. Also, graphical presentations of the same: wind rose plot, wind speed histograms for each sector, etc. Similar information for predicted wind climates.
- **WAsP forms and checklist**. A number of sample forms are provided with the WAsP program. These may be used to record characteristics of the wind data, anemometer or wind turbine site, near-by obstacles and surrounding roughness.
- **Pocket calculator**, notebook, pencil and eraser.

In addition, the following items may come in very handy, though they are not absolutely essential:

- Binoculars
- Odometer or range-finder
- Aerial photographs or satellite imagery

In office

In addition to your PC and a high-quality printer, you may consider:

- **Digitising tablet** (A3 or larger) for digitising the height contour and roughness change lines from standard paper map sheets. The tablet will require software to run it, e.g. Didger from Golden Software.
- **Scanner** (flat-bed, A4 or larger) for scanning of background map images to be employed by the MapEdit program.

Welcome to the new WAsP

WAsP is 100% 32-bit Windows software, which runs under Windows 95, Windows 98, Windows NT 4.0 and Windows 2000. It conforms to standard windows software user-interface conventions, making it easy to learn and easy to use. A brief introduction to the program is given below.

New, faster ways of getting work done

WAsP allows you to organize your work in completely new ways. Operations that used to require batch files can now be accomplished by dragging and dropping with the mouse. A new hierarchical 'workspace' paradigm makes it possible to work with many sites at the same time, sharing wind atlases and maps between them. Proposals for large wind farms can be quickly created and investigated, with changes to contributing data being instantly reflected in all the affected results. Changes to the situation under investigation are made by simple, fast, drag-and-drop operations. By organising their work into exportable 'projects', users can easily share information with others. When projects are exported, all of the files necessary to re-open the same project on another computer are automatically copied into the new location. This also makes it easy to back up work in progress.

Backward-compatibility for existing users

Existing users of WAsP for DOS will be able to use most of their files without adjustments. A few new file formats have been defined, but most files, which worked under WAsP 4 and 5, will work perfectly well with WAsP. Despite the new user interface, it will be possible for 'old hands' to continue to use the same mental model of the WAsP system, while gradually starting to explore and make use of the new features.

A tried-and-tested wind resource calculation engine

Perhaps the most important feature of the new WAsP is an old feature! The WAsP calculation engine is the standard for wind resource calculations, and represents years of experience, refinement and testing. Some enhancements to the core calculation routines have been made for the new WAsP, but you can rest assured that the same algorithms that have made previous versions of the program so successful are working away at the heart of the new program.

Getting started...

We recommend that you work through the new version of Getting Started – the Quick Start Tutorial – to see for yourself what the new WAsP is all about. We hope that you come to like the new way of WAsP'ing even though it may take a little while before you are 'up-to-speed' again.

We have tried to provide the same – or better – functionality in the new version of WAsP. However, there might be some specific features you miss, or features of the old DOS versions you have come to like (!?). If this is the case we have some good news for you.

You can help us make a better WAsP!

Existing users of WAsP have a wealth of experience in wind resource assessment and siting using the old WAsP programs. We therefore invite you to provide us with your feedback. Which old features do you miss the most? Which files have you got which you can only use with the old version? Which new features would you like to have built into WAsP? Your suggestions will – like our own ideas, the frequently asked questions and known issues – be recorded by the WAsP team and displayed on the WAsP home page.

Whatever happened to...

Where have all the good old WAsP features gone? This page provides a list of old features, which have been repackaged or renamed. There are explanations about what's changed and links to information about the new features.

RAWDATA – the meteorological data input routines

This function is now provided by a utility program called the OWC Wizard. This Wizard accepts raw data files and produces *.tab files. Table (or histogram) files are now called observed wind climate files, or OWC files. Hence the name OWC Wizard.

The output format is the same, so you can use *.tab files created with the old WAsP and the new Wizard interchangeably. The new Wizard does not yet accept binary files as raw data input, so you might need to use the old WAsP if you only have binary raw data files.

MAPDATA – the map input, display and editing routines

This function is now shared between WAsP, the new WAsP map editor utility and other software. The WAsP program accepts and can display map files containing height contour lines and roughness change lines. The editing of maps is taken care of by the WAsP map editor utility, from within which you can retrieve, edit, check and store maps. It is also possible to digitise scanned maps on screen using the mouse.

The creation of a new map file by digitisation of paper maps is not possible any more from within the WAsP program. Three possible workarounds are described here. We recommend the Didger program from Golden Software for digitisation of maps. The *.bna output format from this simple and cheap digitising package can be imported directly by WAsP and the new map editor utility.

Batch files - automating the program

You cannot use batch files with the new WAsP. We hope that the new workspace hierarchy structure will provide a flexible alternative way of performing multiple operations.

What on earth is...?

This page provides a list of features which are new, renamed or have been repackaged. There are explanations about what's changed and links to information about the new features.

OWC and the OWC Wizard

OWC stands for observed wind climate. This is just the good old *.tab file. The OWC Wizard is a utility program which builds a tab file from one or more raw data files. In the old WAsP, this was the RAWDATA feature.

User corrections

Corrections specified by the user were stored in the roughness description file (*.rds) in previous versions of WAsP. These corrections are now stored in a new user correction file (*.ucf). The site-specific roughness description (roughness rose) is now stored in a reformatted roughness description file (*.rrd).

Good news for DOS die-hards

Yes, we're still shipping the old ones...

It takes time to get acquainted to new software and changing your work routines; and even more time to get productive – or so it seems, at least. Therefore, we're still maintaining and supporting the DOS versions of WAsP: WAsP 4 (16-bit) and WAsP 5 (32-bit). These packages are included on the WAsP installation CD.

So, if you're comfortable with digitising maps 'the old way' or find it fast and efficient to use the old WAsP map editor, please go ahead: the new WAsP and WAsP map editor utility **MapEdit** both accept the map file formats from previous versions of WAsP.

File format changes

With only one exception, we have left the file formats unchanged for WAsP; the old roughness description file (*.rds) has been divided into a reformatted roughness description file (*.rrd) and a new user correction file (*.ucf). This change of files is described in more detail here.

In addition, an alternative extension has been defined for resource grids (*.wrg), i.e. resource files established with the grid option. The old *.rsf extension can still be used, but in some circumstances, WAsP will be unable to distinguish between a resource grid file with the *.rsf extension and a wind farm file with the *.rsf extension.

Note, that WAsP handles only a subset of the file formats handled by previous versions of WAsP. In addition, some file formats may be updated or changed completely with time. Descriptions of the different file formats recognised by WAsP are given in the Technical Reference section.

Reporting problems

If you have any problems using the WAsP software, please send an e-mail to waspsupport@risoe.dk. If you do not have e-mail, you may send a fax to the number given here.

Don't hesitate

Don't hesitate to send some feedback, even if you are not sure whether it is a bug, a suggestion or just a question. Information about any user difficulty is really valuable, even if they are not caused by program errors. Some users are shy making of bug reports because they wrongly assume that the error it is somehow 'their fault', because they don't fully understand the program. Please, don't hesitate to report a problem to us.

Check the bugs list and FAQ

A list of known issues will be maintained at www.wasp.dk. You may also want to check the list of Frequently Asked Questions (FAQ) which will be maintained at the same address.

Check that you have the latest version

The latest version of the WAsP program can be downloaded from www.wasp.dk in the form of an update file to the main installation on the CD-ROM.

Provide the version number

Let us know which version of WAsP you are using (please provide the full version number). Please also mention which operating system you are running.

Tell us how to reproduce the error

Before you report the problem, try to make it happen again. Include a description of how to reproduce the bug when you send the bug report.

Provide the program's own error description

When WAsP shows you an error message, you can request details. When the details are showing, you can press the 'Copy' button to put a complete exception report onto the Windows system clipboard. Paste this into the e-mail you send.

Provide the file

If the software is having problems with a particular file, then please send it (zipped) along with the description. If the file is bigger than 50 kb, then e-mail first so that we can arrange a more appropriate way of transferring the file.

Provide the whole project

To fix a bug, it is sometimes helpful to be able to reproduce the situation you're describing. The easiest thing is to have the whole project. You can export the whole project to a directory on your computer, then zip it up and send it along with the feedback message. Again, if the resulting file is bigger than 50 kb, then send an e-mail first and we can arrange another way of transferring the file.

Making suggestions

The future development of WAsP could depend on you! Even though we have many ideas ourselves for the future development of the WAsP program, its user interface and built-in models, we welcome very much your suggestions and requests for new features.

Which features to include and how to implement them depend strongly on the response we get from the WAsP users. Please e-mail or fax your comments and suggestions to the addresses given here.

Beginning with the release of WAsP 6 we will maintain a list of the WAsP team's own ideas and the suggestions already received from the users at the WAsP home page.

Frequently Asked Questions (FAQ)

Beginning with the release of WAsP 6 we have established and will maintain this list of Frequently Asked Questions; regarding the use of WAsP and WAsP-related software. Unless otherwise stated, the Q&A's refer to the latest version of WAsP, even though most of the information may be valid for previous versions as well.

How can I use Surfer to make a wind resource map of an area?

Golden Software's Surfer program can read and utilize WAsP's wind farm (RSF) and resource grid files (WRG) directly. In the **Grid** menu of Surfer, choose **Data** and enter the name of the wind farm or resource grid file. You will then get the message "File type not recognised!". Choose 'ASCII Data (.TXT)' and press the 'Ok' button. You may then get the message "Surfer error: Current data columns do not contain 3 or more distinct XYZ points". Disregard this message and carry on, specifying the **Data Columns** used for the *X* and *Y* coordinates and the wind power density/power production: column B contains the *X* coordinate, column C the *Y* coordinate and column *H* the power density or power production. Surfer can now make a grid from the data in the usual way – and a map of the wind resource can be made.

You can also make Surfer recognize these file types by adding the following two lines to the file Surfer32.ini – in the [GS Worksheet Import Filters] section – using a text editor like Notepad:

WAsP Wind Farm=WSIDAT32.DLL;RSF;GSdata

WAsP Resource Grid=WSIDAT32.DLL;WRG;GSdata

How can I generate a WAsP map from gridded data or spot heights?

The Surfer program can make a contour map of an area from spot heights given in a regular grid; a so-called digital elevation model. The grid data may be input directly or it can be generated by Surfer from irregularly spaced spot heights. The Surfer program can further be employed to edit the map contents, e.g. the map limits and contour interval. The height contours of the map can be exported as a 3-D DXF-file from Surfer's **Map** menu (**Contour Map/Export Contours**). This DXF-file can be converted into a WAsP MAP-file by the WAsP Utility Program dxf2map.exe.

Gridded height data can also be transformed directly into a WAsP MAP-file using the WAsP Utility Program grd2map.exe. This program reads Surfer ASCII GRD-files and writes WAsP MAP-files. The vertical contour interval and elevation range for extracted contours may be specified by the user.

WAsP courses and training

The Wind Power Meteorology Program at Risø offers courses and training in wind resource assessment, site characterization, use of the WAsP software and application of the wind atlas methodology.

Standard WAsP course

Realistic assessment of the wind resource is a key parameter in any wind energy project – large or small. The course aims at providing practical experience and confidence in wind data analysis, wind climate estimation and power production calculations – using the WAsP program, a state-of-the art collection of PC tools developed specifically for these purposes.

The standard WAsP course is scheduled for 2½ days and is held every year, at Risø or abroad. The number of participants is usually about 10 to 15 and we aim at providing one teacher for every five participants. An outline of the contents of the course is given here and more detailed information here.

Specific WAsP courses and training

In addition to the standard WAsP course, Risø offers courses and training tailored specifically to meet the needs of a particular institution, company or wind energy project. Such training is usually carried out at the premises of the client and may further include training in e.g. siting of wind-monitoring stations, met. station analysis, site characterization, and reporting of the wind resource assessment activities. Please contact Lars Landberg for more information and a quotation.

Project supervision and QA

For the experienced WAsP user, Risø can offer to review the data and results of any wind resource assessment project – whether wind atlas, wind resource map, wind farm production calculation, or tender document – in order to assure the quality of the work. This transfers the latest knowledge and further build the capacity of your company or institution. Please contact Lars Landberg for more information and a quotation.

WAsP Utility Programs

The WAsP Utility Programs is a collection of DOS (16/32-bit) and Windows (W95/98/NT) programs to calculate, analyze, convert, transform, translate, plot and print WAsP-related data. A brief description of each utility program is given below. Note, that a few utilities are now included in the WAsP package.

Registered users of the WAsP Utility Programs may download the latest update here.

Wind-climatological fingerprint

As in the European Wind Atlas. Fingerprint page with graphs (*.ps or *.plt file) and X-tables (*.txt or *.tex) of daily/yearly and monthly/yearly mean wind speeds.

Fitting Weibull distribution functions

Generates measured and fitted data (*.dat) for e.g. plotting the total and sector-wise wind speed distributions from an Observed Wind Climate file (*.tab). Summary table (*.txt or *.tex) in two different layouts. Conversion of any old WAsP-for-DOS *.tab-file format to the new standard WAsP-for-Windows format.

Plotting the histogram and wind rose

Generates data and Grapher files for plotting the wind speed and direction distributions. Data can be used with other plotting programs as well.

Weibull distribution characteristics

Statistics and data files (on screen and *.dat) for a given Weibull distribution (*A* and *k* parameters). Total power density and window (e.g. 0-25 ms^{-1}) power density. Power production from specified power curve. Data file suitable for plotting.

Plotting the obstacle set-up

Generates data and DOS Grapher files for plotting an obstacle set-up.

Coordinate transformation

Coordinate transformation (ED50 and WGS84) of single points, lists of points and WAsP ASCII *.map files:

- Latitude/longitude to UTM
- UTM to latitude/longitude
- UTM to UTM (zone 32 and 33 only)
- Un-scaling a WAsP ASCII map file to absolute coordinates
- Conversion of WAsP *.map file to *.bln and *.xyz files as well

Conversion of vector map formats

- AutoCAD *.dxf to WAsP *.map file (ASCII *.dxf-file subset only)
- Atlas *.bna to WAsP *.map file (Didger *.bna file)
- MapGen *.dat to WAsP *.map file (Coastline Extractor *.dat file)

Transformation of map and grid files

- Map to grid transformation: WAsP *.map file to Surfer *.grd file
- Grid to map transformation: Surfer *.grd file to WAsP *.map file

Ruggedness index (included in WAsP)

Calculates the ruggedness index (RIX value) for a single site or for multiple sites given in an RSF-file. Input is a WAsP map file. Results for site overall and for each sector.

Map editing (included in WAsP)

Map editing features like WAsP in a Windows environment (W95/98/NT). Roughness line analysis, e.g. joining these where they meet in node points and pointing out lines where the roughness values are in conflict. On-screen digitisation of scanned maps.

Interpolation of wind atlas data sets

Generation of an 'artificial' WAsP wind atlas data set (*.lib file) by spatial interpolation between three other stations/*.lib-files. This is a W95/98/NT utility program.

Plotting the power- and thrust-curves

Generates data and Grapher files for plotting the power-and c_p-curves. Data can be used with other plotting programs as well.

Resource- to grid-file conversion

Calculation of Surfer grid files containing Weibull *A*, Weibull *k*, mean wind speed, mean power density, terrain elevation, or power production. Grid may contain absolute or normalised values. Export to (*x, y, z*) file as well.

Air density calculator

Calculation of air density from the elevation/altitude and mean air temperature at the site.

Printing wind atlas files

Generates text or LaTeX file, resembling the right-hand-side pages of the European Wind Atlas, from a WAsP *.lib file.

PostScript BoundingBox

Finding the BoundingBox of encapsulated PostScript files (*.eps), e.g. Grapher and Surfer for DOS output files.

Sample station description

Proposal for a comprehensive, yet compact, standard description of a wind-measuring station, based on the outputs from WAsP and the Utility Programs.

Further information and ordering

More information can be obtained by contacting the WAsP team at Risø. You can place an order at the WAsP home page. Bug fixes and updates will be available for download from the WAsP home page.

WAsP Engineering

WAsP Engineering is a computer program for the estimation of extreme wind speeds, wind shears, wind profiles and turbulence in complex terrain. Version 1.0 was launched in July 2001 at the European Wind Energy Conference and Exhibition in Copenhagen.

The purpose of WAsP Engineering is to support the estimation of loads on wind turbines and other civil engineering structures situated in complex terrain. The wind properties that are treated are:

1. **Extreme wind speeds**, e.g. the 50-year wind. If a wind turbine is well situated on a hill the mean wind speed and thereby the power production can be increased significantly compared to that over flat terrain. Unfortunately, the 50-year wind will increase correspondingly, maybe calling for increased strength of the blades or other parts of the turbine.
2. **Wind shears and wind profiles**. Strong mean wind shears (large differences in the mean wind speed over the rotor) give large fluctuating loads and consequently fatigue on the wind turbine blades, because the blades move through areas of varying wind speed.
3. **Turbulence**. Turbulence (gusts of all sizes and shapes) causes dynamic loads on various civil engineering structures, including wind turbines. The strength of the turbulence varies from place to place. Over land the turbulence is more intense than over the sea. Also the hills affect the structure of turbulence. We model various terrain dependent properties of turbulence.

A report on the prototype (which is not the same as the test release) of the program finalised May 2000 may be downloaded here.

Please visit the of WAsP Engineering home page for more information.

The WAsP/KAMM method

The wind is simulated with the Karlsruhe Atmospheric Meso-scale Model KAMM using a large-scale climatology, e.g. from the NCEP/NCAR reanalysis data set. Wind atlas files are generated from the simulated winds. The wind atlas files can be read by WAsP to predict the very local wind climate using the local topography.

Please visit www.mesoscale.dk for more information.

Contacting the WAsP team

For general inquiries, sales support, shipping, invoicing etc. send an e-mail to wasp@risoe.dk.

To apply for a licence, send your machine ID number to wasplicence@risoe.dk, quoting your user name.

If you have any problems using the WAsP software, please send an e-mail to waspsupport@risoe.dk. This way your problem and questions will be registered properly and distributed to the right person in the WAsP team.

E-mail: niels.g.mortensen@risoe.dk
ole.rathmann@risoe.dk
lars.landberg@risoe.dk

Web: http://www.wasp.dk

Fax: +45 46 77 59 70

Phone: +45 46 77 50 97 (Ms. Rikke Nielsen)

Post: Wind Energy Department

Risø National Laboratory, VEA-125

DK-4000 Roskilde, Denmark

European Wind Atlas

The European Wind Atlas was published in 1989 for the Commission of the European Communities by Risø National Laboratory. It is a hardback book of 656 pages with 16 colour maps and a data disk. The European Wind Atlas is:

- **A data bank** of European wind climate: it contains comprehensive wind statistics from more than 200 stations covering the entire EC (1989), plus colour maps of the wind resources of each EC country.
- **A handbook** for regional wind resource assessment and the local siting of wind turbines, including computational procedures for the effects of shelter, roughness and orography on power production.
- **The basis** for reliable estimates of the wind resources in the EC countries (1989), whether on a regional scale or at a specific site.

An overview map of the European wind resource based on the Atlas is given here.

Contents | Translations | Application | Data disk | From the Foreword | Reviews | Map

Contents of the Atlas

The Atlas is divided into three parts, each intended for readers with different areas of interest – from laymen to professional meteorologists:

Part 1: The Wind Resource provides an overall view of the wind climate and magnitude and distribution of wind resources in the European Community countries. This part of the Atlas is intended to be useful to politicians, planners and laymen in general. The descriptions, figures, tables and colour maps permit a first, rapid identification of regions with favourable wind resources.

Contents of Part 1: The wind climate of Europe • Wind resource maps.

Part 2: Determining the Wind Resource gives explanations and information needed for the purpose of regional wind resource assessments and the local siting of wind turbines. In addition, it contains descriptions, raw statistics, and wind atlas statistics for 220 meteorological stations in the EC. It also includes methods for calculating the influence on the wind resource of various features in the landscape such as coastlines, forests, hills, and buildings.

Contents of Part 2: General concepts • The roughness of a terrain • Shelter behind obstacles • The effect of height variations in the terrain • Regional wind energy potential • Use of the wind resource maps • Siting • Selection of wind climatology for a site • Roughness classification • Calculation of statistics for a site • Calculation of shelter • Orography • Power production • Determination of mean power production • Power density function • Power duration curve • Optimisation of power production • Station statistics and climatologies • Station description • Raw data summary • Regional climatology and mean values • Windclimatological fingerprints • Station statistics and climatologies • Radiosonde statistics.

Part 3: The Models and the Analysis explains in detail the meteorological background for the Wind Atlas. It describes how the analysis was performed from the data and station information, and discusses the physical and statistical basis for the Wind Atlas models. The validity of the models and the analysis is demonstrated through a number of comparisons between measured and modelled wind statistics.

Contents of Part 3: The physical basis • Surface-layer similarity laws • The geostrophic drag law and the geostrophic wind • The stability model • The roughness change model • The shelter model • The orographic model • The statistical basis • The Wind Atlas analysis model • The Wind Atlas application model • Meteorological data and station description • Radiosonde statistics • Limitations of data and models • Verification of the Wind Atlas methodology • Station intercomparisons • Validation against high meteorological masts • References • List of symbols • Auxiliary tables • Selection criteria and questionnaire • The data disk.

Non-English translations

The text of the Atlas has been translated into French, German, Italian, and Spanish. These translations contain the entire text of the Atlas as well as the statistical tables of the French, German, Italian, and Spanish stations, respectively. One non-English edition may be supplied free of charge when purchasing the English reference edition.

Application of the Atlas

The Atlas is the meteorological basis for estimating the wind climate and wind energy resources of any particular site in the EC. The application of the Atlas as a siting handbook is explained in detail in the Atlas.

To facilitate resource calculations and specific siting of wind turbines, the Wind Atlas is furnished with a disk containing all the regional statistics. The disk files can be used directly with the "Wind Atlas Analysis and Application Program" (WAsP), which was especially developed for the production of the Wind Atlas and for use in practical siting. The WAsP program is not included in the Atlas, but can be obtained from Risø National Laboratory.

Data disk

The observed and model-derived wind statistics from the 220 meteorological stations are furnished on a data disk together with the Atlas – for use with a PC or compatible computer. The data consists of the observed and modelled wind rose and wind speed distributions for each station.

From the Foreword

"The European Wind Atlas is a major outcome of the European Communities' overall effort to promote the market for electricity production from the wind resource in Europe and to develop the technologies and systems associated with it.

This Atlas completes the information previously published in several national wind atlases, and it will doubtless become an essential tool for all planners of wind energy applications in the Community. The data in this new European Atlas are far more comprehensive than those given in previous works. Moreover, this Atlas provides for the first time a coherent overview of all the EC countries, including the large regions with complex terrain. The latter was a major achievement because reliable computer codes had to be developed especially for this task...

I trust that all those interested in the future development of wind energy utilisation in Europe will appreciate this vast work and benefit from the comprehensive information it provides in their future activities." – Dr. W. Palz, Commission of the European Communities (DGXII)

The reviewers wrote

"This book is a welcome attempt to quantify the meteorological aspects of the wind power available within the parts of Europe belonging to the European Community. The economic viability of generating electricity from the wind is very dependent on not only the mean wind speed but also the distribution of the wind speed at a location. This book addresses this with an examination of 10 years' data from 220 meteorological stations across Europe." – K.L. Simms, *Weather* (1)

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"The European Wind Atlas ... uses high quality surface wind observations as its primary data source. The key factor in the development of the atlas has been to transform the measured winds at specific sites into regionally representative values and climatologies. It is this step which sets this work apart from most other wind energy resource studies and has led to a consistent and reliable atlas...

Notwithstanding the weight, I strongly recommend the Atlas to all interested in wind energy and wind climatologies and, for other readers of Boundary-Layer Meteorology, I commend this as an example of the successful, well documented analysis of a complex micro-meteorological issue." – P. Taylor, *Boundary-Layer Meteorology* (2)

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"While wind energy research in the United States starved from lack of funding during the last decade, progress continued in Europe. Denmark established a reputation for designing and manufacturing the world's finest modern wind turbines. The publication of the European Wind Atlas by the Risø Laboratory now confirms Denmark as a world leader in wind resource assessment as well... As the twentyfirst century approaches and the environmental wounds of fossil fuel consumption become more severe, wind and solar energy alternatives will certainly become more attractive. The European Wind Atlas is an important contribution toward the utilization of a major renewable energy resource. It is an essential reference for scientists and engineers involved with wind energy work in Europe as well as for serious students of Europe's climate. It can also serve world-wide as a guide for sophisticated wind energy resource assessment." – B. Martner, *Bulletin of the American Meteorological Society* (3)

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(1) Weather is published by the Royal Meteorological Society. (2) Reprinted by permission of Kluwer Academic Publishers. (3) Reprinted by permission of the American Meteorological Society.

Wind Atlases of the World

The wind atlas methodology and the WAsP program has been applied in more than 80 countries and territories around the world – for national, regional and local studies. A list of major national and regional studies – several of which contains WAsP data files on disk – is given below. The world according to WAsP is shown here.

Algeria

Hammouche, R. (1991). Atlas Vent de l'Algérie. In French. Office National de la Météorologie, Alger. 150 pp.

Australia

Dear, S.J., M.J. Bell and T.J. Lyons (1990). Western Australian Wind Atlas. Report No. 64, Minerals and Energy Research Institute of Western Australia, Perth. 28 pp. + 14 App.

Belgium

European Wind Atlas (1989), see Europe.

Brazil

Barbezier, G.L., E.A. Feitosa and J.S. Rohatgi (1999). Wind Atlas for the Northeast Region of Brazil. WANEB version 1.0. Brazilian Wind Energy Centre, Recife. 46 pp.

Denmark

Petersen, E.L., I. Troen, S. Frandsen and K. Hedegaard (1981). Wind atlas for Denmark. A rational method for wind energy siting. Risø-R-428. Risø National Laboratory, Roskilde. 229 pp.

European Wind Atlas (1989), see Europe.

Mortensen, N.G., L. Landberg, O. Rathmann, G. Jensen and E.L. Petersen (1999). Wind Atlas Analysis of 24 Danish Stations (1987-96). In preparation for publication as Risø-R-1092(EN). Risø National Laboratory, Roskilde.

Egypt

Mortensen, N.G. and Usama Said Said (1996). Wind Atlas for the Gulf of Suez. Measurements and modeling 1991-95. ISBN 87-550-2143-3. Risø National Laboratory, Roskilde; New and Renewable Energy Authority, Cairo. 114 pp.

Europe

Troen, I. and E.L. Petersen (1989). European Wind Atlas. ISBN 87-550-1482-8. Risø National Laboratory, Roskilde. 656 pp.

Finland

Tammelin, B. (1991). Suomen Tuuliatlas. Vind Atlas för Finland (Wind Atlas for Finland). In Finnish/Swedish. Finnish Meteorological Institute, Helsinki. 355 pp.

France

European Wind Atlas (1989), see Europe.

Germany

European Wind Atlas (1989), see Europe.

Traup, S. and B. Kruse (1996). Wind und Wind-energiepotentiale in Deutschland. Winddaten für Windenergienutzer. In German. Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main. 445 pp.

Greece

European Wind Atlas (1989), see Europe.

Greenland

Mortensen, N.G. and L. Landberg (1993). Wind Energy in selected townships of Greenland: Qasigiannguit, Sisimiut and Narsaq. In Danish. Prepared for Nukissiorfiit/Greenland Power Company. Risø-I-718(DA). Risø National Laboratory, Roskilde. 37 pp.

Ireland

European Wind Atlas (1989), see Europe.

Watson, R. and L. Landberg (1999). The Irish Wind Atlas. University College Dublin, Dublin. In preparation.

Italy

European Wind Atlas (1989), see Europe.

Jordan

Højstrup, J. (1989). Wind Atlas for Jordan. Risø National Laboratory, Ministry of Energy and Mineral Resources, Jordan Electrical Authority, and Jordan Meteorological Department. 86 pp.

Luxembourg

European Wind Atlas (1989), see Europe.

The Netherlands

European Wind Atlas (1989), see Europe.

Portugal

European Wind Atlas (1989), see Europe.

Russia

Rathmann, O. (1998). Wind atlas analysis for 12 meteorological stations on the Kola Peninsula. Risø-I-1285(EN). Risø National Laboratory, Roskilde. 36 pp.

Starkov, A.N., L. Landberg, P.P. Bezroukikh and M.M. Borisenko (2000). Russian Wind Atlas. ISBN 5-7542-0067-6. Russian-Danish Institute for Energy Efficiency, Moscow; Risø National Laboratory, Roskilde. 551 pp.

South Africa

Diab, R. (1995). Wind Atlas of South Africa. Department of Mineral and Energy Affairs, Pretoria, 136 pp.

Spain

European Wind Atlas (1989), see Europe.

Sweden

Krieg, R. (1992). Vindatlas för Sverige (Wind Atlas for Sweden). In Swedish. Slutrapport på projekt 506 269-2 på uppdrag av NUTEK. SMHI, Norrköping. 26 pp.

Krieg, R. (1999). Verifiering af beräknad vind-energiproduktion (Verification of estimated wind power productions). In Swedish. SMHI rapport Nr. 28, SMHI, Norrköping. 25 pp + appendices.

United Kingdom

European Wind Atlas (1989), see Europe.

United States of America

Artig, R. (1999). Minnesota Wind Resource Assessment Program. March 1999 report. Minnesota Department of Public Service, St. Paul. 157 pp.

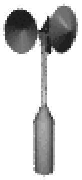
Database on Wind Characteristics

This is a database of wind time-series intended primarily for wind (turbine) design purposes. Here you can find high-resolution (1-40 Hz) time-series, measured under different conditions at 32 different locations inside Europe and United States.

The database is compiled and maintained in Denmark by Kurt S. Hansen, Technical University of Denmark (DTU). The operation and maintenance is funded by Sweden, Norway, The Netherlands, United States and Denmark as an IEA Annex (XVII, operating agent Risø National Laboratory).

More than 53.000 hours of wind speed measurements are available in the database right now (as of 21 July 2000) and wind turbine structural measurements together with wind speed measurements will be included very soon. Further information is given in a folder and in the final project report, both of which may be downloaded from the Web-site.

Visitors are invited to browse through the wind statistics and view time-series (login as guest user). Registered users will obtain access to the advanced search facilities, download of wind statistics and time-series. Structural load measurements are also included in the database!



For further information on this database, please contact winddata@et.dtu.dk.

Risø readings in wind power meteorology

This is a list of selected papers, reports and published conference proceedings authored by or in collaboration with the staff of the Wind Power Meteorology Program of the Wind Energy Department.

Wind power meteorology in general

Petersen, E.L., N.G. Mortensen, L. Landberg, J. Højstrup and H.P. Frank (1998). Wind Power Meteorology. Part I: Climate and turbulence. Wind Energy 1, 2-22.

Petersen, E.L., N.G. Mortensen, L. Landberg, J. Højstrup and H.P. Frank (1998). Wind Power Meteorology. Part II: Siting and Models. Wind Energy 1, 55-72.

Troen, I. and E.L. Petersen (1989). European Wind Atlas. ISBN 87-550-1482-8. Risø National Laboratory, Roskilde. 656 pp.

Wind measurements

Kristensen, L. (1998). Cup anemometer behavior in turbulent environments. J. Atmos. Ocean. Tecnol. 15, 5-17.

Kristensen, L. (1999). The perennial cup anemometer. Wind Energy 2, 59-75.

Mortensen, N.G. (1994). Wind measurements for wind energy applications – a review. Wind Energy Conversion 1994. Proceedings of the 16th British Wind Energy Association Conference, Stirling, June 15-17, 353-360.

Mortensen, N.G. (1994). Flow-response characteristics of the Kaijo Denki omni-directional sonic anemometer (DAT 300/TR-61B), Risø-R-704(EN), Risø National Laboratory, Roskilde, Denmark, 32 pp.

Mortensen, N.G., and J. Højstrup (1995). The Solent sonic – response and associated errors. Ninth Symposium on Meteorological Observations and Instrumentation, Charlotte, NC, March 27-31, 501-506.

WAsP and wind modelling

Bowen, A.J. and N.G. Mortensen (1996). Exploring the limits of WAsP: the Wind Atlas Analysis and Application Program. Proceedings of the 1996 European Union Wind Energy Conference and Exhibition, Göteborg, Sweden, May 20-24, 584-587.

Frank, H.P. and L. Landberg (1997). Modelling the wind climate of Ireland. Boundary-Layer Meteorol. 85, 359-378.

Landberg, L. (1997). The mast on the house. In proceedings from BWEA 19, Edinburgh, 16-18 July, ed. R Hunter, 167-172.

Mortensen, N.G. and E.L. Petersen (1998). Influence of topographical input data on the accuracy of wind flow modeling in complex terrain. Proceedings of the 1997 European Wind Energy Conference and Exhibition, Dublin, Ireland, October 6-9, 317-320.

Walmsley, J.L., I. Troen, D.P. Lalas and P.J. Mason (1990). Surface-layer flow in complex terrain: Comparison of models and full-scale observations. Boundary-Layer Meteorol. 52, 259-281.

Wind atlases

Mortensen, N.G. and Usama Said Said (1996). Wind Atlas for the Gulf of Suez. Measurements and modeling 1991-95. ISBN 87-550-2143-3. Risø National Laboratory, Roskilde, and New and Renewable Energy Authority, Cairo. 114 pp.

Mortensen, N.G., P. Nielsen, L. Landberg, O. Rathmann and M. Nielsen (1999). A detailed and verified wind resource atlas for Denmark. Proceedings of the Tenth International Conference on Wind Engineering, Copenhagen, Denmark, 21-24 June. 2013-2018.

Troen, I. and E.L. Petersen (1989). European Wind Atlas. ISBN 87-550-1482-8. Risø National Laboratory, Roskilde. 656 pp.

Petersen, E.L., I. Troen, S. Frandsen and K. Hedegaard (1981). Windatlas for Denmark. A rational method for wind energy siting, Risø-R-428, Risø National Laboratory, Roskilde, Denmark. 229 pp.

Short term prediction

Landberg, L., and S.J. Watson (1994). Short-term prediction of local wind conditions. Boundary-Layer Meteorol. 70, 171-195.

Landberg, L. (1999). Short-term prediction of the power production from wind farms. J. Wind Eng. Ind. Aerodyn. 80, 207-220.

On the Web

For general information about wind power, as well as links to other web sites related to wind power, a good place to start is www.windpower.org, the award-winning home page of the Danish Wind Turbine Manufacturers Association. A recent download of this entire home page is provided on the WAsP distribution disk.

Wind atlases, wind data and wind characteristics

For information on the wind climate of a particular country or region, you might check the list of wind atlases given here. The national or state meteorological service may also be able to help you; the national weather services are organised in the World Meteorological Organisation. For information on the detailed wind and turbulence characteristics of a given site or type of site, you might check the Database on Wind Characteristics.

Topographical and elevation data

The topographical information needed by WAsP consists of a roughness map and a height contour map. These digital maps are usually constructed by digitisation of ordinary, large-scale topographical (paper) maps. However, elevation and/or land-use information may already be available in digital form, in which case this information may be converted into WAsP-compatible maps. The national or state survey and cadastre should be able to help you find out whether such data exist.

World coast lines

The coastline is a very important elevation and roughness-change line; you can download the geographical coordinates of coastlines around the world using the Coastline Extractor. You can also download the coordinates of lakes, rivers and political boundaries from this site. An example of a map based on these data is given here.

World elevation data

Global elevation and land-cover data are also available over the Internet, e.g. from the Distributed Active Archive Center of the USGS EROS Data Center. The 'Global 30 Arc-Second Elevation Data Set' contains spot heights of node points in a grid with 30 arc-second resolution (926 m or smaller). These data are not detailed enough for WAsP flow modelling, but may be used for overview maps of a region or country; an example of such a map is given here.

Wind turbine and rotor blade manufacturers

For specific information on the characteristics of a particular wind turbine, you should contact the manufacturer directly. A list of major Danish wind turbine and rotor blade manufacturers is given below.

Contact details	Internet home page	E-mail address
Bonus Energy A/S	www.bonus.dk	bonus@bonus.dk
NEG Micon A/S	www.neg-micon.dk	mail@neg-micon.dk
Nordex A/S	www.nordex.dk	nordex@nordex.dk
Norwin A/S	www.norwin.dk	info@norwin.dk
Vestas Wind Systems A/S	www.vestas.dk	vestas@vestas.dk
Wincon West Wind A/S	www.wincon.dk	emn@wincon.dk
LM Glasfiber A/S	www.lm.dk	info@lm.dk

The WAsP library contains wind turbine power curves from all manufacturers mentioned above. More power curves are available in the WAsP 4 package which is included on the CD-ROM.

References

The publications cited in this help facility are listed below.

Beljaars, A.C.M, J.L. Walmsley and P.A. Taylor (1987). A mixed spectral finite-difference model for neutrally stratified boundary-layer flow over roughness changes and topography. Boundary-Layer Meteorol. 38, 273-303.

Beyer, H.G., T. Pahlke, W. Schmidt, H.-P. Waldl and U. de Witt (1994). Wake effects in a linear wind farm. J. Wind Eng. Ind. Aerodyn. 51, 303-318.

Bowen, A.J. and N.G. Mortensen (1996). Exploring the limits of WAsP: the Wind Atlas Analysis and Application Program. Proceedings of the 1996 European Union Wind Energy Conference, Göteborg, Sweden, May 20-24, 584-587.

Bowen, A.J. and N.G. Mortensen (1999). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. In preparation.

Charnock, H. (1955). Wind stress on a water surface. Quart. J. Roy. Meteor. Soc. 81, 639-640.

Jackson, P.S. and J.C.R. Hunt (1975). Turbulent wind flow over a low hill. Quart. J. Roy. Met. Soc. 101, 929-955.

Jensen, N.O. (1984). A Note on Wind Generator Interaction. Risø-M-2411, Risø National Laboratory, Roskilde. 16 p.

Jensen, N.O, E.L. Petersen and I. Troen (1984). Extrapolation of mean wind statistics with special regard to wind energy applications. World Meteorological Organization, WCP-86. 85 pp.

Katic, I. (1986). Wind conditions in wind farms (Vindforhold i mølleparker). In Danish. Risø-M-2582. Risø National Laboratory, Roskilde. 38 p.

Katic, I., J. Højstrup, and N.O. Jensen (1986). A Simple Model for Cluster Efficiency. Proceedings of EWEC'86 European Wind Energy Association, Conference and Exhibition, Rome, 7-9 October 1986. Eds. W. Palz and E. Sesto. Published by A. Raguzzi, Rome, Vol. I, 407-410.

Lettau, H. (1969). Note on aerodynamic roughness-parameter estimation on the basis of roughness-element distribution. J. Appl. Met. 8, 828-832.

Mortensen, N.G. and E.L. Petersen (1997). Influence of topographical input data on the accuracy of wind flow modelling in complex terrain. Proceedings of the 1997 European Wind Energy Conference, Dublin, Ireland, October 6-9, 317-320.

Perera, M.D. (1981). Shelter behind two-dimensional solid and porous fences. J. Wind Engin. and Industrial Aerodyn. 8, 93-104.

Petersen, E.L., I. Troen, S. Frandsen and K. Hedegaard (1981). Windatlas for Denmark. A rational method for wind energy siting. Risø-R-428. Risø National Laboratory, Denmark. 229 pp. Risø-R-428, 229 pp.

Petersen, E.L and I. Troen (1986a). Estimation of wind resources. In: Wind Energy in Denmark. Research and technological development. Ed. Fl. Øster. Published by the Danish Ministry of Energy, 29-36.

Petersen, E.L. and I. Troen (1986b). The European Wind Atlas. Proceedings of the European Wind Energy Association Conference and Exhibition, Rome, October 7-9, 1986, 191-200.

Rathmann, O., N.G. Mortensen, L. Landberg and A. Bowen (1996). Assessing the accuracy of WAsP in non-simple terrain. Wind Energy Conversion 1996. Proceedings of the 18th British Wind Energy Association Conference, Exeter, England, 25-27 September 1996, 413-418.

Rutkis, J. (1971). Tables on relative relief in middle and western Europe. University of Uppsala, Department of Physical Geography, UNGI Rapport 9. 21 pp.

Salmon J.R., A.J. Bowen, A.M. Hoff, R. Johnson, R.E. Mickle, P.A. Taylor, G. Tetzlaff and J.L. Walmsley (1987). The Askervein Hill Project: Mean wind variations at fixed height above ground. Boundary-Layer Meteorol. 43, 247-271.

Taylor, P.A., J.L. Walmsley and J.R. Salmon (1983). A simple model of neutrally stratified boundary-layer flow over real terrain incorporating wavenumber-dependent scaling. Boundary-Layer Meteorol. 26, 169-189.

Taylor, P.A. and H.W. Teunissen (1987). The Askervein Hill Project: Overview and background data. Boundary-Layer Meteorol. 39, 15-39.

Taylor, P.A. and J.R. Salmon (1993). A model for the correction of surface wind data for sheltering by upwind obstacles. J. Appl. Met. 32, 1683-1694.

Troen, I. (1990). A high resolution spectral model for flow in complex terrain. Ninth Symposium on Turbulence and Diffusion, Roskilde, April 30 - May 3, 1990, 417-420.

Troen, I. and E.L. Petersen (1989). European Wind Atlas. ISBN 87-550-1482-8. Risø National Laboratory, Roskilde. 656 p.

William-Olsson, W. (1974). A map of the relative relief of the western half of Europe, 1:4,000,000. Esselte Map Service, Stockholm.

Wood, N. (1995) The onset of separation in neutral, turbulent flow over hills. Boundary-Layer Meteorology 76, 137-164.

WAsP forms

A number of sample forms are provided in the 'Forms' folder of the main WAsP directory. These forms may be used to record characteristics of the wind speed and direction data, the anemometer or wind turbine site, the meteorological station, the near-by obstacles, the surrounding roughness and for exchange of data storing units/cards on a met. station. The forms provided are:

- Data Description Form (Data.doc)
- Site Description Form (Site.doc)
- Station Description Form (Station.doc)
- Obstacle Description Form (Obstacle.doc)
- Roughness Description Form (Roughnes.doc)
- Data Storing Unit Exchange Form (DSU.doc)

The Roughness Description Form is used for the site-specific roughness description or roughness rose. However, most often the roughnesses are specified in the form of roughness change lines in a map; to establish these a copy of the topographical map is most useful.

The Data Storing Unit Exchange Form was developed specifically for Aanderaa systems, but can easily be adapted to other systems/dataloggers.

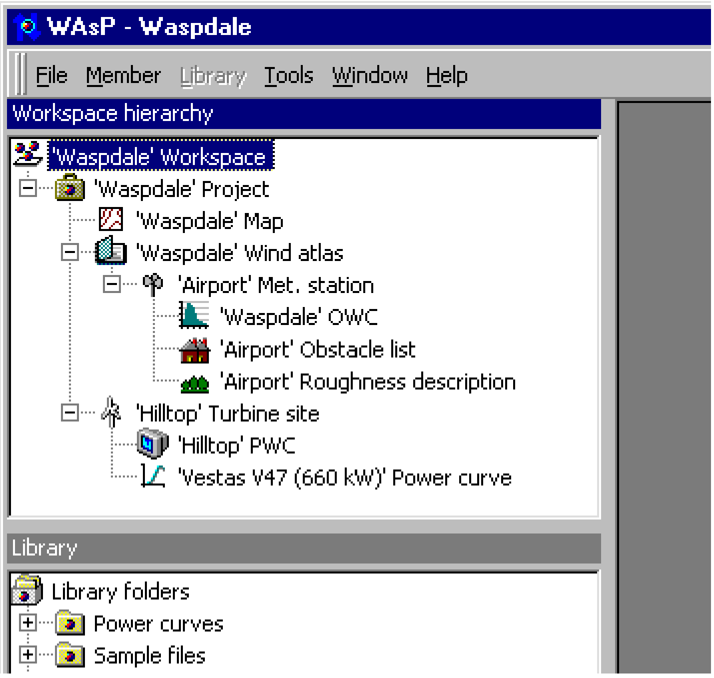
Sample data and workspaces

In addition to the sample data used for the Quick Start Tutorial, three sample workspaces are installed in the folder '\WAsP Workspaces\Samples' during the installation: 'WAsPdale', 'Wind farmer' and 'Resource grid'. You may **Open** any of these workspaces and study how typical WAsP applications are set up in the workspace hierarchy.

A collection of sample wind turbine power curves are installed in the folder '\Program Files\WAsP\Power curves'. These are also available directly from the WAsP Library.

Sample workspace #1: WAsPdale

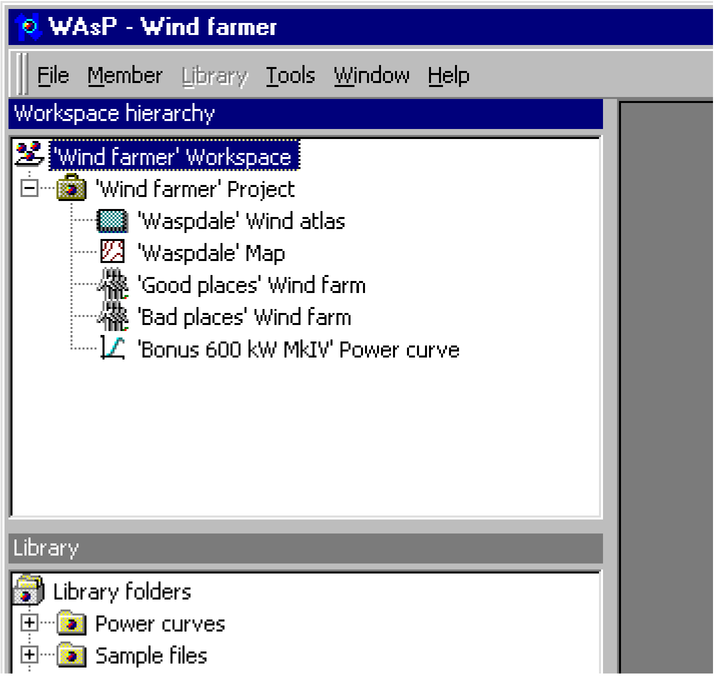
The 'WAsPdale' workspace is an example of the classic WAsP session: analysing the wind data from a met. station to obtain the regional wind climate (wind atlas) and then using the same wind atlas data set to predict the wind climate and power production at a nearby turbine site:



Note, that both the met. station and the turbine site are located in the same map; this is typical, but not necessary. The regional wind climate is assumed to be the same at both sites.

Sample wokspace #2: Wind farmer

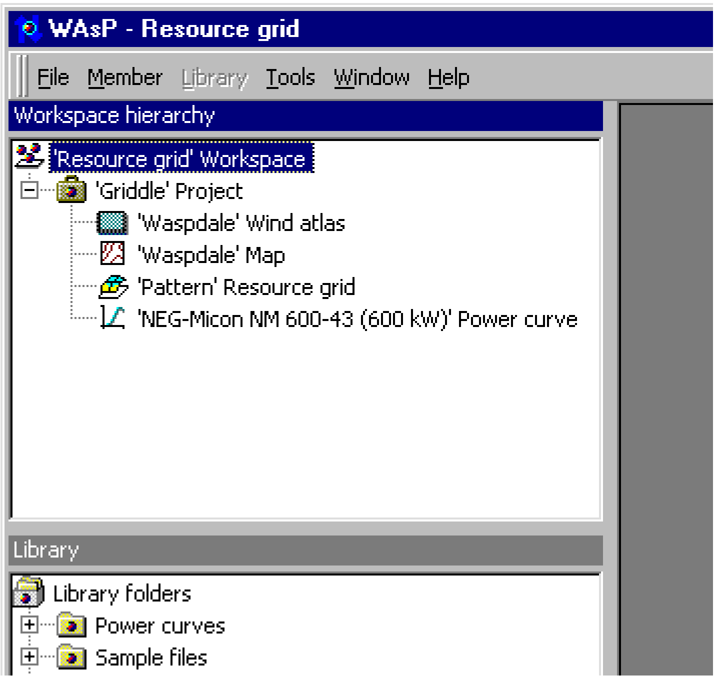
The 'Wind farmer' workspace is an example of another typical application: an existing wind atlas data set is used to predict the power production of several wind farms (or different layouts) in a given area:



Note, that the wind atlas, map and power curve are common to both wind farms.

Sample workspace #3: Resource grid

The 'Resource grid' workspace is an example of how to investigate the variation in the wind resource over an area: an existing wind atlas data set is used to predict the wind climate and power production of several wind turbine sites in a given area:



Again, the wind atlas, map and power curve are common to all the modelled wind turbine sites. The turbine sites are arranged in a regular grid and the resource grid can be used to establish a wind speed or power production map of the area – suitable for micro-siting of the actual turbine sites in a wind farm.

Air density table

Air density [kg/m^3] as a function of elevation *Z* [m a.s.l.] and mean temperature (from -25ºC to 40ºC) at the same elevation. A lapse rate of 6.5 K/km and a sea level pressure of 1013.25 hPa are assumed. Power curves are often referenced to 'standard conditions' corresponding to sea level pressure and 15ºC.

Z	**-5**	0	**5**	**10**	**15**	20	**25**	**30**	**35**	40
0	1.316	1.292	1.269	1.247	1.225	1.204	1.184	1.164	1.145	1.127
100	1.300	1.276	1.254	1.232	1.211	1.190	1.170	1.151	1.133	1.115
200	1.283	1.260	1.238	1.217	1.196	1.176	1.157	1.138	1.120	1.103
300	1.267	1.245	1.223	1.202	1.182	1.163	1.144	1.126	1.108	1.091
400	1.251	1.230	1.208	1.188	1.169	1.150	1.131	1.113	1.096	1.079
Z	**-10**	**-5**	0	**5**	**10**	**15**	20	**25**	**30**	**35**
500	1.258	1.236	1.214	1.194	1.174	1.155	1.136	1.118	1.101	1.084
600	1.242	1.220	1.199	1.179	1.160	1.141	1.123	1.106	1.089	1.072
700	1.226	1.205	1.185	1.165	1.146	1.128	1.110	1.093	1.077	1.061
800	1.210	1.190	1.170	1.151	1.133	1.115	1.098	1.081	1.065	1.049
900	1.195	1.175	1.156	1.138	1.120	1.102	1.085	1.069	1.053	1.038
Z	**-15**	**-10**	**-5**	0	**5**	**10**	**15**	20	**25**	**30**
1000	1.200	1.180	1.161	1.142	1.124	1.106	1.089	1.073	1.057	1.042
1100	1.184	1.165	1.146	1.128	1.111	1.094	1.077	1.061	1.045	1.030
1200	1.169	1.151	1.132	1.115	1.097	1.081	1.065	1.049	1.034	1.019
1300	1.154	1.136	1.118	1.101	1.084	1.068	1.052	1.037	1.022	1.008
1400	1.140	1.122	1.105	1.088	1.072	1.056	1.040	1.025	1.011	0.997
Z	-20	**-15**	**-10**	**-5**	0	**5**	**10**	**15**	20	**25**
1500	1.143	1.125	1.108	1.091	1.075	1.059	1.043	1.028	1.014	1.000
1600	1.128	1.111	1.094	1.078	1.062	1.046	1.031	1.017	1.003	0.989

1700	1.114	1.097	1.081	1.065	1.049	1.034	1.019	1.005	0.991	0.978
1800	1.100	1.083	1.067	1.052	1.037	1.022	1.008	0.994	0.980	0.967
1900	1.086	1.070	1.054	1.039	1.024	1.010	0.996	0.983	0.969	0.957
z	**-25**	-20	**-15**	**-10**	**-5**	0	**5**	**10**	**15**	20
2000	1.088	1.072	1.056	1.041	1.026	1.012	0.998	0.985	0.971	0.959
2100	1.074	1.058	1.043	1.028	1.014	1.000	0.987	0.973	0.961	0.948
2200	1.060	1.045	1.030	1.016	1.002	0.988	0.975	0.962	0.950	0.938
2300	1.046	1.031	1.017	1.003	0.990	0.977	0.964	0.951	0.939	0.927
2400	1.033	1.018	1.005	0.991	0.978	0.965	0.953	0.941	0.929	0.917

The air density for a specific elevation and mean annual air temperature may be calculated with the WAsP air density calculator.

Golden Software demos

Golden Software's Windows-based demo software is fully-featured and you can use your own data to experiment with the software. However, the demos do not allow you to print, save, copy, cut, or export. The following demos are available on the WAsP CD-ROM, in the folder 'Golden Software':

- **Surfer 7 Demo** (s7demo.exe, 10.5 MB): Creates contour and 3-D wireframe maps. For Windows 95, 98, Me, NT 4 and 2000.
- **Grapher 3 Demo** (g3demo.exe, 11.6 MB): Creates *(x,y)* graphs. For Windows 95, 98, Me, NT 4 and 2000.
- **MapViewer 4 Demo** (mapvdemo.exe, 13.6 MB): Creates thematic maps. For Windows 95, 98, Me, NT 4 and 2000.
- **Didger 2 Demo** (d2demo.exe, 10.4 MB): Creates digital images from paper images. For Windows 95, 98, Me, NT 4 and 2000. Tutorial included in the demo!

The demos may also be downloaded free of charge from Golden Software's download page. To view the entire Golden Software site, please visit www.goldensoftware.com.

Installation

To install a demo, click the **Start** button, then choose **Run**. Type the path and file name for the appropriate EXE file, or use the browse button to locate the EXE file. Press OK and setup will begin.

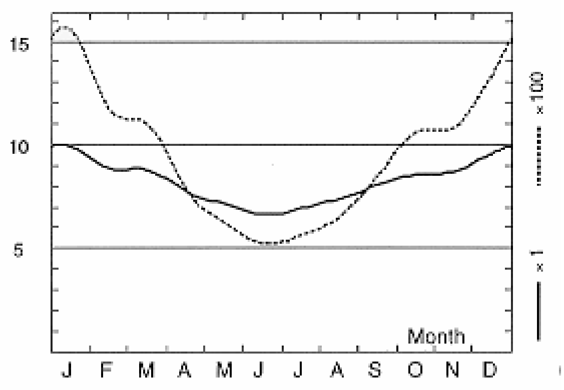
Introduction

The so-called wind-climatological fingerprint was first introduced in the European Wind Atlas. The purpose of this graphical presentation of wind data – given at the end of each national section in the Atlas – is to give a compact and informative overview of the wind data used for the Atlas. Wind-climatological fingerprints have been used in many wind atlases and reports; therefore we present the explanation to the various graphs here.

The first line states the name of the meteorological station and the period over which the data were collected. This is followed by the height above ground level where measurements were taken, the mean value, the standard deviation and the mean value of the cube of the measured wind speeds. The graphical presentation consists of five graphs, described in the following.

The mean year

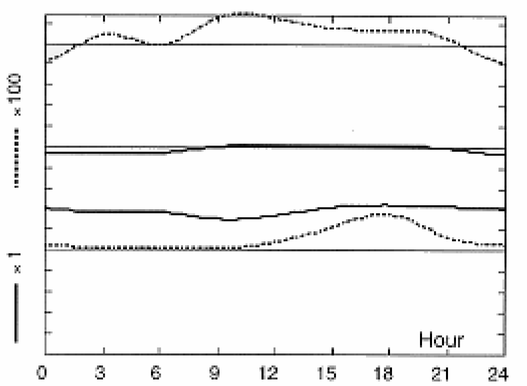
The average seasonal variation of the measured wind speed (full line) and cube of wind speed (dashed line) is shown in the top left graph. All data associated with the same calendar month are averaged and the results plotted at the midpoint in each of the indicated monthly intervals. The unit on the ordinate is ms^{-1} for mean speeds and m^3s^{-3} for the mean of the cube of the wind speed.



Values read from the graph must be multiplied by the scale factor given to the right. The continuous curves are obtained by interpolation using a periodic cubic spline. The speed data are also contained in the tables on the station description pages.

The mean days

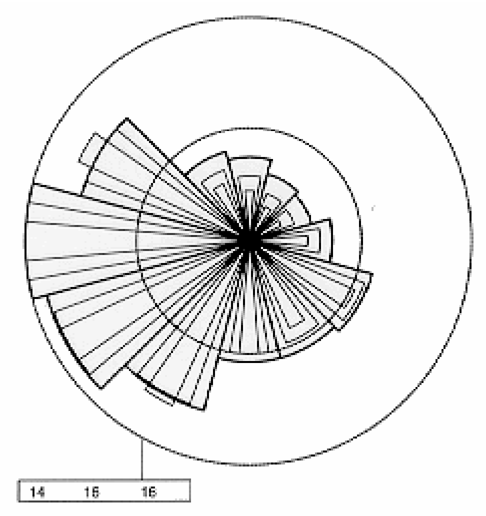
The average daily variation of the measured wind speed for the months of January and July is shown in the top right graph. The average hourly variation of wind speed is shown in full lines for January and July and for the cube of wind speed dashed lines are used. Data from all months of January (July) associated with the same time of day are averaged. Results obtained for each of the indicated standard hours are plotted using an interpolating smooth curve (periodic cubic spline). The mean ordinate for each curve is identical to the ordinate on the corresponding mean year curve (top left graph) at the January (July) points. The unit on the ordinate is ms^{-1} for mean speeds and m^3s^{-3} for the mean of the cube of speed.



Values read from the graph must be multiplied by the scale factor given to the left. Mean days for each calendar month are calculated and define – for each calendar month – a mean or reference day which is used as reference in calculating the spectrum below. The speed values are contained in the tables in the station descriptions.

The wind rose

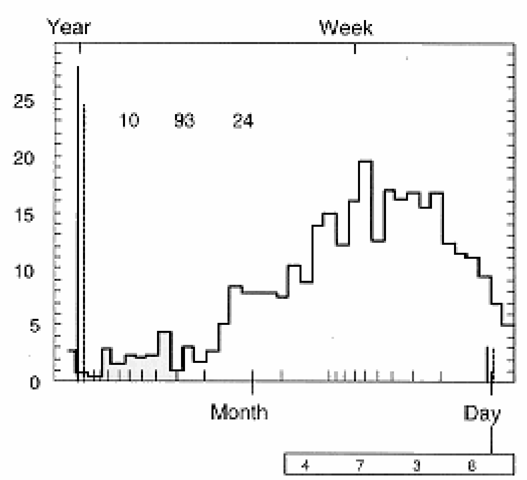
The relative frequencies of winds coming from each of twelve sectors are shown in the middle left graph as the radial extent of the circle segments spanning the sectors (thick lines). The contribution from each sector to the total mean speed and to the total mean cube of speed are given as the narrower segments and the central segments respectively.



For each quantity the normalisation is such that the largest segment extends to the outer dotted circle. The corresponding value for each of the three quantities is given in the small box in per cent (numbers given to the nearest integer). The inner dotted circle corresponds to half of this value.

The spectrum

The contribution to the total variance of wind speed for a range of periods is shown by the full curve in the middle right graph. The vertical scale is arbitrarily adjusted to centre the curve. The abscissa gives the periods on a logarithmic scale. The curve is calculated from the total time series by first subtracting the monthly mean day values from each day data, hour by hour. The monthly mean days for all twelve months were calculated as described for January and July above. The mean days are in this context considered deterministic in contrast to the calculated time series of deviations which form the stochastic part. This is followed by a Fourier transform of the deviations and the spectral estimates are squared and block averaged over bands of equal relative bandwidth corresponding to the widths of the steps in the curve.

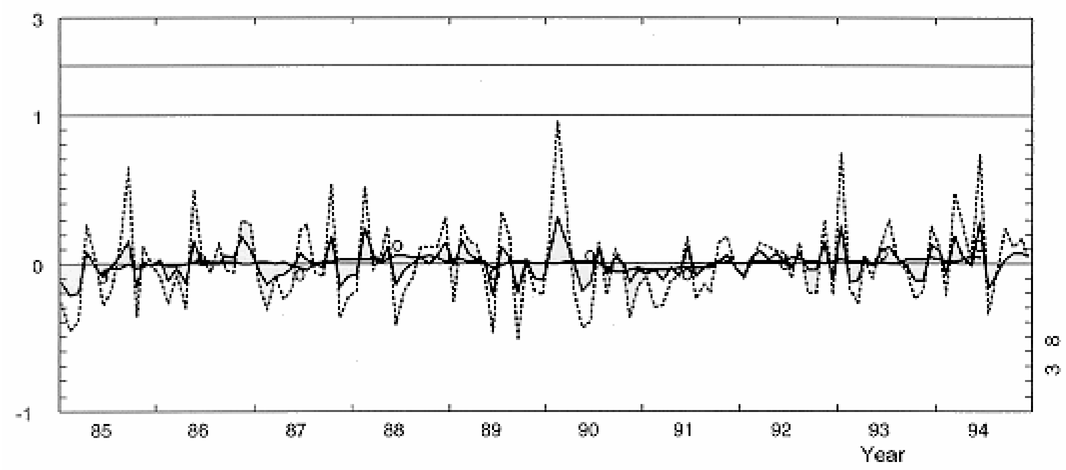


The full vertical bar on the left side gives the contribution to the standard deviation of wind speed in the whole set of data from periods which fit into one year. This is calculated as the standard deviation of the *mean year* (top left). The adjacent dashed bar gives similarly the mean year contribution to the standard deviation of the cube of wind speed. Units are per cent of the total standard deviation of the data. Similarly the bars on the right give the contributions to the standard deviations of speed and cube of speed by periods which fit into one day, i.e. 24, 12, 8 and 6 hours in the present case of basic 3-hourly data.

The numbers listed at the top left inside the graph are the contribution to the total standard deviation in per cent by the random variations contained in the variance spectrum, divided into the part with periods longer than one year, periods between one year and one day, and periods smaller than one day (the sum of squares of the contributions of the three random parts together with the contributions from the deterministic mean year and mean day adds to unity). The numbers in the small box below the graph give the relative standard deviation for speed and cube of speed for the mean January day (first two numbers) and the mean July day (last two numbers).

The time print

The month-by-month relative deviation from the mean months is shown in the bottom graph. For each month the average speed and cube of speed is calculated and the expected value from the corresponding calendar month in the *mean year* (top left) is subtracted. The relative deviation is shown by the jagged lines – full line corresponding to speed and dashed line corresponding to cube of speed. The smoother full line shows the year-by-year relative deviation of mean speed from the total average. Each point on this curve gives the relative deviation in the period extending backwards and forwards one half year (centred block averages). The centre value for each calendar year thus gives the deviation for that particular year. The open circles show similarly the relative deviation of the mean cube of speed for each calendar year.



The numbers to the right give the root mean square of the calendar year deviations in per cent for speed (lower number) and cube of speed (upper number). The vertical scale is linear from -1 to +1, and shifts at +1 to a coarser linear scale which is adjusted to accommodate the largest deviations.