**US Army Corps
of Engineers**
Waterways Experiment
Station

Aquatic Plant Control Research Program

HYDRIL (Version 1.0): A Simulation Model for Growth of Hydrilla

by   *William A. Boyd, WES*
        Elly P. H. Best, AScI Corporation

WES

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HYDRIL (Version 1.0): A Simulation Model for Growth of *Hydrilla*

by William A. Boyd

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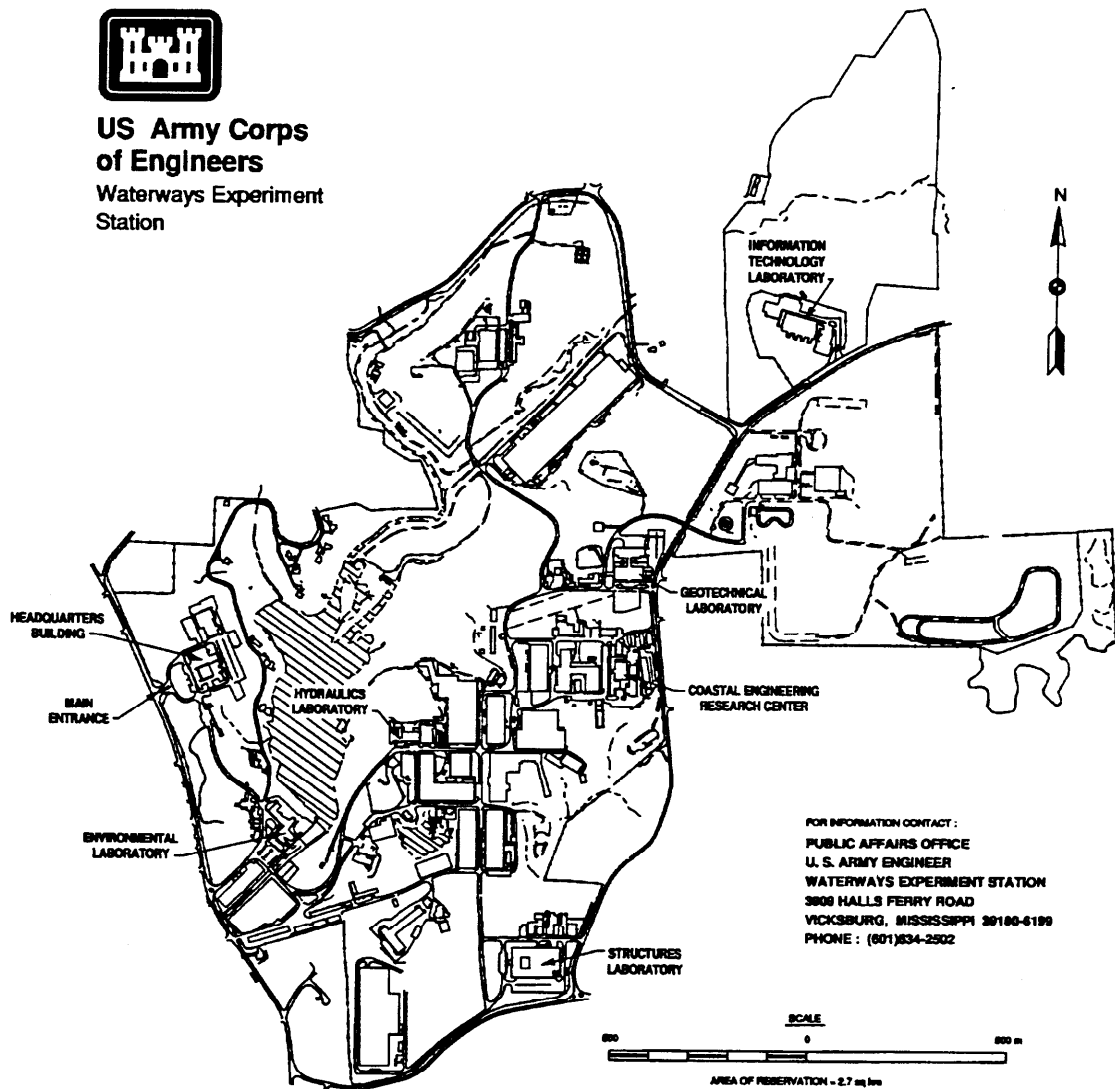3909 Halls Ferry Road
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Final report

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SCALE
600   0   600 m

AREA OF RESERVATION = 2.7 sq km

Contents

Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32440. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP) by Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel, Jr., was Assistant Manager, ERRAP, for the APCRP. Program monitor during this study was Ms. Denise White, HQUSACE.

Principal Investigator for this study was Mr. R. M. Stewart, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. The work described herein was performed by Mr. William A. Boyd, EPEB, and Dr. Elly P. H. Best, under contract through the AScI Corporation. Mr. Boyd and Dr. Best prepared this report. The report was reviewed internally by Dr. John D. Madsen, EPEB, and Mr. Joel McAllister, Computer Sciences Corporation.

This investigation was performed under the general supervision of Dr. Richard E. Price, Acting Chief, EPEB, Mr. Donald L. Robey, Chief, EPED, and Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

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1 Introduction

A simulation model for the dynamics of a submersed *Hydrilla* vegetation (dioecious biotype) has been developed, called HYDRIL. The model is based on the carbon flow through the vegetation. It includes several aspects that affect biomass dynamics, such as latitude, seasonal changes in climate, pH effects on carbon availability, wintering strategies, grazing (removal of aboveground and tuber biomass), and mechanical control (removal of aboveground biomass). The characteristics of the vegetation and of site can be easily modified by the user.

HYDRIL can be used to gain insight into the processes affecting the dynamics of a *Hydrilla* vegetation in relatively shallow, hard water (0.1- to 2.5-m depth; DIC concentration > 0.8 mmol). It has been calibrated on data pertaining to a *Hydrilla* vegetation in Lake Orange, Florida. At that site, no aboveground wintering biomass is present, and growth starts from the tuber bank. Peak biomass is reached late in August, and tuber formation takes place in autumn, replenishing the tuber bank.

HYDRIL simulates the dynamics of plant biomass and tuber bank density at Lake Orange over a period of 1 to 5 years. It has been used to calculate plant biomass and tuber density for other sites in subtropical (Florida) and tropical (India) areas, where it gave good results.

Sensitivity analyses show that plant biomass of a *Hydrilla* population is strongly influenced by photosynthetic activity at light saturation, initial light-use efficiency, and photosynthetic surface area. However, tuber density in the tuber bank is influenced by initial tuber density (at the beginning of the year) and the relative growth and death rates of the tubers. Changes in water transparency and depth can cause large changes in plant biomass on a short term and in tuber density on a longer term. Grazing of tubers from the tuber bank decreases tuber density and may lead finally to population extinction.

HYDRIL can be used as a tool to predict the dynamics of a *Hydrilla* vegetation over 1- to 5-year periods. Running the model with different parameter values specific for any particular site helps in gaining insight into the predominant mechanisms regulating submersed plant dynamics.

A detailed description of the model is given by Best and Boyd (In Preparation). Output parameters available are listed in Appendix A.

2 Installation and Execution of the Model

System Requirements

There are few requirements for running HYDRIL (Version 1.0). The minimum RAM memory requirement should be at least 512 kb. A mathematical coprocessor is in general not required but will often speed up the calculations considerably. A free hard disk space of about 1 Mb is required.

Installing HYDRILLA (Version 1.0)

Create a new directory, with the name "HYDRILLA," using the DOS command MKDIR. For example, the DOS command "MKDIR C:\HYDRILLA" creates a new directory on the C drive called HYDRILLA. Copy the contents of the floppy diskette to the directory C:\HYDRILLA by using the following command:

XCOPY A:*.* C:\HYDRILLA*.* /s

This diskette contains the HYDRILLA.EXE file, all necessary input data files, as well as a file used to display the model's output graphically (TTSELECT.EXE). Input files included with this diskette are as follows:

a. MODEL.DAT

b. TIMER.DAT

c. CONTROL.DAT

d. RERUNS.DAT

Available weather data files are included in the subdirectory /WEATHER. The user can select any one of these weather files as input for the HYDRIL model or may choose to create a weather file specific to a particular site. The

content of the weather data files is discussed in Chapter 3 of this manual, and an example of a typical weather data file can be seen in Appendix B.

Executing HYDRIL (Version 1.0)

The HYDRIL model does not require interactive input during execution. The runs have been specified completely in the data files. To execute the model, simply type

HYDRIL <CR> (carriage return)

An introductory screen appears, and the user is prompted to press <ENTER>. During execution, the model will display the run number, year number, and day number on the screen each time output to file is done. During execution, errors and warnings may occur from the weather system and/or from the other modules of the model. These errors/warnings generally consist of one line of text. If the simulation is terminated by an error during the dynamic section of the run, the outputs generated before the error in that particular run occurred are written to a temporary file but are not written to the output file until the terminal section of the model is reached.

3 Program Structure and Data Files

Program Structure

The source code for HYDRIL (Version 1.0) is written in Fortran77. The model runs within a system called the FORTRAN Simulation Environment (Version 2.1), hereafter referred to as FSE. The FSE allows a simulation model to be written with emphasis on the modeling itself rather than on other things such as time, file input/output (i/o), etc. More information is available on running the model within the FSE in Chapter 5 of this manual.

Subroutines called during the execution of the HYDRIL model include MODELS, MODEL, ASTRO, TOTASS, and ASSIM. A brief description of each subroutine follows:

MODELS - This subroutine is the interface routine between the FSE-driver and the simulation model. The FSE-driver calls this routine and transfers relevant "environment" variables (such as TIME, OUTPUT, etc.) to this routine.

MODEL - This subroutine is called from subroutine MODELS. It is the routine where specific calculations for *Hydrilla* growth begin.

ASTRO - This subroutine is called from the MODEL routine each day of the simulation period. It calculates astronomic daylength, photoperiodic daylength, and diurnal radiation characteristics.

TOTASS - It is called in the MODEL subroutine. This subroutine calculates daily total gross assimilation by performing a Gaussian integration over time. At three different times of the day, radiation is computed and used to determine assimilation.

ASSIM - This subroutine is called from subroutine TOTASS. Plant biomass is distributed within the layers of the plant, and the instantaneous carbon dioxide assimilation rate of the plant is computed in this subroutine.

A diagram illustrating the program structure of the model is shown in
Figure 1.

Data Files

Most of the parameters and initial values of the various processes are read
from data files. This has the advantage in that the model does not have to be
recompiled and linked each time changes are implemented to the input data.
There are four input files required to run the HYDRIL model (excluding the
weather data file) with a potential for other input files available. The model
also typically creates three output data files. The input and output files asso-
ciated with HYDRIL are discussed in this section.

Input files

The MODEL.DAT file: This data file contains initial constants, model
parameters, as well as data used for functions. An example of the
MODEL.DAT file is shown in Appendix B.

The TIMER.DAT file: This data file specifies variables for the following:

a. Time control.

    (1) Start time and finish time.

    (2) Time step integration.

    (3) Year.

b. Output.

    (1) Time between different outputs.

    (2) Format of the output file.

    (3) Selection of output variables.

c. Weather control.

    (1) Directory in which the weather data are stored.

    (2) Country code.

    (3) Station number.

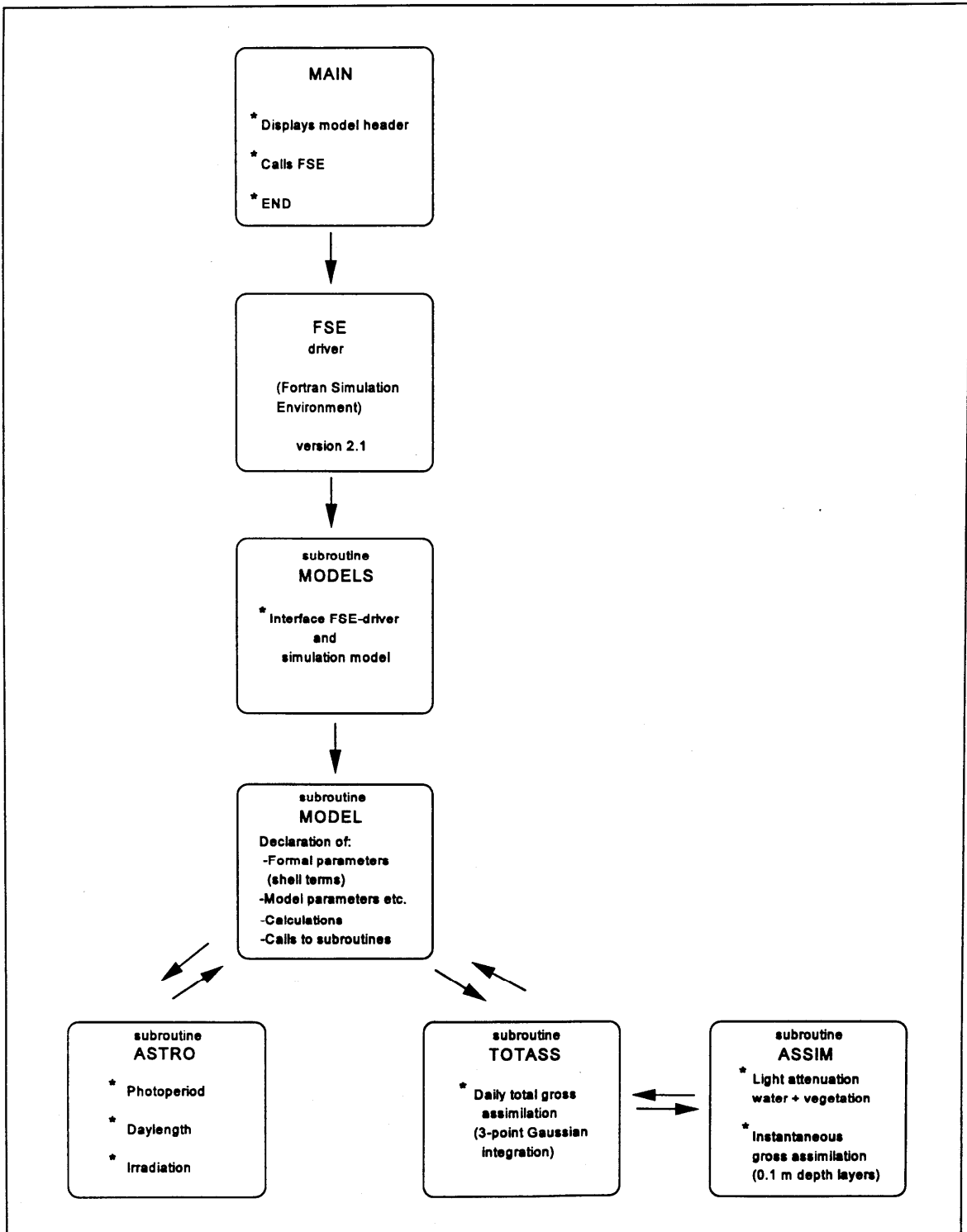An example of the TIMER.DAT file is shown in Appendix B.

Figure 1.   Relational diagram illustrating organization of the model HYDRIL and its subroutines in combination with FSE (Version 2.1) shell

The RERUNS.DAT file: If the reruns file is absent or empty, the model will execute a single run (1 year) from the standard data files. By creating a reruns file, the model will execute additional runs with different parameters and/or initial values for the state variables (or even different input files). Therefore, the total number of runs made by the model is always one more than the number of rerun sets (see Appendix B). The format of the rerun files is identical to that of the other data files except that the names of variables may appear in the file more than once.

The CONTROL.DAT file: This file contains the names of both input and output files used during the execution of HYDRIL. An example of the CONTROL.DAT file is shown in Appendix B.

Output files

HYDRIL creates three standard output files with a potential fourth, binary file: RES.DAT, MODEL.LOG, WEATHER.LOG, and RES.BIN.

The RES.DAT file: This file contains the output of the model with the reruns (if present) merged below each other in the file. The format of the output file RES.DAT depends on the value of the variable IPFORM from the timer file (see Appendix B).

The MODEL.LOG file: This file may contain the messages from routines used during the simulation. Messages about replacements by the reruns facility can be particularly useful. To make sure the execution of the model is without errors, this file should be inspected.

The WEATHER.LOG file: This file contains all the messages generated by the weather system. By default, all the comment headers of the data files, all warnings, and all errors from the weather system are written to this log file. If errors or warnings occur during a run, a message is displayed shortly before the termination of the model about possible errors or warnings. These messages are explained in more detail in the log file.

The RES.BIN file: The variable "DELTMP" found in the TIMER.DAT file (Appendix B) determines if the temporary output data (RES.BIN) should be deleted or saved at termination of the simulation (DELTMP = 'N', Do not Delete, DELTMP = 'Y', Delete). Using this file, it is possible to generate graphs of the model's output on IBM-PCs and compatibles after termination of the simulation. This can be done using the TTSELECT program, provided DELTMP is set to 'N' in the timer file. This program is included in this distribution package. For more details on TTSELECT, see Displaying Output.

Weather data files

The weather data system basically consists of two parts: the weather data files and a program to retrieve data from those files (Van Kraalingen et al. 1991). A single data file can contain, at most, the daily weather data from one meteorological station for one particular year. The country name (abbreviated), station number, and year to which the data refer are reflected in the name of the data file (e.g., NL1.983 applies to data from the Dutch (NL) meteorological station in Wageningen (1) for the year 1983).

Daily values are provided for the following weather parameters:

Name		Unit
Global radiation	(daily total)	$kJ/m^2/day$
Minimum air temperature		degrees Celsius
Maximum air temperature		degrees Celsius
Vapor pressure		kPa
Wind speed	(daily average)	m/s
Rain	(daily total)	mm/day

The user can create a weather data file that is unique to a particular site. The file consists of four parts: a file header containing some explanatory text, one line with location parameters of the station, lines with measured data, and, optionally, so-called status lines giving information on the way missing data should be handled by the reading program (see Van Kraalingen et al. 1991). An example of a weather file can be seen in Appendix B.

Displaying Output

The program TTSELECT.EXE is included within this distribution package. Execution of this program allows the user to graphically view output parameters stored in the file RES.BIN. To use this feature of the package, after termination of the HYDRIL simulation, type the following command:

TTSELECT <CR> (carriage return)

A list of all possible output parameters will then be displayed at the top of the computer screen. The user must select two or more of these parameters by entering the parameter name separated by a comma (NOTE: Parameter names must be entered exactly as they appear on the screen). The first parameter entered (always TIME) will appear as the x-axis variable, while all other variables entered will be plotted along the y-axis. Once all output parameter names are entered, the user must follow instructions on the screen by pressing a <CR> (carriage return). The output graph will then be displayed.

There are several options available once the graph is displayed: (a) the plot can be saved as a file; (b) it can be saved as a screen dump file for later

printing; or (c) it can be printed on a Hewlett Packard DeskJet or LaserJet printer. If desired, another set of parameters can be viewed by entering different output parameters. At anytime, the user may exit the TTSELECT.EXE program by typing CONTROL Z followed by a <CR> (carriage return).

4   Program Output

Example Runs

Example simulations using HYDRIL (Version 1.0) were made to provide further information to facilitate proper execution and to demonstrate applications. The following summary includes an example using MODEL.DAT values shown in Appendix B (reference values with plant biomass beginning at zero grams.m^{-2}) and an example in which there is plant biomass present at the beginning of the simulation.

The user can produce simulation results for a specific scenario by modifying parameters found in the MODEL.DAT file. HYDRIL can quickly provide information on the growth and development rate of *Hydrilla* over a specified period.

Example 1:   Reference

The current MODEL.DAT file (see Appendix B) contains data required to execute a reference run. Note that under the section "Initial constants" in the MODEL.DAT file, all initial plant biomass values are set to zero. These values include the initial dry matter (living and dead) of leaves, stems, roots, and storage components and would indicate that at the beginning of the simulation there is no plant material, living or dead, in the system. In this situation, growth starts from tubers in the tuber bank. The simulation is executed for 1 full year using weather data contained in the file 'USA1.980'. This file contains weather data obtained from station USGA, in 1980 by the University of Florida at Gainesville, FL, and is located on the subdirectory C:\HYDRILLA\WEATHER.

For this reference run, the model can be executed without changing any input files used by the model. To ensure that the current directory is HYDRILLA, from the C drive, type the command:

CD/HYDRILLA <CR>

and then type

HYDRIL <CR>

to execute the simulation model.

After the introductory screen is displayed and execution begins, the model will display the run number, year number, and day number on the terminal screen each time output to file is done. Upon completion, HYDRIL lists the names and contents of output files created.

Example 2: Initial biomass > 0.0 g

Example 2 run uses an almost identical MODEL.DAT file as used with the reference; the only difference is the initial plant biomass values under the section "Initial constants." This run begins with 200 g of live biomass present per square meter on Day 1 of the simulation. The biomass present corresponds with field data measured for Lake Trafford, Florida (Bowes, Holaday, and Haller 1979). Biomass is partitioned over the leaves, stems, roots, and storage components of the plant as follows. Of the total plant live weight, excluding the tubers, 0.34 is leaves, 0.6 stems, and 0.06 roots (Haller and Sutton 1976; Van, Haller, and Garrard 1978; Van der Zweerde 1981). The total plant live weight is composed of 14-percent storage component (largely starch); thus, 200 g live plant mass contains 200 - (0.14 × 200) = 172 g plant organs. The rest is plant storage organ. The weights are calculated below:

$$IWLVG = 0.34 \times 172 = 58.5 \qquad \text{! initial dry matter of green leaves}$$
$$(g\ DW.m^{-2})$$
$$IWRTG = 0.06 \times 172 = 10.3 \qquad \text{! initial dry matter of live roots}$$
$$(g\ DW.m^{-2})$$
$$IWSTG = 0.60 \times 172 = 103.2 \qquad \text{! initial dry matter of green stems}$$
$$(g\ DW.m^{-2})$$
$$IWSO = 0.14 \times 200 = 28.0 \qquad \text{! initial dry matter of storage comp.}$$
$$(g\ DW.m^{-2}).$$

The calculated initial values for plant organ weights must be changed in the MODEL.DAT file. The MODEL.DAT file should be saved and HYDRIL executed as described for the reference run.

Example Output

The output of each example run is discussed and compared in this section of the manual. These results demonstrate the impact beginning biomass can

have on the simulated biomass of *Hydrilla* and on other output parameters. The total live dry weight of *Hydrilla* for both example runs is shown in Figure 2A. The reference run started with 0 g biomass at Day 1 of the simulation and only shows live plant biomass from Day 68 onwards. Live biomass peaks at Day 260 at 270 g DW.m^{-2}. The Lake Trafford, Florida, run started with 200 g DW.m^{-2}, and peak biomass of 649 g.DW.m^{-2} was reached at Day 175 of the simulation.

A similar pattern emerged when comparing the total plant mass produced per square meter (Figure 2B). The total plant mass in the reference run is 200 g lower than that in the Lake Trafford, Florida, run, and the difference is 600 g DW.m^{-2} by Day 175 of the simulation. However, by Day 365, the difference between the total dry weight of the simulations is again near 200 g DW.m^{-2}.

Although initial biomass influenced the total live and total (live+dead) dry weight to a great extent, it did not influence tuber bank weight. The latter was equal in both example runs (Figure 2C).

It is hoped that these example runs and their output provided in this section of the users' manual will help users conceptualize simulation runs that will generate useful information to address specific questions.

Use of Different Weather Files

An important factor influencing *Hydrilla* biomass is climate. Phenology is tied indirectly to air and/or water temperature through development rate. Weather data are available for different climatological conditions ranging from temperate to tropical. To illustrate the impact that climate can have on *Hydrilla* biomass and tuber production, HYDRIL was executed using a weather file taken from a temperate as well as a tropical climate. Following is a description of each weather file:

Weather File 1 (Tropical)	Country: India Station: Patancheru Year: 1978 Longitude: 78° 28' E Latitude: 17° 27' N Elevation: 21 m
Weather File 2 (Temperate)	Country: United States of America Station: USGA Year: 1980 Longitude: 82° 22' W Latitude: 29° 38' N Elevation: 7 m
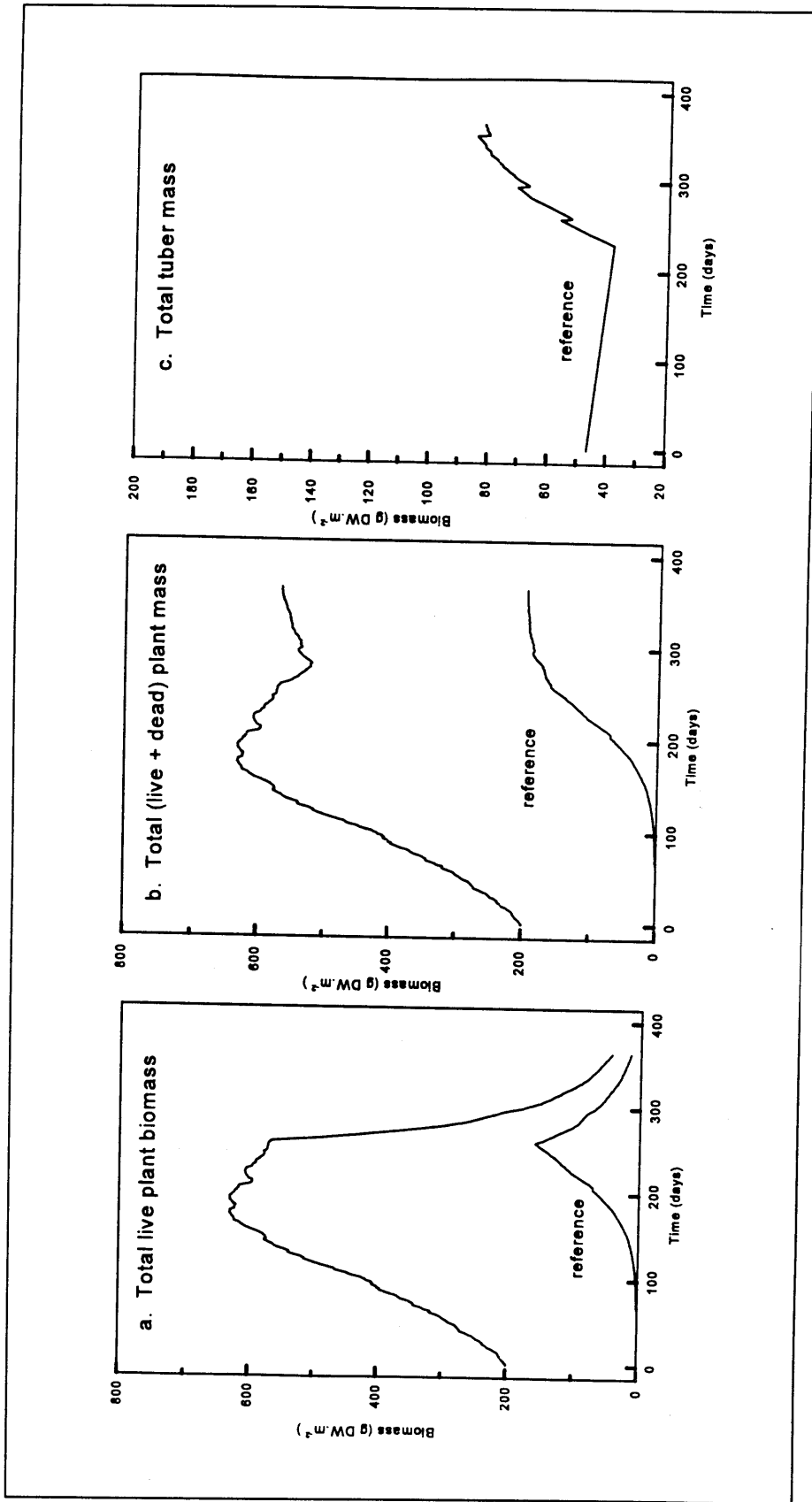
Figure 2. Simulated live biomass, total plant mass, and total tuber mass of *Hydrilla*

Output of each simulation is shown in Figures 3 and 4. Figure 3 illustrates differences in the simulated live plant biomass due to climate over a 1-year period. As shown, live biomass values were more than twofold higher in the temperate climate as in the tropical, and peak biomass levels occurred earlier in the tropical climate. Simulated tuber biomass (Figure 4) was initiated with the same value for both climates (i.e., 500 tubers at 0.1 g each). However, biomass levels for tubers in the temperate climate exceeded those found in the tropical climate.
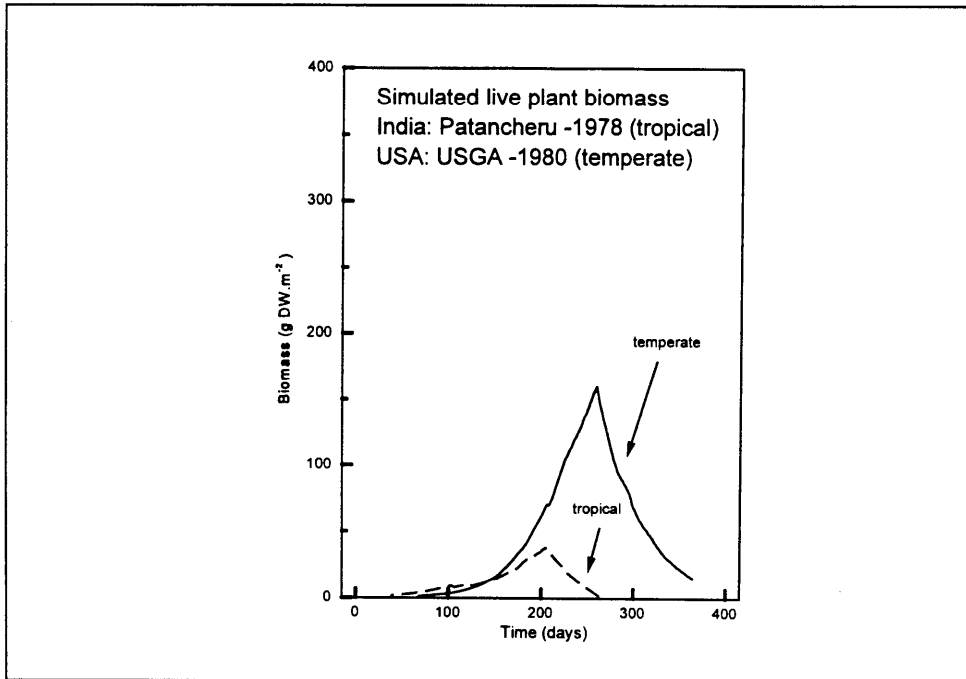
Figure 3.   Simulated live plant biomass using weather data files for station USGA (United States 1980) and Patancheru (India 1978)

Removing Plant Biomass By Mechanical Harvesting

HYDRIL can also be used to calculate the effect of various control methods on biomass and the survival of a *Hydrilla* stand. The model can simulate what occurs during harvesting operations by indicating (a) that harvesting occurs (HAR = 1), (b) the day at which harvesting occurs, and (c) the harvesting depth below the water surface in the MODEL.DAT file. All plant biomass contained in those layers affected by the harvesting depth is removed in the simulation run.
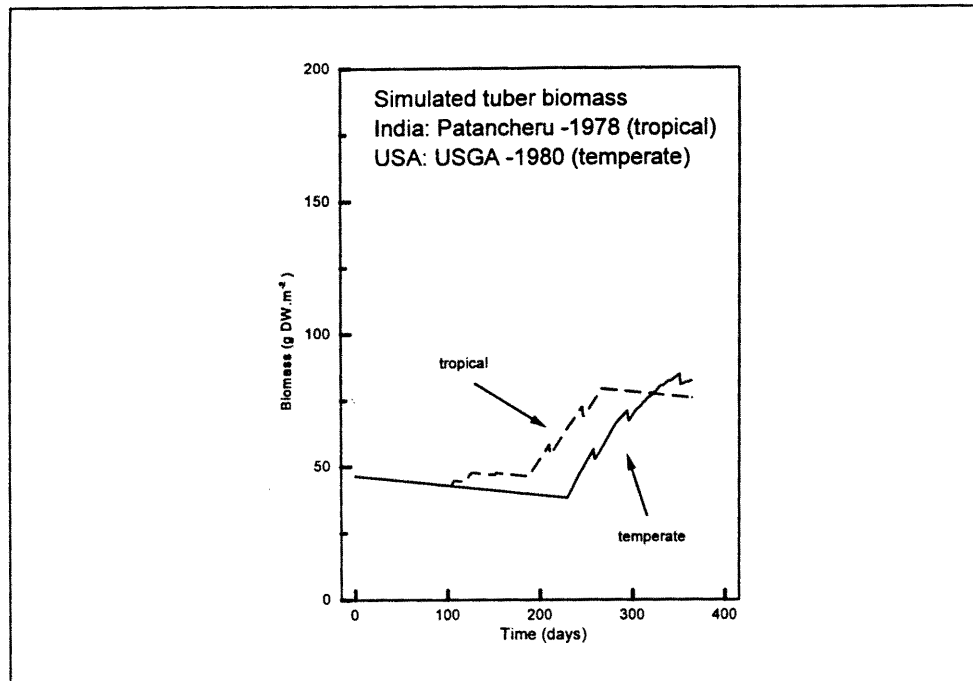
Figure 4. Simulated tuber biomass using weather data files for station USGA (United States 1980) and Patancheru (India 1978)

Multiple Year Runs

HYDRIL has the capacity to generate multiple year simulation runs. This is a critical feature when examining plant growth for consecutive years and/or in the analysis of the effect of a different value for an input parameter. Multiple year simulation runs can be accomplished using the RERUNS.DAT file, which is illustrated in Appendix B of this manual. If the RERUNS.DAT file is absent or empty, the model will execute a single run using the data from the standard data files (i.e., MODEL.DAT and TIMER.DAT). If the RERUNS.DAT file is present and contains different parameters and/or initial values for the state variables, the total number of runs made by the model is always one more than the number of rerun sets. Names of variables originating from different data files can be redefined in the same rerun file. Arrays can also be redefined in a rerun file. The order and number of variables should be the same in each set. A new set starts when the first variable is repeated (see Appendix B).

5 Running the Model Within a Shell

This chapter gives a brief description of how the FSE-shell drives the HYDRIL model. All execution starts with a MAIN program (Figure 1). This is a short program that displays the header and calls the FSE-driver. The FSE-driver then performs a number of actions. It reads the input and output file names needed by the model from the file CONTROL.DAT. This file contains the names of the input files TIMER.DAT, RERUNS.DAT, and MODEL.DAT. The CONTROL.DAT file also contains names of the model's output files (RES.DAT and MODEL.LOG). From the weather control variables in the TIMER.DAT file, the weather system determines which weather data file is required.

The FSE-driver then calls a MODELS subroutine and transfers all relevant "environment" variables (such as TIME, OUTPUT, etc.) to this routine. The MODELS subroutine provides the interface between the FSE-driver and the simulation model. This routine in turn calls the MODEL subroutine, which begins execution of the various routines within the HYDRIL source code.

It is not necessary to know the FORTRAN details of what is going on in the FSE-driver. A discussion of information that is passed from the FSE-driver to the model and vice versa can be found in Van Kraalingen (1995).

6 Model Features

Features of HYDRIL are as follows:

  a. Phenology is tied indirectly to air temperature through development and is, therefore, independent of day of year; thus, the model can be used under climatological conditions ranging from temperate to tropical.

  b. Plant growth starts from the tuber bank in the sediment and/or from rooted plants.

  c. Photosynthetic response is instantaneous to irradiation.

  d. Removal of biomass through harvesting can be calculated if desired.

  e. Air and/or water temperatures can be used to run the model.

  f. The model can be used for vegetation at various water depths, ranging from 0.1 to 2.5 m.

  g. Plant parameter values and climatological variables can be easily changed.

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7   Application Possibilities

HYDRIL can be used to assess the behavior of a *Hydrilla* vegetation under various climatological and site-specific conditions, and it can be run with user-specified input values for plant biomass and tuber bank density.

Effects of man-made control activities, like harvesting at different times and at various water depths, can also be calculated. Thus, in the latter case, it can be used as a tool for aquatic plant management agencies.

The present version of HYDRIL (1.0) has been developed as a stand-alone simulation model. It can relatively easily be modified to communicate with ecosystem models, because it has been written in FORTRAN77 and its structure is simple. It is planned to link HYDRIL to a Geographical Information System through an appropriate interface such as AEGIS+ (Luyten et al. 1994).

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Appendix A
Output Parameters Available

Abbreviation	Explanation	Dimension
DAVTMP	Daily average temperature	°C
DAYL	Day length	hr
DDTMP	Daily average daytime temperature	°C
DVS	Development stage of the crop	-
FGROS	Instantaneous CO_2 assimilation rate of the crop	$g\ CO_2.m^{-2}.hr^{-1}$
NDTUB	Dormant tuber number	$dorm.\ tub.m^{-2}$
NGTUB	Germinating tuber number	$germ.\ tub.m^{-2}$
NNTUB	New tuber number	$new\ tub.m^{-2}$
NT	Initial tuber density	$init.\ tub.m^{-2}$
NTUBD	Dead tuber number	$dead\ tub.m^{-2}$
REMOB	Remobilization rate of carbohydrates	$g\ CH_20.m^{-2}.day^{-1}$
TGW	Total live plant dry weight (excluding tubers)	$g\ DW.m^{-2}$
TGWM	Total live dry weight measured (field site)	$g\ DW.m^{-2}$
TRANS	Translocation rate of carbohydrates	$g\ CH_20.m^{-2}.day^{-1}$
TW	Total live+dead plant dry weight (excluding tubers)	$g\ DW.m^{-2}$
TWLVD	Total dry weight of dead leaves	$g\ DW.m^{-2}$
TWLVG	Total dry weight of green leaves	$g\ DW.m^{-2}$

TWNTUB	Total dry weight of new tubers	g DW.m^{-2}
TWRTG	Total dry weight of live roots	g DW.m^{-2}
TWSO	Total dry weight of storage component	g DW.m^{-2}
TWSTD	Total dry weight of dead stems	g DW.m^{-2}
TWSTG	Total dry weight of live stems	g DW.m^{-2}
TWTUB	Total dry weight of tubers	g DW.m^{-2}

Appendix B
Examples of Data Files

Example of MODEL.DAT file

* Model data file generated by FST translator version 1.15 TEST
*
* contains
* - Initial constants as far as specified with INCOM statements,
* - Model parameters,
* - AFGEN functions,
* - A SCALE array in case of a general translation
*
* File: HYDRIL.FOR
* Date: 06-28-95
* Time: 15:40:06

* Initial constants
* --------------------
```
INTUB   = 0.1    ! Initial dry weight of a tuber (g DW.tuber$^{-1}$)
IWLVD   = 0.     ! Initial dry matter of dead leaves (g DW.m$^{-2}$)
IWLVG   = 0.     ! Initial dry matter of green (live) leaves (g DW.m$^{-2}$)
IWRTD   = 0.     ! Initial dry matter of dead roots (g DW.m$^{-2}$)
IWRTG   = 0.     ! Initial dry matter of live roots (g DW.m$^{-2}$)
IWSO    = 0.     ! Initial dry matter of storage component (g DW.m$^{-2}$)
IWSTD   = 0.     ! Initial dry matter of dead stems (g DW.m$^{-2}$)
IWSTG   = 0.     ! Initial dry matter of live stems (g DW.m$^{-2}$)
NUL     = 0.     ! Zero (0)
REMOB   = 0.0    ! Remobilization rate of carbohydrates (g CH$_2$O.m$^{-2}$.d$^{-1}$)
```

* Model parameters
* ------------------------
```
YRNUM   = 1.        ! Year number simulation (1-5) (y)
AMX     = 0.0158    ! Potential CO$_2$ assimilation rate at light
                    ! saturation of shoot tips (g CO$_2$.g DW$^{-1}$.h$^{-1}$)
```

ASRQSO	= 1.41	! Assim. req. for stor. comp. (g $CH_2O.g\ DW^{-1}$ stor. org.)
CVT	= 1.1	! Conv. factor of translocated dry matter into CH_2O (-)
DAYEM	= 1.	! First julian day number (d)
DEPTH	= 1.0	! Water depth (m)
EE	= 0.000011	! Initial light use efficiency for shoot tips (g $CO_2.J^{-1}$)
HAR	= 0.	! Harvesting (0=no harvesting, 1=harvesting)
HARDAY	= 74.	! Harvesting day number (d)
HARDEP	= 1.0	! Harvesting depth (measured from water surface) (m)
NINTUB	= 7.0	! Tuber no. concur. initiated per plt (co.in.tub.plant^{-1})
NPL	= 35.	! Plant density (plants.m^{-2})
NT	= 500.	! Initial tuber density (initial tubers.m^{-2})
Q10	= 2.	! Factor accounting for increase in maintenance resp. ! with a 10 °C rise in temperature (-)
RC	= 0.06	! Reflection coeff. of irradiation at water surface (-)
RCSHST	= 12.0	! Relation coeff. tuber wt. - stem length (m.g DW^{-1})
RDTU	= 0.36	! Relative death rate of tubers (on number basis) (d^{-1})
REDAM	= 0.581	! Reduction factor to relate AMX to pH and oxygen ! levels of water (-)
ROC	= 0.0576	! Relative conv. rate of tuber into plant mat. ! (g $CH_2O.g\ DW^{-1}.d^{-1}$)
RTR	= 0.4	! Max. rel. tuber growth rate at 20 °C (g DW.tuber$^{-1}.d^{-1}$)
TBASE	= 3.	! Base temperature for juvenile plant growth (°C)
TL	= 0.1	! Thickness per plant layer (m)

* AFGEN functions
* ---------------------
  ! Daytime temperature effect on AMX as function
  ! of DVS (-,-)

AMTMPT =
 -30., 1., 0., 0.00001, 16., 0.53, 20., 0.97, 24., 1., 32., 0.94, 45., 0.86,
50., 0.00001

     ! Fraction of total dry matter increase allocated
     ! to leaves as function of DVS (-,-)
FLVT =
 0., 0.34, 3.5, 0.34, 4.0, 0.34

     ! Fraction of total dry matter increase allocated
     ! to stems as function of DVS (-,-)

FSTT =
0., 0.60, 3.5, 0.60, 4.0, 0.60

! Fraction of total dry matter increase allocated
! to roots as function of DVS (-,-)

FRTT =
0., 0.06, 3.5, 0.06, 4.0, 0.06

! Leaf dry matter allocation to each layer of the
! plant as function of DVS (-,-)

FLT =
0., 0.36, 3.5, 0.36, 4.0, 0.36

! Plant species specific light extinction coefficient
! as function of DVS (m^2.g DW^{-1},-)

KT =
0., 0.01, 3.5, 0.01, 4.0, 0.01

! Water type specific light extinction coefficient
! as function of day number (m^{-1},d)

LT =
0., 0.83, 365., 0.83

! Relative death rate of leaves as function of daily
! average temperature (g DW.g DW.d^{-1}, °C)

RDRT =
0., 0.033, 10., 0.033, 15., 0.033, 30., 0.033, 50., 0.033

! Relative death rate of stems and roots as function
! of daily average temperature (g DW.g DW.d^{-1}, °C)

RDST =
0., 0.033, 10., 0.033, 15., 0.033, 30., 0.033, 50., 0.033

! Reduction factor for AMX to account for senescence
! plant parts over vertical axis of vegetation (relative;-)

REDFT =
0.0, 1.0, 1.0, 1.0, 5.0, 1.0

! Dry matter allocation to each plant layer (relative;-)

DMPCT =
   1.0, .21, 2.0, .21, 3.0, .10, 4.0, .10, 5.0, .09, 6.0, .09

                     ! Daily water temperature as function of day number
                     ! (°C,d)

WTMPT =
   1., 0., 46., 0., 135., 0., 227., 0., 319., 0., 365., 0.

                     ! Initial tuber density measured (field site) as function
                     ! of day number (tubers.m^{-2},d)

NTMT =
   1., 330., 46., 330., 135., 128., 227., 128., 319., 362., 365., 120.

                     ! Total live dry weight measured (field site) as function
                     ! of day number (g DW.m^{-2},d)

TGWMT =
   1., 200., 46., 200., 135., 575., 227., 735., 319., 263., 365., 200.

Example of TIMER.DAT file


```
* Timer file contains
*
*
* - The used DRIVER and TRACE in case of GENERAL translation
* - The TIMER variables used in both translation modes
* - Additional TIMER variables in case of GENERAL translation
* - The WEATHER control variables if weather data are used
* - Miscellaneous FSE variables in case of FSE translation
*
* File:  HYDRIL.FOR
* Date:  06-28-95
* Time:  15:40:06


* TIMER variables used in GENERAL and FSE translation modes
* ----------------------------------------------------------------------------
STTIME    = 1.       ! start time
FINTIM    = 365.     ! finish time
DELT      = 1.       ! time step (for Runge-Kutta first guess)
PRDEL     = 1.       ! output time step
IPFORM    = 4        ! code for output table format:
                     ! 4 = spaces between columns
                     ! 5 = TAB's between columns (spreadsheet output)
                     ! 6 = two column output
```

! The string array PRSEL contains the output variables for which
! formatted tables have to be made. One or more times there is a
! series of variable names terminated by the word <TABLE>.
! The translator writes the variables in each PRINT statement to
! a separate table.

PRSEL =

'DAVTMP',
'DAYL   ',
'DDTMP ',
'DVS   ',
'FGROS ',
'NDTUB ',
'NGTUB ',
'NNTUB ',
'NT   ',
'NTUBD ',
'REMOB ',
'TGW   ',
'TGWM   ',
'TRANS ',
'TW   ',
'TWLVD ',
'TWLVG ',
'TWNTUB',
'TWRTG ',
'TWSO   ',
'TWSTD ',
'TWSTG ',
'TWTUB ',

'<TABLE>'

COPINF	= 'N'	! Switch variable whether to copy the input files ! to the output file ('N' = do not copy, ! 'Y' = copy)
DELTMP	= 'N'	! Switch variable what should be done with the ! temporary output file ('N' = do not delete, ! 'Y' = delete)
IFLAG	= 1101	! Indicates where weather error and warnings ! go (1101 means errors and warnings to log ! file, errors to screen, see FSE manual)
*IOBSD	= 1991,182	! List of observation data for which output is ! required. The list should consist of pairs ! <year>,<day> combination

```
* WEATHER  control  variables
* ------------------------------------
WTRDIR   =   'C:\HYDRILLA\WEATHER\'
CNTR     =   'USA'        ! Country code
ISTN     =   1            ! Station code
IYEAR    =   1980         ! Year
```

Example of RERUNS.DAT file

```
* RERUNS  file  . . .   to produce multiple runs  . . .
*
* File:  Hydril.For
* Date:  06-01-95
* Time:  11:02:00


* RERUNS variables used in GENERAL and FSE translation modes
* ------------------------------------------------------------------
YRNUM    = 2.          ! 2nd year of simulation
HAR      = 1.          ! 1 = YES, harvesting does occur
HARDAY   = 74.         ! Harvesting occurs on Julian Day 74
HARDEP   = 0.5         ! Depth reached by the harvester is 0.5 m
YRNUM    = 3.          ! 3rd year of simulation
HAR      = 1.          ! 1 = YES, harvesting does occur
HARDAY   = 181.        ! Harvesting occurs on Julian Day 181
HARDEP   = 0.5         ! Depth reached by harvester is 0.5 m
```

Example of CONTROL.DAT file

```
* ----------------------------------------------------------------- *
* File names to be used by FSE 2.1                       *
*                                                        *
* The input files  (except FILEIR)  may be used in reruns.  *
* Up to five input data files may be used  (FILEI1-5)    *
* ----------------------------------------------------------------- *

     FILEON  =   'RES.DAT'        ! Normal output file
     FILEOL  =   'MODEL.LOG'      ! Log file
     FILEIR  =   'RERUNS.DAT'     ! Reruns file
     FILEIT  =   'TIMER.DAT'      ! File with timer data
     FILEI1  =   'MODEL.DAT'      ! First input data file

* FILEI2  =  ' '                  ! Second input data file (not used)
* FILEI3  =  ' '                  ! Third input data file (not used)
* FILEI4  =  ' '                  ! Fourth input data file (not used)
* FILEI5  =  ' '                  ! Fifth input data file (not used)
```

Example of a weather data file

```
* Country:    United States of America
* Station:    USGA
* Year:       1980
* Source:     University of Florida at Gainesville, Florida
* Author:     John Doe
* Longitude:  82  22W
* Latitude:   29  38N
* Elevation:  7 m
* Comments:   Missing values are indicated by -99.
*
* Columns:
* =========
* station number
* year
* day
```
* irradiation $(kJ.m^{-2}.d^{-1})$
* minimum temperature (degrees Celsius)
* maximum temperature (degrees Celsius)
* vapor pressure (kPa)
* mean wind speed $(m.s^{-1})$
* precipitation $(mm.d^{-1})$
```
* --------------------------------------------------*
   82.37   29.63   7.   0.00   0.00
```

1	1980	1	8700.	2.8	14.4	0.000	0.0	0.0
1	1980	2	13900.	-1.1	17.2	0.000	0.0	0.0
1	1980	3	13000.	-1.1	18.9	0.000	0.0	0.0
1	1980	4	2000.	5.0	18.9	0.000	0.0	27.9
1	1980	5	13600.	5.0	16.1	0.000	0.0	0.0
1	1980	6	14200.	-2.2	12.2	0.000	0.0	0.0
1	1980	7	13600.	-1.1	20.0	0.000	0.0	0.0
1	1980	8	9100.	5.0	22.8	0.000	0.0	0.0
1	1980	9	6800.	10.6	23.9	0.000	0.0	0.0
1	1980	10	4400.	13.3	22.8	0.000	0.0	0.0
1	1980	11	7300.	12.8	25.0	0.000	0.0	0.0
1	1980	12	2600.	13.3	21.7	0.000	0.0	2.5
1	1980	13	2800.	9.4	13.9	0.000	0.0	35.6
1	1980	14	4200.	10.0	12.8	0.000	0.0	5.6
1	1980	15	13900.	6.7	18.9	0.000	0.0	0.0
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
1	1980	364	2800.	5.6	11.7	0.000	0.0	0.3
1	1980	365	2200.	3.9	18.3	0.000	0.0	0.0
1	1980	366	12500.	1.7	17.8	0.000	0.0	0.0

* NOTE: Longitude and latitude in the header are listed in degrees and minutes while they are listed in degrees only on the first line of the weather data.

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This manual was written as a practical guide for the operational use of HYDRIL (Version 1.0), a personal computer-based software package that simulates the growth of *Hydrilla verticillata*. This manual includes general instructions for installing and using the HYDRIL software package as well as example runs to provide further information to facilitate proper execution and to demonstrate applications.

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