DOCUMENTATION

RMA-11 -- A THREE DIMENSIONAL FINITE ELEMENT MODEL FOR WATER QUALITY IN ESTUARIES AND STREAMS

Version 4.4E

by

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I INTRODUCTION

1.1 Summary

RMA-11 is a finite element water quality model for simulation of three-dimensional estuaries, bays, lakes and rivers. It is also capable of simulating one and two-dimensional approximations to systems either separately or in combined form. It is designed to accept input of velocities and depths, either from an ASCII data file or from binary results files produced by the two-dimensional hydrodynamic model, RMA-2, or the three-dimensional stratified flow model, RMA-10. Results in the form of velocities and depth from the hydrodynamic models are used in the solution of the advection diffusion constituent transport equations. Additional terms for each constituent represent source or sinks and growth or decay.

The governing transport equations are presented in Chapter 2. Chapter 3 presents the governing relations for the water quality parameters implemented in RMA-11. The heat budget equations are given in Chapter 5 and the user instructions in Chapter 6. References are includes as Chapter 7 and two appendices present the formulation used to model the formation of ice and the modifications implemented for the addition of wave driven shears for sand transport.

The model operates independently of the time steps in the hydrodynamic model; input velocities and depths are automatically interpolated.

Constituents that optionally may be represented are:

(a) Temperature with a full atmospheric heat budget at the water surface,
(b) BOD/DO,
(c) The nitrogen cycle (including organic nitrogen, ammonia, nitrite and nitrates)
(d) The phosphorous cycle (including organic phosphorous and phosphates).
(e) Algae growth and decay.
(f) Cohesive suspended sediment.
(g) Non-cohesive suspended sediment such as sand.
(h) Arbitrary conservative or non-conservative constituents that may be linked to each other.
(i) Coliforms with related decay.
(j) Salinity

Each individual constituent is appropriately linked to derive growth and decay based on current concentrations. Additional terms represent benthic and sediment sources and sinks.

A full list of the constituents of the model is presented below

1 - Arbitrary Non-Conservative (up to 5):
2 - BOD:
3 - DO:
4 - Org-N:
5 - NH3:
6 - N02:
7 - NO3:
8 - Org-P:
9 - PO4:
10 - Algae as Chlorophyll a:
11 - Temperature:
12: - Suspended sediment (Cohesive)
13: - Suspended sediment (Non-cohesive - sand)

14: - Salinity
15: - Coliform

Figure 1 shows in chart form the major interactions between the nutrient related constituents. More complete details are presented in Chapter 3 for the constituent properties and in Chapter 4 for the heat budget

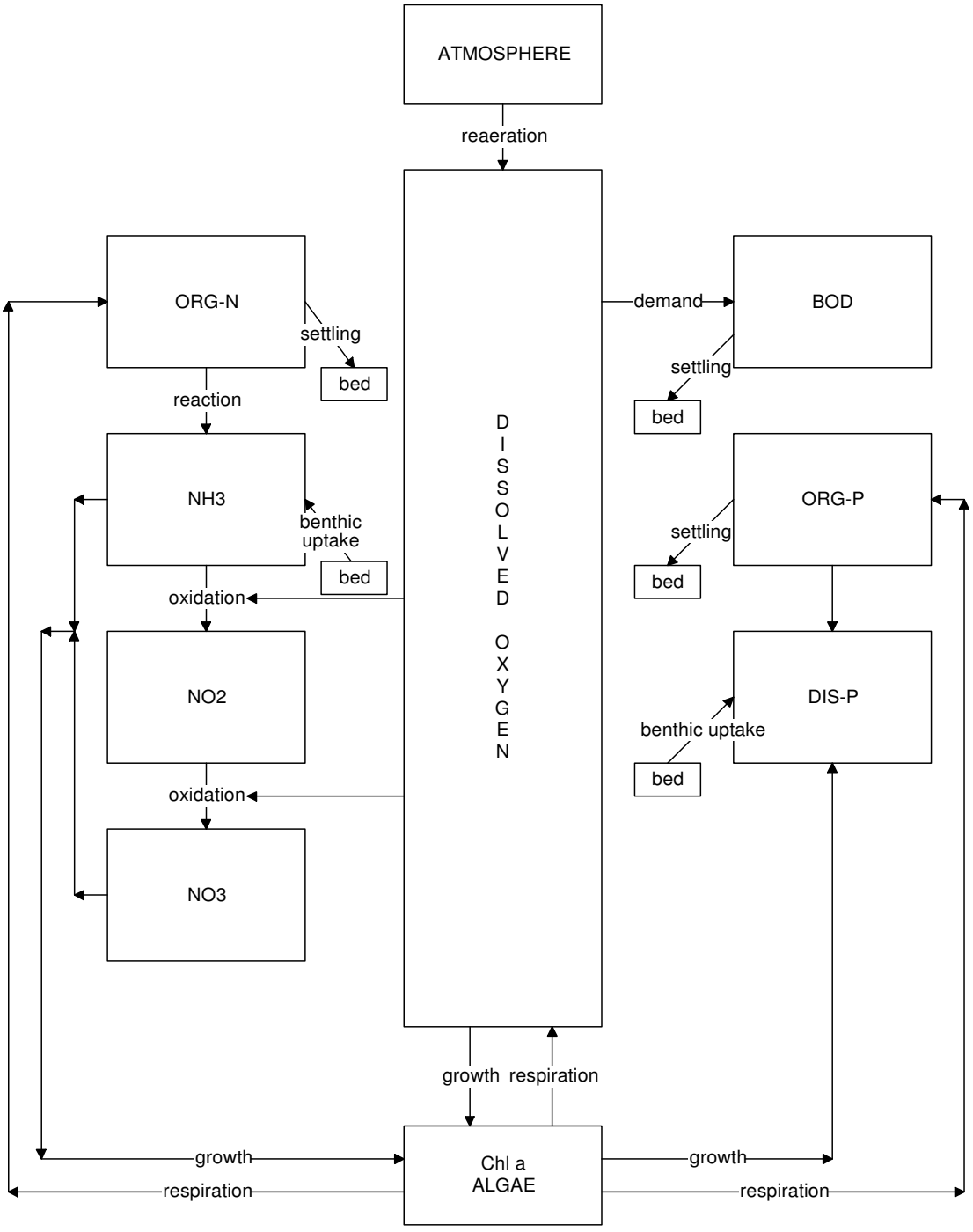

Figure 1 Major Nutrient interactions

RMA-11 has been developed from the earlier two-dimensional transport models, RMA-4Q and RMA-4. The documentation of RMA-4 (King 1994) gives details of basic test cases and methods (limited to one and two-dimensions). The three-dimensional finite element structure is identical to RMA-10, details of the shapes of the finite elements used and basis functions may be found in King (1993). This documentation is designed to present the governing equations, constituent relations and input instructions so that a user can understand and execute the model.

1.2 Current Model Status

This version of RMA-11 represents an ongoing release as features are added. A number of options that are intended for implementation are not yet operational.

- Element elimination and reintroduction due to wetting and drying with the marsh option active. This has been introduced at version 4.2C.
- Element elimination and reintroduction due to wetting and drying. However, see note to version 3.2B
- Introduction of element loads at a single level in three-dimensions. This is now implemented in version 3.2C
- Automatic tracking of concentrations at tidal boundaries for the purpose of reintroducing fractions of pollutants on tide reversal.

As these features are introduced the documentation will be modified to reflect the changes.

Version 4.4e (Dec 2006)
A bug introduced in 4.4d associated with junctions has been corrected. The reordering section of the model has been corrected so that erroneous reordering data (missing or duplicated element numbers are correctly trapped.

Version 4.4d (Oct 2006)
In the Intel Fortran version the model will now terminate completely when the run completes. This thus enables batch running of the model although RMA-11 generated error messages will also cause a normal end.
This version corrects the method for computation of overall mass in the system (the earlier method did not correctly account for mass in the process of erosion from the bed.
A further correction alters the way kinetics and settling/erosion occurs so that it remains active for elements when one node has a water level above the bed. That is when the transition to dry occurs inside an element it remains active kinetically.
Two additional (optional) parameters have been added to the CSS4 data line to permit layer thickness to be defined for all layers by the user and to permit particle erosion from all layers. This latter option is initiated by defining an erosion rate for each layer.
The method for computation of concentrations at control structures has been reviewed. The model has been set so that the concentrations at midside nodes within the control structure are now set to be equal to the upstream nodal concentration at all times and the downstream node concentration is either made equal or independent depending on the flow in the control structure.

Version 4.4c (June 2006)

This version implements a series of updates designed to ensure overall mass conservation when cohesive and non-cohesive sediments are simulated. A new ASCII output file option allows for output of a time series of total suspended sediment and bed sediments so that mass conservation checks are possible. Note that file only records masses in the system and does not account for input loadings or mass leaving/entering the system at flow boundaries.

Version 4.4b (May 2006)
This version corrects several errors in the model that were associated with the transfer to a fully allocated memory storage system.

Version 4.4a (March 2006)
This version corrects an error in the model that can occur when cohesive transport is being simulated. It is in the special case where the lowest bed layer or an "old layer" is exhausted by erosion. The amount of mass released may be inaccurate.

Version 4.4 (Dec 2005)
This version introduces allocatable files for all the main variables of the model. It is no longer necessary recompile for larger size models. Instead the model now computes sizes from the input data for:

- Maximum allowable number of nodes
- Maximum allowable number of elements
- Maximum allowable number of water quality constituents
- Maximum number of time steps
- Maximum number of lines and number of data blocks in the water quality graph file.

At present, for certain cases such as 3-D simulations, the user will be required to input the limits for number of nodes and number of elements. These values may be updated in the LIMITS block of the R11 data input file
For other limiting data values, default values are set that may also be reset in the LIMITS block.

Version 4.3c (Oct 2005)
This version offers more options for pump operation, see the pump data file for details.

Version 4.3b (June 2005)
This version offers reformats scratch files to permit longer simulations with multiple file writes.

Version 4.3a (May 2005)
This version offers a new option for computation of diffusion coefficients based on the Smagorinsky method for computation of the eddy viscosity and the Prandtl Schmidt number for conversion to a diffusion coefficient. Currently this option is only implemented for 2-D depth averaged simulations.

Version 4.3 (Feb 2005)
This version represents a major revision.
1 A series of changes have been implemented to make execution simpler by enabling some allocatable arrays in the FORTRAN logic. For those who wish to use fixed dimension arrays, alternative versions of the source code are supplied. These changes have caused the introduction of a new optional data block at the end of the file FILE block of the R11 file (see Chapter 6 of the user document).

2 A new data format for R4Q files has been established (old R4Q files will still function) so that all data lines in the R4Q file are unique and more readily interpreted in pre-processors.
3 The bed tracking functions for cohesive and non-cohesive simulations have been updated and the model will now (optionally) adjust velocities when the effective water depth is changed by settling/erosion. The model will also save a 2-D geometry file with the updated bed elevation for use in geomorphological simulations.
4 An additional option has been added to the coliform formulation that allows direct use of a T90 for sunlight. See Chapter 3 for more information.
5 Bugs associated with global rainfall inflows have been fixed.

Version 4.2C (Jan 2005)

This revision updates RMA-11 to make it consistent with updates to RMA-2 with regard to dropping out of elements when the "marshing" opton is used. The definition of IDRPT has been updated on the C3 data line.

PLEASE NOTE THAT THIS OPTION WILL ONLY FUNCTION CORRECTLY AT PRESENT WHEN RMA-2 RESULTS ARE SAVED IN SMS FORMAT.

To read in RMA-2 results files the VELSMSFL option in the file structure has been documented.

A second set of revisions updates the handling of meteorologic files to permit input of solar radiation data and allow input of dew point in pace of wet bulb temperatures.

This version has been updated to incorporate consistent treatment of type 999 elements that may have been used in RMA-2.

Finally, a series of bugs when handling shear-stress and erosion in 3-D applications have been corrected.

Version 4.2B (July 2004)

This revision updates RMA-11 to make it consistent with updates to RMA-2 with regard to 1-D elements. It adds the element exclusion option for cross-section interpolation and add to a new option on the R4Q file that allows the user to specify a maximum change limit that will stop the program when a nodal change exceeds the preset amount.

Version 4.2a (Jan 2004)

An optional output has been added that allows computed diffusion coefficients to be saved to a file. This option allows up to 18 elements to be defined and will save a typical value for each element for each time step. This option is limited to 1-D/2-D elements.

Version 4.2 (Nov 2003)

This version of RMA-11 expands the capability to permit more general cross-sections to input for 1-D elements now available in RMA (Version 7.3). A new input option causes the model to expect a file containing cross-section data. This cross-section data may be defined at a series of cross-section locations that do not correspond to any of the nodal locations. A series of weighting parameters are then required for interpolation of the cross-sections to the 1-D nodes. Cross-sections are input as area/surface width data for a series of elevations. RMA-11 assumes the lowest elevation in each set is the bed elevation. The input instructions have been amended to show input formats required for the cross-section file. see section 6.9.

A new pumping control input option has been added that permits flows into and out of elements to be linked depending elevation at a control node. Multiple pumps are allowed and flows and levels are input from a separate file, see section 6.10.

Version 4.1 (Mar 2003)

This version of RMA-11 expands the overall capability of RMA-11 to add components that form the bed. The options are currently limited to an attached algae species that takes nutrients from the water column and limited species of Nitrogen and Phosphorous. The user is referred to the revised Chapter 3 for more details of the changes and Chapter 6 for changes to the input data.

A second addition to the model revised the treatment of sand transport with the object of making transport rates indepenedent of time step once again the user is referred to the revised Chapter 3 for more details and Chapter 6 for changes to the input data.

Version 4.0A (Jan 2003)

This minor revision has been designed to allow the user to specify benthos source rates for organic nitrogen and BOD, reflecting conditions that might be expected in the vicinity of mangrove swamps. Additional data values are required on the data lines for the element type based input for organic nitrogen and BOD in the R4Q file. A time overlay option has been added to the input stream (see IOV) to allow users to over-write times on hotstart files.

Version 4.0 (June 2002)

- This revision has been designed to update the usability of RMA-11 to reflect the growing need for more digits in nodal coordinates and to allow for the potential development of over 32,768 equations. The limit of 32,768 nodes was originally created the use of a number of INTEGER*2 arrays (to save memory space at a time of much smaller computers) for storage of cross-reference information on nodal numbers. Version 7.0 changes the relevant INTEGER*2 arrays to INTEGER*4 arrays. The coordinate array is now stored in double precision thus permitting up to 16 digits in coordinate definition. RMA-11 has been modified to allow input of geometry files either from old format GEO files or from a newly developed format output by version 7.0 of RMAGEN.
- A second set of major changes has been the addition of a sand transport option for wave and current transport that uses the logic of the 1993 program in Van Rijn (1993). The options for surface roughness have also been expanded so that the user may input wave and current roughness by element type number.
- The input by element type has been expanded so that user can define multiple element types at the beginning of each set, thus reducing data input in the R4Q file.
- The user may now input geometry and velocity results files in SMS compatible “BIN” and “SOL” format and output results in “QSL” format for display using SMS.

Version 3.2C (Jan 2002)

This revision incorporates a number of changes designed to allow element loading in 3-D elements to translate to loading in 2-D elements when the COL option is used and active. This version also tracks missing nodes in a more consistent manner. Loads are now applied consistently to all or selected layers in a 3-D network.

Version 3.2B (Oct 2001)

This release incorporates a number of changes designed to improve performance when wetting and drying is active in 3-D applications. Roundoff errors have been detected when the 3-D system becomes very shallow; as a consequence the COL

option of RMA-10 has now been fully implemented in RMA-11. This required two steps by the user:

1 Add a type COL line that defines the transition elevation
2 Save the RMA-10 results using OUTBNRMA. This is required to correctly transmit the water surface elevation.

Note, these changes do not affect applications that derive results files form RMA-2.

Version 3.2A[1] (July 2001)

This revision incorporates a number of features:

1 An additional transport option for non-cohesive sediment
2 The settling formulation for both cohesive and non-cohesive sediment has been modified so that the settled bed is represented by a linear function. In other words, the settling and erosion rates are only computed at corner nodes.
3 Because RMA-2 and RMA-10 can pass values of water surface elevation that are below the bed level (when the marsh option is turned on), RMA-11 has been modified so that chemical and thermal kinetics are diabled for these locations.

Version 2.6(h) (July 2001)

This revision implements two changes, to simplify execution:

1. The Compaq version of the model can now be executed via a shortcut on the desktop and on completion the DOS window will remain open.
2. The Compaq version of the model has been modified to recognise the path of the input r10 file and switch directories appropriately.

Version 2.6(g) (May 2001)

1. Implementation of alternate input of continuity lines directly in the binary geo files from RMAGEN
2. Allow for expansion of RMA-2 results to 3-D with no distribution and compute vertical velocities
3. Correct bug to permit input of *.rma results files

Version 2.6(f) (Feb 2001).

This revision incorporates:

1 The ability to input continuity lines from the geometry file (using version 6.0 of RMAGEN) has been added.
2 Addition of computation of vertical velocities when expanding 2-D results to 3-D.
3 Correction to volume calculation for 2-D lateral element loads
4 Changes to output format to separate an echo check file form the main output and to allow rewinding of the output file to reduce output volume.
5 Addition of type RMA results and velocity input files.

Version 2.6(e) (Sep 2000). Incorporates:

1 Improved error messages
2 An additional diffusion option

Version 2.6(d) (Mar 2000). Incorporates:

1 Reduction of kinetics to zero for drying elements
2 Refined treatment of linear distribution of settling for 2-d and 3-d sand and clay

[1]Note that version numbers 2.7 to 3.1 have been skipped

3 Additional logic for 1-D overbank elements

Version 2.6(c) (May 1999). Incorporates:
1 Linear function for distribution of 2-d sand settling
2 Testing for blank leading characters in file names

Version 2.6(b) (Mar 1999). Incorporates:
1 Changes to permit input of solar radiation in met data.
2 Addition of year

Version 2.6(a) incorporates
1 Changes to permit computation of ice formation at the water surface. A new routine ICETHK has been added. The formulation is documented in Appendix A

Version 2.6 (April 1998) Incorporates
1. Changes to permit wind wave shear in cohesive sediment simulation.
2. Restructured tracking of bedforms in cohesive sediment simulation.
3. Changes to permit tracking of outgoing mass so that return flow concentrations can be adjusted. This approach treats the specified concentration as background level.

Version 2.5 (April 1997) Incorporates:
1. Changes to aspects of the cohesive sediment routines to permit settling based on existing concentrations.
2. Cleanup of the file output for easier reading.
3. Changes to input of the main data file to allow line beginning with COM, com or left blank to be treated as comments.
4. Changes to file formats to allow pure binary file operations,

Version 2.4 (Aug. 1996) permits automatic sensing of incoming and outgoing tides or flows so that boundary conditions are only applied when flow is into the system. The tracking of scratch files has also been improved to permit more effective deletion during execution.

Version 2.3 (June 1996) This version represents the updates designed to add coliforms, and more files for later display. Changes have been made to add more options for diffusion coefficients and alternate element loading conditions. Changes to numerous routines have been made as a result.

Version 2.2 (Nov. 1995) represents a change in approach to input of file data. All files except the main *.R11 file are now defined in the *.R11 file. This permits easier file definition and reduces likelihood of error. A second change has added the year of simulation to simplify long term simulation data preparation.

Version 2.1 (Nov. 1995) represents a change in approach to time keeping. The model now references all time to Julian days and hours of the year. Data is now set up on graph files to include days and hours and results are reported in the same format. This version also includes a series of changes to make it easier to prepare data for the model. The format of the input quality graph file has been changed to conform to the current system of labelling data lines. A meteorologic data file has been introduced to allow easier organization of the data input. The MMET switch on data line type C1 is no longer required. The model requests a name for the met file. If no name is given, it assumed that the meteorologic data (if required) is on the input

water quality file as with earlier versions. For further information of the necessary formats, see Chapter 6 of the guide. An additional change, new with this version permits the user to define special nodes for time series ASCII output of selected water quality parameters. The frequency and starting time for this output is entered as data on control line C3.

Version 2.0 (Sept. 1995) was designated to reflect a change in the output binary results file format to include velocities. This change has been made to conform to new capabilities for results display in RMAPLT.

1.3 Associated Programs

RMAGEN is a pre-processor graphics module designed for preparation and editing of finite element geometric networks. It may be used to prepare the input geometry files for RMA-11

RMA11PR is a pre-processor graphics module designed for preparation and editing of the main input data file used in RMA-11.

RMA4QPR is a pre-processor graphics module designed for preparation and editing of the water quality parameter input data file used in RMA-11.

RMAPLT is graphics module that may be used to examine the binary results file generated by RMA-11. It is capable of presenting contour plots of concentrations, and time history and section plots.

RMA-2 is a two-dimensional finite element model for simulation of the hydrodynamics of estuaries and streams that may be used to generate input velocity and depth files for RMA-11.

RMA-10 is a three-dimensional finite element model for simulation of the stratified flow in estuaries and streams that may be used to generate input velocity and depth files for RMA-11.

CONVRM4 and CONVRM4Q are utilities that may be used to convert input files for RMA4Q to RMA-11 format.