ADCIRC - Version 30.02

Methodologies and Input/Output Requirements for Enhanced Provisions for Flow Entering and Exiting the Computational Domain

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A Brief Report Describing Products 1 & 2 with Accompanying Software Delivered to the
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1. Summary

ADCIRC Version 30.02 has been delivered electronically together with 6 sets of example input files. This version of the code includes the modifications described in TASK 1 and TASK 2 of the proposal entitled "The Implementation of External and Internal Discharge Conditions and Constrictions Into ADCIRC." Version 30.02 of the code now allows for user specified flow inflow and/or outflow from external boundaries, external barrier flow boundaries which act as weirs which can be overtopped as well as internal barrier flow boundaries which act as weirs which can be overtopped. This brief report describes the basic methodologies used, the input/output changes in the code and the six example cases included in the delivery.

2. Basic Methodology

Modifications have been made in ADCIRC version 30.02 to allow for a wide range of flow type boundary condition implementations. The standard no normal flow specified boundary condition of earlier versions of the code has been expanded to include the following implementations:

(a) Essential No Normal Flow on External Boundaries with Free Tangential Slip Allowed: In this case the portion of the boundary integral in the Generalized Wave Continuity Equation (GWCE) corresponding to the specified no normal flow external boundaries is set equal to zero. Furthermore the normal direction velocity component at the no flow external boundary nodes is set equal to zero in the momentum equations by eliminating the normal direction momentum equation (obtained after re-orienting the x-y momentum equations into n-t (normal-tangential) directions) and replacing this momentum equation with the boundary condition $u_n^* = 0$. The tangential direction momentum equation at no normal flow external boundary nodes is not modified allowing for free tangential slip. This procedure results in model predicted normal velocities and flows on no normal flow external boundaries exactly equaling zero.

(b) Essential No Normal Flow on External Boundaries with No Tangential Slip Enforced: In this case the portion of the boundary integral in the GWCE corresponding to the specified no normal flow external boundaries is again set equal to zero. Furthermore the normal direction velocity component at the no flow external boundary nodes is again set equal to zero in the momentum equations by eliminating the normal direction momentum equation (obtained after re-orienting the x-y momentum equations into n-t directions) and replacing this momentum equation with the boundary condition $u_n^* = 0$. The tangential direction momentum equation at no normal flow external boundary nodes is replaced by $u_t^* = 0$ resulting in zero tangential velocity components (i.e. no slip) at these nodes. This procedure results in model predicted normal velocities and flows on no normal flow external boundaries exactly equaling zero in addition to no tangential velocity components on these boundaries. We note that strictly speaking, the no slip boundary condition is only mathematically justifiable if lateral viscous terms are used in the simulation and only physically justifiable if the lateral boundary layer is resolved with a sufficient level of grid resolution.

(c) Natural No Normal Flow on External Boundaries with Free Tangential Slip Allowed: In this case the portion of the boundary integral in the GWCE corresponding to the specified no normal flow external boundaries is again set equal to zero. However, the momentum equations at no normal flow external boundary nodes are not modified with any specified normal and/or tangential velocities. This procedure results in model predicted normal flows on no normal flow external boundaries approximately but not exactly equaling to zero in addition to free tangential velocity components on these boundaries. We do note that the residual normal flow on the boundary is consistent with the interior domain flow errors and is therefore not of concern! In fact, normal flows on the no normal flow external boundaries are exactly equal to zero in the limit as grid size becomes very small.

(d) Essential No Normal Flow on Internal Boundaries with Free Tangential Slip Allowed: In this case the portion of the boundary integral in the GWCE corresponding to the specified internal boundaries is set equal to zero. Furthermore, the normal direction velocity component at the no flow internal boundary nodes is set equal to zero in the momentum equations by eliminating the normal direction momentum equation (obtained after re-orienting the *x-y* momentum equations into *n-t* directions) and replacing this momentum equation with the boundary condition $u_n^* = 0$. The tangential direction momentum equation at no normal flow internal boundary nodes is not modified allowing for free tangential slip. This procedure results in model predicted normal velocities and flows on no normal flow internal boundaries exactly equaling zero.

(e) Essential No Normal Flow on Internal Boundaries with No Tangential Slip Enforced: In this case the portion of the boundary integral in the GWCE corresponding to the specified no normal flow internal boundaries is again set equal to zero. Furthermore the normal direction velocity component at the no flow internal boundary nodes is again set equal to zero in the momentum equations by eliminating the normal direction momentum equation (obtained after re-orienting the *x-y* momentum equations into *n-t* directions) and replacing this momentum equation with the boundary condition $u_n^* = 0$ The tangential direction momentum equation at no normal flow internal boundary nodes is replaced by $u_t^* = 0$ resulting in no tangential velocity components at these nodes. This procedure results in model predicted normal velocities and flows on no normal flow internal boundaries exactly equaling zero in addition to no tangential velocity components at these boundary nodes Again, we note that strictly speaking, this type of boundary condition is only mathematically justifiable if lateral viscous terms are used in the simulation and only physically justifiable if the lateral boundary layer is resolved with a sufficient level of grid resolution.

(f) Natural No Normal Flow on Internal Boundaries with Free Tangential Slip Allowed: In this case the portion of the boundary integral in the GWCE corresponding to the specified no normal flow internal boundaries is again set equal to zero However, the momentum equations at no normal flow internal boundary nodes are not modified with any specified normal and/or tangential velocities This procedure results in model predicted normal flows on no normal flow internal boundaries approximately but not exactly equaling to zero in addition to free tangential velocity components on these boundaries. Normal flows on the no normal flow internal boundaries are exactly equal to zero in the limit as grid size becomes very small

ADCIRC version 30.02 also incorporates the ability for the user to specify non-zero normal flow boundary conditions on external boundaries. This feature is most useful in specifying riverine or other type discharge outflows although it can also be used to specify the interaction between adjacent basins on open ocean boundaries if flows on the open ocean boundary are known or can be estimated. The specified normal flow external boundary conditions include the following implementations:

(g) <u>Essential Specified Normal Flow on External Boundaries with Free Tangential Slip Allowed:</u> In this case the portion of the boundary integral in the GWCE corresponding to the specified normal flow external boundaries is evaluated using the user specified values of normal flow at the corresponding nodes. The user specified normal flow, Q_n^*, is assumed to vary linearly between nodes on each specified normal flow external boundary segment when the flow integral in the GWCE is computed. Furthermore, the normal direction velocity component at specified normal flow external boundary nodes is set equal to the user specified normal velocity value by eliminating the normal direction momentum equation (obtained after re-orienting the x-y momentum equations into n-t directions) and replacing this momentum equation with the modified boundary condition:

$$u_n^* = Q_n^*/(\zeta + h) \qquad (1)$$

where

u_n^* = Normal direction velocity to the boundary at a specified normal flow external boundary node

Q_n^* = User specified normal direction flow component at a specified normal flow external boundary node

ζ = Free surface water elevation relative to the geoid

h = Depth of water relative to the geoid

The tangential direction momentum equation at no normal flow external boundary nodes is not modified allowing for free tangential slip. This procedure results in model predicted normal velocities and flows on specified normal flow external boundaries exactly matching user specified values.

(h) <u>Essential Specified Normal Flow on External Boundaries with No Tangential Slip Enforced:</u> In this case the portion of the boundary integral in the GWCE corresponding to the specified normal flow external boundaries is again evaluated using the user specified values of normal flow at the corresponding nodes. The user specified normal flow, Q_n^*, is assumed to vary linearly between nodes on each specified normal flow external boundary segment when the flow integral in the GWCE is computed. Furthermore the normal direction velocity component at the specified normal flow external boundary nodes is set equal to the user specified normal velocity values by eliminating the normal direction momentum equation (obtained after re-orienting the *x-y* momentum equations into *n-t* directions) and replacing this momentum equation with the modified boundary condition, Equation (1). The tangential direction momentum equation at specified normal flow external boundary nodes is replaced by $u_t^* = 0$ resulting in no tangential velocity components at these nodes. This procedure results in model predicted normal velocities and flows on specified normal flow external boundaries exactly matching user specified values in addition to no tangential velocity components on these boundaries. Again care must be taken when using the no slip feature that this is indeed a reasonable boundary condition.

(i) <u>Natural Specified Normal Flow on External Boundaries with Free Tangential Slip Allowed:</u> In this case the portion of the boundary integral in the GWCE corresponding to the specified normal flow external boundaries is again evaluated using the user specified and linearly interpolated values of normal flow at the corresponding nodes. However, the momentum equations at specified normal flow external boundary nodes are not modified with any specified normal and/or tangential velocities. This procedure results in model predicted normal flows on specified normal flow external boundaries approximately but not exactly equaling the user specified values in addition to free tangential velocity components on these boundaries. Normal flows on the specified normal flow external boundaries will match user specified values in the limit as grid size becomes very small.

ADCIRC version 30.02 also incorporates the ability for the user to specify external barrier type boundaries which, when overtopped, discharge flow out of the computational domain. The basic assumption is that when a specified external barrier boundary section overtops, free surface supercritical outflow occurs and is computed as:

$$\text{For } \zeta \leq h_b \quad \Rightarrow \quad Q_n^{**} = 0 \tag{2a}$$

$$\text{For } \zeta > h_b \quad \Rightarrow \quad Q_n^{**} = -\frac{2}{3}\, C_R\, \mu\, (\zeta - h_b)\left[\frac{2}{3}\, g(\zeta - h_b)\right]^{\frac{1}{2}} \tag{2b}$$

where

Q_n^{**} = Normal outflow per unit width on the external barrier segment

ζ = Free surface elevation relative to the geoid

h_b = Height of the barrier above the geoid

C_R = Ramp coefficient used for all forcing functions in ADCIRC

μ = Coefficient of free surface flow; This coefficient varies with the shape of the external barrier flow boundary (typical value =1.0)

g = Acceleration due to gravity

This formula is given by Leendertse (***Aspects of SIMSYS2D - A System for Two-Dimensional Flow Computation***, RAND/R-3572-USGS, 1987) and is simply the formula for a broad crested weir (e.g. see Henderson, ***Open Channel Flow***, Section 6.6) The computed normal outflow has been implemented within the framework of normal flow boundary conditions and it is possible to specify:

(j) Essential Normal External Barrier Flow Boundary with Free Tangential Slip Allowed:

In this case the portion of the boundary integral in the GWCE corresponding to the external barrier boundaries is evaluated using the calculated nodal values of Q_n^{**}. Nodal values of Q_n^{**} are calculated using Equations (2a) and (2b) at each external barrier boundary node based on the nodal values of the variable ζ and the nodal input values of h_b and μ. Q_n^{**} is assumed to vary linearly between nodes on each external barrier boundary segment when the flow integral in the GWCE is computed. Furthermore the normal direction velocity component is computed as:

$$u_n^* = \frac{Q_n^{**}}{(\zeta + h)} \tag{3}$$

where

u_n^* = Normal direction velocity to the boundary at a external barrier boundary node

h = Depth of water relative to the geoid

and is enforced in the momentum equations by eliminating the normal direction momentum equations at the external barrier boundary nodes (obtained after re-orienting the *x-y* momentum equations into *n-t* directions) and replacing these with Equation (3). The tangential direction momentum equation at external barrier boundary nodes is not modified allowing for free tangential slip. This procedure does result in model predicted normal flows (computed with the predicted nodal velocities and elevations using $Q_n = u_n(\zeta + h)$) on external barrier boundaries exactly matching the value of Q_n^{**} as computed by the broad crested weir formula, Equations (2a) and (2b).

(k) <u>Essential Normal External Barrier Flow Boundary with No Tangential Slip Enforced:</u> In this case the portion of the boundary integral in the GWCE corresponding to the external barrier boundaries is again evaluated using the calculated nodal values of Q_n^{**}. Nodal values of Q_n^{**} are calculated using Equations (2a) and (2b) at each external barrier boundary node based on the nodal values of the variable ζ and the nodal input values of h_b and μ. Q_n^{**} is assumed to vary linearly between nodes on each external barrier boundary segment when the flow integral in the GWCE is computed. Furthermore the normal direction velocity component u_n^*, computed using Equation (3), is enforced in the momentum equations by replacing the normal direction momentum equation at the external barrier boundary nodes (obtained after re-orienting the *x-y* momentum equations into *n-t* directions). The tangential direction momentum equation at external barrier boundary nodes is set to zero resulting in no tangential velocity components at external barrier boundary nodes. This procedure does result in model predicted normal flows on external barrier boundaries exactly matching the value of Q_n^{**} as computed by the broad crested weir formula, Equations (2a) and (2b), in addition to no tangential velocity components at external barrier boundaries. Again caution must be exercised in implementing any no tangential slip type boundary condition.

(l) Natural Normal External Barrier Flow Boundary with Free Tangential Slip Allowed: In this case the portion of the boundary integral in the GWCE corresponding to the external barrier boundaries is again evaluated using the calculated nodal values of Q_n^{**}. Nodal values of Q_n^{**} are computed using Equations (2a) and (2b) at each external barrier boundary node based on the nodal values of the variable ζ and the nodal input values of h_b and μ. Q_n^{**} is assumed to vary linearly between nodes on each external barrier boundary segment when the flow integral in the GWCE is computed. In this case the momentum equations at boundary nodes are not modified with any specified normal and/or tangential velocities. This procedure results in model predicted normal flows on external barrier boundaries approximately matching the value of Q_n^{**} as computed by the broad crested weir formula, Equations (2a) and (2b) in addition to free tangential velocity components at external barrier boundaries. Normal flows on external barrier boundaries exactly match the value of Q_n^{**} as computed by the broad crested weir formula in the limit as grid size becomes very small.

3. Changes in Input Requirements and Output Files

The modifications made in ADCIRC to allow for the wider range of flow type boundary conditions including specified normal flow external boundaries as well as overtopping external barrier flow boundaries are set up such that version 30.02 is fully backward compatible with input files from previous versions (up to version 24.16) assuming that no specified normal flow external boundaries and/or no external barriers boundaries are being considered. If specified normal flow external boundaries and/or external barrier flow boundaries are being considered, the UNIT 14 and 15 input files must be modified as follows:

(a) UNIT 14 Input File: No Normal flow external boundary segments are specified as flow boundary segments in the same way as in previous versions except that the boundary type, ***IBTYPE***, is now designated equal to either 0, 10 or 20 depending on the exact treatment desired for these boundary segments:

IBTYPE = 0: Essential No Normal Flow on External Boundaries with Free Tangential Slip Allowed

IBTYPE = 10: Essential No Normal Flow on External Boundaries with No Tangential Slip Enforced

IBTYPE = 20: Natural No Normal Flow on External Boundaries with Free Tangential Slip Allowed

No Normal flow internal boundary segments are specified as internal boundary segments in the same way as in previous versions except that the boundary type, ***IBTYPE***, is now designated equal to either 1, 11 or 21 depending on the exact treatment desired for these boundary segments:

IBTYPE = 1: Essential No Normal Flow on Internal Boundaries with Free Tangential Slip Allowed

IBTYPE = 11: Essential No Normal Flow on Internal Boundaries with No

Tangential Slip Enforced

IBTYPE = 21: Natural No Normal Flow on Internal Boundaries with Free Tangential Slip Allowed

Specified Normal flow external boundary segments are defined as flow boundary segments with boundary type, ***IBTYPE***, designated equal to either 2, 12 or 22 depending on the exact treatment desired for these boundary segments:

IBTYPE = 2: Essential Specified Normal Flow on External Boundaries with Free Tangential Slip Allowed

IBTYPE = 12: Essential Specified Normal Flow on External Boundaries with No Tangential Slip Enforced

IBTYPE = 22: Natural Specified Normal Flow on External Boundaries with Free Tangential Slip Allowed

External barrier flow boundary segments are specified as flow boundary segments with boundary type, ***IBTYPE***, designated equal to either 3, 13 or 23 depending on the exact treatment desired for the external barrier boundaries:

IBTYPE = 3: Essential Normal External Barrier Flow Boundary with Free Tangential Slip Allowed

IBTYPE = 13: Essential Normal External Barrier Flow Boundary with No Tangential Slip Enforced

IBTYPE = 23: Natural Normal External Barrier Flow Boundary with Free Tangential Slip Allowed

(b) <u>UNIT 15 Input File</u>: If either specified normal flow on external boundaries or external barrier flow boundary segments are defined in the UNIT 14 input file, the UNIT 15 input file will require additional input information Specified normal flow on external boundary information can either be defined as a periodic function constructed using Fourier synthesis (in a similar way that surface elevation is forced on elevation boundaries) or this information can be defined as non-periodic and input in time history form from UNIT 20. If any specified normal flow on external boundaries exist in the UNIT 14 input file (i.e. ***IBTYPE*** = 2, 12 or 22), we must input:

NFFR = The number of forcing frequencies on specified normal flow external boundaries in case we wish to input specified normal external boundary flow as a periodic function. In case we want to input the specified normal flows in time history form we set ***NFFR*** = 0.

If ***NFFR*** > 0, specified normal external flow information will be periodic and synthesized from the following information:

FBOUNTAG(I); I = 1, NFFR = An alphanumeric descriptor (i.e., the constituent name) that precedes ***FAMIG(I), FFF(I), FFACE(I)*** for each of the ***NFFR*** constituents forced on the specified normal flow external boundaries. ***FBOUNTAG(I)*** is simply specified in order for the user to identify constituents in this input file as well as the UNIT 16 output file. It is read in using an A10 format.

FAMIG(I), FFF(I), FFACE(I); I=1, NFFR = The specified normal flow external boundary forcing frequency, the nodal factor and equilibrium argument (in degrees) for constituents forced on the specified normal flow external boundary. The specified normal flow external boundary forcing function is determined at corresponding boundary nodes as:

$$Q_n^{**}(x, y, t) = \sum_i^{NFFR} A_i^{SNFB}(x, y)\, f_i^{SNFB}(t_0) \times$$

$$\cos[2\pi(t - t_0)/T_i^{SNFB} + v_i^{SNFB}(t_0) - \Psi_i^{SNFB}(x, y)] \qquad (4)$$

The frequency of each constituent included in the specified normal flow external boundary forcing function, ***FAMIG(I)***, is calculated as $2\pi/T_i^{SNFB}$ where T_i^{SNFB} equals the specified normal flow external boundary forcing period (in seconds) for the i^{th} constituent. In general, it is very important to specify frequencies precisely, at least to eight significant figures. Furthermore, if the same constituents are forced in the tidal potential and/or elevation boundary forcing functions, the values of the common frequencies should be identical to those specified for the tidal potential and/or elevation boundary forcing functions The nodal factor and equilibrium argument, ***FFF(I)*** and ***FFACE(I)*** ($f_i^{SNFB}(t_0)$ and $v_i^{SNFB}(t_0)$ respectively), are computed based on the actual time and date that ***REFTIM*** represents (note that ***REFTIM***=t_0). Guidelines as to how to compute f_i^{SNFB} and v_i^{SNFB} are given by Schureman (1941) and Foreman (1977). If equilibrium tides are directly computed, f_i^{SNFB} and v_i^{SNFB} should be specified as 1.0 and 0.0 for all constituents (although care must be used in the harmonic analysis of the response to ensure that all nodal factors and equilibrium arguments are specified equal to 1.0 and 0.0, respectively). Again, the specification of f_i^{SNFB} and v_i^{SNFB} should be consistent with values specified for boundary forcing constituents when identical forcing frequencies appear in both the tidal potential and/or elevation boundary forcing functions. Other terms in Equation 4 are specified in this input file. ***REFTIM***=t_0 has already been specified and the amplitudes of each of the constituents A_i^{SNFB} as well as their phases Ψ_i^{SNFB} are specified next in the UNIT 15 input file for each of the nodes identified as specified normal flow external boundary nodes in the UNIT 14 input file.

FALPHA = An alphanumeric identifier that precedes each of the ***NFFR*** sets of amplitudes and phases, ***QNAM(I,J), QNPH(I,J); J=1, NFLBN***, at the specified normal flow external boundary nodes for each specified forcing frequency. ***FALPHA*** is simply included in order for the user to identify constituents in this input file as well as the UNIT 16 output file. Both ***FBOUNTAG(I)*** and ***FALPHA*** are printed out with the nodal amplitudes and phases in the UNIT 16 output file, enabling the user to ensure that the amplitudes and phases were read in in the correct sequence. ***FALPHA*** is read in using an A10 format.

QNAM(I,J), QNPH(I,J); J=1, NFLBN; I=1, NFFR = The amplitudes, A_i^{SNFB}, and phases (in degrees), Ψ_i^{SNFB}, of the harmonic forcing function for normal flow per unit width given in Equation 4 at the ***J=1, NFLBN*** specified normal flow external boundary nodes for frequency ***I***. The variable ***NFLBN*** is defined and read in from the UNIT 14 input. **These amplitudes and phases represent the equilibrium tidal constituents.** This information is input sequentially in the same order as the specified normal flow external boundary nodes appear in the UNIT 14 input file. The amplitudes must be read in with units which are consistent with the specified ***G***, i.e., typically meters^2/second or feet^2/second. Furthermore, the phases must be read in in degrees relative to Greenwich Mean Time if time refers to GMT.

If ***NFFR*** is specified equal to zero, then the specified normal flow is assumed to be non-periodic and we input only:

FTIMINC = the time increment (in seconds) at which specified normal external boundary flow information is read in from the UNIT 20 file.

If any normal external barrier flow boundaries are specified in the UNIT 14 input file (***IBTYPE*** = 3, 13 and/or 23), we require the specification of

BARLANHT(J) = h_b = the height of the barrier above the geoid and

BARLANCF(J) = μ = the coefficient of free surface flow (typical value =1.0)

at all external barrier boundary nodes. This information is input sequentially in the same order as the external barrier boundary nodes appear in the UNIT 14 input file. Finally, we note that normal flows at either specified normal flow external boundary nodes or external barrier boundary nodes can be tracked using the specified UNIT 61 and 62 station output file features with appropriately specified coordinates.

(c) UNIT 20 Input File: If ***NFFR*** is specified equal to zero in the UNIT 15 input file, we must provide the following information in the UNIT 20 input file.

QNIN(I) I=1, NFLBN = Specified normal flow information at appropriate nodes read in starting at ***TIME*** = ***STATIM*** and provided every ***FTIMINC*** seconds.

All specified normal flow external boundary and external barrier flow boundary information is output to the UNIT 16 output file with additional detailed boundary segment information.

All input and output requirements and/or changes are thoroughly described in the header of ADCIRC version 30.02. Finally we note that the set up program has also been modified to work with ADCIRC version 30.02. The matching version, ADSETUP Version 30.02, is also backward compatible up to version 24.16 input files. Changes in ADSETUP Version 30.02 are transparent to the user.

4. Sample Input Files

Three example input files have been included with the PRODUCT 1 deliveries. These example problems illustrate the modified capabilities of ADCIRC Version 30.02 and consist of:

(a) Example 3c grid (UNIT 14) and input (UNIT 15) files This periodic (T= 1.45 days) example considers a quarter annular domain with bathymetry varying between 0.5 ft. and 12 ft. below the geoid. The outer boundary is specified as an elevation specified boundary for which elevation amplitude eventually ramps up to 2.0 ft For the dynamic steady state, water periodically propagates in toward the inner annulus while wetting the inner portions of the domain as water level rises The inner boundary is specified as a external barrier flow boundary with a specified barrier boundary height equal to 0.5 ft. above the geoid. When this external barrier boundary is overtopped, flow leaves the domain in an appropriate fashion. As water recedes, flow over the inner external barrier boundary eventually stops and furthermore element drying occurs.

(b) Example 4c grid (UNIT 14) and input (UNIT 15) files. This steady state example considers a quarter annular domain with bathymetry varying between 0.5 ft. above the geoid and 12 ft. below the geoid. The outer boundary is specified as an elevation specified boundary for which elevation steadily ramps up to 2.0 ft. Water propagates in toward the inner annulus while wetting the inner portions of the domain as water level rises The inner boundary is specified as a external barrier flow boundary with a specified barrier boundary height equal to 0.5 ft above the geoid. When this external barrier boundary is overtopped, flow leaves the domain in an appropriate fashion.

(c) Example 5b grid (UNIT 14) and input (UNIT 15) files. This steady state example considers a quarter annular domain with bathymetry varying between 0.5 ft above the geoid and 12 ft below the geoid. The outer boundary is specified as a specified normal flow external boundary for which normal flow steadily ramps up to 3.0 ft^2/sec. Water propagates in toward the inner annulus while wetting the inner portions of the domain as water level rises. The inner boundary is specified as a external barrier flow boundary with a specified barrier boundary height equal to 0.5 ft above the geoid. When this external barrier boundary is overtopped, flow leaves the domain in an appropriate fashion.

5. List of Items Included in Product 2

(a) This brief report

(b) adcirc30_02.f

(c) adcsetup30_02.f

(d) example3d.inp and example3d.grd

(e) example4d.inp and example4d.grd

(f) example5c.inp and example5c.grd

(g) example7c.inp and example7c.grd

(g) example8a.inp and example8a.grd

(i) example8b.inp and example8b.grd