6 SUMMARY AND DISCUSSION

6.1 Summary

WASH123D has taken a step beyond previous models. It was developed to cover dentric river/stream/canal networks and overland regime (land surface) and subsurface media including vadose and saturated (groundwater) zones. It incorporates natural junctions and control structures such as weirs, gates, culverts, levees, and pumps in river/stream/canal networks. It also includes management structures such as storage ponds, pumping stations, culverts, and levees in the overland regime. In the subsurface media, management devices such as pumping/injecting wells, drainage pipes, and drainage channels are also included. Numerous management rules of these control structures and pumping operations have been implemented.

WASH123D is designed to deal with physics-based multi-processes occurring in watersheds. These include density dependent flow and thermal and salinity transport over the entire hydrologic cycle. The processes include (1) evaporation from surface waters (rivers, lakes, reservoirs, ponds, etc) in the terrestrial environment; (2) evportransipiration from plants, grass, and forest from the land surface; (3) infiltration to vadose zone through land surface and recharges (percolations) to groundwater through water tables; (4) overland flow and thermal and salinity transport in surface runoff; (5) hydraulics and hydrodynamics and thermal and salinity transport in densdric river networks; and (6) subsurface flow and thermal and salinity transport in both vadose and saturated zones.

Physics-based fluid flows in stream/river network, overland regime, and subsurface media are considered. Kinematic, diffusive, and fully dynamic wave approaches are all included for applications to dentric rivers and overland regime. Richards' quation is employed for subsurface flow. Junctions and control structures including weirs, gates, culverts, levees, pumping, and storage ponds are included to facilitate management. Boundary conditions for junctions and internal structures are implemented to explicitly enforce mass balance. Interface boundary conditions are rigorously dealt with by imposing the continuity of fluxes and the continuity of state variables or the formulation of fluxes when the state variables are discontinuous. Many optional numerical methods were employed for robust and efficient simulations and for application-dependent simulations.

New paradigms of diagonalizing reaction-based transport equations were employed to simulate water quality transport equations governed by advection-dispersion-reaction transport equations. As a result of these generic approaches, WASH123D can easily be employed to model bigogeochemical cycles (including nitrogen, oxygen, phosphorous, and carbon cycles and biota kinetics (including Algae, Phyotoplankton, Zooplakton, Caliform, Bacteria, Plants, etc.). In fact, once one's ability to transform biogeochemical processes into reaction networks and come up with rate equations for every reaction is achieved, one can employ WASH123D to model his/her system of reactive transport in surface runoff, surface water, and subsurface flows on watershed scales.

WASH123D can be applied to (1) one-dimensional river/stream network only, (2) two-dimensional overland regime only, (3) three-dimensional subsurface media only, (4) coupled one-dimenional river networks and two-dimensional overland regime, (5) coupled two-dimensional overland regime and three-dimensional subsurface media, (6) coupled three-dimensional subsurface meida and one-dimensional river networks, and (7) coupled one-dimensional river networks, two-dimensional overland regime, and three-dimensional subsurface media. For each application one can simulate flows alone, sediment transport alone, water quality transport alone, or flow and sediment and water quality transport simultaneously. When both flow and transport are simulated, the flow fields are computed first. Then the transport is calculated using the computed flow fields at respective times. Temperature- and salinity-dependent flow is considered.

A total of 17 flow examples were given, which could serve as templates for users in applying WASH123D to either research problems or real-world field applications. These examples are presented to demonstrate the design capability of WASH123D, to show the needs of various approaches to simulate flow in river networks and overland flow problems, and to illustrate some realistic problems using WASH123D.

A total of 13 water quality transport problems were given: six examples for one-dimensional problems, four examples for two-dimensional problems, and three examples for three-dimensional problems. These examples are used to (1) verify the correctness of computer implementation, (2) demonstrate the need of various numerical options and coupling between transport and biogeochemical processes depending on application circumstances, (3) show the generality of the water quality modeling paradigm that embodies the widely used water quality models as specific examples, (4) validate the capability of the models to simulate laboratory experiments, and indicate its potential applications to field problems.

WASH123D could also be applied to (1) Design of flood protection works, (2) Design of wetlands and water conservation areas, (3) Assessment of impacts of tropical storms on flooding, (4) Investigationn of deep injection of fresh water for future use, (5) Dredge material disposal facility design, (6) Study of hazardous and toxic waste remediation, (7) Wellhead protection area definition, (8) Environmental restoration plans, and etc.

WASH123D has been coupled with a bay/estuary model and is ready for coupling with atmospheric models.

6.2 Discussion

Further refinements and enhancements can be made of WASH123D in several areas. First the governing equations for surface water flows and scalar transport should be cast in curvilinear coordinates along river directions for one-dimensional river networks (straightforward) and land surface fitted curvilinear coordinate (not so straightforward) for two-dimesnional overland regime. These modifications will make the model applicable to landscapes of steep slopes. Second high performance parallel computing (partially done by US Army Corps) should be implemented to make the application of the model to large scale problems computationally more tractable. Third, robust and user's friendly graphical interface pre- and post-processors (almost done by US Army Corps) should be developed to make the learning curves of the model much shorter. Fourth, adaptive local grid refinement algorithms such as LEZOOMPC (Yeh 1990; Yeh, et al., 1992; Yeh, et al., 1995; Cheng, et al., 1996a, 1996b; Cheng et al, 1998a) should be incorporated in the discretization of sharp moving front problems to greatly speed up the computations. Fifth, optimal matrix solvers with computational efforts proportional to N (where N is the number of unknowns) such as algebraic-based multigrid method (Ruge and Stuben, 1985, 1987; Stuben and Trottenberg, 1982; Stuben, 1999a, 1999b) or geometric-based multigrid methods (Brandt, 1984; Bramble, et al., 1988; Xu and Zikatanov, 2000; Cheng, et al., 1998b; Li, et al., 2000, 2005) should be provided to greatly increase the computational speed. The algebraic-based multigrid methods will demand excessive CPU storages and are in general very difficult to achieve optimal performances for matrix equations resulting from generic nonlinear problems. On the other hand, geometric-based multigrid methods require extensive problem specific developments.