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TECHNICAL COMPLETION REPORT

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WATER RESOURCES
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TITLE: Elements of Tidal Marsh Circulation

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PROBLEM AND RESEARCH OBJECTIVES

Problem Description

Flows in tidal marshes are not described well by the classical equations of open channel flow. The geometry of the marsh complicates analysis of the system. Water depths in tidal marshes are usually small, varying from a few centimeters or even dry at low tide to a meter or more at high tide. At low tides, the flow can be channelized and is often essentially one-dimensional. At high tides the system frequently must be described using a more complete two-dimensional approximation. A model is thus required that permits transitions between differing areas of the system. It must accurately represent the changes of the areas inundated during the tidal cycle. It must also be capable of operating to the resolution necessary to characterize the flow regime in the marsh.

Vegetation within the marsh presents a variable resistance to flow particularly in this range of depths. A parameter like Manning's n is insufficient to characterize the variable friction resistance to flow. A new formulation is required which accounts for head losses within the vegetation as well as flow transitions between the channels and vegetated marsh surface. This formulation will be independent of the model used and is relevant whether the model is one-dimensional or two-dimensional. Factors that contribute to head losses in marshes are: turbulent energy losses, bottom friction, wind stress, drag from the erect plants that obstruct the flow, and secondary currents within the vegetation. The relative magnitudes of these effects have not been quantified in previous research. Direct observation of small scale hydrodynamic phenomena is difficult because of the shallow depths, frequently inaccessible field conditions during high tides and the spatial heterogeneity over the marsh surface. Most computation of flow in tidal marshes is carried out using the lumped friction parameter of classical open channel flow. This parameter is a calibration coefficient and has only a limited physical basis.

An additional problem that must be addressed is the influence of tidal marsh inundation on the circulation within the estuary proper. Typical estuary models build the equivalent of sea wall on the estuary perimeter. Depths at these locations typically do not go to zero and the marsh behind these arbitrary boundaries is excluded from the analysis. A model is thus required that can cost effectively and accurately incorporate these areas into the estuarial analysis.

Research Objectives

The goal of this project has been to describe the physical processes controlling tidal marsh hydrodynamics using small scale experiments and mathematical analysis of the physics of the system. A second objective has been to develop a mathematical description of these processes that can be applied at differing scales. The success of a macro scale model is dependent on an accurate physical description of the micro scale processes. To evaluate the extension to larger scale a limited set of field data has been tested and used to validate the model.

Although this macro scale model is immediately useful for wetland management and planning, the ability to describe flow regimes will be important for future studies of sediment transport, water quality, and aquatic biology in tidal marshes.

This study has focused on analysis of tidal marshes although the methodology is sufficiently general that it can be applied to freshwater and upland wetlands subject to transient inundation or flooding.

METHODOLOGY

This study has developed a new mathematical description of flow in tidal marshes. The method has been tested and evaluated using experimental data. The new governing equations represent a modification of the conventional shallow water equations. They are based on the analysis of physical phenomena at three spatial scales within the marsh:

1. Micro scale flow through marsh vegetation
2. Meso scale flow through hummocks and minor drainage channels.
3. Macro scale flow exchange between the tidal marsh and the estuary channels.

An analysis of the physics of the system supplemented with physical experiments has been carried out in the laboratory to investigate the relationships between vegetation characteristics and head loss. A revised resistance equation has been developed that uses physical properties of the marsh system as parameters. The new description of head loss replaces the Manning's n formulation

Field data is not available for analysis of micro scale processes. Therefore, flow through marsh vegetation has been studied by a combination of physical modeling and analysis of the physics of the system. Detailed hydrodynamic analyses of the micro scale process have provided the basis for parameterization of the larger scale and marsh flows.. This formulation is general and not dependent on the numerical method used for solution of the equations. The equations and the new friction formulation have been incorporated into an existing finite element estuarial model and it has been applied to an existing marsh for calibration and validation.

Data for net head loss through the marsh was collected at a test site in San Francisco Bay. This data was used to validate the new methodology when it was applied for aggregated analysis.

Finally, the new friction terms and the numerical techniques have been documented for the users of model and in the literature cited later.

This study was designed to follow a series of tasks, as outlined in the original proposal. In the paragraphs that follow activities in each task will be described.

Task 1 Develop a field data base and select a test site

The test site selected was the restored tidal marsh at Hayward Regional Shoreline on the shore of San Francisco Bay. This location is administered by the East Bay Regional Park District in Oakland. The marsh is a former salt evaporation pond, it was restored to tidal action in 1980 and developed significant stands of typical marsh vegetation. The marsh is surrounded by dikes with a limited access to the main bay. It is ideal for calibration and verification of numerical model because of its semi-diurnal tidal regime and well defined boundary conditions. The marsh is small in aerial extent and accessible so that field data was readily obtained.

Task 2 Perform field reconnaissance

The elevation of the marsh surface and the channel profiles were surveyed, the vegetation was analyzed for stem density and stem characteristics and existing maps and aerial photographs were analyzed to define

Task 6 Calibrate and verify macro scale model, incorporating new friction relationships and equivalent continuum theory

The new version of RMA-2 has been applied to the Hayward test site with differing levels of resolution. The results of these simulations have then been compared with the field data gathered on site. The results are presented in Roig (1992).

Task 7 Perform sensitivity analyses

Sensitivity has been evaluated for the revised friction formulation and for the Hayward marsh simulation. These basic tests served to validate the new model formulation.

In a separate series of tests the influence of overall mesh refinement and of incorporating marsh detail in estuarial simulations has been evaluated. San Pablo Bay and the Straits of Carquinez were selected as test sites for these comparisons.

The required mesh refinement for an accurate study of tidal flows in an estuary is a more of an art than a science. A section of San Pablo Bay was studied with increasing levels of refinement. Simulations that showed a perfectly satisfactory agreement with measured values were shown to have erratic and meaningless tidal residual currents. It was hypothesized that tidal residual currents could be used as a measure of model performance. The model results showed that with increasing refinement, consistent tidal residuals could be developed. Details of this aspect of the study are presented in King (1992).

The influence of incorporating marsh areas was evaluated by modifying an existing representation of San Pablo Bay that was part of a data set for all of San Francisco Bay. The revised data set was designed to incorporate all the marshes surrounding the bay, the previous data set limited the boundary geometry to areas that were always inundated during the tidal cycle. Comparison of the velocity fields at nodes representative of the entire area showed velocity changes as large as 0.1 meter/sec and changes of direction as large as 40 degrees. Whilst it is true that not all locations were influenced to the same degree, this confirms the contention that estuarial simulation cannot arbitrarily be cut off at the low tide line. Wetlands, mud flats and marshes must be included in the simulation process until it can be demonstrated that their influence is negligible.

Task 7 Document the revised modeling approach

Technical papers describing aspects of the new modeling approach have been presented at national conferences and are published in the proceedings. Additional technical papers are in preparation for submittal to appropriate journals. Full details documenting the revised formulation, the data, and the tests are incorporated in the Ph.D. thesis (Roig 1992).

PRINCIPAL FINDINGS AND SIGNIFICANCE

Benefits of Problem Solution

Protection and restoration of tidal wetlands in California are currently the subject of investigations by the Department of Water Resources, The Department of Fish and Game, CALTRANS, and the U.S. Army Corps of Engineers. It is important that the long term potential for restored wetland be analyzed in a careful fashion. Understanding of tidal marsh hydrodynamics is an essential component. Transport by the flowing water is the single most significant vector for energy and mass transfers in the marsh ecosystem.

The mathematical model of marsh hydrodynamics serves as a baseline tool for scientists trying to understand key processes such as sediment deposition, nutrient exchange and biological reactions that

control the long term fate of the wetlands. A model of this type, when incorporated into an estuarial simulation allows evaluation of headloss through the wetlands, tidal residence in the wetlands and computation of tidal exchange between the marsh and the adjacent estuaries.

The model is already in use by engineers and researchers at the Waterways Experiment Station of the U.S. Army Corps of Engineers, the University of Bristol in England and by consultants in Australia.

Cooperating Agencies

East bay Regional Parks, Oakland, California.

California Department of Water Resources, Sacramento, California.

Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

PUBLICATIONS

I. P. King and L.C. Roig (1991) "Finite element modeling of flow in wetlands," presented at the National Conference on Hydraulic Engineering, American Society of Civil Engineers, July 29-August 2, 1991, Nashville, Tennessee, and published in Hydraulic Engineering, Richard M. Shane (ed), American Society of Civil Engineers, New York, NY, 1991 pp 286-291.

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C. Martin (1992) "Finite Element Modeling of San Pablo Bay," Project report in partial. satisfaction for the degree of Master of Engineering, Department of Civil Engineering, University of California, Davis , CA. expected completion December 1992.