ANALYSIS OF HONDURAN SHRIMP FARM IMPACTS ON CHANNEL ESTUARIES OF THE GULF OF FONSECA

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Progress Report

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ABSTRACT

This report summarizes progress on a project to analyze water quality and hydromechanical data from the channel estuaries of the Gulf of Fonseca in Honduras and to develop suitable water quality models. The overall objective is to perform quantitative computation of the carrying capacity of the estuarine system for a viable shrimp farming industry. The study addresses Estero el Pedregal and Estero San Bernardo, which are typical of many of the river-channel estuaries within the larger Gulf of Fonseca along which shrimp farming is being developed. It has been established that hydrographic conditions in the regions in which shrimp farming operates, including tidal range and period, freshwater throughflow, physiography and morphology (especially the role of tidal flats), and tidal currents and related parameters—mixing and dispersion—are at least as important as chemical quality in the effects of farm effluent on estuary quality. Models are under development for tidal hydrodynamics, salinity, and dissolved oxygen. The lack of good field data has been the principal impediment to modeling these systems in the past, and the database has been considerably improved in the past several years due to the efforts of CRSP researchers, the Peace Corps, and concerned individuals and shrimp farms in the region.

INTRODUCTION

This project addresses the overall problem of establishing the assimilative capacity, i.e., the "carrying capacity," for shrimp mariculture in the Rio Choluteca delta areas of Honduras, on the Gulf of Fonseca. Because of the intensive development of this industry in recent years, the proximity of the shrimp farms, and the large volumes of daily water exchange, there is great concern that accumulation of waste byproducts from these mariculture facilities will impose a limit to the number of ponds that can be operated. This self-limiting density, if it exists, must be quantified as a basic management parameter; if the number of shrimp ponds exceeds this self-limiting density, the viability of the industry could be compromised.

The problem of shrimp aquaculture management requires an evaluation of water quality in the regions of existing and proposed shrimp farm operation, especially how that water quality is influenced by the anticipated wasteloads from the shrimp farms themselves and from other wastewater discharges that may be located in the region. The first step in the analysis is to establish the extent of impacts the existing shrimp farms have on the estuarine environment. This entails data collection and analysis, and the development of quantitative models. Both activities are underway. Data collection is being undertaken by Auburn University personnel in Honduras in a companion CRSP project (Green et al., 1999). The present project addresses data analysis and mathematical model development. Once developed, the mathematical model(s) will serve both a diagnostic and a prognostic function in management of the industry in this region.

Both data collection and mathematical model formulation must be commensurate with the level of detail required for accurate depiction of water quality and its controlling processes. The level of detail in both time and space is dictated by the geographical complexity of the watercourse and how variable that watercourse is in time. Estuaries in general, and those debouching into the Gulf of Fonseca in particular, are geometrically complex. Most of the Fonseca shrimp farms are located on dendritic, confluent channel estuaries that drain a mangrove-fringed tidal delta (see Wolanski, 1993). Temporal complexity is induced by both the high tidal exchange of the region and the variability in inflow due to the tropical Pacific climatology. The present study concentrates on two of the more important channel estuaries, Estero Pedregal and Estero San Bernardo, both in the eastern arm of the Gulf of Fonseca.

METHODS AND MATERIALS

Evaluation of assimilative capacity requires a suitable mathematical model to determine the concentrations of key parameters that result from a given level of wasteloading. In any watercourse, the concentration of a constituent is governed by transport processes (including mixing) and kinetic processes, so a model of that constituent must include a determination of hydrodynamic transports as well as a mass balance of the water quality constituents. In an estuary, assimilative capacity is a strong function of position. There will be areas in almost any estuary that are well-circulated and subject to regular water-mass replacement, which will generally have a high assimilative capacity. There will also be areas that are poorly circulated with frequent stagnation (dead zones), which will have a low assimilative capacity. The location of the hypothetical wasteload relative to well-circulated or poorly circulated zones, and relative to other existing wasteloads, is important to the ability of the estuary to assimilate that wasteload. Moreover, the distribution of critical regions of the estuary and the associated assimilative capacity will vary with hydrodynamic conditions. Therefore, a model is needed of space-time distribution of the concentration of controlling parameters in the estuary.

While the magnitude and geographical distribution of the mass influxes of contaminants are clearly an important control, an equally important control is the hydrodynamic capacity of the estuary for dilution and transport. For an estuary, the complex geometry and complicated hydrodynamics make data analysis and model formulation especially difficult. This is why the hydrography of an estuary must be understood in order to evaluate its water quality. In other words, the hydrography of the estuary dictates the relation between mass loads of contaminants and the severity of the resulting water quality decline. An action that alters either the hydrography or the waste loading has the potential of altering water quality. Shrimp farming can do either.

The work in the present project has proceeded along two separate but related directions. First is the acquisition, compilation, and analysis of data relating to the hydrography and water quality of the study estuaries. Second is the formulation and application of mathematical models. Data collection in the study area has been underway for several years, and most of these data pertain to the operation and metabolism of the shrimp ponds themselves. Estuary water was sampled at the intakes to the pond operations. In conjunction with the present study, data collection has been extended into the estuary channels. Methods and procedures of data collection activities for this phase of the work are described in Green et al. (1999). (In the present context, only those data sets being used in the analysis and modeling work are discussed.)

Data analysis is based upon closing volume and mass balances for subsections of the study estuaries on various time and space scales (see Ward and Montague, 1996, and references therein). In most cases, this has been carried out in conjunction with model development. Two models are presently being applied to the study estuaries. The first is a section-mean tidal hydrodynamic model (Dronkers, 1964; Vreugdenhil, 1989). This model is a numerical solution to the differential equations of momentum and continuity. The value of this model is that it provides a means to compute the tidal currents in the estuary based upon the tidal stage, which is measured or predicted at the mouth of the estuary. The currents, rather than tide stage, are really the important hydrographic feature, since it is the currents that are responsible for transport and tidal dispersion. The numerical solution is implemented in a program designed for operation on a DOS-based personal computer (PC).

The second model is a section-mean longitudinal mass budget model for the concentration of a substance along the axis of the estuary (Ward and Espey, 1971). The large-scale tidal-mean distribution of waterborne substances such as salinity, dissolved oxygen (DO), and nutrients varies on time scales of days to weeks, so this model is designed to depict these slower, long-term established concentration profiles. Again, the model is a numerical solution to the governing differential equations implemented in a code for operation on a PC platform.

Preliminary development and application of both of these models were made for the Pedregal system, presented in Ward (1995), and summarized in the following section. While these applications were illuminating, practically no field data from the systems existed at that time, and guesses had to be made for fundamental input data such as water depths, cross-sectional areas, zones of tidal inundation, salinity dispersion, and inflow. Moreover, the only water quality data extant for validating the models were those analyzed from intake samples at the shrimp farms, through a cooperative program between the shrimp farmers, Honduran agencies, and the CRSP (Teichert-Coddington, 1995). A prime objective of the present project is to incorporate field data from the study estuaries into the model development and application.

PROJECT ACCOMPLISHMENTS AND RESULTS

The systems given specific study in this project are the Pedregal and San Bernardo, two of several channel estuaries draining into the eastern arm of the Gulf of Fonseca. An important geometric feature of each of these systems is its declining cross-sectional area with distance upstream. These are horn-shaped estuaries, whose channels have a longitudinally diminishing capacity for flow, as well as an increasing resistance to flow. Another important geometric feature is the large tidal flats adjacent to the estuary, which communicate with the main tidal channel through small scoured tidal passes through the mangrove fringe. In such systems, tidal flats have the capacity to store a great amount of water on the rising tide, and release that water back to the tidal channel as the tide stage falls. The resulting tidal prism is much larger than would be anticipated based solely upon the cross section of the tidal channel.

Shrimp farming concessions have been granted extending over 30 km up the length of both systems, though shrimp farm development is presently limited to about the first 20 km. These shrimp farms eliminate the tidal flats, hydraulically isolating these areas by enclosure within levees to create the shrimp ponds. The farms exchange water between pond and estuary on each tidal cycle (12.4-hr period). For modeling purposes, data on actual producing-pond areas as of 1994 for the larger operations were compiled.

Hydrodynamics

Preliminary application of a tidal hydrodynamic model was made to the Pedregal system including its principal tributary, the Jagua (though a more complex model with additional branching channels could certainly be implemented). A record of tidal variation was obtained by Auburn personnel by installing a digital-logging pressure gauge at the Pedregal intake to the Granjas Marinas farm. Two segments of this tide were selected to represent high- and low-range scenarios and were used to drive the model at the mouth of the Pedregal. Time integrations of several tidal cycles were carried out, solving for tidal current and water level throughout the estuary, from which three fundamental hydrodynamic indicators were determined:

1) Length of the tidal excursion (the distance that a parcel of water moves on the flooding tide);
2) Average tidal-current speed, which is useful in estimating dispersion and in re-aeration; and
3) Tidal prism (the volume of water carried past a fixed point on the flooding tide, a direct measure of dilution volume).

Two scenarios were examined (Ward, 1995): 1) the pre-aquaculture geometry, with flooding tidal flats, as indicated on topographic maps of this region; and 2) 1994 shrimp-farm development, in which the tidal-flat areas were reduced by the amount of pond areas. Tidal excursions computed by the model appear to be on the correct order, compared to observations of Currie (1994) based on tracking buoys in the lower Estero Real, and were found to range approximately a factor of two between the two tidal conditions. The difference in tidal prism between the natural geometry and the shrimp-farm development is particularly striking. For the Pedregal, elimination of a total of 1,500 ha of tidal flat reduces the tidal prism in the lower reaches of the estuary by 10 to 35%, due to the reduction in the capacity of the estuary to store water on the rising tide. This translates to a direct reduction in the diluting capacity of the estuary's tidal exchange, and emphasizes the importance of better quantifying this aspect of shrimp pond installation.

Critical to this estimate are the inundation areas of tidal flats. For the preliminary model computations, these were judged ("eye-balled") from topographic maps of the Pedregal area. More recently, Mr. Felix Wainwright, a regional expert on the Fonseca mangrove swamps, has prepared a detailed map and accompanying report (Wainwright, 1996) for this project addressing tidal inundation along both the Pedregal and San Bernardo systems (the latter including a portion of Estero La Berberia, which is outside the scope of the present study, but should be examined at some point in the future). This work is based on his personal observations and field experience in the region, and is being used to re-segment the hydrodynamic model to better depict this aspect of estuary hydrography.

Estuary depth and cross-sectional areas are also needed for model input. In the preliminary model runs, these were estimated from informal surveys conducted by researchers from Auburn and University of Texas personnel in the lowermost reach of the Pedregal and guessed elsewhere. Since then, additional data on water depths have been obtained by a Peace Corps Volunteer (PCV) in the area and during water quality surveys carried out by Auburn University researchers. In addition, one of the major shrimp farms, Granjas Marinas San Bernardo (GMSB) assigned its surveyors to performing detailed cross-section surveys at three stations in the lower Pedregal and three stations in the lower Bernardo, adjacent to its concession. These survey data were transmitted late in 1997, and are being used to revise the input for the hydrodynamic model.

Water Quality

The distribution of various constituents in the estuary is the central concern in quantifying assimilative capacity and the potential for aquaculture self-limitation. This is determined by application of a mass-transport model, and in this study is approached using the same numerical segmentation as the tidal hydrodynamic model. There are two separate time scales involved for water quality: the intratidal, representing the upstream-downstream movement of the mass field in response to tides; and the intertidal, representing the long-term (weeks to months) trend of concentration distribution. The former is governed by tidal mechanics and short-timebase storms, while the intertidal time scale is governed by longer-term hydroclimatology and the evolution of conditions in the Gulf of Fonseca (primarily salinity structure). From the standpoint of evaluating carrying capacity for shrimp farm operations, the intertidal time scale is more important. In the present study, we are approaching this by application of a one-dimensional equilibrium-time model (section-mean tidal-averaged steady-state). We are also investigating the utility of a time-varying model, similar to that of Hauck and Ward (1980), to better represent response of the system to wet and dry seasonality. At present, two key constituents are being studied: salinity and dissolved oxygen.

Although salinity in an estuary is not really susceptible to management control, modeling of salinity nonetheless serves several important functions. First, because salinity is a natural, conservative tracer, it can be used to verify the ability of the model to compute advective and dispersive transport, by comparison of the model results to salinity data. (Other nonconservative parameters, such as dissolved oxygen or nutrients, cannot be used this way, because of the complicating effect of multiple sources and sinks on their concentrations.) Second, salinity exerts a control on some of the kinetic processes affecting other parameters; for example, oxygen saturation is reduced with increasing salinity. Third, the location of the horizontal salinity gradient can be an indicator for other processes potentially important to shrimp farming, especially the principal zone of density-current intrusion.

The DO model is more complex. DO in the estuary is the end product of several kinetic processes, all acting simultaneously. These include sources of oxygen through mechanical re-aeration and photosynthetic production, and sinks of oxygen through oxidation of organic matter in the water column and benthic fluxes on the estuary bed (e.g., Thomann and Mueller, 1987). The chief effect of shrimp farm effluent on DO is through the load of oxygen-demanding organics. For present purposes, biochemical oxygen demand (BOD) is being used to quantify this. In the model, BOD is computed first, then fed forward into the dissolved oxygen calculation. This requires inputs on the oxygen-demanding wasteloads, which are assumed to be the Rio Choluteca load and the effluents from shrimp ponds. For preliminary model computations, the latter were estimated from shrimp pond data collected by Auburn personnel. This model application demonstrated the importance of having better data on organic loads from shrimp ponds, and a more intensive data collection effort was implemented by CRSP researchers. These newer data are being compiled for use in the present project (Teichert-Coddington, pers. comm.).

The water quality of the estuaries, both in reality and in the model, is strongly dependent upon hydrology. For the preliminary model exercises on the Pedregal, hydrological conditions were determined based upon flows of the Rio Choluteca, which entered the lower Pedregal through the Jagua distributary (this has since been modified; see below). Two different levels of river flow were examined in the preliminary work, one corresponding to the dry-season base flow, the other to a moderate level of inflow that still allowed some salinity intrusion into the Pedregal (Ward, 1995). As matters turned out, under the higher flow regime, the BOD and DO of Estero la Jagua and the lower Pedregal were found to be dominated by the quality of the Rio Choluteca inflow (which includes the waste loads from the cities of Tegucigalpa and Choluteca), with the shrimp farms having only minor influence. This finding is consistent with those of CRSP researcher Teichert-Coddington based upon the chemical data he had collected along the estuary. The greatest impact of the shrimp farm operations on estuary quality was found to occur for the dry-season flow, and this would therefore be the condition under which self-limitation would be most pronounced. A recent development will modify this conclusion, however, namely that the Rio Choluteca has been diverted into another channel by an earthen dam, and presently does not debouch into the Jagua-Pedregal.

Obviously, there are no stream-gauging stations on the distributaries of the mangrove deltas. In this project, the flow in the Rio Choluteca (gauged in Choluteca) has thus far been used as an index to flows in the tidal periphery of Fonseca, but the adequacy of this estimation is now being questioned. The Rio Choluteca has a large watershed, extending into the highlands above Tegucigalpa, and its flow reflects the hydroclimatology of the entire area, basically the Pacific side of the continental divide. The channel estuaries on Fonseca, however, have low-lying swampy watersheds that are limited in area to the immediate periphery of the Gulf. While these exhibit the same overall seasonal shift in climate as this region of Central America, viz. alternation of dry and wet seasons (see Ward, 1995), they are responsive to a much more marine climatology. We are presently exploring the possibility of estimating the runoff into these channel estuaries from rainfall data in the region.

Field data on instream concentrations comprise an indispensable component of a modeling study, both to help quantify terms in the model for which no external measurements exist, and to appraise the predictive accuracy of the model. The preliminary model applications were based upon estuary data from 1994 on salinity and DO in the Pedregal. These data came from analyses of water samples drawn from the intakes of the shrimp ponds. While these data are valuable in many respects, they suffer from the following problems: 1) too sparse a sampling network (limited to locations of farm intakes); 2) too limited sampling of the longitudinal extent of the estuary; and 3) lack of information about stratification. There was a clear necessity to perform surveys in the estuaries themselves, from their mouths at the Gulf of Fonseca and extending a substantial distance upstream. Since 1994, a number of such surveys have been carried out. Those data sets that have been processed, compiled and in use in the present work are summarized in Table 1. (Additional surveys have been performed but data compilation has not been completed.) The surveys marked with a double asterisk (**) in Table 1 were carried out by a PCV on assignment in the Choluteca region.

DISCUSSION AND PROJECT STATUS

Once a model is available, it allows evaluation of alternative scenarios, such as determining the relative importance of geographical location, physical parameters, hydrography, and kinetics. As an example, the preliminary model was applied to demonstrate the importance of geographical location on the effect of a shrimp farm on the estuary water (see Ward, 1995). The model was used to determine the DO in the Jagua (under dry-season conditions) for successive locations of a single shrimp farm from 1.5 to 13 km upstream from the confluence with the Pedregal. With distance upstream, there is a reduction in estuary cross section, tidal prism, and mixing (dispersion), so the same organic mass load results in a higher BOD concentration, and has a greater impact on DO. With the farm located farther upstream than 10 km, the DO in the estuary was driven to levels too low for aquatic life. This experiment illustrated the facts that: 1) the impact of a specific shrimp farm depends not only upon its load but its location within the estuary and 2) that a mass load in such a highly dispersive system as these river-channel estuaries affects quality a great distance both downstream and upstream from the point of discharge.

Under a projected future scenario based upon full development of the farm concessions extant in 1995, the model predicted both the Pedregal and the Jagua to have dry-season DOs below a critical value of 3 mg l^{-1}. Although these results were based upon estimates (i.e., judgments and guesses) of estuary physiography, hydromechanics, kinetics, and hydrology, they indicated the potential to exceed the assimilative capacity of both systems at the projected level of future development. Concerns expressed by the CRSP project team and the shrimp farm interests themselves have led to a moratorium on new farm development in Honduras until the assimilative capacity can be better quantified.

In the present study, we are continuing the focus on salinity and DO. The same kind of modeling could be applied, with some minor modifications, to nitrogen and phosphorus nutrients and to specific toxicants such as ammonia or indicators such as chlorophyll *a*. While modeling for other parameters exceeds the present scope, for longer-term purposes, data collection in Honduras and the model formulation in this project are addressing these expanded

Table 1. Inventory of field data sets for Honduran estuaries. DO = dissolved oxygen; S = salinity; T = temperature.

Estuary	Date(s)	Parameters	Number of Stations	Sampled Reach (km)	Comments
PEDREGAL					
	Jan-Dec 93	DO	1	n/a	daily AM & PM*
	21 Nov 94	S/T/DO	11	21	vertical profiles**
	10 Mar 95	S/T/DO	10	21	vertical profiles**
	4 Mar 96	S/T/DO	7	11	vertical profiles
	11 Mar 96	S/T/DO	7	11	vertical profiles
	19 Mar 96	S/T/DO	7	11	vertical profiles
	26 Mar 96	S/T/DO	7	11	vertical profiles
	3 Apr 96	S/T/DO	7	11	vertical profiles
SAN BERNARDO					
	20 Jan 95	S/T/DO	9	28	vertical profiles**
	11 Mar 95	S/T/DO	8	25	vertical profiles**
	17 Mar 96	S/T/DO	8	13	vertical profiles
	25 Mar 96	S/T/DO	8	13	vertical profiles
	1 Apr 96	S/T/DO	8	13	vertical profiles

* Data from farm intake
** Data runs made at both high and low tidal stages

objectives. A model developed using field data with specific physiographic and hydrographic inputs can be used to better define critical conditions. Such a model can also be used to evaluate any number of different shrimp farm development scenarios, to see which would be possible given the hydrographic environment and which would result in unacceptably degraded water quality.

On a broader perspective, there are additional aspects of the hydromechanics and water quality of the Honduras environment that are not being addressed in the present study, but may need attention in the future. For example, the channel estuaries draining Nicaragua are expected to become the focus for intensified shrimp farm development. Several field and/or planning studies have already been performed addressing these estuaries, e.g. SAPROF Team (1992) and Currie (1994, 1996). Thus far, no modeling has been carried out nor planned, but clearly the same management concerns as in Honduras must be addressed in Nicaragua. Moreover, the combined shrimp industry in both countries, operating in such proximity, will probably need to be evaluated for carrying capacity limitations of the Fonseca system. There are other kinds of operational problems for which the type of model being developed in the present project would not be appropriate, but for which others would. Some of the deeper, more energetic sub-estuaries of the Fonseca system, such as Estero de los Barrancones and others near Salvador, may require more complex models, which perhaps include the vertical dimension. The interaction between individual farms, in which the effluent from one farm is drawn into the intakes of another, may necessitate detailed field studies and (if modeling is necessary) higher-dimensioned and more refined modeling.

The single greatest future concern, beyond characterization of the channel estuaries, is a larger-scale hydrographic analysis, quantifying the exchange between these estuaries and the adjacent Gulf of Fonseca, and the renewal of Fonseca water by exchange with the Pacific. A concerted data collection effort in the Gulf of Fonseca proper, with high resolution in the eastern arm out from the shrimp farming regions, would be immensely valuable in illuminating its hydrography. The design of such a program has been outlined for some time (Ward, 1994), but because sampling in the waters of three different countries would be involved, its implementation must be negotiated at the highest levels of the respective governments. Despite protracted efforts of CRSP and other agencies in the region, the data collection program has not yet been initiated. Another alternative is the application of an advanced primitive-equation estuary hydrodynamic model such as the Princeton Ocean Model. Specifications for such a modeling study have been formulated by this project, and the work is presently being considered by the U.S. Environmental Protection Agency.

ANTICIPATED BENEFITS

The formulation of models using water quality and estuarine dynamics data for predicting carrying capacity of estuaries will be of incalculable benefit to the shrimp industry and Honduran government agencies charged with land use planning and environmental regulation. Environmental management of estuarine systems and regional land use planning cannot be accurately accomplished without the models, because reasonable estimations of carrying capacity would be impossible. The Honduran government has in fact stopped further shrimp farm development until an objective determination of carrying capacity has been achieved for the various estuaries. The program of data collection and carrying capacity estimation implemented by the CRSP can be used as a model by other countries in the region with similar issues to resolve.

LITERATURE CITED

Currie, D.J., 1994. Ordenamiento de camaronicultura, Estero Real, Nicaragua. Reporte de Estudio, GOPA Consultants, Hamburg, Germany.

Currie, D.J., 1996. Evaluacion del monitoreo de aguas del estero real de Febrero 1994 a Abril 1995. Unpubl. Ms., Guatemala.

Dronkers, J.J., 1964: Tidal Computations in Rivers and Coastal Waters. North-Holland Publishing Co., Amsterdam, 518 pp.

Green, B.W., D.R. Teichert-Coddington, and C.E. Boyd, 1999. Estuarine water quality monitoring and estuarine carrying capacity. In: K. McElwee, D. Burke, M. Niles, and H. Egna (Editors), Sixteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, OR, pp. 103-113.

Hauck, L. and G. Ward, 1980. Hydrodynamic-mass transfer model of deltaic systems. In: P. Hamilton and K. MacDonald (Editors), Estuarine and Wetland Processes with Emphasis on Modeling. Plenum Press, New York, pp. 247-268.

SAPROF Team, 1992. Annex IV: Additional Environmental Impact Study. In: Choluteca River Basin Agricultural Development Project, Supporting Report. Special Assistance for Project Formation, Overseas Economic Cooperation Fund, Japan, 61 pp.

Teichert-Coddington, D., 1995. Estuarine water quality and sustainable shrimp culture in Honduras. In: Browdy, C.L. and J.S. Hopkins (Editors), Proceedings of the Special Session on Shrimp Farming, Aquaculture '95, 1-4 February 1995, San Diego, CA, pp. 144-156.

Teichert-Coddington, D., personal communication, 1997.

Thomann, R. and J. Mueller, 1987. Principles of Surface Water Quality Modeling and Control. Harper and Row, New York, 644 pp.

Vreugdenhil, C., 1989. Computational Hydraulics: An Introduction. Springer-Verlag, Berlin, 182 pp.

Wainwright, F., 1996. Cuantificacion de areas de esteros que drenan al Golfo y que pertenecen a la cuenca del Rio Negro, Depto. de Choluteca. Unpubl. ms., 15 pp.

Ward, G., 1994. Outline of Golfo de Fonseca hydrographic sampling program. Memorandum report. Center for Research in Water Resources, University of Texas, Austin, 6 pp.

Ward, G., 1995. Hydrographic limits to shrimp aquaculture in el Golfo de Fonseca. Keynote lecture, III Simposio Centroamericano sobre Camarón Cultivado, 26-29 April 1995, Tegucigalpa, Honduras.

Ward, G. and W. Espey, 1971. Estuarine Modeling: An Assessment. Report 16070 DZV 02/71, Environmental Protection Agency, Washington, D.C.

Ward, G. and C. Montague, 1996. Estuaries. In: L. Mays (Editor), Handbook of Water Resources Engineering. McGraw-Hill Book Co., New York, 497 pp.

Wolanski, E., 1993. Hydrodynamics of mangrove swamps and their coastal waters. Hydrobiol., 247:141-161.