NWRI CONTRIBUTION 85-137

Skafel (30)

SHORELINE EVOLUTION MODELS

ANNOTATED BIBLIOGRAPHY

by

M.G. Skafel

Shore Processes Section
Hydraulics Division
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario, Canada

December 1985

ABSTRACT

This annotated bibliography reviews the literature on shoreline evolution models. All of the models deal with sand size sediment, and employ a sediment transport model coupled with a simple sediment continuity relation. Treatments of the wave climate, offshore transport, and fine-grained sediment are typically inadequate. Little work has been done on calibration or verification.

RÉSUMÉ

La présente bibliographie analytique revoit les ouvrages qui portent sur les modèles d'évolution des littoraux. Tous les modèles traitent des sédiments qui ont la taille du sable et utilisent un modèle de transport des sédiments jumelé à une relation simple de sédimentation continue. Le traitement du climat des vagues, du transport des sédiments au large des côtes et des sédiments finement granulés est typiquement insuffisant. On a effectué peu de travaux d'étalonnage ou de vérification.

MANAGEMENT PERSPECTIVE

Reliable predictions of shore sediments are not feasible although a number of models have been proposed. This report identifies a model with the best prospects for success and proposes some action to improve it. Verification remains a major problem. Joint activity with Queen's University staff is proposed.

Shore changes remain environmental concerns for all shore development. Reliable predictions are essential to assess the effects of change.

T. Milne Dick
Chief
Hydraulics Division

PERSPECTIVE-GESTION

Il est impossible de prévoir de façon fiable les sédiments littoraux bien qu'on ait proposé un certain nombre de modèles. Le présent rapport décrit le modèle qui a les meilleures chances de succès et propose certaines mesures pour l'améliorer. La vérification demeure l'un des principaux problèmes à résoudre. On propose de travailler conjointement avec le personnel de l'Université Queen's.

L'évolution des littoraux demeure une préoccupation environnementale quant à tous les travaux d'aménagement des littoraux. Il est essentiel d'obtenir des prévisions fiables pour évaluer l'incidence de l'évolution.

Le chef,

T.Milne Dick
Division de l'hydraulique

1.0 INTRODUCTION

Sound management of the shorelines of lakes and oceans susceptible to erosion requires the capability to predict how shores will evolve with time under various scenarios. This is necessary, for example, to provide guidance in the establishment of building codes for the shore zone, or for the determining the effects on the shoreline of developments such as breakwaters, groynes and seawalls. The purpose of this bibliography is to identify and review briefly the literature on shoreline evolution models.

The attention of researchers has focussed on shores composed of sand sized sediments; only papers dealing with that type of shore are reviewed in this report. Kraus (1983) has classified beach change prediction models into four categories, as functions of spatial and temporal scales. Figure 1, reproduced from his paper, puts the various models into proper context. It is the one line and multi-line models that are the subject of this bibliography. These types of models can be used for examining longshore scales from hundreds of metres to about 10 kilometres, over time scales of several months to about 10 years. Offshore coverage depends on the model but is of the order of tens of metres.

Numerous models which are of various levels of sophistication have been developed to predict the transport along the shore of sediment due to waves striking obliquely. This mechanism has been considered the most important one in causing the changes in shore location. These models can be considered bulk models, in that the details of the mechanisms of transport are typically not described. Some of the models incorporate onshore-offshore movement of sediment, but it plays a secondary role in the evolution processes.

One of the earliest models of shore evolution was the theoretical work of Pelnard-Considère who derived an analytical solution to a simple groyne situation.

From a practical point of view, some of the early work incorporating calculations of longshore transport looked at the variation of the transport rate along the shoreline and made qualitative comments about the likely zones of erosion and accretion. The next logical step was to formalize this approach by combining the longshore sediment calculations with a continuity of sediment relation and to solve the system of equations using numerical methods (analytical solutions are only available for a very few situations).

2.0 MODEL ELEMENTS

The models can be thought of as containing the following major elements: a section dealing with waves; a section relating the amount of longshore transport to the waves; a sediment continuity relation; a shoreline location section. The level of sophistication of treatment of each element varies greatly, depending on the model.

2.1 Waves

Common to most models, offshore, usually deep water, wave conditions are routed to the breaker zone by means of refraction routines. Some models assume parallel contours, allowing the use of Snell's law, others accept complex bathymetry. Some models are designed to deal with structures such as breakwaters and groynes and compute diffraction in the lee of the structure.

For a model to provide a meaningful prediction of shoreline evolution it is imperative that the wave climate used in the computations be a meaningful one. Most of the papers and reports reviewed provided very limited discussion (or none at all) on the wave climate.

2.2 Longshore Sediment Transport

Various relations for calculating the longshore sediment transport are used. The version given in the Shore Protection Manual (1984), has received considerable attention, undoubtably because of its simplicity. In principle, any relation could be substituted into a particular model. Van de Graaf and Van Overeem (1979) give a comparison of five formulae. Swart and Fleming (1980) used six formulae, and describe them briefly. (As many as twelve relations are identified by Fleming et al., 1984.)

2.3 Continuity Equation

The continuity of sediment in the shore zone can usually formulated in the following manner:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

where A is the vertical cross section area of beach, Q is the longshore sediment transport (in the x-direction) through a section, calculated from one of the formulae referenced in Sec. 2.2, and t is time. Some simplifying assumption is made relating the area, A, to the offshore coordinate (y), and a depth of closure (water depth below which there is no transport) to arrive at a relation of the form:

$$\frac{1}{h}\frac{\partial Q}{\partial x} + \frac{\partial y}{\partial t} = 0$$

where h is the closure depth. Selection of h ranges from the assumption of a triangular prism of sand out to some depth (for example, an arbitrary constant) to an equilibrium profile relation. Various approaches have been used to solve the equations. Some models allow the change in shoreline to feed back into the wave refraction computations, others do not.

3.0 CALIBRATION OF MODELS

Generally speaking the models reviewed are neither carefully calibrated or validated. That this is so is not surprising. To quote Le Méhauté and Soldate (1977): "The lack of well-accepted laws of sediment transport, offshore-onshore movement, and poor wave statistics have made the task of calibrating mathematical models very difficult." In addition there is a limited amount of field data that are suitable for use in testing models. At best, some of the authors provide graphical comparisons between model results and field measurements.

4.0 DISCUSSION AND RECOMMENDATIONS

From this review of the models presented in the literature, it is apparent that their use could be a worthwhile tool for coastal engineers. Because of the obvious limitations in the present knowledge of nearshore processes, the models cannot be expected to provide the whole answer to a specific situation. The engineer would still have to use all his other resources and techniques to make sound assessments and recommendations.

On the other hand, increased availability of computing capability, including microcomputers, suggests that it is worthwhile to make use of the more sophisticated models available in making a model operational at, for example, the National Water Research Institute. In that regard, the multi-line model of Perlin and Dean (1983) has been acquired. It is recommended that it be made operational,and its capabilities and limitations explored.

One of the most serious limitations to the modelling of the shoreline is a suitable treatment of the wave climate. This subject has not been dealt with adequately in the models that were reviewed. Typically, only quite simplified wave climates have been used even with the more complex models. Le Méhauté et al. (1983) recognized the limitations imposed by simplistic wave climates. In recent years considerable advances have been made in predicting wave climates using wind records (Baird and Glodowski, 1978, Fleming et al., 1984). It is recommended that these predictive techniques be investigated and incorporated into a suitable model such as the Perlin and Dean model.

Onshore-offshore movement of sediment, especially cohesive fine-grained sediment (silt, clay) has not been adequately addressed. The movement of this material is important to understanding the transport of toxics, and to address the question of turbidity and its relation to the biota in the water.

The problem remains of calibrating a suitable model. Recent discussions with J.W. Kamphuis, Queen's University, suggest a possible approach on this subject would be to utilize the substantial data set and expertize on laboratory testing of artificial island models at Queen's. It is recommended that cooperation on this subject be pursued.

REFERENCES

Baird, W.F. and C.W. Glodowski. 1978. Estimation of Wave Energy Using a Wind Wave Hindcast Technique. Proc. International Symposium on Wave and Tidal Energy, Canterbury, England, F3:39-54.

Fleming, C.A., K.L. Philpott, and B.M. Pinchin. 1984. Evaluation of Coastal Sediment Transport Estimation Techniques. National Research Council Canada, Canadian Coastal Sediment Study, Report No. 10.

Kraus, N.C. 1983. Applications of a Shoreline Prediction Model. ASCE Speciality Conference, Coastal Structures '83, pp. 632-645.

Le Méhauté, B. and M. Soldate. 1977. Mathematical Modelling of Shoreline Evolution. U.S.Army, CERC Misc. Report No. 77-10,Oct.

Le Méhauté, B., J.D. Wang, Chia-Chi Lu. 1983. Wave Data Discretization for Shoreline Processes. ASCE Jl. WPCOE 109(1), Feb. pp. 63-78.

Perlin, M. and R.G. Dean. 1983. A Numerical Model to Simulate Sediment Transport in the Vicinity of Coastal Structures. U.S.Army, CERC Misc. Report No. 83-10, May.

Shore Protection Manual. 1984. U.S.Army, Coastal Engineering Research Center, WES, Vicksburg, Miss., Two volumes.

Swart, D.H. and C.A. Fleming. 1980. Longshore Water and Sediment Movement. ASCE, Proc. 17th International Conference on Coastal Engineering, pp. 1275-1294.

Van de Graaf, J. and J. Van Overeem. 1979. Evaluation of Sediment Transport Formulae in Coastal Engineering Practice. Coastal Engineering, 3, pp. 1-32.

ANNOTATED BIBLIOGRAPHY

Bakker, W.T. 1968 The dynamics of a coast with a groyne. Proc. 11th International Conference on Coastal Engineering (ICCE), pp. 492-517.

A two line model is derived: 'beach' and 'inshore'. The littoral drift is along both; on-offshore transport depends on beach steepness. The influence of the groyne system is threefold: reflects short period beach processes on adjacent areas; retards erosion; increase lee-side scour. Diffraction and currents are not included.

Bakker, W.T., E.H.J. Klein Breteler and A. Rose. 1970. The Dynamics of coast with a groyne system. 12th ICCE, pp. 1001-1020.

An extension of Bakker (1968). The influence of diffraction behind the groyne is includedin the model. Coastal constants are expressed in terms of wave height and direction. Details of the finite difference for of the 1 line and 2 line models are presented. No comparisons are presented.

Borah, D.K. and A. Balloffet. 1983. Beach evolution caused by Littoral drift barrier. ASCE speciality conference: Coastal Structures '83, pp690-702. See also ASCE Jl. Waterway, Port, Coastal and Ocean Engineering 111(4), pp. 645-660.

The model was formulated according to that of Le Méhauté and Soldate. Provision was made for diffraction. Several aspects were elaborated and modified.

Caruso, H.A. 1983. Shoreline evolution with a numerical model. Proc., Internat. Conf. on Coastal and Port Engineering in Developing Countries (ICCPEDC), Colombo, Sri Lanka, pp. 1-15.

A 1 line model is presented; the depth of closure is assumed constant. The transport rate and wave angle are considered as functions of time or space, separately, and examples calculated.

Coëffé, Y. and P. Pechon. 1982. Modelling of sea-bed evolution under wave action. 18th ICCE, pp. 1149-1160.

Wave refraction calculations are followed by those for longshore current; sediment transport is estimated according to Bijker's formula; bed evolution follows from the continuity equation. An inner and outer loop are used: after several times through one, the outer is done to correct the refraction and currents for the changing bathymetry. The model was tested for a semi-circular bay, and the results seem good.

Dally, W.R. and R.G. Dean. 1984. Suspended sediment transport and beach profile evolution. ASCE Jl.WPCOE 110(1), Feb. pp. 15-33.

A simplified analytic investigation of local suspended sediment transort in the onshore-offshore mode is presented, and adapted to a computer solution to model beach profile evolution. Five criteria for a good model are establish, four of which are at least qualitatively satisfied. Normal (concave up) or storm (bars) profiles are modelled. The procedure accepts water level changes. Quantitative accuracy has yet to be achieved. (Assumption,p.17, seems odd: first order linear theory is used, but it is assumed that the majority of sand is entrained under the crest rather than symmetrical entrainment.

Hanson, H and N.C. Kraus. 1985. Seawall constraint in shoreline numerical model. ASCE Jl WPCOE 111(6) pp. 1079-1086.

The 1 line model is reviewed and the seawall constraint formulated to the same level of idealization: no reflection, scour, etc. Sample calculations are given.

Hashimoto, H., and T. Uda 1980 An application of an empirical prediction model of beach profile change to the Ogawara Coast. Coastal Engng. in Japan, 23, pp.191-204.

An application of the empirical eigenfunction method. The model is shown to be effective in the analysis of profile changes near coastal structures.

Horikawa, K. 1981. Coastal sediment processes, in "Annual Review of Fluid Mechanics" 13, ed. by Van Dyke et al.

Beach profile changes are typically seasonal; alongshore changes in beach topography are caused mainly by variation in the longshore sediment transport rate. Brief reviews of models are presented, including Pelnard- Considère (also described in Le Méhauté and Soldate, 1977); Price, Tomlinson, and Willis; Bakker, Klein, Breteler, and Roos (two line model).

Komar, P.D. 1983. Computer models of shoreline change. In CRC Handbook "Coastal Processes and Erosion", edited by P.D.Komar. Boca Raton Florida: CRC Press, Inc. pp. 205-216.

The general approach to 1 line models is presented. Fortran coding for a simple model is given. Some applications, with examples, are discussed.

Kraus, N.C. 1983. Applications of a shoreline prediction model. ASCE Speciality conference: Coastal Structures '83. pp. 632-645.

In the introductory remarks the author divides models into three categories: 1-line (shoreline); multi-line; 3-D; and macro-process. His model is a 1-line model with a uniformly sloping bottom with parallel contours; shoaling, refraction, and diffraction. Some details are provided. The longshore transport equation incorporates a correction to the CERC formula to account for a systematic longshore variation in the breaking wave height. Depth of closure for the continuity equation is related to wave conditions. Results compared to a field situation are in qualitative agreement.

Kraus, N.C., and S. Harikai. 1983. Numerical model of the shoreline change at Oarai Beach. Coastal Engng. 7(1), pp. 1-28.

Considerable field data is presented. Waves are refracted to just outside the diffraction zone, and a diffraction coefficient applied. A longshore sediment predictor is used and there is a term for the longshore variation in H. A one line model is used for the shoreline location, using the sediment continuity. Two methods of solution are discussed: explicit, which is easy to code but unstable for large time increments; implicit, which requires complex coding but is stable. The model was calibrated and verified for Oarai.

Le Méhauté, B. and M. Soldate. 1977. Mathematical modeling of shoreline evolution. U.S.Army, CERC, Misc. Report No. 77-10 Oct.

A critical literature review is presented, with emphasis on long term evolution. The one line theory of Pelnard-Considere is presented. Refinements are introduced by considering changes of beach slope, diffraction, wave variation, and sea level variations. Hooked bays are reviewed. The authors conclude that a finite difference numerical scheme could be developed for engineering purposes, for small wave angles.

Le Méhauté, B. and M. Soldate. 1980. A numerical model for predicting shoreline changes. U.S.Army, CERC Misc. Report No. 80-6, July.

The basic idea of Pelnard-Considère (1-D problem) has been generalized to essentially its limits of applicability. The processes of refraction and diffraction have been incorporated, as well as deterministic variations in lake level, bluff height and beach slope. The resulting theory is presented in two equivalent forms: one in terms of behaviour of the shoreline y(x,t) alone; the other expressed explicitly in the longshore transport Q(x,t) and implicitly in y(x,t). A severe limitation is the use of statistical wave summaries. The program listing is given. See also: Le Méhauté and Soldate 1978 Mathematical modeling of shoreline evolution. Tetra Tech Report No. TC-831 (prepared for CERC).; Le Méhauté and Soldate 1978 Mathematical Modeling of shoreline evolution. 16th ICCE, pp. 1163-1179.

Le Méhauté, B., J.D. Wang, Chia-Chi Lu 1983 Wave data discretization for shoreline processes. ASCE Jl.WPCOE 109(1) Feb. pp. 63-78.

The treatment of wave climate data for shoreline evolution models is discussed. The fineness in discretization of wave angle is more critical than wave height, due to the importance of the order of sequential wave events. A Monte Carlo simulation is proposed to determine the shoreline in a probabilistic sense.

Lin, M.C. 1982. Numerical modeling of beach evolution. 18th ICCE, Abstracts, pp. 108-109, (Not in proceedings).

A 1-line model with onshore offshore transport is described. Depth of closure is twice the average breaking wave height. The Liu and Dalrymple (Jl. Marine Res. 36(2) (1978) formula is used to calculate the longshore transport, to include the effect of large wave angle. The Willis (16th ICCE) formulation for sediment concentration is used. Refraction is included. Results are reasonable good for a beach in Taiwan.

Matsuoka, M. and Y. Ozawa. 1983. Application of a numerical model to the prediction of shoreline changes. ASCE speciality conference: Coastal Structures '83, pp. 646-659.

The model is described in to parts. The first part deals with wave deformation. Refraction is calculated using the equations of Munk and Arthur; diffraction using the method of Mitsui (1st term of asymptotic expansion); shoaling coefficient; breaker criterion developed by Goda. The second part deals with the shoreline changes, and uses a one line approach. Laboratory tests are compared with the model, with qualitative comparison, similarly with an application to prototype groins and an offshore breakwater. The spectral method of Karlsson is proposed for calculating wave energy for complicated bathymetries.

Muir Wood, A.M. and C.A. Fleming. 1981. "Coastal Hydraulics", 2nd Edition. London: The MacMillan Press Ltd.

The method of Pelnard Considère is reviewed. A 2-line theory is referred to, as is the solution of the equations in finite difference form.

Ozasa, H. and A.H. Brampton. 1980. Mathematical modelling of beaches backed by seawalls. Coastal Engng. 4(1), pp. 47-63.

A simple mathematical model, an extension of the Price, Tomlinson and Willis (1972) model is presented. It is a "one line" theory. When the berm is seaward of the wall one continuity equation is presented, and it is adjusted when the wall intersects the beach face. A transport model is used which takes into account wave height variation along the beach. The authors use the observation that the top of the beach is more or less at the mean water level when the wall is an influence, and the alongshore transport then stops. The numerical scheme is presented. The results are compared to a physical model with good agreement.

Perlin, M. 1979. Predicting beach planforms in the lee of a breakwater. ASCE speciality conference, Coastal Structures 1979, pp. 792-808.

A one line implicit finite difference scheme after Perlin (1977, M.Sc. thesis) is presented. Refraction is accounted for using Snell's law and diffraction using the semi-infinite breakwater theory of Penny and Price.

Perlin, M. and R.G. Dean. 1978. Prediction of beach planforms with littoral controls. 17th ICCE, pp. 1818-1838.

Three models are presented: one line explicit; one line implicit; two line explicit. Simplified refraction and diffraction calculations are incorporated. Several examples are given and the results are mixed. Research needs are listed.

Perlin, M. and R.G. Dean. 1983. A numerical model to simulate sediment transport in the vicinity of coastal structures. U.S. Army, CERC Misc. Report No. 83-10, May.

An n-line numerical model is presented. Features of the model include: longshore and on-offshore sediment transport; a new distribution of longshore sediment transport across the surf zone based on laboratory results; wave climate is specified on the boundary, not necessarily deep water; sediment continuity and transport are implicit equations allowing a large time step; the sediment transport or the contour positions are specified at the boundaries. See also: Perlin and Dean 1985 3-D model of bathymetric responses to structures. ASCE Jl WPCOE 111(2) March, pp. 153-170.

Price, W.A., A.H. Brampton and M.W.Owen. 1981. The prediction of shoreline changes following the construction of coastal harbours. PIANC XXVth International Navigation Congress, pp. 933-940.

An application of the model developed by Ozasa and Brampton (1980). Limited comparisons appear good.

Price, W.A., K.W. Tomlinson and D.H. Willis. 1972. Predicting changes in the plan shape of beaches. 13th ICCE, pp. 1321-1329.

A one line model is presented; the sand volume is represented by a trianglular prism. The continuity equation for sediment in the alongshore direction is solved in two ways. In one the equation is differentiated and the difference form developed; in the other the difference form is written first, and substitution made for the volume. The latter is considered better because it is "exact" and various relations for the volume can be used, even if they are not easily differentiable. Furthermore, less computation time is required. The only drawback is that the volume and the location of the shoreline are not known at the same locations, so boundary conditions are difficult to define. The model was compared to a physical model (using coal as the sediment) and results are described as reasonable. The next step is to include refraction. See also: Willis and Price (1975) Trends in the application of research to solve coastal engineering problems. In "Nearshore Sediment Dynamics and Sedimentation" ed. by J. Hails and A. Carr, John Wiley and Sons, pp 111-122. The model is described again briefly. It is improved to allow beach changes to effect refraction.

Sato, K., T. Asakawa, R. Kawamata. 1983. Applied numerical model for estimation of net sand transport. ICCPEDC, pp. 1178-1191.

A numerical model is presented to estimate bathymetry changes, taking into account refraction and diffraction and currents. Sediment transport is modelled outside the surf zone only. The model is neither calibrated nor verified.

Wang, J.D. 1980. Criterion for stability of shoreline planform. 17th ICCE, pp. 1295-1305.

Examines model for stability of plane beaches to determine under what conditions they will no longer remain straight.

Wang, H., R.A. Dalrymple and J.C. Shiau. 1975. Computer simulation of beach erosion and profile modification due to waves. ASCE speciality conference, Modeling Techniques 1975, pp. 1369-1384.

The method of Noda et al. (1974) is used to determine the wave height and direction at grid points, not on rays. The relation of Komar and Inman is used to calculate the gross amount of sand transport; assuming suspended load, a method is devised to apportion the littoral drift across a section. The relation for longshore current derived by Longuet-Higgins using radiation stress is employed. The amount of erosion or deposition for each beach grid is found by multiplying the net littoral drift by the respective distribution factors across the surf zone. The equilibrium profile results when all the distrbution factors become equal.

Walton, T.L., Jr. and T.Y. Chin. 1979. A review of analytical techniques to solve the sand transport equation and some simplified solutions. ASCE speciality conference, Coastal Structures 1979, pp. 809-837.

A one line evolution model equation is derived using two different approaches: Shore Protection Manual relation; assumption of totally suspended load. An equilibrium profile is assumed. The model is not valid where diffraction is important. The author points out that the form of the equation is the same as the heat diffusion equation, and that some situations have analytical solutions, such as that solved by Pelnard-Considère.

Watanabe, A. 1982. Numerical models of nearshore currents and beach deformation. Coastal Engng. in Japan 25, pp. 147-161.

A one line model is developed in which waves, currents and beach deformaton are simulated. The model includes the nonlinear effects of mean momentum convection, wave setup and shore flooding, and wave current interaction.

Willis, D.H. 1977. Evaluation of along shore transport models. ASCE speciality conference, Coastal Sediments 1977, pp. 350-365.

A beach evolution model using a CERC type formula for longshore transport is compared to a new model employing a modified method of Ackers and White to calculate the sediment loads. The method of Abernathy and Gilbert (circular arcs across triangles) is used to refract the waves to the breaker zone. The alongshore current model uses the output from the refraction portion of the programme to calculate alongshore currents (Longuet-Higgins). From the velocity distribution the alongshore discharge of sand is calculated. There are problems with the stability of the longshore current model. See also NRCC Mech. Engng. Div. Report, HY-92, March,1978.

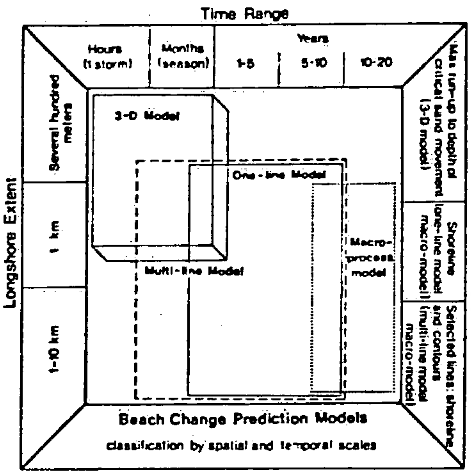

Fig. 1 Classes of numerical models.

(from Kraus, 1983)