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COMMENTS ON MODELING ALLUVIAL RIVERS

Stevan BRUK

Consultant
c/o UNESCO SC/OPS
7 place de Fontenoy
75007 Paris, France

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Abstract

The main criterion of modeling is how well it serves to support the right decisions. Predictive capability depends not only on correct simulation of sedimentation phenomena, but also on the nature of the decision which has to be supported. A code for simulating sediment phenomena consists of its uncontested hard core and the protective belt, comprising the auxiliary hypotheses, assumptions and parameters. Calibration of complex models by integrated effects is ambiguous because the same effects can be obtained by different sets of parameters, the errors sometimes canceling out each others. Increasing the complexity of a model can improve its simulation capability, but introduces increasing data error. Long term prediction of river phenomena is limited because of the chaotic response of the highly non linear relationships. In the light of the above difficulties, a pragmatic approach to river modeling is suggested, based on site-specific simulation rather than on generally valid codes.

Keywords: rivers, sediments, simulation, modeling, prediction.

Introduction

The purpose of this paper is to comment on some questions related to modeling of alluvial rivers, which increasingly attract the attention of the profession. Rather than discussing modeling details, these questions are viewed from a broader perspective of the potential user, the river engineer or decision maker, insisting on a pragmatic approach to an urgent engineering task.

Reference to several excellent, recently published papers on the use of models for solving river problems [CUNGE (1989); DE VRIES et al (1991); DE VRIES (1993)] encourages the writer to restrain this paper[1] to short comments, avoiding lengthy explanations, posing questions rather than offering answers.

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[1] This paper is based on the contribution of the writer to the Workshop on Understanding Sedimentation Processes and Model Evaluation, August 1993, San Francisco.

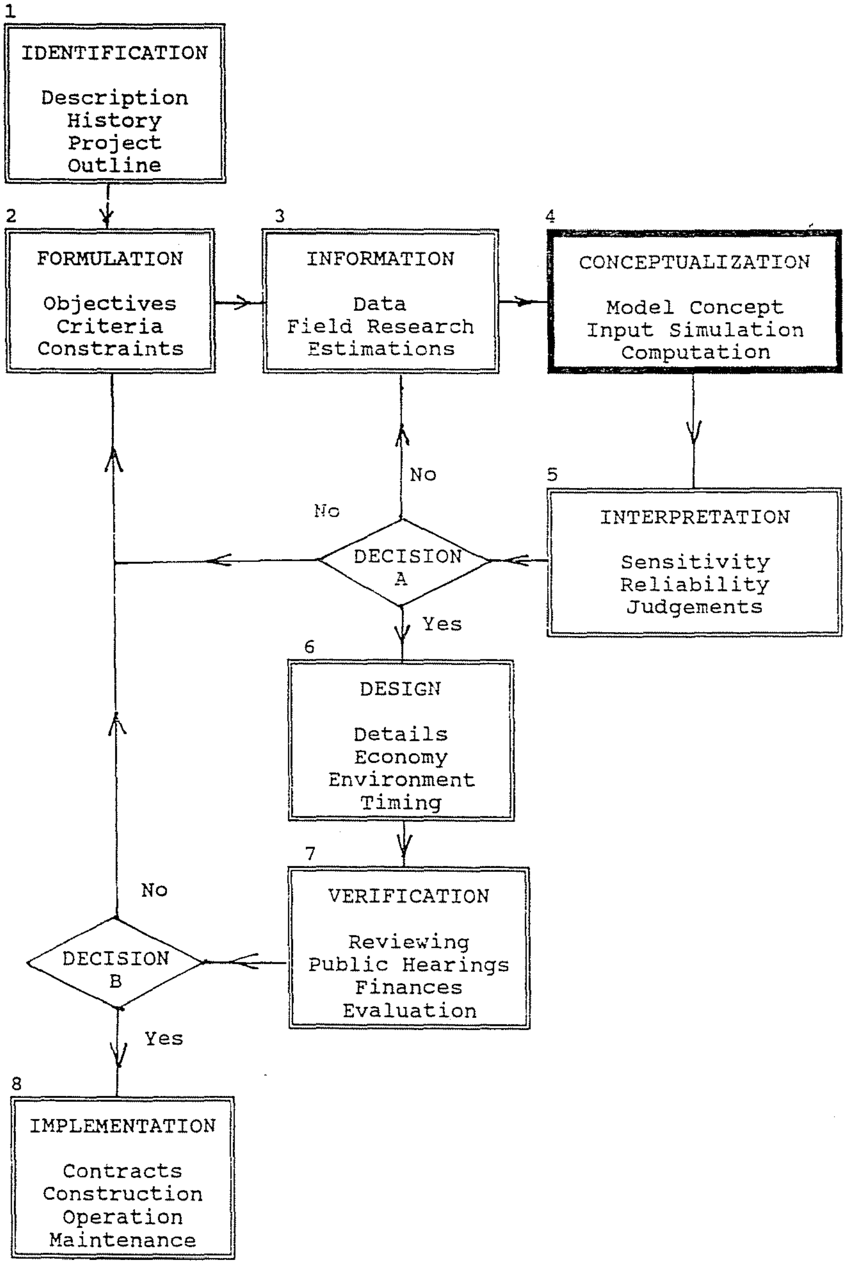

Fig. 1. Flow chart of project activities. (The modeling is comprised in step 2.)

On the Predictive Capability of Models

Modeling of sediment phenomena is not an objective by itself: models are made to help decisions (DJORDJEVIC, 1993). The model is part of the decision process, leading from the formulation to the implementation of a project (*Fig. 1*). Thus, the main criterion of modeling is not just how well it simulates physical phenomena, but rather *how useful the model was in supporting the right decisions.* The usefulness depends not only on the model, but also on the nature of the problem itself.

The weak point all sedimentation models is the sediment transport function, which is imperfectly known and very hard to verify for prototype data. While the flow of water is comparatively well understood[2], conceptual difficulties persist in the interpretation of sediment transport, especially bed-load transport, bank erosion and accretion, channel mobility. Pragmatically, imperfect theoretical concepts are supplemented by empirical information, based on physical experiment and engineering observation.[3]

Essentially, all bed-load transport formulas correlate data obtained by laboratory flume experiments. D. B. SIMONS (1992) lists some 18 formulas used in the USA and elsewhere, and at least the same number could be added taking into account formulas used in Russia, India, China, etc. Prediction accuracy is 'acceptable' even with an error of 100% (DE VRIES, (1993); verification by data from nature is almost impossible, except in very special, favorable situations LOY, G. et al, 1992; SOEHNGEN et al, 1992). Bed load is practically unmeasurable in rivers during floods, when most of the sediment moves.

Sediment transport is highly sensitive to changes of velocity, i. e. flow conditions, and inversely, velocities (or flow conditions) are much less sensitive to changes in sediment transport. This property of the sediment function is important from the point of view of the predictive capability for different engineering objectives:

- In spite of inaccurate sediment transport simulation, models can successfully predict the flow conditions caused by the change of sediment transport as, for instance, in the case of a sudden increase or decrease of the sediment load.

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[2] Though, simple cases such as flow in composite channels still represent research topics (ACKERS, 1993; SMART, 1992).

[3] The low level of understanding two-phase flow is illustrated by the lack of conceptual unity between such closely related phenomena as alluvial river flow, sediment transport in rigid beds and hydraulic transport in pipes (NALLURI – KITHSRI, 1992).

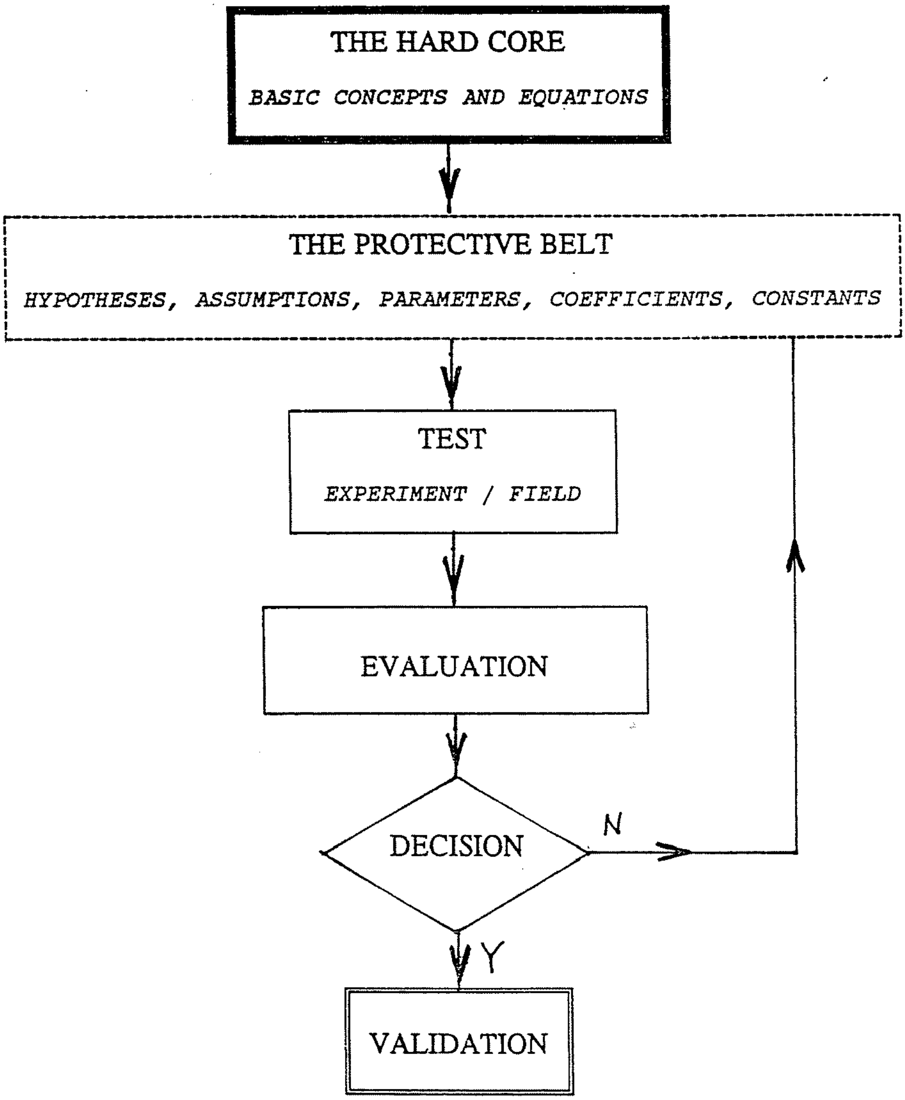

Fig. 2. Validation of a simulation code

- Since the structure of the sediment transport function is better known than the coefficients, the relative values of sediment transport can be evaluated even if the coefficients are not well known.
- If the absolute magnitude of sediment transport is of interest, errors caused by the imperfect knowledge of the sediment transport may jeopardize the predictive ability of the model. Assessment of sediment transport is here more relevant than the computer code of modeling.

Validation of Codes[4] for the Simulation of River Phenomena

An approach to validating codes could possibly be found in the concepts of Imre Lakatos[5] (1970): alike a scientific theory, a code can be considered as consisting of a 'hard core' and a 'protective belt' built around it. The hard core is deducted from theory and cannot be modified without major changes in scientific perception. The 'protective belt' consists of a hierarchy of auxiliary hypotheses, assumptions, parameters and constants. All elements of the protective belt can be adjusted in the light of experiments and field observations, without affecting the hard core and without contesting the validity of the model (*Fig. 2*).

Following this concept, the hard core of river flow simulation should comprise the fundamental equations of hydromechanics, while all the additional hypotheses, assumptions, semi-empirical or empirical relationships (e. g. sediment transport equations) can be included in the protective belt. Whatever the results of testing were, no one would ever challenge the hard core of the model, while the model developers would not hesitate to change any element of the protective belt in order to obtain a good fit between predictions and measurements[6].

Codes often contain speculative arguments and nonsubstantiated hypotheses which are needed to close the system of equations. These should not be closed into the 'hard core', but should be put into the protective belt, open to verification and modifications in the course of validation.

Any simulation code which contains several hypotheses and many parameters can be adjusted to interpret known facts. The acid test whether

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[4] Difference is made here between the code, which is the mathematical pro T U *(* modeling, and the model, which is the application of the code to a case study. See Cunge 1989).

[5] Rather than to scientific theories, I. Lakatos refers to 'research programmes', such as Newtonian mechanics, quantum physics, etc. His ideas are freely used here to assess codes for the simulation of physical phenomena in an applied branch of science.

[6] Typically, modelers of river morphology are indifferent to applying this or that sediment transport equation in their models see (Fan, 1988 and Fan – Yen, 1992).

it represents a creative, progressive approach is its ability to predict new facts, which then are proved by experience.

On Model Calibration

The comparison between model and prototype is based on measurable quantities such as water levels, channel forms, etc, which are in fact integrated effects of the modelled fluvial processes. Now, similar integrated effects can be obtained by a quasi infinite combination of the multitude of relationships and parameters built into the model.

Therefore, *corroboration of predicted and observed cumulative effects does not prove each and every parameter or relationship:* many of these can be just wrong, the errors mutually canceling out each other, For instance, overestimated sediment input compensated underestimated trap efficiency of the Iron Gates Reservoir on the Danube (VARGA et al, 1989), making the prediction acceptable, in spite of the imperfections of the model.

Additional difficulties arise from the lack of reliable historical data. It is rightly recommended to concentrate efforts on measurement and data collection, in order to create reliable data bases for model development and calibration (JOLANKAY 1992). In the lack of such data, just like in the case of scale models, predictive calculations are often carried out by incompletely calibrated and non-validated mathematical models, in good faith that the results will not be far from reality. The predictions are better for strong interventions into the natural regime of the river and are the worst when comparing two 'natural' states of the river.

On Limitations in Improving Simulation of River Behavior

The capability of a model to simulate reality can be improved by better mathematical description of the phenomena and by including more parameters into the analysis. However, higher complexity of the model requires more input data, and each data carries a certain amount of error: the more parameters are used in the model, the larger is the cumulative effect of data error.

From a pragmatic point of view, best is the simplest code with lowest data requirements, but still able to support efficiently the required engineering or management decisions. Conceptualization should start with the simplest model possible, increasing gradually its complexity in response to requirements for higher precision of predictions.

Alternative Approaches to Explaining River Behavior

Observers were always impressed by the life-like behavior of rivers, their amazing capability for self-adjustment to a variable environment. For instance, rivers adapt resistance as a response to change of water flow or sediment input. Each and every part of the river changes in time, but the identity of the whole remains.

Certain laws of comportment of such systems can be detected, even without explicit knowledge of all the factors by which it is influenced. This is why *very useful information has been extracted from the observation of river forms,* such as the well-known 'regime formulae' for rivers or canals (BLENCH, 1969), or the study of morphometric relationships (VELIKANOV, 1955).

The advantages offered by approaching rivers from the side of general physics are also far from being exhausted (BAGNOLD, 1966; YANG - KONG, 1991). Pragmatic approach to the solution of river problems should not disregard these principles, although they cannot always be substantiated by exact arguments. Their heuristic value is undeniable.

Is Long-term Prediction of River Evolution Possible?

An all important change in perceiving modern physics is the growing recognition of the *inherent impossibility of long-term predictions for highly non-linear systems* (DAVIES - GRIBBIN, 1992):

> ' ... because no system can in principle be described with perfection, completely accurate long-term weather forecasting can never be achieved — *nor can accurate forecasting of any other chaotic system.*[7] We stress that this is not just a human limitation. The Universe itself cannot 'know' its own working with absolute precision, and therefore cannot 'predict' what will happen next, in every detail.'[8].

This explains the difficulty in simulating movable bed rivers, which are complex non-linear systems with stochastic input: *the incapacity of predicting long-term evolution of rivers is not just a human deficiency due to imperfect knowledge, but is caused by inherent properties of the river itself.*

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[7] underlined by S. B.

[8] Paraphrasing the above statement, one could say: 'It is not just that we don't know what will happen next to a river: the river itself cannot know that'.

The impact of this on simulation of fluvial processes has yet to be evaluated. A mathematical or scale model which would simulate a real river near to perfection, should manifest the same indeterminism as the river itself: repeated tests would result in different evolutions of the river, the difference increasing with the increase of time-span of prediction[9]. The definition of the *time-scale of acceptable prediction accuracy* is thus an important research task of simulation.

Pragmatic Approach to Modeling River Phenomena

The above comments only point out some difficulties and limitations of modeling rivers for engineering purposes, and by no means are intended to challenge its general usefulness. At the present moment, however, the obstacles on the way of a general solution of river modeling call for a pragmatic approach, responding to the urgent needs of the profession.

The ultimate criterion is the support given by the model to reach the best decisions and it is far better to base decisions on even imperfect models than to rely on intuition, vague impressions or simplified calculations. The interpretation of model results is then a joint task of both the modeler and the user of the model.

A pragmatic approach to river modeling would consist in developing site-specific methods based on carefully analyzed case studies rather than general simulation codes, which cannot yet be validated. Large rivers like the Brahmaputra, Mississipi, Yangtze, Volga, Nile, etc, merit to be explored and described one-by-one, individually, critically evaluting the factual experience gained in carrying out river projects and finding out the best, site-specific means and methods of simulation. Medium sized and small rivers probably should be classified into categories, deciding about the most appropriate ways of modeling for each category.

In parallel with the indispensable efforts to develop generally valid simulation codes, the urgent need of the engineering profession for decision support to river projects could temporarily be responded by site-specific monographs for selected rivers and river categories. No need to say that this would need intense cooperation on common principles which would make such monographs mutually comparable.

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[9] Reference is made to the statements of E. MOSSELMAN (1992): 'Chaos in river morphology is still a hardly explored subject, ... ' and also: 'Chaotic behavior of rivers would imply that, beyond a certain limit, long-term predictions of bed topography patterns or river platforms cannot be made more accurate by, for instance, improving the sediment transport formula or bank erosion equation'.

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