Chapter 2

1-D HYDRODYNAMIC and TRANSPORT MODEL SYSTEMS

Contents

We begin with a restatement of the physical problem and a definition of terms.

2.1 Physical Problem

Unsteady flow and conservative contaminant (e.g. salinity) transport in a network of tidal channels.

2.2 Forcing

Downstream tide stage or discharge and upstream river stage or discharge hydrographs at open boundaries[1]. Contaminant concentration or contaminant flux at downstream and upstream open

[1]Boundaries are either *open* or *closed*. Closed boundaries are no flow (solid wall) boundaries, where $Q = 0$. These are uniquely defined as to both spatial location and physical character. In contrast, open boundaries have neither a unique spatial location nor a unique physical character. The only certainty is that they are open to flow. Their location is determined as part of the modeling process, and their physical character depends on the their location and precisely what is happening there.

boundaries. Non-point lateral inflows (outflows) of water and/or contaminant along the channel. Point contaminant sources.

2.3 Space and Time Resolution

Adequate resolution of tide and flood hydrographs, and of point and non-point sources.

2.4 Field Equations

Incompressible flow is assumed, in which the mass density ρ is constant.

Mass conservation for water.

$$\underset{\text{storage}}{b\frac{\partial \eta}{\partial t}} + \underset{\text{advection}}{\frac{\partial Q}{\partial x}} = \underset{\substack{\text{lateral}\\\text{inflow}}}{q} \tag{2.4.1}$$

in which x is local position, t is local time, $\eta(x,t)$ is the local water surface elevation to a fixed horizontal datum, $Q(x,t)$ is the local discharge or cross-section-integrated flow, $b(x,t)$ is the local surface width and $q(x,t)$ is the local lateral inflow per unit length. NOTE in particular that η is NOT the water depth (see Figure 2.1). Each term in Equation 2.4.1 has dimensions $\mathrm{L}^2\mathrm{T}^{-1}$; in FSS (ft-sec-slug) units, as adopted in all the subsequent balances, this is $\mathrm{ft}^2\mathrm{s}^{-1}$.

Momentum conservation for water.

$$\underset{\substack{\text{temporal}\\\text{inertia}}}{\frac{\partial Q}{\partial t}} + \underset{\substack{\text{advective}\\\text{inertia}}}{\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)} = \underset{\text{gravity}}{-gA\frac{\partial \eta}{\partial x}} - \underset{\text{friction}}{\frac{\tau_0}{\rho}P} \tag{2.4.2}$$

in which g is the gravitational acceleration, $A(x,t)$ is the local flow cross-section and $P(x,t)$ is the local wetted perimeter. The boundary shear $\tau_0(x,t)$ is estimated from a friction model, either

$$\tau_0 = \begin{cases} \dfrac{f}{8}\rho\dfrac{|Q|Q}{A^2} & \text{for Darcy-Weisbach model} \\ \dfrac{g}{\mathcal{C}^2}\rho\dfrac{|Q|Q}{A^2} & \text{for Chezy model} \\ \dfrac{g}{R^{1/3}}\left(\dfrac{n}{1.49}\right)^2\rho\dfrac{|Q|Q}{A^2} & \text{for Manning model [FSS (ft-sec-slug) units]} \end{cases} \tag{2.4.3}$$

in which f, $\mathcal{C}$ and n are the Darcy-Weisbach, Chezy and Manning friction factors respectively. $R = A/P$ is the local hydraulic radius. Each term in Equation 2.4.2 has dimensions $\mathrm{L}^3\mathrm{T}^{-2}$; in FSS units, as adopted in all the subsequent balances, this is $\mathrm{ft}^3\mathrm{s}^{-2}$.

Mass conservation for conservative contaminant.

$$\underbrace{\frac{\partial}{\partial t}(AC)}_{\text{comtaminant storage}} + \underbrace{\frac{\partial}{\partial x}(QC)}_{\text{comtaminant advection}} = \underbrace{\frac{\partial}{\partial x}\left(E_x A \frac{\partial C}{\partial x}\right)}_{\text{comtaminant dispersion}} + \underbrace{S}_{\text{comtaminant source}} \tag{2.4.4}$$

where $C(x,t)$ is the local cross-section-averaged contaminant concentration, $E_x(x,t)$ is the local longitudinal dispersion coefficient and $S(x,t)$ is a local point or non-point contaminant source. Each term in Equation 2.4.4 has dimensions $\mathrm{L}^2\mathrm{T}^{-1}$; in FSS units, as adopted in all the subsequent balances, this is $\mathrm{ft}^2\mathrm{s}^{-1}$.

Assuming that the friction factor, the lateral inflow q and the contaminant sources S can be defined, the dependent variables[2] are the local water surface elevation $\eta(x,t)$ and the local cross-section-integrated flow $Q(x,t)$ in the hydrodynamic Equations 2.4.1 and 2.4.2 and the local cross-section-averaged contaminant concentration $C(x,t)$ in the contaminant transport Equation 2.4.4. In a natural channel, the surface width b, the flow area A and hydraulic radius R are dependent on η and x.

2.5 Channel Geometry

b, A, P and R are space and time variable. Both the local water surface elevation $\eta(x,t)$ and the local bed elevation $Z(x)$ are measured from a fixed HORIZONTAL datum plane (MSL or NGVD or ...)

2.6 Schematic Channel

In most of the present schematic applications, the channels have a trapezoidal cross-section, as sketched in Figure 2.1 The bed width B will be fixed for each schematic channel reach but may vary from reach to reach. The bed elevation Z may change along the reach, at most in a linear manner with distance x along the channel. The side slopes of the schematic channels are 1 (vertical) to SS (horizontal). All trapezoidal channels have $\mathsf{SS} = 2$. The special case of a rectangular channel[3] has $\mathsf{SS} = 0$.

In most of the schematic problems outlined in the following, lateral inflows q and contaminant sources S are zero throughout. The exception is hydrodynamic problem H8, whose specific focus is lateral inflow.

[2] The flow area $A(x,t)$ is an appropriate substitute for $\eta(x,t)$. In this case, $\eta(x,t)$ would be eliminated from the conservation equations, by the substitutions $\partial A/\partial t = b\partial\eta/\partial t$ in Equation 2.4.1, and $\partial A/\partial x = b\partial\eta/\partial x$ in Equation 2.4.2.

[3] H9 through H11

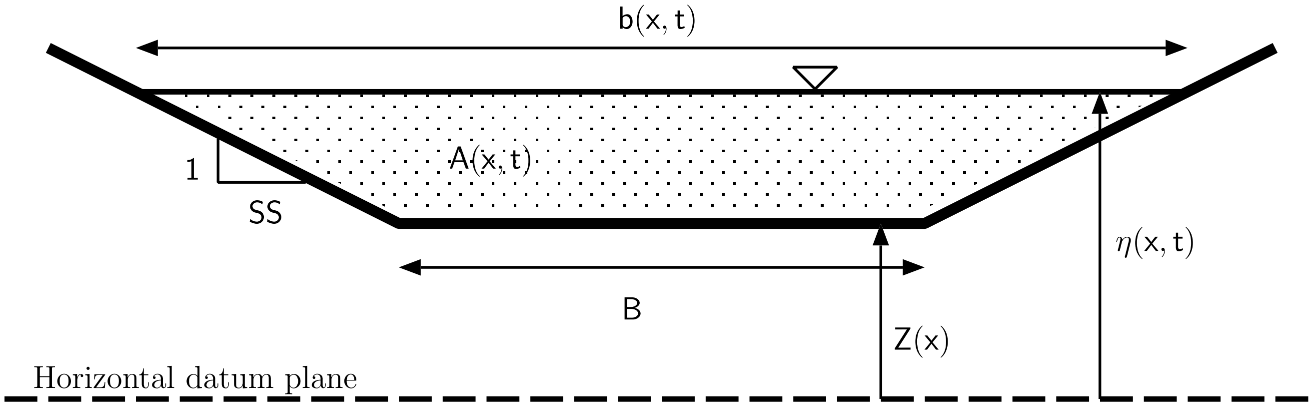

Figure 2.1: Cross-Section of Schematic Channel.

2.7 Evaluation

A set of benchmark test for the routine evaluation of numerical models of the hydrodynamics (H1 through H11) and contaminant transport (M1 through M4) in networks of estuarine channels has been defined.

Each problem has a separate focus, and the details are deferred to Chapters 4 through 18. Two modes of evaluation are routinely employed:

1. analysis of predicted response patterns, and

2. analysis of conservation balances

The expected response pattern changes with the focus, and is discussed in context in the following chapters.

Though numerical models of unsteady, gradually-varied flow are theoretically based on the continuous Equations 2.4.1 and 2.4.2, the equations actually solved by numerical model code are discretized transformations of these equations. Independent confirmation that the numerical predictions do indeed satisfy Equations 2.4.1 and 2.4.2 is a useful independent check on a numerical code. The methodology for these analyses is outlined in Appendix D.

A direct comparison of the predicted response from the participant models would potentially be useful. The present value was unfortunately compromised by

- the absence of a datum for comparison

  With the inclusion of nonlinearities in the field equations, analytical solutions are not possible. An exact solution is not available.

- participant re-definitions of the problem statements

  These were generally minor (different cross-section shape, different space step, different time step, different boundary conditions, ...), but sufficient to question the source of any differences.

Problem H11, introduced late in the review process, provided the most suitable opportunity for direct comparison. But even here the exact solution is unknown, and the comparison was to another code at a very fine resolution.

The benchmark tests are designed to exercise the complete response spectrum of a numerical model, including aspects such as mass and momentum balances, free and forced modes, boundary forcing and numerical fidelity.

Not one of the benchmark tests is a routine application of the one-dimensional hydrodynamic and transport models to the San Francisco Bay-Delta waterways. Each is a focussed schematic problem that is intended to explore the response envelope, and in some cases to stretch that envelope. Each problem is a legitimate sub-set of all the processes that make up a complete flow pattern.

Not all response patterns come to the fore in every problem. It may be that some aspects exercised by the benchmark tests do not have a significant role in historical Bay-Delta modeling. But it cannot be said with certainty that future scenarios (levee breaks, flow control structures, diversions, new channels, extreme floods, tsunami penetration, salinity barriers, . . .) will not accord them an enhanced role.

And not all models will have an established capability to accommodate every test. This is expected. But it is also an important observation in identifying both the range of applicability and the limits of applicability.