inSTREAM-2D: The Individual-based Stream Trout Research and Environmental Assessment Model with Two-Dimensional Habitat Simulation

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Chapter 1

Introduction and Overview

1.1 Objectives

This report describes *inSTREAM-2D*, a new version (number 4.3) of the Individual-based Stream Trout Research and Environmental Assessment Model that uses two-dimensional hydrodynamic simulation to represent hydraulic habitat. *inSTREAM* is an individual-based model designed to represent the effects of habitat variables such as flow, temperature, turbidity, channel shape, and hiding cover on trout populations[1][2]. Spatial variation in habitat is represented by depicting the stream environment as a collection of cells; conditions are assumed uniform within a cell but key variables such as depth, velocity, and distance to hiding cover vary among cells. Previous versions of *inSTREAM* used the one-dimensional PHABSIM hydraulic models[3] to represent how cell depth and velocity vary with flow.

The PHABSIM approach has the drawback of representing the stream as a collection of rectangular cells, so channel shape is distorted (Fig. 1.1). The PHABSIM models are also highly empirical, relying on measurements of depth and velocity in each cell for accurate simulation. This empirical approach makes PHABSIM useful for small streams where low depths and complex hydraulics make hydrodynamic models difficult or impossible to use.

For larger streams, hydrodynamic models have important advantages. This class of model is highly mechanistic, relying more on physical laws (e.g., conservation of mass and momentum) and less on detailed field data for accuracy. Field data requirements are limited to a one-time survey of channel shape and observations of water surface elevation for calibration of specific flows. Hydrodynamic models retain the channel's true shape in two dimensions, so cells are no longer rectangular.

In this project we modified *inSTREAM* to use two-dimensional habitat

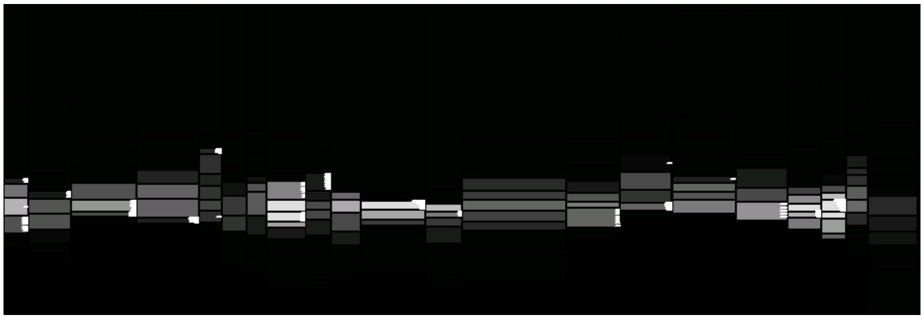

Figure 1.1: Habitat depiction in previous versions of *inSTREAM*. Flow is from right to left; cells are shaded by depth (deeper cells are whiter). Fish are depicted as white line segments at the upstream end of each cell. Because cells must be rectangular and fall in straight transects across the channel, the true channel geometry is distorted.

input and then conducted a pilot application of *inSTREAM-2D* to the South Fork Eel River. We used the RMA2 hydrodynamic model; RMA2 is a widely used model originally developed by the US Army Corps of Engineers. We used RMA2 within the "Surface water Modeling System" (SMS), a package of commercial software tools for building the model's mesh and displaying and interpreting its results (see: www.ems-i.com).

1.2 Participants and Acknowledgements

This project was conducted by Lang, Railsback & Associates (LRA) and the USDA Forest Service, Pacific Southwest Research Station, under Joint Venture Agreement 03-JV-11272133-025, *Individual-based Modeling of Stream Trout Populations*. In-kind contributions of software, documentation, and LRA labor were provided by the Electric Power Research Institute under their agreement EP-P3215/C1529, *Green River Trout and Pikeminnow Modeling*, with LRA. Additional support was provided by the National Center for Environmental Research (NCER) STAR Program, US Environmental Protection Agency, under EPA Agreement RD-83088601-0 with Humboldt State University.

The Forest Service lead scientist was Bret Harvey, Redwood Sciences Laboratory. Diane Sutherland assisted with field data collection and geographic information system (GIS) analysis.

The LRA project manager was Steve Railsback, and Margaret Lang participated in field studies and hydraulic modeling. Dr. Eileen Cashman conducted the hydrodynamic model calibration as a subcontractor to LRA. Steve Jackson, also a subcontractor to LRA, designed and implemented the changes in *inSTREAM* software.

1.3 Report objectives and format

This document serves as the final report for Joint Venture Agreement 03-JV-11272133-025. Its objectives are to:

1. Document field data and methods for the SF Eel River pilot application site,
2. Document hydrodynamic modeling methods,
3. Document changes in the assumptions and methods of *inSTREAM* made to accommodate two-dimensional hydraulic habitat input, and
4. Document the resulting changes in *inSTREAM*'s software (including input files and graphical displays).

Each of the following chapters addresses one of these objectives. Chapters 4 and 5 serve as documentation of *inSTREAM-2D* and its software by describing the ways it differs from the completely documented[1] previous version.

A copy of the *inSTREAM-2D* software, with input for the SF Eel River site, will be delivered to the Forest Service with this report.

Chapter 2

Study Site and Field Methods

2.1 Study Site

The site for the pilot application of *inSTREAM-2D* is a reach of the South Fork Eel River near Myers Flat, Humboldt County, California. The reach is approximately 1 km in length, with its downstream end at Lansdale Bar. This site was chosen to represent habitat of the mainstem SF Eel, which is typified by extensive gravel bars, long pools and shallow riffles, and banks sometimes armored with very large rocks placed to protect adjacent highways. During low flows, the site is dominated by long, relatively deep pools separated by distinct but gentle riffles (Fig. 2.1a). During higher flows, there are no distinct riffles and velocities are high except along the very margins (Fig. 2.1b).

We marked the study site boundaries by setting reinforcing bar pins on both sides of the channel, at both the upstream and downstream ends of the reach. (Some of these pins likely were moved or buried in the high flows of December, 2005.)

2.2 Field Data Collection and Analysis

2.2.1 Channel topography

The primary input to the hydrodynamic model is channel topography data: XYZ coordinates for points that describe the river channel shape in sufficient resolution to capture the hydraulic complexities deemed important for understanding fish responses to flow. The hydrodynamic model operates over a mesh of polygon elements that are determined from the channel topography data, but the model polygons do not necessarily use the points

(a)

(b)

Figure 2.1: The SF Eel study site, at (a) a typical late-summer low flow and (b) a flow of 85 m^3/s. Photo (a) looks downstream toward Lansdale Bar; photo (b) looks upstream from the rock outcrop in the center of (a). Submerged in the center of photo (b) is the gravel bar from which (a) was taken.

measured in the field as their corners; instead, SMS allows polygon corners to be interpolated from the field data. Therefore, the points measured in the field are selected primarily to capture the important local changes in bed slope, in both horizontal dimensions. Because of the way habitat variables were estimated (Sect. 2.2.3), it was not necessary to capture changes in these variables in the topographic survey.

We collected topographic data primarily via total station surveying technology. Once the total station was set up, it was located within a local coordinate system (later linked to UTM coordinates) using temporary benchmarks. Then we collected XYZ for points as needed to define the channel shape. Much of the site is made up of large, relatively flat gravel bars which require few points to define. Likewise, the banks above the active channel (required for modeling flood flows) were surveyed relatively coarsely as they tended to be relatively uniform in slope. Points were collected more densely in areas where slope changed more rapidly, such as in pool bottoms and riffles.

Most of the site could be surveyed on foot, climbing the bank and wading. We used a canoe in pools too deep for wading: one person maneuvered the canoe and held it relatively steady while a second person held the total station target rod on the bottom until a measurement could be obtained.

A total of surveyed 1428 points were used in the hydrodynamic model. These topographic data were imported into SMS for display and review before modeling began (Fig. 2.2).

2.2.2 Hydraulic simulation and calibration data

Running the hydrodynamic model for a specific flow requires, at a minimum, the water surface elevation at the downstream end of the study reach. Additional data on elevation within and at the upper end of the reach is also needed at some flows for calibration (Sect. 3.3). The most complete longitudinal water surface elevation profile was collected at a flow of 1.85 m^3/s, but water surface elevations were also collected at flows of 12, 76, and 56 m^3/s.

To complete a rating curve for the downstream end of the reach (which allows us to simulate any flow by interpolating its downstream water surface elevation from the rating curve), water surface elevations at four additional flows were estimated using an iterative process with RMA2. The rating curve is at Fig. 2.3.

2.2.3 Cell habitat variables

Several static habitat variables are used by *inSTREAM* for each cell: the fraction of cell area providing velocity shelters for drift feeding, a representative distance to hiding cover, and fraction with spawning gravel fraction. In previous applications, these variables were evaluated in the field by laying out the boundaries among cells and estimating values for each cell. This

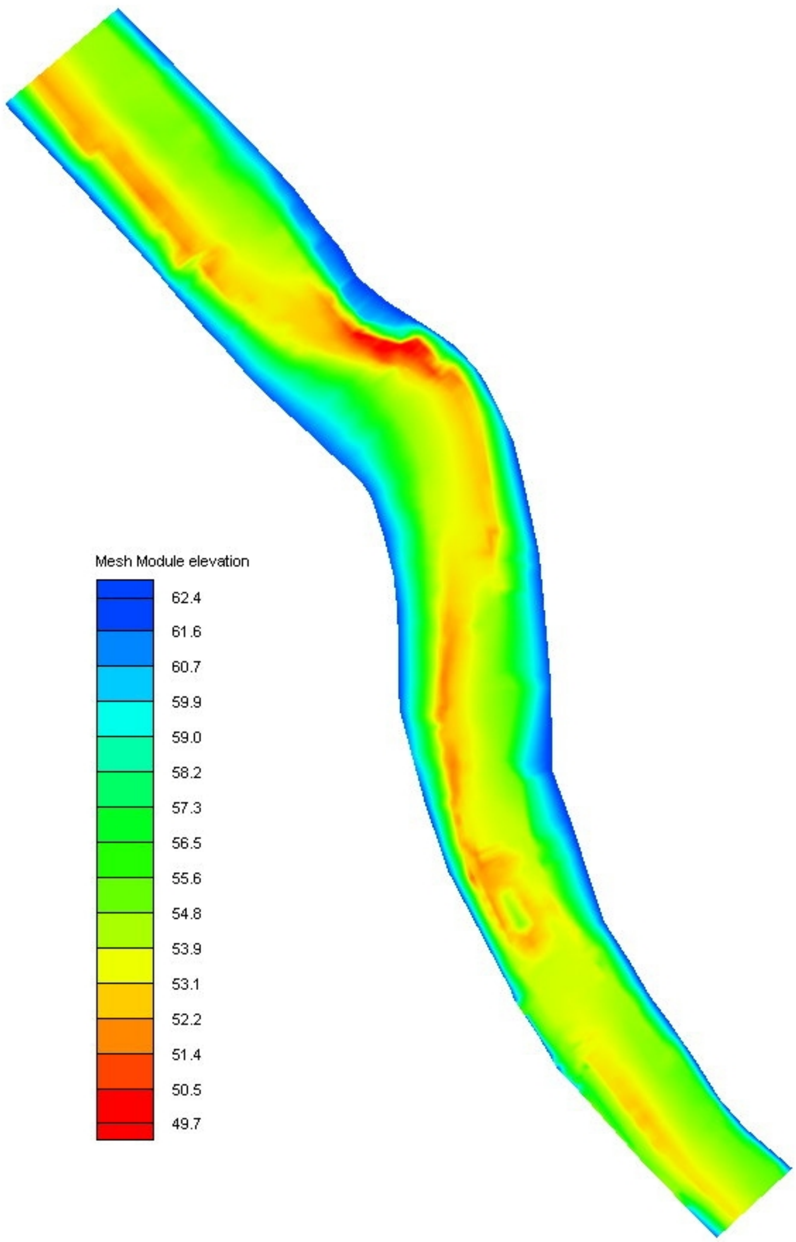

Figure 2.2: Topographic model of the study site, generated by SMS from our field data. Elevations (m) are on an arbitrary local datum.

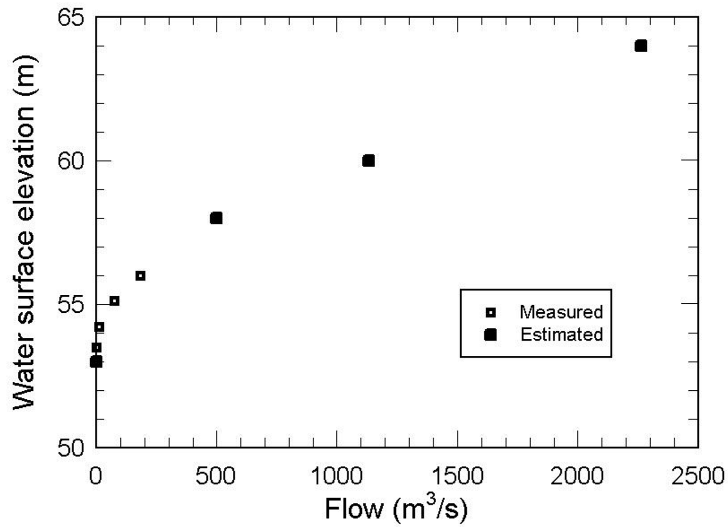

Figure 2.3: Rating curve for the downstream end of the modeled reach. Elevations are on the local datum used in Fig. 2.2.

approach is not feasible for *inSTREAM-2D* because there are many more cells, with their boundaries determined in the office as the hydrodynamic model is built (Sect. 3).

Estimating spawning gravel availability is unimportant for the SF Eel River site because almost the entire active channel has small gravel substrate that could be used for spawning. In contrast, hiding cover is quite rare and hence likely to be critical for predicting habitat use and survival of trout.

To evaluate the distance to hiding cover for each cell, patches of hiding cover were mapped in the field. This mapping used Global Positioning System (GPS) technology, a "Rover" unit with base station and backpack-mounted antenna with data recorder (Fig. 2.4). (Experimentation at the site found the GPS Rover inadequate for the topographic survey because it was insufficiently accurate in the Z dimension—elevation. However, hiding cover location need only be mapped in the X and Y—horizontal—dimensions, so the Rover was sufficiently accurate.) The base station was set up on a mid-reach gravel bar. The mobile antenna was then used to collect XY points defining polygons around patches of hiding cover such as vegetation and large rock substrate.

The three cell habitat variables were then derived in the office using GIS. The *inSTREAM-2D* software exports cell centroid and corner coordinates, which were imported to the GIS and overlain by the field cover survey data. Habitat variable values were then assigned to cells using

(a)

(b)

Figure 2.4: Habitat variable survey techniques. (a) The GPS Rover base station. (b) The Rover's mobile antenna for collecting point locations.

GIS analysis supplemented by field notes. However, the cell fraction with spawning gravel was arbitrarily set to 0.1 for all cells due to the abundance of gravel (making gravel availability unimportant in the spawning site selection algorithm).

2.2.4 Time series input: flow, temperature, and turbidity

Daily values of flow, temperature, and turbidity are input to *inSTREAM* to represent temporal variation in habitat. Flow data are readily available from the US Geological Survey station at Miranda, a few km upstream of the study site (designated as: 11476500 South Fork Eel River near Miranda, CA). Flows have been measured since 1939 at this gage.

Temperature data are much scarcer. Even though water temperatures have been heavily studied in the Eel River basin, the focus has been on summer peak temperatures; values for other times of year are rare. As part of this project, a temperature and turbidity gage was installed at the study site (but destroyed by high flows in December, 2005). For use until adequate data from this gage are available, at least for testing and demonstrating *inSTREAM-2D*, a temperature input file was synthesized using the following methods.

1. Summer temperature data from SF Eel River at Dyerville Bridge (downstream of the study site) were obtained from the Forest Science Project data base. These data include 266 daily minimum and maximum values measured between June and September of 1996-98. Daily mean was estimated as halfway between the reported minimum and maximum.

2. Air temperatures for the same period were obtained from the National Weather Service Cooperative Observer Network station (number 048490) at Standish-Hickey State Park. Daily mean air temperature was estimated as halfway between the reported minimum and maximum.

3. A correlation model was built to relate the measured summer water temperatures to air temperature, river flow (from the USGS gage at Miranda), and day length (hours of daylight, calculated using the same algorithm used by *inSTREAM*). The model is:

   $$T_W = 0.184T_A + 1.52L - 1.63\ln Q - 1.88$$

   where T_W is water temperature, T_A is air temperature, L is day length (hr), and Q is flow (m^3/s. This model was used to calculate water temperature for days lacking measured values. This is not a reliable approach because the model was fit to summer data but applied year-round.

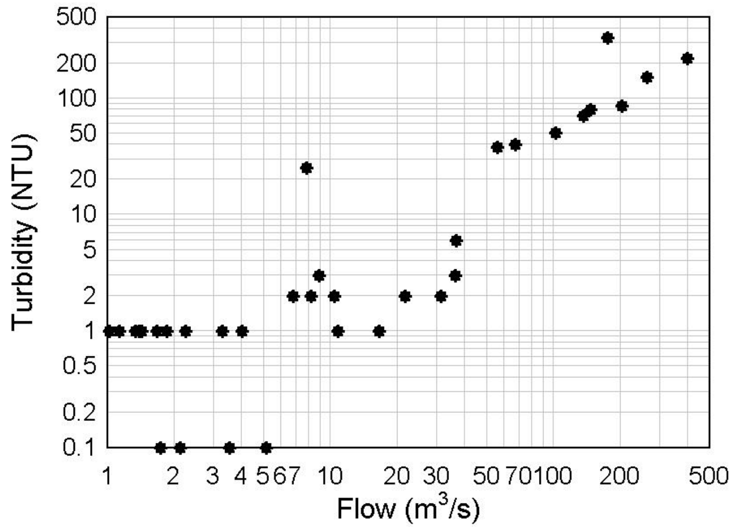

Figure 2.5: Relation between turbidity and flow from USGS Miranda gage data.

4. However, the air temperature data are available only from June 1996 through September, 2001. For other times, the 1996-2001 air temperature record was simply repeated.

The resulting temperature record has peak annual temperatures of about 23C occurring in August, and annual minimum temperatures of around 5C.

Preliminary turbidity input were developed from US Geological Survey data. At its Miranda flow gage, the USGS collected one turbidity sample (in nephelometric turbidity units, NTU) per month from October, 1997 through September, 1980. Comparison to flow occurring on the days that samples were taken indicates a strong relationship, but one that is not particularly good in the range of 5-50 NTU where *inSTREAM* is most sensitive to turbidity (Fig. 2.5). To reduce error within this range, we estimated daily turbidity input from daily flow using the relation:

$$if\,(Q < 60)\;\; U = 0.53\exp\left(0.065Q\right);\; else\, U = 0.56Q - 6$$

Chapter 3

Hydrodynamic Simulation

3.1 The Hydrodynamic Model

RMA2 is a finite-element hydrodynamic model, meaning that it solves physical equations (for conservation of mass and momentum, and for the counteracting forces of gravity and bed friction) among small spatial *elements*. This model is two-dimensional in the horizontal dimensions, meaning that the elements can be thought of as bottom-to-top vertical columns within the river, with velocity averaged over their depth. The elements can be 3- or 4-sided polygons, and are delineated by *nodes*, points in the horizontal plane. Corner nodes define the corners of the polygon; two, four, or even more elements share each corner node. (The model also uses *midpoint nodes* for computation; these are points halfway between two corner nodes.)

RMA2 is also a dynamic model, meaning that it can simulate how depth and velocity changes over time as flow at the upstream end of the reach is varied. However, we do not use this capability, instead simulating a series of steady flows and exporting the depth and velocity of each element, at each flow, to *inSTREAM*. To simulate a flow, RMA2 needs as input the water surface elevation at the downstream end of the reach corresponding to that flow.

3.2 Spatial Resolution

A key question for any model is what spatial resolution to use. For *inSTREAM*, this question requires consideration of both hydraulic and biological processes. Both RMA2 and *inSTREAM* represent space as two-dimensional cells (or elements), but the reasons for choosing cell sizes differ between the two models. The foraging component of *inSTREAM* was designed assuming cell velocity represents the mean water column velocity over an area at least as large as the feeding territory of an adult trout; hydraulic complexities at smaller scales are treated as velocity shelter within the cell. Users of RMA2 must choose element sizes that provide the level of hydraulic detail they need; the model is capable of simulating small-scale eddies etc. but only if sufficiently detailed topographic input and small elements are used. Smaller (and, therefore, more) elements of course increase the computations needed to run RAM2 and may reduce its ability to converge on a stable solution. It is possible to use RMA2 at a higher resolution than that of the trout model, by averaging hydraulic simulation results over the cells used by *inSTREAM*.

For the SF Eel River pilot study site, we chose to use the same spatial grid for both RMA2 and *inSTREAM*. Elements of several m^2 area capture the site's hydraulic characteristics with sufficient accuracy, and are also an appropriate size for *inSTREAM*'s cells (as we continue to represent finer-scale hydraulic complexities via the cell's velocity shelter parameter).

3.3 Mesh Generation and Calibration

The first major step in applying RMA2 to a site is generating the mesh of elements. The mesh must be customized to local topographic features: more detail is needed where topographic and hydraulic gradients are steepest. We used SMS's tools to generate a mesh that captured the site's topography while also trying to maintain element sizes suitable also as cell sizes of *inSTREAM*. The mesh was refined along the steep banks and in areas with more topographic detail, such as the mid-channel bars that are exposed at low flows and the holes and very large boulders picked up in the field survey. The resulting mesh of 1340 elements can be seen in the *inSTREAM-2D* graphics in Chapter 5.

The hydrodynamic model is calibrated by simulating flows at which water surface elevations (and, potentially, velocity at known locations) have been measured (Sect. 2.2.2). Calibration to reproduce observed water surface elevations is normally conducted by adjusting the Manning equation n bed roughness parameter. Elements are each assigned to a *roughness category*; all elements of the same roughness category have the same value of the roughness parameter n. Five roughness categories were used (Fig. 3.1), representing the main channel (highly dominated by small gravel), riffles, sand bars, vegetation, and bedrock. The calibrated n values ranged from 0.02 to 0.05, well within the range of typical values.

A second calibration variable used in RMA2 is the eddy viscosity; lower values allow sharper gradients in velocity magnitude and direction. Calibration values ranged from 500 pa/s for vegetation to 1000 pa/s for the main channel.

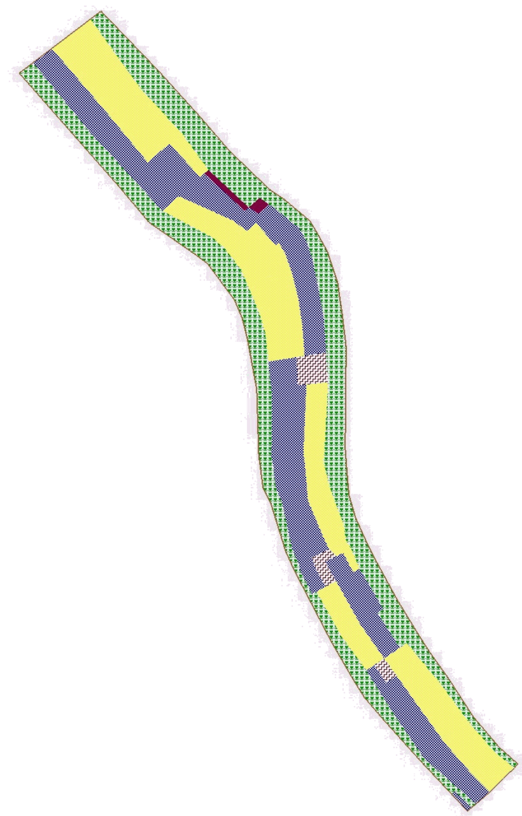

Figure 3.1: Map of roughness categories in the hydrodynamic model. Yellow: sand bar; blue: main channel; green: floodplain vegetation; dark brown: bedrock; zigzag: riffles.

3.4 Simulation Flows

As the input needed to *inSTREAM-2D*, we simulated the depth and velocity in each element over a wide range of flows. The upper end of this range was limited by the lack of calibration data at flood flows; unfortunately, flows three orders of magnitude higher than our highest-flow calibration data set are not uncommon. Using our estimated rating curve (Fig. 2.3), we simulated flows of 2, 12, 76, 185, 500, and 1000 m^3/s. Example results for low and high flows are shown in figs. 3.2 and 3.3.

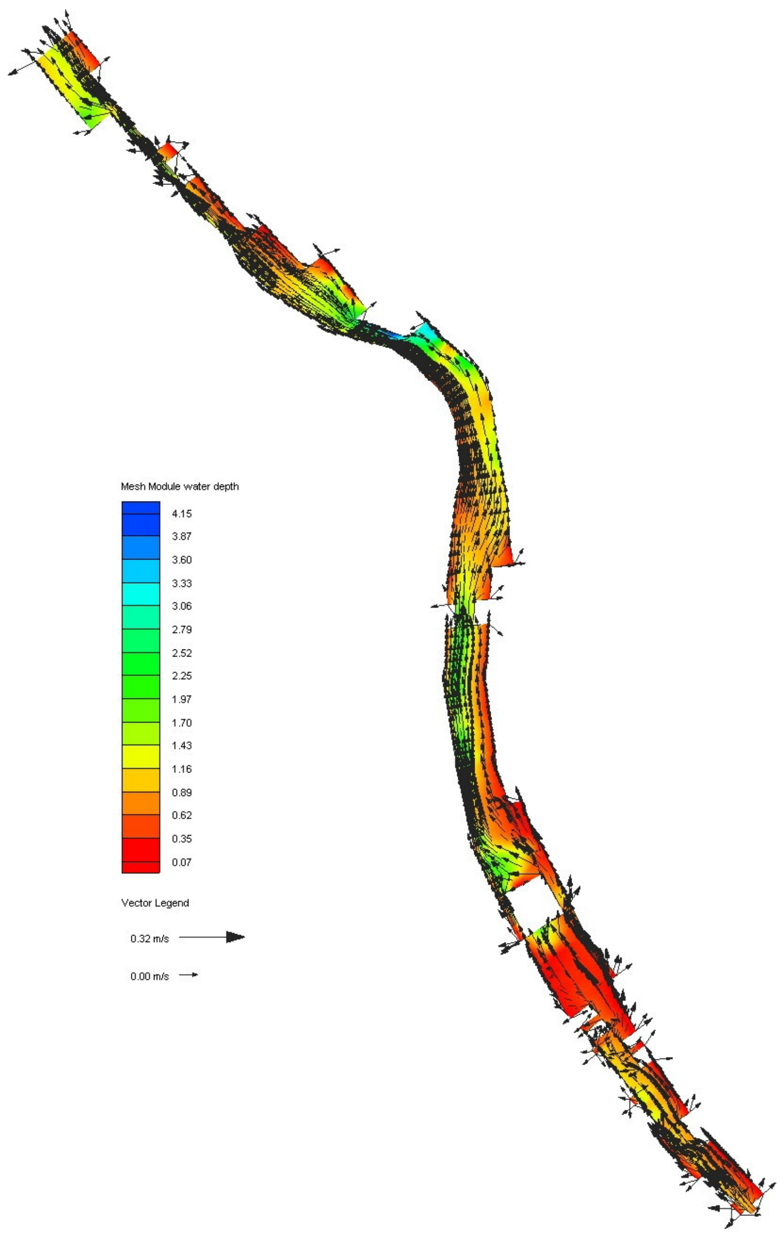

Figure 3.2: Example RMA2 results, for a low flow of 2 m^3/s. The arrows represent velocity and the colors represent depth.

Figure 3.3: Example RMA2 results, for a high flow of 1000 m^3/s. Only velocity is displayed, via color shading.

Chapter 4

Modifications to the Trout Model

This chapter describes changes in the trout model itself—the specific assumptions, equations, and parameter values incorporated in *inSTREAM*—necessary to link it to the two-dimensional hydrodynamic model. We started with *inSTREAM* version 4.2, the current and fully-documented[1] update of the model. Few changes to the model were required, and no changes in rules for trout behavior.

4.1 Multiple Reaches: Disabled

Version 4.2 of *inSTREAM* can simulate multiple habitat reaches, and fish can move from the end of one reach to the end of another reach linked to it. This capability has been disabled in *inSTREAM-2D*. Implementing multiple reaches required a model fish to be able to determine how far it is from the end of its reach, and to identify cells within a certain distance of the end of an adjacent reach. These requirements were easily met with a one-dimensional model but not so easily with the two-dimensional model. The multiple-reach capability likely can be restored without too much trouble.

4.2 Barriers: Disabled

Previous versions had the capability to simulate barriers to upstream movement such as cascades. Barriers were specified only by their location in the upstream-downstream dimension. With the two-dimensional depiction of habitat, it is no longer trivial to represent barriers or to determine whether any cell is upstream or downstream of a barrier. Therefore, this capability has also been at least temporarily disabled.

4.3 Cell Shape, Location, Velocity and Depth

The SMS output used to build the habitat space in *inSTREAM-2D* is (1) a geometry file of the X, Y, Z coordinates of the hydrodynamic model's nodes (Sect. 3.1), and (2) a file of depth and velocity values for each node, with one such file for each of many flows. (See also Ch. 5). The X and Y coordinates are UTM northings and eastings, in m.

The trout model cells have the same size, shape, and relative location as the corresponding RMA2 elements. Each cell has 3 or 4 corner nodes, and therefore is a 3- or 4-sided polygon. The *inSTREAM-2D* habitat space converts the UTM coordinates to a set of internal coordinates, also in m, by subtracting the minimum UTM coordinate. (The lowest UTM northing in the geometry input file is subtracted from all northings, etc.) Therefore, these internal coordinates start at 0,0.

The habitat space also calculates important geometric variables of each cell from the corner node coordinates: cell area and centroid coordinates. The centroid is used as the cells' midpoints were used in previous versions (especially, by fish determining which cells are close enough to consider as movement destinations). Published numerical methods were used to calculate cell area[4] and centroid coordinates[5].

During *inSTREAM-2d* simulations, the velocity and depth of each cell is interpolated linearly from the daily river flow. To make this interpolation, each cell has two "interpolation tables" that contain the depth and velocity at each of the flows simulated in SMS and imported to *inSTREAM-2d* (Sect. 3.4). At flows greater than the highest imported from SMS, depth and velocity are extrapolated from their values at the highest two flows in the interpolation tables. At flows less than the lowest imported from SMS, the depth and velocity in most cells is typically zero because most cells are typically dry at the lowest SMS-simulated flow. For cells not dry at this lowest flow in the interpolation table, depth and velocity are assumed to approach zero linearly as flow approaches zero.

When the interpolation tables are built, *inSTREAM-2D* uses the data for each flow simulated in SMS to determine a velocity and depth for each cell (remember that SMS calculates depths and velocities for each *node*). Cell depths and velocities are determined simply by averaging the values for each of the cell's corner nodes. Users should be aware that this process tends to smooth out the spatial variation in depth and velocity predicted by RMA2.

4.4 Drift Food Availability

Previous versions of *inSTREAM* modeled the availability of drift food in a cell (total grams of food per hour) using the equation: *driftHourlyCellTotal = 3600* $\times$ *cellWidth* $\times$ *cellDepth* $\times$ *cellVelocity* $\times$ *habDriftConc* $\times$ *(cellLength / habDriftRegenDist)*. This equation was formulated assuming that the cell's cross-sectional area defined by *cellWidth* $\times$ *cellDepth* is perpendicular to flow, because the model was one-dimensional. This assumption is not true in *inSTREAM-2D*, in which (a) the direction of velocity can change with flow, and (b) we cannot specify which dimensions of a cell are its "width" or "length".

However, the above equation can be rearranged to refer to cell area (which we do know) instead of depth and width: *driftHourlyCellTotal* = *3600* $\times$ *cellArea* $\times$ *cellDepth* $\times$ *cellVelocity* $\times$ *habDriftConc* / *habDriftRegenDist*. We now use this equation to determine drift food availability.

4.5 Adjacent Cells

When model trout execute their habitat selection method, they start by identifying cells that are within a radius that defines potential movement destinations; this radius increases with fish size. For small trout, there may be no cells (except their current location) within the radius. In this case, the model assumes that trout can at least move to adjacent cells. The one-dimensional versions of *inSTREAM* identified adjacent cells as the four cells directly upstream, downstream, left, and right of the midpoint of the fish's cell. In *inSTREAM-2D*, we instead identify adjacent cells as those sharing any nodes with the fish's cell. Therefore, a small fish will often have eight or more cells to chose from instead of only four.

Chapter 5

Modifications to the Trout Model Software

This chapter documents how the software for *inSTREAM-2D* differs from the fully documented software for version 4.2 of *inSTREAM*[1]. Linking the trout model to a two-dimensional hydrodynamic model required major changes in how habitat input are provided and how the model is displayed in its graphical user interface. Most of the code changes are in the new classes UTMCell (which contains general methods for cells) and FishCell (with cell methods specific to the trout model; these two new classes replace the Cell class of previous *inSTREAM* versions); and in revisions to the class HabitatSpace.

The sections in this chapter each describe a major change in the software. Any input files or outputs not discussed here can be assumed unchanged from version 4.2.

5.1 Habitat Conventions and Units

Previous versions of *inSTREAM* read the X and Y dimensions of transects and cells from theIn previous versions of *inSTREAM*, input describing the size and location of habitat cells was contained in a cell data input file, as described in Sect. 20.4.1 of [1]. This file is not used in *inSTREAM-2D*; instead, input describing the geometry of cells is imported directly from SMS. For *inSTREAM-2D* to work, the coordinates used in SMS need not be actual UTM coordinates but they must follow the UTM format of northings and eastings: X is distance north and Y is distance east of some datum, in meters.

As in previous versions, all input for coordinates is in units of meters (m) but all internal calculations and output are in centimeters (cm). All calculations and output for cell area and distance between cells remain in cm. One new exception to this convention is that the new output files for cell centroids and corner coordinates (Sect. 5.3) are in m.

Because *inSTREAM-2D* no longer uses transects, cells are labeled only by their unique cell number. Unfortunately, cell location cannot be determined directly from the cell number; users must probe the habitat display (Sect. 5.6) to find the location of a cell from its number, or to find the numbers of cells in a particular place.

5.2 Cell Geometry Input File

SMS produces a "geometry" output file, with a filename suffice of `.geo`. *inSTREAM-2D* opens the SMS geometry file and reads from it the coordinates of each nodes associated with each element (Sect. 3.1) in the hydrodynamic model. These coordinates are used to define the location, shape, and size of the trout model's cells.

The name of the geometry file is provided to *inSTREAM* by including it in the `Reach.Setup` file, discussed below (Sect. 5.5).

5.3 Cell Habitat Variables Input File

In addition to the cell geometry input discussed above, the cell data input file used in previous versions of *inSTREAM* also provided two habitat variables that vary among cells but are constant over time: the cell's typical distance to hiding cover and fraction of spawning gravel. One advantage of *inSTREAM-2D* is that these variables can now be generated from maps of hiding cover and spawning gravel, using a GIS. Several changes were made to facilitate use of GIS to generate cell habitat variables.

First, the inSTREAM-2D software generates two output files containing cell coordinates in a format easy to import into a GIS. After the software reads the geometry file and creates the cells, it writes a file called `CellCentroids.rpt` that includes (after three header lines) one line for each cell. These lines contain a cell number and the X and Y (northing and easting) coordinates (in m) of the cell's centroid. The second output file written at the same time is `CellCorners.rpt`. In a similar format it provides the coordinate of each of the cell's corners; each line contains the cell number and then X and Y coordinates of the cell's first through fourth (or third, for three-sided cells) corners.

Second, a new cell habitat variables input file is imported to *inSTREAM-2D*. This file contains the value of distance to hiding cover and fraction spawning gravel for each cell. This file must start with three header lines that are ignored by the computer. Typically the third of these lines contains column labels. Then the rest of the file must contain one line for each cell. The following values must appear on each such line, separated by spaces or tabs.

1. The cell number, an integer. These cell numbers correspond to those in the cell centroids and corner points output files.

2. Fraction of cell area with velocity shelter for drift feeding.

3. The cell's distance to hiding cover.

4. Fraction of cell area with spawning gravel.

The name of the habitat variables file is provided in the `Reach.Setup` file (Sect. 5.5).

5.4 Hydraulic Data Input Files

Hydraulic data input files are how *inSTREAM* imports hydraulic simulation results from a hydraulic model. Each such file includes the results (depth and velocity in each cell) for flows that were simulated in the hydraulic model. These inputs are used to generate interpolation tables within each cell, so for any river flow the cell can determine its depth and velocity. In *inSTREAM-2D* we retain the approach from previous versions of importing, without alteration, files generated by the hydraulic model. The software imports two files generated by SMS for each simulated flow, containing the depth and velocity at each node in the hydrodynamic model. The hydraulic simulation process is:

- SMS is used to simulate hydraulic conditions at steady state for many separate flows over a wide range. This range should encompass the full range of daily flows that will be simulated with *inSTREAM-2D*. (If *inSTREAM-2D* needs to simulate a daily flow outside the range simulated in SMS, it must extrapolate the depth and velocity in each cell. Extrapolation is much less likely to be accurate than simulation in SMS and can produce absurd results in some situations.) Within the range, simulating more flows increases the accuracy of the interpolated depths and velocities. For our pilot application we simulated flows of 2, 12, 76, 185, 500, and 1000 m^3/s; in full applications we would simulate many more flows (perhaps 20) within this range. Different calibrations of the hydrodynamic model can be used over this range, but the same element geometry must be used.

- For each of these single-flow simulations, export a pair of depth and velocity output files from SMS. These files contain depth and velocity values for each node.

- The *inSTREAM-2D* software imports each of the depth and velocity files, without alteration. It builds from them two interpolation tables for each cell, from which the cell can interpolate depth and velocity for any given flow rate. For each flow simulated in SMS, cell depth and velocity are calculated as the mean of values at the cell's corner nodes.

The names of the depth and velocity output files from SMS to be imported by *inSTREAM*, and the flow associated with each file, are specified in the `Reach.Setup` file (Sect. 5.5).

5.5 Reach Setup File

The reach setup file (always called `Reach.Setup`) provides information used to build the representation of space in *inSTREAM*. Even though *inSTREAM-2D* can only simulate one stream reach (Sect. 4), it still uses the reach setup file to provide the names of input files for that reach. For *inSTREAM-2D*, `Reach.Setup` has a format illustrated by this example and explained below:

```
Reach.Setup file.
Only one reach can be input for inSTREAM-2D.
Reach name, param file name, junct.  nums, input file names.

REACHBEGIN
reachName                                     SFEelAtLansdaleBar
habParamFile                                      SFEelHab.Params

habDownstreamJunctionNumber                                     0
habUpstreamJunctionNumber                                       1

cellGeomFile                                    SFEelLansdale.geo
cellHabVarsFile                    SFEelLansdaleCellHabVars.Data
flowFile                                 SFEelAtMirandaFlow.Data
temperatureFile                          SFEelAtMirandaTemp.Data
turbidityFile                            SFEelAtMirandaTurb.Data

reachFlow                                                       2
reachVelocityFile                                  vel_mag_Q2.dat
reachDepthFile                                 water_depth_Q2.dat

reachFlow                                                      12
reachVelocityFile                            velocity_mag_Q12.dat
reachDepthFile                                water_depth_Q12.dat

reachFlow                                                      76
reachVelocityFile                            velocity_mag_Q76.dat
reachDepthFile                                water_depth_Q76.dat

reachFlow                                                     185
reachVelocityFile                           velocity_mag_Q185.dat
```

```
reachDepthFile                         water_depth_Q185.dat

reachFlow                                               500
reachVelocityFile                     velocity_mag_Q500.dat
reachDepthFile                         water_depth_Q500.dat

reachFlow                                              1000
reachVelocityFile                    velocity_mag_Q1000.dat
reachDepthFile                        water_depth_Q1000.dat

REACHEND
```

This file starts with three lines of comments that are ignored by the software. Then one block of information for the single simulated reach. This block starts with the `REACHBEGIN` line and ends with the `REACHEND` line. Within the block, the following variables are input:

reachName: The name of the stream or river reach being simulated.

habParamFile: The name of the habitat parameter file for the reach.

habDownstreamJunctionNumber: An arbitrary integer reach number, ignored in this version of *inSTREAM*.

habUpstreamJunctionNumber: An arbitrary integer reach number, ignored in this version of *inSTREAM*.

cellGeomFile: The name of the cell geometry file (Sect. 5.2).

cellHabVarsFile: The name of the cell habitat variable input file (Sect. 5.3).

flowFile: The name of the daily flow input file (daily flow values for the periods simulated by *inSTREAM*).

temperatureFile: The name of the daily temperature input file.

turbidityFile: The name of the daily turbidity input file.

reachFlow: The first of three lines in each of several blocks of input, one such block for each flow simulated in SMS for input to *inSTREAM-2D* (Sect. 5.4). The value for this line is the flow rate used to generate the velocity and depth files. The value is a floating point variable.

reachVelocityFile: The name of the SMS velocity file for the flow in the previous line.

reachDepthFile: The name of the SMS depth file for the flow in the first line of the 3-line block.

The blocks of input (reachFlow, reachVelocityFile, reachDepthFile) for each flow simulated in SMS need not be in order of ascending flow; the *inSTREAM-2D* software sorts them by flow before using them to build the interpolation tables for each cell.

5.6 Graphical Display

The graphical display of cells and fish (or "animation window") was changed from that of previous versions (Fig. 1.1) to reflect both the two-dimensionality of habitat in *inSTREAM-2D* and the greater size of study sites where it is likely to be used. The new display is shown in Fig. 5.1.

Key features of the display include:

- As in previous versions, cell boundaries are drawn and cells are shaded by either their depth or velocity. (The choice between depth and velocity is made in the `Observer.Setup` file; shade scaling is controlled by code in the `drawSelfOn` method of class `UTMCell`.) Clicking on a cell with the left mouse button opens a probe display showing cell variables such as area, depth, and velocity. Clicking with the right mouse button opens probes to all the fish in the cell.

- Unlike previous versions, individual fish are not displayed. Instead, a colored dot appears in cells that contain fish. (With a large study site, individual fish displayed as in Fig. 1.1 are very difficult to see.) Information on the fish in a cell can only be obtained by right-clicking on the cell to open probe displays to the fish.

- The X dimension is now explicitly east-west and the Y dimension is now north-south: the left side of the display is west and the top is north.

- The HabitatSpace probe display (Fig. 5.2) includes two new methods that can be used to "tag" (color in blue) the cell with a specified number. Simply enter the number in the box to the right of the "tagCellNumber" button, click on the button, and make the model execute at least one more time step; the cell will turn blue.

- As in previous versions, the size of the display can be controlled separately in the X and Y dimensions. In the `Observer.Setup` file, the parameters `rasterResolutionX` and `rasterResolutionY` can be thought of as the number of cm per display pixel: increasing their value reduces the display size in the corresponding dimension. These two parameters can be changed unequally to control the "perspective" of the display (Fig. 5.3).

Because the cells are no longer rectangular, they cannot be displayed using Swarm's method for drawing rectangles. Instead, each cell maintains

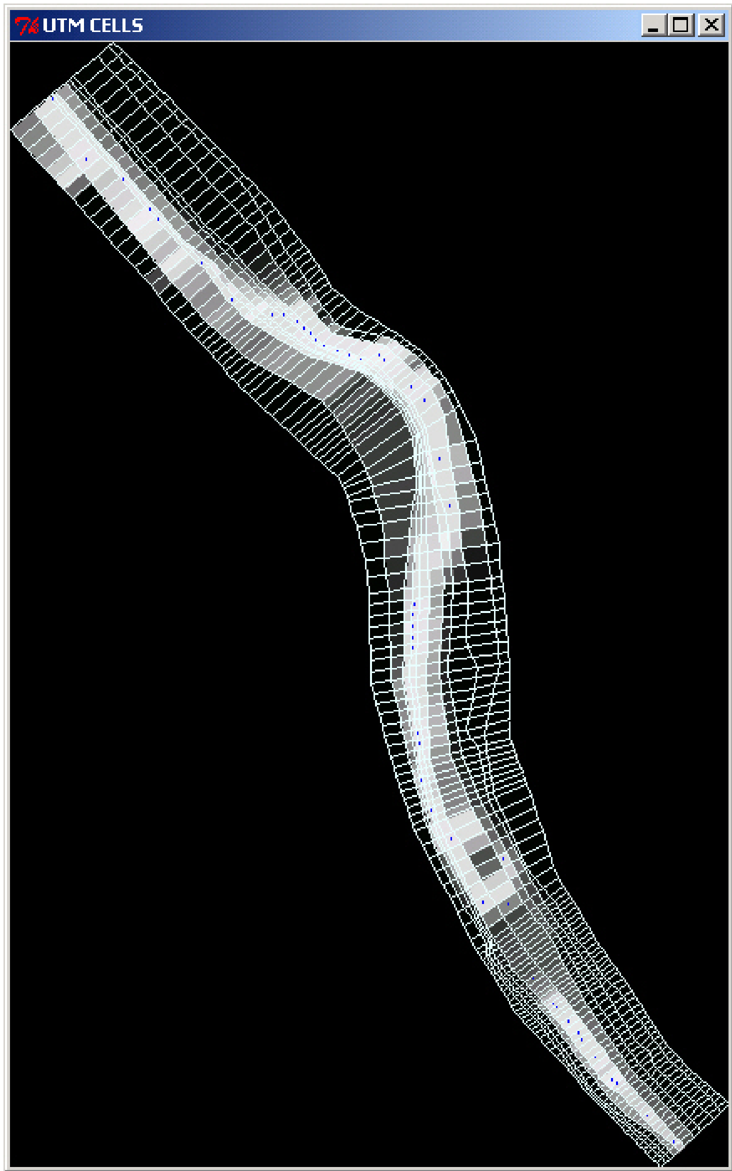

Figure 5.1: Graphical display for *inSTREAM-2D*.

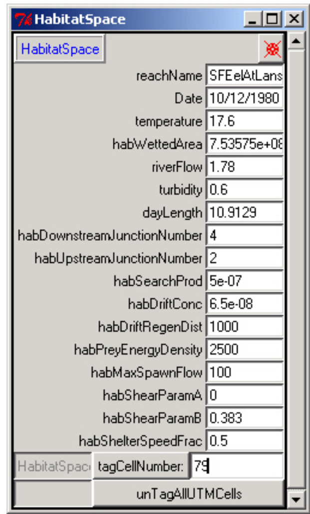

Figure 5.2: HabitatSpace probe display, including new methods to tag cells by their cell numbers.

a list of all the display pixels in itself, and each pixel is redrawn when the display is updated.

5.7 New code classes

Several new Objective-C classes were added to the *inSTREAM* software to implement *inSTREAM-2D*. These are briefly documented here.

FishCell. A subclass of UTMCell that contains code specific to the trout model: drawing the cell's fish on the animation raster, maintaining the cell's list of fish, maintaining habitat variables other than depth and velocity, building and maintaining the survival probability managers that model mortality risks in each cell, and writing cell-related output.

UTMCell. A superclass for habitat cells built from UTM coordinates. This class contains the variables and methods for setting corner coordinates, creating a one-dimensional array of pixels in the cell, calculating the cell's centroid coordinates, building a list of adjacent cells, determining whether a pair of raster coordinates defines a point that is within the cell, drawing itself on the animation raster with a color shade determined by depth or velocity, and tagging (changing the color of) itself and neighbor cells.

UTMInputData. Provides the methods that read the hydraulic data input files (Sect. 5.4) into arrays. One array is built per node in the

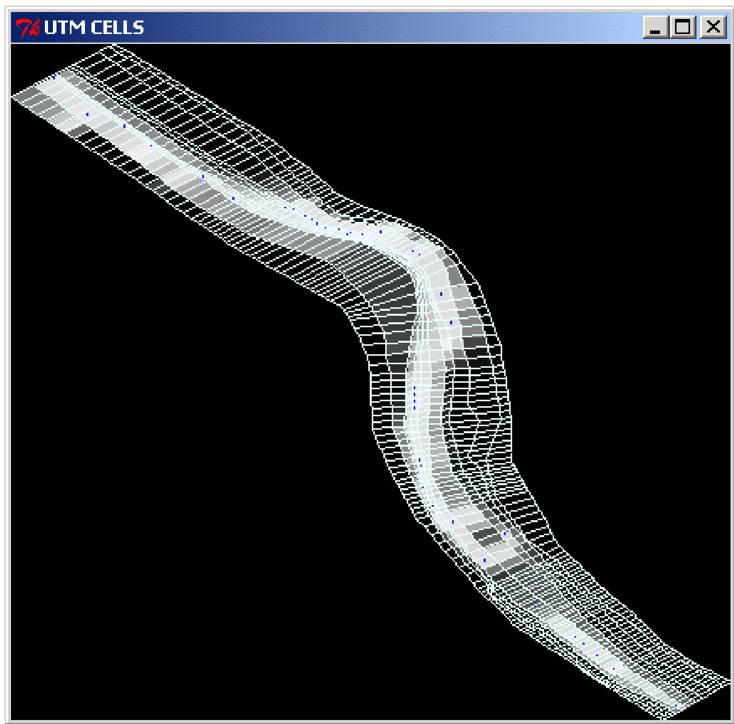

Figure 5.3: Graphical display with the perspective altered. In Fig. 5.1, `rasterResolutionX` and `rasterResolutionY` are both set to 250. Here, `rasterResolutionY` is higher than `rasterResolutionX` so the view appears to be from the south instead of from directly above the site.

hydrodynamic model. Converts input from meters to centimeters.

UTMInterpolatorFactory. Provides methods that build the depth and velocity lookup tables for each cell. The arrays created by UTMInputData for each node are read and averaged to calculate a depth and velocity for each cell, for each flow in the hydraulic data input files.

5.8 Output files

Output files reporting cell-specific habitat data (e.g., the optional file reporting habitat variables and fish abundance in each cell) were changed from identifying cells by their transect and cell numbers to identifying cells by a unique cell number. (Cell numbers are consistent across all outputs, and can be observed from the graphical display; Sect. 5.6.)

Several of the optional output files were disabled in *inSTREAM-2D*. These include the cell velocity and depth reports (these reported depth and velocity in a format convenient for testing against the one-dimensional PHABSIM hydraulic input files). However, the "CellDepthAreaVelocity" report still works and can be used to obtain the depth and velocity in each cell.

Bibliography

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