**PROCEDURES AND PROGRAMS FOR COMPARING NATURAL AND SIMULATED MEANDERS**

This set of instructions is primarily for use in judging the ability of meander simulation models to replicate the actual pattern of meandering of a natural stream. It works best when there is a long-term record of meandering of a long stretch of a natural meandering stream whose properties (width, depth, sinuosity, meandering behavior) do not change downstream or through time. Junctions between a stream and a large tributary and changes in land-use or floodplain width are examples of situations which might invalidate this approach. The occurrence of cutoffs in the natural or simulated stream histories complicates analysis but does not necessarily make this approach impossible. The procedure for analysis involves several steps, which will be discussed in more detail subsequently.

1. Identify natural streams with a long historical record and suitable properties.
2. Characterize the natural stream with regard to meander wavelength and mean high-flow-stage width (at a minimum) and ideally with measurements of reach-length channel gradient, high-flow discharge, bed material size, and cutoff history/locations. The easiest type of stream morphology to simulate are those where only neck cutoffs occur.
3. Digitize the natural stream centerline for both the initial and final timelines.
4. Parameterize the simulation model using whatever information is available for the target natural stream. At a minimum, simulation model parameters should be adjusted to match the average meander wavelength to that of the natural stream when the simulation model is run for long time periods.
5. Run the simulation model over a sufficient model time starting from the natural stream initial planform to produce total migration that exceeds that of the natural stream. Have the simulation produce output data at frequent intervals.
6. Statistically match the simulated and natural stream systems to find the simulation time with the best fit to the natural streams system. The total area enclosed between the simulated stream and the natural stream planforms is a good measure of goodness-of-fit. Locations near cutoffs can optionally be excluded.
7. Repeat the simulation with different meander models and variations in model assumption and parameters to evaluate which model(s) are most accurate in replicating natural meandering behavior, and in which ways and which model assumptions cause failure to duplicate natural meandering behavior.

Steps 1 and 2 are pretty self-explanatory and will not be elaborated on here.

**Step 3.** **Centerline digitization**

The essential length unit for modeling and analysis is the average channel width, preferably corresponding to relatively high-flow stage (bankful but not flood flow). Both the initial and final centerlines for the period of record should be digitized, either proceeding upstream or downstream (for logistical reasons Howard’s meandering model requires input from downstream to upstream, but data is easily inverted after measurement). The channel centerline (not thalweg, even if that were known) should be digitized at a frequency of ~0.3 to 0.7 channel widths. Of course, the data should be portrayed in a projection with equal x and y scales (e.g., not in lat-lon coordinates, although that can be corrected later). If the centerline is very carefully digitized, only one iteration of digitizing is necessary. In order to reduce noise for multivariate planform analysis Howard and Hemberger (1991) and Matsubara and Howard (2014) used three independent digitizings and combined the data using the program ***combine\_digit.f90***. So at this point there should be a file of digitized points in some coordinate system (meters, feet, furlongs, etc.) and the mean channel width in the same units. The program ***space.pas*** can then be used to resample the centerline at one-width-equivalent increments (which is what the nominal Howard version of J&P uses, although that could be slightly increased or decreased if desired). The initial and final planforms should both be digitized, but there does have to be a 1:1 correspondence between digitized points.

**Step 4. Model Parameterization**

Different meander simulation models require different numbers of parameters. The J&P model requires only 4 parameters (in the Howard, 1992 version these are width-depth ratio, a parameter related to the relationship between curvature and cross-stream bed slope, the Froude number, and the coefficient of friction, Cf). Unless the stream is operating near a Froude number of one, what mostly determines meander evolution and meander scaling are the width-depth ratio and the coefficient of friction. Even those two parameters are difficult to determine for many rivers. The most straightforward way to use the J&P model are to assume a fairly modest Froude number, say 0.2, use the average value for the cross-sectional parameter mentioned in J&P, and experiment with reasonable values for aspect ratio and coefficient of friction that produce the same average wavelength of meandering (measured along-stream in width-equivalent units) between simulated and natural meanders. A better situation occurs if the stream gradient and effective flow discharge can be estimated. The Howard version of the J&P model that simulates downstream sediment transport requires grain size and upstream bed sediment flux. If effective discharge, channel width, and channel gradient can be approximated then sediment transport relationships can be used to predict upstream sediment flux and grain size. This level of detail is not necessary for versions of the simulations that don’t model downstream sediment transport. Even if the parameters for the sediment transport version of the model can be estimated, it is still necessary to check whether the simulation model produces meander wavelengths essentially equal to the natural stream. Other meander evolution models will require more information in order to parameterize them. The Howard and Hemberger (1991) meander morphometry model can be used to objectively measure simulated and natural meander average wavelength.

**Step 5. Run Simulations**

This is pretty self-explanatory. A wide variety of models and parameter values can be utilized to find optimal models.

**Step 6. Calculation of Goodness of Fit of Natural and Simulated Channel Evolution**

A number of methods might be utilized to assess the ability of a meander evolution model to replicate the actual history of meandering. The metric used by Matsubara and Howard (2014) was to measure the total included area between the model planform and the natural end-member planform. If the red curve is the natural stream final planform and the blue curve is a stage in the simulation of meander migration starting from the natural stream initial planform, then the sum of the orange areas in the following diagram divided by the stream length (averaging the natural and simulated path lengths) is the

misfit. A program ***test\_fit.f90*** was used by Matsubara and Howard (2014) to measure the misfit. Because bank erodibility generally cannot be determined *a priori*, the meander program is used with an arbitrary bank erodibility to find the best fit, which then scales the bank erodibility. The occurrence of cutoffs is the most difficult aspect of meandering to replicate in simulation modeling, both in terms of location and timing. Matsubara and Howard (2014) adopted the procedure to run the simulation forward to the occurrence of a natural cutoff, then force the cutoff in the model and then continue the simulation until the best fit is obtained.