

User Manual for Matlab GUI Plume Stretching and Folding

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This manual describes Version 1.1 of a graphical user interface (GUI), developed in Matlab R2014b, that allows users to develop, test, and record pumping schemes of the kind described by Mays and Neupauer (2012). The model assumes a flat, homogeneous aquifer of infinite extent with a circular plume initially located at the origin. The evolution of this plume tracked after injections and extractions through wells located on a unit circle, while neglecting diffusion, dispersion, and transients. The layout of the GUI is shown in Figure 1, whose table has been populated with the 12-step sequence analyzed by Mays and Neupauer (2012).

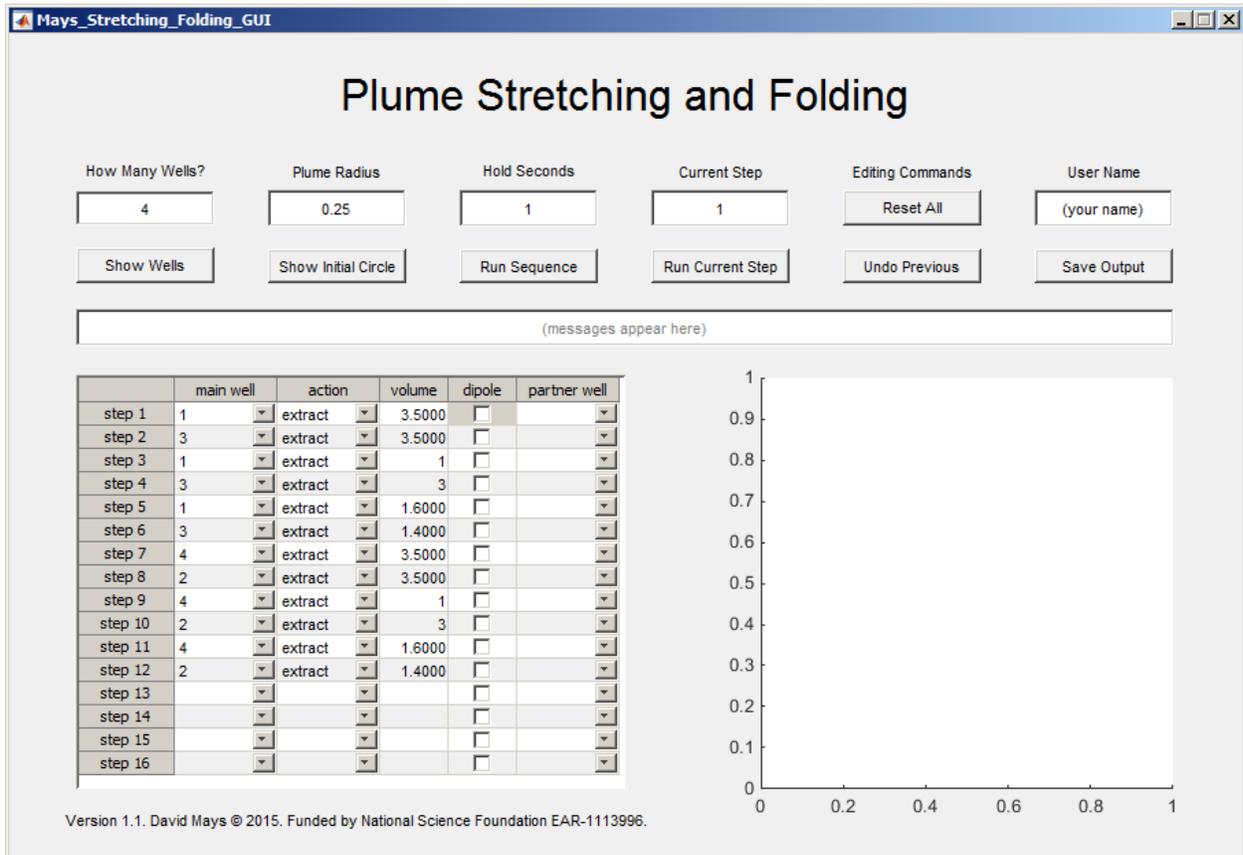


Figure 1: Graphical user interface (GUI) for plume stretching and folding.

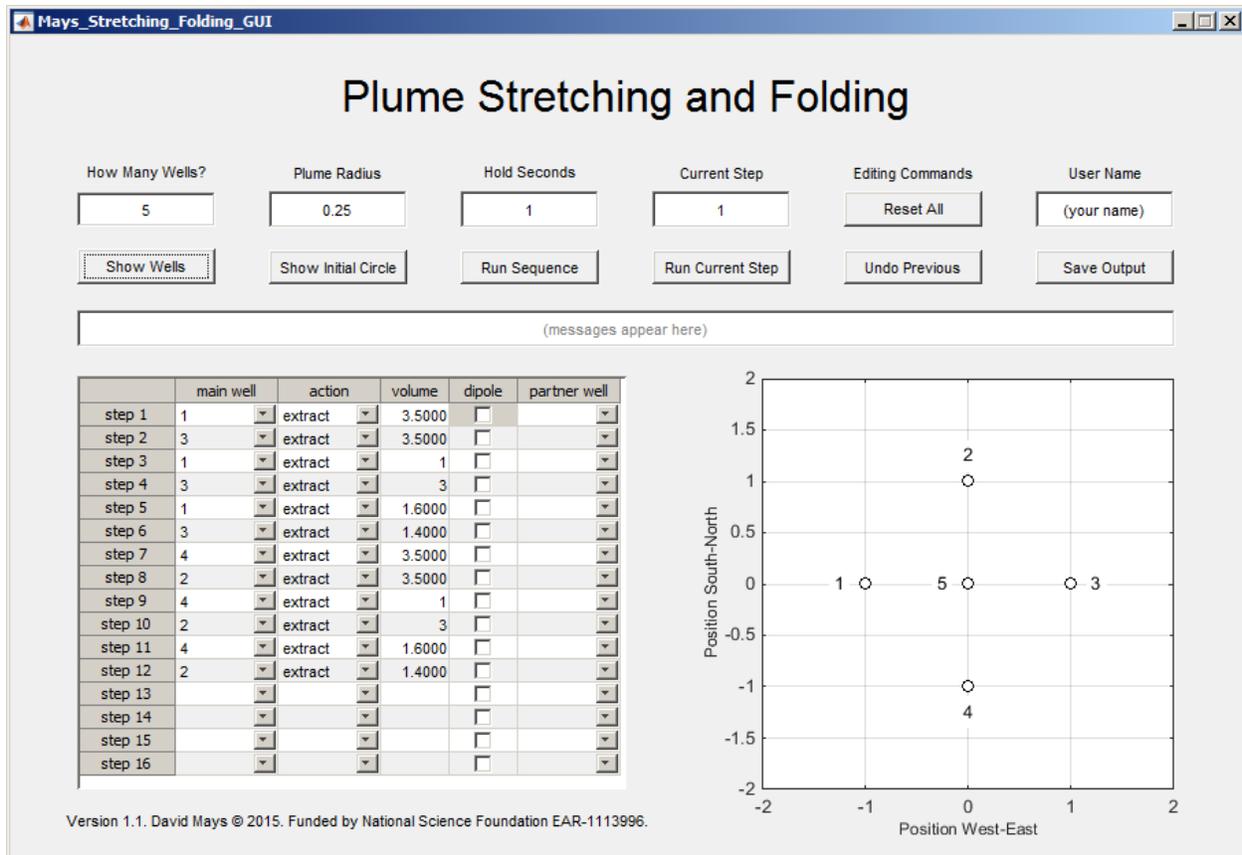


Figure 2: GUI after clicking button “Show Wells”.

The controls on the GUI are as follows:

- How many wells? Users can enter any number of wells ≥ 2 . Even numbers of wells are uniformly distributed on a unit circle, with the first well located at $(-1,0)$. Odd numbers of wells are distributed the same as the next lowest even number of wells, with an additional well at the origin. Clicking the button “Show Wells” generates results shown on Figure 2.
- Plume Radius. Users can enter any positive number for the radius of the initial plume. Clicking on the button “Show Initial Circle” generates the results shown in Figure 3.
- Hold Seconds. This field specifies the delay, in seconds, between each step of the simulation. The entire sequence can be executed by clicking “Run Sequence” (Figure 4).
- Current Step. This specifies the next step executed by “Run Current Step”, which then increments this field by one. When current step is 1, this button restarts the simulation.
- Reset All. This button restarts the GUI with default values and a blank table.
- Undo Previous. When using the “Run Current Step” button, users can undo one previous step. Undo is not available for the first step (instead users can restart the simulation). Undo is unavailable when running an entire sequence using the “Run Sequence” button.
- User Name. Users can enter their name here. Upon clicking the button “Save Output”, this name will be appended with a date and time stamp to create a uniquely-named tab-delimited text file. The contents of this text file for the example shown in Figure 4 are given in Table 1.

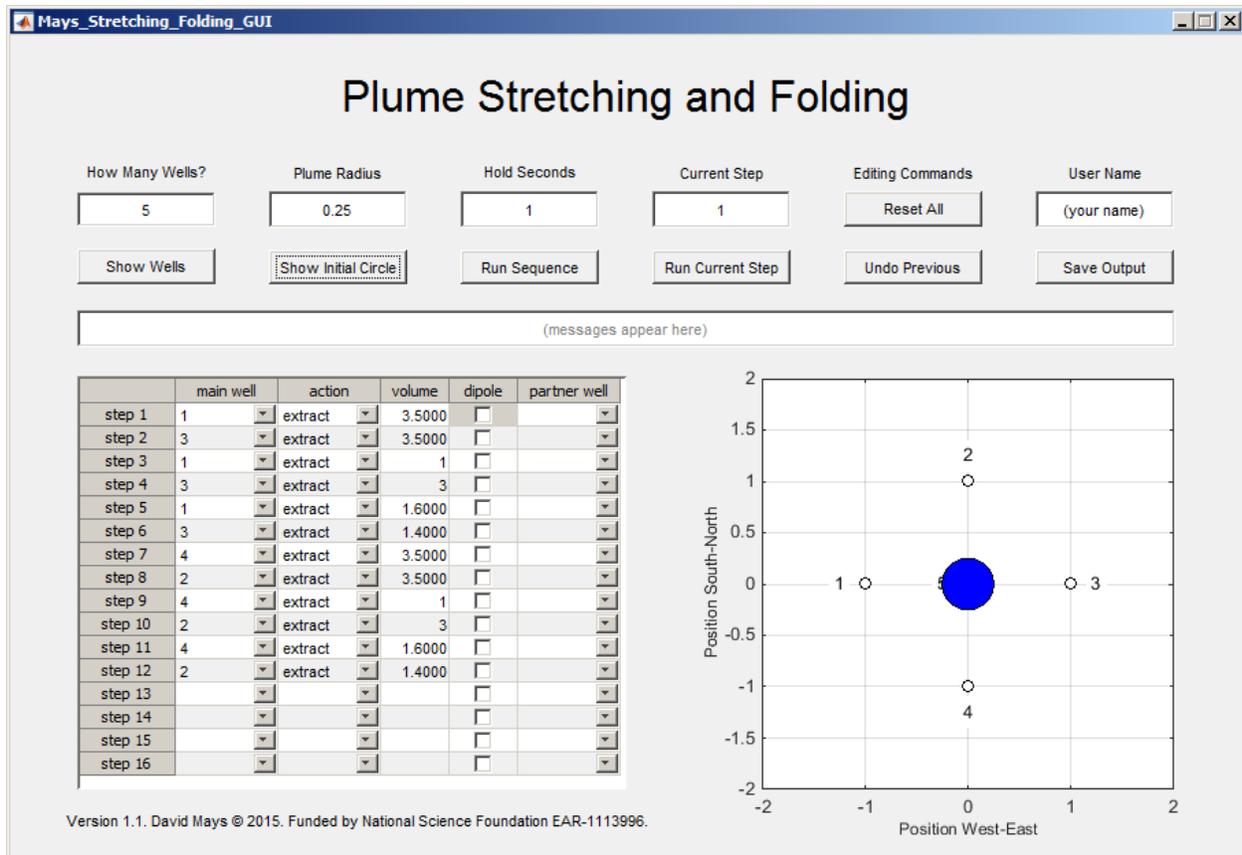


Figure 3: GUI after clicking button “Show Initial Circle”.

The pumping scheme itself is entered in the table, whose five columns are as follows:

- **Main Well.** Specifies the well whose action and volume will be specified in the next two columns. Users must select well numbers no higher than “How Many Wells?”.
- **Action.** Specifies whether the main well is set to inject or extract.
- **Volume.** Specifies the volume to be injected or extracted, where each unit corresponds to the volume of fluid contained in the unit circle. Positive volumes match the action specified. Negative volumes are opposite the action specified, such that injecting +1 is equivalent to extracting -1.
- **Dipole.** Logical checkbox to indicate that the main well is mirrored by a partner well whose action is opposite that of the main well.
- **Partner Well.** When dipole is enabled, this field specifies the partner well. Users must select well numbers no higher than their maximum, and must not repeat the main well.

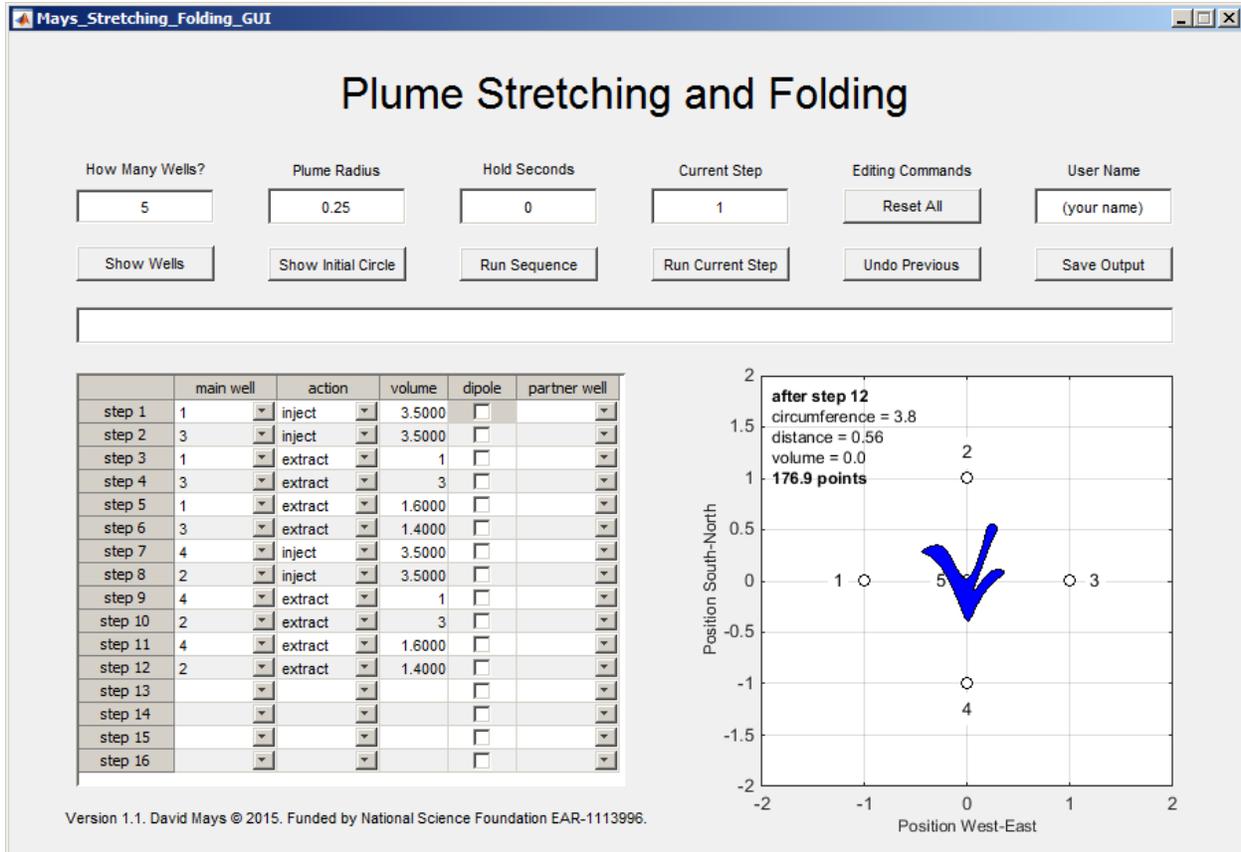


Figure 4: GUI after entering 12-step pumping sequence from Mays and Neupauer (2012) and then clicking button “Run Sequence”.

After each step of the pumping scheme, the following information is displayed:

- **Circumference.** The circumference, L , is the distance around the plume’s edge. The initial circumference, L_o , is $2\pi r$.
- **Distance.** This is the maximum distance, R_{\max} from any point in the plume to its center. It is recorded in order to penalize pumping schemes that stretch well but do not fold, which encourages designers to keep their plumes within a minimum subset of the aquifer.
- **Volume.** This is net injection volume. Negative values indicate net extraction.
- **Score.** Keeping score encourages stretching and folding while minimizing costs. The score, S , is calculated as follows:

$$S = \frac{(L - L_o)^2}{C \pi R_{\max}^2},$$

where πR_{\max}^2 is the area of a circle with radius R_{\max} . The score encourages stretching through $(L - L_o)^2$, encourages folding by penalizing with R_{\max}^{-2} , and encourages thrift by penalizing with cost C^{-1} , where C is \$1000 times the sum of all injections and extractions. Because dipoles operate two wells simultaneously, they contribute to the cost twice.

Table 1: Contents of text file generated by clicking button “Save Output” on Figure 4, where “NaN” is Matlab’s standard output for “not a number”.

Name	Given_Surname			
N_Wells	4			
Circumference	3.8			
Outer	0.56			
SumV	28			
Score	176.9			
Main	Action	Volume	Dipole	Partner
1	1	3.5	0	NaN
3	1	3.5	0	NaN
1	0	-1	0	NaN
3	0	-3	0	NaN
1	0	-1.6	0	NaN
3	0	-1.4	0	NaN
4	1	3.5	0	NaN
2	1	3.5	0	NaN
4	0	-1	0	NaN
2	0	-3	0	NaN
4	0	-1.6	0	NaN
2	0	-1.4	0	NaN
NaN	0	0	0	NaN
NaN	0	0	0	NaN
NaN	0	0	0	NaN
NaN	0	0	0	NaN

Technical Notes

Particle tracking assumes 3,601 particles initially distributed on a circle of radius r . For single wells, particles are moved using the analytical equations in Mays and Neupauer (2012). For dipoles, particles are moved using the analytical equations in the Appendix of Jones and Aref (1988). Their implicit equations are solved using Matlab’s `fzero` function.

Revision History

Version 1.0 3/28/2015

Version 1.1 10/12/2015 (added reset and undo features, improved error checking, fixed bugs)

Acknowledgments

Undergraduate students Louis Dankovich and Ryan Tigera programmed related GUIs in 2012 and 2014, respectively. Funding was provided by National Science Foundation EAR-1113996.

References

- Jones, S. W., and H. Aref (1988), Chaotic advection in pulsed source sink systems, *Phys. Fluids*, 31(3), 469-485.
- Mays, D.C. and R.M. Neupauer (2012), Plume spreading in groundwater by stretching and folding, *Water Resour. Res.*, 48, W07501, doi:10.1029/2011WR011567.