User Manual for *SlugPen*:

A software for parsing raw data collected by a heat-flow measurement system

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1 Introduction

SlugPen is a parsing program for separating and decimating measurements collected by a multi-penetration heat-flow measurement system prior to data processing. Data processing is done in a subsequent software, *SlugHeat*. This tutorial corresponds with the 2022 update of *SlugPen*.

The data logger of the multi-penetration heat-flow probe records temperature, acceleration, and pressure values at a pre-selected sampling interval (typically 2-5 seconds) during an entire deployment. Each heat-flow station generally comprises 5 to 20 penetrations of the seafloor, each of which must be processed separately. However, the instrument presents a single long ASCII file of raw data, so we must first distinguish between penetrations. In addition, thermal data are generally corrected based on field calibration, and values are shifted relative to bottom water as part of processing.

The development of *SlugPen* provides the user with a graphical interface to assess data quality and create individual files for each penetration for processing. While examining temperature, tilt, and depth time-series of a single deployment, the researcher chooses the timing of each penetration, heat pulse fire, and sensor calibration period. The latter two selections are optional as there may not be a heat pulse fired every measurement, and a single sensor calibration period is often used for an entire station. An auxiliary application allows the user to input defining information such as cruise, station, instrument, datum, probe ID, number of thermistors, latitude, longitude, average tilt, and average depth. All user indicated constraints as well as the temperature, pressure, tilt, and heat pulse data recorded by the probe, are written to two text files, called the PEN file and TAP file, and saved as variables to a binary (MAT) file specific to that penetration.

Included in this tutorial is an outline of steps through a general workflow in *SlugPen* for a single deployment of the multi-penetration heat-flow probe. The example raw data file, `ExampleRaw_SlugPenTutorial`, shows data recorded by a single deployment which includes five separate penetrations. In this tutorial, we will generate PEN and TAP text files as well a MAT file for one of these penetrations, which will be ready to be read into the subsequent data processing software, *SlugHeat*.

2 System requirements

1. MATLAB Version 2020b or later (Version 2022b or later is preferred)
2. MATLAB Image Processing Toolbox
3. All required files and subfolders in current working directory or in MATLAB Path, including:
   (a) Main application (`SlugPen`)
   (b) All functions (as `.m` files), including:
      - `cbSensValueChange.m`
      - `rbmmed.m`
   (c) Auxiliary applications (as `.mlapp` files)
      - `SetPenInfo.mlapp`
   (d) Graphics subfolder (`images`), including:
      - `arrowpen.png`
      - `SlugPenLogo.png`
      - `UCSC-HydrogeologyLogo.jpg`
      - `x.png`

3 System set up

1. Ensure all required files and subfolders (listed in previous section) **are in your current working directory or in your MATLAB path**

   To *temporarily* add directory to MATLAB path:
   In MATLAB Command Window:

```
>> addpath(genpath(pwd))
```

   To *permanently* add directory to MATLAB path:
   In MATLAB toolbar at top right of application:

   (a) Select *'Set Path'* in MATLAB toolbar
   (b) Select *'Add with Subfolders...'*
   (c) Open current directory
   (d) Press *'Save'*

   To check that correct directory and all subfolders are in your MATLAB path:
   In MATLAB Command Window:

```
>> path
```

2. **Install Image Processing Toolbox**

   (a) Select Add-Ons form the Add-Ons drop-down menu from the MATLAB desktop
   (b) Search 'Image Processing Toolbox' in the Add-On Explorer GUI
   (c) Install the toolbox (Fig 1)

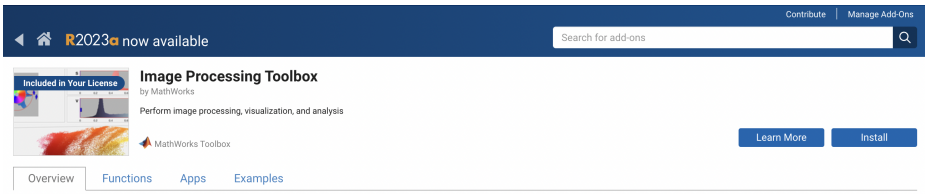

Figure 1: Image Processing Toolbox is a MATLAB Add-On that is required to run *SlugPen*

   To check that the correct version of MATLAB and the Image Processing Toolbox is installed:
   In MATLAB Command Window:

```
>> ver
```

3. Launch *SlugPen*

Once you ensure all necessary functions and subdirectories are in your current working directory or in your MATLAB path and you have installed the Image Processing Toolbox, you can launch the program.

In MATLAB command window:

```
>> SlugPen
```

The *SlugPen* application immediately displays the main GUI, though no data is loaded in or plotted yet. See Fig 2. The command window on the left-hand side of the application shows all input information, including input parameters, penetration information, data and plot controls, and processing commands.

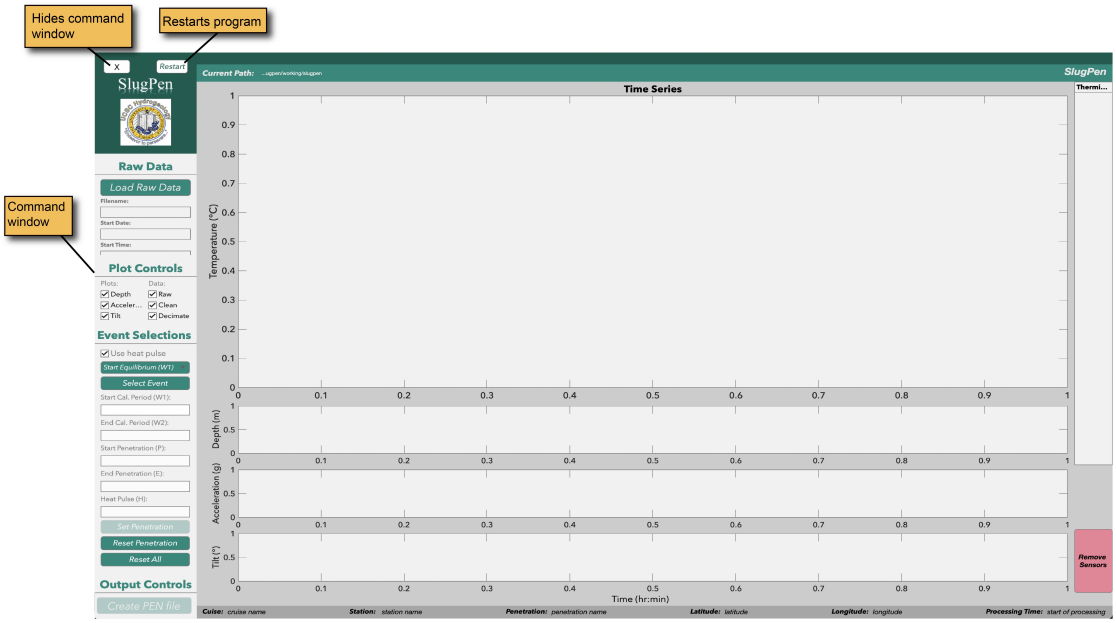

Figure 2: *SlugPen* application launched. No deployment data from the probe is loaded in yet. Left-hand side shows command window for data and plot control.

4 Pre-process .raw text file to be compatible with SlugPen

You will first need to use the PreProcessRawFile script to convert your .raw text file to a .mat file that can be loaded into *SlugPen*. Run this script in the command line:

```
>> PreProcessRawFile
```

When prompted, select your .raw text file that you obtained from the heat flow probe. This will generate a .mat file with the same name as your .raw file, placed in the output folder. If the code breaks, it is because your .raw text file format is incompatible with the PreProcessRawFile script. These formats for .raw text files from the probe change a lot, so this is likely to happen sometimes. You'll need to update the PreProcessRawFile.m script to be compatible with your .raw file format. We created this script so that when there are incompatibilities like this, you will only need to modify this PreProcessRawFile.m scipt and SlugPen can remain unchanged. The .mat file format is best because it is quicker and more flexible than reading in text files.

5 Load in raw data

Next, load in the raw data file generated by the multi-penetration heat-flow probe data logger. This should be a RAW (*.raw*) text file with all measurements recorded by the probe throughout an entire deployment.

1. **Press *'Load Raw Data'* button**
2. **Select a RAW (*.raw*) file** in the pop-up window (Fig 3), which defines all raw data recorded in a single deployment.
   - Note: If you do not see the pop-up window, you may need to click anywhere on the screen after pressing *'Load Raw Data'* button or look on other screens, if applicable. The pop-up window should become visible.
3. **Press *'Open'*** to load in raw data.

All data recorded by the probe is loaded, including all temperature, pressure, and acceleration measurements recorded by the probe. Acceleration is used to calculate tilt and pressure is used to calculate depth below sea level. Time series are plotted on the main screen showing temperature, depth, acceleration, and tilt variations with time (Fig 4). In the top plot (temperature time series), each line color is a separate temperature sensor (thermistor), which line the probe and therefore vary with depth. Sensors with higher numbers are shallower and sensors with lower numbers are deeper (i.e, T1 is the deepest). The number of sensors could vary with different probe constructions. In this example, depth was not recorded, therefore it is plotted as zero during the entire deployment.

View the command window *Raw Data* box (Fig 5) to scroll through key information defining that deployment.

The command window *Plot Controls* box allows control of plot and data display (Fig 6). Checked plots and data will be displayed, while unchecked plots and data will be hidden. Plots to display or hide include the depth, acceleration, and tilt time series. The temperature time series will always be displayed and cannot be hidden. Data to display or hide include raw, clean, and decimated *temperatures*. Generally, the data logger records measurements every two seconds. These measurements may include outliers that need to be removed. Also, processing often requires far fewer measurements than that recorded every two seconds. Therefore, options for cleaning and decimating data are included in *SlugPen*. These include:

- **Raw:** all raw temperatures recorded every two seconds, exactly as they are recorded by the probe

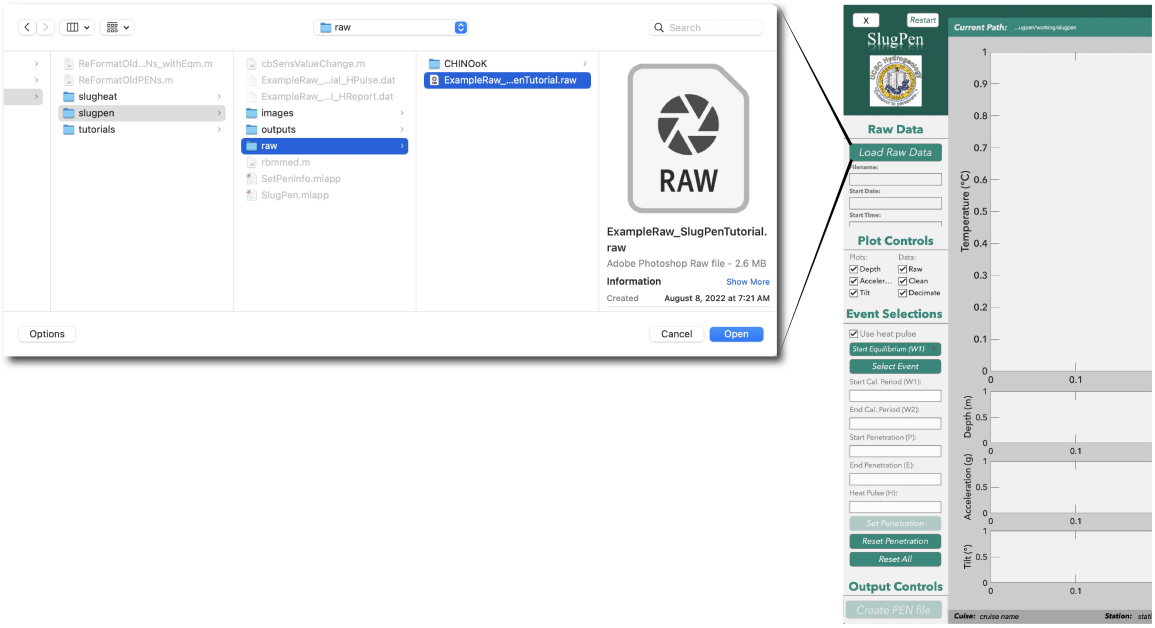

Figure 3: *SlugPen* example pop-up window to select a RAW data file that will be used to load the raw data from a single deployment into the program.

- **Clean:** all temperatures recorded every two seconds but with inaccurate outliers filtered out
- **Decimate:** only every tenth filtered temperature measurement

The filtered, decimated data (plotted as 'Decimate' data) is used in the PEN, TAP, MAT files.

To remove data from a certain sensor,

1. **Uncheck the sensor** in the sensor legend to right of plots.
2. **Press *'Remove Sensors'* button** below the sensors legend. All data from removed sensors will be recorded as 'NaN' in the PEN and MAT files and will be ignored in subsequent processing software.

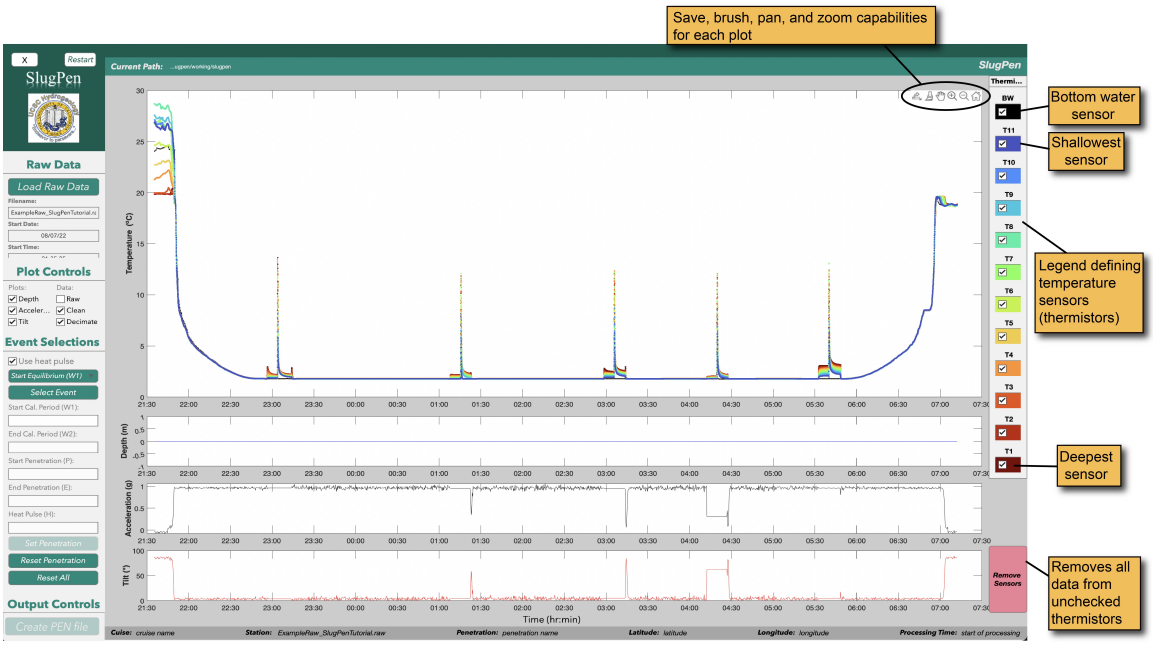

Figure 4: *SlugPen* example raw data loaded in and plotted

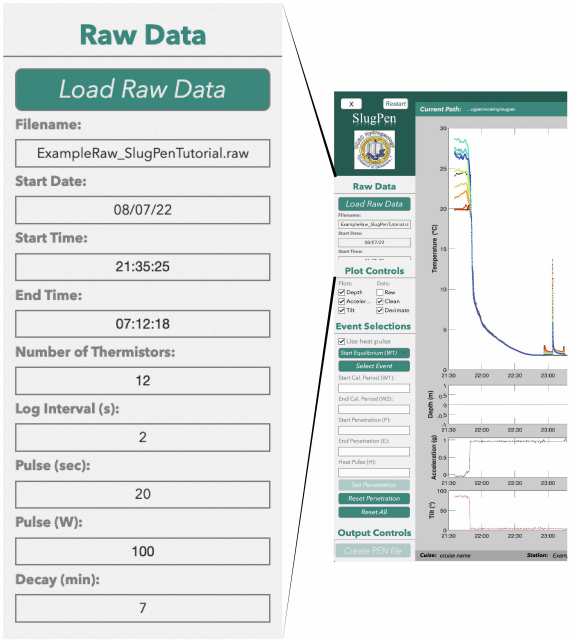

Figure 5: *SlugPen Raw Data* box on command window defining key information for raw file loaded in, including filename, start date, start time, end time, number of thermistors, log interval(s), duration of heat pulse fire, power of heat pulse, and decay time allowed from start of penetration to when the heat pulse is fired.

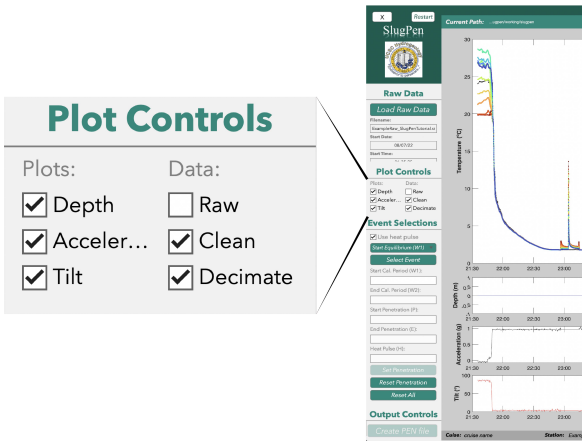

Figure 6: *SlugPen Plot Controls* box on command window showing which plots and data are displayed. Checked plots and data will be displayed, while unchecked plots and data will be hidden.

6 Select timing of events

Once the raw data is loaded in, select the timing of significant events including:

- **Sensor calibration period:** This should be a time where temperatures are relatively unchanging. The sensor calibration period can be the same for *all penetrations* or a separate calibration period can be defined for *each penetration*. In general, using the same calibration period for all penetrations in a single deployment is sufficient.
- **Penetration period:** Start and end times of each penetration must be defined in order parse measurements made during each.
- **Heat pulse fire:** If there is a calibrated heat pulse firing (this is not required as some penetrations will not be accompanied by a heat pulse), the timing of the firing must be defined for each penetration. This is typically seen with a very significant increase in temperature.

These selections can be made using plots of the various raw data including temperature time series (for example, start of penetration should be accompanied by a temperature rise), depth time series (for example, penetrations will occur at seafloor depths), and tilt time series (for example, tilt should be relatively unchanging during a penetration). The steps for selecting timing of these events for an individual penetration are accomplished using the *Event Selections* box in the command window (see Fig 7). Using the **zoom and pan** plots tools (on the top right-hand corner of each plot) will be very useful in selecting event times. Start by zooming in to a single penetration and follow steps, as follows.

1. **Define heat pulse settings:** Use *heat pulse checkbox* to define whether there is a fire of a calibrated heat pulse during this penetration.
2. **Select which event to define:** Use the events drop-down menu to choose an event to define. Once an event is chosen, **press the *Select Event* button**.
3. **Define the timing of the event:** Once an event is chosen, a drawpoint tool will appear on the plots, controlled by the user's mouse. Hover this drawpoint tool above the point on any of the plots and click to define when that event occurs.

4. **Continue to next event:** Select another event in the events drop-down menu and use the drawpoint tool again to define the timing of this event.

When the timing of an event is chosen, a dashed line corresponding with selected time and event will be plotted on all plots, and these times will appear in the text edit fields on the command window corresponding with each event. Continue with this process until all events have a defined timing. See Fig 7 for an example of the required event selections for a single penetration.

– Note: to re-select an event time, simply choose that event in the drop-down menu again and re-select. All event times are modifiable until a penetration is set by the user.

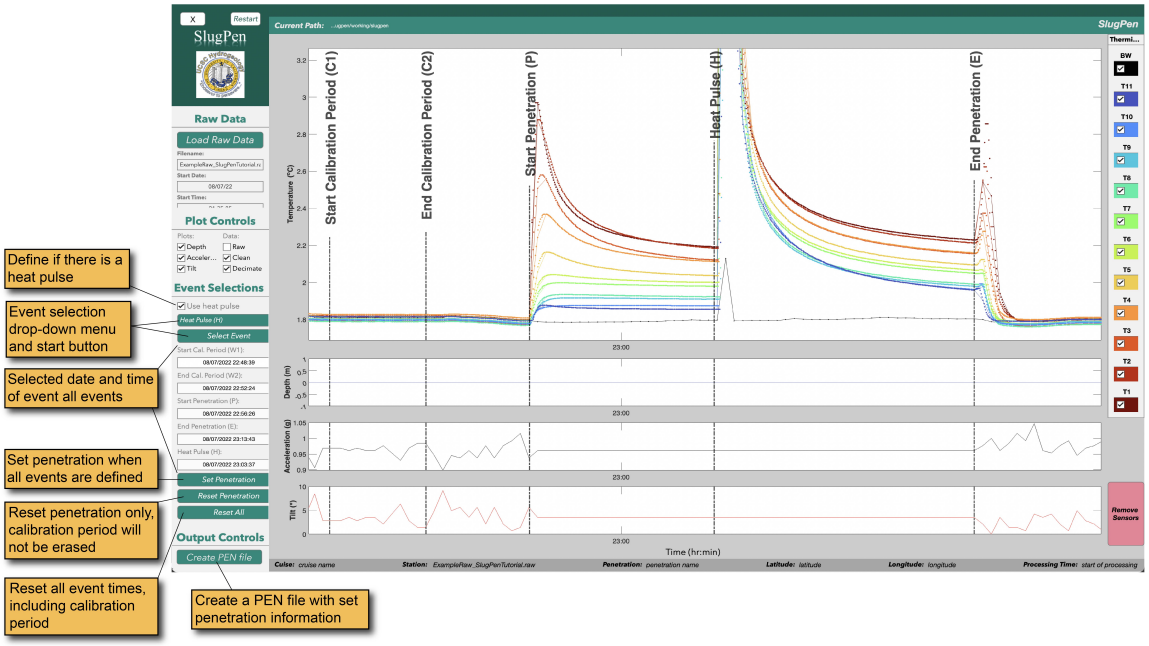

Figure 7: *SlugPen* selection of a single penetration, including all significant events: start of calibration period, end of calibration period, start of penetration, heat pulse firing, and end of penetration.

7 Set penetration

When all required events have a selected time, the *Set Penetration* button will become available, and all measurements for that penetration can be parsed.

1. **Press the *Set Penetration* button**, which will launch an auxiliary application for important penetration information to be defined (Fig 8).

2. **Fill out key information** for the penetration to be recorded in the PEN, TAP, and MAT output files.

3. **Press *Set* button** once all edit fields are filled with correct penetration information and close the auxiliary application.

– Note: 'Total number of thermistors (excluding BW)' refers to the total number of thermistors on the probe, even if their data is being ignored, excluding the bottom water thermistor (aka the *top sensor*). 'Number of active thermistors only (excluding BW)' refers to only the thermistors whose data is being used, excluding the bottom water thermistor. For example, if T1 is removed before the penetration is set, it will be included in 'Total number of thermistors (excluding BW)' but excluded in 'Number of active thermistors only (excluding BW)'. If data from all thermistors are being used, these values will be equal, as shown in Fig 8.

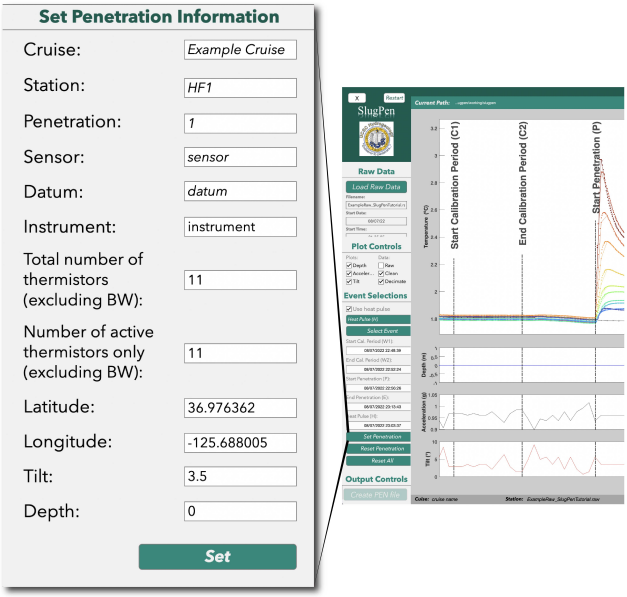

Figure 8: *SlugPen* auxiliary application launched with *Set Penetration* button on command window. User can fill out important information regarding the penetration to be recorded in the PEN, TAP, and MAT files.

8 Create PEN, TAP, and MAT files

Press *'Create PEN file'*, which will be become available once all required information is provided to define a single penetration. This generates the PEN, TAP, and MAT outputs files ready to be processed in subsequent software.

PEN, TAP, and MAT output files are not only saved in the `/outputs` subdirectory in your `/SlugPen` directory but will also be saved to your `/inputs` subdirectory in your `/SlugHeat` directory, if it exists in the same location as your `/SlugPen` directory. Therefore, ensure your `/SlugHeat` directory is in the same location as your `SlugPen` directory. The general format for a PEN file is shown in Figure 9.

Other outputs saved in the `/outputs` subdirectory in your `/SlugPen` directory include DAT (*.dat*) files. There are two DAT files for each penetration, called `ExampleRaw_SlugPenTutorial_HPulse.dat`

General format:

Station #	Penetration #	'Cruise'	Datum
Lat	Lon	Av. Depth	Av. Tilt
Logger ID	Probe ID	Num. Sensors	Pulse power (J)

Pen record

HP record

	BW1	BW2	BW3	BW4	.....
$	T1	T2	T3	T4	.....
$	T1	T2	T3	T4	.....
Record #	T1	T2	T3	T4	.....
Record #	T1	T2	T3	T4	.....

Example:

```
HF3 3 'chinook-TEST' datum
-999.000000 -999.000000      0    4.80
instrument  sensor  11  686.66
     7
    29
          1.794    1.799    1.771    1.808    1.778    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.776    1.813    1.784    1.
    $     1.801    1.805    1.777    1.813    1.784    1.
    1     1.798    1.802    1.773    1.810    1.782    1.
    2     1.798    1.802    1.773    1.810    1.781    1.
    3     1.797    1.801    1.773    1.809    1.780    1.
    4     1.797    1.801    1.773    1.810    1.781    1.
    5     1.796    1.801    1.773    1.811    1.781    1.
    6     1.794    1.799    1.771    1.808    1.778    1.
    7     1.792    1.796    1.769    1.806    1.777    1.
    8     1.790    1.794    1.766    1.804    1.774    1.
    9     1.785    1.790    1.764    1.800    1.770    1.
   10     1.833    1.927    1.845    1.831    1.835    1.
   11     2.796    2.527    2.369    2.336    2.244    2.
```

Bottom water temperatures

Calibration temperatures

Penetration temperatures

Figure 9: *SlugPen* Example PEN (.pen) text file that is the primary output file for SlugPen and input file for SlugHeat.

and `ExampleRaw_SlugPenTutorial_HReport.dat` in this example. A file ending in `_HPulse.dat` reports the instrument's record of the start of the heat pulse while a file ending in `_HReport.dat` reports the instrument's record of the end of the heat pulse including the time, acceleration, battery voltage, and the power of the pulse in joules.

9 Next penetration

To define the next penetration in the deployment, either:

1. **Press the *'Reset Penetration'* button** on the command window, which will reset all event selections *EXCEPT* for the calibration period, or
2. **Press the *'Reset All'* button** on the command window, which will reset *all* event selections, including the calibration period

You will then need to define all event timings and key information for this new penetration and create new output files. These will be saved in the same `/outputs` subdirectory. Repeat until all penetrations are parsed and have separate PEN, TAP, and MAT files. These files will be used as input files in the processing software, *SlugHeat*.