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Hydropower Biological Evaluation Toolset Best Practices Guide

AUGUST 2021

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HYDROPASSAGE
U.S. DEPARTMENT OF ENERGY

HYDROPOWER BIOLOGICAL EVALUATION TOOLSET BEST PRACTICES GUIDE

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U.S. DEPARTMENT OF ENERGY
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PREFACE

DOCUMENT CONVENTIONS

The following conventions are used in the procedures presented in this guide:

- **USE** all bolded cap verbs (as done in this bulleted item) to highlight each user action to be taken.
- Initial **CAP** tab and button labels and other screen content labels as they are shown in screenshots (enclosed within quotation marks).
- **USE** *italics* for selections or inputs from users.
- **USE** bold font for each **Note:** and place notes in full line-length blue-shaded "boxes" from left margin to right margin:

Note: Like this.

- **USE** subordinate numbering for subordinate action statements (Apply List style from dropdown styles menu, and tab to desired level of subordination); for example:
    1. Step 1.
        a. Subordinate step.
            i. Etc.
- **USE** bullets (and subordinate bullets) when listing items (that are not numbered verb-first statements of action).
- **UNDERLINE** <u>either</u> and <u>or</u> in either/or statements.
- **CAP** OR used between optional enumerated steps.
- **UNDERLINE** and bold **<u>Do not</u>** in statements telling users what <u>not</u> to do.

Acknowledgments

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Acronyms and Abbreviations

3-D	three-dimensional
BioPA	Biological Performance Assessment
DOE	U.S. Department of Energy
HBET	Hydropower Biological Evaluation Tools
MSL	mean sea level (Unit: Foot)
PDR	People's Democratic Republic
PNNL	Pacific Northwest National Laboratory
RF	radio frequency (Unit: Hz)

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1.0 INTRODUCTION

Field studies using live fish are often used for direct evaluations of turbine biological performance (e.g., fish passage survival and injury assessments). Yet these methods cannot determine the specific hydraulic conditions or physical stresses experienced by the fish, the locations where deleterious conditions occur, or the specific causes of the biological response. Using the Sensor Fish (SF) autonomous sensor package developed by Pacific Northwest National Laboratory (PNNL), this deficiency can be overcome because the SF can be released independently or concurrently with live fish directly into operating infrastructure to collect high-frequency measurements of hydraulic conditions such as pressure, acceleration, and rotation acting on a body in situ during downstream passage.

The Hydropower Biological Evaluation Tools (HBET; Hou et al. 2018) software package, developed by PNNL, is designed to assemble, organize, and process data collected by the SF and/or by studies that use live fish to evaluate biological performance. HBET was developed specifically to design SF field studies, process the raw data, and analyze the processed data efficiently and scientifically. Its objectives are to facilitate SF studies focused on characterizing hydraulic conditions and to apply SF data for evaluating the impacts on fish from passage through hydro-structures. HBET allows users to design new studies, analyze data, perform statistical analyses, and evaluate predicted biological responses. It can be used by researchers, turbine designers, hydropower operators, and regulators to evaluate hydro-structures to enhance environmental sustainability in a cost-effective manner.

1.1 GUIDE PURPOSE AND SCOPE

This document is designed to provide HBET and SF users with a set of best practices for using both technologies. It is intended to help facilitate the use of the technologies by providing guidance for every step of the process. The steps include using previously collected SF data to design a new SF field study, conducting a

SF field evaluation, processing and analyzing the data, and generating reports and comparisons with other previously performed SF evaluations.

The appendix to this document also provides guidance on the preparation of SF for field deployment.

To help illustrate the process of using HBET this document uses a previously performed SF study (NamNgum_Dataset_2016) conducted at Nam Ngum Dam (Martinez et al. 2019) as an example, and the turbine study (Detroit_Dataset_2009) performed in 2009 in Detroit Dam as the example of project reference.

1.2 EXAMPLE CASE STUDY OF SENSOR FISH ASSESSMENT AT THE NAM NGUM DAM, LAOS

The Mekong River is the second-most biodiverse river in the world and its basin is home to the world's largest freshwater fishery. Within the Lower Mekong Basin, freshwater fish, such as several species from the Carp (Cyprinidae Family), Gouramis, and Airbreathing catfish families, are a very important source of protein for the local population—accounting for 48% of the total animal protein consumed in the Lao People's Democratic Republic (PDR) and 79% in Cambodia. People living along the Mekong rely on the river for sustenance and their livelihoods. There are plans to develop numerous new large and small hydropower projects on the mainstem Mekong and its tributaries, but currently there is little information available to guide the design and construction of fish-friendly hydropower systems in a way that is ecologically safe for the numerous species in the region. A set of preliminary guidelines have been drafted by the Mekong River Commission that state that new hydropower projects must provide effective (i.e., 95% survival for target species) upstream and downstream fish passage. With efforts under way to incorporate safe and effective upstream and downstream fish passage at new hydropower projects on the Mekong River mainstem, it is also important to understand fish passage conditions at existing hydropower projects in the Lower Mekong Basin.

Nam Ngum Dam, operated by EDL-Gen Public Co, is located on the Nam Ngum River in Lao PDR approximately 60 km north of the capital city of Vientiane. Nam Ngum Dam is a gravity concrete dam, 70 m high and 468 m long. It was the first hydropower project built in Lao PDR. Construction of the dam was performed in three stages. The first stage was completed in 1971 and included two 17.5 MW Francis turbine units along with intakes for three more turbine units. The second stage was completed in 1980 and included two 40 MW Francis turbine units and four radial spillway gates. The third stage was completed in 1984 and added a third 40 MW Francis turbine unit, resulting a total capacity of 155 MW. The Nam Ngum Dam was primarily built to provide power to Lao PDR, but it also provides flood protection, enables implementation of lift irrigation, facilitates a fishery in its reservoir, and allows to the development of recreational opportunities that promote tourism.

SF are used to study the effects of turbine passage, and were the subject of this evaluation of the Nam Ngum Dam turbines. A significant advantage of using SF rather than other methods, such as tagged live fish and acoustic telemetry, is that it is possible to determine the portion of the passage that causes events that could injure fish and provide relative estimates of fish survival. The data obtained from the SF consists of time histories of different sensor readings that contain repeatable characteristics that allow the passage to be subdivided into different regions. By studying existing hydropower structures, the biological effects on specific species in the region can be studied in situ, which in turn can be used to guide engineering design and project operation of new hydropower projects to reduce ecological impact.

1.3 EXAMPLE CASE STUDY OF SENSOR FISH ASSESSMENT AT THE DETROIT DAM, USA

Detroit Dam, located at river mile 60.9 of the North Santiam River in Marion County, Oregon, is a storage dam used for flood control, power generation, irrigation, navigation, and to enable river recreation. The dam, a concrete gravity structure approximately 463 ft tall and 1580 ft long, has a powerhouse containing two Francis turbine units with a hydraulic capacity of 5340 cubic feet per second (cfs) and a total capacity of 100 megawatts (MW). The entrance to the 15 ft diameter turbine penstock is located at an elevation of 1403.0 ft above MSL, descending to an elevation of 1203.0 ft above MSL at the turbine wicket gates. Each Francis turbine at Detroit Dam operates at 70,000 horsepower and 163.6 revolutions per minute. The runner diameter is 130 in., and the runner opening height is 49.5 in. The velocity of the periphery of the runner is 92.8 feet per second (fps). Maximum discharge is 5340 cfs, and there are 13 blades and 24 wicket gates.

To evaluate characterization of fish passage conditions through a Francis turbine, a total of 20 SF data sets were acquired representing passage information through the turbine via the penstock at Detroit Dam between October 20 and 21, 2009. The pipe terminus elevation for injection of SF into the test turbine intake was confirmed to be at 1409 ft above MSL. The forebay elevation for the turbine passage segment of this study was approximately 1513 ft above MSL, 56 ft below the maximum pool elevation of 1569 ft above MSL.

1.4 Contents and Organization

Section 2.0 provides an overview of the SF and HBET technologies, associated terminology used in this guide, and related publications that provide additional detail about the SF and HBET. The ensuing sections describe the best practices for using HBET to design studies (Section 3.0), prepare data (Section 4.0), process and analyze data (Section 5.0), and report the results of biological response evaluations.

This document presents best practices by topic and the different sections reflect the general workflow associated with using HBET to assess the physical characteristics and fish passage conditions of a hydraulic structure such as a hydropower turbine or spillway. The method for collecting field data using the SF is described in Appendix A.

Please note that any option/feature not covered in this document can be found in the user guide (https://www.dropbox.com/s/5ezriidwyyvzjce/HBET2.0UserGuide.pdf?dl=0).

2.0 SENSOR FISH AND HBET TECHNOLOGY

In combination, the SF and HBET technologies described below enable users to characterize the hydraulic conditions of hydropower structures and estimate fish injury and mortality rates from various stressors. Related definitions, sources of more detailed information, and licensing contact information are also provided this chapter.

2.1 SENSOR FISH

The SF measures pressure, three-dimensional (3-D) linear accelerations, 3-D rotational velocities, and 3-D orientation in situ at a sample rate of 2048 Hz, while the device is entrained in the flow through a hydro-structure. The SF was designed to have a size and density similar to a yearling salmon smolt—a diameter of 24.5 mm, length of 89.9 mm, and a weight of 42.1 g—and a nearly neutrally buoyant body in freshwater. A rechargeable battery supplies power to the SF. The recovery module makes the SF positively buoyant and float to the surface for recovery after a pre-programmed time. The components were placed so that the center of gravity is very close to the geometric center.

The SF Mini was developed for evaluating hydraulic conditions in structures where the original SF could be too large, such as in small hydroelectric turbine-scale models of larger turbines. The SF Mini's flat, flexible, and cluster features make it adaptable to specific applications, as indicated below (see Figure 2.1):

- Flat – It can be rigidly mounted to an operating mechanical device to investigate machine dynamics using a self-contained device.
- Flexible – It uses multiple sets of SF Mini electronics encapsulated in a silicone body that attempts to replicate a juvenile salmonid for investigating blade strike.
- Cluster – It uses multiple sets of SF Mini electronics to measure pressure in three orthogonal directions to investigate collisions with rigid bodies.

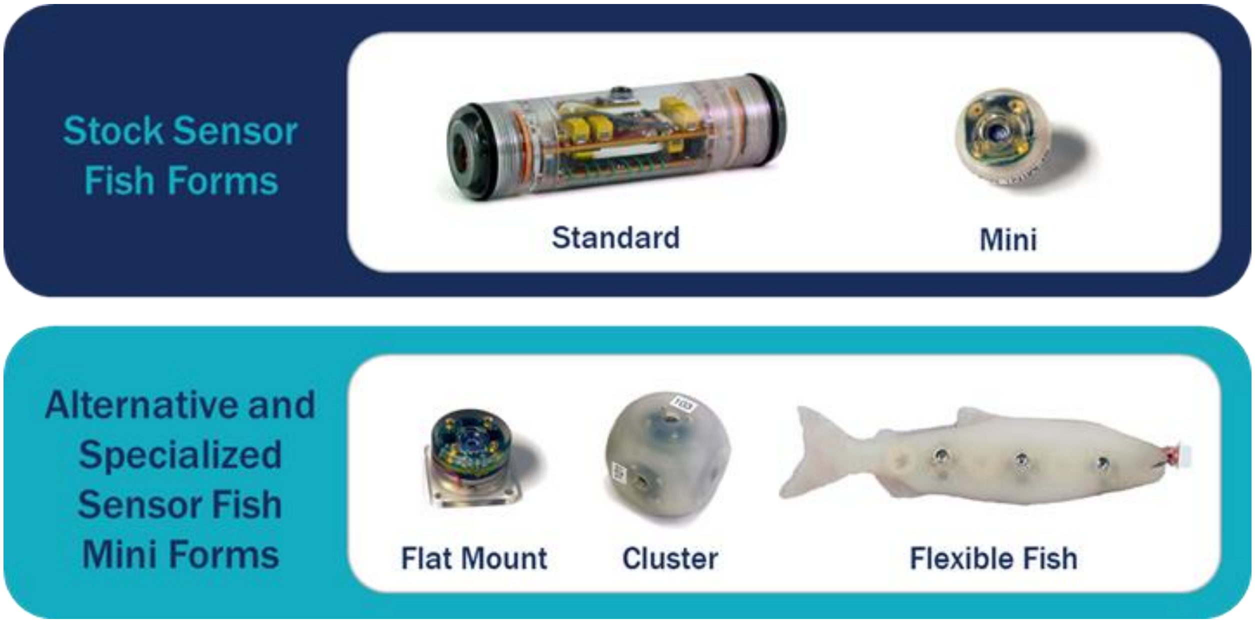


Figure 2.1. The SF Suite highlighting the SF Mini's flat, flexible, and cluster features.

In a calm hydraulic environment, a live fish can change its orientation in response to flow. However, in a more severe hydraulic environment, such as when a fish enters the fast-moving and turbulent conditions in a turbine, little is known about its ability to sense and avoid obstacles or compensate for changes in density related to the changes in pressure. As a result, the current practice is to assume that fish behave as passive neutrally buoyant objects during passage. Laboratory experiments involving live fish can be performed to develop biological response models that then are used to correlate with the measurements collected by SF, thereby allowing researchers to understand how hydraulic conditions affect fish (Pflugrath et al. 2021).

2.2 HYDROPOWER BIOLOGICAL EVALUATION TOOLSET

HBET is an integrated suite of science-based tools that has a user-friendly interface and a remotely accessible database. It uses hydraulic characterization data collected in situ with SF to predict impacts on fish from entrainment through turbines or other hydraulic structures at new or rehabilitated hydropower plants. The Data Analysis portion of the toolset analyzes SF data to identify events, such as strike or shear events, that could injure fish. In the Evaluating Biological Response portion of the toolset, existing dose–response relationships, and those currently under development, can be used to understand how events of interest can affect fish. Methodologies for determining the relationship between the sample size (i.e., the number of SF releases) and the precision of the measurements are implemented in the Design New Study portion of the toolset, which enables users to design SF studies to meet specific objectives.

HBET, along with another program named the Biological Performance Assessment tool (BioPA), is part of a project known as HydroPASSAGE. Both HBET and BioPA can provide estimates of the levels and types of forces fish are predicted to encounter in turbines. However, when using hydraulic dose data obtained from direct measurements, HBET can be used to evaluate existing hydropower structures; while when using data from computational fluid dynamics models, BioPA is more commonly used in turbine design. If validated with live fish field studies, both capabilities can be cost-effective alternatives to live fish field studies when investigating fish injury and mortality rates.

2.3 Terminology Definitions

Term	Definition
Acceleration	A method of quantifying exposure to fluid shear. The rate at which a fish's velocity changes over time. Represented as $m \cdot s^{-2}$.
Acclimation Pressure	The pressure to which a fish is acclimated (neutrally buoyant for pelagic fish) prior to exposure to rapid decompression.
Biological Response	The relationship between a stressor that a fish may experience during turbine passage with the predicted response (injury or mortality). Biological response relationships inform biological design criteria for turbine design and operation. Equations are developed to estimate the probability of response or P(R).
Dose–response Relationship	Also known as Biological Response Models, describes the probability of a response (injury or mortality) for a fish as a function of exposure to various magnitudes of a stressor.
Functional Mortality	Fish that have injuries that will likely lead to mortality directly or indirectly (i.e., ecological death).
Injury	Any injury that is a result of a fish being exposed to a stressor.
LRP	The natural logarithm of the ratio of acclimation pressure to nadir pressure (P_A/P_N).
Major Injury	Life-threatening injuries. Major injury equations include all fish with major injuries or worse.
Minor Injury	Non-life-threatening injuries. Minor injury equations include all fish with minor injuries or worse.
Mortal Injury	Injuries that are statistically analyzed and found to be highly associated with and significant predictors of mortality. Mortal injury equations include all fish with mortal injuries or worse.
Mortality	Fish that die as a result of exposure to a stressor.
Nadir Pressure	The lowest pressure that a fish experiences during exposure to rapid decompression.
Strain Rate	A method of quantifying exposure to fluid shear. The change in water velocity with respect to distance. Represented as $cm \cdot s^{-1} \cdot cm^{-1}$ or simplified as s^{-1}.
Time Mark	A specific point in the time history of the Sensor Fish data file chosen by users to split the whole record into regions, such as entrance, wicket gate, etc.

2.4 Contact Information for Licensing SF/HBET Technology

For information about licensing SF or HBET technology, please contact Technology Commercialization Manager Sara Hunt (sara.hunt@pnnl.gov) or the PNNL Technology Deployment and Outreach Office (techcomm@pnnl.gov): https://www.pnnl.gov/available-technologies.

3.0 STUDY DESIGN

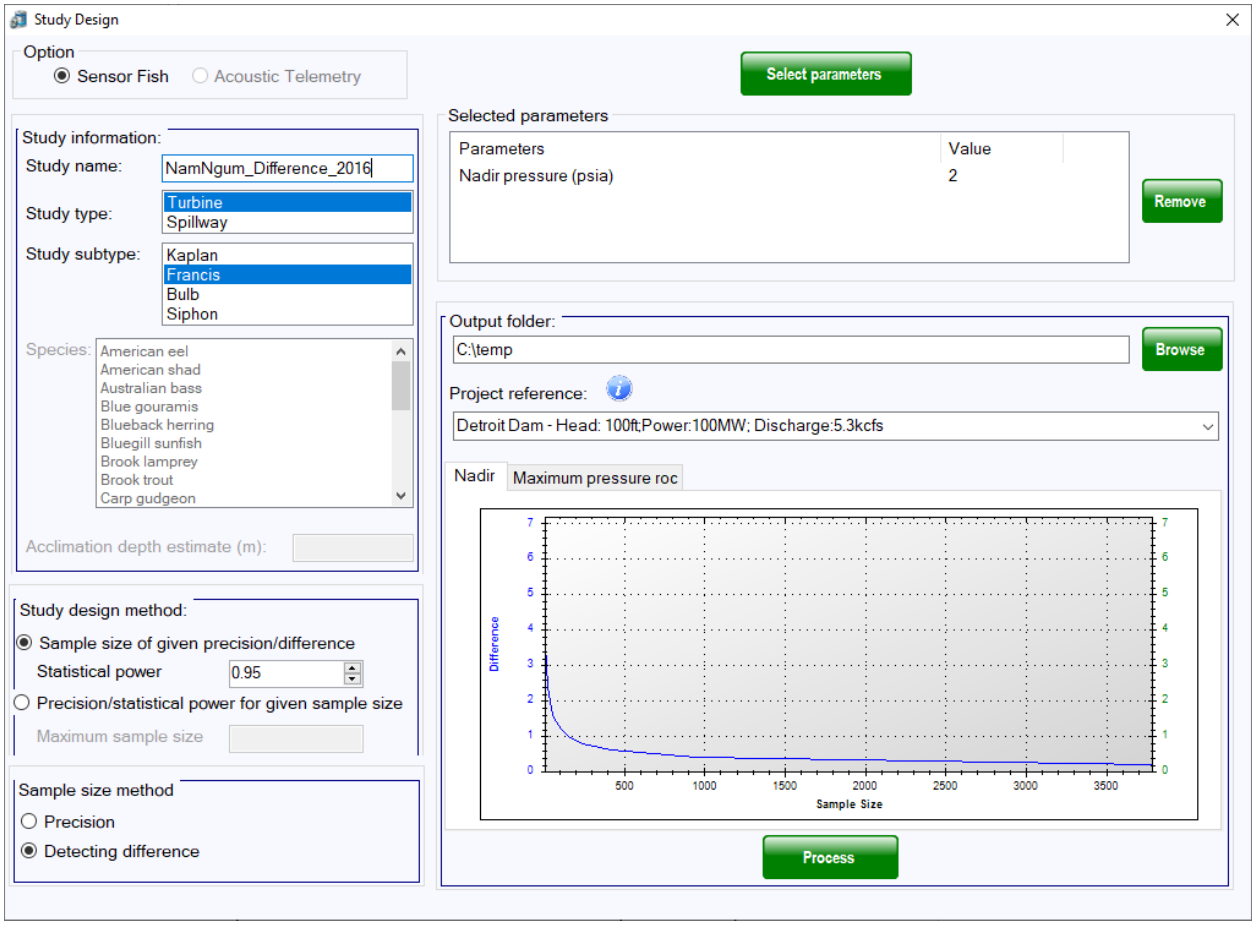
The Study Design component of HBET aims to develop testable hypotheses and to determine experimental designs, which enable detailed consideration of the design of hydraulic structures and operational elements that affect the structure's biological performance during the design phase of new construction or rehabilitation. Previously performed SF studies are used as project references for designing new SF studies. HBET allows users to select parameters that should be used for the study (e.g., nadir pressure). The Study Design component can be used to determine the sample size for desired precision or differences, or estimate the likelihood to achieve the desired precision or detect differences for a given sample size.

3.1 USING HBET TO DESIGN A NEW SF STUDY BASED ON PREVIOUS STUDIES

The two use cases presented below can be used to validate one another's results. The first use case delineates the process for estimating the sample size (number of SF) for given conditions, and the second one delineates the process for determining the likelihood for the sample size to consist of a given number.

3.1.1 USE CASE 1: DETECTING DIFFERENCES IN NADIR PRESSURE FROM A PREVIOUS STUDY

Use Case 1 is intended to describe how to design a study for detecting differences in nadir pressures from a previous study. To design a study to detect differences in nadir pressure from a previous study, take the steps enumerated below. The following image depicts the screen view for the Study Design function in HBET.



Note: In the “Option” section, “Sensor Fish” is automatically selected because a “Acoustic Telemetry” study design has not been implemented in the current version of HBET.

1. In the “Study information” section,
   a. **INPUT** the study name:

      “NamNgum_Difference_2016”.

      We recommend using the following format to name the study:

      “StudySite_Reason_Year”.

   b. **CHOOSE** the study type and study subtype:

      Turbine and *Francis* because the installed turbine in Nam Ngum Dam is a Francis turbine.

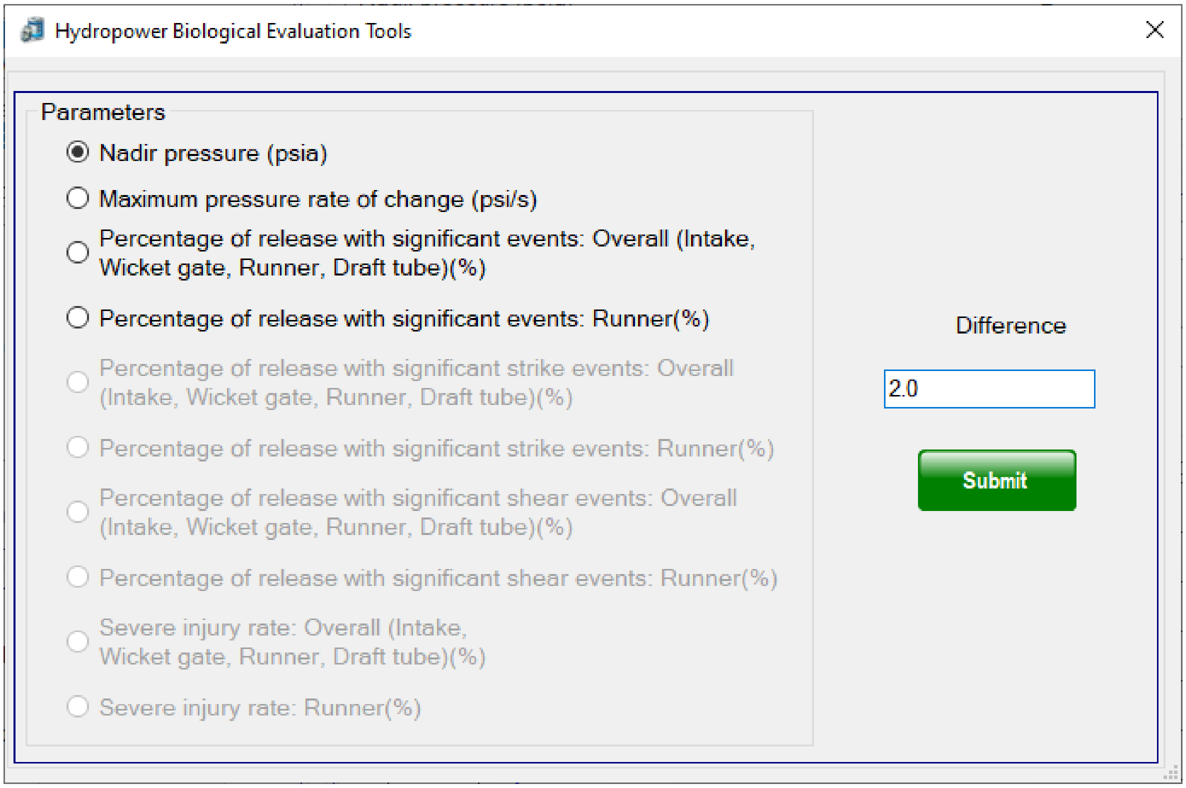
   c. **SKIP** Species and Acclimation depth estimate (m). They have not yet been implemented in the current version of HBET.

2. **CHOOSE** “*Sample size of given precision/difference*” in the “Study design method” section and **CHOOSE** “*Detecting difference”* in the “Sample size method” section.

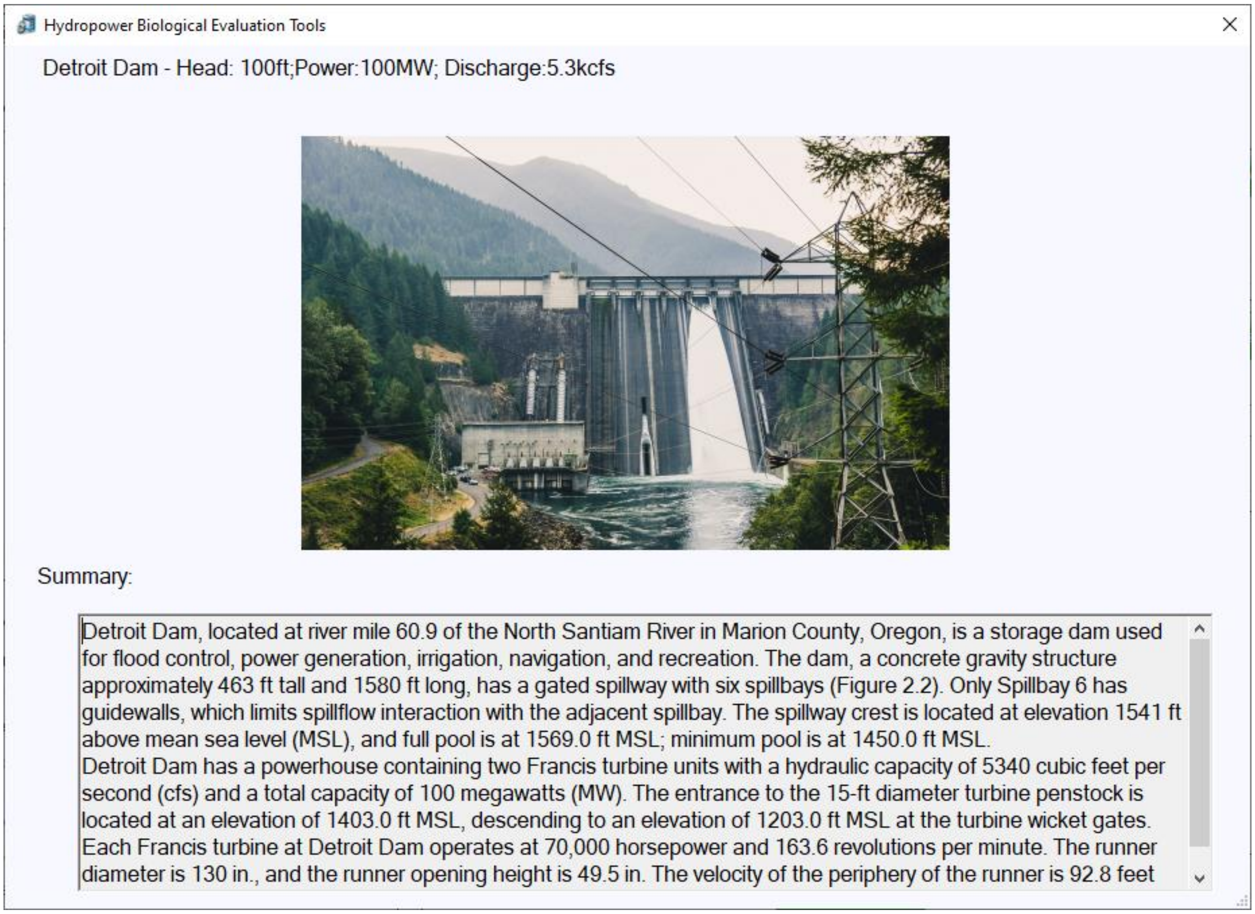
   Now the “*statistical power*” should be editable.

   CHANGE the value of the “*statistical power*” to the desired precision. For this example, the statistical power will be set to 0.95”.

3. **CLICK** the “Select parameters” button in the pop-up windows, **CHOOSE** the “*Nadir pressure (psia)*” parameter, **INPUT** *2.0* as the value of the difference, then **CLICK** the “Submit” button (as shown in the screenshot below).

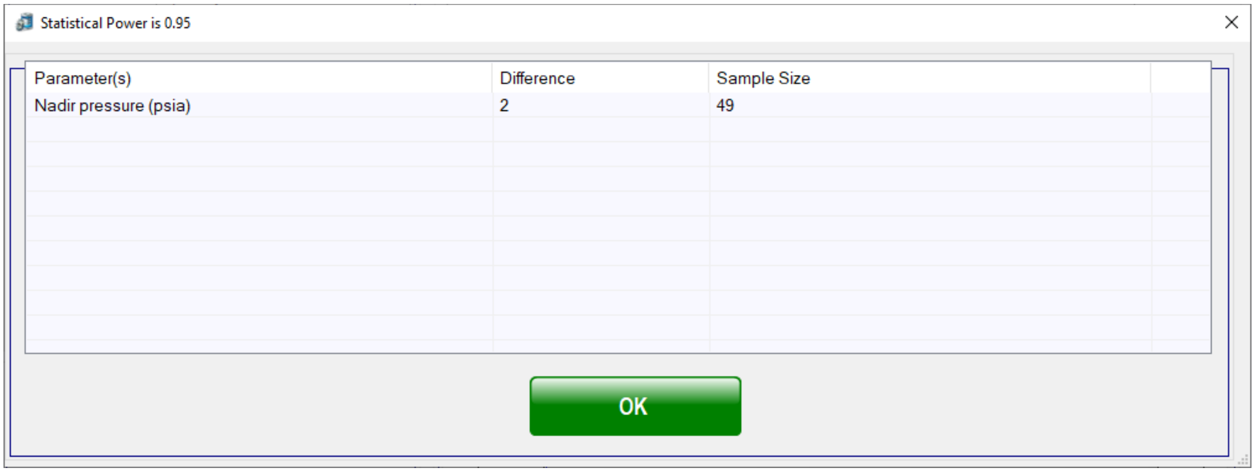


4. In the “Output folder”,
   a. **INPUT** “*C:\temp*” OR
   b. **CLICK** the “*Browser*” button to **CHOOSE** “*C:\temp*” as the output folder.
   c. **MAKE SURE** the directory “*C:\temp*” exists.
5. In the “Project reference” section in the “Study Design” window, **CHOOSE** “*Detroit Dam - Head: 100ft;Power:100MW; Discharge:5.3kcfs*” because we do not have baseline data at Nam Ngum Dam and Detroit and Nam Ngum have similar characteristics; then **CLICK** the “" button to see more information about the selected project reference(as shown in the screenshot below).



6. **CLICK** the “Process” button in the “Study Design” window:

   From the information given in the screenshot below, HBET suggests that the required sample size is 49 to have a likelihood of 95% to detect the difference 2.0 psi of nadir pressure from the design associated with the “*Detroit Dam - Head: 100ft;Power:100MW; Discharge:5.3kcfs*” project reference.

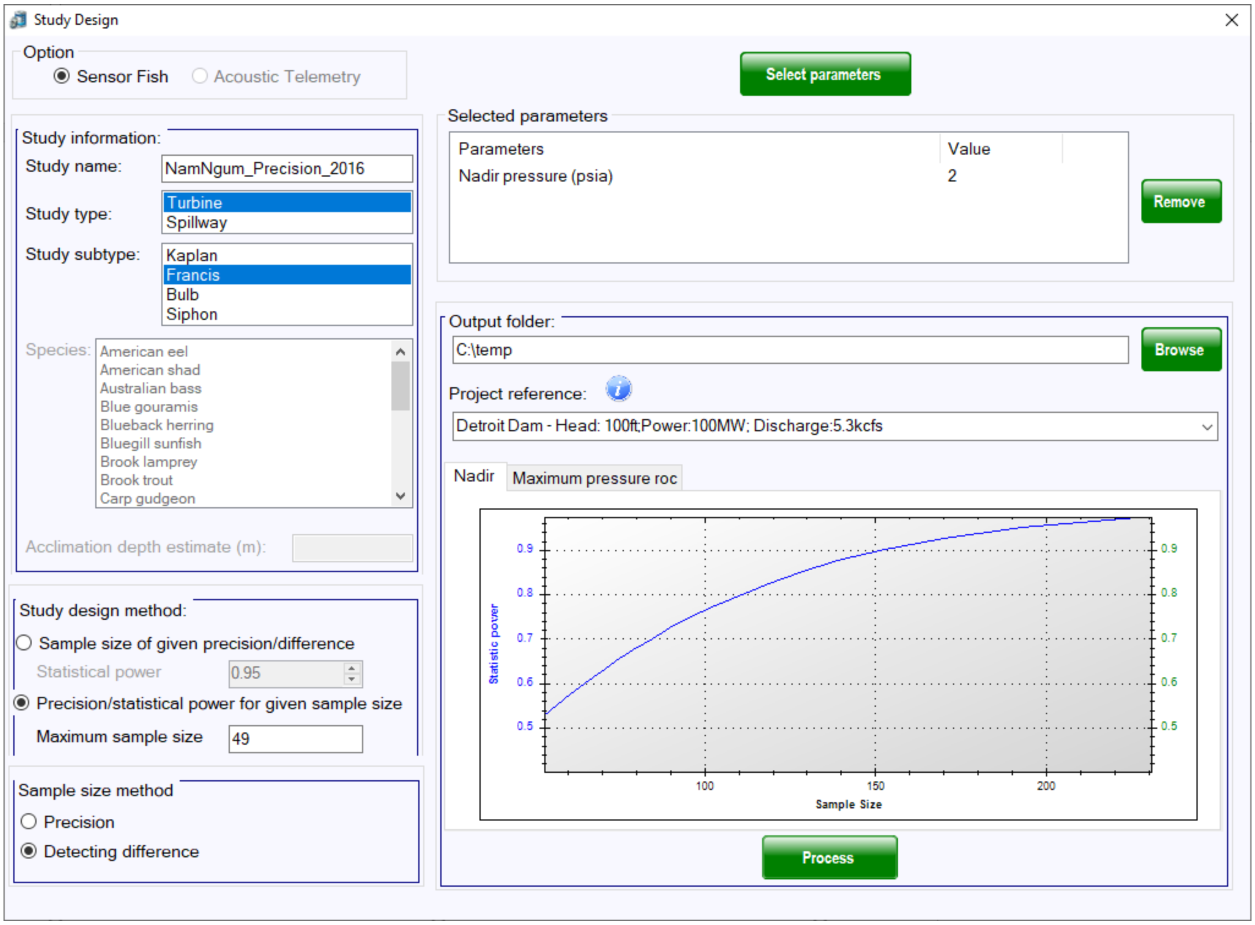

Statistical Power is 0.95

Parameter(s)	Difference	Sample Size
Nadir pressure (psia)	2	49

OK

3.1.2 USE CASE 2: PRECISION THAT CAN BE OBTAINED FOR A SPECIFIC SAMPLE SIZE

For Use Case 2, to design a study for estimated precision that can be obtained for a specific sample size, take the steps enumerated below.



Note: In the "Option" section, "Sensor Fish" is automatically selected because a "Acoustic Telemetry" study design has not been implemented in the current version of HBET.

7. In the "Study information" section,
   a. **INPUT** the study name:

      "NamNgum_Difference_2016".

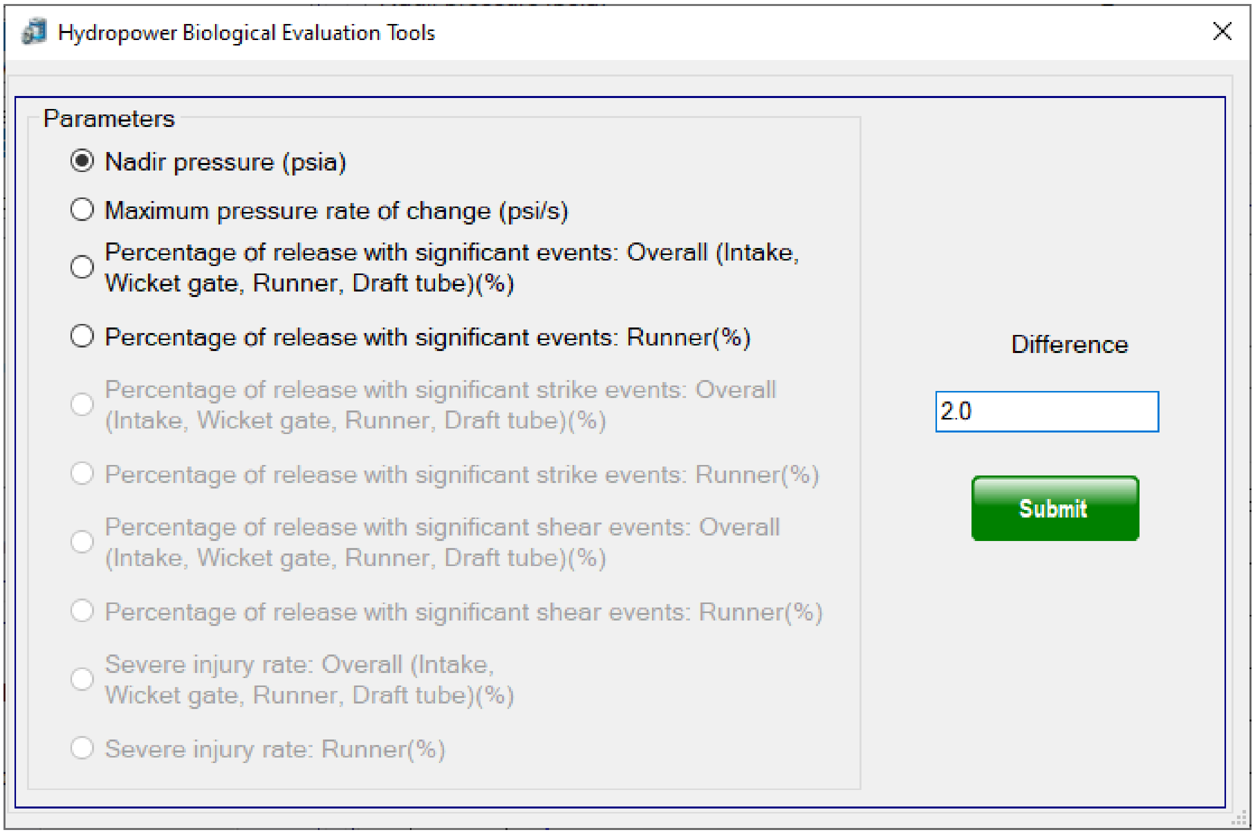
      We recommend using the following format to name the study:

      "StudySite_Reason_Year".
   b. **CHOOSE** the study type and study subtype:

      Turbine and *Francis* because the installed turbine in Nam Ngum Dam is a Francis turbine.
   c. **SKIP** Species and Acclimation depth estimate (m). They have not yet been implemented in the current version of HBET.
8. **CHOOSE** "Precision/statistical power for given sample size" in the "Study design method" section, then **CHOOSE** "*Detecting difference"* in the "Sample size method" section.

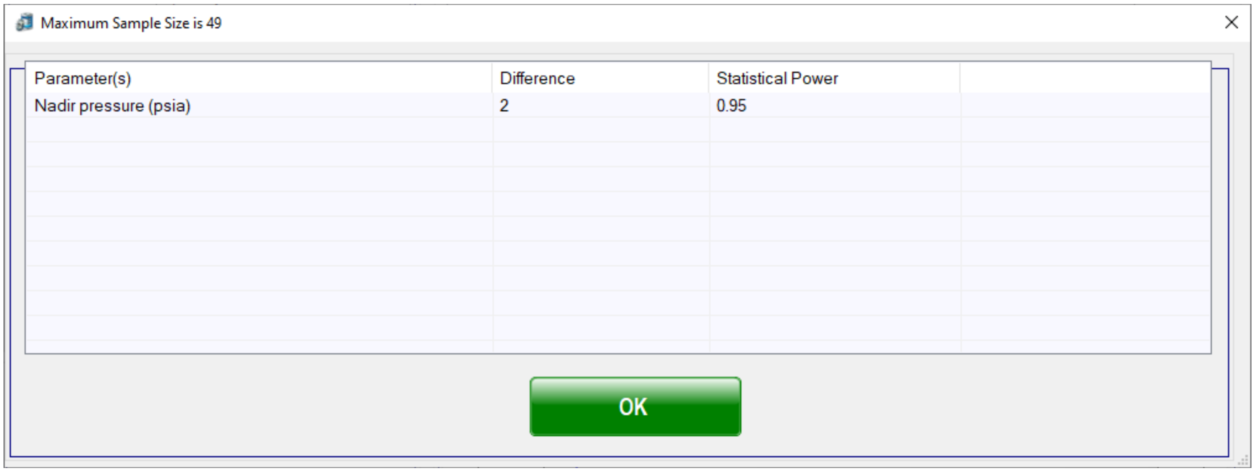
Now the "*Maximum sample size*" should be editable.

9. **CHANGE** the value of "*Maximum sample size*" from the default blank to *49*, which is the suggested sample size from Use Case 1.
10. **CLICK** the "Select parameters" button, and in the pop-up window, **CHOOSE** the "*Nadir pressure (psia)*" parameter, **INPUT** *2.0* as the value of the difference, then **CLICK** the "*Submit*" button (as shown in the screenshot below).



11. In the "Output folder",
    a. **INPUT** "*C:\temp*" OR
    b. **CLICK** the "*Browser*" button to **CHOOSE** "*C:\temp*" as the output folder.
    c. **MAKE SURE** the directory "*C:\temp*" exists.
12. In the "Project reference" section in the "Study Design" window, **CHOOSE** "*Detroit Dam - Head: 100ft;Power:100MW; Discharge:5.3kcfs*" because we do not have baseline data at Nam Ngum Dam and Detroit and Nam Ngum have similar characteristics.
13. **CLICK** the Process button in the "Study Design" window.

    From the information given in the screenshot (shown in the screenshot below), HBET suggests that for the given sample size of 49, the likelihood to get the difference 2.0 psia of nadir pressure from the design associated with the "*Detroit Dam - Head: 100ft;Power:100MW;Discharge:5.3kcfs*" project reference is 95%.



Note: Please use the recommended sample size 50 if the “Study Design” process is skipped for any reason.

4.0 DATA PREPARATION

4.1 USING FIELD NOTES TO GENERATE THE FIELD SHEET FOR UPLOADING DATA TO HBET

The asterisks (*) in Table 4.1 indicate values must be provided for the corresponding attributes before uploading all associated SF data files to HBET; other columns/cells may be left blank if the data are unavailable. The user must specify the data folder and the file name of each release in the field sheet, based on the location and name of SF data files, because only the files listed in specified file locations with specified file names in the field sheet will be successfully uploaded. Similarly, the user needs to fill in the "*Calibration File Name*" column with both the data folder and file names (e.g., *C:\temp\sf9_cal_20141215.txt*) to upload the calibration file.

Table 4.1. Attributes for field sheet file for uploading data to HBET.

Attributes	Description	Required (*)
Test Date	The date in MM/DD/YYYY when SF was deployed and recovered	*
Dam	The name of the study site	*
Study Type	Turbine, spillway, etc.	*
Study Subtype	Kaplan, Francis, etc.	*
Treatment	The name of the treatment. Usually consists of the information about test location and test conditions.	*
Sensor Fish ID	The serial number of the SF.	
Calibration File Name	The calibration file used to calibrate the SF. There should be a corresponding calibration for each SF.	(*) if the data file uploaded is in .raw2 format.
Data Folder	The directory where the data files are stored. This directory should be accessible by the user who launches HBET.	*
File Name	Name of the data file.	*
Location	Location where SF was released.	
Unit	The number of unit where SF was released.	
Block #	The number of block where SF was released.	
Test Condition	The test condition, such as *Upper 1%*	
Tag Number	The tag number, such as *164.300*	
Deployment Time	The time in hh:mm where SF was deployed	*
Recovery Time	The time in hh:mm where SF was recovered.	*
Barometric Pressure (inhg)	The measured atmospheric pressure in inhg where and when the SF was deployed	(*) if Barometric Pressure (psia) is not available
Barometric pressure (psia)	The measured atmospheric pressure in psia where and when the SF was deployed	(*) if Barometric Pressure (inhg) is not available
Target Discharge (kcfs)	The estimated discharge in kcfs where and when the SF was deployed	
Pipe (ft)	The length of the pipe in feet used to deploy the SF	
Discharge (kcfs)	The actual discharge in kcfs where and when the SF was deployed	
Wicket Gate (% Open)	The percentage of the wicket gate what is opened	

Attributes	Description	Required (*)
Blade Angle (% Open)	The percentage of the blade angle that is opened	
Total Discharge (kcfs)	The total discharge of the study site where and when the SF was deployed	
Generation (MW)	The power generated where and when the SF was deployed	
FB elevation (ft)	The forebay elevation in ft where and when the SF was deployed	
TW elevation (ft)	The tail water elevation in feet where and when the SF was deployed	
Head (ft)	The head elevation in feet where and when the SF was deployed	

4.2 UPLOADING DATA TO HBET

There are two methods for uploading files into the database: batch upload, which allows the user to upload multiple files as a batch, and single upload, which allows the user to upload different types of single files. Batch upload is preferred for uploading all SF data files, as well as the corresponding calibration file, associated with a specific study. Single upload is useful if the user wants to add report files or miscellaneous files to a specific study or add result files to a specific treatment condition. The user may add a calibration file to a specific deployment using single upload if the calibration file is missing for a specific deployment. The user may also add plot files to a specific deployment using single upload if plots of the specific SF data file have been generated in software other than HBET (e.g., MATLAB). Uploading a SF data file using single upload is not recommended because the data file uploaded through single upload will not be available in the attribute window or for query.

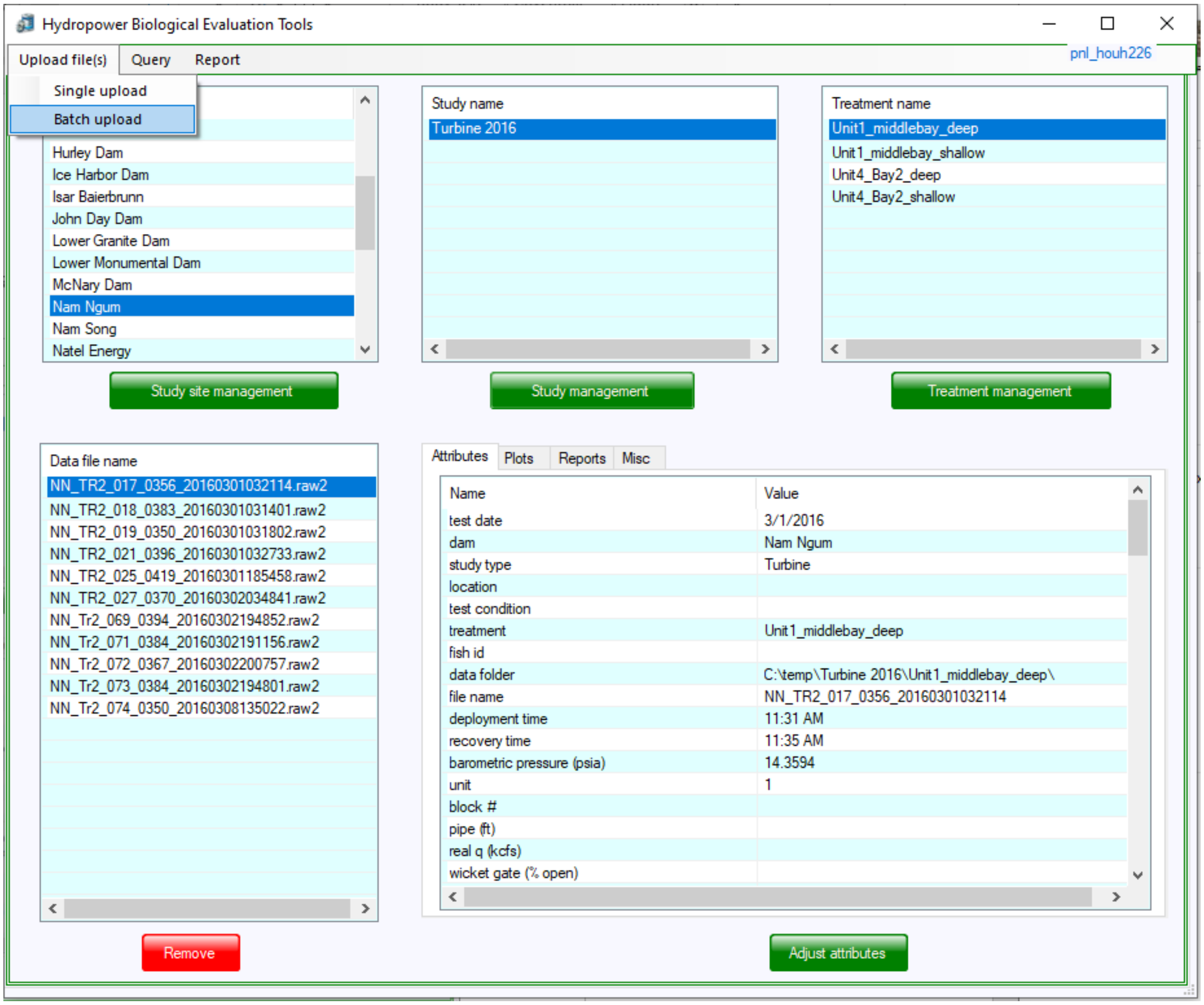
4.2.1 USE CASE 1: BATCH UPLOADING

To perform batch uploading, take the steps enumerated below.

1. **MOVE** all files under the "*C:\temp*" directory. The file structure will look like the following:

Directory name	Files	Descriptions
C:\temp\Turbine 2016	Turbine 2016_fieldsheet.xlsx	Field sheet book file
C:\temp\Turbine 2016\Unit1_middlebay_deep	*.raw2	SF data file
	* _Info.txt	Time mark file
	sf9_cal*.txt	Calibration file
C:\temp\Turbine 2016\Unit1_middlebay_deep\Processed\Plots\No_ZoomIn_Depth	*.jpg	Plot file with original scale
C:\temp\Turbine 2016\Unit1_middlebay_deep\Processed\Plots\ZoomIn_T0_T4	*.jpg	Plot file with zoomed in T0 to T4
…		

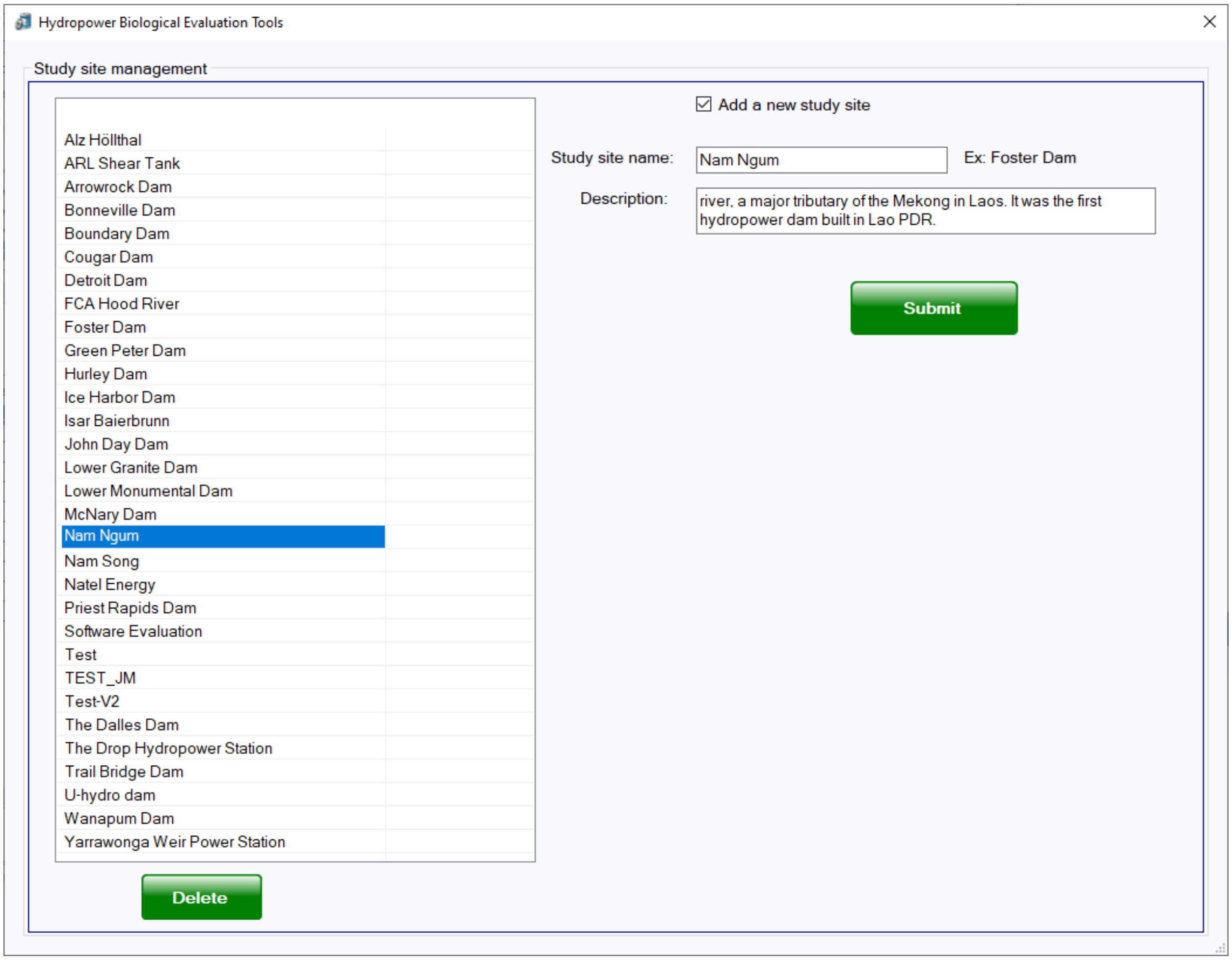
2. **CLICK** the "*Data Management*" button in the HBET startup screen shown below.



3. If the study site list doesn't include "*Nam Ngum*", **CLICK** the "*Study site management*" button.
4. In the pop-up window, **CHECK** "*Add a new study site*", and **ENTER** "*Nam Ngum*" as the study site name.
5. **ENTER** the optional description "The Nam Ngum Dam is a hydroelectric dam on the Nam Ngum river, a major tributary of the Mekong in Laos. It was the first hydropower dam built in Lao PDR."

Note: The description section has a maximum number of 255 characters.

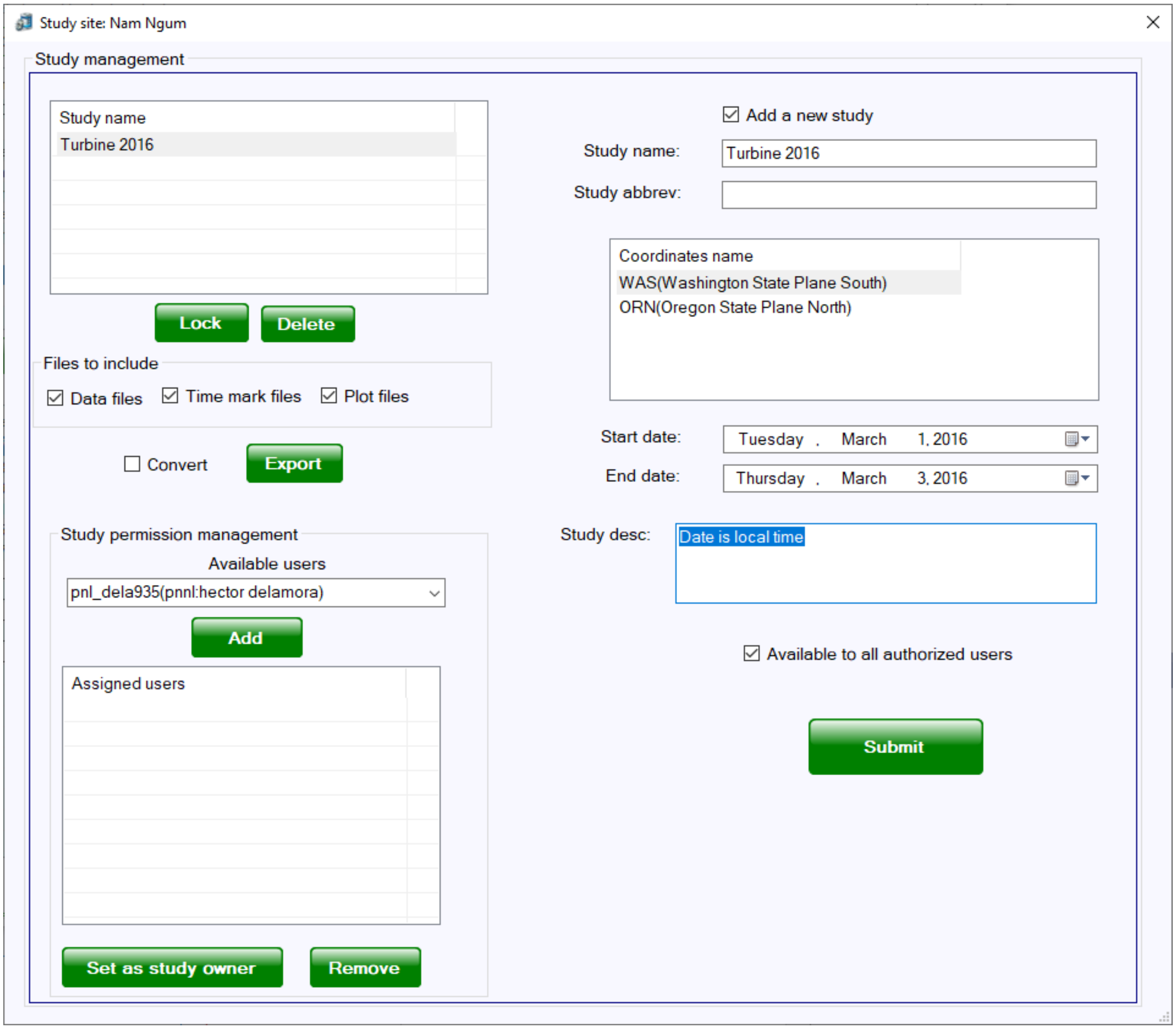
6. Then **CLICK** the "*Submit*" button (shown in the screenshot below).



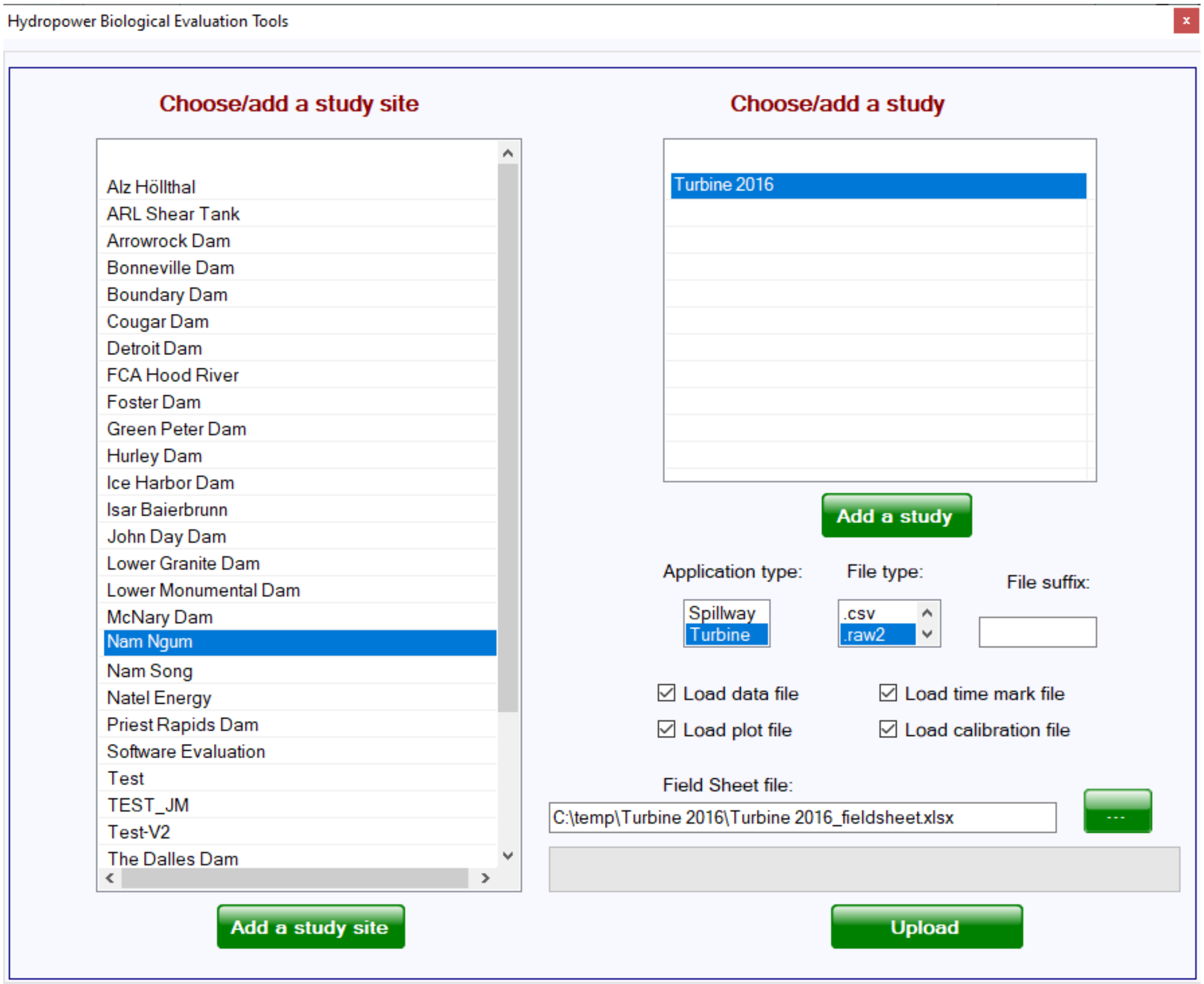
7. **SELECT** “*Nam Ngum Dam*” in the Study site name list, then **CLICK** the “*Study Management*” button.
8. In the pop-up window,
   a. **CHECK** “*Add a new study*”.
   b. **ENTER** “*Turbine 2016*” as study name
   c. **IGNORE** the “*Study abbrev.*” and “*Coordinates name*” because these parameters are not used in the current version of HBET.
   d. **CHANGE** the start date to “*February 1, 2016*” and the end date to “*February 29, 2016*”, then **ENTER** the optional study description “*Date is local time*”.

Note: that the description section has a maximum number of 255 characters).

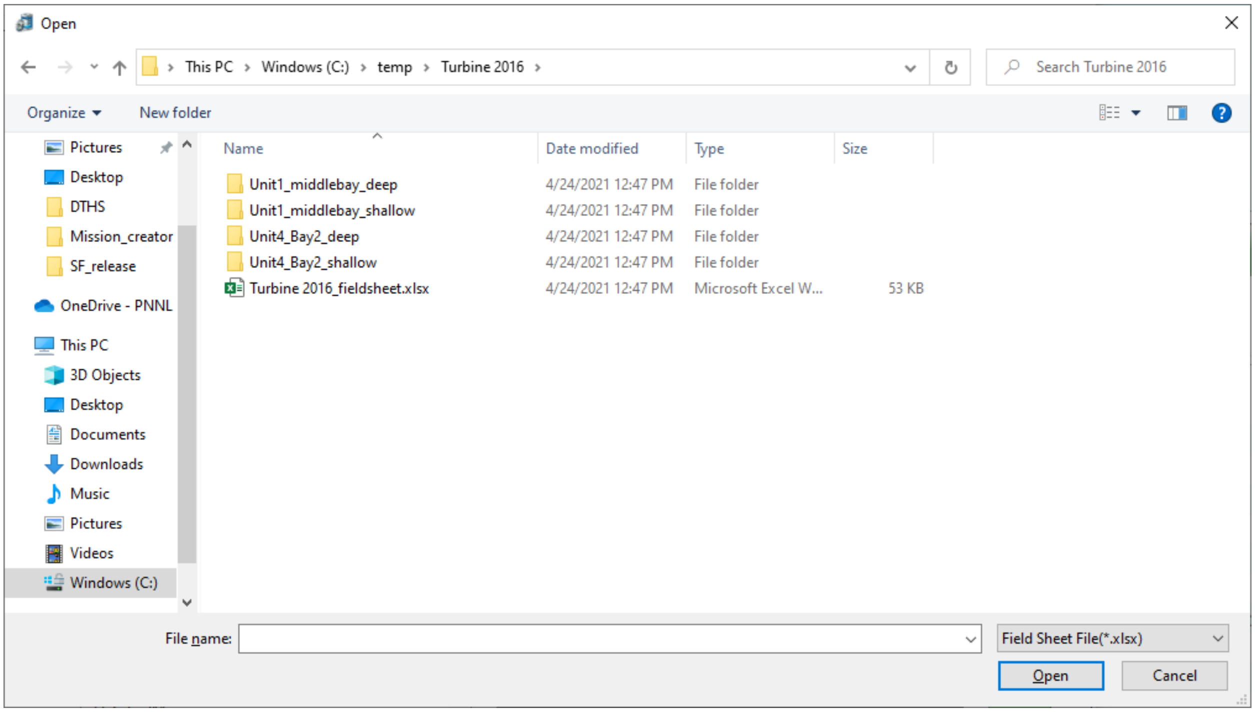
9. Then **CLICK** the “*Submit*” button (shown in the screenshot below).



10. From the menu bar on the "*data management*" window, **SELECT** "*Upload file(s)*" and **CHOOSE** "*Batch upload*" (shown in the screenshot below).

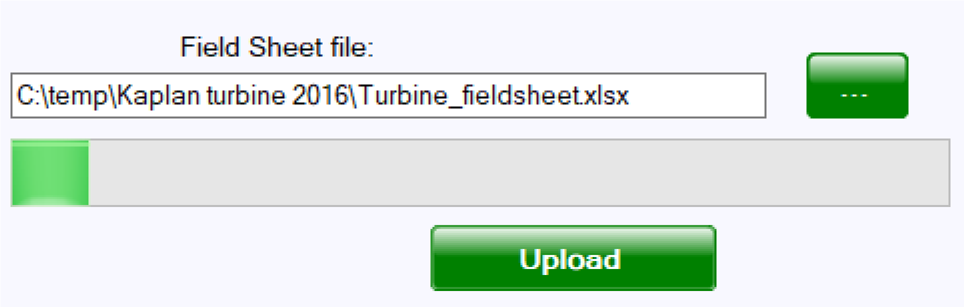


11. **SELECT** “*Nam Ngum*” in the study site.
12. **CHOOSE** “*Turbine 2016*” study if not selected.
13. **CHOOSE** “*Turbine*” as the application type and “*.raw2*” as the file type.
14. **ENTER** “C:\temp\Turbine\Turbine_fieldsheet.xlsx” or **USE** the “…” button to browser.
15. If using the “…” button to browser, **MAKE SURE** that the file filter of the popped-up window matches the file extension of the field sheet book file (see screenshot below).

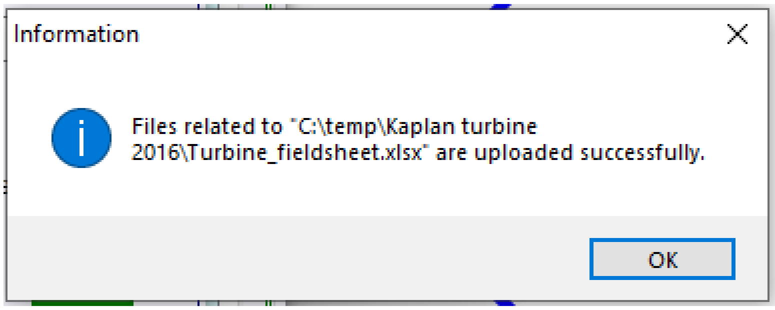


16. **CHECK** “Load data file”.
17. **UNCHECK** *“Load time mark file*” and “*Load plot file*” if no time mark files and plot files have been created yet. This is the most common case when just returning from the field.
18. **CLICK** the “Upload” button to upload.

    This process is time-consuming, please be patient. A status bar will be updated in real time showing the status of the process:



A notification message will show up once the uploading is complete:



19. If the uploading fails, as indicated by an error message or no progress bar showing, **PERFORM** the following corrections:

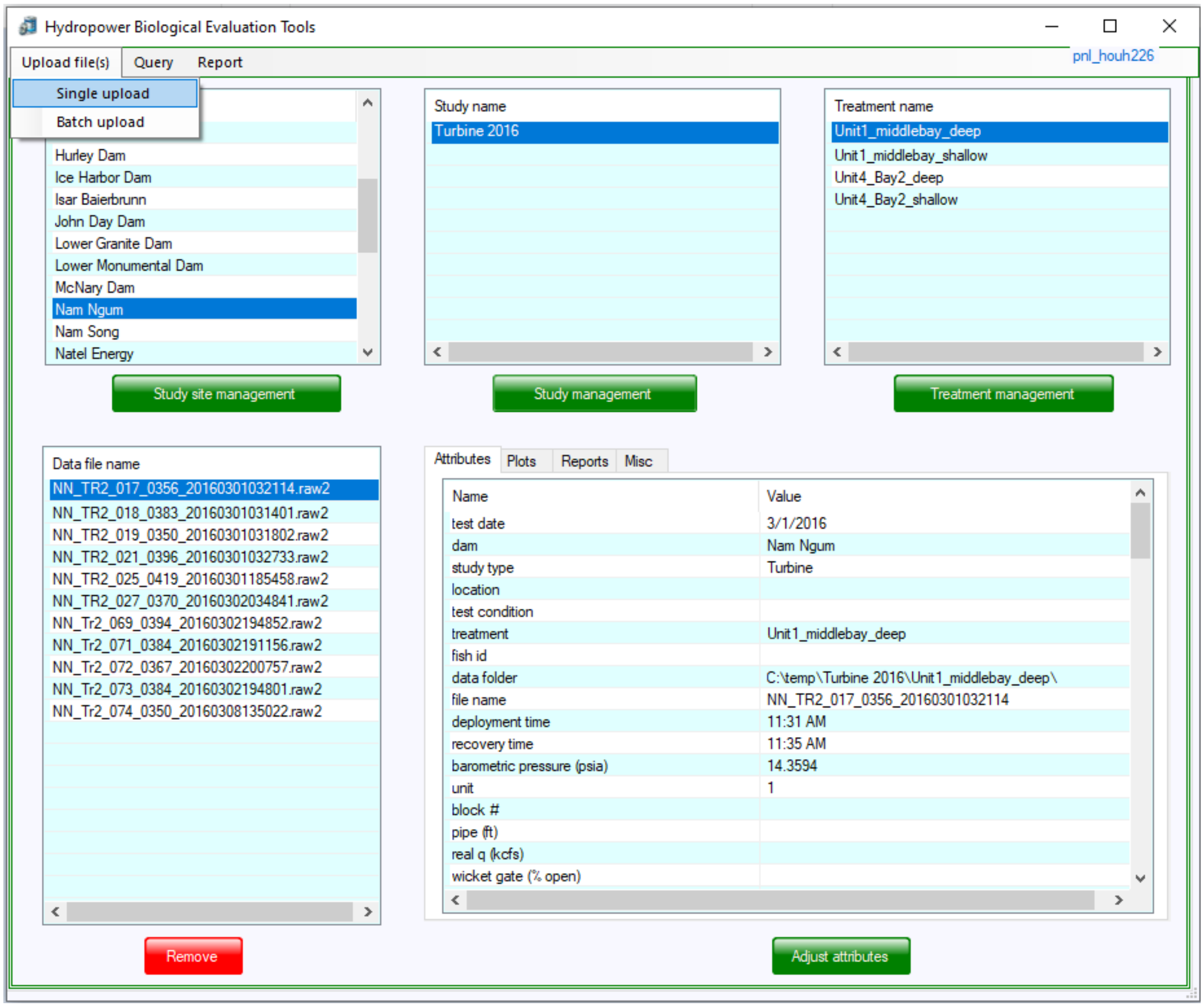
Reason	Solution
The selected field sheet book file is not accessible	**MAKE SURE** that the file is not opened by any other application.
Incomplete data	**REFER** to the Use Field Notes to Generate the Field Sheet for Uploading Data to HBET section to **MAKE SURE** all required fields are filled in.
Invalid test date	**MAKE SURE** the test date is in format MM/DD/YYYY.
Invalid Deployment Time and Recovery Time	**MAKE SURE** the format of Deployment Time and Recovery Time are hh:mm.
Data file folder is not accessible	**MAKE SURE** the user launching HBET has the reading access to the data file folder.
Wrong data file	**MAKE SURE** the data file has the correct file name.
Calibration file is not accessible	**MAKE SURE** the user launching HBET has the reading access to the calibration file.

20. For any of the situations listed above**, DELETE** the study, **FIX** the field sheet book file, then **REPEAT** Steps 2 through 18.

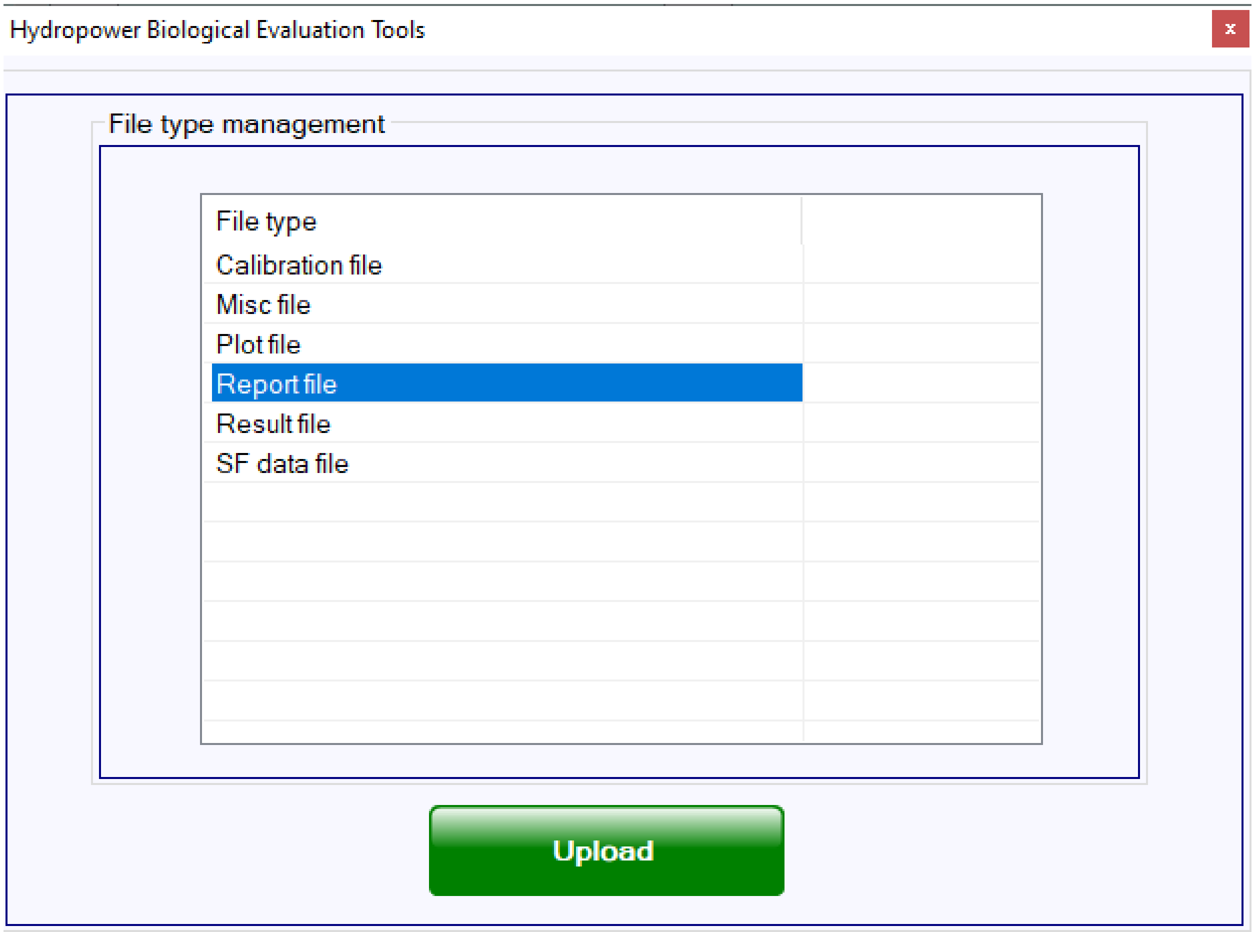
4.2.2 USE CASE 2: UPLOADING A SINGLE REPORT FILE TO A STUDY IN HBET

To upload a single report file (Journal article, conference paper, or technical report) to the selected study in HEBT, take the steps enumerated below.

1. **MOVE** the file "*Nam_Ngum_EcologicalEngineering_CLEAN.pdf*" into the "*C:\temp*" directory.
2. **CLICK** the "*Data Management*" button in the startup screen of HBET, then **CLICK** the "*Single upload*" menu item (as shown in the screenshot below).



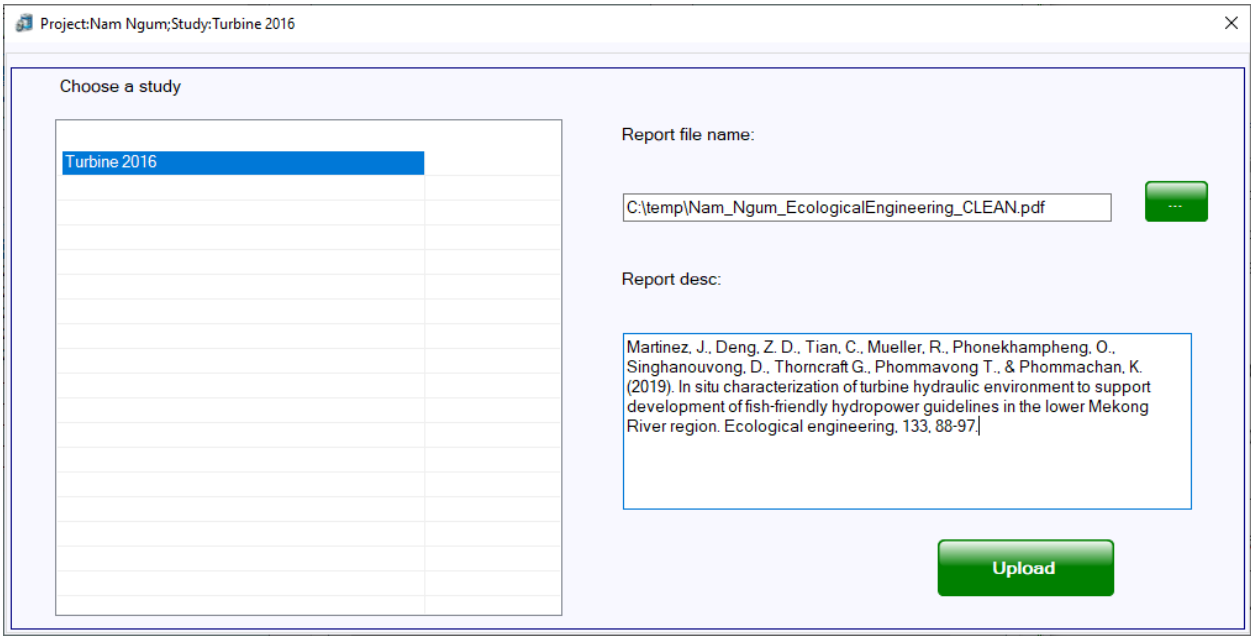
3. **CHOOSE** "*Report file*" as the file type, then **CLICK** the "*Upload*" button (as shown in the screenshot below).



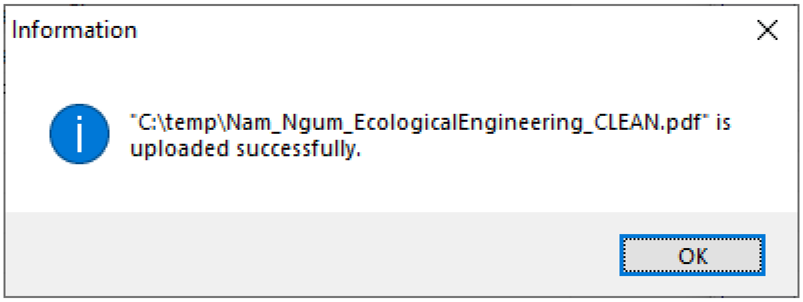
4. **SELECT** “Turbine 2016”, then **ENTER**:

- “C:\temp\Nam_Ngum_EcologicalEngineering_CLEAN.pdf” as the report file name
- “Martinez, J., Deng, Z. D., Tian, C., Mueller, R., Phonekhampheng, O., Singhanouvong, D., Thorncraft G., Phommavong T., & Phommachan, K. (2019). In situ characterization of turbine hydraulic environment to support development of fish-friendly hydropower guidelines in the lower Mekong River region. Ecological engineering, 133, 88-97” (as the report description).

Then **CLICK** the “*Upload*” button:



A notification message will show up once the uploading is complete:



5.0 DATA PROCESSING AND ANALYSIS

Measurements collected by the SF are saved in a binary format and must be converted to physical units using calibration coefficients determined for each specific SF. By converting raw sensor data to physical units, a data set of time histories for pressure, 3-D acceleration, and 3-D rotational velocity are generated. These data are analyzed to identify events of interest that characterize the hydraulic environment and can also be used to correlate events with live fish injuries.

> Please **note**: The key in the Data Analysis component of HBET is to create correct time marks to divide the passage into different regions.

Before starting,

1. **CLICK** the icon on the left side of the corresponding application type to see some examples. For example, if the study type is turbine, **CLICK** the icon on the left of the "*Turbine*" radio button in the bottom left corner to see the included example.
2. **SET** the time marks ascendingly; e.g., starting from T0, then T1, and so on.
3. **MAKE SURE** that T0-T4 are defined such that T0≤T1≤T2≤T3≤T4. For "*User-defined*" application type, make sure T0-T6 are defined such that T0≤T1≤T2≤T3≤T4≤T5≤T6.

   Resetting a time mark will overwrite its previous value.
4. To zoom in on an area, **MOVE** the cursor to the top left of that area, **HOLD** the left button of the mouse, and **MOVE** the cursor to the bottom right of that area, then **RELEASE** the left button of the mouse.

   The selected area will be automatically enlarged.

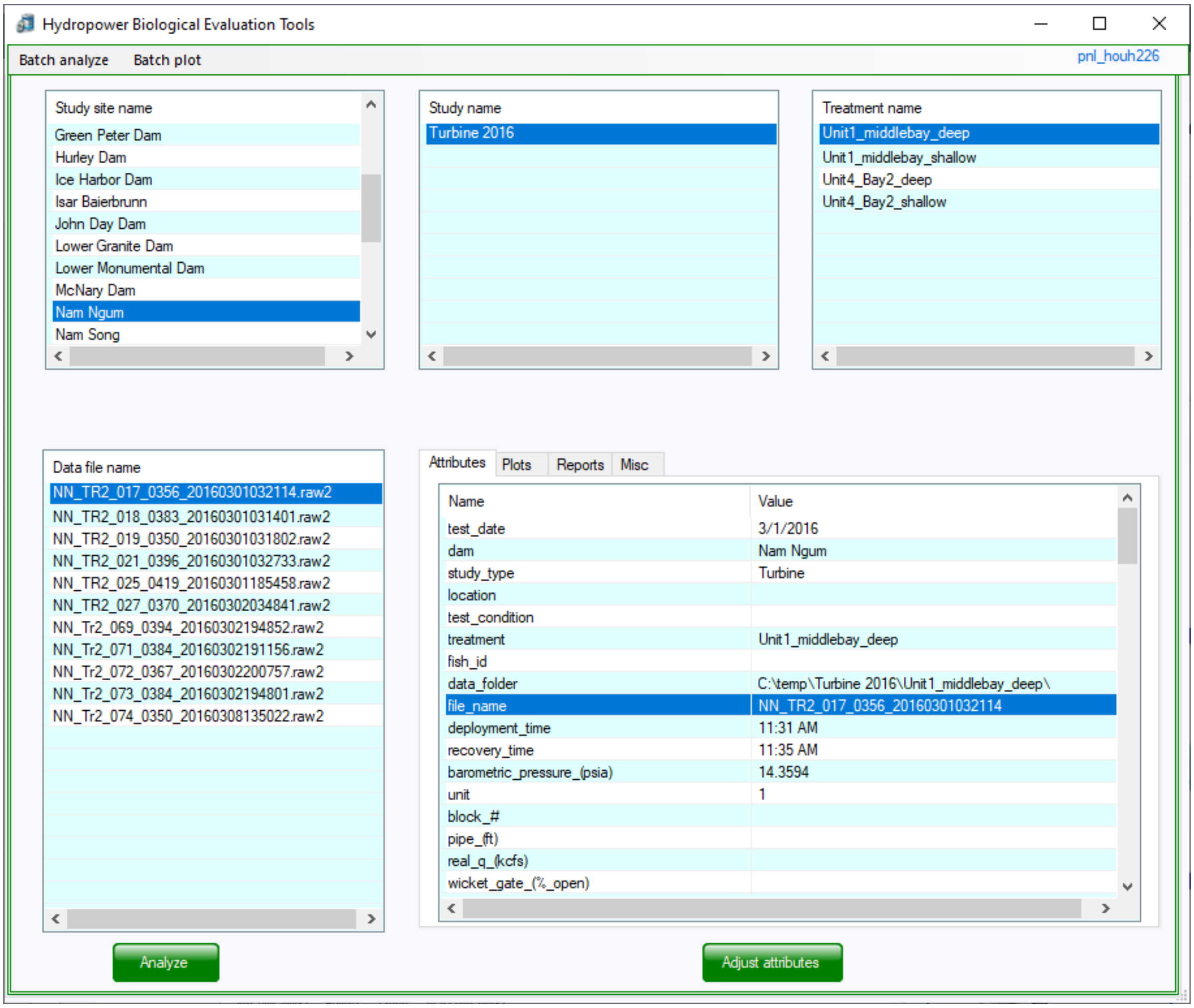
5.1 PROCESSING THE SF DATA BY DIVIDING THE PASSAGE INTO DIFFERENT REGIONS

The first step in processing the SF data is to divide the passage into different regions, and time markers are used for the division.

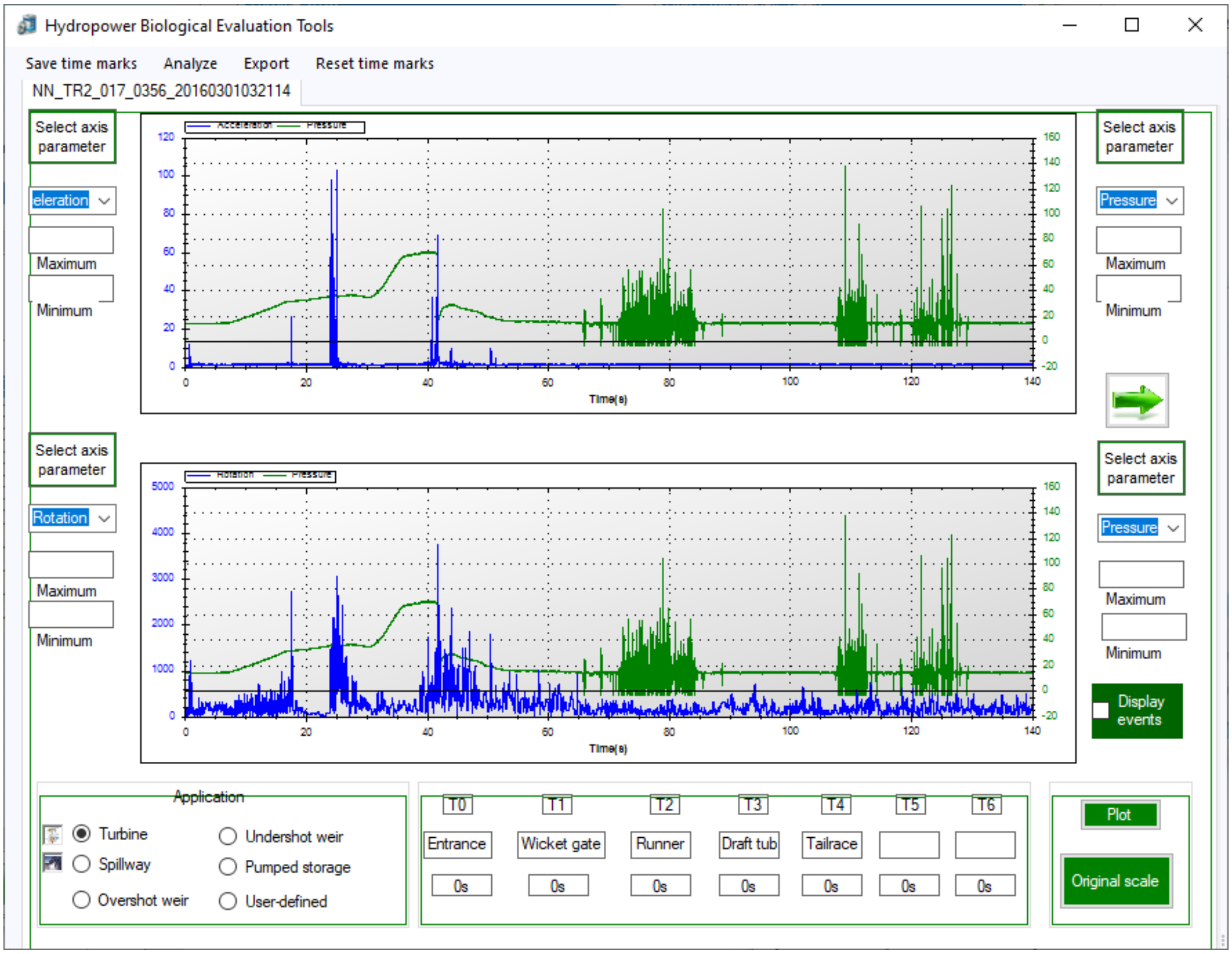
5.1.1 USE CASE 1: CREATING TIME MARKS FOR A DATA FILE

To create time marks for data file "*NN_TR2_017_0356_20160301032114.raw2*", take the steps enumerated below.

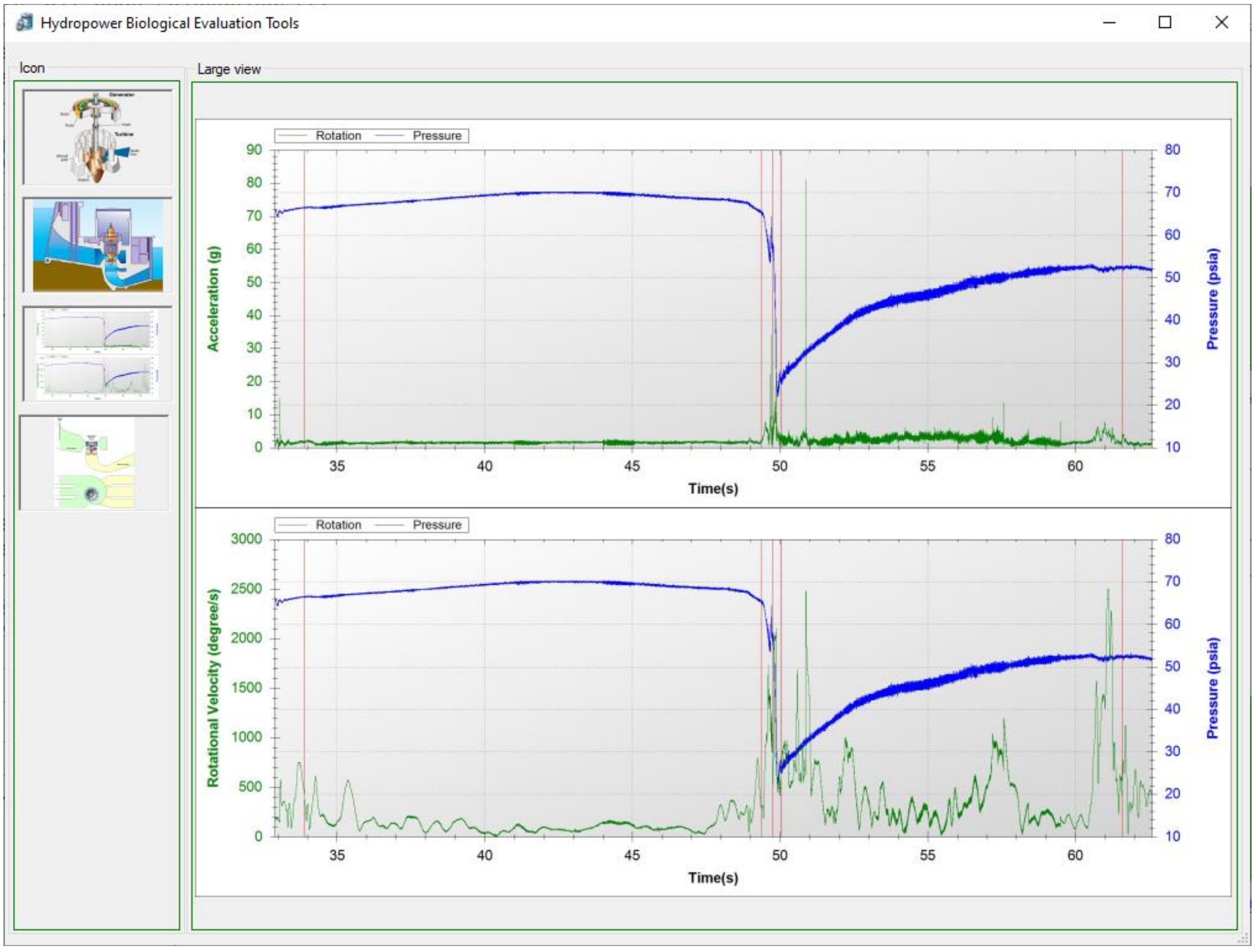
1. **CLICK** the "*Data Analysis*" button in the HBET startup screen (as shown in the screenshot below).



2. **SELECT** "Nam Ngum" study site and **MAKE SURE** the data file "*NN_TR2_017_0356_20160301032114.raw2*" was selected, then **CLICK** the "Analyze" button:

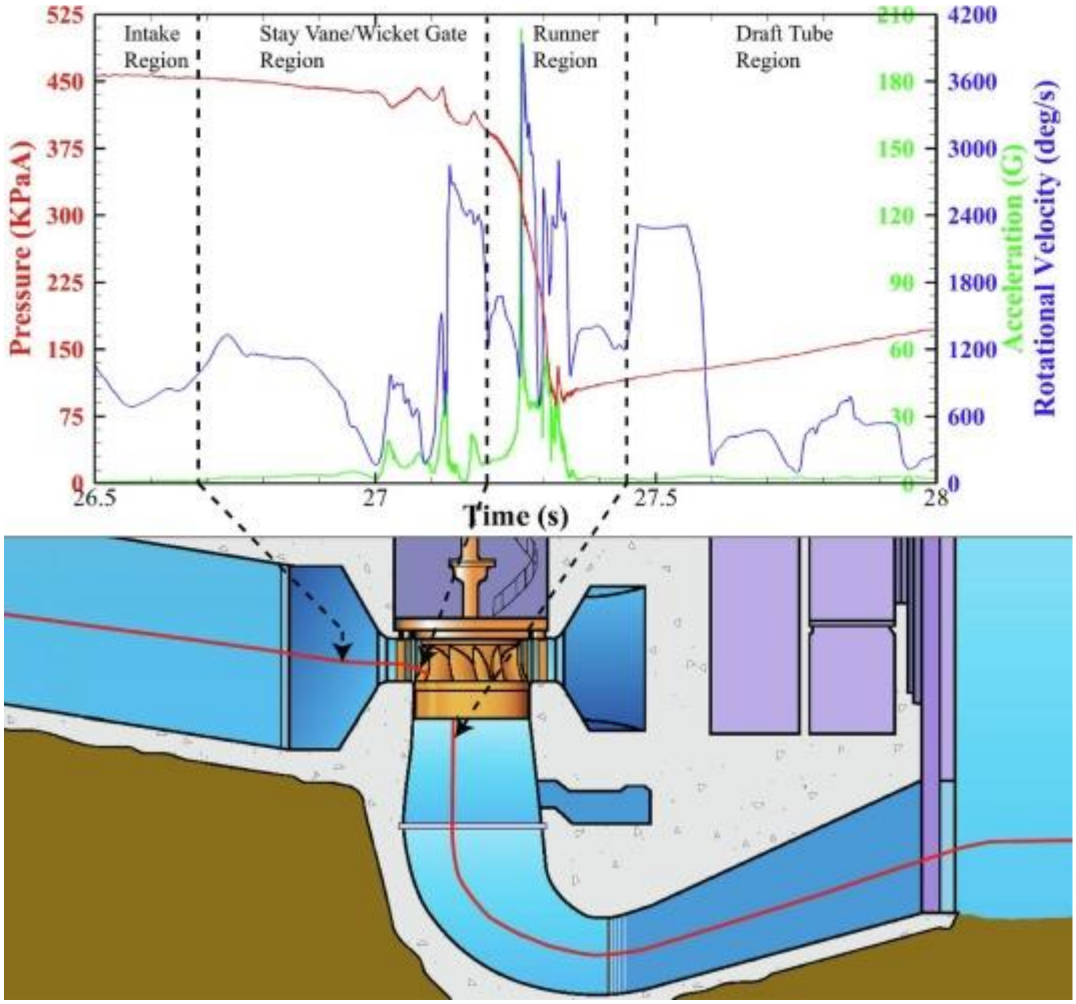


3. **SELECT** “Turbine” in the “Application” section.
4. **CLICK** the icon on the left of the selected application as shown in the screenshot above, and **GO THROUGH** all the attached figures, then **CLOSE** the window by **CLICKING** the “x” button (see screenshot below).



The regions of interest for passage through the turbine are listed below:

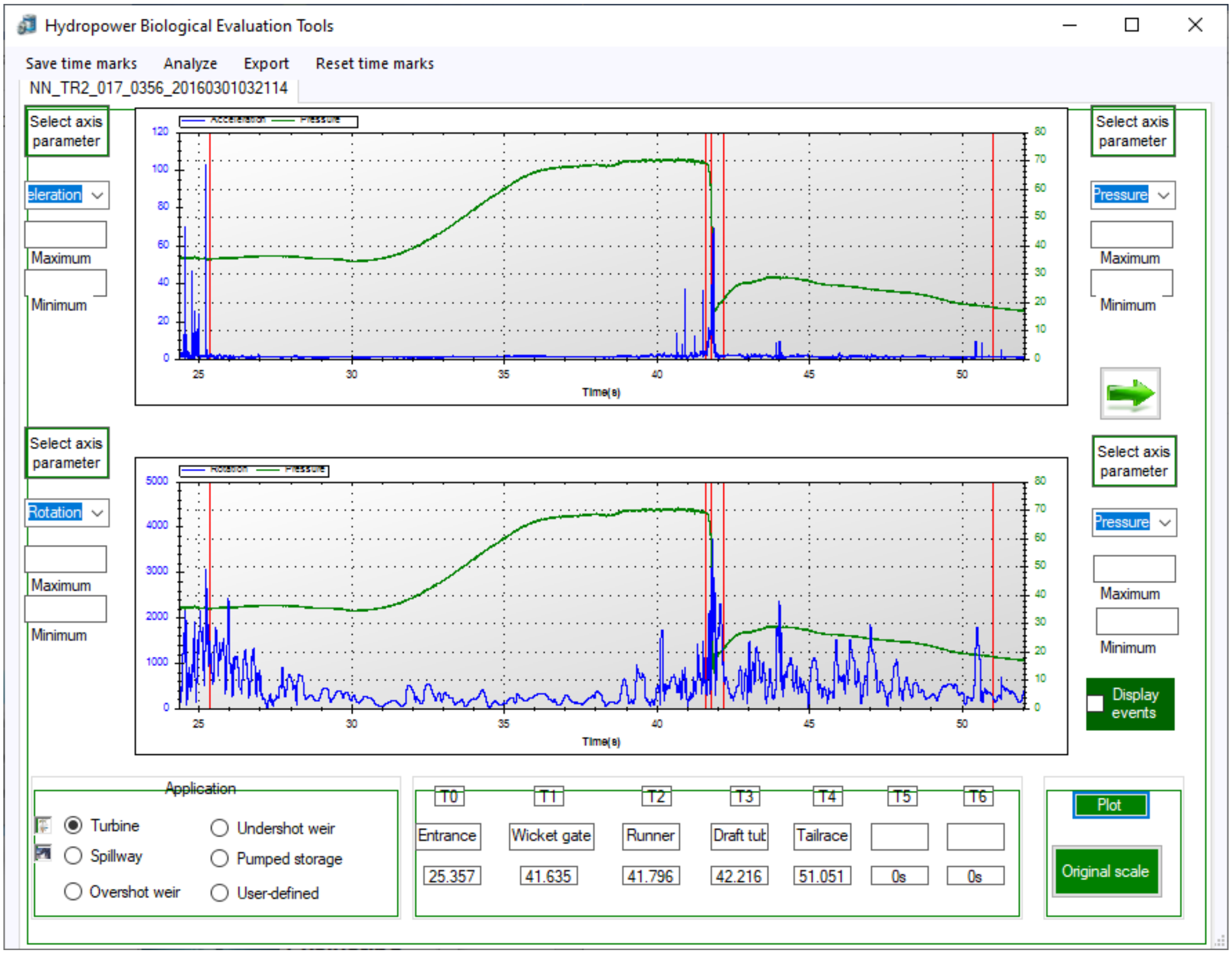
- **Intake/Entrance Region**: Region from the release location in the dam forebay to the entrance of the stay vanes. The characteristics of this region are a gradually increasing pressure as the SF traverses the intake toward the runner and low acceleration and rotational velocity magnitude. Typically there are no severe hydraulic conditions within the intake region that could harm fish.
- **Stay-Vane/Wicket-Gate Region**: Region from the upstream side of the stay vanes to the downstream side of the wicket gates. The characteristics of this region are the pressure beginning to drop and increases in the acceleration and rotational velocity magnitude. The primary concerns regarding fish passage in this region are shear forces and collisions with the stay vanes or wicket gates. Depending on the specifics of the turbine design (e.g., number and spacing of stay vanes) this region is typically an area of concern during fish passage.
- **Runner Region**: Region from just downstream of the wicket gates to downstream of the runner blades. The characteristics of this region are a sudden large drop in pressure as the SF passes the runner blades. These drops in pressure can result in subatmospheric pressures that can cause barotrauma injury in fish. The characteristics also include higher levels of acceleration and rotational velocity magnitude. In addition to potential barotrauma, the other primary concerns regarding fish passage in this region are shear forces, collisions with the runner blade or hub, strike from the runner blade, or grinding between the runner blade and the runner housing. This region typically has the highest potential for fish injuries. In addition to the potential injury sources during runner passage, turbulence can result in high levels of rotational velocity that can disorient fish and cause delayed mortality from sources such as predation.



- **Draft Tube Region**: Region from just after runner passage to the draft tube exit. The characteristics of this region are a gradual increase in pressure followed by a stabilization in the pressure. Turbulence in the draft tube can result in high levels of rotational velocity that can disorient fish and lead to delayed mortality.
- **Tailrace Region**: Region from draft tube exit into the tailrace. Typically there are no severe hydraulic conditions within the tailrace region that could directly injure fish.

5. **MOVE** the mouse along the pressure curve to the start time of “*Entrance*”, then **RIGHT-CLICK** the mouse and **CHOOSE** “*Set as T0*”. In this example, the value should be 25.357910 seconds.
6. Follow previous step to **SET** the values for the start time of “*Wicket gate*”, “*Runner*”, “*Draft tube*” and “*Tailrace*” as T1, T2, T3 and T4. In this example, the values should be 41.635253, 41.796386, 42.216308 and 51.051757, respectively.
7. **CLICK** the “Plot” button.

   The screen will only show data related to T0 to T4, and a red vertical line will show for each time mark (see screenshot below).



5.1 ANALYZING THE DATA SET TO COMPUTE METRICS RELATED TO THE HYDRAULIC CHARACTERISTICS

After time markers are created, users can proceed to analyze the SF data file. There are two ways to do the analysis: “Single analyze” and “Batch analyze”.

5.1.1 USE CASE 1: ANALYZE A SINGLE DATA FILE “*NN_TR2_017_0356_20160301032114.RAW2*”

To analyze the single SF data file “NN_TR2_017_0356_20160301032114.raw2”, take the steps enumerated below.

1. Click the “Data Analysis” button in the HBET startup screen, **SELECT** “Nam Ngum” study site, **MAKE SURE** the data file “NN_TR2_017_0356_20160301032114.raw2” was selected, then **CLICK** the “Analyze” button.
2. **MAKE SURE** time marks have been set.
3. **CLICK** the “Analyze” menu item.

   The selected data file will be analyzed; the process takes about 5 seconds.

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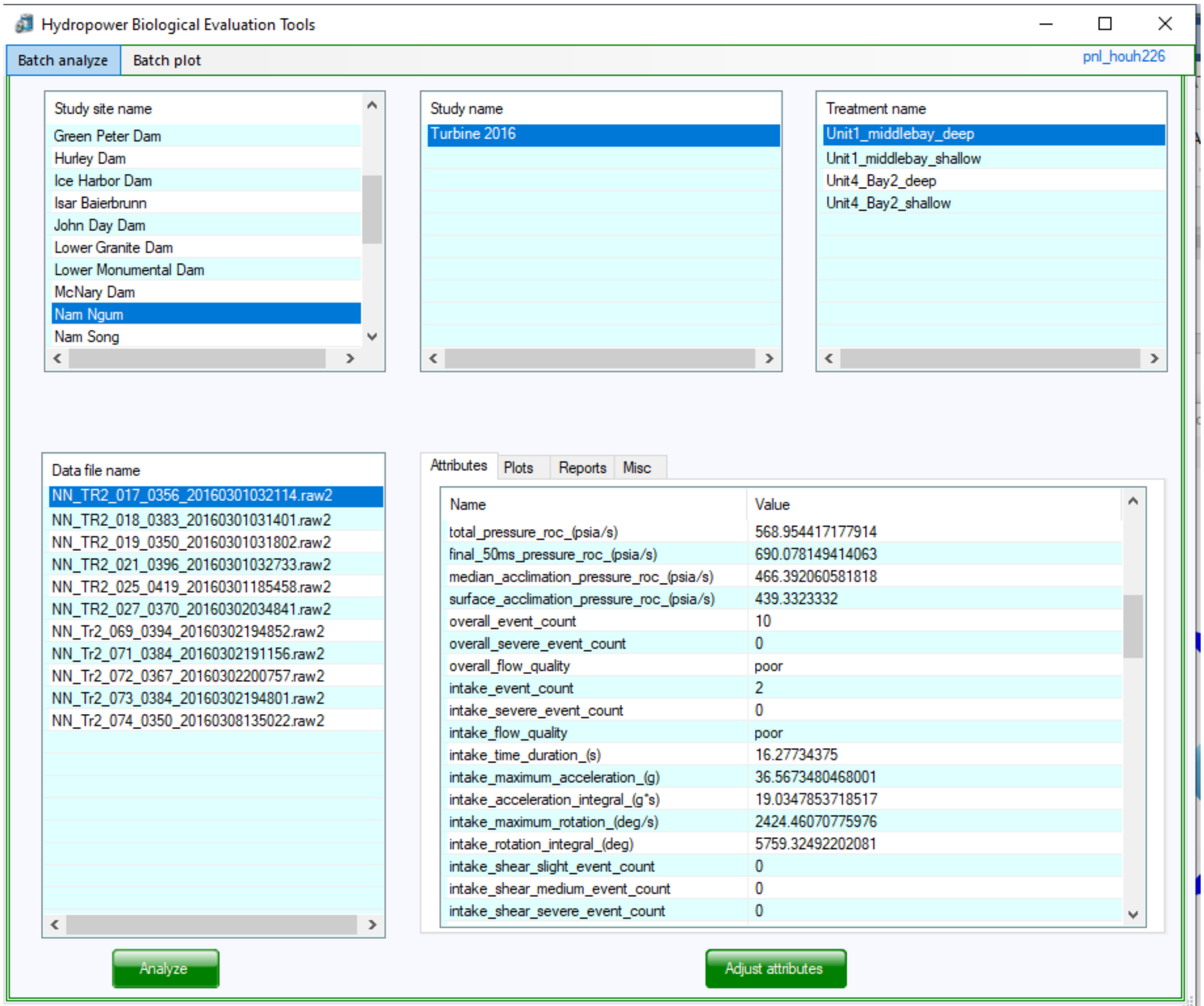
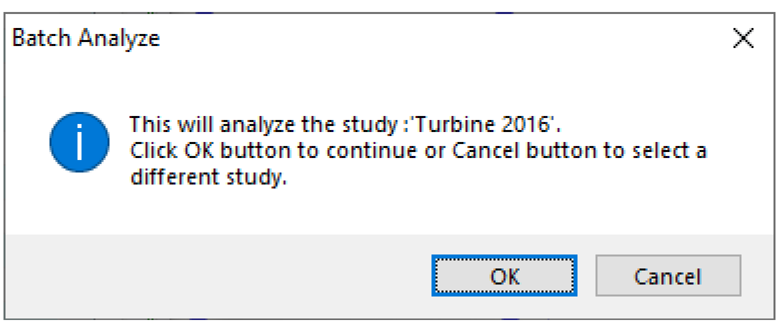
5.1.2 USE CASE 2: BATCH ANALYZING DATA FILES

To batch analyze the whole “Turbine 2016” study in “Nam Ngum” study site, take the steps enumerated below.

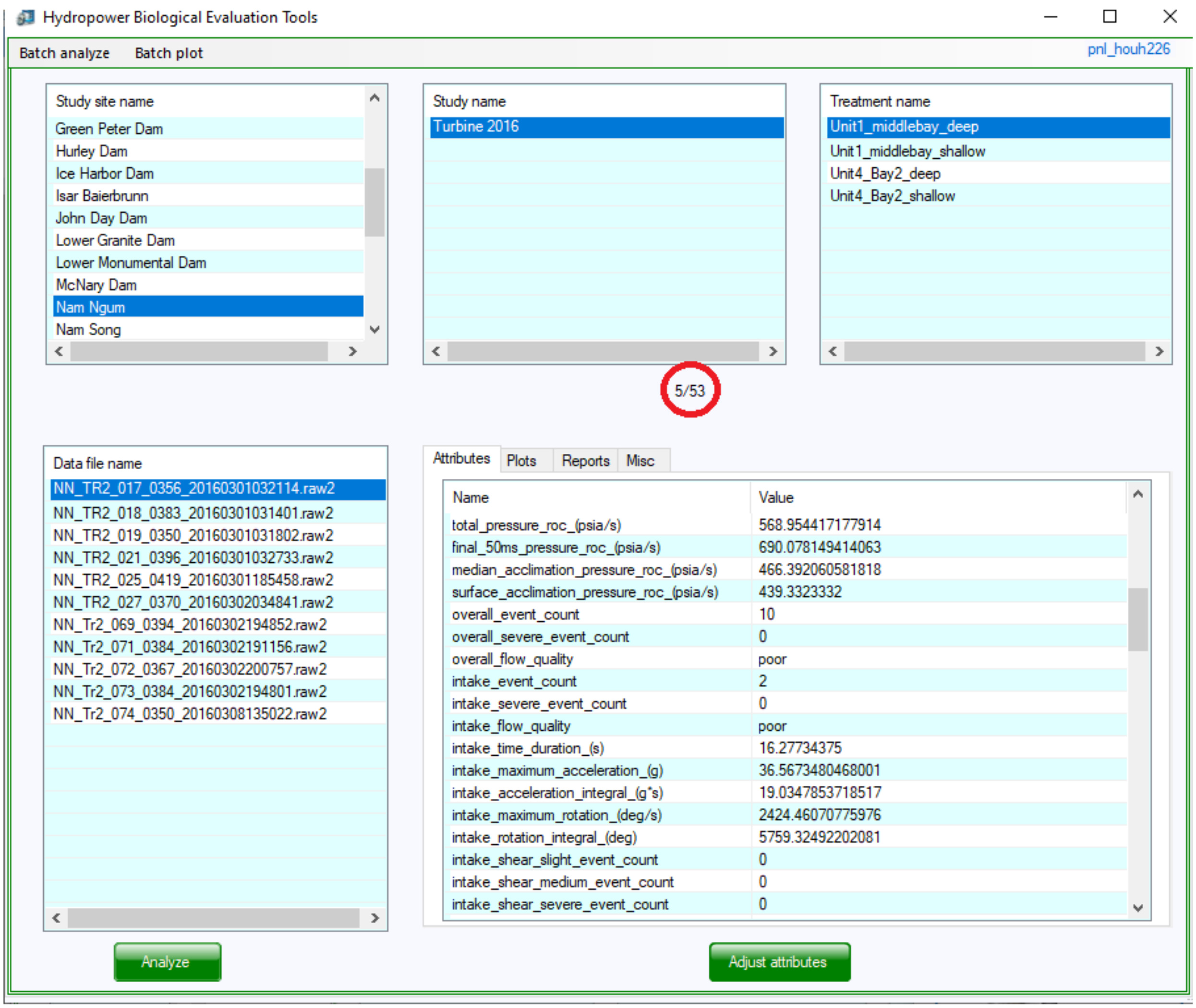
1. **CLICK** the “Data Analysis” button in the HBET startup screen, **SELECT** the “Nam Ngum” study site, **MAKE SURE** “Turbine 2016” study is selected, then **SELECT** “Batch Analyze” (see screenshot below).



2. **CLICK** “OK” in the pop-up message box to proceed:



The process is time-consuming, and the screen will display the real-time process status:



A message box will show up once the process is done.

6.0 REPORTING

Users can use the "Evaluating Biological Response" feature to estimate injury rate for different fish species, and "Report" feature to generate statistical information of the selected studies/treatments.

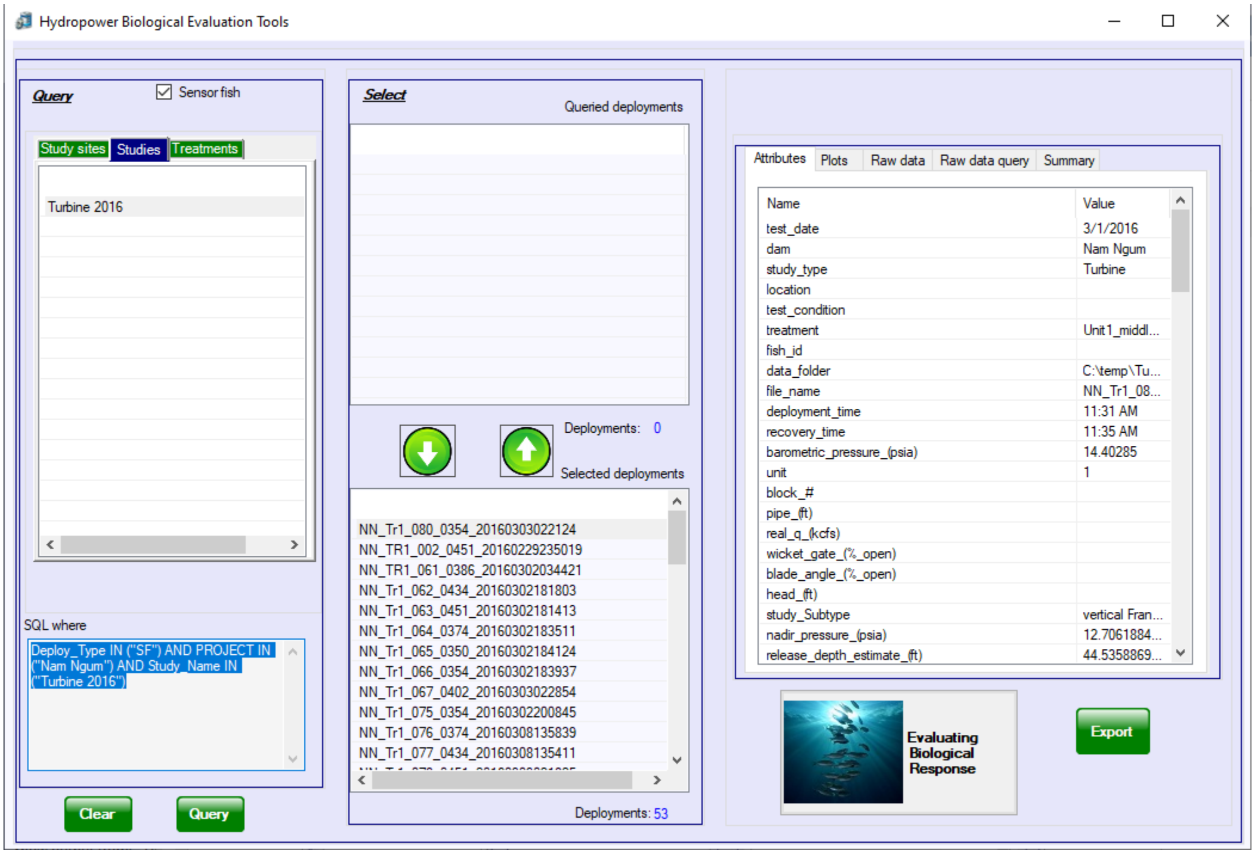
6.1 PERFORM BIOLOGICAL RESPONSE EVALUATION (EBR)

The following use cases show the steps to evaluate biological response for selected fish species.

6.1.1 USE CASE 1: ESTIMATING THE RAPID DECOMPRESSION INJURY RATE

To estimate the rapid decompression injury rate for fish species (we choose Chinook Salmon and Rainbow Trout here *ONLY* for demonstration purpose), take the steps enumerated below.

1. **CLICK** the "*Evaluating Biological Response*" button in the HBET startup screen.
2. In the Query section of the screen, **CLICK** "Study sites", then
   a. **SELECT** "*Nam Ngum*", OR
   b. **PASTE** in the following content: Deploy_Type IN ('SF') AND PROJECT IN ('Nam Ngum') AND Study_Name IN ('Turbine 2016')
   c. **CLICK** the "*Query*" button, then **MOVE** all "*Queried deployments*" into "*Selected deployments*", as shown in the following screenshot.



3. **CLICK** the "Evaluating Biological Response" button, in the pop-up window.

   a. Then **ENTER** "*C:\temp*" as the output folder, OR

   b. **CLICK** "*Browser*" button to choose a directory(see the screenshot below).

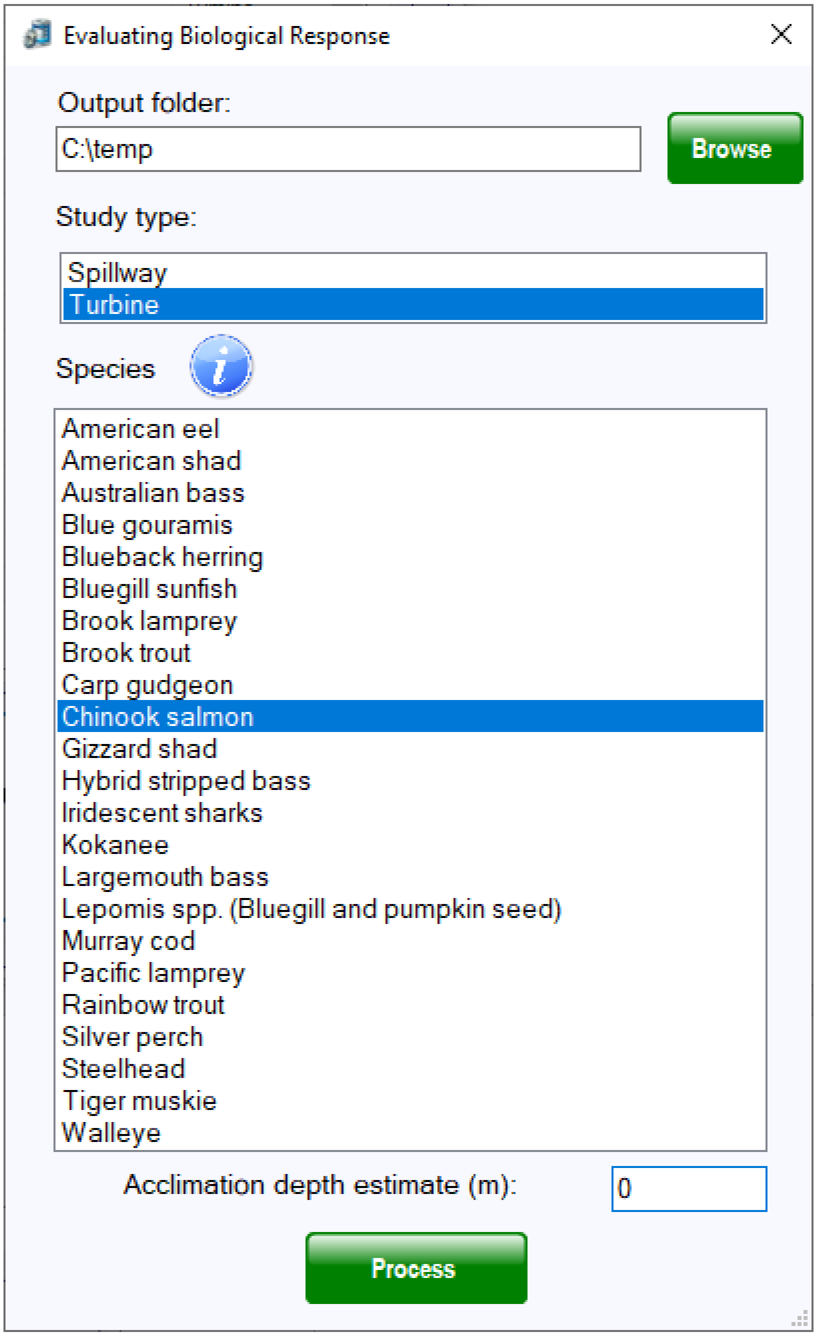
   c. **LEAVE** the study type as "Turbine", **CHOOSE** "Chinook Salmon" as the fish species, and **ENTER** 0 as the acclimation depth estimate (m).

   The acclimation pressure is important for estimating the effects of rapid decompression on fish. The swim bladder is a gas-filled organ that fish use to regulate buoyancy. Rapid decompression causes the swim bladder to expand within the fish, which is the main source of injury from rapid decompression. Fish that are acclimated to deeper depths require a greater amount of gas within the swim bladder to achieve neutral buoyancy. Therefore, fish with a greater acclimation depth have more potential to be injured during exposure to rapid decompression.

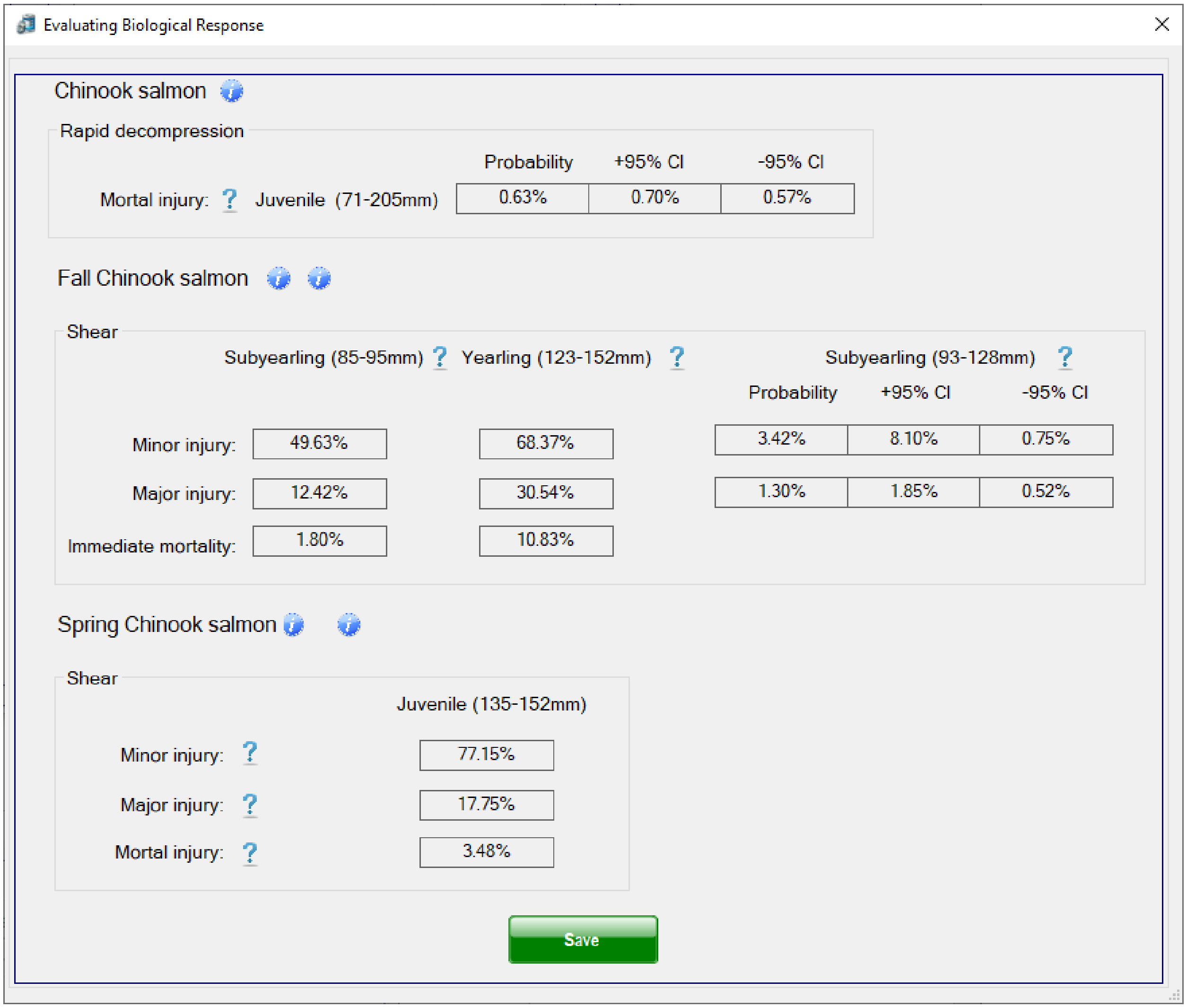
   d. If the acclimation pressure of a selected species is unknown, it may be wise to

      (1) **SELECT** "*0*", which would estimate the minimum effect of rapid decompression.

      (2) Then **RERUN** the analysis with the acclimation depth set to the maximum depth of the forebay, which would estimate the maximum effect of rapid decompression.



After clicking the “Process” button, the estimated injury rate will be shown as follows:



4. **CLOSE** the pop-up window, and **REPEAT** the Step 3 using 2 and 10 as the acclimation depth estimate (m).

   The results should be similar to the following table:

Rapid decompression injury rate estimate for Nam Ngum Dam 2016 data

	Fish length	0 m Probability	2 m Probability	10 m Probability
Chinook Salmon	Juvenile (71-205 mm)	0.63%	1.23%	7.15%
Rainbow Trout	Juvenile (104-156 mm)	0.67%	1.24%	6.44%

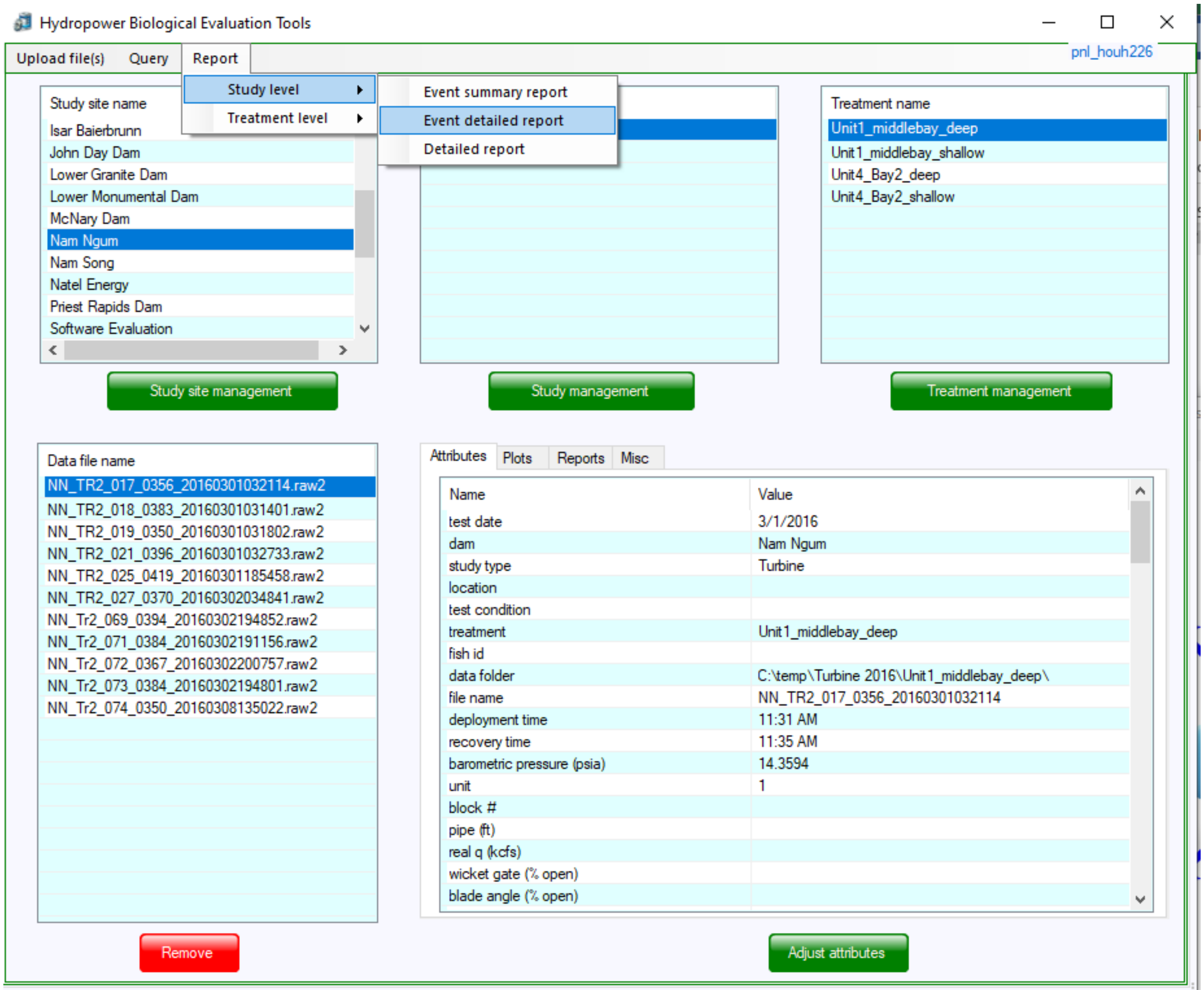
6.2 GENERATING AND INTERPRETING REPORTS

Reports generated will be saved in “*.csv*” format and can be used for further processing by other applications.

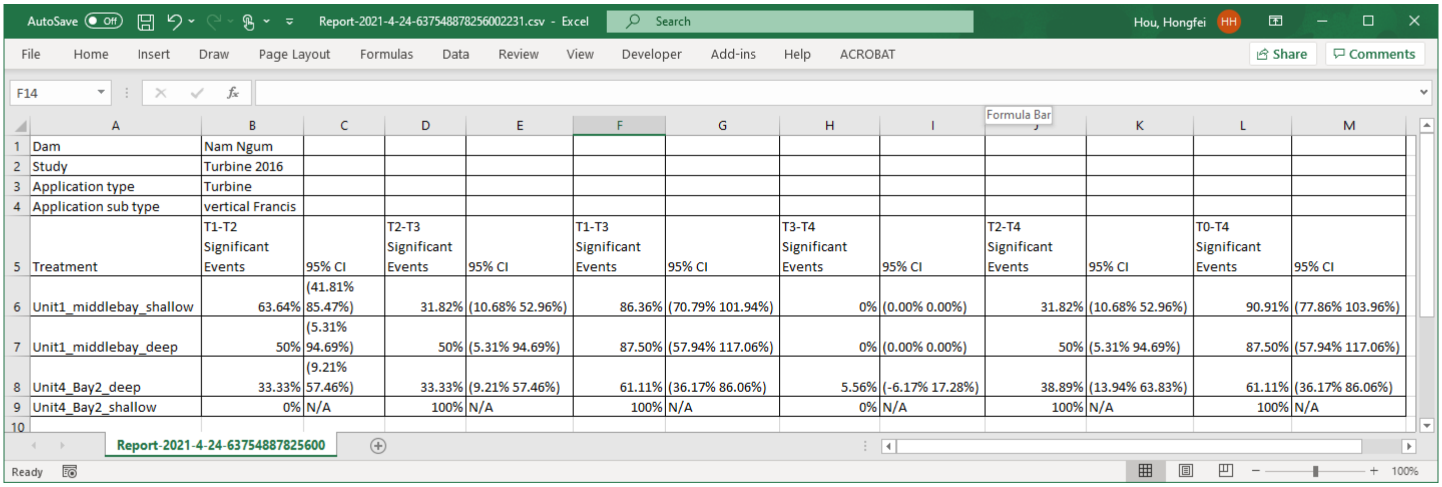
6.2.1 USE CASE 1: GENERATING THE STUDY LEVEL "*EVENT DETAILED REPORT*"

To generate the study level "*Event summary report*", take the steps enumerated below.

1. **CLICK** the "*Data management*" button in the HBET startup window.
2. **CLICK** the "*Report*" menu item, then **CHOOSE** "*Study level*" and "*Event Summary report*" as shown in the following screenshot.



3. In the pop-up window, **SELECT** "*Nam Ngum*".
   a. Then **CLICK** the "*Study*" tab, and **SELECT** "*Turbine 2016*".
   b. **CLICK** the "*Arrow*" button to add the selected study "*Turbine 2016*".
   c. Then **CLICK** the "*Process*" button; the result should be similar to the following screenshot:



Dam	Nam Ngum											
Study	Turbine 2016											
Application type	Turbine											
Application sub type	vertical Francis											
Treatment	T1-T2 Significant Events	95% CI	T2-T3 Significant Events	95% CI	T1-T3 Significant Events	95% CI	T3-T4 Significant Events	95% CI	T2-T4 Significant Events	95% CI	T0-T4 Significant Events	95% CI
Unit1_middlebay_shallow	63.64%	(41.81% 85.47%)	31.82%	(10.68% 52.96%)	86.36%	(70.79% 101.94%)	0%	(0.00% 0.00%)	31.82%	(10.68% 52.96%)	90.91%	(77.86% 103.96%)
Unit1_middlebay_deep	50%	(5.31% 94.69%)	50%	(5.31% 94.69%)	87.50%	(57.94% 117.06%)	0%	(0.00% 0.00%)	50%	(5.31% 94.69%)	87.50%	(57.94% 117.06%)
Unit4_Bay2_deep	33.33%	(9.21% 57.46%)	33.33%	(9.21% 57.46%)	61.11%	(36.17% 86.06%)	5.56%	(-6.17% 17.28%)	38.89%	(13.94% 63.83%)	61.11%	(36.17% 86.06%)
Unit4_Bay2_shallow	0%	N/A	100%	N/A	100%	N/A	0%	N/A	100%	N/A	100%	N/A

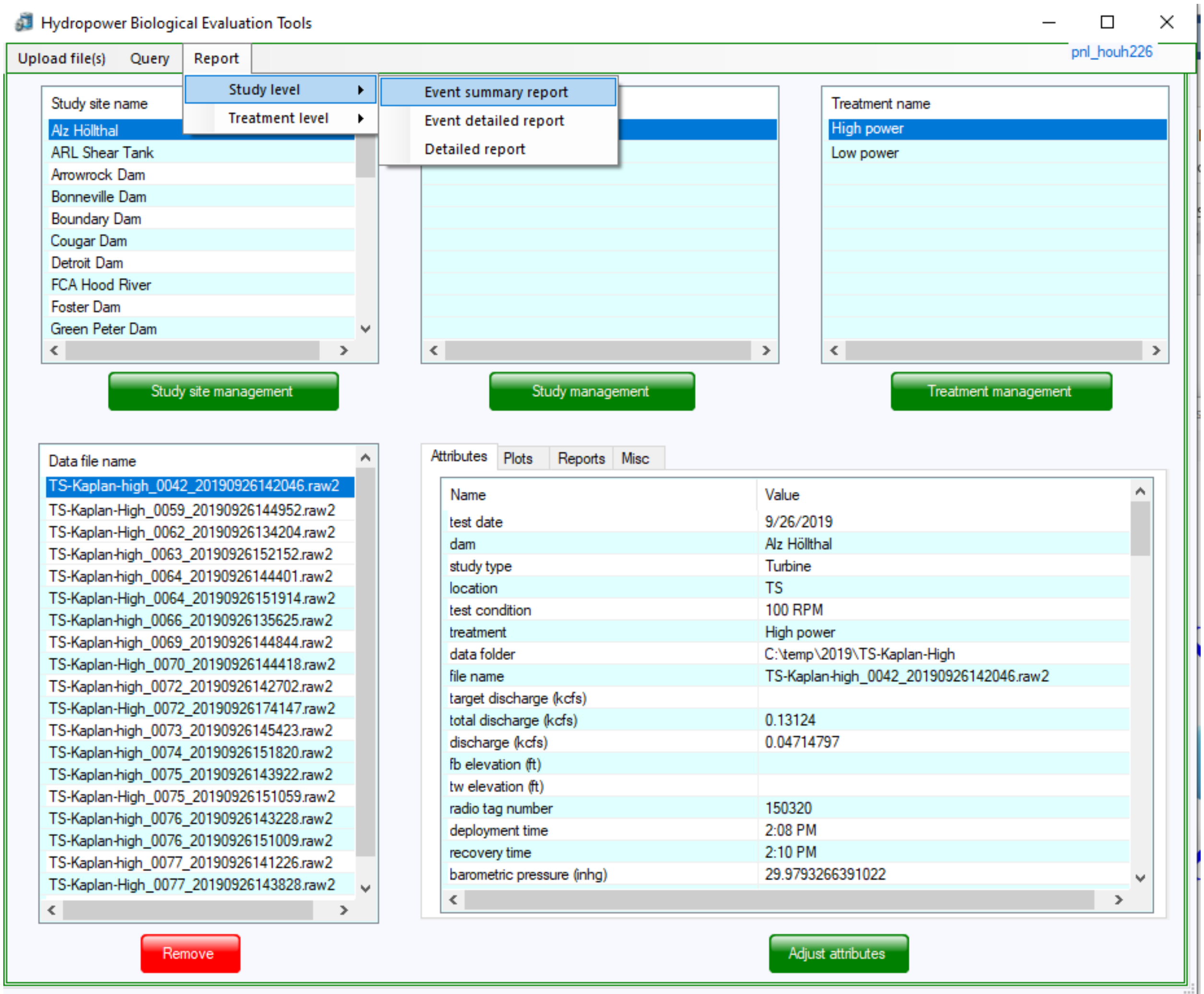
The results contain detailed information about each treatment (listed below) of the selected study:

- forebay elevation
- tail water elevation
- valid releases
- total severe events
- mean severe events per release
- mean Nadir pressure (psia)
- proportion of releases with " Severe " events attributed to strike (%)
- proportion of releases with "Severe" events attributed to shear (%)
- intake severe event %
- intake severe strike event %
- intake severe shear event %
- intake mean severe event
- wicket-gate severe event %
- wicket-gate severe strike event %
- wicket-gate severe shear event %
- wicket-gate mean severe event
- turbine severe event %
- turbine severe strike event %
- turbine severe shear event %
- turbine mean severe event
- draft tube severe event %
- draft tube severe strike event %
- draft tube severe shear event %
- and draft tube mean severe event
- the average duration of intake, wicket gate, turbine and draft tube.

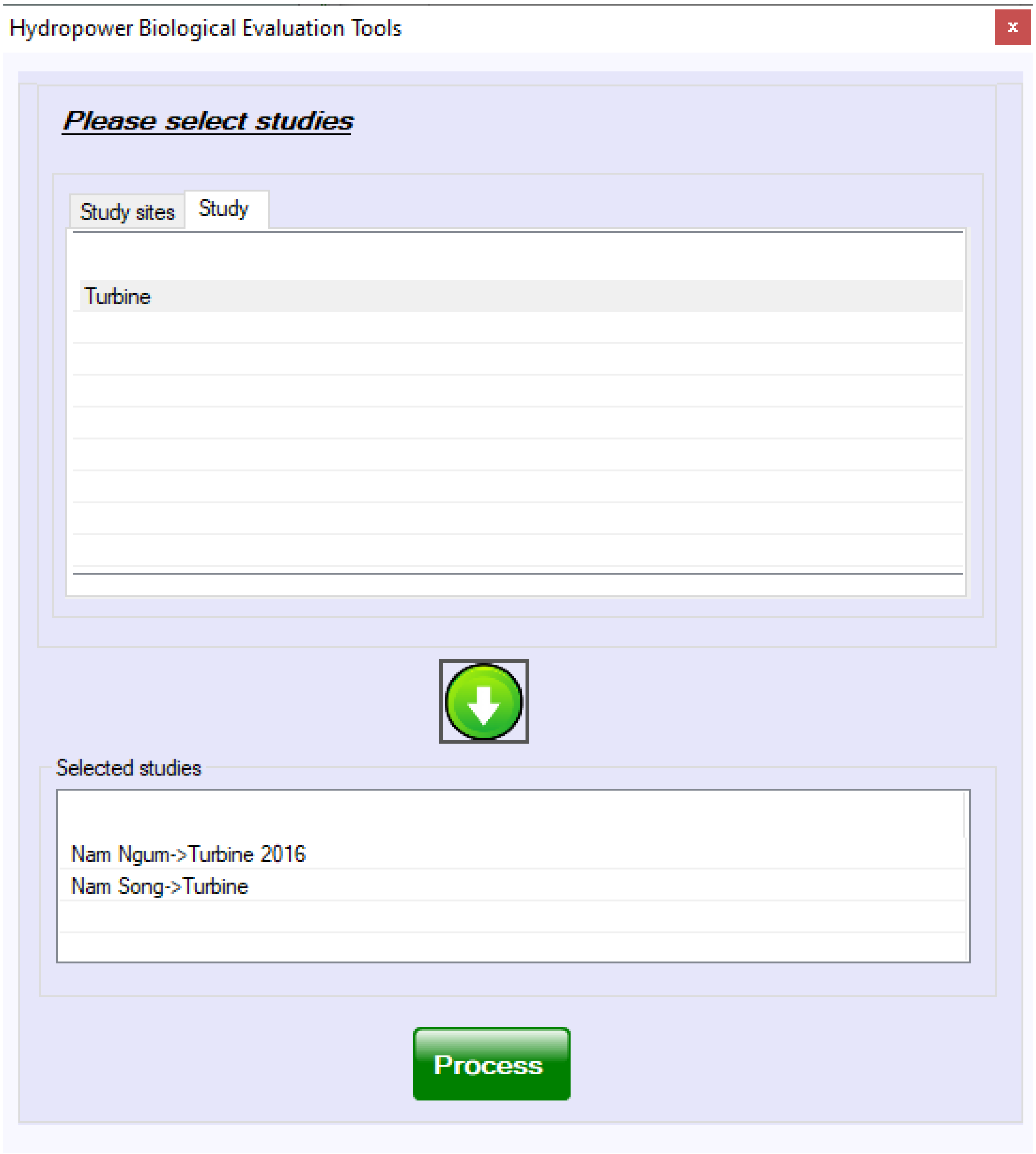
6.2.2 USE CASE 2: COMPARING THE "TURBINE 2016" STUDY FOR "NAM NGUM" DAM WITH THE "TURBINE" STUDY FOR "NAM SONG DAM"

To compare these two studies, take the steps enumerated below.

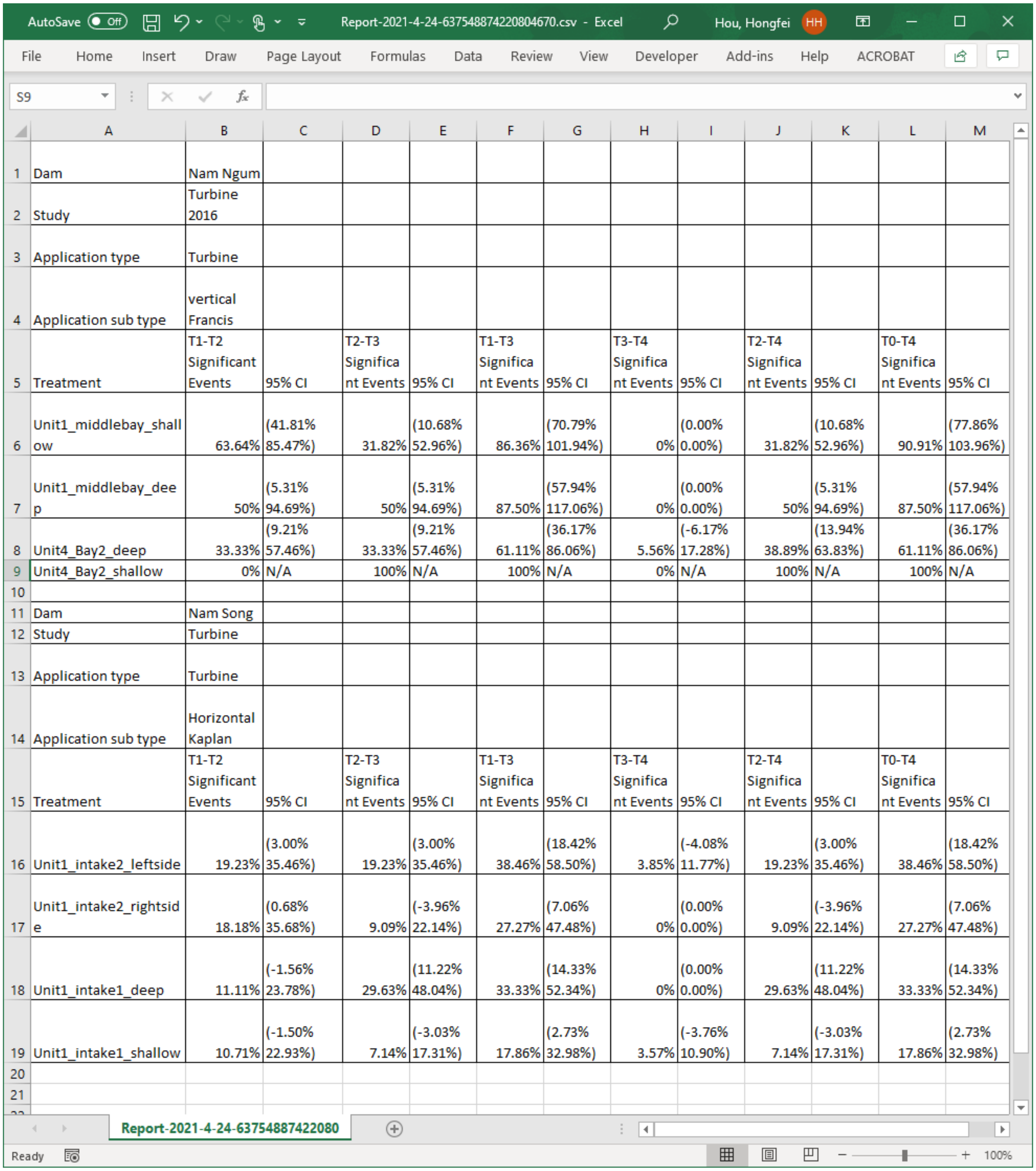
1. **CLICK** the "*Data management*" button in the HBET startup window.
2. **CLICK** the "*Report*" menu item, then **CHOOSE** "*Study level*" and "*Event Summary report*", as shown in the following screenshot:



3. In the pop-up window, **SELECT** "*Nam Ngum*", then **CLICK** "*Study*" tab, **SELECT** "*Turbine 2016*", and **CLICK** the "*Arrow*" button to add the selected study "*Turbine 2016*".
4. Repeat Step 3 to add "Turbine" study for "Nam Song Dam", as shown in the following screenshot.



5. **CLICK** the “Process” button, and the results should be similar to the following:



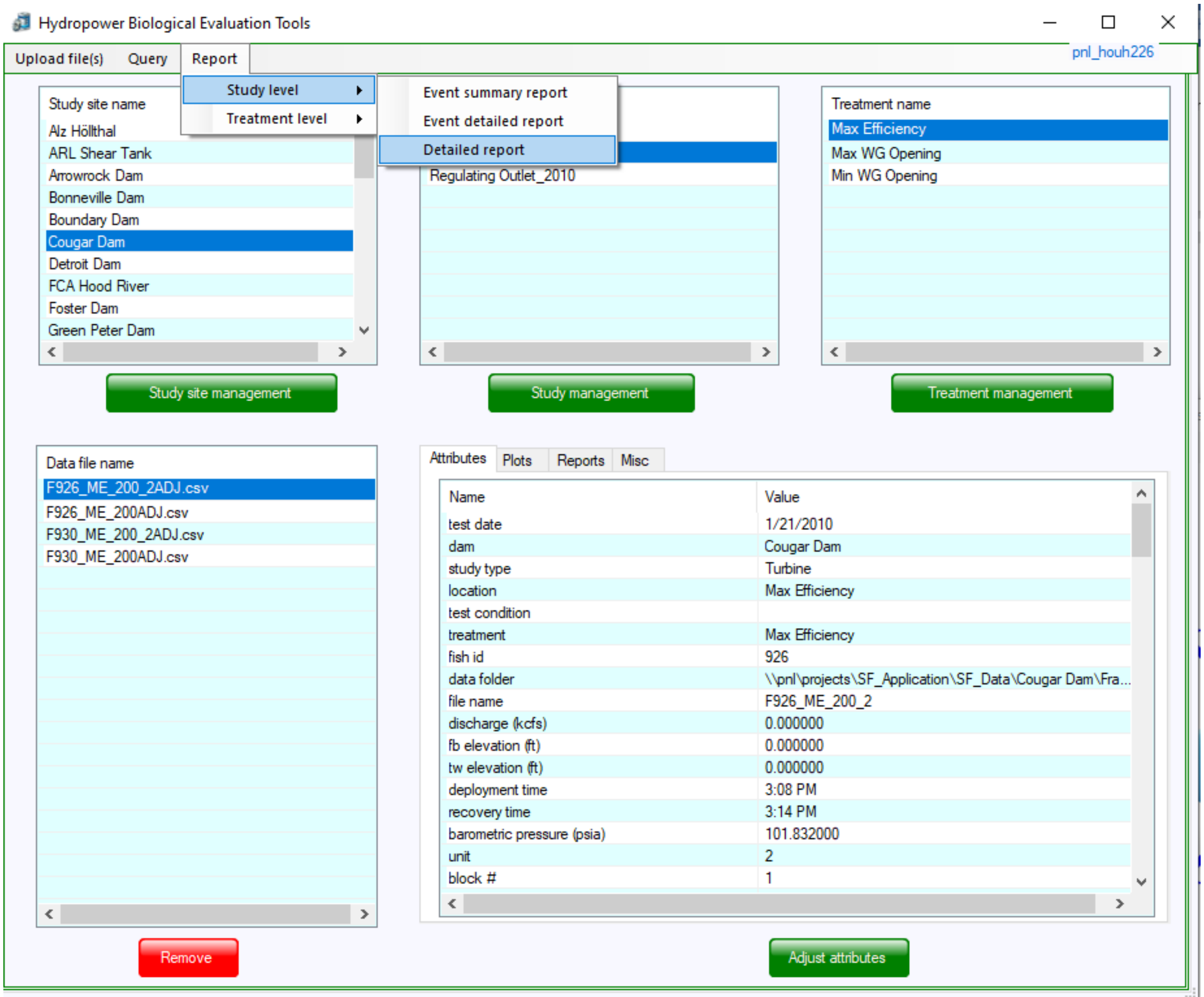
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Dam	Nam Ngum											
2	Study	Turbine 2016											
3	Application type	Turbine											
4	Application sub type	vertical Francis											
5	Treatment	T1-T2 Significant Events	95% CI	T2-T3 Significant Events	95% CI	T1-T3 Significant Events	95% CI	T3-T4 Significant Events	95% CI	T2-T4 Significant Events	95% CI	T0-T4 Significant Events	95% CI
6	Unit1_middlebay_shallow	63.64%	(41.81% 85.47%)	31.82%	(10.68% 52.96%)	86.36%	(70.79% 101.94%)	0%	(0.00% 0.00%)	31.82%	(10.68% 52.96%)	90.91%	(77.86% 103.96%)
7	Unit1_middlebay_deep	50%	(5.31% 94.69%)	50%	(5.31% 94.69%)	87.50%	(57.94% 117.06%)	0%	(0.00% 0.00%)	50%	(5.31% 94.69%)	87.50%	(57.94% 117.06%)
8	Unit4_Bay2_deep	33.33%	(9.21% 57.46%)	33.33%	(9.21% 57.46%)	61.11%	(36.17% 86.06%)	5.56%	(-6.17% 17.28%)	38.89%	(13.94% 63.83%)	61.11%	(36.17% 86.06%)
9	Unit4_Bay2_shallow	0%	N/A	100%	N/A	100%	N/A	0%	N/A	100%	N/A	100%	N/A
10													
11	Dam	Nam Song											
12	Study	Turbine											
13	Application type	Turbine											
14	Application sub type	Horizontal Kaplan											
15	Treatment	T1-T2 Significant Events	95% CI	T2-T3 Significant Events	95% CI	T1-T3 Significant Events	95% CI	T3-T4 Significant Events	95% CI	T2-T4 Significant Events	95% CI	T0-T4 Significant Events	95% CI
16	Unit1_intake2_leftside	19.23%	(3.00% 35.46%)	19.23%	(3.00% 35.46%)	38.46%	(18.42% 58.50%)	3.85%	(-4.08% 11.77%)	19.23%	(3.00% 35.46%)	38.46%	(18.42% 58.50%)
17	Unit1_intake2_rightside	18.18%	(0.68% 35.68%)	9.09%	(-3.96% 22.14%)	27.27%	(7.06% 47.48%)	0%	(0.00% 0.00%)	9.09%	(-3.96% 22.14%)	27.27%	(7.06% 47.48%)
18	Unit1_intake1_deep	11.11%	(-1.56% 23.78%)	29.63%	(11.22% 48.04%)	33.33%	(14.33% 52.34%)	0%	(0.00% 0.00%)	29.63%	(11.22% 48.04%)	33.33%	(14.33% 52.34%)
19	Unit1_intake1_shallow	10.71%	(-1.50% 22.93%)	7.14%	(-3.03% 17.31%)	17.86%	(2.73% 32.98%)	3.57%	(-3.76% 10.90%)	7.14%	(-3.03% 17.31%)	17.86%	(2.73% 32.98%)

The results contain the significant events information about each treatment of the selected studies: wicket-gate significant events w/o 95% CI, turbine significant events w/o 95% CI, intake and wicket-gate significant events w/o 95% CI, draft tube significant events w/o 95% CI, wicket-gate and turbine significant events w/o 95% CI and all region significant events w/o 95% CI.

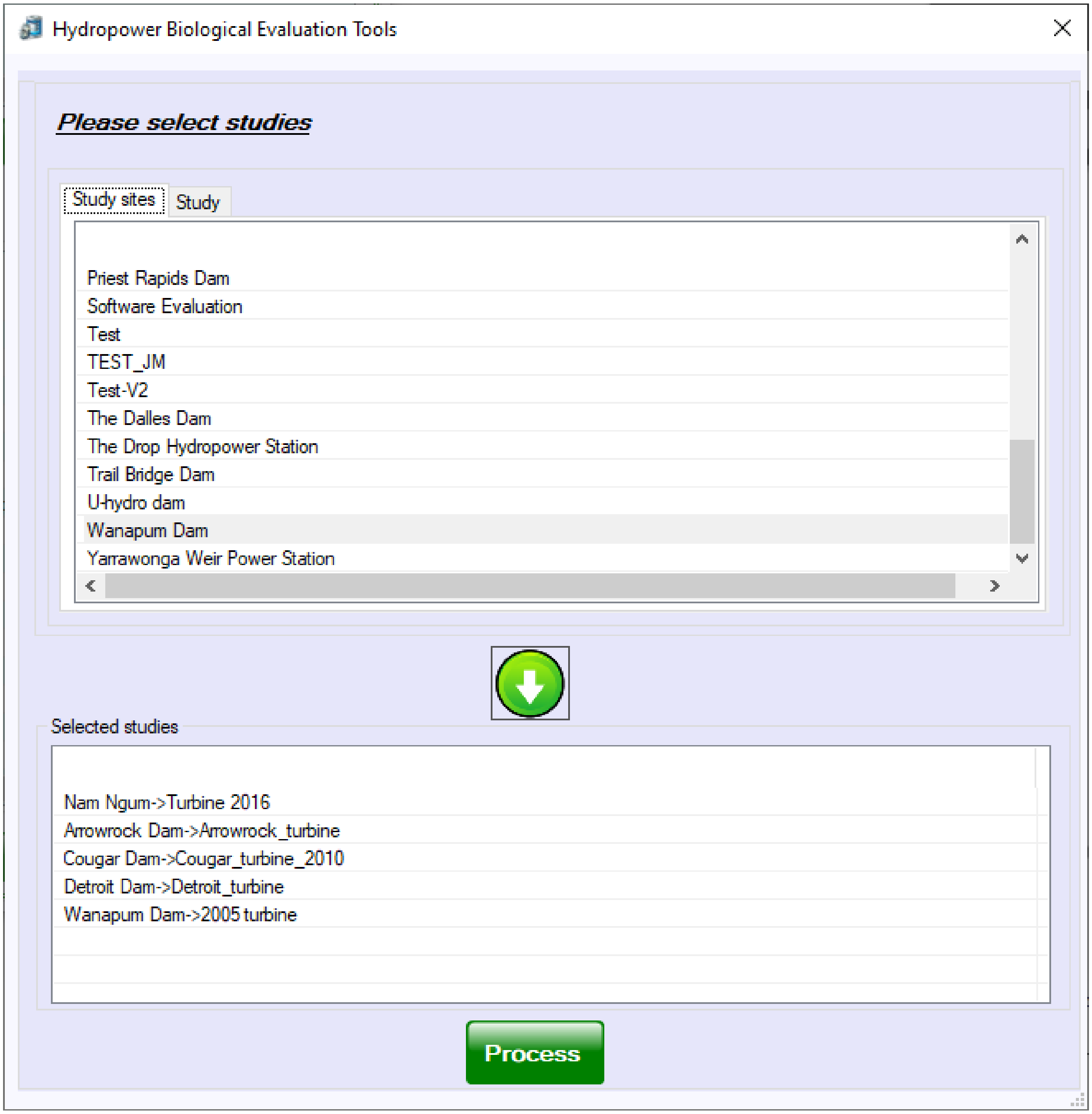
6.2.3 USE CASE 3: COMPARING SEVERE ACCELERATION EVENTS WITH OTHER STUDIES

To compare severe acceleration events with other studies, take the steps enumerated below.

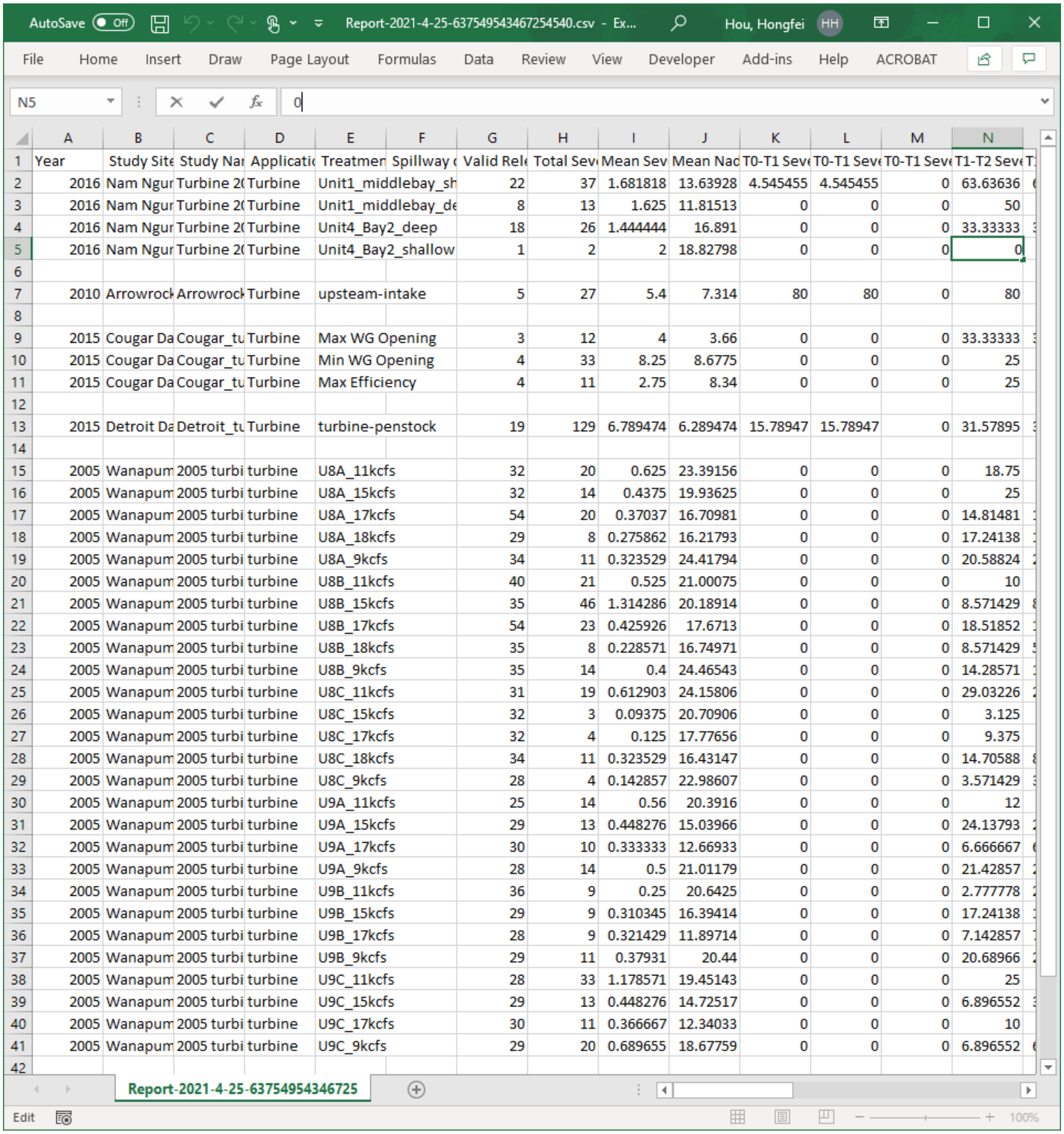
1. **CLICK** the "*Data management*" button in the HBET startup window.
2. **CLICK** the "*Report*" menu item, then **CHOOSE** "*Study level*" and "*Detailed report*", as shown in the screenshot below.



3. In the pop-up window, **SELECT** "*Nam Ngum*"; then **CLICK** the "*Study*" tab, **SELECT** "*Turbine 2016*", and **CLICK** the "*Arrow*" button to add the selected study "*Turbine 2016*".
4. **REPEAT** Step 3 to **ADD** the "Arrowrock_turbine" study for "Arrowrock Dam", "Cougar_turbine_2010" study for "Cougar Dam", "Detroit_turbine" study for "Detroit Dam, and "2005 turbine" study for "Wanapum Dam", as shown in the following screenshot.



5. **CLICK** the “Process” button, and the results should be similar to the following:



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Year	Study Site	Study Nai	Applicati	Treatmen	Spillway (	Valid Rel	Total Sev	Mean Sev	Mean Nad	T0-T1 Sev	T0-T1 Sev	T0-T1 Sev	T1-T2 Sev
2	2016	Nam Ngur	Turbine 2(	Turbine	Unit1_middlebay_sh		22	37	1.681818	13.63928	4.545455	4.545455	0	63.63636
3	2016	Nam Ngur	Turbine 2(	Turbine	Unit1_middlebay_de		8	13	1.625	11.81513	0	0	0	50
4	2016	Nam Ngur	Turbine 2(	Turbine	Unit4_Bay2_deep		18	26	1.444444	16.891	0	0	0	33.33333
5	2016	Nam Ngur	Turbine 2(	Turbine	Unit4_Bay2_shallow		1	2	2	18.82798	0	0	0	0
6														
7	2010	Arrowrocl	Arrowrocl	Turbine	upsteam-intake		5	27	5.4	7.314	80	80	0	80
8														
9	2015	Cougar Da	Cougar_tu	Turbine	Max WG Opening		3	12	4	3.66	0	0	0	33.33333
10	2015	Cougar Da	Cougar_tu	Turbine	Min WG Opening		4	33	8.25	8.6775	0	0	0	25
11	2015	Cougar Da	Cougar_tu	Turbine	Max Efficiency		4	11	2.75	8.34	0	0	0	25
12														
13	2015	Detroit Da	Detroit_tu	Turbine	turbine-penstock		19	129	6.789474	6.289474	15.78947	15.78947	0	31.57895
14														
15	2005	Wanapum	2005 turbi	turbine	U8A_11kcfs		32	20	0.625	23.39156	0	0	0	18.75
16	2005	Wanapum	2005 turbi	turbine	U8A_15kcfs		32	14	0.4375	19.93625	0	0	0	25
17	2005	Wanapum	2005 turbi	turbine	U8A_17kcfs		54	20	0.37037	16.70981	0	0	0	14.81481
18	2005	Wanapum	2005 turbi	turbine	U8A_18kcfs		29	8	0.275862	16.21793	0	0	0	17.24138
19	2005	Wanapum	2005 turbi	turbine	U8A_9kcfs		34	11	0.323529	24.41794	0	0	0	20.58824
20	2005	Wanapum	2005 turbi	turbine	U8B_11kcfs		40	21	0.525	21.00075	0	0	0	10
21	2005	Wanapum	2005 turbi	turbine	U8B_15kcfs		35	46	1.314286	20.18914	0	0	0	8.571429
22	2005	Wanapum	2005 turbi	turbine	U8B_17kcfs		54	23	0.425926	17.6713	0	0	0	18.51852
23	2005	Wanapum	2005 turbi	turbine	U8B_18kcfs		35	8	0.228571	16.74971	0	0	0	8.571429
24	2005	Wanapum	2005 turbi	turbine	U8B_9kcfs		35	14	0.4	24.46543	0	0	0	14.28571
25	2005	Wanapum	2005 turbi	turbine	U8C_11kcfs		31	19	0.612903	24.15806	0	0	0	29.03226
26	2005	Wanapum	2005 turbi	turbine	U8C_15kcfs		32	3	0.09375	20.70906	0	0	0	3.125
27	2005	Wanapum	2005 turbi	turbine	U8C_17kcfs		32	4	0.125	17.77656	0	0	0	9.375
28	2005	Wanapum	2005 turbi	turbine	U8C_18kcfs		34	11	0.323529	16.43147	0	0	0	14.70588
29	2005	Wanapum	2005 turbi	turbine	U8C_9kcfs		28	4	0.142857	22.98607	0	0	0	3.571429
30	2005	Wanapum	2005 turbi	turbine	U9A_11kcfs		25	14	0.56	20.3916	0	0	0	12
31	2005	Wanapum	2005 turbi	turbine	U9A_15kcfs		29	13	0.448276	15.03966	0	0	0	24.13793
32	2005	Wanapum	2005 turbi	turbine	U9A_17kcfs		30	10	0.333333	12.66933	0	0	0	6.666667
33	2005	Wanapum	2005 turbi	turbine	U9A_9kcfs		28	14	0.5	21.01179	0	0	0	21.42857
34	2005	Wanapum	2005 turbi	turbine	U9B_11kcfs		36	9	0.25	20.6425	0	0	0	2.777778
35	2005	Wanapum	2005 turbi	turbine	U9B_15kcfs		29	9	0.310345	16.39414	0	0	0	17.24138
36	2005	Wanapum	2005 turbi	turbine	U9B_17kcfs		28	9	0.321429	11.89714	0	0	0	7.142857
37	2005	Wanapum	2005 turbi	turbine	U9B_9kcfs		29	11	0.37931	20.44	0	0	0	20.68966
38	2005	Wanapum	2005 turbi	turbine	U9C_11kcfs		28	33	1.178571	19.45143	0	0	0	25
39	2005	Wanapum	2005 turbi	turbine	U9C_15kcfs		29	13	0.448276	14.72517	0	0	0	6.896552
40	2005	Wanapum	2005 turbi	turbine	U9C_17kcfs		30	11	0.366667	12.34033	0	0	0	10
41	2005	Wanapum	2005 turbi	turbine	U9C_9kcfs		29	20	0.689655	18.67759	0	0	0	6.896552
42														

The results contain detailed severe events for each treatment included in the selected studies:

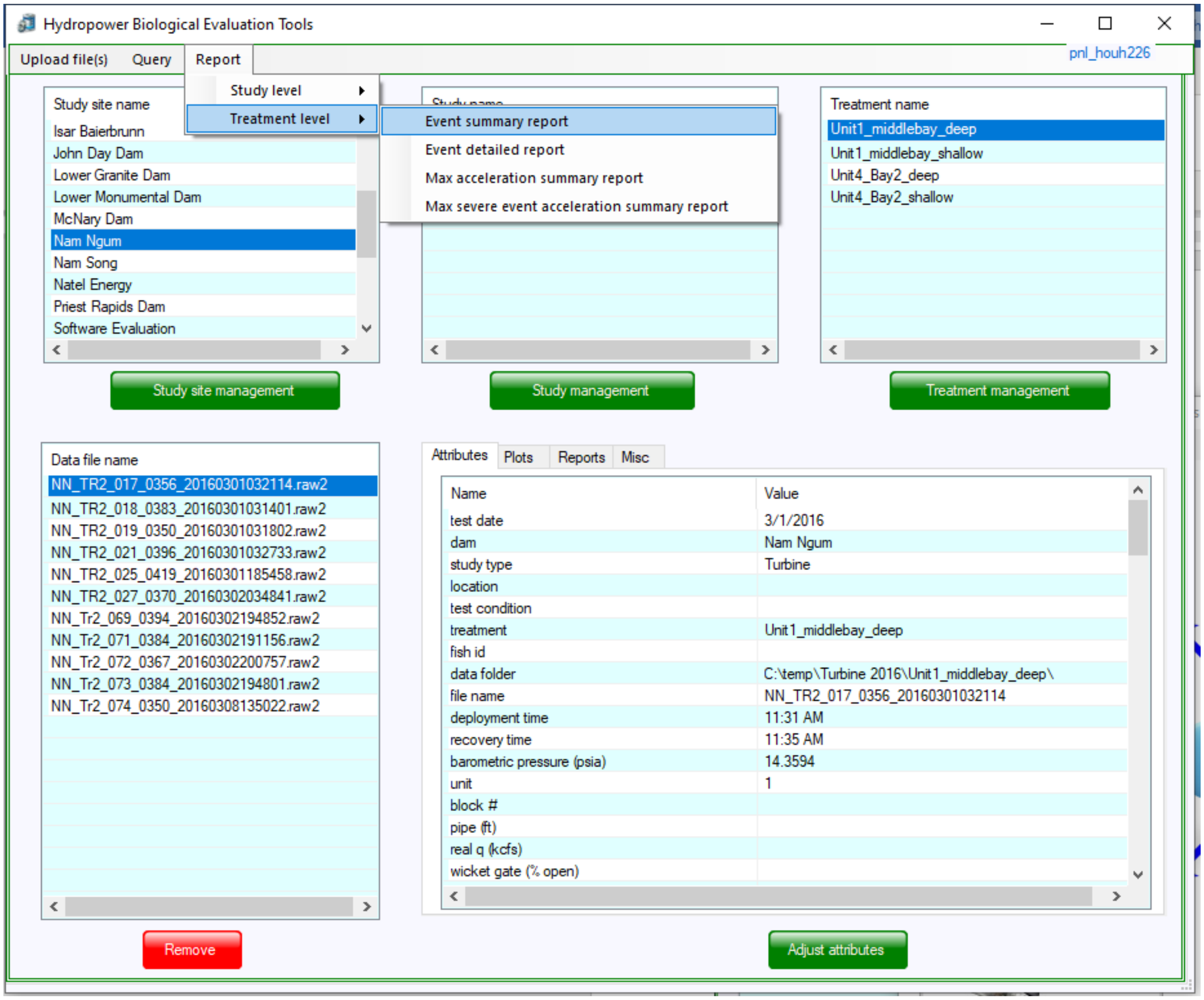
- total severe events
- mean severe events per release
- proportion of releases with "Severe " events (%)
- proportion of releases with "Severe " events attributed to strike (%)
- proportion of releases with "Severe" events attributed to shear (%)
- wicket-gate severe event %
- wicket-gate severe strike event %
- wicket-gate severe shear event %
- wicket-gate mean severe event
- turbine severe event %
- turbine severe strike event %

- intake severe event %
- intake severe strike event %
- intake severe shear event %
- intake mean severe event
- turbine severe shear event %
- turbine mean severe event
- draft tube severe event %
- draft tube severe strike event %
- draft tube severe shear event %
- and draft tube mean severe event.

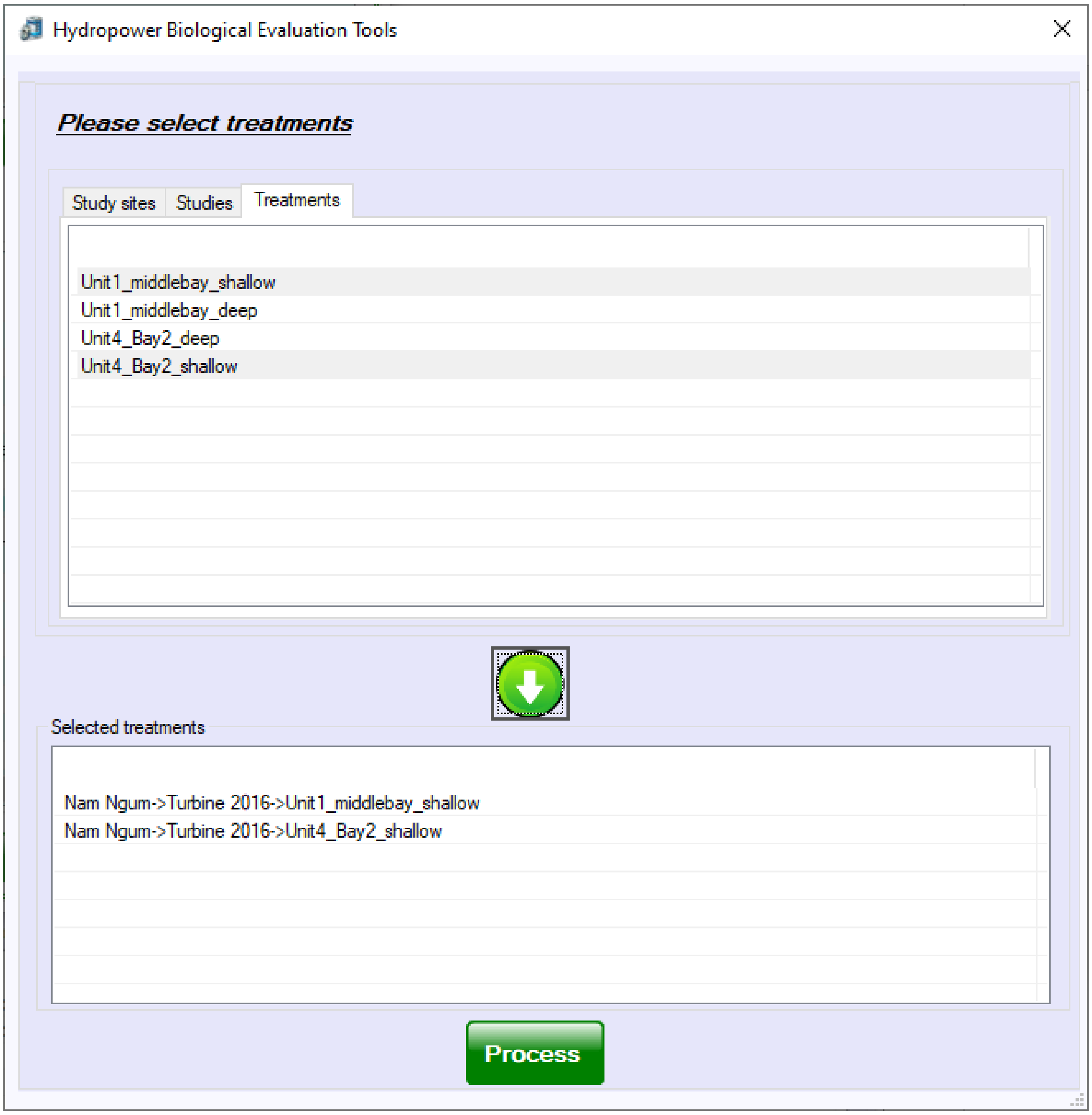
6.2.4 Use Case 4: Comparing Treatment "Unit1_middlebay_deep" with Treatment "Unit4_Bay2_deep"

To compare these two treatments, take the steps enumerated below.

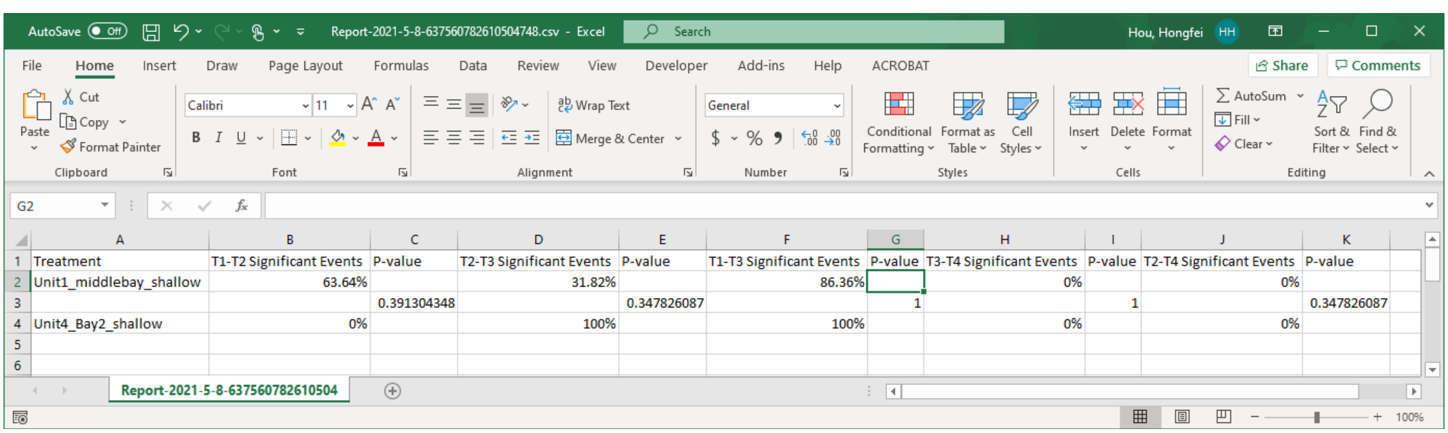
1. **CLICK** the "*Data management*" button in the HBET startup window.
2. **CLICK** the "*Report*" menu item, then **CHOOSE** "*Treatment level*" and "*Event Summary report*", as shown in the following screenshot.



3. In the pop-up window, **SELECT** "*Nam Ngum*"; then **CLICK** "*Study*" tab, **SELECT** "*Turbine 2016*", **CLICK** "*Treatments*", and **CHOOSE** these two treatments and **CLICK** the "down arrow" icon to add these two treatments, as shown in the following screenshot.



4. **CLICK** the “Process” button, and the processed results should be similar to the following:



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Appendix A – Sensor Fish Data Acquisition

Data acquisition is an important step when using the Hydropower Biological Evaluation Tools (HBET). The associated process entails preparing supplies, setting up a Sensor Fish (SF) release system, releasing and subsequently recovering the SF, and downloading the SF data. Each of the process components is addressed in the following sections.

A.1 Preparing and Performing the SF Field Deployment

Field deployment of the SF involves field preparation, selecting the appropriate SF release system, using recommended release and recovery accessories, configuring the SF in the SF Communicator software for data acquisition, conducting the release and recovery processes, and downloading data from the SF after recovery.

A.1.1 Field Preparation

Field preparations are made to test and prepare the SF release and recovery system, including preparing the SF self-inflating balloons and a field sheet for detailed field note-taking.

A.1.1.1 Preparing the Dummy SF

To test the SF release system and to allow the release and recovery crews to practice the process, it is useful to construct a low-cost "dummy" (i.e., non-functional) SF that can be used in place of actual SF. These dummy SFs have similar weight and dimensions and can be constructed simply from low-cost materials, as detailed in the instructions below. Figure A.1 shows an example of the components of a dummy SF used for testing the release system and practicing the recovery process.

Figure A.1. Dummy Sensor Fish components.

To construct a low-cost dummy SF, complete the steps enumerated below.

1. **CUT** a section of 1-in. outside diameter polycarbonate tubing (https://www.mcmaster.com/8585k201) to approximately a 2.5-in. length.
   a. **USE** rubber stoppers (https://www.mcmaster.com/9545k116-9545K14) to **SEAL** the tube.
   b. **USING** a hollow needle, **PUNCTURE** the rubber stopper from top to bottom, then **FEED** a loop of relatively high-test braided fishing line through the needle so that the fishing line can be run through the stopper.

   This loop of fishing line (Figure A.2) can be used to **ATTACH** self-inflating balloons whose construction is described later.

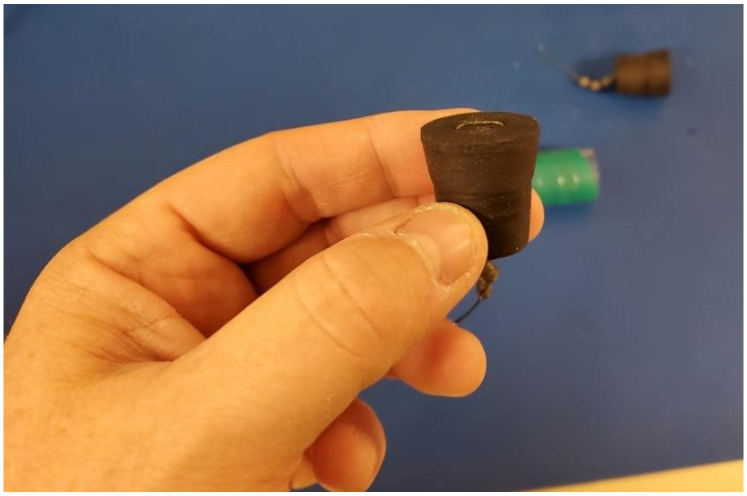


Figure A.2. Rubber stopper and the loop of braided fishing line used to attach self-inflating balloons.

2. To make the dummy SF neutrally buoyant, **ATTACH** the lead split shot fishing weights to the ends of the fishing line that end up inside the dummy SF (Figure A.3).

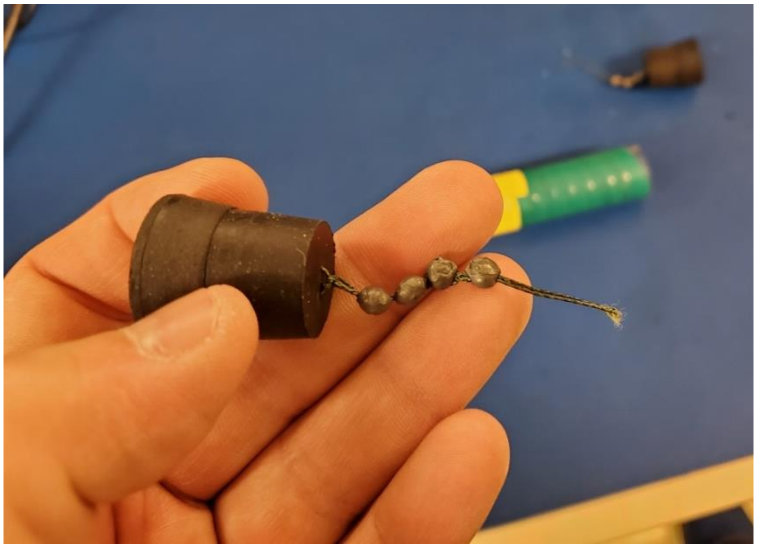


Figure A.3. Split shot fishing weights attached to fishing line to make the dummy Sensor Fish neutrally buoyant.

3. To make the dummy SF easier to visually locate, **WRAP** colored electrical tape around the polycarbonate tube (Figure A.1).

A.1.1.2 PREPARING THE SF RECOVERY SYSTEM

The primary method used to cause the SF to float to the surface after it has passed through the hydraulic structure being tested is using the weight drop recovery system that is built into the SF. This system uses a circuit board attached to each end of the SF. The circuit boards have a small loop of resistance heating wire attached to them. Custom tungsten weights are tied to the resistance heating wire using fishing line that can be thermally cut while underwater. The mass of these weights is such that the SF is neutrally buoyant in freshwater while they are attached, but if at least one of these weights is dropped the SF will become positively buoyant and float to the surface. Because this recovery system is electronically actuated it can be programed to activate after a user-defined amount of time after the end of the data collection period. This allows the user to control how quickly the SF becomes buoyant for different scenarios when it could be beneficial to have the SF surface as quickly as possible or to delay how quickly it surfaces. The process for preparing the recovery system components involves manufacturing a silicone mold that is used for molding the custom tungsten weights, using this mold to manufacture the tungsten weights, and the performing the final assembly step during which the tungsten weights are tied to the recovery system circuit boards.

To manufacture the silicone mold for the tungsten weights, complete the steps enumerated below.

1. **MACHINE** or **3-D PRINT** the negative for the silicone mold used for manufacturing the tungsten weights, using the following files:
   - custom_weight_mold_v2.sldprt Under "\weight_mold" in SF_CAD.zip
   - dummy_part_mold_cup.sldprt Under "\weight_mold" in SF_CAD.zip.
2. **PLACE** alignment pins in the holes for the mold negative, and **USE** these pins to **SECURE** the cup that contains the silicone while it is curing.
   - Dowl Pin, Part Number: 91595A031 https://www.mcmaster.com/91595A031/
3. **USE** a piece of electrical tape to **SEAL** the seam to prevent the silicone from seeping out of the mold while it cures.
4. **SPRAY** the inside of the mold negative with Universal™ Mold Release.
   - https://www.smooth-on.com/products/universal-mold-release/
5. **USING** Mold Star™ 15 Slow silicone, **MIX** the individual Part A and Part B components separately.
   - https://shop.smooth-on.com/mold-star-15-slow
6. **MEASURE** out 85–90 grams of Part A and 8.5–9.0 grams of Part B (the ratio is 10 to 1), and **MIX** thoroughly.
7. **PLACE** the mixed silicone inside a vacuum chamber for 5–7 minutes to degas the silicone before pouring it into the mold.
   a. **USE** a large enough cup to prevent spillage when the liquid expands due to escaping gas bubbles.
   b. Visually **OBSERVE** the degassing process and **BE READY** to reduce the vacuum if it appears the silicone is about to overflow the top of the container.
   c. Slowly **POUR** the mixed and degassed silicone into the prepared mold negative, and **TAP** the mold against a tabletop to **MAKE SURE** the silicone has spread evenly throughout the mold negative.
8. **PLACE** the mold negative that has been filled with silicone back inside the vacuum chamber for 30 minutes to ensure that any air trapped in the silicone is removed.
9. **ALLOW** the silicone to cure for 24 hours before removing it from the mold.
10. **REMOVE** the silicone mold from the mold negative and **ALLOW** it to cure for an additional 24 hours before being used to manufacture the tungsten weights.

    Each silicone mold is good for approximately 15–20 uses before the silicone mold will start to become damaged when removing the weights, causing defects of the weights manufactured. At this point a new mold should be manufactured.

To manufacture the tungsten weights using the silicone mold, complete the steps enumerated below.

1. **PREPARE** the mold by **INSTALLING** pins that will create the hole through the middle of the weight, and then **COAT** the mold with dry-release lubricating spray (Figure A.4).

- Dowl Pin, Part Number: 91595A031 https://www.mcmaster.com/91595A031/

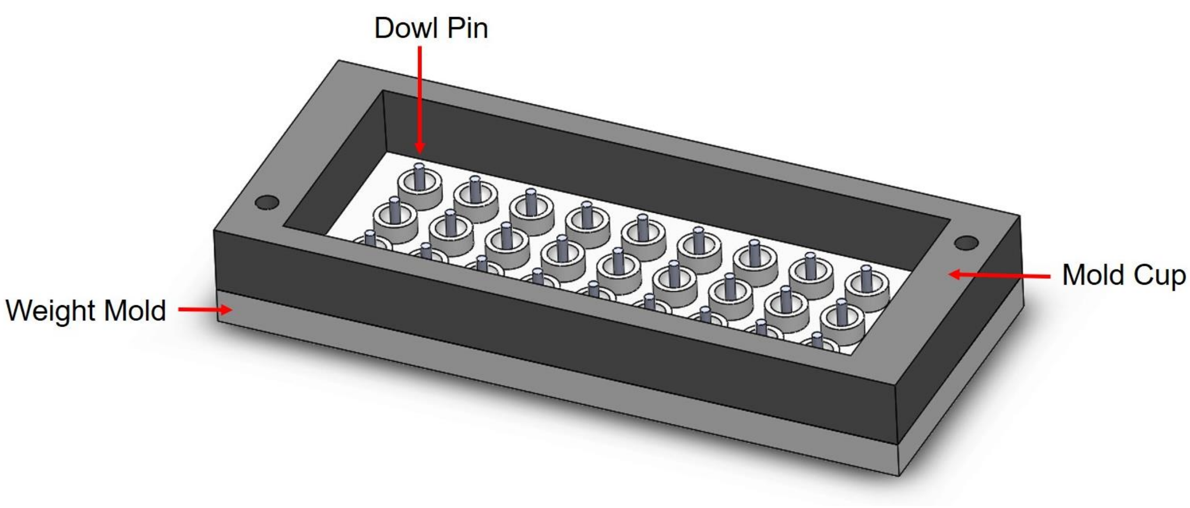


Figure A.4. Silicon weight mold components.

2. **PREPARE** the resin used for manufacturing the tungsten weights.

   The resin is a three-part mixture of the following components and amounts, which produces enough to fill three the silicone weight molds:

- Technon™ tungsten powder– 150 grams
  - https://www.tungstenheavypowder.com/technon-poly-kits/
  - **Note:** The resin included in the kit is not used.
- EPO-TEK 301 – 11.77 grams mixed
  - https://www.laddresearch.com/chemicals/epo-tek-301-epoxy-resin-5059
  - Part A – 9.42 grams
  - Part B – 2.35 grams

3. **MIX** the two parts of the EpoTek 301 separately before **MIXING** the 5 to 1 ratio of Part A and Part B.
4. Slowly **POUR** the tungsten powder into the EpoTek 301 while continuously **MIXING**.
5. **PLACE** the resin mixture in a vacuum chamber for 5 minutes to remove any gas introduced during mixing of the different components.
6. **REMOVE** the degassed tungsten resin mixture from the vacuum chamber and slowly **POUR** it into the silicone mold to **FILL** the cavities in the mold.
7. After filling the cavities in the mold, **SCRAPE** off the excess material, then **PLACE** the mold in the vacuum chamber for 5 minutes.
8. **REMOVE** the mold from the vacuum chamber and **FILL** any holes with the extra material.

9. **ALLOW** the resin to cure for 24 hours.
10. **REMOVE** the cured weights by **BENDING** and **FLEXING** the silicone mold.
11. After the weights are removed from the mold, **PULL** the pins out of the weights.

Note: It may be necessary to tap the pins through by placing the pin sticking out of the weight in a hole (i.e., piece of wood with a hold drilled in it) and carefully tapping it with a small hammer.

MEASURE the mass of each weight and **DISCARD** those that weigh less than 2.5 grams.

12. **SAND** each weight until the mass is 2.5 grams; **BE SURE** to **REMOVE** any jagged features that extrude from the body of the weight to avoid their getting snagged on the foam ring (Figure A.6).

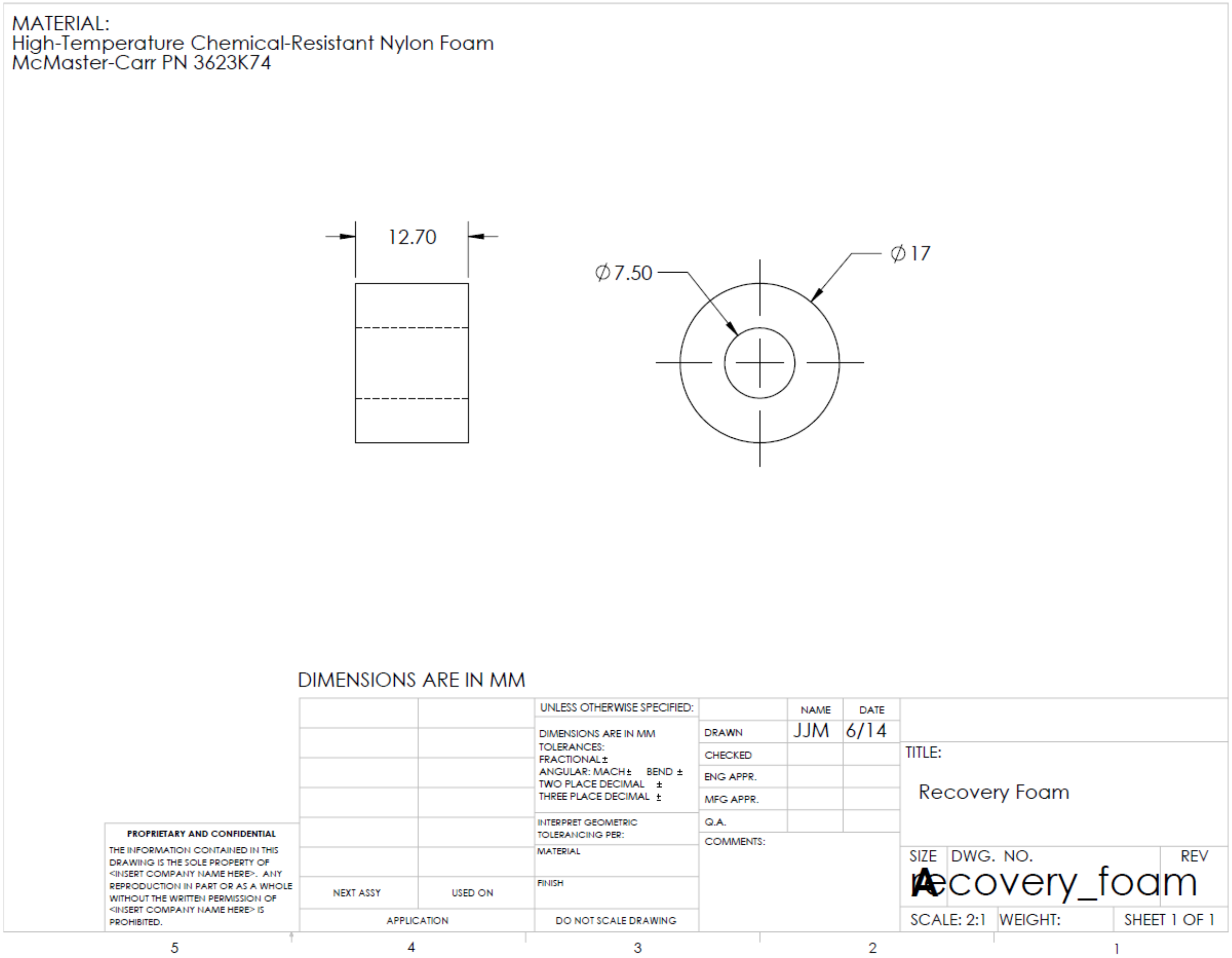


Figure A.5. CAD drawing of the foam rings used in the SF recovery system.

13. **CLEAN** the silicone mold by **SCRAPING** off the excess cured resin.
14. **CLEAN** the pins for reuse **USING** a strong solvent (e.g., Zip Strip®), and **FOLLOW** the safety precautions for the solvent that is used for removing the cured resin from the pins.

To assemble the SF recovery modules, complete the steps enumerated below.

1. **COLLECT** the necessary supplies to assemble the SF recovery modules (Figure A.6).

- Berkley NanoFil uni-filament fishing line – 8 lb test
  - https://www.amazon.com/Berkley-NanoFil-Uni-Filament-Fishing-Line/dp/B0053X88W6?th=1
- Sensor Fish tying cup
  - atying_cup.sldprt: Under "\recovery_assembly_tools" in SF_CAD.zip
- Threaded weight-tying tool
  - A weight_tying_tool.sldprt: Under "\recovery_assembly_tools" in SF_CAD.zip
- SF recovery boards with a loop of resistance heating wire
- Plastic fishing beads (Outer Diameter: 3 mm and Inner Diameter: 1 mm)
- Custom tungsten weights
- Foam rings
  - Manufactured from Part Number: 3623K74 (https://www.mcmaster.com/3623K74/)
- Small springs
  - Part Number: 9657K286 (https://www.mcmaster.com/9657K286/)
- Petroleum jelly (e.g., Vaseline®).

Figure A.6. Supplies needed to assemble the SF recovery modules (fishing line and petroleum jelly not shown).

2. **CUT** a piece of the fishing line to a length of approximately 6 to 8 in.
3. **THREAD** the fishing line through the SF recovery board.
   a. **THREAD** one end of the fishing line through one of the two rings on the recovery board.
   b. **WRAP** the string around the small cutting wire four times by **CROSSING** it under the wire five times (see Figure A.7 and Figure A.8).

c. **THREAD** the end of the fishing line through the last loop.

d. **APPLY** a coat of petroleum jelly over the area where the fishing line is wrapped around the resistance heating wire.

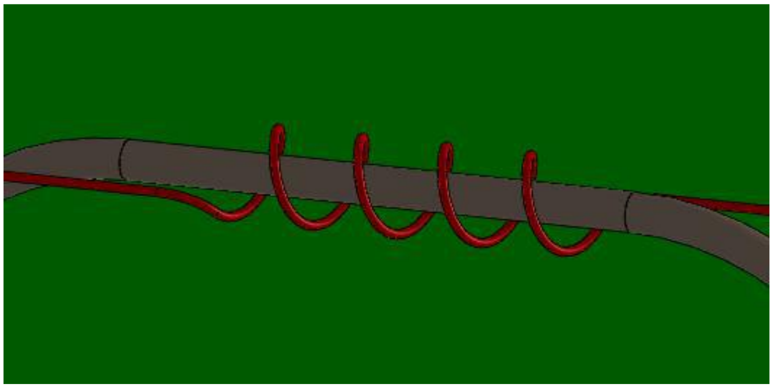


Figure A.7. Number of times to wrap the fishing line around the resistance heating wire.

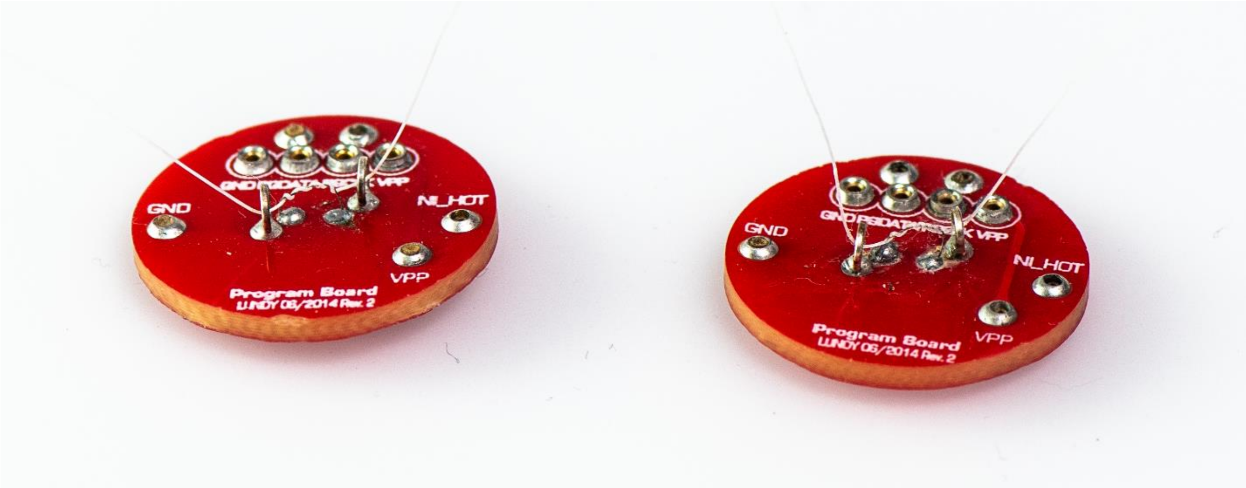


Figure A.8. Example showing the fishing line attached to the SF recovery board.

4. **PLACE** the recovery board, with threaded fishing line, in the SF tying cup so that the pins line up with the connectors on the SF recovery board (Figure A.9).

Figure A.9. Fishing line attached to the SF recovery board.

5. **INSERT** a spring into the small hole in the center of one of the foam rings (see Figure A.10).

Figure A.10. Spring inserted in foam ring.

6. **THREAD** the two loose ends of the fishing line, installed in the recovery board, through the spring that is installed in the foam ring (Figure A.11).
7. **POSITION** the foam ring inside the SF tying cup on top of the recovery board. The fishing line attached to the SF recovery board is inserted through the center of the spring .

Figure A.11. The loose ends of the fishing line, installed in the recovery board, threaded through the spring that is installed in the foam ring.

8. **THREAD** the two loose ends of the string through the hole in the middle of a SF weight and **SLIDE** it down to meet the spring (**Error! Reference source not found.**).

9. **THREAD** a fishing bead onto one of the loose ends of the fishing line and **SLIDE** is down to meet the weight.

Figure A.12. Fishing bead slid down to meet the weight.

10. Carefully **THREAD** the two loose ends of the fishing line through the hole in the center of the SF weight-tying tool, then **SLIDE** the tool down and **POSITION** it so that the weight is properly positioned in the weight cavity on the bottom side of the weight-tying tool (Figure A.13).
11. **ENGAGE** the weight-tying tool threads with the SF tying cup threads and **TIGHTEN**.
    a. With the weight-tying tool positioned over the weight and SF tying cup, carefully **COMPRESS** the spring by **PRESSING** down firmly.
    b. **TWIST** the weight-tying tool against the SF cap until the tying cup threads engage.
    c. **TIGHTEN** the tool until the spring is fully compressed and the bottom of the weight-tying tool meets the recovery board. While tightening the tool **BE SURE** to **PULL** tight any slack in the fishing line.

Figure A.13. Weight properly positioned in the weight cavity on the bottom side of the weight-tying tool.

12. To fasten the weight in place:
    a. **TUG** on the loose ends of the fishing line to **ENSURE** that the they are fully extended out from inside the SF cap.

b. **TIE** three simple overhand knots using the two loose ends of the fishing line. **BE SURE** to **PULL** each knot as tight as possible prior to making the subsequent knot(s) (see Figure A.14).

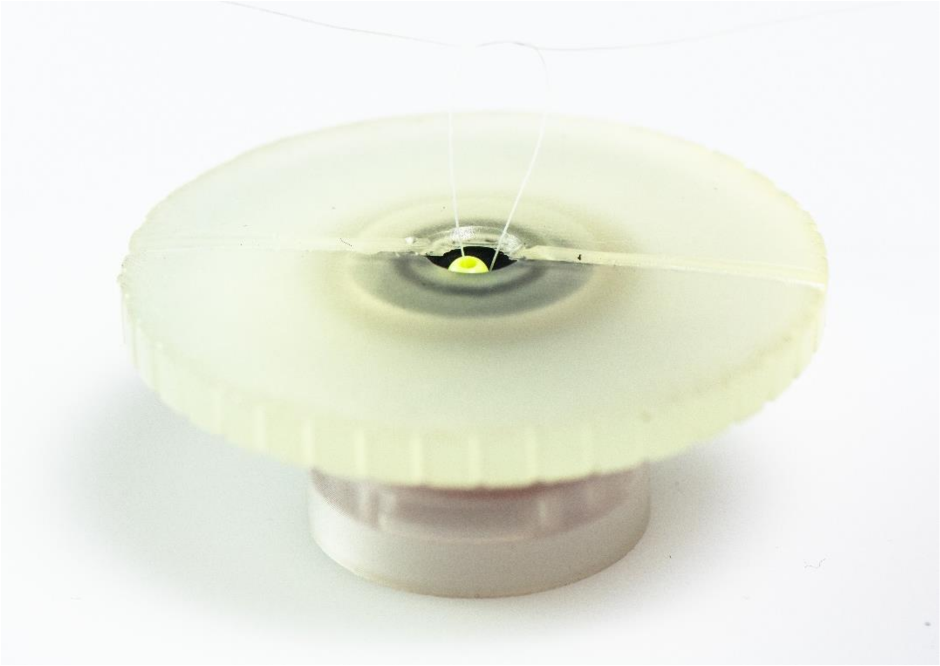


Figure A.14. Fastening the weight in place with overhand knots.

13. After the three knots have been tied and tightened,

    a. **REMOVE** the weight-tying tool.

    b. **CUT** away the excess fishing line, but **LEAVE** at least a half-inch above the last knot in case the knot slips slightly.

    c. Carefully **REMOVE** the entire assembly from the SF cap.

    d. **Apply** a drop of superglue over the knot to prevent the knot from becoming loose over time (Figure A.15).

Figure A.15. Applying a drop of super glue over the knot.

A.1.1.3 PREPARING SELF-INFLATING BALLOONS

Self-inflating balloons are a secondary method used to cause the SF to float to the surface after it has passed through the hydraulic structure being tested. The self-inflating balloons operate by using an acid and a base to generate gas that inflates the balloon. A mixture of an acid in powder form (oxalic acid; $H_2C_2O_4$) and a base in powder form (sodium bicarbonate; $NaHCO_3$) are mixed and this mixture is placed into vegetable-based pill capsules. These pill capsules are placed in a small balloon, which is sealed using a silicone stopper. To activate the self-inflating balloon, a needle is used to extract air from the balloon before injecting water through the stopper. Two versions of these balloons have been designed, one version that inflates in 1 to 2 minutes and another version that inflates in 3 to 5 minutes. The construction of these two versions of the self-inflating balloons is nearly identical. The only difference is once the size 3 vegetable capsules filled with the acid and base powders are constructed those pills are then placed inside another vegetable capsule one size larger (size #2; smaller gauge = larger pill). This requires the water to need to dissolve through two pill capsules before reaching the acid and base powder, thereby causing the process to take a longer amount of time. The balloons that inflate in 1 to 2 minutes are sufficient for most typical studies. The only other method to slightly manipulate the inflation time is by using warmer/colder water, so it is important to consider whether the balloons are being filled with river water that happens to be very cold/warm.

While the capsules can be filled by hand, it is much faster to use a low-cost capsule-filling machine that allows many capsules to be filled at one time. These capsule-filling machines may vary between vendors, so the user should follow the specific instructions for their capsule-filling machine. One tip for using a capsule-filling machine is to purchase the capsules that have already been separated by the top and bottom pieces, otherwise the user would need to manually separate the capsules and separate the parts into tops and bottoms.

To prepare the self-inflating balloons, complete the steps enumerated below.

1. **FILL** size 3 vegetable capsules with the acid and base powders; see https://www.capsulcn.com/size-3-clear-empty-vegetarian-capsules

a. **MIX** 2 parts $NaHCO_3$ (sodium bicarbonate) and 1 part $H_2C_2O_4$ (oxalic acid). The 2:1 ratio is by mass. The base/acid should be in fine powder form; if crystalized, **GRIND** it down using a mortar and pestle.

b. **FILL** the capsules by hand (for very small batches) OR **USE** a capsule-filling machine for size #3 capsules.

2. **FABRICATE** a mold for manufacturing custom silicone stoppers that seal the self-inflating balloons.

a. **FOLLOW** the same general instructions for manufacturing the silicone mold for the tungsten weights.

(1) a stopper_cup.sldprt: Under "\stopper_mold" in SF_CAD.zip

(2) stopper_mold.sldprt: Under "\stopper_mold" in SF_CAD.zip

b. **MIX** a 1:1 ratio of Smooth-On Mold Star 15 Slow rubber silicone; see https://shop.smooth-on.com/mold-star-15-slow

c. **FABRICATE** the silicone stoppers

(1) **MIX** a 1:1 ratio of Smooth-On Mold Star 15 Slow rubber silicone; https://shop.smooth-on.com/mold-star-15-slow.

(2) **PLACE** the silicone mold, fabricated in the previous step, over a piece of paper.

(3) **POUR** the Mold Star 15 silicone into each cavity of the mold until all cavities are evenly filled.

(4) **ALLOW** the stoppers to cure for 4 hours before removing them from the mold.

d. **ASSEMBLE** the self-inflating balloons.

(1) **CUT** a 6 in. length of high-test braided fishing line (~50 lb).

(2) **USE** a hollow needle to pierce through the side of the silicone stopper, **FEED** the length of fishing line halfway through the stopper, and **REMOVE** the needle **LEAVING** the fishing line in place.

(3) I**NSERT** two of the #3 vegetable capsules that have been filled with the acid/base powder into the balloon;

(a) Standard YoYo Balloons 100 pieces C-Smile https://suzukiballoons.com/english/yoyo.html

(b) **USING** a pair of castration pliers, **OPEN** the end of the balloon wide enough to **INSERT** the silicone stopper (see Figure A.16).

Figure A.16. An example of castration pliers used to open the end of the balloons to insert the silicone stoppers.

(c) **USE** the same pliers to open up a pair of O-rings and **PLACE** them around the outside of the balloon to secure the stopper in place.

e. **ATTACH** the self-inflating balloons to SF caps (see Figure A.17).

(1) **PLACE** one end of the fishing line through one of the small holes in the cap, and **PULL** it through the large hole in the center of the cap.

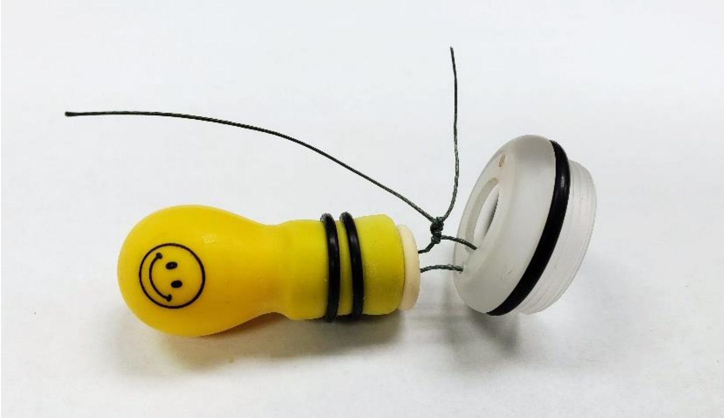


Figure A.17. Attaching a self-inflating balloon to the SF cap.

(2) **TIE** the two ends of the string together **LEAVING** about 0.5 to 1.0 in. between the top of the cap and the base of the balloon.

(3) **USE** 8 overhand knots to **SECURE** the balloon to the cap.

(4) **LEAVE** some extra fishing line (~1 in.), because cutting too close to the knot could result in the knot coming undone.

f. **TEST** the knot by **USING** your fingers to **GRAB** the fishing line on each side of the knot and **PULLING** with your fingers. **Do not PULL** on the fishing line too close to the balloon because it could cause the line to rip through the silicone stopper.

A.1.1.4 PREPARING FIELD NOTES

To ensure that the necessary metadata that will need to be included when the SF data are uploaded into HBET, it is necessary to prepare a suitable field sheet that can be used to manually capture important information about releases. This is done not only for information that will be needed for uploading SF data into HBET, but also to document field parameters that can be used to refine the recovery process (e.g., success rate for weight drop recovery system or self-inflating balloons). Please **MAKE SURE** to **RECORD** the following:

- test date,
- study site,
- study type,
- study subtype,
- treatment name,
- calibration file,
- deployment time,
- recover time, and
- operation data, such as:
  - barometric pressure (inhg),
  - barometric pressure (psia),
  - target discharge (kcfs),
  - pipe (ft),
  - discharge (kcfs),
  - wicket gate (% open),
  - blade angle (% open),
  - total discharge (kcfs),
  - generation (MW),
  - Forebay (FB) elevation (ft),
  - TW elevation (ft),
  - head (ft),
  - location,
  - unit,
  - block #,
  - test condition,
  - tag number.

A.1.2 RELEASE SYSTEM

A number of release methods—release tank, pipe and plunger, downrigger—are available and their application depends on the circumstances in which they are being used.

A.1.2.1 RELEASE TANK METHOD

The first SF release system method that is recommended uses a release tank with running water that flushes the SF through the rigid or flexible release pipe running to the desired release location (e.g., turbine intake at desired height). Because this system uses flowing water, once the proper flow has been set, the SF can simply be dropped into inlet pipe and the flowing water will move the SF out the end of the release pipe. One key advantage of this system is that it can also be used to safely conduct live fish releases for studies that use fish tagged with self-inflating balloons. By using the same release system, the SF data collected within the release system can be used to determine if the system could be causing injuries to live fish, as opposed to the injuries being caused by the hydraulic structure being studied. This system has been used for several studies at different hydropower dams, such as Ice Harbor Dam (see Figure A.18).

Figure A.18. For the baseline turbine characterization at Ice Harbor Dam stainless steel (SS) release pipes were attached to support frames of the submersible traveling screen in Slot B of Unit 1.

Each pipe terminus at Ice Harbor Dam had a sweep elbow to assure the SF were introduced at the desired depth and orientation to intake flows, thereby minimizing shear forces from the flow convergence. To reduce vibrations helical stakes were attached to the exterior of the pipe to reduce vortex shedding (Figure A.19).

Figure A.19. Helical stakes attached to the exterior of the pipe to reduce vortex shedding.

For the release tank, a polyethylene tank (Figure A.20) was fabricated with a combination of polyvinyl chloride (PVC) fittings to create the top end of the release system. Water flow to the release tank was controlled by diverting flow into the tank portion of the release system, as required, from the water supplied by a pump deployed in the gate well. Two valves are adjusted to get the desired flow. The first valve is located directly beneath the release tank and is used to set the bulk flow that travels through the release pipes. The second valve, located on a vertical section of pipe forked off of the main water inlet, is used to fill the tank, which has a vertical stand pipe to allow the tank to fill with excess water running over the top of the stand pipe. If the flow is set properly, SF can simply be dropped into the top of the standpipe after activation. For some scenarios, it may be beneficial to pull the standpipe after releasing the SF to release a larger volume of water to help push the SF through a potentially longer release pipe. For studies involving live fish, the standpipe can also be pulled to release a larger volume of water that can help cushion the fish as it travels through the release system.

Figure A.21. Release tank showing the locations of the valves.

A.1.2.2 PVC PIPE AND PLUNGER

For many scenarios, especially those not involving live fish, the release tank method may not be necessary and methods that require less labor to set up may be better suited to a scenario. One of these methods involves using standard PVC pipes, as were used at a study characterizing a siphon turbine. For that case, a 38 mm PVC pipe was secured to a rigid structure with one end of the PVC pipe at an accessible location above the water surface and the other end at the desired release depth. A smaller 19 mm diameter PVC pipe is used as a plunger to push SF through the larger release pipe.

A.1.2.3 DOWNRIGGER

One drawback of the PVC pipe and plunger method is that you are limited by the length of PVC pipe that can be used. If there is a long distance to the desired release depth, a fishing downrigger device can be used to release the SF, as was done in a study at Nam Ngum Dam in Laos. For this study a fishing downrigger release (RC-95; Black Marine Products, Naples, Florida [Figure A.22]) was attached to the line of a fishing pole. The downrigger release was clipped to a loop of fishing line tied to the SF. After attaching the SF to the release, the fishing pole was used to lower the SF to the desired release depth. Once at the desired depth, a quick upward motion of the fishing pole caused the release to trigger, releasing the attached SF.

Figure A.22. Black's downrigger release clip.

A.1.3 RELEASE AND RECOVERY ACCESSORIES

Many supplies are needed to release and recover SF. Each of these items and brief accompanying description are listed in Table A.1.

Table A.1. Supplies needed for release and recovery of Sensor Fish.

Supplies	Description
Digital watch	• Could be a phone clock, smart watch, etc. • Used for noting important times (e.g., release time, radio frequency (RF) detection time, recovery time).
Barometric pressure sensor	• Used for recording the barometric pressure, which is needed when uploading the SF data into HBET.
Magnets	• The SF is activated by the release crew using a magnet. • Once recovered, the SF is similarly deactivated (to conserve battery life) using a magnet. • Small neodymium magnets tend to work well, but even weaker magnets (i.e., refrigerator magnets) will still work.
Syringe 	• A 10 mL, or larger, syringe with a luer lock connection for attaching needles • Used to hold the water that is injected into the self-inflating balloons.

Supplies	Description
Needle 	• A 22G pencil-point needle (also known as a spinal needle) is used to pierce the silicone stopper in the self-inflating balloon to inject water. • The pencil-point needle has the opening on the side, as opposed to the end, which allows it to pierce through the stopper without coring a hole through the material.
Field sheets printed on waterproof paper	• It is desirable to have the field sheets that will be used to capture important metadata printed on waterproof paper (e.g., Rite in the Rain®).
Tweezers or small needle nose pliers	• Useful for removing the recovery boards after the SF has been recovered prior to downloading the data. • When SF is done being used the recovery board, and foam, should be removed from both ends to prevent corrosion.
Paper towels	• Useful for removing most of the water from the download end of the SF.
Compressed air duster (i.e., “computer duster”)	• Useful for removing remaining moisture from download end of the SF after using a paper towel.
Two-way radios	• Used for communicating information between the release and recovery crews.
Dip nets	• Dip nets with a handle length suitable for the recovery location (e.g., from boat or riverbank).
Radiofrequency (RF) receivers and handheld antennas	• The SF have a built-in 164~168 MHz RF transmitter that will transmit momentarily after the SF is activated but before it actually begins recording data, to allow the user to ensure it is working. • The RF transmitter will also transmit after data are finished being collected to assist in locating and recapturing the SF.

A.1.4 CONFIGURING SF IN SF COMMUNICATOR SOFTWARE

Before deploying, users need to clear the SF of previously recorded data. This action can take as long as 3 minutes to complete per SF, depending on the set Recording Time. After erasing, set the Delay Time, Recording Time, Resurface Time, and Radio Tag settings (see Figure A.23) using the associated buttons if necessary, because these settings will not change after data are erased.

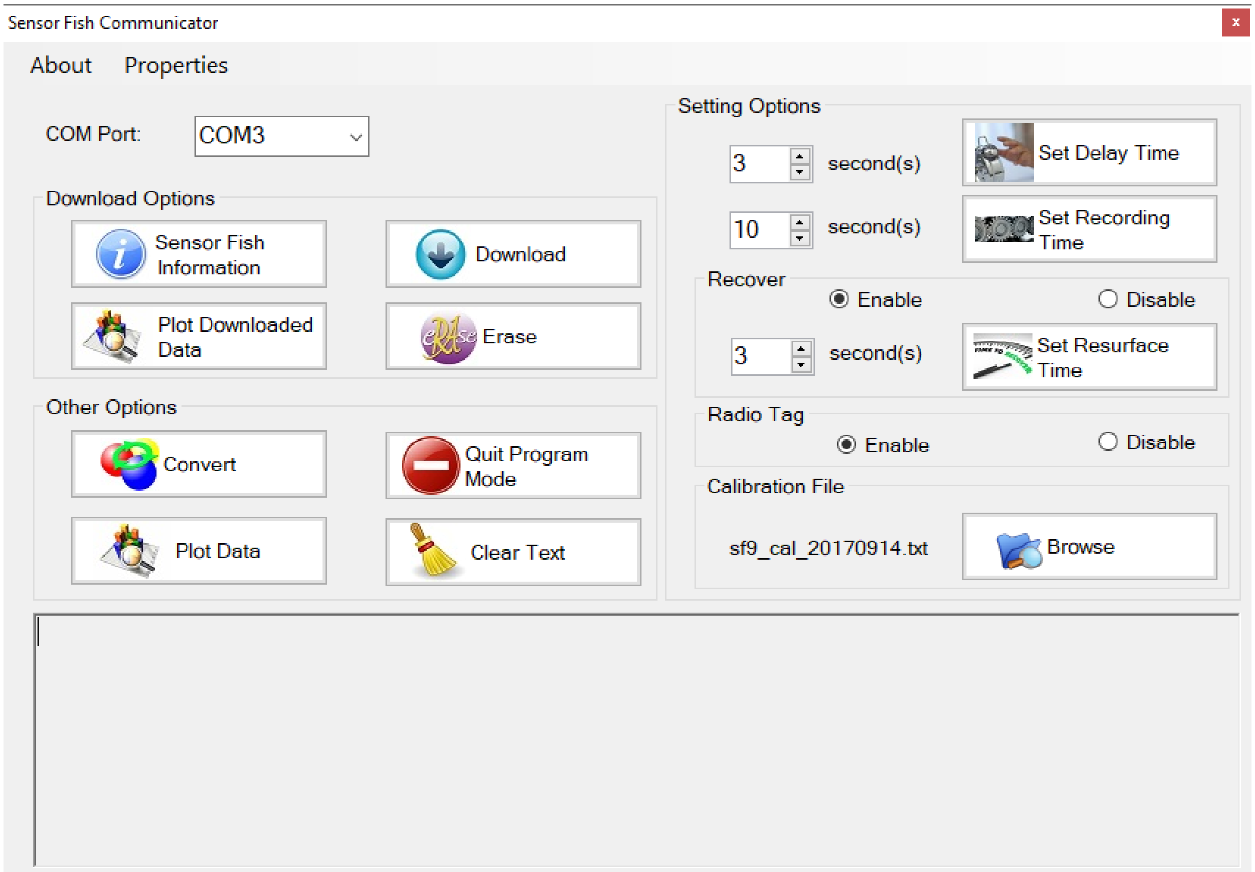


Figure A.23. The SF Communicator software user interface.

The delay time is the time period the SF waits before beginning data collection. Units are in seconds; the default is 5 seconds. The Recording Time is the period that the SF will collect data once the delay time has elapsed. The maximum collection time is 292 seconds; the default is 60 seconds. The Resurface Time is the period between data recording and the start of resurfacing procedures. The maximum delay time is 900 seconds; the default is 5 seconds. The SF has the capability to emit a radio frequency (RF) signal. If this function is preferred, select the “Enable” radio button; if not, select the “Disable” radio button.

A.1.5 Release Process

Although SF are released one at a time, a batch of SF will typically be released before the recovery crew will return the SF for downloading. All the SF that will be released in a batch are configured using the SF Communicator software. Once configured, recovery boards will be attached to each end of the SF and a SF cap with a balloon tied on will also be threaded onto each side. Information that needs to be documented on the field sheet will then be written down, especially the frequency associated with the built-in RF transmitter for each SF.

To release a SF, take the steps enumerated below.

1. **PREPARE** for SF activation and release.
    a. **USE** two-way radios to confirm that the recovery crew is in position and ready.
    b. **COMMUNICATE** the list of SF serial numbers and the associated radio frequencies, in the order they will be released, to the recovery crew members.

c. **SET** the RF receiver to the frequency associated with the specific SF to be released.

d. **FILL** the syringe with water, **LEAVING** a small volume of space for removing air from the balloon, and then **ATTACH** the needle.

e. **HOLD** one of the balloons and carefully **INSERT** the needle through the silicone stopper.

f. **PULL** the syringe plunger to **REMOVE** any air in the balloon.

g. **INJECT** approximately 7 mL of water into the balloon.

h. **REPEAT** the process for the balloon on the opposite end of the SF.

i. With water injected into the balloons on both sides, quickly **CHECK** the buoyancy of the SF to ensure it is close to neutrally buoyant.

   The SF now is ready to be activated and released.

2. **INFORM** the recovery crew which SF, and the associated frequency, is about to be released.
3. **USE** a magnet to activate the SF.
4. **WATCH** the LED on the SF blink once per second for the number of seconds set as the delay time.
   - Each time the LED blinks the RF receiver should detect the transmission.
   - **WAIT** until the LED stops blinking (RF transmitter also stops), which indicates it is now recording.
5. On the field sheet, **DOCUMENT** the time of activation and the barometric pressure.
6. **NOTIFY** the recovery crew that the SF has been released.
7. **WAIT** for the recovery crew to detect the RF transmission, indicating it has made it through the structure and is now downstream, before **REPEATING** the process with the next SF that has been prepared.

   a. The release crew will **NOTE** the time that the recovery crew detects the RF transmission.

   b. When the recovery crew recovers a SF, they will **COMMUNICATE** to the release crew the following information to be added to the field sheet:
      - SF serial number recovered
      - Inflation status of the two balloons
      - Status of the weight drop recovery system
      - If the LEDs are blinking
      - If not blinking the SF was likely damaged.
      - Any obvious signs of damage to the SF.

8. After all the SF in the batch have been released, the recovery crew will:

   a. **RETURN** the SF to the release crew.

   b. If any SF that had their RF transmitter detected were not recovered, the recovery crew will periodically **CYCLE THROUGH** the associated frequencies to **DETERMINE** if the SF is still within detection range and if it seems to have moved locations.

A.1.6 RECOVERY PROCESS

The recovery process entails staging recovery crews at appropriate locations where it is possible to get a net to the SF floating in the tailrace. This often involves strategically locating personnel where they can work together. Some recovery methods and basic recommendations are provided in Table A.2.

Table A.2. Recovery method recommendations.

Recovery Method	Recommendations
Motorboat	• A boat operator will operate the boat and help handle note-taking and radio communications. • Another person on the boat will use the RF receiver to locate the SF to guide the boat operator toward it so that they can net it out of the water.
Kayak	• A person will operate a kayak and have a two-way radio for communication. • The kayaker will typically work with someone on land who can operate the RF receiver and help guide the kayaker toward the SF.
Riverbank or tailrace deck	• A person with a RF receiver will help locate and spot the SF from land, and if it is close enough, they will use a long-handled dip net to recover the SF.

A.1.7 Downloading Data from the SF

A.1.7.1 Creating a Naming Convention

One of the most important parts of the SF data downloading process is coming up with a naming convention that will make it easier in the future to link each file with the field notes. At a minimum the filename should contain the following information, and be assembled (e.g., separated by underscores) in a way that is consistent.

- A unique number for each release
  - This should be the first part of the filename.
  - If the study involves control releases, typically studies with live fish, then a character can be used to distinguish between regular releases (“R”) and control releases (“C”).
  - The number of digits should be fixed with leading zeros (e.g., “R007”) so that the files will be properly sorted by release number when sorting the filenames by alphabetical or numerical order.
- An indication of the release location (e.g., unit number, release depth)
  - This will be highly dependent on the study but should at least contain the structure (i.e., dam) name and any other release location parameter that may vary.
- An indication of the treatment group (e.g., peak efficiency, generator limit, etc.)
- The SF serial number.

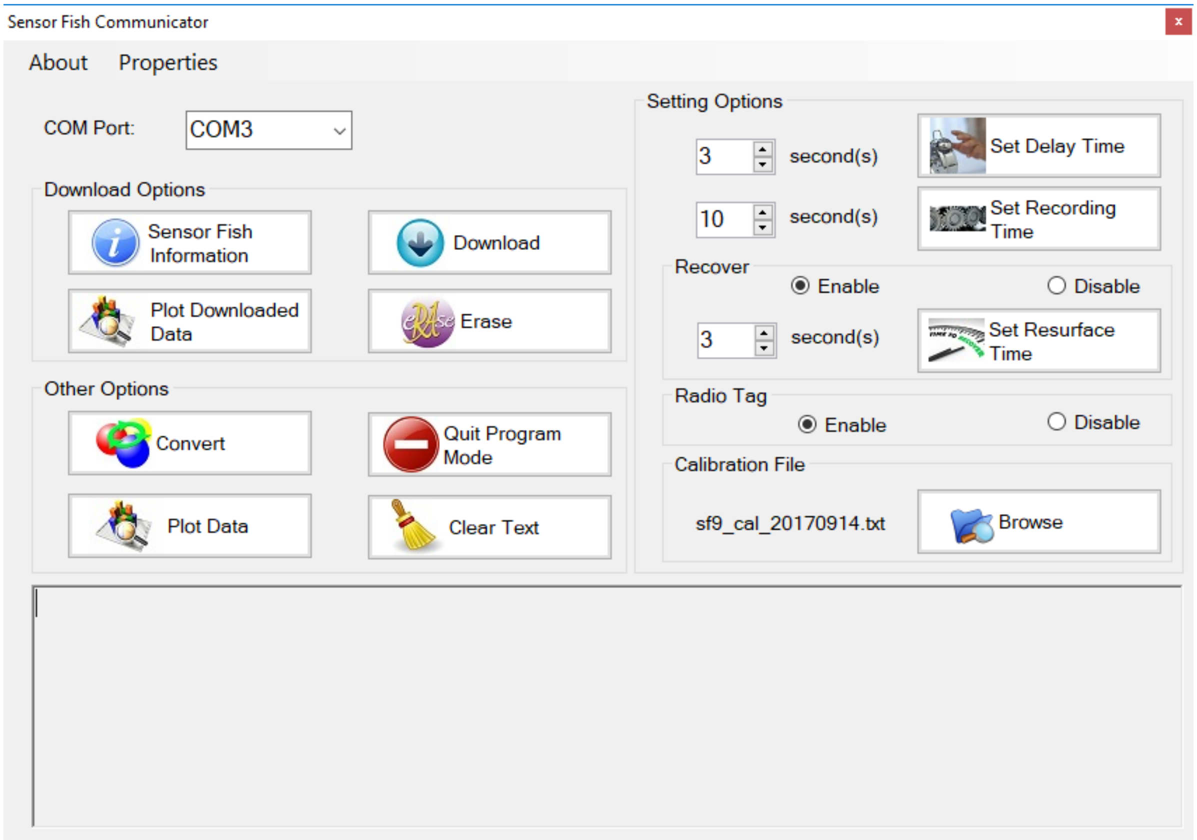
The SF Communicator software will also automatically add the serial number to the filename, but it is a good practice to also include it in the manual portion of the filename. Having this redundancy is useful for quality assurance/quality control purposes if a typo was made in the manual portion of the filename and/or the handwritten field notes.

The SF Communicator software is used to configure the SF before deployment, and then download the data from each SF after recovery. After downloading, please **USE** the “Plot Downloaded Data” feature to view the pressure, acceleration, rotation and magnetic data. If the data are not valid, **ERASE** the data and **REDEPLOY** the SF.

A.1.7.2 Use Case 1: Downloading a Data File From a SF

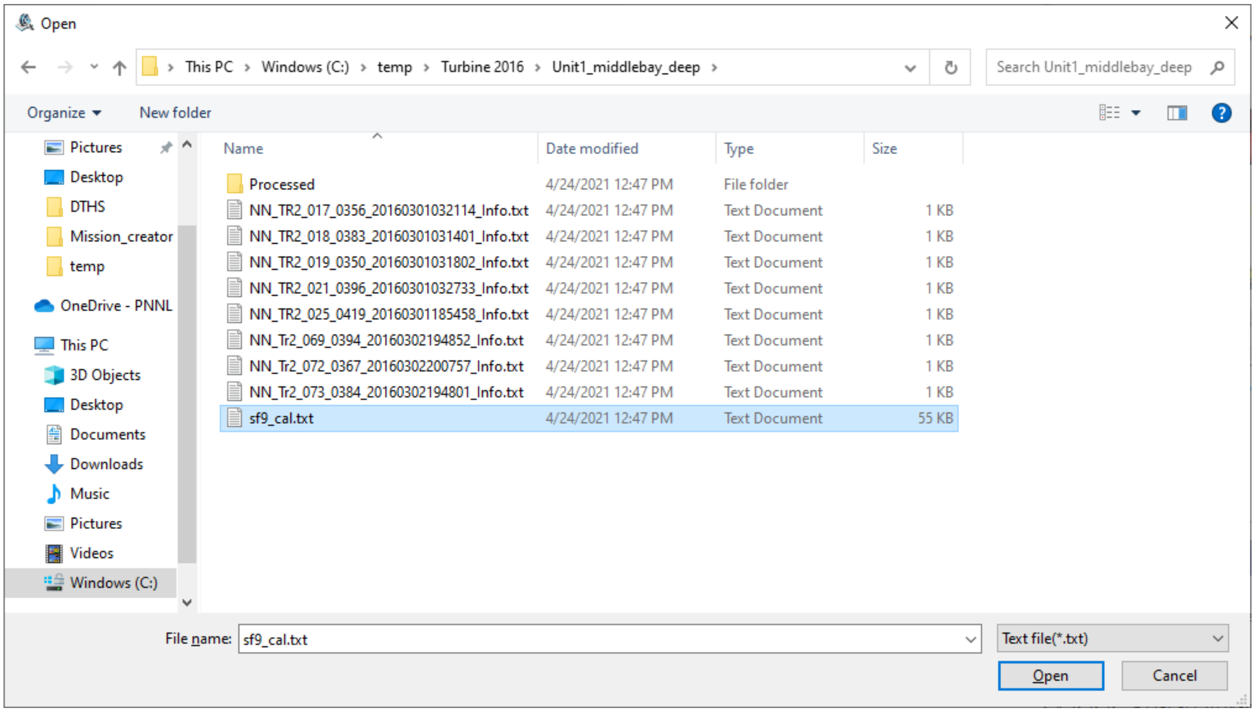
To download a data file from a SF, take the steps enumerated below.

1. **CONNECT** the SF to the computer.

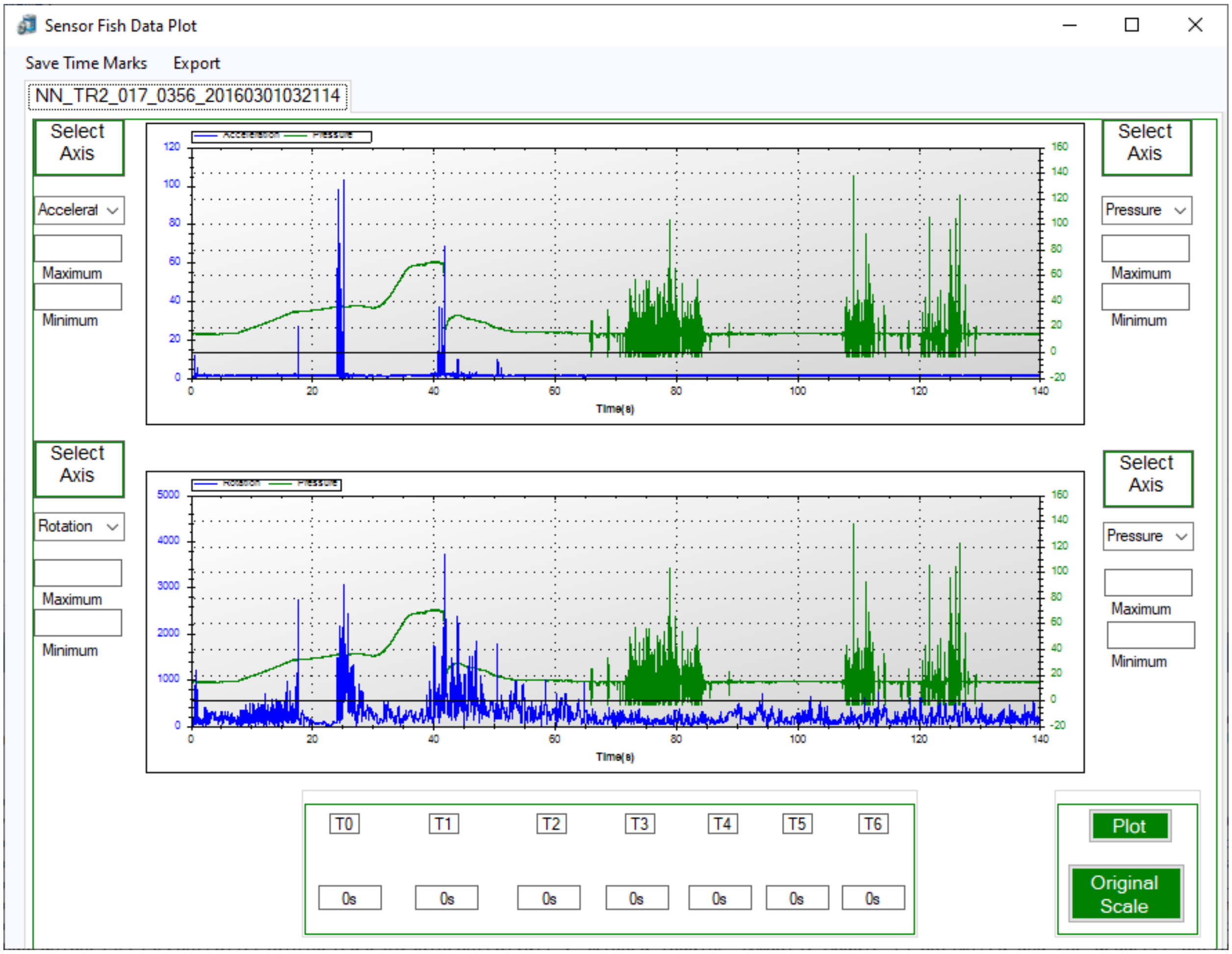


2. **START UP** the "*Sensor Fish Communicator*" applications.
3. **CHOOSE** the correct "COM Port", then **CLICK** the "*Sensor Fish Information*" button; the version information will show in the bottom of the screen.

   If no information is showing, please **CHECK** whether the SF is powered on, and if the "*COM Port*" is correct.



4. **CHOOSE** the correct calibration file using the "*Browse*" button.
5. **CLICK** the "*Download*" button, **CHOOSE** "*C:\temp*" as the storage folder, and **ENTER** "*NN_TR2_017_0356_*" as the prefix of the file, where "*NN*" is the abbreviation of the study site, "*TR2*" refers to the second treatments, "*017*" means it is the 17th deployed SF, and "*0356*" is the serial number of the SF.



6. After downloading, **CLICK** "*Plot Downloaded Data*" button to view the data.
7. **CLOSE** the above window, **CLICK** the "Erase" button to erase all the recording from the SF so that it will be ready for another deployment. Please **MAKE SURE** to **ERASE** data and **PREPARE** the SF for additional releases after a successful download.

A.1.8 SF RADIO RECEIVER

A radio receiver can assist in locating and recapturing a SF that has a bulit-in radio transmitter. Two simple radio receivers are described below in case users do not have a dedicated RF telemetery receiver system.

A.1.8.1 HAM RADIO

A ham radio (for example, https://www.amazon.com/BaoFeng-BF-F8HP-Two-Way-136-174Mhz-400-520Mhz/dp/B00MAULSOK) can detect the RF signal from SF in the range of approximately 100 ft. The frequency of the ham radio needs to be set to match the transmitting frequency of SF.

A.1.8.1 MODIFIED HAM RADIO

A modified ham radio can have a longer detection range. Here is an exemplary component list to modify the ham radio (see Figure A.24).

- BNC Connector: https://www.digikey.com/en/products/detail/molex/0733860041/6217421 or https://www.digikey.com/en/products/detail/pomona-electronics/4291/736816.
- BNC Cable: https://www.digikey.com/en/products/detail/tpi-test-products-int/58-012-1M/268021
- Yagi antenna: https://www.mouser.com/ProductDetail/Laird-Connectivity/YS1503?qs=EU6FO9ffTwfV2U3eNeoj2A%3D%3D

By removing the original antenna of ham radio, putting the BNC connector on, and connecting the Yagi antenna with the BNC cable, the detection range can be increased to at least 200 to 230 ft.

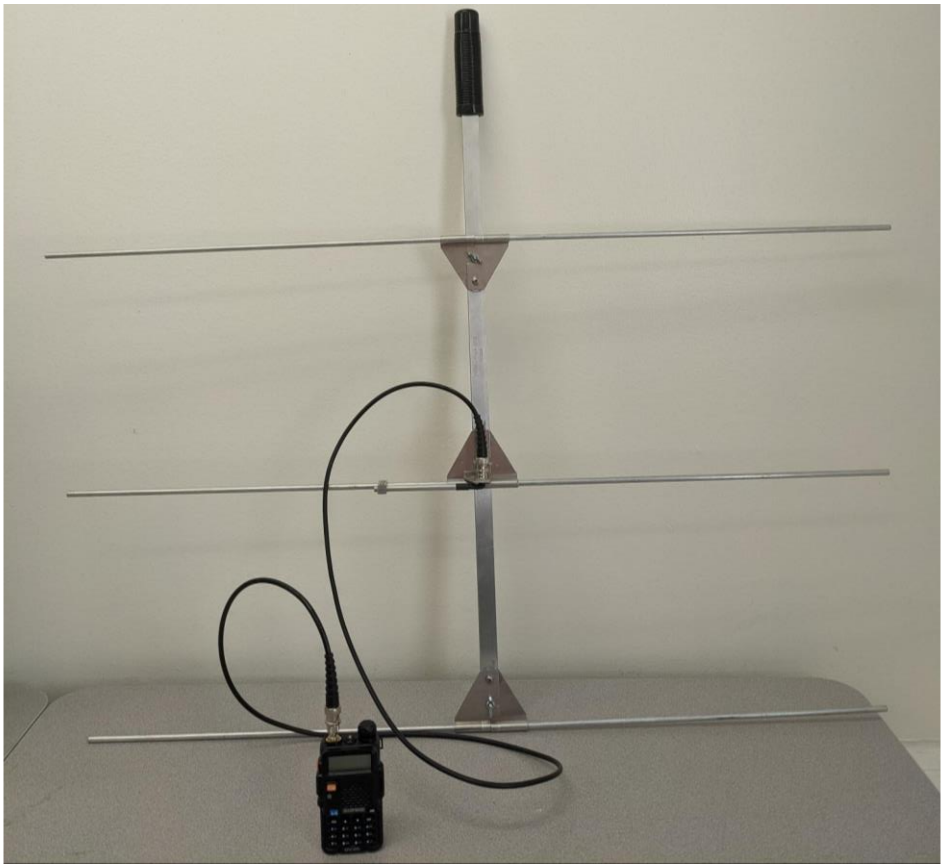


Figure A.24. Example of modified ham radio

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Energy Efficiency & Renewable Energy

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

For information about licensing the BioPA toolset, HBET, and Sensor Fish:

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