

# Chapter 2. Quantitative Calibration of DSM2

## 2.1 Summary

For the first time in its use, DSM2, the 1D hydrodynamic and water quality simulation model of the Sacramento-San Joaquin Delta, is being calibrated in a quantitative manner with mathematically-based techniques. This chapter describes the background, motivation, goals, and status of the project, as well as preliminary findings.

## 2.2 Background

Calibration, as used with physically-based numerical models, is the process of comparing model output with observed data; changing appropriate parameters in the model; running the model with the new parameter values and comparing again; and repeating until the discrepancy between observed and computed data is considered acceptable and the model “calibrated.”

In the past, Delta models, including DSM2, have been calibrated with traditional methods, using only channel friction (Manning's N) values and dispersion coefficients as calibration parameters. (Liu & Sandhu, 2012). The traditional approach implicitly assumes that other inputs are either perfect (and therefore their values should not change), or that adding more parameters would render an already complex process nearly impossible to perform by hand.

The traditional approach also assumes, in the case of DSM2, that each channel's calibration parameter (friction or dispersion coefficient) is independent of other channels. This leads to an ill-posed system which is simplified by ad hoc grouping of parameters (all friction parameters of channels in a group are adjusted by the same value or percent). The comparison-adjustment cycle is usually done manually, perhaps using automatically prepared graphs of observed and computed values, which is time-consuming and subjective.

Poor data resulting in uncertain modeling of Delta agricultural diversions and drainage remains as a problem and certainly affects our ability to develop a calibrated model. Until considerably more accurate estimates are available (unlikely in the near future for drainage flows and qualities), they are legitimate candidates for calibration parameters. However, to add these to a traditional manual calibration would overburden an already difficult process.

## 2.3 Motivation

The traditional calibration process, using little automation, is lengthy, labor-intensive, and subjective. It is not repeatable: two independent people or groups performing a calibration of the same model with the

same observed data will surely arrive at fairly different parameter values. And the traditional process is not quantifiable: there are no practical ways of calculating and comparing parameter sensitivity and robustness of the final parameter value set; we do not know how good the "final" calibration really is, and there are no estimates of error ranges in the production model.

A mathematically-based calibration, on the other hand, reduces or eliminates the shortcomings of the traditional calibration. Adding more calibration parameters candidates to the process results only in longer computer time, not greater conceptual difficulty, as with a manual calibration. Its big disadvantage is the requirement to make far more model runs than in the traditional method. But since the runs can be made in parallel, with a network of fast multi-core desktop computers (which the Delta Modeling Section possesses), this potential disadvantage does not exist. It is not only desirable but now entirely practical to abandon the traditional approach to calibration of DSM2 and adopt a modern procedure.

## 2.4 Goals

We have several goals with this project:

- To test the chosen software, described below, to see if it is ready, or can be made ready, to run with DSM2 and its input/output files.
- To develop pre- and post-processors at DWR to streamline and automate the process of preparing input files necessary for the chosen calibration software.
- To examine the sensitivity of various parameters, including non-traditional parameters, on DSM2 output.
- To calibrate DSM2 with only channel Manning's N and dispersion coefficients as parameters and compare with a traditional (manual) calibration to see what improvement, if any, a quantitative calibration can offer over a manual calibration.
- To calibrate DSM2 with new bathymetry, new estimates for Delta consumptive use, and additional calibration parameters such as agricultural drainage flows and water qualities, for use as a production calibration for DSM2 studies.

## 2.5 PEST Overview

The parameter estimation (PEST) software package (S.S. Papadopoulos & Associates, 2014) was chosen to calibrate DSM2 after a lengthy search through academic literature and the Internet. Coincidentally it has already been used in the Modeling Support Branch to calibrate the Integrated Water Flow Model groundwater model.

The best description of PEST comes from its manual (Doherty, 2010):

*The purpose of PEST...is to assist in data interpretation, model calibration and predictive analysis. Where model parameters and/or excitations need to be adjusted until model-generated numbers fit a set of observations as closely as possible...PEST should be able to do the job. PEST will adjust model parameters and/or excitations until the fit between model outputs and laboratory or field observations is optimized in the weighted least squares sense. Where parameter values inferred through this process are nonunique, PEST will analyze the repercussions of this nonuniqueness on predictions made by the model...a model*

*does not have to be recast as a subroutine and recompiled before it can be used within a parameter estimation process.*

Several compelling features of PEST are noted:

- Mature methodology and software. The methods used are described in peer-reviewed literature as well as readily available "gray literature," that is, institutional documents such as USGS reports. The software has been used for years, it is actively supported and is continuously updated.
- The method includes regularization (Doherty, 2010):
  - *In its broadest sense, "regularization" is a term used to describe the process whereby a large number of parameters can be simultaneously estimated without incurring the numerical instability that normally accompanies parameter nonuniqueness. Numerical stability is normally achieved through the provision of "supplementary information" to the parameter estimation process. Such supplementary information" often takes the form of preferred values for parameters, or for relationships between parameters.*
- In other words, PEST can be easily set up to eliminate unimportant parameters and not allow the remaining parameter values to zoom off to extreme limits.
- In predictive analysis mode, PEST will estimate the error involved in the accepted calibration. Thus, for the first time, we should be able to estimate error limits in studies using DSM2.

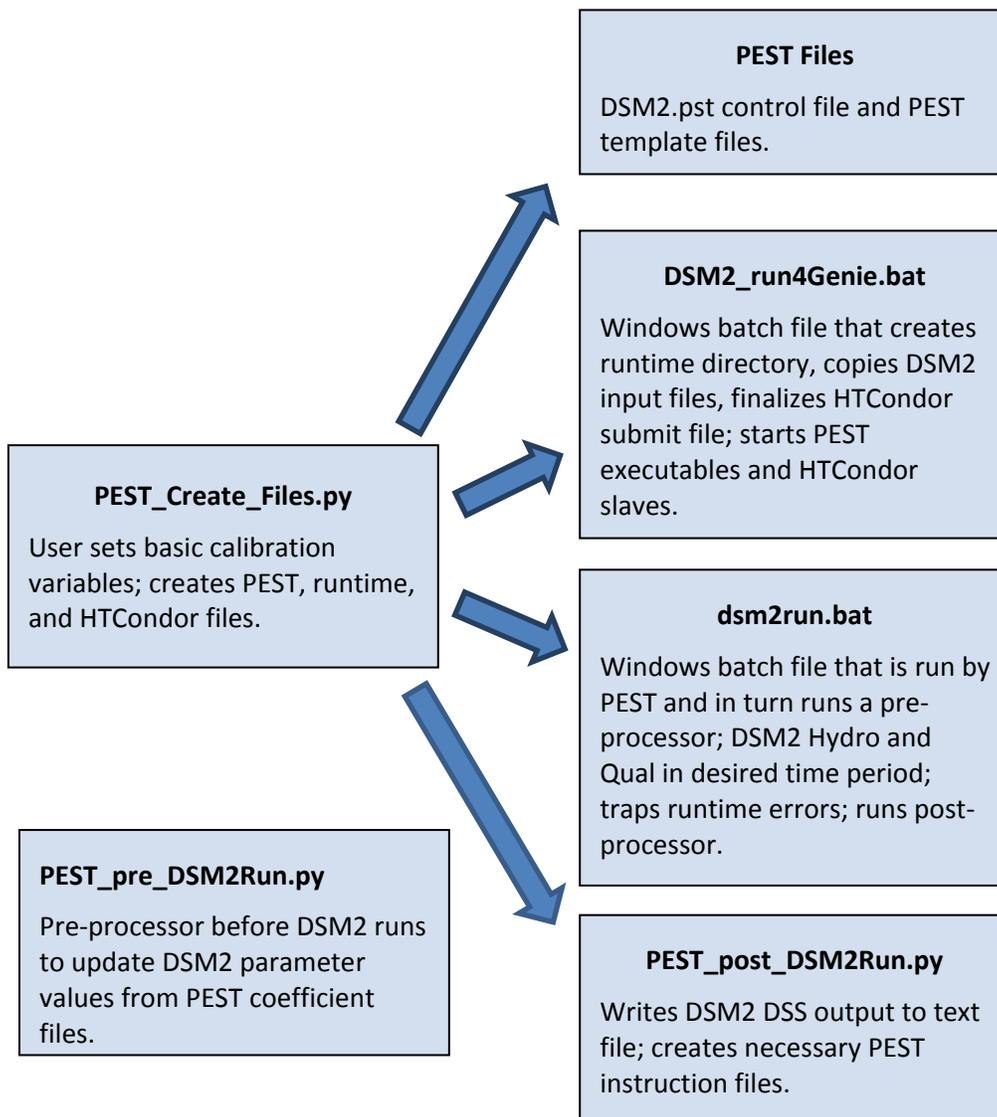
## 2.6 Connection to DSM2

PEST must be able to start the forward model in batch (unattended) mode, read all the model output as text files, and adjust parameters and create new text input files for the model. DSM2 is nearly ideal for these broad requirements, with the exception of its output, which is in the form of HEC-DSS files. To deal with the DSS-text file issue, its post-processor is used immediately after every DSM2 run, to convert the necessary DSS model timeseries to text files (described below).

The individual DSM2 (Hydro and Qual) runs are typically one year in length, which takes only a few minutes to process on a modern desktop computer. However, because hundreds or thousands of runs are done for a single calibration run, it is necessary to parallelize the runs, that is, run them simultaneously. We use HTCondor (University of Wisconsin-Madison, 2014), developed and maintained by the University of Wisconsin, to conveniently queue, run, and manage several dozen simultaneous runs on the network of multi-core desktop machines in the Delta Modeling Section.

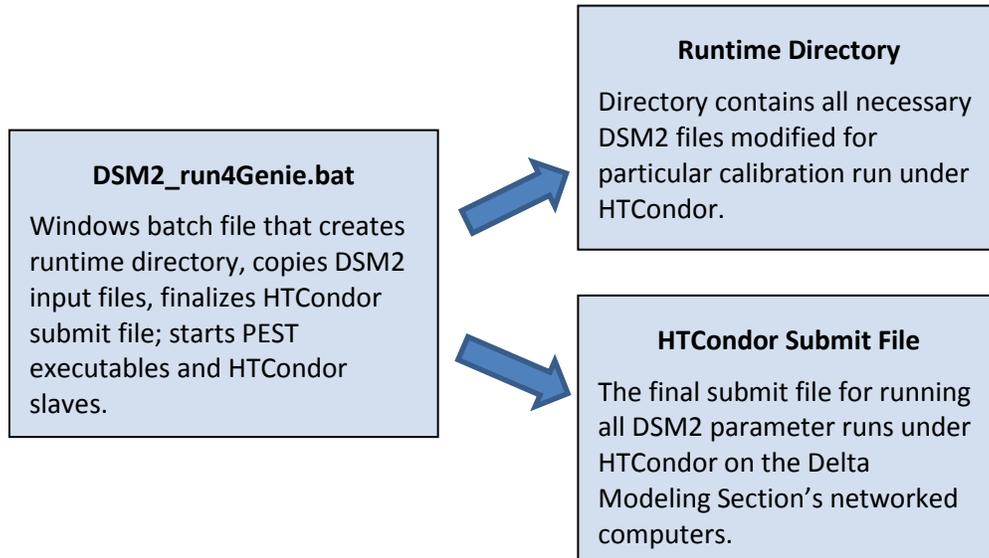
The creation of the several input files and scripts necessary to run DSM2 under HTCondor and PEST was automated. The principle script file, PEST\_Create\_Files.py, is written in Python and creates several other files (Figure 2-1).

**Figure 2-1 Initialization Files Block Diagram**



Once PEST\_Create\_Files.py is run, a calibration run is started by running the Windows batch file DSM2\_run4Genie.bat. This creates a unique directory for the calibration run, copies DSM2 executables and input files and modifies the appropriate files for the calibration, finalizes the HTCondor submit file, and starts the Genie runtime manager, the PEST program, and a few dozen batch programs under HTCondor which run pre- and post-processors for DSM2 and the DSM2 programs Hydro and Qual (Figure 2-2).

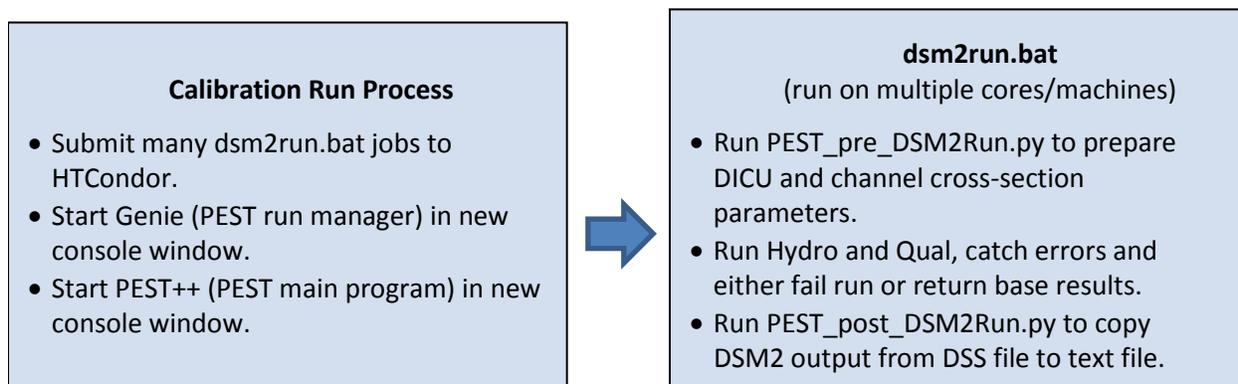
**Figure 2-2 Calibration Preparation and Start Block Diagram**



An actual calibration process (Figure 2-3) consists of:

- Genie, the PEST++ run manager, which communicates between PEST++ and the many PEST++ slave jobs running on multiple-core desktop computers under HTCondor on the local network;
- PEST++, which implements the mathematical theory behind the PEST concept and controls the numerical calibration procedure;
- dsm2run.bat, which runs a pre-processor, DSM2 Hydro and Qual, and a post-processor, and traps runtime errors. If desired, errors can simply trigger the return of DSM2 baserun results, which causes PEST to think that particular parameter value does not affect DSM2 results. Otherwise, an error fails the calibration run.

**Figure 2-3 Calibration Run Block Diagram**



## 2.7 Traditional and Non-Traditional Potential Parameters

In past calibrations of DSM2 and other Delta models, only channel roughness (Manning's N value) and dispersion coefficients have been adjusted to improve model output fit to observed data. However, all inputs have some unknown error associated with them so all inputs should be candidates for calibration. Using an automated calibration procedure lets us add additional parameters with little extra effort, and the quantitative nature of the PEST procedure allows us to compare all parameter groups easily for their sensitivity, that is, their effect on improvement of calibration fit.

Therefore, in addition to Manning's N and dispersion coefficient values, we are also including:

- DICU (Delta Island Consumptive Use) diversion flows, return drainage flows, and return flow water quality;
- Reservoir and gate flow coefficients;
- Channel bathymetry, in the form of changes to either cross-sectional layer width or elevation, which in turn affects area and hydraulic radius;
- Channel lengths.

The last potential parameter may seem uncalled for. It is fairly easy to accurately measure the actual streamflow length for each DSM2 channel using ArcMap or other geo-referenced tools. However, a few channels in DSM2 represent complex braided channels in the real Delta. Figure 2-4 shows an example, where the green channel is a line representation of DSM2 channel 313; the dark blue line is a nominal channel centerline, which length will be used by DSM2; and the pale blue lines the map representation of the actual Delta channels. These complex channels may benefit from the use of an adjusted channel length.

Figure 2-4 DSM2 Channel 313



## 2.8 Status and Preliminary Findings

As of this writing, we have confirmed that DSM2 is a suitable candidate for calibration using PEST. Nearly all of the setup is automated with Python and Windows Batch programs<sup>3</sup>, and some analysis is automated with Gawk programs to read and reformat PEST output to a style convenient for Excel and ArcMap. Statistical analysis is performed by the contractor using R programs.

To simplify the initial calibration we are not formally introducing new parameters yet (though they have all been tested), nor has new bathymetry or DICU replacements been used. Instead, we are calibrating only with Manning's N and dispersion coefficients in each channel, with existing bathymetry and DICU values. In addition to being a simple initial case, this will let us compare the quantitative calibration with the traditional manual calibration.

So far we have made the following informal findings:

- Manning's N is the dominant parameter. DSM2 output is much more sensitive to Manning's than to dispersion coefficients, agricultural diversions and drainages, and most channel bathymetry changes.
- It is easy to gain significant improvement in the RMS error using only Manning's N during the calibration period (summer 2009). However, using the modified parameters in the validation period (summer 2002) shows only slight improvement. We speculate this could be
  - the calibration and validation periods are too far apart, reflecting changes to the Delta, or
  - the calibration is calibrating to noise in the observed data which is different or absent in the validation period.
  - We expect to resolve this in future work.
- It is desirable to highly automate the entire process, as it then becomes almost trivial to try different numerical experiments. Incremental computing power comes at essentially zero cost so a highly automated process reduces elapsed time to only the parallel running time of DSM2.

## 2.9 Sensitivity Maps

We find it desirable to display several items of information in a dynamic map of the Delta. ArcMap, an ESRI GIS product, was used for this.

Figure 2-5 shows an example sensitivity map of Manning's N values in channels in the western Delta. Lighter green indicates less sensitive, darker green, more sensitive. In other words, a dark green channel's Manning's N value is a more powerful calibration "knob" than a light green channel. Circles (solid or rings) mark observation stations that are not used in the calibration; Pushpins indicate stations which have data that are used.

It is interesting to note some general patterns. Most Montezuma Slough channels are moderately sensitive except for channel 515. Other Suisun Marsh channels have little effect on Delta output. Channels which represent bays and are "dead ends" (e.g. channels 572, 573, 574, and 575) are less important than channels in the main river and that convey flow.

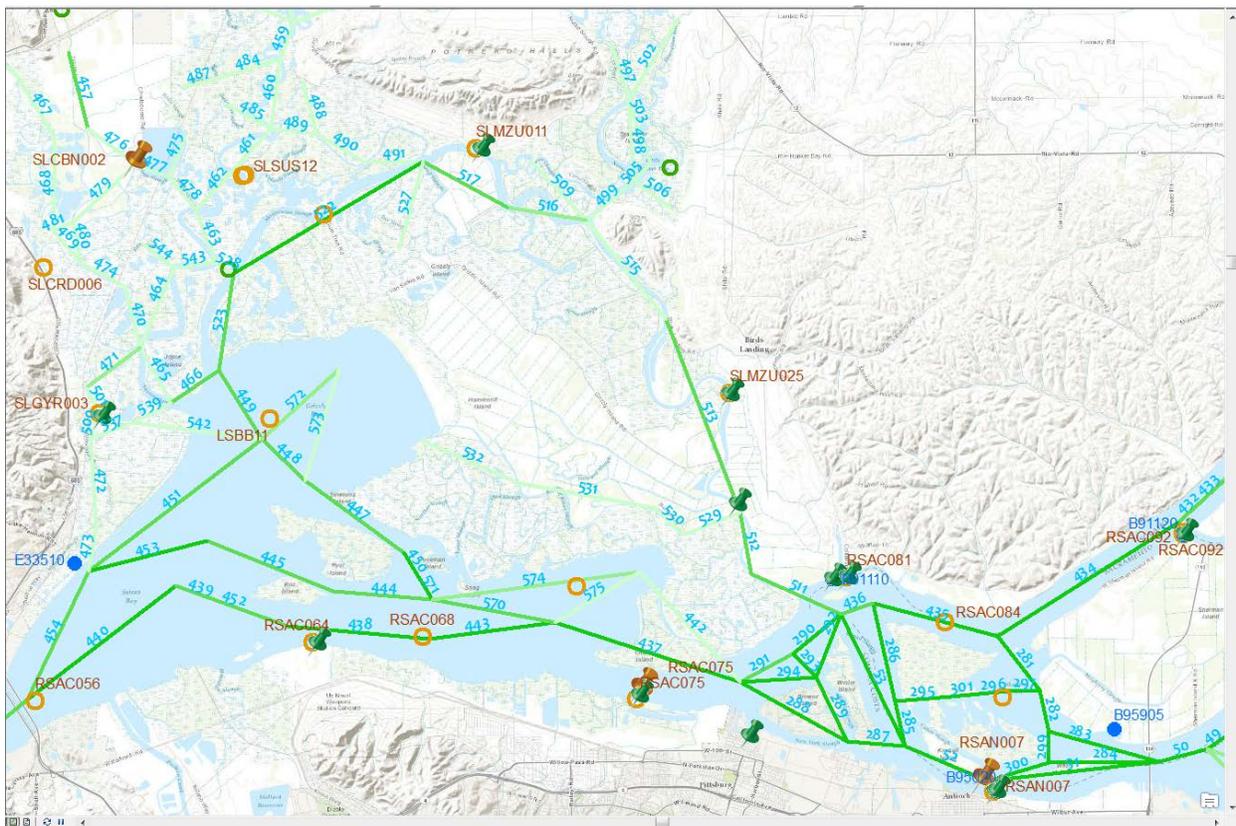
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<sup>3</sup> To be sure, the various scripts comprising the automation should be rewritten to modern programming standards.

Further inland (Figure 2-6) we see similar sensitivity among channels with little variance from channel to channel. In this map we have placed DSM2 agricultural nodes, colored according to their sensitivity to DICU diversion flow: pink is relatively insensitive, red is relatively sensitive. Here we see some groups forming. For instance, a few nodes in Old River and the South Delta show high sensitivity, and one node adjacent to Discovery Bay (198) shows very high sensitivity compared to its neighbors.

Another way of viewing calibration parameters is showing their final value compared to their starting value. Figure 2-7 is similar to Figure 2-6 except the nodes are now colored according to their final calibration adjustment coefficient for diversion flows. This adjustment coefficient ranges from about 0.5 (bright red), indicating half the pre-calibration diversion flow, to about 1.5 (bright green), indicating 50% more diversion flow. This gives us a direction to the sensitivity—whether a particular parameter is adjusting up or down from its initial value. PEST has just been modified to incorporate both sensitivity and direction in a single value, so future displays will require only one map to show both types of information.

Figure 2-5 West Delta Sensitivity Map







### 2.10.2 Using better Bathymetry and Delta Evapotranspiration of Applied Water (DETAW)

Known improvements for DSM2 are its channel bathymetry and estimates of channel diversions, drainage return flows, and return flow water quality.

A separate effort (Wang & Ateljevich, 2012) has developed good quality bathymetric digital elevation maps (DEMs) of the Delta. Concurrent with the calibration project, another project with a GIS contractor is developing a modern, GIS-based cross-section development and editing program for use with DSM2. This project should be finished before the calibration project and will be used with the bathymetry DEMs to develop new cross sections for DSM2.

Much better ET estimates for the Delta have been developed (DiGiorgio, 2009); (Kadir, 2006). They will be incorporated for the final calibration of DSM2.

## 2.11 Acknowledgments

This work would not be possible without a contract with S. S. Papadopoulos & Associates (SSP&A), funded by the State Water Project and supported and approved by Tara Smith (Chief, Delta Modeling Section), Dr. Francis Chung (Chief, Modeling Support Branch) and Kathy Kelly (former Chief, Bay-Delta Office). Matt Tonkin, President of SSP&A is the principle contractor and developed many of the theoretical methods and implementations in software. Chris Muffels of SSP&A developed the Genie run manager.

## 2.12 References

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