Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 6
DSM2-PTM Improvements

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6 DSM2-PTM Improvements

6.1 Introduction

This chapter describes bug fixes and related tests of DSM2-PTM, with a focus on convergence tests for different PTM time steps. Bugs discovered are:

1. Missing advection: in the loop through the sub-time steps within one PTM time step, the last sub-time cycle is usually missed. This can delay particle motion and the accumulated error can be significant.
2. First time-step error: PTM reads hydrodynamics information from the tide file and the first time-step has an initial calculation error. This leads to erroneous results when particles are released at the beginning of PTM simulation start time.
3. Time interpolation factor (θ) inconsistence: two different weighting average factors between the current and the previous time step are inconsistent for flow, depth, cross-section area, and stage.
4. Missing dispersion: when a particle arrives at the end of a channel, the random motion in the Y and Z axes is missed for the last sub-time step. This leads to erroneous results, especially in a grid system with many connected channels such as the Delta.
5. Error warning for transfer: an error exists in the function that checks flow balance for nodes connecting transfers and reservoirs. This doesn't affect the calculated value but will slow down the module running when the grid has this kind of waterbody combination.

6.2 Background

DSM2-PTM is a quasi-three-dimensional particle tracking model which is used extensively in Sacramento-San Joaquin Delta studies. This model has been verified, calibrated, and documented in several reports (Smith, 1998), (Miller, 2000), (Wilbur, 2000), (Miller, 2002). Recently, the authors conducted several tests of DSM2-PTM, as part of the DSM2 Version 8.1 package.

Various test grids were applied, e.g., chained channels, bifurcated channels, reservoir, transfer, etc., as well as the Sacramento-San Joaquin Delta historical grid. Various hydrodynamic environments were also applied, e.g., steady uniform flow and tidal time-varying flow.

This chapter lists bugs found and corresponding corrections. The attachments include the primary configuration of the tests and important result comparison in plots. Please contact the authors for detailed information about the tests and the results.

6.3 Bugs and Corresponding Fixes

6.3.1 Missing advection

In DSM2-PTM, the user-defined time step is divided into sub-time steps for particle movement calculation. The sub-time step is calculated by dividing the time step by the number of sub-time steps, and then subtracted from the original time step for each sub-time step cycle. Because of the limited numerical precision of the variables, the summation of sub-time step does not add up to the PTM time step exactly. This bug usually results in the last sub time-step being smaller than the normal one. The current design does not perform this last sub time-step, since the loop exits when the time left is less than the sub-time step size.

PSEUDO-CODE OF PREVIOUS SUB-TIME STEP CALCULATION

```
If (time left >= sub-time step)
   Move particles within one sub-time step
   Subtract sub-time step from time left
Else
   Exit loop
```

It is hard to estimate the typical amount of accumulated effect of the error, since the size of the unspent time depends on the sub-time step, which in turn depends on the channel geometry and dispersion coefficient, i.e. either a different input time step or different channel geometry could result in different amount of the error.

It is supposed that this error would result in delay for particle movements. In a uniform flow environment, the amount of this error could build up quickly. As Attachment B-1 shows, the delay in cases with certain time steps could be large compared to others. In a time-varying tidal environment, this delay could be hard to identify, due to the frequently alternating flow direction.

To correct this bug, we introduce a new variable (`tmToAdv`) and add an `IF` conditional control statement. This will ensure all the time is spent.

PSEUDO-CODE OF CORRECTED SUB-TIME STEP CALCULATION

```
If (time left > 0)
      If (time left ≤ sub-time step)
            Replace sub-time step with time left
      Move particles within 1 sub-time step
      Subtract sub-time step from time left
Else
      Exit loop
```

6.3.2 First time step error

Another bug is in the PTM hydrodynamic I/O routine. DSM2-PTM reads the DSM2-HYDRO tide file for flow information (flow rate, cross-section area, etc.), then calculates weighted flow averages over the current and previous time steps. However, this routine assumes the previous time step is already read and stored in memory, which is not the case for the first time step. Uninitialized values are set to zero, thus the weighted averaged values for the first time step are not correct (half values of the current time step in the previous code), much less than what they are supposed to be.

This error only affects the first time step of a simulation, causing particle velocities to be larger than expected (same flow, smaller cross-section area), i.e. earlier arrival. Fortunately, this influence can't be large since it's only one time step. Besides, this error could be avoided by releasing particles with a delay. Therefore, this first time step error would not be serious for most cases.

To correct this error, we introduce an `IF` conditional control statement. This will adjust the flow variable values back to its correct value.

PSEUDO-CODE OF CORRECTED FIRST TIME STEP ERROR

If (current time == start time)

```
      depth = depth / θ
      stage = stage / θ
      area = area / θ
```

6.3.3 Time interpolation factor (θ) inconsistence

PTM uses a weight parameter *theta* (θ) between the current and previous time steps when calculating averages for several variables (flow, depth, cross-section area, and stage). For example, for down_node cross-section area in channels, the following function is applied:

PSEUDO-CODE OF TIME INTERPOLATION EQUATION FOR VARIABLES

area = area_current * θ + area_previous * (1- θ)

θ was defined twice in the program: flow is calculated in DSM2-HYDRO module (`netcntrl_common.f`); stage, depth, cross-section area are using what is defined in DSM2-PTM module (`ptm_local_data.f`). The two modules used different θ values. The effect of this inconsistence depends on hydrodynamic conditions. To correct the error, several changes were made in the PTM Fortran code.

6.3.4 Missing dispersion

When a particle arrives at the end of a channel, the random motion in the Y and Z axes are missed for the corresponding sub time-step.

Less dispersion could make the velocity profile more centralized to their average velocity, which results in particles more centralized to their average arrival time ("steeper" arrival curve), and this dispersion error would accumulate in a grid with more junction nodes. However, the effect of this error is minimal since the amount of dispersion is usually small in PTM (the Delta is an advection-dominant system).

To correct this error, two Y and Z calculation lines of code were added to the calculation method.

6.3.5 Error Warning for Node Flow Balance Check at Transfer

PTM checks input flow for all waterbodies connected to each node, in each time step. It requires the sum of each node's flows to be close to zero, within a tolerance 2 cfs.

However, for a transfer flow connected to reservoirs, the signing definition for water body "reservoir" omits in the case of flow transfers into reservoir. A warning (Figure 6-1) will be displayed every time-step. This will slow down the simulation when such a condition exists.

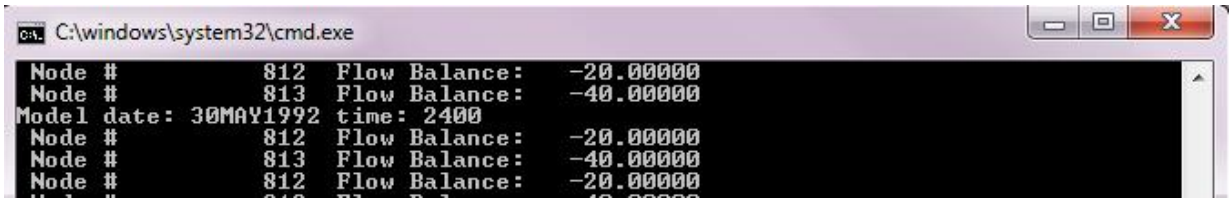


Figure 6-1 Warning message from balance check at transfer bug

To correct this error, a condition control has been added to eliminate the false warning message.

6.4 Debug Tests and Analysis

The designed standard PTM test suite (Zhou, Chapter 5, DSM2-PTM Standard Test Suite Design and Automation, 2013) is used to perform tests for new PTM (as well as DSM2 HYDRO versions) (Table 6-1), with application of all the basic test grids, Delta test grids, and Convergence test grids. Only those with obvious effect are included in the report appendices, to show the improvement. Contact the authors for further information.

- Version v806 is the original scenario. It has both HYDRO and PTM from the standard package of DSM2 v8.0.6. It includes all the bugs described previously.

- Version h811 is the scenario with newly developed "Hydro 8.1.1." It provides the hydrodynamic environment for this PTM debug study, i.e. all the other debug tests utilize the same "hydro.exe," which makes it the baseline scenario for all the investigations (when the updates on grids, boundary, etc. of DSM2 version 8.1.1 are completed, the corresponding tests will also be included). Its changes from v806 could be up to 4% at Delta historical boundary outputs.
- Version pf is the scenario with newly developed "PTM particle filter" feature. It doesn't introduce any change for the normal running results (details in the report of Particle filter development). Thus it's been incorporated in all the versions after v806.
- Versions b1 through b4 are combinations of Hydro v8.1.1 (h811) with individual PTM bug fixes for the errors described above.

Table 6-1 Test version names and their explanation for convergence test

Test Version Name	HYDRO	PTM	Expected Results After Debug
v806	v806	v806	Original
h811	v811, with v806 grids and boundary inputs	v806	Baseline
pf		v806 + filter feature	No change
b1		v806 + bug1 fix	Earlier arrival
b2		v806 + bug2 fix	Slightly delay at beginning
b3		v806 + bug3 fix	Depend on HYDRO
b4		v806 + bug4 fix	Slightly delay
v811		v806 + all bugs fixes	Mixed effect

* Tests are not conducted for Bug 5, since it doesn't affect the simulation results.

Each debug's test has its fixed version on top of baseline version separately, in order to view its effect clearly. Since Bug 2 and 3 are related, additional tests are conducted for their combined effect.

- The fix of bug 1 improves the convergence among different time steps, with the biggest improvement on time step 5 min (For details in convergence test of chain channels, see attachment B_1). Other bug fixes do not show such obvious improvement.
- Tests in Delta historical grid show that the impact of debugging on simulation result is not significant, and consistent in the complex Delta grid system, especially with tidal effect. But differences could be up to 2-3% at boundary output locations.

Figure 6-2 illustrates the test result samples of the bug 1 fix, showing its difference from the version 806. Details are included in Appendices A, B1-3, C-3.

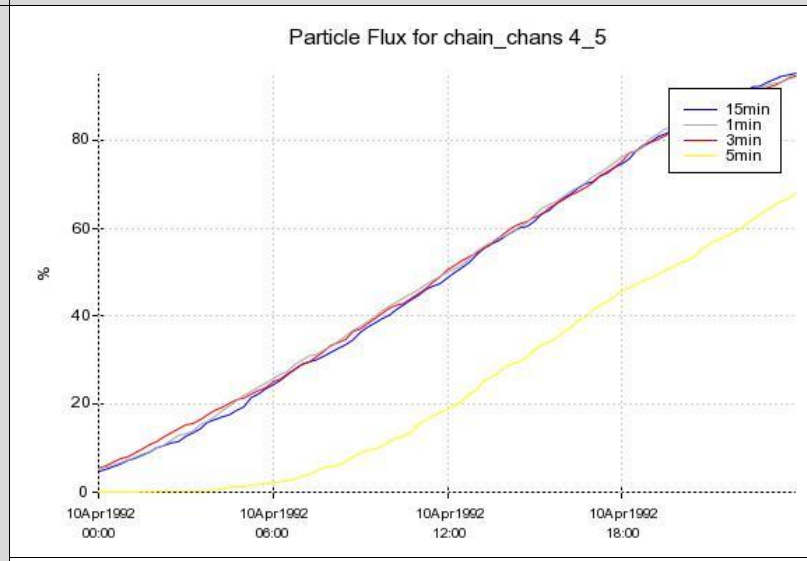
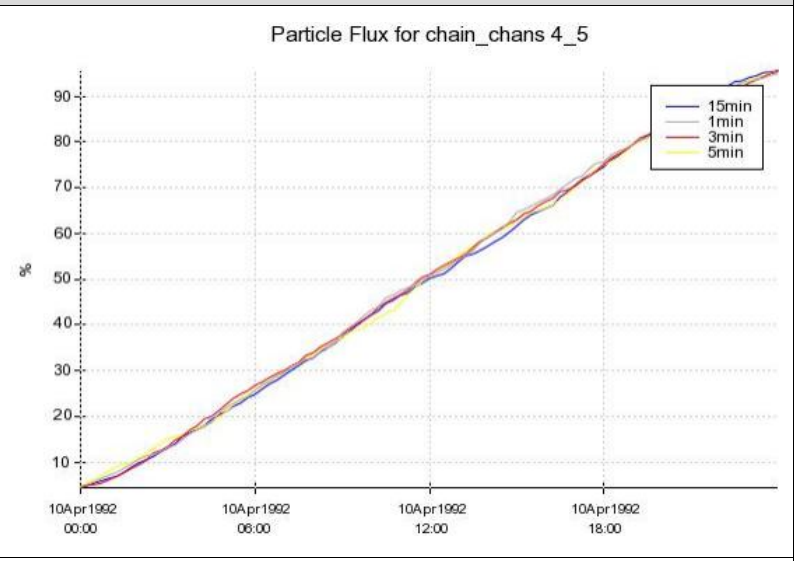
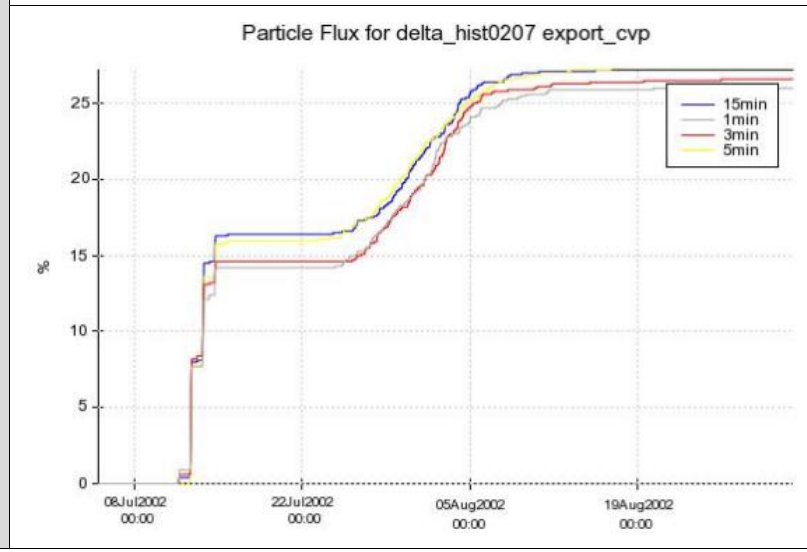
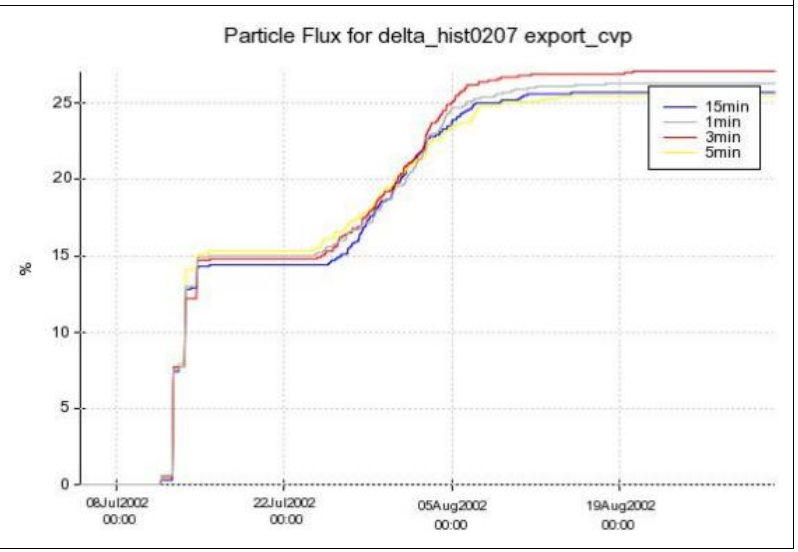
	Version 806	After bug 1 fix
Test on chain channels (Appendix B-1)		
Test on Delta historical (Appendix B-2)		

Figure 6-2 Extractions of convergence test result for bug 1 (missing advection) fix

6.5 Conclusions

This chapter lists the major debugging work for DSM2-PTM and corresponding tests and analyses. Improvement of the PTM is validated, with the fixes of missing advection and dispersion calculation, inconsistence of time interpolation, and lack of convergence among different PTM input time steps.

6.6 Acknowledgements

Xiaochun Wang and Tara Smith helped with the test scenarios and reviewing reports.

6.7 References

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6.8 Appendices

Note: All appendices are stored in DWR Bay-Delta Office DSM2 User Group website:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/

Use the following links to access each individual appendix:

Appendix A: Test Grids for DSM2-PTM v806 Debugging:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/A_testgrid.docx

Appendix B-1: Convergence Tests on Chain channels, steady flow:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B1_convg_chain.docx

Appendix B-2: Convergence Tests on Delta Dry Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B2_convg_delta0207.docx

Appendix B-3: Convergence Tests on Delta Wet Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B3_converg_delta9601.docx

Appendix C-1: Comparison Tests on Chain channels, steady uniform flow:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C1_cmp_chain.docx

Appendix C-2: Comparison Tests on Delta Dry Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C2_cmp_delta0207.docx

Appendix C-3: Comparison Tests on Delta Wet Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C3_cmp_delta9601.docx


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