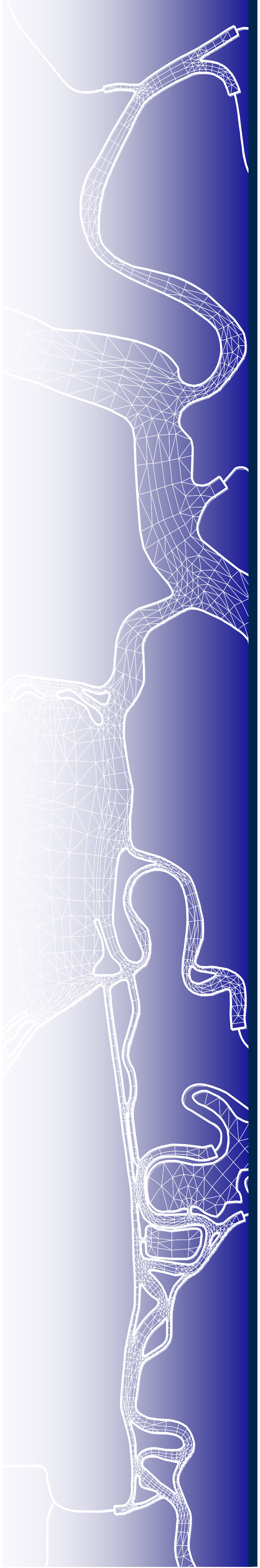
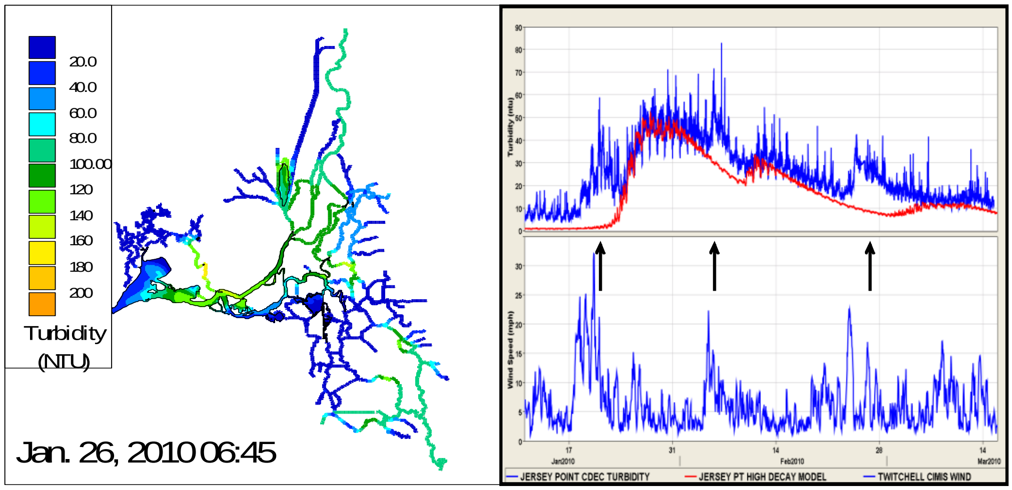


Turbidity and Adult Delta Smelt Modeling with the RMA Delta Models: Simulations for Water Years 2002, 2004, 2008 and 2009



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1. Executive Summary

As part of the 2-Gate project, Metropolitan Water District of Southern California (MWD) has funded the development and application of a transport model simulating the distribution of turbidity in the Delta and a particle tracking model simulating a habitat-seeking behavior for adult delta smelt (RMA 2008, 2009a, 2009b, 2010a, 2010b). The particle tracking model uses EC and turbidity gradients as well as hydrodynamics to drive delta smelt movement, simulating their hypothesized turbidity-seeking behavior and their potential to become "salvage" in the State Water Project (SWP) and Central Valley Project (CVP) export locations.

Although turbidity is an easily measured indication of water clarity and automated devices have been installed in many Delta locations in the last two years, turbidity transport cannot be modeled directly using numerical models. In comparison, suspended sediment concentration (SSC) is more difficult and expensive to measure and sampling is generally not automated, however there are governing equations for mass conservation and force balance for SSC[1]. Calculations from a numerical model of suspended sediment transport can be used to estimate turbidity by establishing empirical relationships between the suspended sediment measurements and turbidity measurements at a given location. Unfortunately, the data requirements for developing suspended sediment model boundary conditions and model parameters are numerous and these data are not yet available in the Delta. Until these data sets are developed by USGS researchers, transport models of turbidity distributions using a decay-coefficient approach are being used to estimate turbidity in the Delta. As discussed below and in recent documents (RMA 2010a, 2010b), in the interim, the RMA turbidity model has not only provided useful results directly, it has also highlighted particular areas in the Delta and processes conceptualized in a suspended sediment model that will provide the greatest additional information that a simple turbidity model cannot provide.

Based on the limited turbidity data available in Water Year (WY) 2007 for model calibration, the original turbidity transport model developed for the 2-Gate project used a single decay coefficient to estimate in-Delta turbidity. With the inclusion of numerous turbidity data collection sites starting in late 2009, the WY2007 calibration was modified in WY2010 to improve the representation of Delta turbidity. The recalibration of the turbidity model resulted in a three-parameter decay coefficient regime that better estimated turbidity in WY2010 than the single coefficient regime. The decay rates in the WY2010 calibration are about a factor of two higher than the WY2007 calibration rates throughout much of the Delta.

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1 http://www.deltacouncil.ca.gov/sites/default/files/documents/files/workshop_OCAP_2010_presentation_16_Wright_Shoellhamer.pdf

The WY2010 turbidity calibration was tested in hindcasts for WY2010 and WY2011 – these results are documented elsewhere (RMA 2101b, 2011). In the current document, simulation results developed using the WY2010 calibration are compared with simulation results using the earlier WY2007 turbidity calibration and with turbidity data available for WY2002, WY2004 and WY2008. A hindcast using the WY2010 turbidity calibration was also prepared for WY2009 and compared with available turbidity data. Adult delta smelt particle tracking model simulations run with turbidity results using the WY2010 turbidity model are compared with the salvage data available for all four WYs.

In WY2002 and WY2004, direct turbidity measurements were not available to use in developing model boundary conditions. Instead, an approximation for turbidity boundary conditions was prepared using suspended sediment concentration (SSC) data and a rough estimate of the relation between SSC and turbidity suggested by MWD staff (Dave Fullerton, pers. com.) of NTU=SSC*0.5, where NTU is the unit for turbidity measurement. In the central Delta in WY2002 and WY2004, turbidity model results using the WY2007 calibration are nearly a factor of two higher than the results using the WY2010 calibration.

Turbidity data was available at the Sacramento and San Joaquin R. model boundaries in WY2008 and WY2009. In WY2008, the turbidity model using the WY2007 calibration presents a better visual fit to the data at some locations while at others the simulation using the WY2010 calibration presents a better fit. In general for the WY2008 hindcast, the simulation run with the WY2007 calibration tended to overestimate the data at peaks, while the simulation run with the WY2010 calibration tended to underestimate the data in general. The WY2009 hindcast results using WY2010 calibration were lower than data before the turbidity pulse at many locations, although once the turbidity pulse arrived in late February the model generally overestimated the data. A hindcast simulation using the WY2007 calibration was not run in WY2009.

The delta smelt behavioral model was run for all four WYs with simulations using the WY2010 calibration as a test of the behavioral model parameterization. The parameters in the adult delta smelt behavioral model were originally calibrated using modeled turbidity distributions in WY2002 and WY2004 prepared using the WY2007 turbidity model calibration. Although the turbidity model boundary conditions for these years were set using SSC and the estimate NTU=SSC*0.5 due to a lack of turbidity data, these years were used in preference to later years as delta smelt salvage numbers were high and salvage data patterns were distinctive. The threshold for delta smelt behavioral response to turbidity, the critical behavioral parameter, was therefore set using a turbidity model set with a rough approximation of turbidity.

The particle counts reaching the SWP and CVP export locations in the adult delta smelt particle tracking model in WY2002 and WY2004 generally followed the trend of salvage data, with a single peak in WY2002 and a double peak in WY2004. The timing of the WY2002 particle peak was about two weeks late. The relative magnitudes of the SWP and CVP particle counts followed the actual salvage counts in both WYs, with SWP counts higher than CVP counts. Salvage numbers were low in WY2008 and extremely low in WY2009, and particle counts for the adult delta smelt particle tracking model followed these general trends. Overall, the parameterization of the adult delta smelt behavioral model did not exhibit a clear need for recalibration when applied to turbidity distributions developed with the WY2010 turbidity model calibration.

As mentioned in previous documentation (RMA 2010b, 2011), a turbidity model based on decay coefficients is not capable of capturing all processes in sediment transport, so some mismatch between the model and turbidity data is expected as turbidity measurements are used as a proxy for suspended sediment concentration. The modeling results presented herein and in previous documents (RMA 2008, 2009a, 2009b, 2010a, 2010b, 2011) illustrate the difficulties in several aspects of the turbidity/suspended sediment relationship: the relationship can vary by location, by the annual characteristics of upstream suspended sediment load, by the characteristics of the underlying sediment, and by meteorological effects (wind, rain and run-off). As a consequence, it can be expected that any turbidity model calibration will work in some years and in some locations better than in others. In the set of simulations discussed herein, it was shown that the WY2010 turbidity model calibration performed visibly better in WY2009 than in WY2008. With the superior boundary conditions available in WY2011 (RMA, 2011), the WY2010 turbidity calibration performed extremely well.

Overall, the move to a true suspended sediment model seems desirable, as some factors such as sediment re-suspension due to wind and changes in SSC boundary conditions due to variation in particle size are better handled with a physically-based numerical model. However, since delta smelt apparently respond to turbidity (water clarity) not suspended sediment concentration, quantifying the relationship between suspended sediment and turbidity at the model boundaries and at numerous in-Delta locations needs to be considered concurrently. In addition, a methodology for calculating Delta-wide turbidity distributions from SSC-modeled distributions will need to be developed.

2. Objectives

The model results summarized in this document satisfy two main objectives. One objective is to compare turbidity simulations prepared with the three-parameter decay coefficient regime, the WY2010 calibrated model, with simulations prepared with the WY2007 calibrated model for four WYs. The other objective is to run the adult delta smelt behavioral model for these WYs using turbidity results estimated with the WY2010 turbidity model, and compare particle counts at the south Delta export locations to salvage data for delta smelt.

To accomplish these objectives, turbidity hindcasts were developed for Water Years (WYs) 2002, 2004, 2008 and 2009 using the WY2010 calibration of the turbidity model. These modeled turbidity results are compared with the turbidity data available for those years and with the modeled results using the previous WY2007 calibration. Using the adult delta smelt behavioral model with the WY2010 turbidity model results, particle tracking simulations run for the four WYs and the resulting particle counts are compared to adult delta smelt salvage numbers at the SWP and CVP export locations.

3. Background

The work discussed in this document builds on previous work funded by MWD to develop methodologies to model and forecast turbidity (RMA 2008, 2009a, 2009b, 2010a, 2010b) and to simulate the movement of adult delta smelt during periods of high Delta inflow based on simulated distributions of salinity (represented as electrical conductivity, EC) and turbidity using a particle tracking behavior model (RMA 2008). Because turbidity is hypothesized to be an important driver for the distribution of adult delta smelt, the ability to minimize adult entrainment is assumed to be dependent on monitoring and potentially controlling and reducing the progress of turbidity plumes from the Sacramento and San Joaquin Rivers, and possibly from other boundary inflows, into the central Delta downstream of the export facilities.

Based on limited turbidity data, the original RMA turbidity model developed for the 2-Gate project used a single decay coefficient regime, called the WY2007 model or WY2007 calibration herein, and used a model grid that did not adequately represent the flow split between the Mokelumne River and Little Potato Slough. In addition, the behavioral parameters in the adult delta smelt model were calibrated using turbidity distributions calculated using WY2007 model. These turbidity simulations were based on less-than-ideal boundary conditions where turbidity was estimated from SSC measurements at the Sacramento and San Joaquin boundaries and the relationship NTU-SSC*0.5 suggested by MWD staff (Dave Fullerton, pers. com.).

With the inclusion of numerous WY2010 turbidity data collection sites and a refinement of the RMA grid in the vicinity of the Mokelumne River and Little Potato Slough, a recalibration of the WY2007 turbidity model resulted in a different decay coefficient regime, called the WY2010 model or WY2010 calibration herein.

In order to assess the changes to the turbidity distribution due to the WY2010 calibration and the inclusion of the improved grid, turbidity hindcast simulations were run. Simulations of the adult delta smelt behavioral model run with turbidity simulated with the WY2010 turbidity model, but behavioral parameters calibrated to the WY2007 model, were prepared and compared salvage data for the four WYs.

The results of these modeling exercises are discussed in this document.

3.1. Previous turbidity/suspended sediment models

Due to a lack of turbidity measurements, turbidity simulations for the winters of WY2000 through WY2004 used suspended sediment concentration (SSC) data for the Sacramento and San Joaquin Rivers for setting turbidity boundary values, with SSC values divided by two (SSC*0.5) (RMA 2008) as suggested by MWD staff (Dave Fullerton, pers. com.). In the earliest turbidity simulations, turbidity was simulated as a conservative constituent. In-Delta data for the models simulating the winters of WY2000 through WY2004 were not adequate to determine if this was a reasonable approximation.

By WY2008, turbidity data was available at several stations in the Delta including the Sacramento and San Joaquin River boundaries. There were eleven turbidity monitoring stations with available data for at least part of the December 2007 – March 2008 simulation period. Locations are shown in Figure 3-1.

In the initial WY2008 simulation with turbidity simulated as a conservative constituent, computed turbidity concentrations were found to be higher than observed at all monitoring stations. A complete sediment transport simulation was not feasible due to lack of data (*e.g.* particle size information on SSC in inflow) and limitations on time and budget. Therefore, a reconnaissance-level calibration of turbidity was performed using an exponential decay rate to approximate sediment settling and other losses. An exponential decay rate was applied rather than a constant settling rate because it more closely approximated a sediment transport simulation by allowing more rapid decline in turbidity when concentrations are high. Through iterative calibration simulations, the decay rate found to result in the best fit with observed data was -0.05/day. Measured turbidity data from CDEC and BDAT were used for the model calibration.

Hydrodynamics and turbidity were simulated using this single-parameter calibration with the RMA Delta Model for the period of December 1, 2007 through March 31, 2008 using turbidity data for boundary conditions. RMA2 and RMA11 boundary conditions for this period are shown in Table 3-1. This period was selected as turbidity measurements were more numerous and because delta smelt salvage spikes were seen at the south Delta export facilities. Increased turbidity resulting from the high flows in the Sacramento River and reverse flows in the south Delta were suspected to have contributed to the large delta smelt salvage numbers. Subsequently, WY2002, WY2004 and WY2008 were modeled with this single-parameter RMA turbidity model. This model will be referred to as the “WY2007” turbidity calibration, or, simply as the WY2007 model.

Hydrodynamics and turbidity were simulated and turbidity was re-calibrated (also a “reconnaissance” level calibration) using the RMA Delta Model for WY2010. Locations of turbidity data available at that time are shown in Figure 3-2. This model will be referred to as the

"WY2010" turbidity calibration, or simply as the WY2010 model. Other turbidity simulations using the WY2010 calibration are documented in (RMA 2010b, 2011).

3.2. Relationship between turbidity and suspended sediment measurements

The modeling in this project relies on a combination of suspended sediment concentration (SSC) and turbidity measurements and to some extent on understanding the relationship between the two. This material was covered in previous documentation (RMA 2010b), but is repeated here for completeness.

Suspended sediment concentration can be defined as the ratio of the mass of dry sediment in a water-sediment mixture to the mass of the mixture, and it is expressed in milligrams of dry sediment per liter of water-sediment mixture[2] (Gray *et al*. 2000). Turbidity is an expression of the optical properties of a liquid that cause light to be absorbed or scattered rather than transmitted through a sample[3]. Turbidity is caused by the presence of suspended and dissolved matter in the water column[1.] (*e.g.*, clay, slit, organic matter).

Suspended-sediment concentration is typically reported in units of mg L^{-1} while turbidity is typically reported in units of NTU, Nephelometric Turbidity Units. A third related measurement, total suspended solids (TSS), is not used in this project. The analytical methods for TSS and SSC differ, and the measurements are not comparable as sediment sizes vary, particularly when sand-size material composes a substantial fraction of the sediment sample (Gray *et al.* 2000). The SSC method produces reliable results, while the TSS method has been reported as unreliable for the analysis of natural-water samples (Gray *et al.* 2000).

Instruments have been developed that allow for nearly continuous monitoring and data logging of turbidity. Different instrument designs for turbidity measurement have different capabilities in terms of range of application and the ability to account for different properties of the turbid water, such as the color of the mixture. As a consequence, different instruments do not yield equivalent results in all situations[1]. SSC measurements are made from samples collected in the field and brought back to the laboratory for analysis, so real-time monitoring is not practical. When using standard sample collection and processing methods, SSC measurements are reported to produce reliable results (Gray *et al.* 2000).

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[2] https://encrypted.google.com/search?hl=en&defl=en&q=define:suspended+sediment+concentration&sa=X&ei=sFiJTOmkHo_msQOk-eG7BA&ved=0CA8QkAE

[3] http://water.usgs.gov/owq/FieldManual/Chapter6/6.7_contents.html, Chapter 6.7, Version 2.1 (dated 9/2005) , by Chauncey W. Anderson

USGS researchers have documented the relationships between the SSC and NTU at several locations in San Francisco Bay using two types of turbidity sensors recording data at 15-minute intervals (Buchanan and Lionberger 2006). SSC samples included all insoluble particles not passing through 0.45-micrometer membrane filter. Turbidity sensor data was deemed invalid if voltage outputs were unusually high and of short duration or if voltage outputs increase rapidly. Sensors were calibrated before and after cleaning using water-sample data - cleaning sensors resulted in a decrease in sensor output. Detection of the point where instrument fouling rendered data unusable was somewhat subjective.

Due to various factors such as instrument fouling and interference by local organisms (e.g., fish), linear statistical relationships between SSC and NTU developed using non-parametric regression could vary by more than a factor of two between locations. Simplifying their analysis considerably, the authors found SSC in mg L^{-1} could range from 0.9*NTU to 2.3*NTU (plus or minus a constant), depending on parameters such as depth of instrument (surface, mid-depth or bottom) and sensor type (Buchanan and Lionberger 2006). However, output of side-by-side sensors with different instrument designs were "virtually identical" (Buchanan and Lionberger 2006). Other researchers (Ganju *et al.* 2006) have found that turbidity and SSC are proportional throughout San Francisco Bay. As this study (Ganju *et al.* 2006) also used data collected at Rio Vista in arriving at this conclusion, it is reasonable to assume that turbidity and SSC are also proportional along the Sacramento River mainstem.

3.3. RMA Delta Model configuration

3.3.1. RMA numerical models

Documentation on the RMA suite of finite element hydrodynamic and water quality models employed for this study can be found in (RMA 2010b). Hydrodynamics are simulated using RMA2, a two-dimensional depth-averaged finite element model. Salinity and turbidity are simulated using RMA11. RMA11 has been designed for compatibility with model results obtained from one-, two-, or three-dimensional hydrodynamic simulations (King, 1995). Velocities and water depths obtained from hydrodynamic model results are used to solve the advection-dispersion equation for each water quality constituent simulated.

3.3.2. Grid and bathymetry

The RMA finite element grid of the Delta, shown in Figure 3-3, extends from Martinez to the confluence of the American and Sacramento Rivers and to Vernalis on the San Joaquin River. A two-dimensional depth-averaged approximation is used to represent the Suisun Bay region, the Sacramento-San Joaquin confluence area, Sherman Lake, Liberty Island, the Sacramento River up to Rio Vista, Big Break, the San Joaquin River up to its confluence with Middle River, False River, Franks Tract and surrounding channels, WY2007 River south of Franks Tract, and the

Delta Cross Channel area. Delta channels and tributary streams are represented using a one-dimensional cross-sectionally averaged approximation.

The RMA-Delta network used for the modeling covered in this document is the same as that used in preparing the WY2010 and Wy2011 forecasts (RMA 2010b, 2011). This network incorporates several updates to the Delta network used in the 2-Gates study (RMA 2008):

1) Liberty Island is represented with two-dimensional elements.
2) The eastside streams and sloughs were updated to more recent bathymetry and calibrated to flow monitoring data from a USGS 2005 field data collection program for the Mokelumne River system.
3) The channels of the north Delta were updated and calibrated with more recently available bathymetry and flow monitoring data.
4) The network detail and calibration for the Suisun Marsh region was improved.

These updates particularly improved the flow calibration for the Delta Cross Channel and other areas in the north Delta.

3.3.3. Stage and flow boundaries

Boundary conditions for hydrodynamics include tidal elevations at the Martinez boundary and tributary inflows to the system and exports (see Figure 3-3). Details on setting the hydrodynamic boundary conditions for the simulations are covered in Section 5.2 as different strategies were used depending on the WY.

Delta exports applied in the model include State Water Project (SWP), Central Valley Project (CVP), Contra Costa Water District diversions and exports at Rock Slough and at the WY2007 River and Victoria Canal intakes, respectively. Exports are also applied at the North Bay Aqueduct.

3.3.4. Gates and barriers

Permanent gates and temporary barriers represented in the model include the Delta Cross Channel (DCC), Old River near Tracy (DMC) barrier, Old River at Head barrier, Middle River barrier, Montezuma Slough salinity control gates, Grant Line Canal barrier, and Lawler buffer ditch culvert (see Figure 3-4). In addition, there is a tidal gate at Rock Slough. Inflow into Clifton Court Forebay (CCF) is controlled by a series of gates – in RMA2 this is modeled as a boundary outflow. Historical gate and barrier operations were applied following standard RMA protocol.

3.3.5. DICU flows

Delta Island Consumptive Use (DICU) flow values were applied on a monthly average basis and were derived from monthly DSM2 input values[4].

3.3.6. Salinity and turbidity

Salinity and turbidity concentrations are required at all inflow locations and at the stage boundary at Martinez. Electrical conductivity (EC) is used as a surrogate for salinity and modeled as a conservative constituent. Turbidity is conceptualized as a non-conservative constituent with decay. At DICU locations, the turbidity of the inflow is assumed to be the ambient concentration (i.e., the DICU inflow concentration is equal to the concentration in that cell during the computational step). EC concentrations at DICU locations are derived from DSM2 input values.

3.3.7. Turbidity model – regional decay values

A three-region model, shown in Figure 3-5, was used to model the turbidity regime with three decay parameters.

3.4. Meteorological data (CIMIS)

CIMIS meteorological data was used as an ancillary source of information to check the relationship between wind and rain events (i.e., storms) and increases in measured turbidity at some in-Delta locations.

[4] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/dicu.cfm

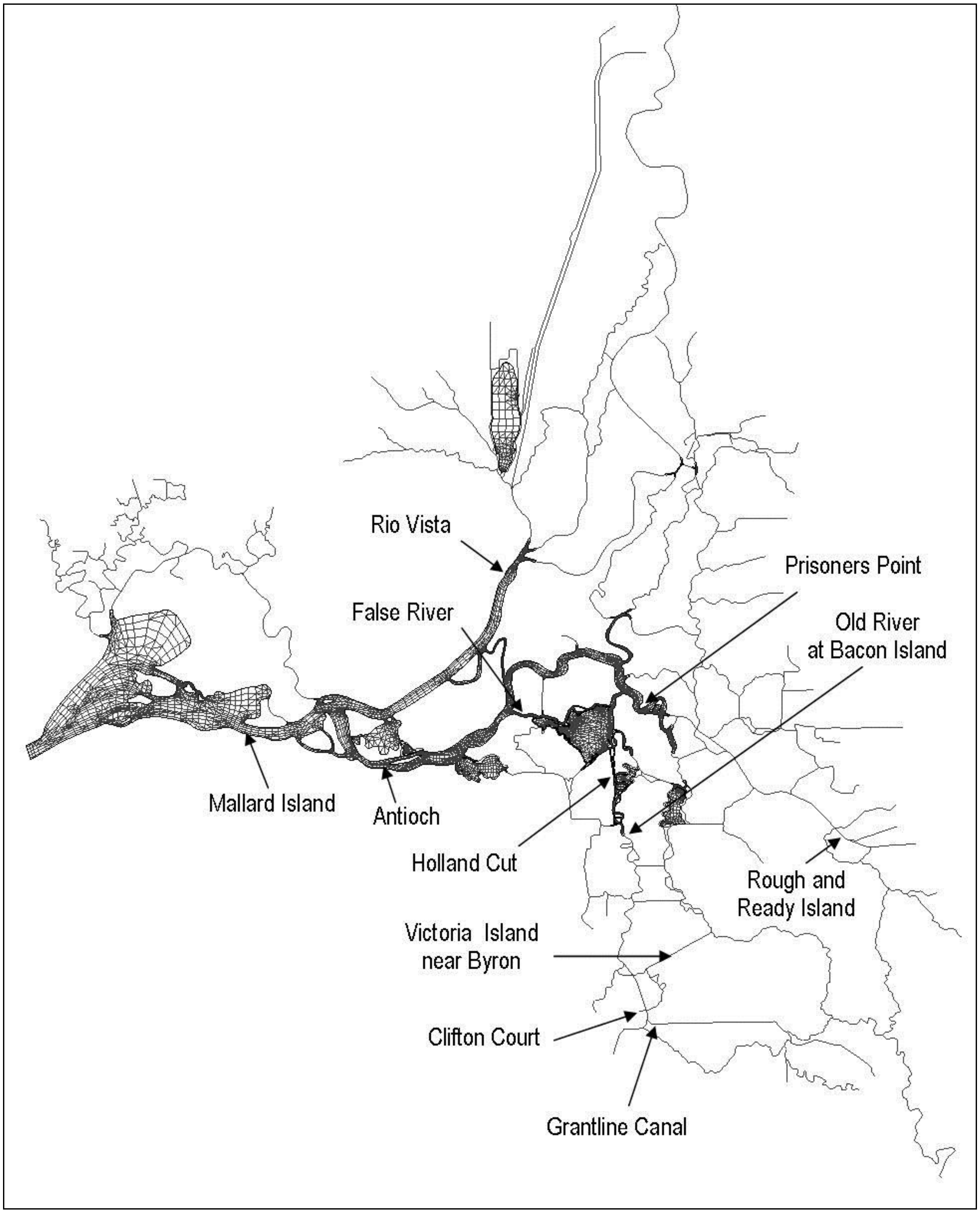

Figure 3-1 Locations of pre-12/2009 turbidity monitoring stations in a previous RMA grid.

Table 3-1 Inflows, outflows and turbidity data sources used to set model boundary conditions for 2007/8 calibration.

Model Input Locations	BC type	Data Source	Monitoring Location	BC type	Data Source	Monitoring Location
Martinez	Tidal elevation	NOAA	Martinez	Turbidity	CDEC	Martinez
Sacramento River	Inflow	USGS	Sacramento River at Freeport	Turbidity	CDEC	Sacramento River at Hood
San Joaquin River	Inflow	USGS	San Joaquin River at Vernalis	Turbidity	CDEC	San Joaquin River at Mossdale
Yolo Bypass	Inflow	CDEC	Yolo Bypass at Lisbon	Turbidity	CDEC	Sacramento River at Hood
Cosumnes River	Inflow	CDEC	Cosumnes River at Michigan Bar	Turbidity	CDEC	Sacramento River at Hood
Mokelumne River	Inflow	CDEC	Comanche Reservoir Outflow	Turbidity	CDEC	Sacramento River at Hood
Calaveras	Inflow	CDEC	Mormon Slough at Bellota	Turbidity	CDEC	No boundary condition applied - set at ambient
SWP	Outflow	BDAT	Clifton Court	--	--	--
CVP	Outflow	CDEC	Tracy Pumping Plant	--	--	--
CCWD Rock Slough Intake	Outflow	CCWD	near Brentwood	--	--	--
CCWD WY2007 River Intake	Outflow	CCWD	near Discovery Bay Flow diversion	--	--	--
North Bay Aqueduct	Outflow	CDEC	Barker Slough Pumping Plant	--	--	--

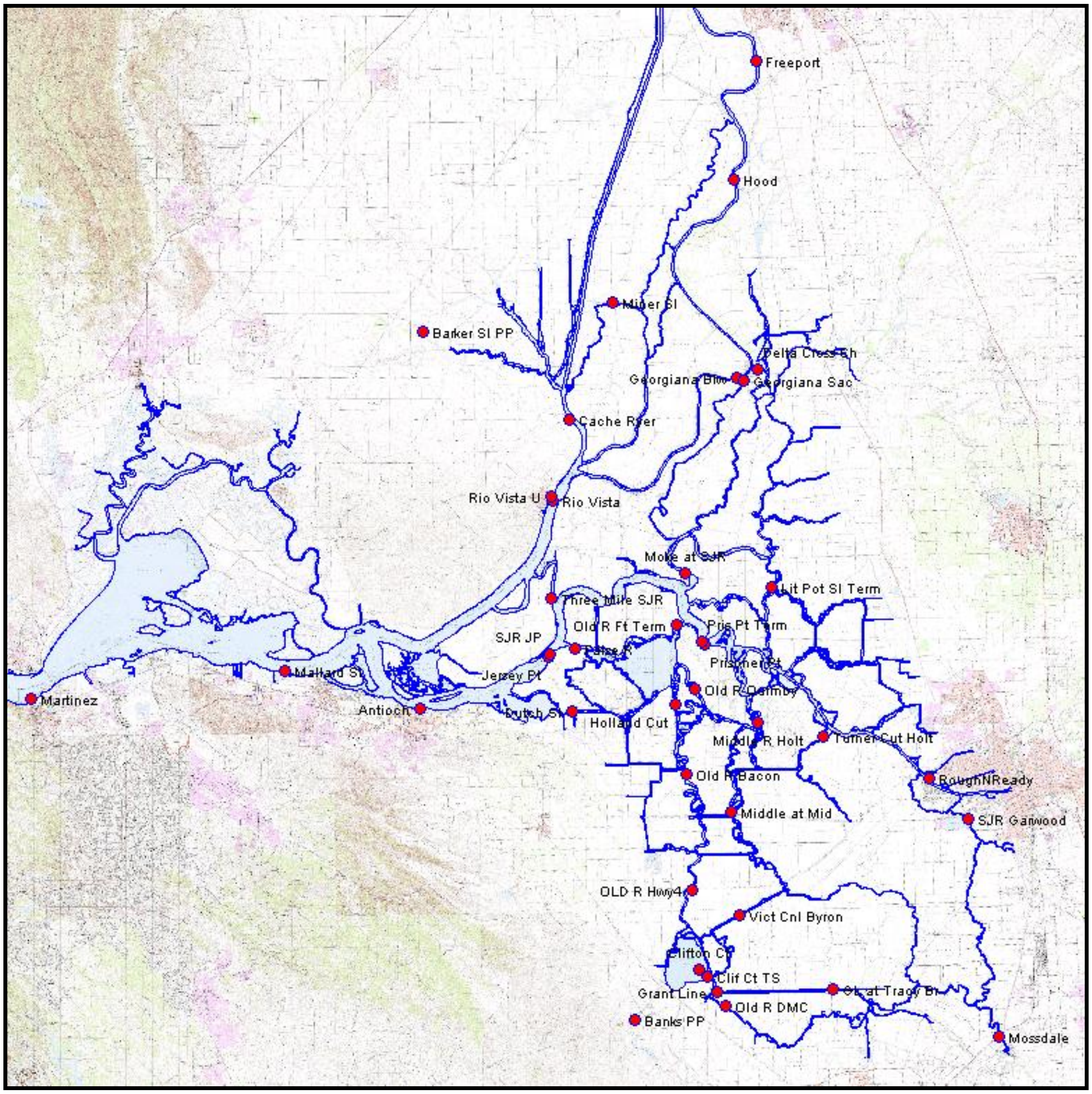

Figure 3-2 Locations of turbidity monitoring stations available by WY2010.

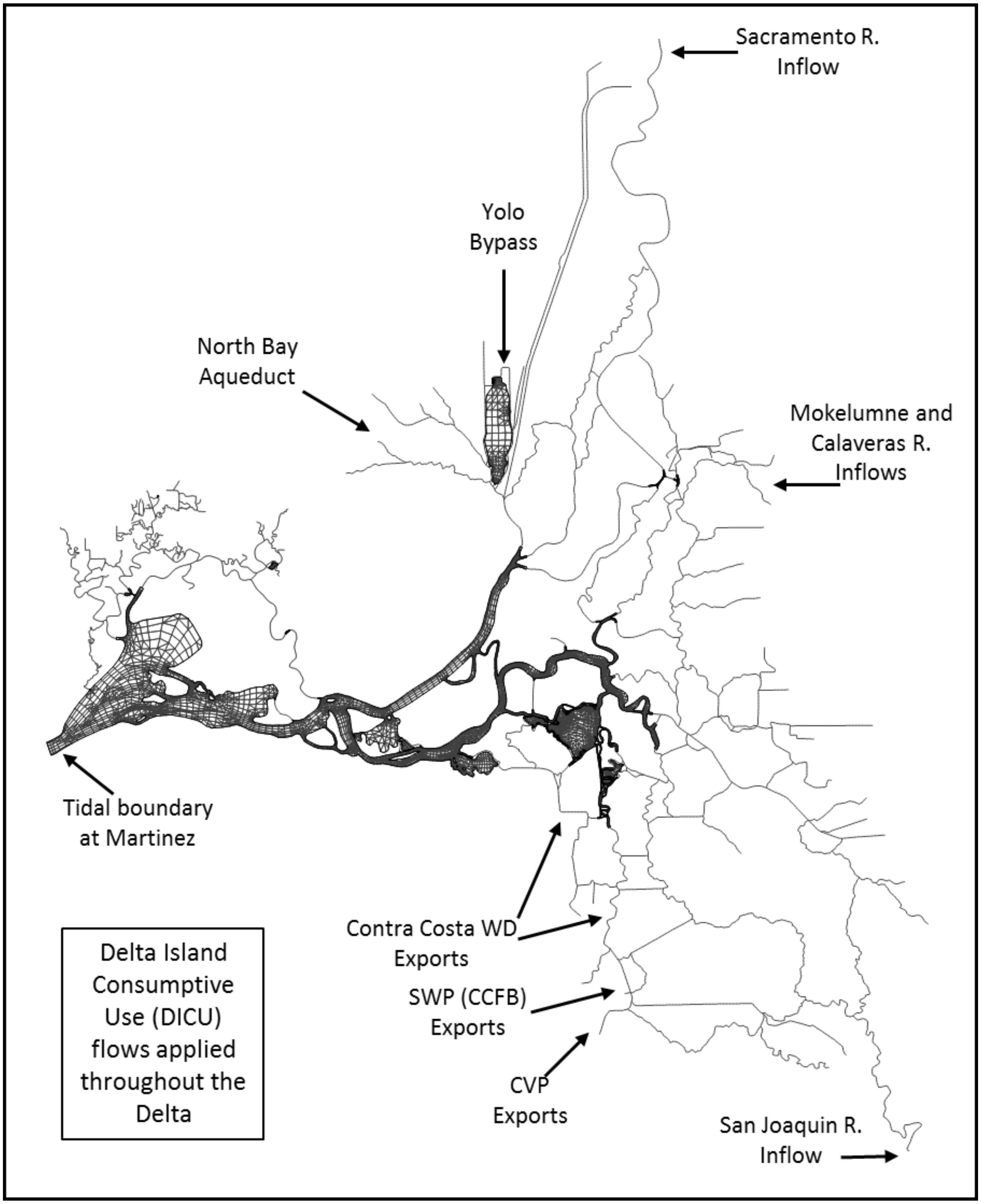

Figure 3-3 Finite element model configuration of the Sacramento – San Joaquin Delta.

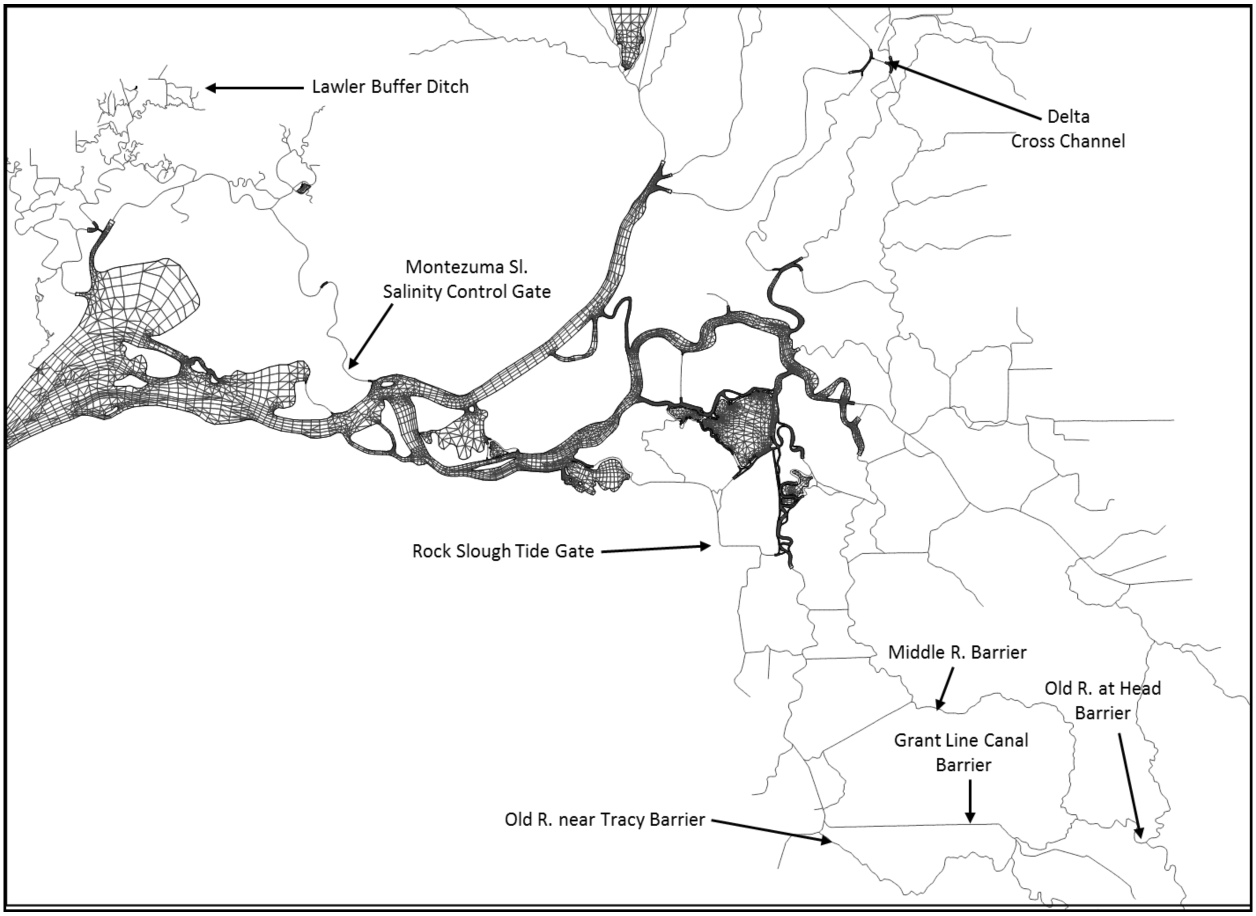

Figure 3-4 Approximate gate and barrier locations in the RMA grid.

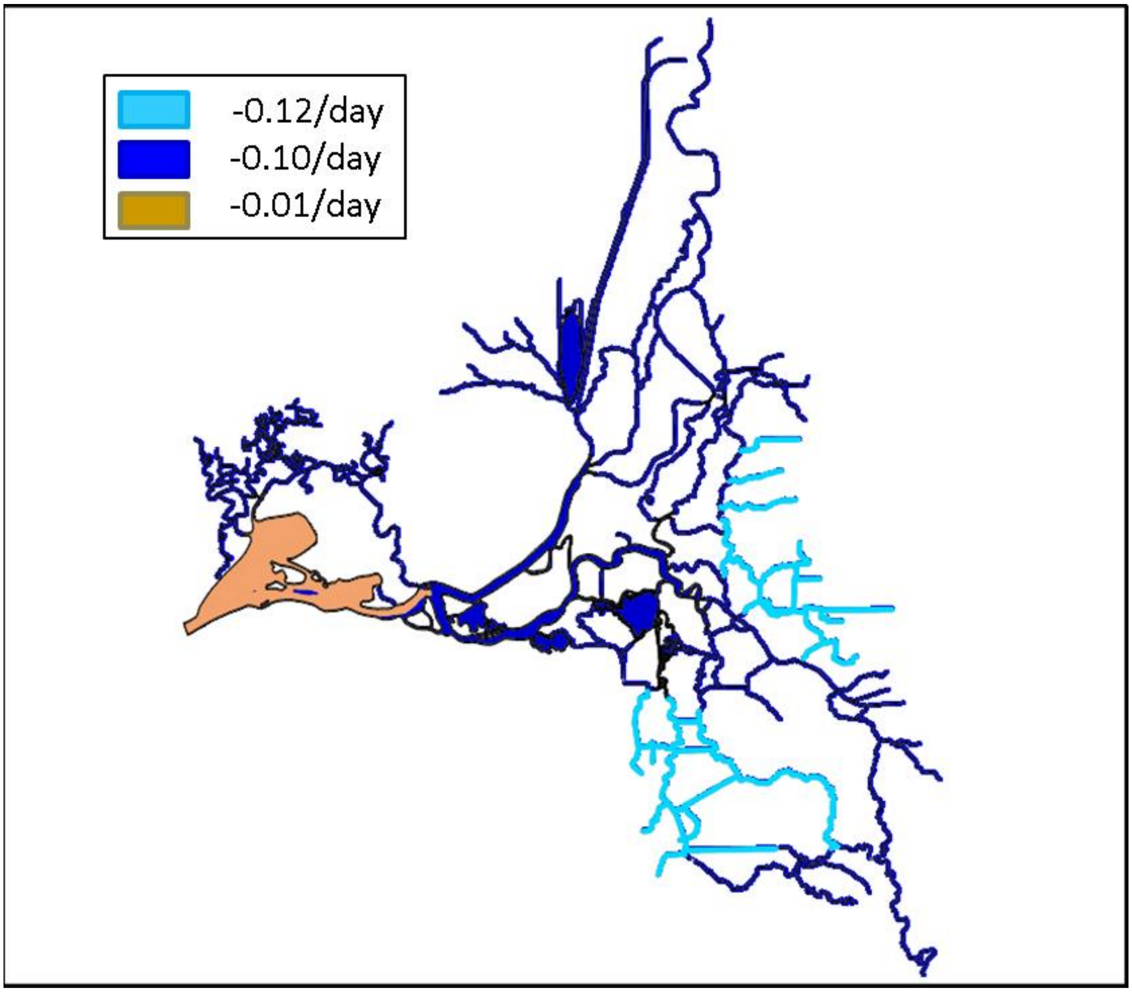

Figure 3-5 Decay values and regions used in the WY2010 turbidity model. The previous turbidity model had a single decay value of -0.5/day.

4. Adult delta smelt particle tracking models

The basic hypotheses behind the adult delta smelt behavior model are covered in previous documents (RMA 2009, RMA 2010b), but some information is repeated here for clarity. In addition, the information needed to interpret current model results is summarized in this section although it also appears in previous documents (RMA 2010b, 2011).

4.1. *Adult delta smelt behavior model - hypothesis*

The basic hypothesis of the behavior model is as follows: Adult Delta Smelt desire to move upstream from the Suisun Bay region during the late fall or early winter to spawn. The fish wait until the first storm events of the season increase the turbidity in the interior of the Delta. The fish prefer to avoid water with very low turbidity because of higher risk of predation and/or lack of food supply. The fish determine the desired direction of travel by sensing local gradients of salinity and turbidity. Initially, when they are in the Suisun Bay Region, the upstream direction is determined by a decreasing gradient for salinity. Once into the interior of the Delta where the salinity gradient is very small, the fish randomly explore the Delta channels to find suitable spawning habitat. If the turbidity is too low, the fish will move in the direction of increasing turbidity. If the turbidity gradient is too small however and it cannot be determined which direction leads to higher turbidity, the fish will hide.

Delta smelt are relatively small fish and not strong swimmers, so it is hypothesized that they will use a “surfing” mechanism to move with tidal flows though the Delta channels without expending a large amount of energy. In open channel flow, peak velocities are near the surface toward the middle of the channel, while near the bed or along shallow banks the velocity is very low. If a fish chooses to move with the tidal flow, it can easily move toward the surface where the velocity is highest. Conversely, if the fish chooses not to move with the tidal flow, then it can move toward the bottom where the velocity is very low. This allows the fish to ride the tidal flow in a preferred direction. For example, if the turbidity at the current location is too low and the fish desires to move toward more turbid water, it would tend to hold its position (move to the bottom) if the turbidity gradient along the direction of flow was such that the tidal flow was bringing higher turbidity water toward it. When the tide turned and flow directions reversed, the fish would move toward the surface to go with the tidal flow. Because tidal excursions in the Delta channels are quite large, often on the order of several kilometers, fish can move very quickly using this surfing mechanism.

Recent evidence suggests that delta smelt may use lateral movement across a channel in order to maintain their position or move upstream against the net current. The fish would move into the shallows where velocities are low during ebb tide, and move into the deeper main channel where velocity is higher on flood tide. While the current formulation of the adult delta smelt behavior model does not utilize lateral movement to perform tidal surfing, it would be possible to include this mechanism. This would enable the model to test the sensitivity of results to incorporation of the lateral movement hypothesis. Inclusion of lateral movement could have some impact on model results, as it could potentially bias movement toward side channels. For example, in the area near Rio Vista, particle movement upstream and downstream of this location could be influenced either to enter or miss Cache Slough or Threemile Slough, depending on lateral movement in the Sacramento River. However, it not expected that including this mechanism will have a major influence on longitudinal movement in general.

4.2. Adult delta smelt behavior model- behavior algorithm

The behavior algorithm utilizes the local concentration and gradient of electrical conductivity (EC, simulated as a surrogate for salinity) and turbidity computed by the RMA Delta Model to determine behavioral adjustments to the transport velocity for a neutrally buoyant passive particle moving with the streamline velocity. At each tracking step, the transport velocity is computed for a neutrally buoyant passive particle moving with the streamline velocity computed by the RMA Delta Model and subject to a random velocity component representing turbulent dispersion. The behavior model is then used to determine an adjustment to the transport velocity. The behavior algorithm utilizes the local concentration and gradient of electrical conductivity (EC, simulated as a surrogate for salinity) and turbidity computed by the RMA Delta Model to determine the adjustment to the transport velocity.

The behavior algorithm is implemented as follows:

- If the local EC is greater than the required maximum limit
    - Surf toward lower EC.
- Else if the local turbidity is lower than the required minimum limit
    - If the local turbidity gradient is greater than the minimum detectible gradient
        - Surf toward higher turbidity
    - Else if the local turbidity gradient is lower than the minimum detectible gradient
        - Hide
- Else if the local EC is lower than the desired minimum limit
    - Surf toward higher EC.
- If the local EC and local turbidity are within required limits
    - Randomly move (explore desirable habitat).

The surfing behavior is implemented by applying a scalar velocity factor to the transport velocity vector computed for neutrally buoyant particles. The velocity factors for moving with the tidal flow and resisting tidal flow are user defined constants. Random movement to explore desirable habitat is currently implemented as tidal surfing in a random direction. When a particle is at a location where the EC is below the required maximum limit and the turbidity is above the required minimum limit, a direction, either with or against the mean flow, is selected randomly within a user-defined time interval.

4.3. Adult delta smelt modeled period and particle count.

For the hindcasts, at the start of the simulation and before turbidity starts to increase due to a flow event, 50,000 particles were randomly distributed in the Suisun Bay Region. This insertion occurred November 01 in each model, except in WY2009 when particles are inserted in December 2008 – the WY2009 delta smelt model ran from December through the end of March 2009 as turbidity didn't increase until late February 2009.

4.4. Particle observation locations

Particle numbers were recorded periodically during the simulation at individual locations, such as at the state (SWP) and federal (CVP) export locations. Particle numbers can also be evaluated at pre-defined regions of the model grid (Figure 4-2 through Figure 4-4).

4.5. Delta smelt salvage data

Delta smelt salvage data was obtained from the Bureau of Reclamations Mid-Pacific Central Valley Office (CVO) region website and from the California Department of Fish and Game website. The CVO web location that hosts the previous monthly reports is:

http://www.usbr.gov/mp/cvo/fishrpt.html

Links to current fish salvage data, as well as other CVO operational data, can be found at:

http://www.usbr.gov/mp/cvo/

Daily historical records of salvage data can be found at:

http://www.dfg.ca.gov/delta/apps/salvage/SalvageExportCalendar.aspx

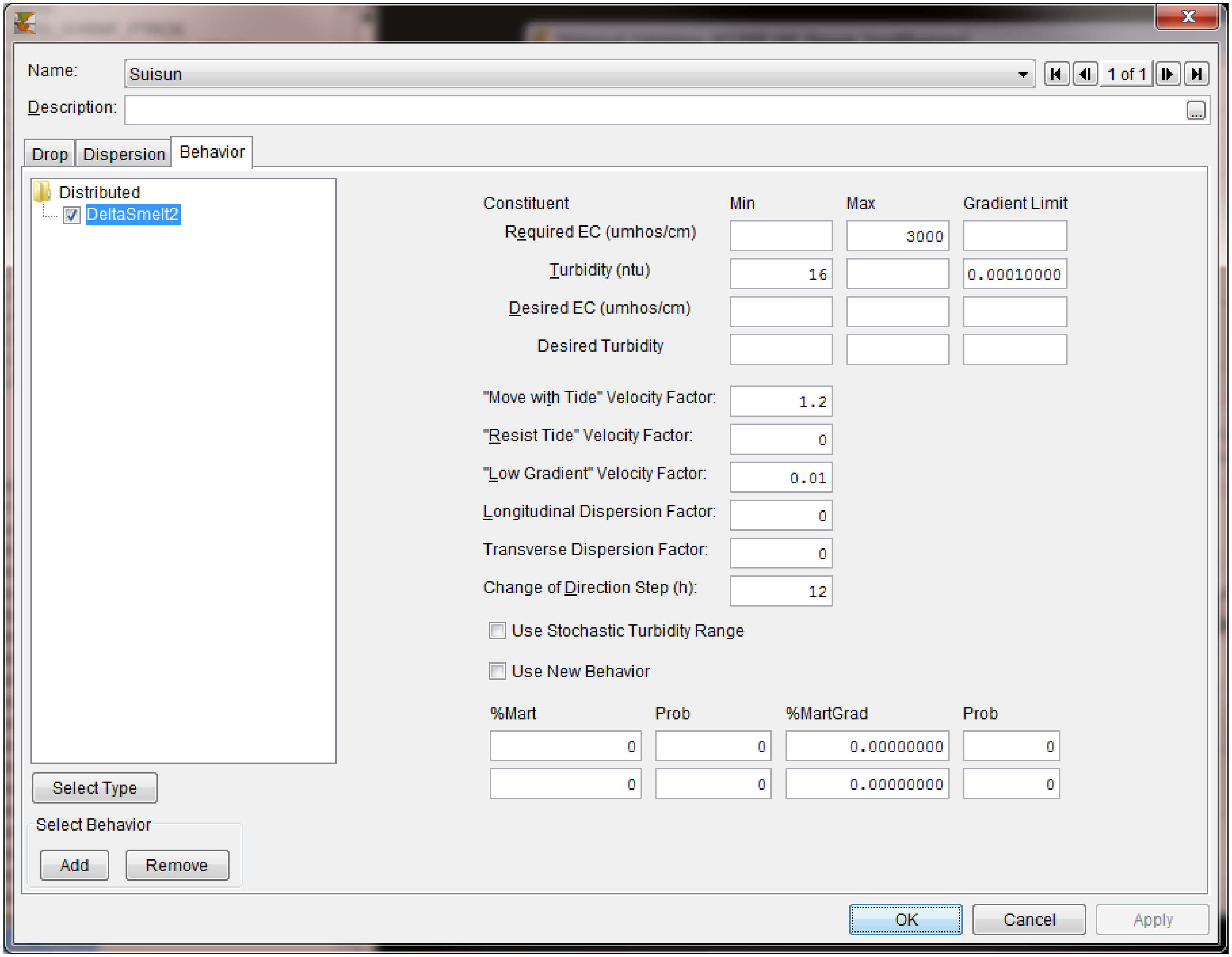

Figure 4-1 Parameter settings in the adult delta smelt particle tracking model.

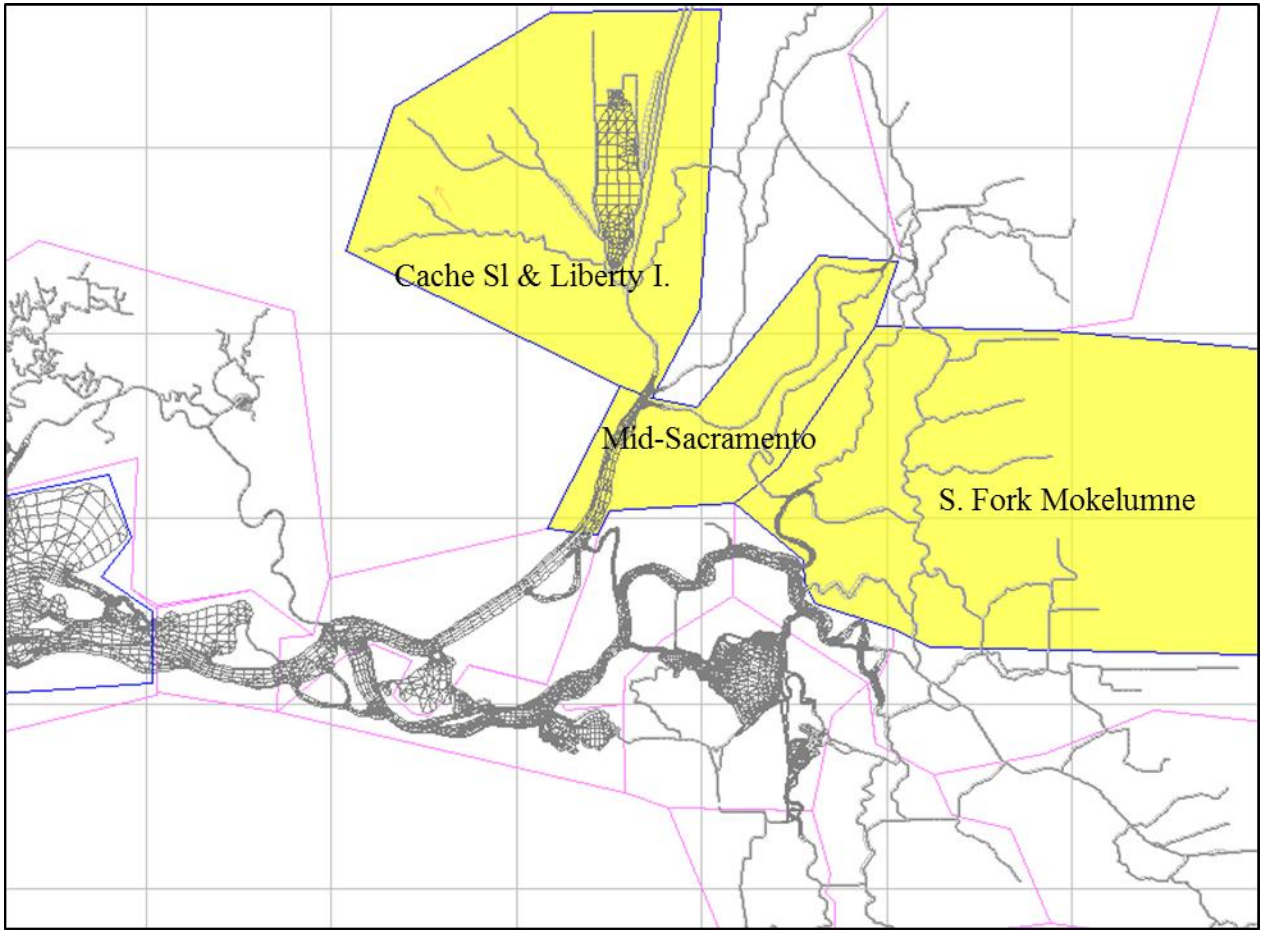

Figure 4-2 The fate of particles in the delta smelt PTM model is recorded in many regions including the three regions shown above in the north Delta.

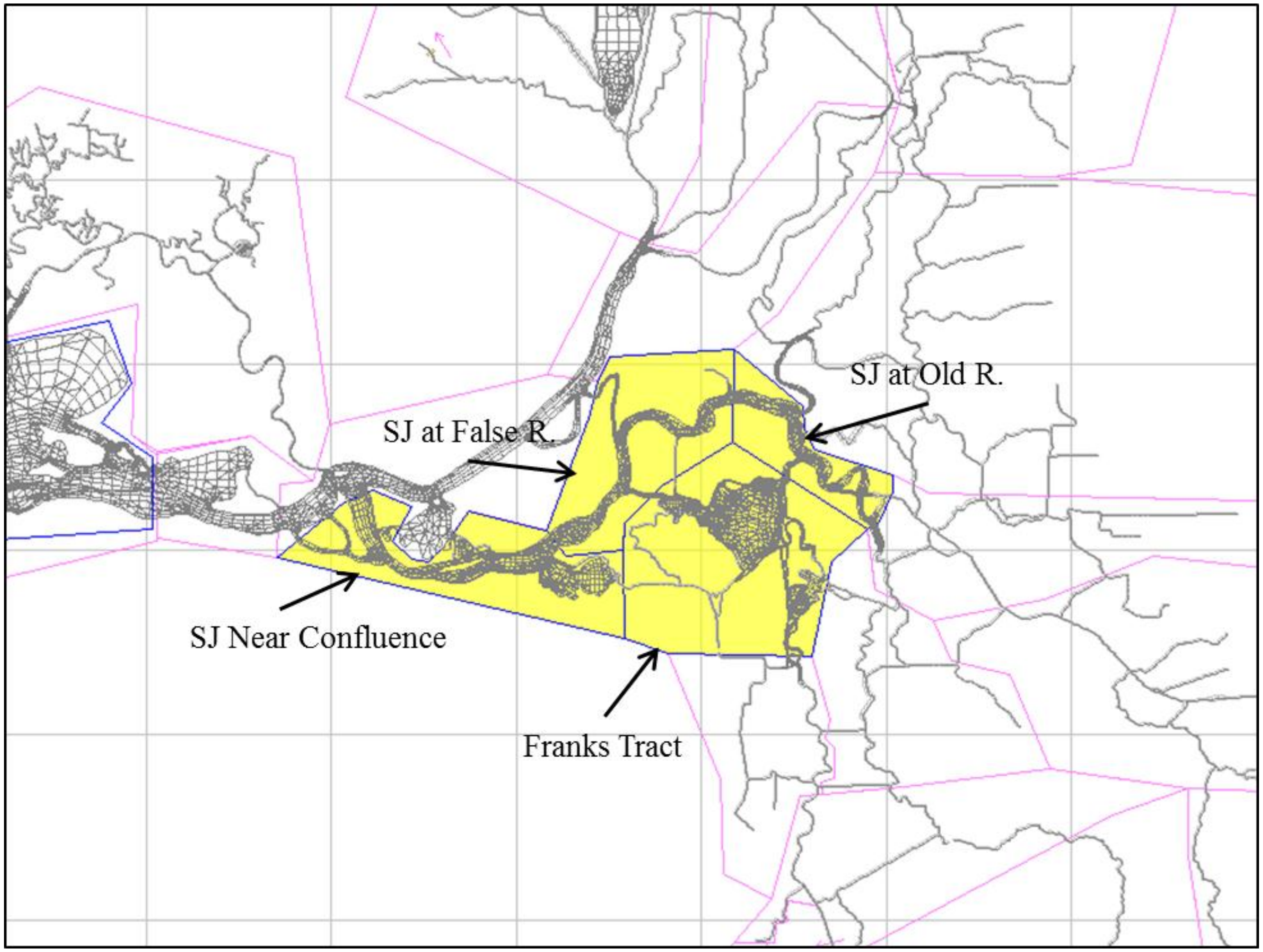

Figure 4-3 The fate of particles in the delta smelt PTM model is recorded in many regions including the four regions shown above in the central Delta.

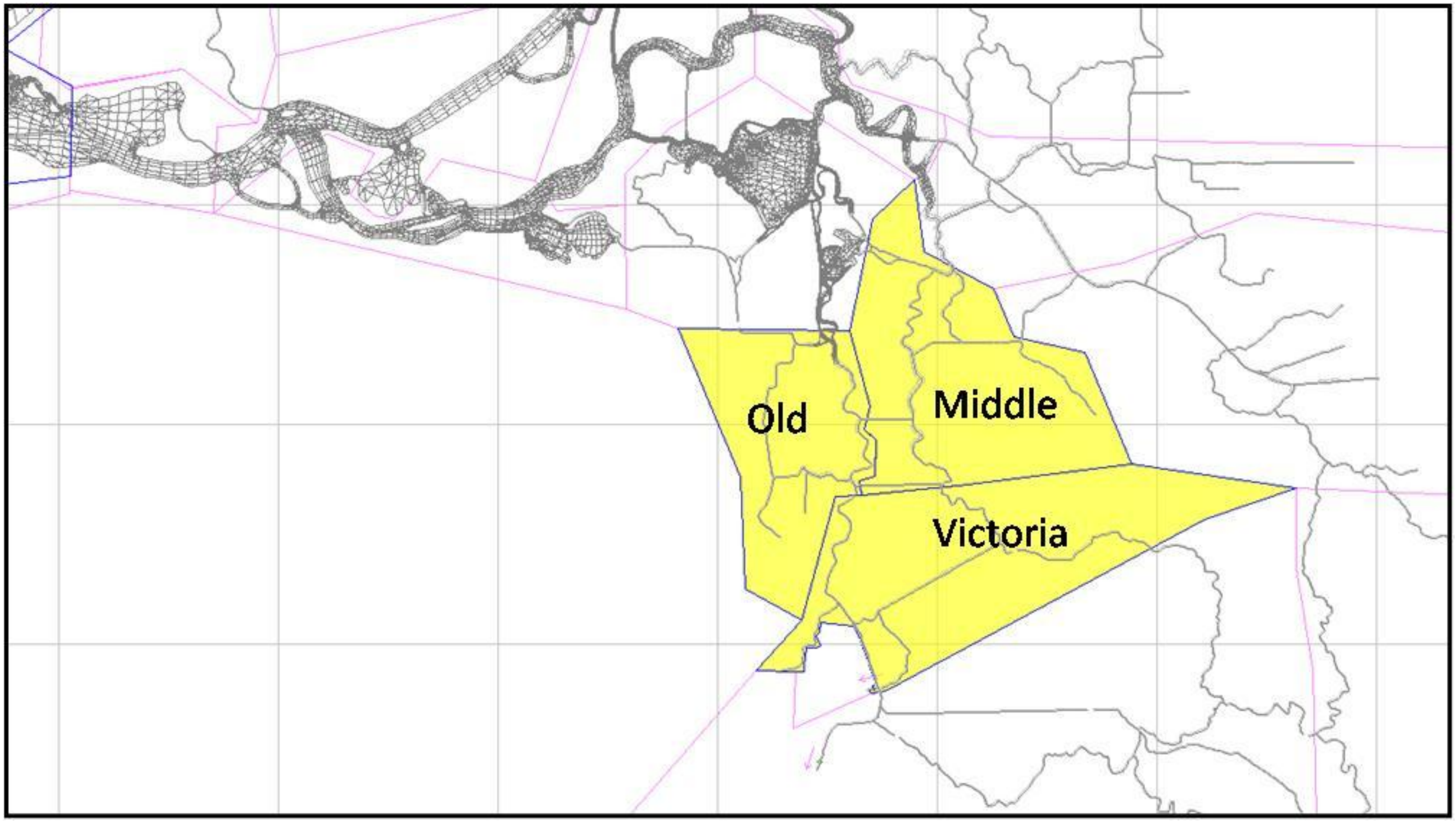

Figure 4-4 The fate of particles in the delta smelt PTM model is recorded in many regions including the three regions shown above in the south Delta. Particle fate is also recorded at the SWP and CVP export facilities – particles are removed from the simulation at these export locations.

5. Model Development

5.1. Background

Flow, salinity (EC) and turbidity simulations of the winter period (November – March) in WY2002, WY2004, WY2008 and WY2009 are documented in this report — all periods except WY2009 had been modeled previously using the one-parameter turbidity model (the WY2007 turbidity calibration). The RMA2 flow models and the RMA11 salinity (EC) models were prepared using standard RMA protocol for each of the four periods simulated. Each of the RMA2 and RMA11 models was run from November through the end of March. Three of the adult delta smelt particle tracking models ran for this period – the WY2009 delta smelt model ran from December through the end of March 2009 as turbidity didn't increase until late February 2009.

WY2002 and WY2004 were prepared with turbidity boundary conditions estimated by suspended sediment concentration available at the San Joaquin and Sacramento R. boundaries, while WY2008 and WY2009 boundary conditions used turbidity data available at the San Joaquin and Sacramento R. boundaries. Using the WY2010 three-parameter turbidity model, the WY2002 and WY2004 simulations were prepared with identical boundary conditions to the previous runs using the WY2007 calibration – only the model grid and the turbidity parameterization differed for the WY2010 calibration simulations for WY2002 and WY2004. Because these years were prepared using SSC instead of turbidity and were used to set adult delta smelt model parameters, using the original "turbidity/SSC" boundary conditions allowed for a direct comparison of delta smelt particle tracking results. Note that the Calaveras River turbidity boundary was set at 0.0 NTU originally – subsequent modeling (RMA 2010b, 2011) results showed that the Calaveras boundary could impact central Delta turbidity during high flow periods on the river.

The Cosumnes, Mokelumne, Calaveras and Yolo boundaries for the WY2008 and WY2009 simulations were prepared using a methodology developed forecasting turbidity boundary conditions in WY2010 (RMA 2010b). Although the WY2008 period was modeled previously, the set-up for the turbidity boundary conditions on the Cosumnes, Mokelumne, Calaveras and Yolo boundaries differs from the original simulation using the WY2007 one-parameter turbidity model. This allowed a comparison of the new methodology – calibration and boundary condition methodology – with the original WY2007 methods at a time when there were several in-Delta turbidity monitoring stations for comparison.

The parameters in the adult delta smelt model were originally calibrated using the WY2007 turbidity calibration. This model was not recalibrated for use with the WY2010 3-parameter turbidity model, so the modeling in this document also serves as a test of the parameterization in the adult delta smelt model.

5.2. Boundary conditions

Boundary conditions for flow, stage, salinity (EC) and turbidity are summarized in Table 5-1 for WY2002 and WY2004 and in Table 5-2 for WY2008 and WY2009.

5.2.1. Flow and stage boundaries

Flow and stage boundary conditions were developed using a combination of CDEC data and Dayflow[5] data. The stage boundary at Martinez was developed using CDEC data shifted by 0.3 feet. The stage shift is implemented to produce a better salinity approximation.

Figure 5-1 through Figure 5-6 illustrate a comparison of inflow boundary values for the four modeled periods. Figure 5-7 is a comparison of State plus Federal (SWP+CVP) export levels for the four modeled periods.

5.2.1. DICU (flow, EC, turbidity)

Delta Island Consumptive Use (DICU) values for flow were applied on a monthly average basis and were derived from monthly DSM2 input values[6]. At DICU locations, the turbidity of the inflow is assumed to be the ambient concentration (i.e., the DICU inflow concentration is equal to the concentration in that cell during the computational step). EC concentration at DICU locations was derived from DSM2 input values.

5.2.2. Gate and barrier operations

The timing and implementation of structures for historical gate and barrier operations were developed from raw text data at:

http://www.iep.water.ca.gov/dsm2pwt/Bay-Delta_barriers_activ.txt

Clifton Court Forebay inflows were developed using standard RMA protocol either from DSM2 HYDRO model 15-minute flow output or using CDEC data. Permanent gates and temporary barriers represented in the model include the Delta Cross Channel (DCC), WY2007 River near Tracy (DMC) barrier, WY2007 River at Head barrier, Middle River barrier, Montezuma Slough salinity control gates, Grant Line Canal barrier, and Lawler buffer ditch culvert (see Figure 3-4). In addition, there is a tidal gate at Rock Slough.

5.2.3. Turbidity boundaries

Figure 5-8 through Figure 5-13 illustrate a comparison of turbidity boundary values for the four modeled periods.

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[5] http://www.water.ca.gov/dayflow/

[6] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/dicu.cfm

Turbidity boundary conditions for the Sacramento R. boundary at Freeport and the San Joaquin R. boundary at Vernalis were developed using SSC data for WY2002 and WY2004. The SSC data was multiplied by a factor 0.5 to estimate turbidity values (*i.e.*, NTU = SSC*0.5) For WY2008 and WY2009, turbidity data was available at Freeport for the Sacramento R. boundary and at Vernalis and Mossdale for the San Joaquin R. boundary.

Following simulation conditions established in previously developed WY2002 and WY2004 models, the Sacramento turbidity boundary was used at the Cosumnes, Mokelumne and Yolo Bypass boundaries – the Calaveras boundary was set at zero NTU. The results from the two sets of models using different calibration parameters can thus be compared directly. In WY2008 and WY2009 (see Table 5-2), the methodology developed to forecast turbidity in WY2010 was used to set turbidity boundaries on the Cosumnes, Mokelumne, Calaveras and Yolo boundaries (RMA 2010b).

5.2.4. EC boundaries

EC boundary conditions were developed using data from publically-available data sources, such as CDEC, USGS and DWR Water Data library. Martinez salinity boundary is calculated from data as the average of top and bottom salinity (EC) at Martinez.

5.3. Development of initial conditions for RMA models

Initial conditions for RMA11 water quality models are developed using RMA utility functions and our standard methodology for 'warm starts'. A' warm start' produces an initial condition for a water quality parameter based on data values obtained for the simulation start date at multiple Delta locations, and then using a diffusion solution to populate the entire grid with concentrations using the data to seed the calculation. EC and turbidity data are selected from raw data the start date at all available EC and turbidity locations. When turbidity data was not available, the model was initialized to 10 NTU. The initial condition for the RMA2 flow models was developed by running the model for a five day period prior to the start of the modeled period, generally November 01 in each modeled period. This initial hydrodynamic run was then used with the initial condition for each water quality parameter from the diffusion solution and appropriate time series data to produce an initial condition on the start date for each simulation.

RMA models produce restart files at the end of the calculation for each month. When multiple months are simulated, subsequent months are run with the initial conditions read in from these restart files.

The particle tracking simulations for WY2002, WY2004 and WY2008 each began on November 01 with the insertion of 50,000 particles, while the WY2009 simulation and particle insertion began on December 01, 2008 as turbidity did not increase in the Delta until late February, 2009.

5.4. Comparison of flow and turbidity/suspended sediment boundary conditions

Figure 5-1through Figure 5-6 illustrate a flow comparison for each of the four simulation periods at the RMA2 model inflow boundaries.

High flows on the Sacramento and San Joaquin Rivers generally dictate turbidity increases in the Delta, although the other boundaries may also influence turbidity depending on the level of flow and turbidity. High flow (~ 60,000 cfs) occurred in late December through early January on the Sacramento River in WY2002 and WY2004, with WY2002 having a concurrent high flow (~ 6,000 cfs) on the San Joaquin River while WY2004 San Joaquin flows remained low. WY 2002 had a second high flow event in late February on both the Sacramento (~70,000 cfs) and San Joaquin (~4,000 cfs) Rivers, and also in the Yolo Bypass (~ 100,000 cfs).

Sacramento River flows were more moderate in WY2008 (~ 40,000 cfs max) and WY2009 (~ 45,000 cfs max). The highest Sacramento River flows in WY2008 occurred in late January through early February – the timing of the high flow (~ 4,500 cfs max) on the San Joaquin River was similar. In WY2009, flow remained low on the San Joaquin River throughout the simulation period.

Figure 5-8 through Figure 5-13 illustrate a comparison of the turbidity boundary values for each of the four simulation periods at the RMA11 model boundaries. At the Sacramento River boundary (Figure 5-8), it is notable that the measured turbidity values used in WY2008 and WY2009 are nearly double the estimated turbidity (SSC*0.5) values used in WY2002 and WY2004 despite lower flows in the latter periods (Figure 5-1). The situation is similar on the San Joaquin River boundary (Figure 5-9), where higher flows (Figure 5-2) in WY2002 and WY2004 were generally accompanied by lower estimated turbidity (SSC*0.5) than measured turbidity by about a factor of two.

Table 5-1 Sources of flow/stage, salinity and turbidity boundary conditions for WY2002 and WY2004.

	Flow/Stage	Salinity	Turbidity
Freeport/Sacramento R.	Dayflow-Freeport	RSAC142-CDEC	Freeport SSC*0.5
Vernalis/San Joaquin R.	Dayflow-Vernalis	RSAN087-CDEC	Vernalis SSC*0.5
Yolo Bypass	Estimated from CDEC/USGS Lisbon and Yolo Bypass data	RSAC142-CDEC	Freeport SSC*0.5
Mokelumne R.	Dayflow-Mokelumne	Constant = 120 uS/cm	Freeport SSC*0.5
Cosumnes R.	Dayflow-Cosumnes	Constant = 120 uS/cm	Freeport SSC*0.5
Calaveras R.	Max of Dayflow Misc and RCAL009/CDEC	Constant = 500 uS/cm	Constant = 0.0 NTU
Martinez	CDEC data for MRZ stage + 0.3 ft.	Average of top and bottom CDEC data at MRZ	Estimated from USGS SSC data at MRZ and MAL

Table 5-2 Sources of flow/stage, salinity and turbidity boundary conditions for WY2008 and WY2009.

	Flow/Stage	Salinity	Turbidity
Freeport/Sacramento R.	Dayflow-Freeport	Hood-CDEC	Freeport-CDEC
Vernalis/San Joaquin R.	Dayflow-Vernalis	Mossdale-CDEC	Vernalis+Mossdale-CDEC
Yolo Bypass	Estimated from CDEC/USGS Lisbon and Yolo Bypass data	Hood-CDEC	Synthesized via flow transformation: NTU=20+(CFS)/50
Mokelumne R.	Dayflow-Mokelumne	Constant = 60 uS/cm	Synthesized via flow transformation: NTU=10+(CFS)/10
Cosumnes R.	Dayflow-Cosumnes	Constant = 60 uS/cm	Synthesized via flow transformation: NTU=(CFS)/10
Calaveras R.	Max of Dayflow Misc and RCAL009/CDEC	Constant = 500 uS/cm	Synthesized via flow transformation: NTU=20+(CFS)/15
Martinez	CDEC data for MRZ stage + 0.3 ft.	Average of top and bottom CDEC data at MRZ	Estimated from USGS SSC data at MRZ and MAL

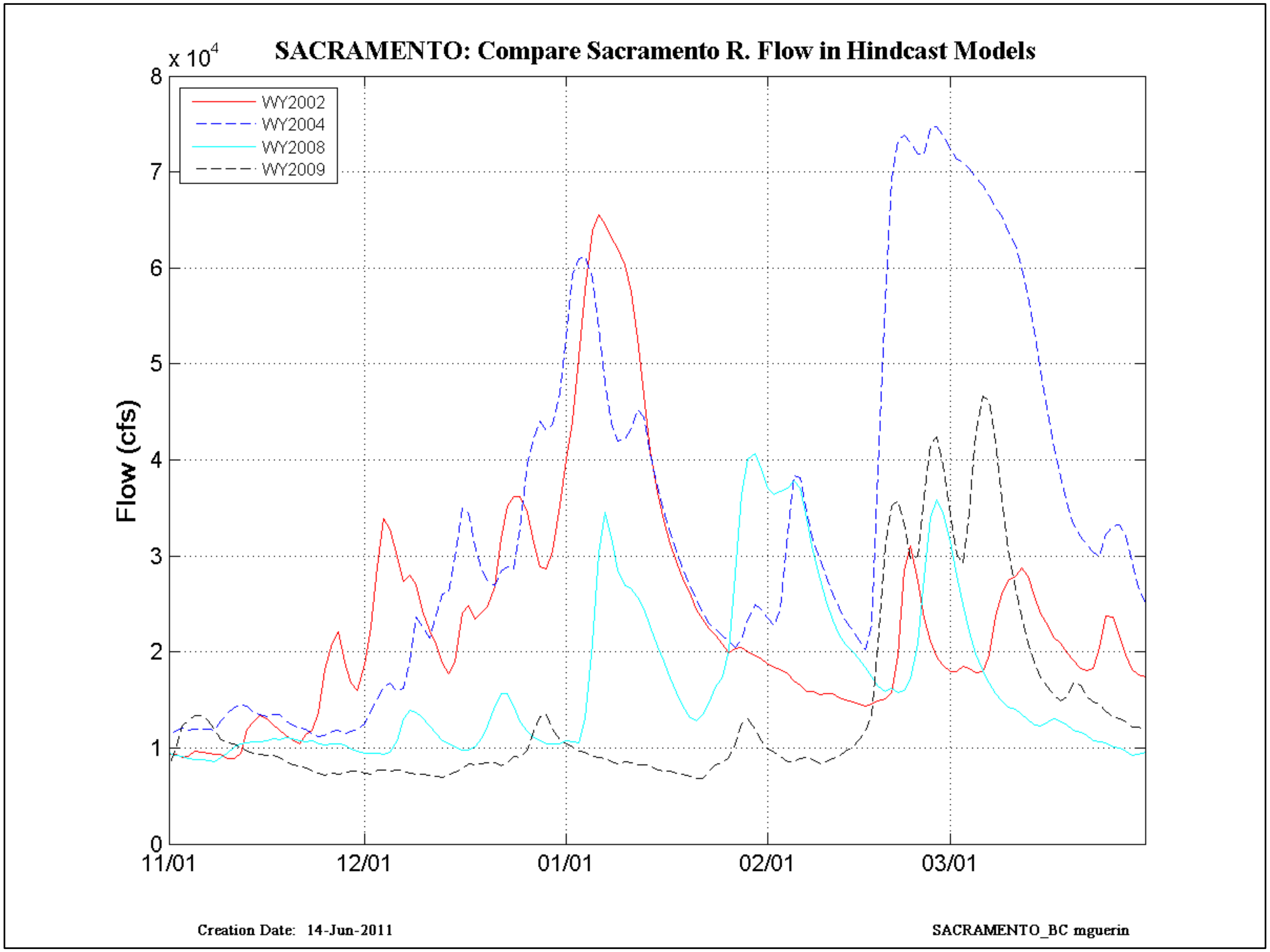

Figure 5-1 Comparison of Sacramento River flows for WY2002, WY2004, WY2008 and WY2009 simulation periods.

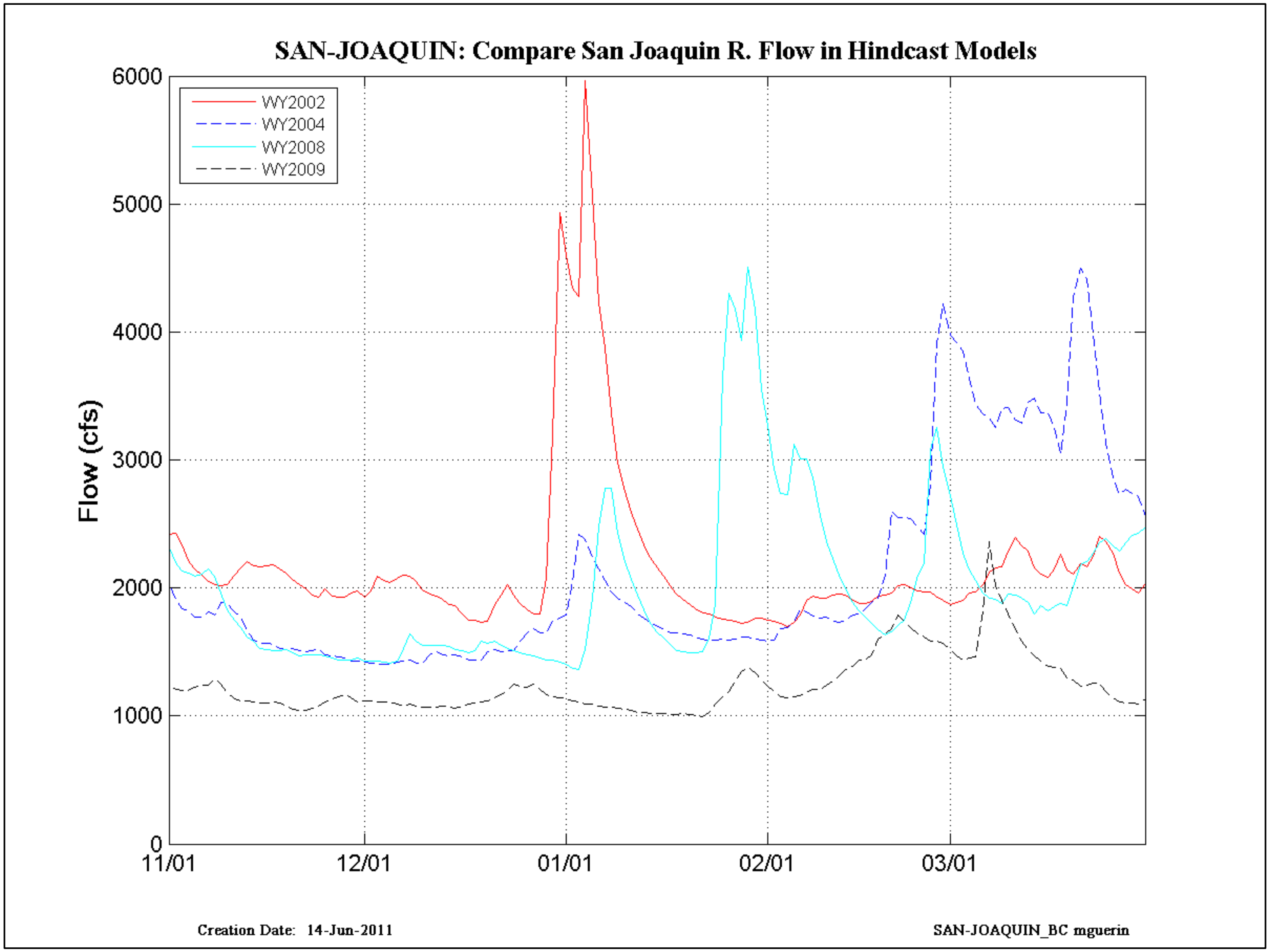

Figure 5-2 Comparison of San Joaquin River flows for WY2002, WY2004, WY2008 and WY2009 simulation periods.

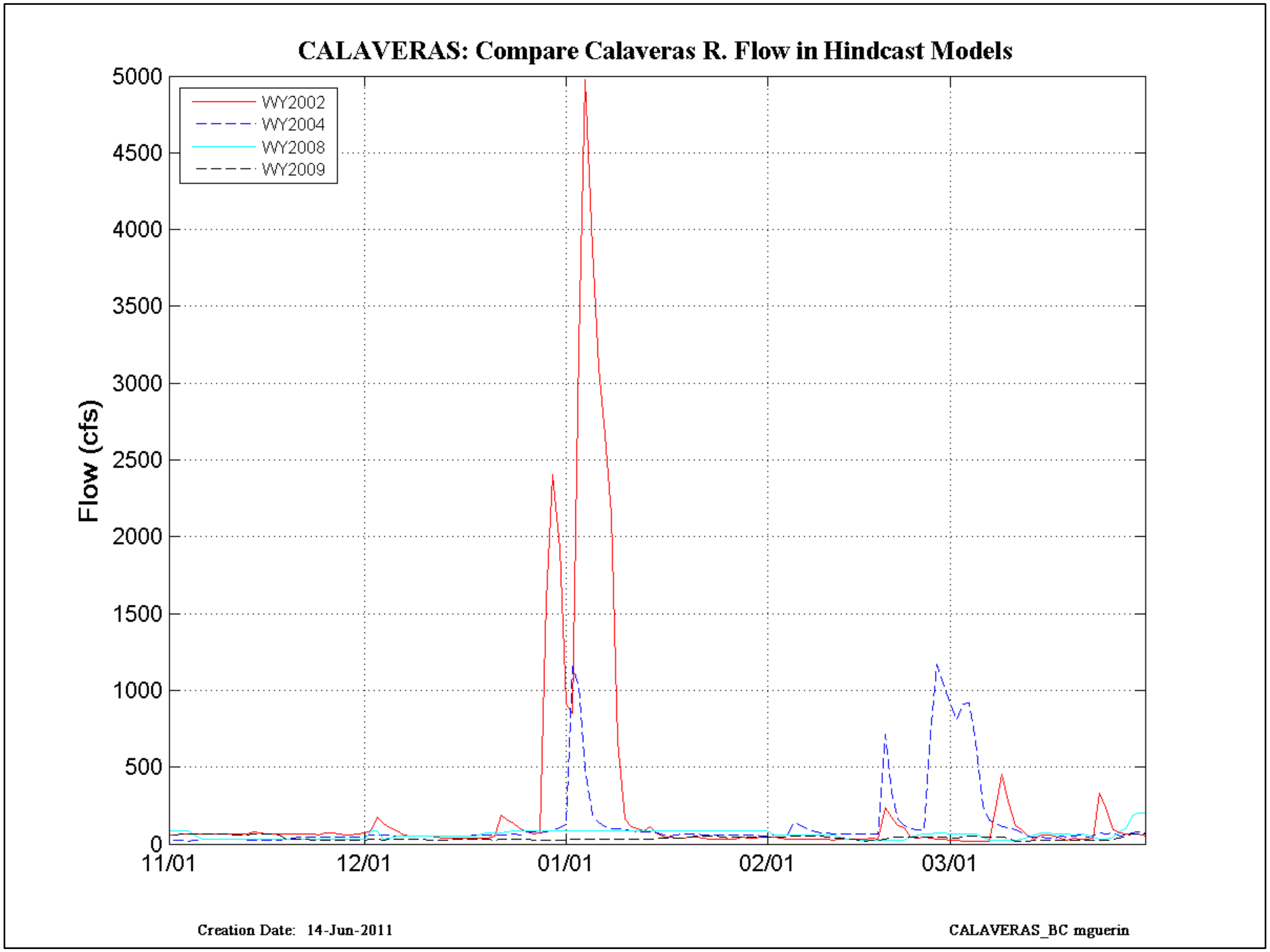

Figure 5-3 Comparison of Calaveras River flows for WY2002, WY2004, WY2008 and WY2009 simulation periods.

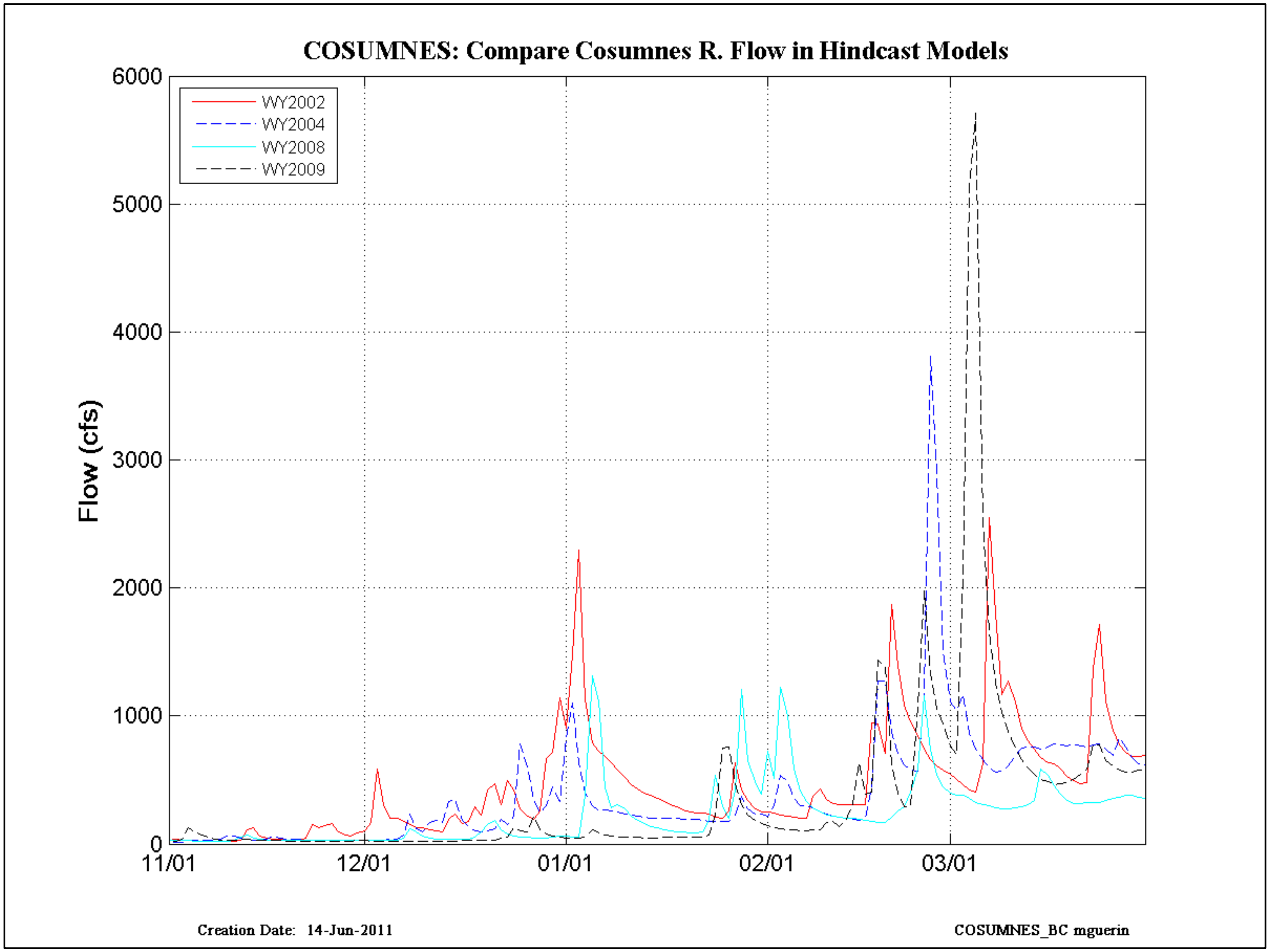

Figure 5-4 Comparison of Cosumnes River flows for WY2002, WY2004, WY2008 and WY2009 simulation periods.

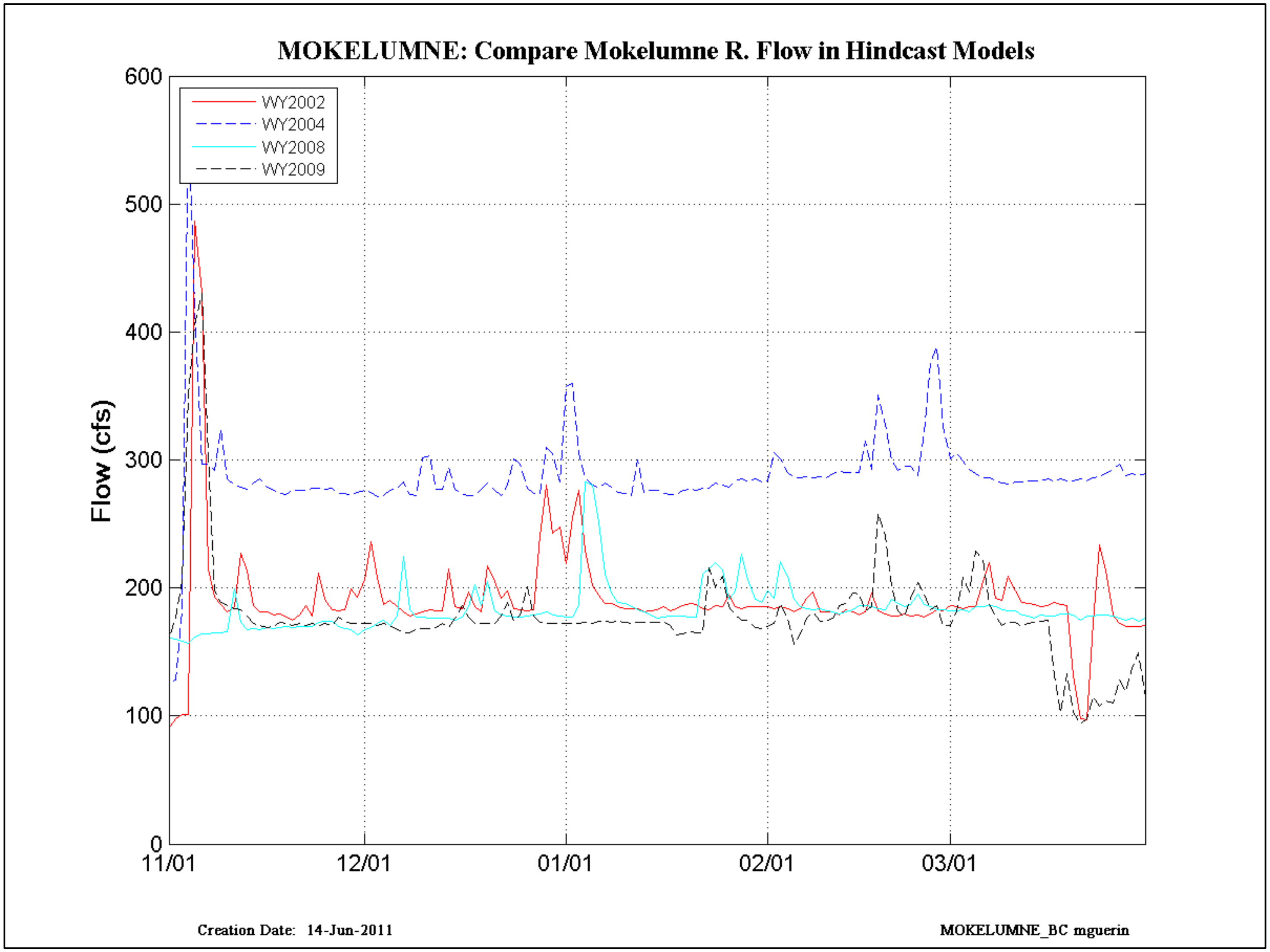

Figure 5-5 Comparison of Mokelumne River flows for WY2002, WY2004, WY2008 and WY2009 simulation periods

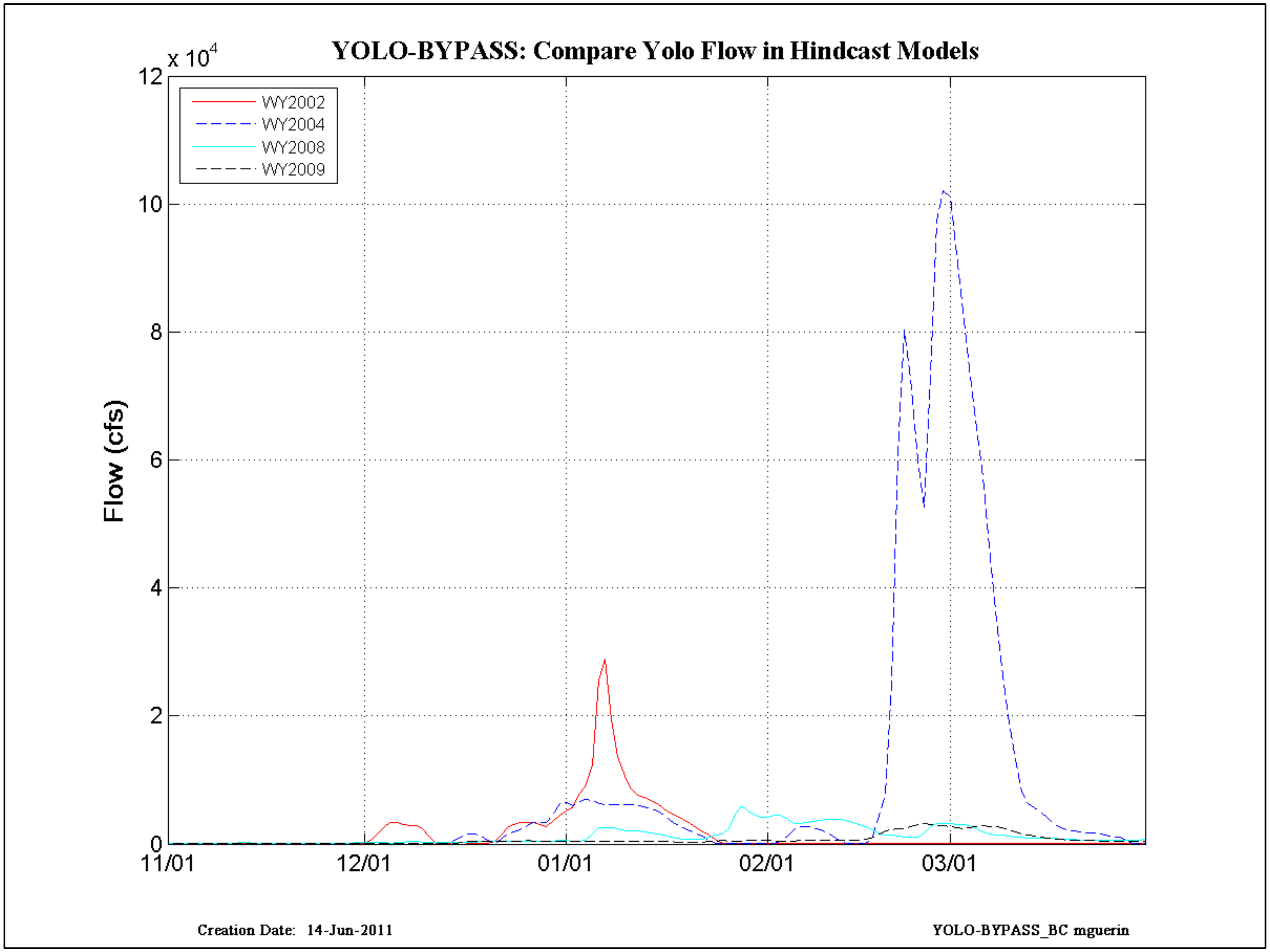

Figure 5-6 Comparison of Yolo Bypass flows for WY2002, WY2004, WY2008 and WY2009 simulation periods.

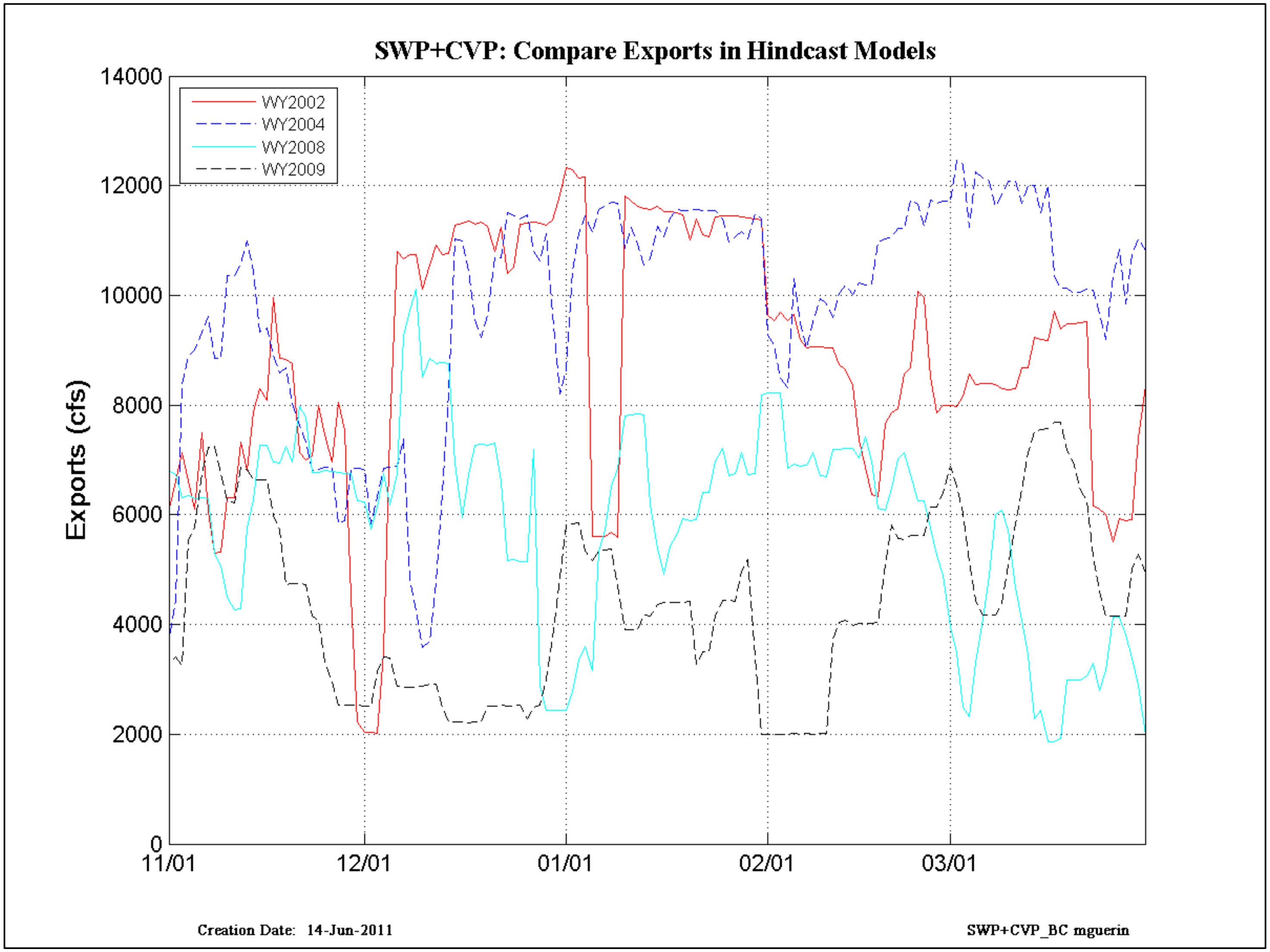

Figure 5-7 Comparison of SWP+CVP export levels for WY2002, WY2004, WY2008 and WY2009 simulation periods.

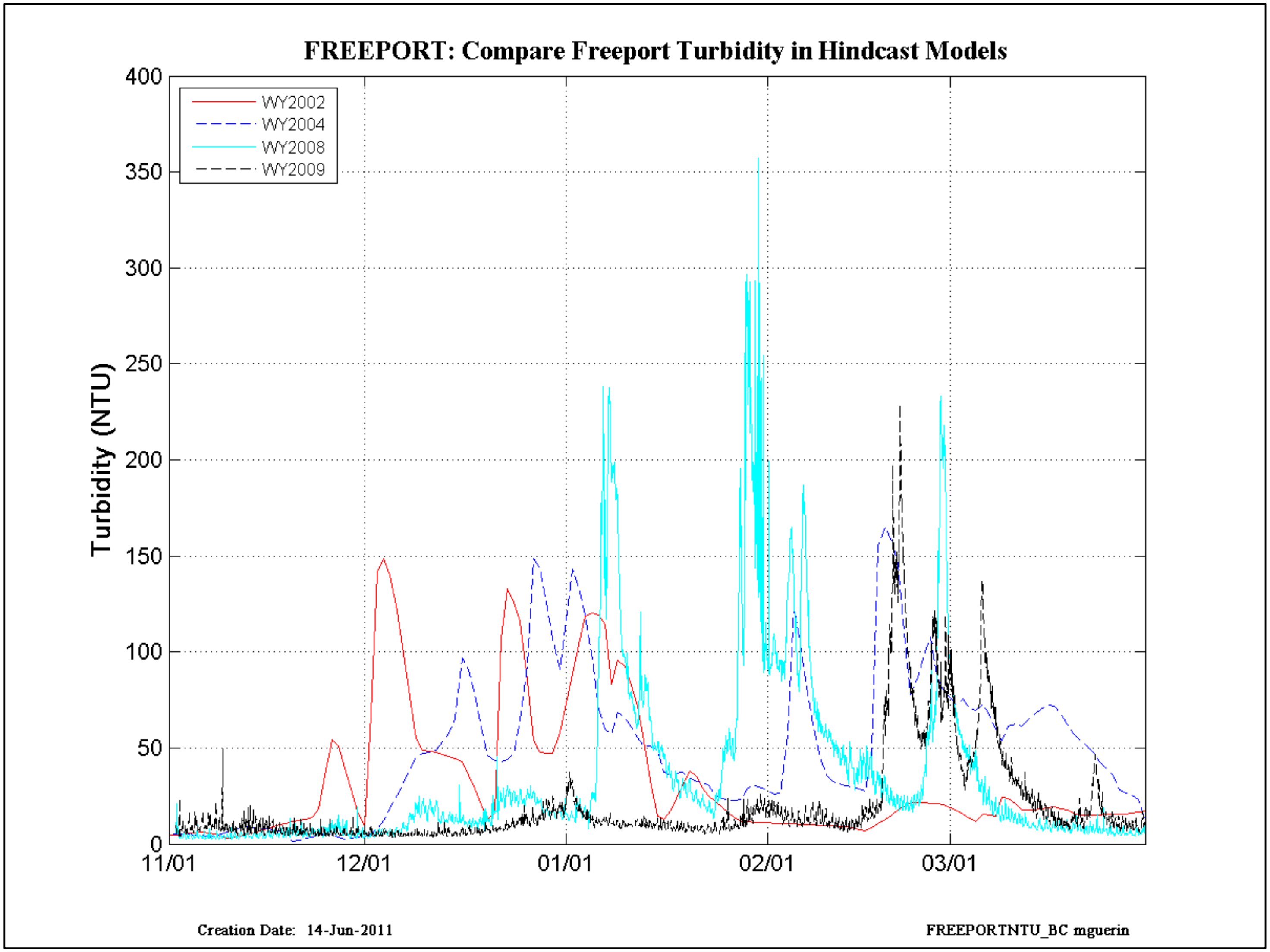

Figure 5-8 Comparison of Sacramento River turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

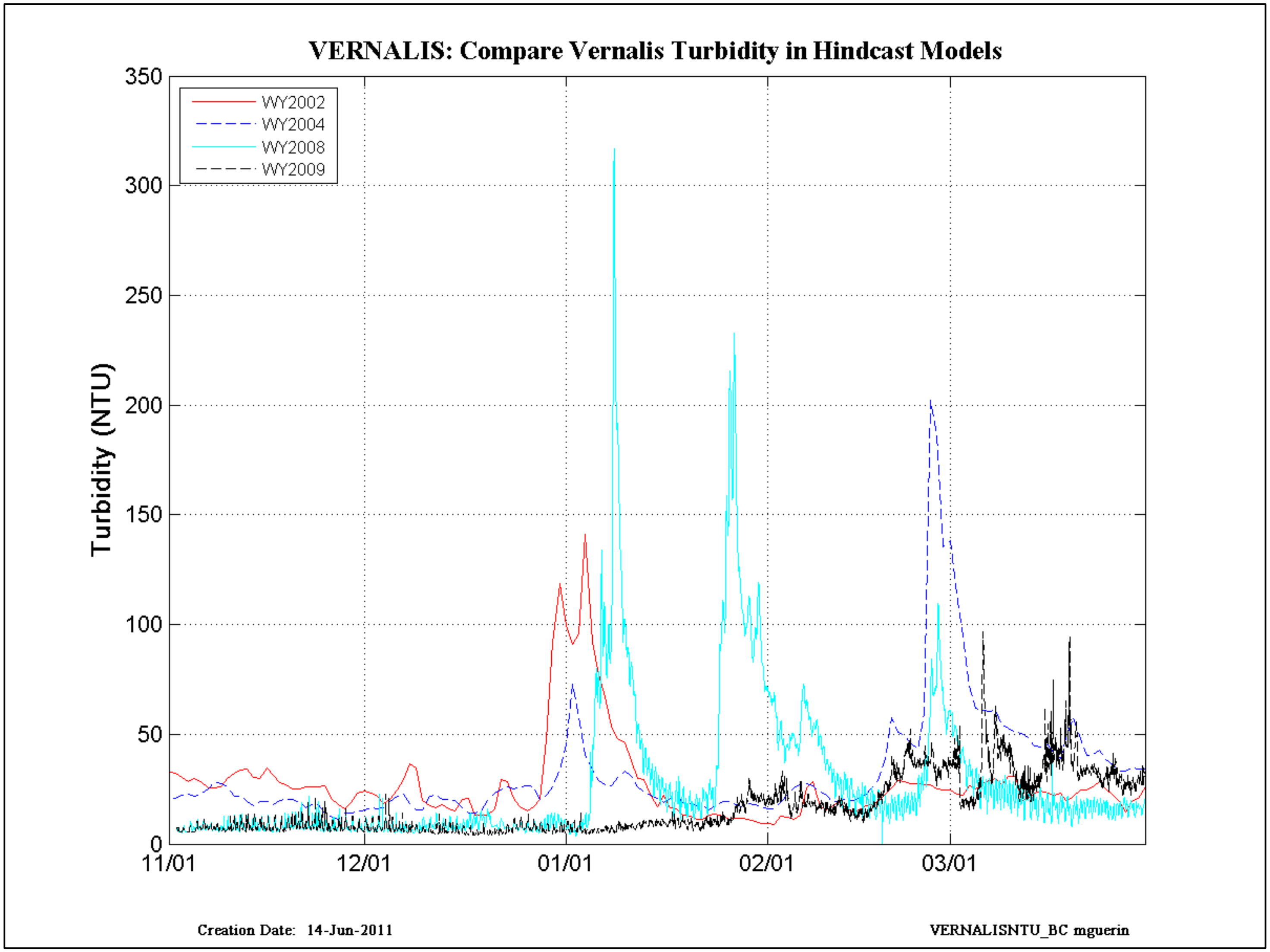

Figure 5-9 Comparison of San Joaquin R. turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

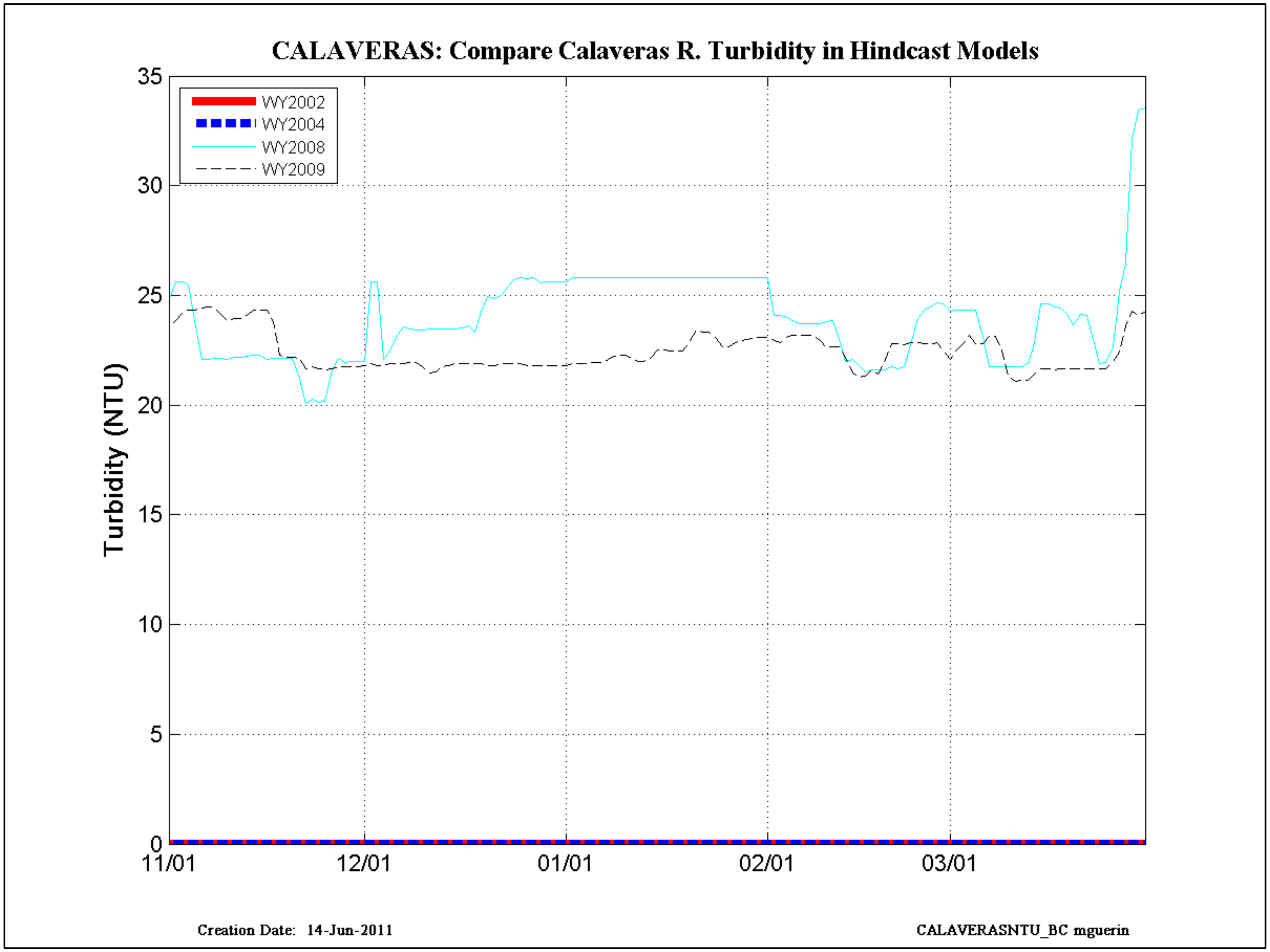

Figure 5-10 Comparison of Calaveras River turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

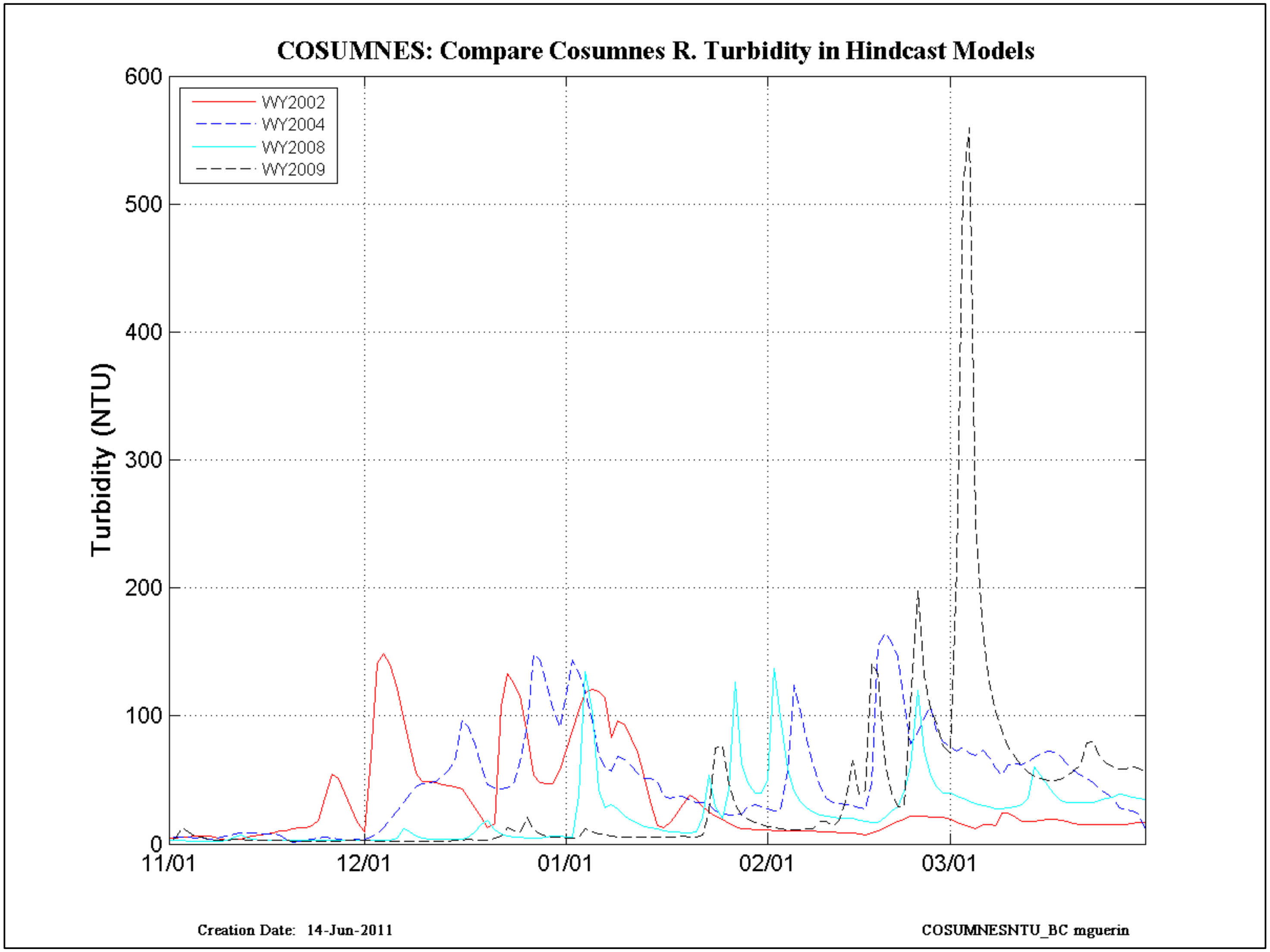

Figure 5-11 Comparison of Cosumnes River turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

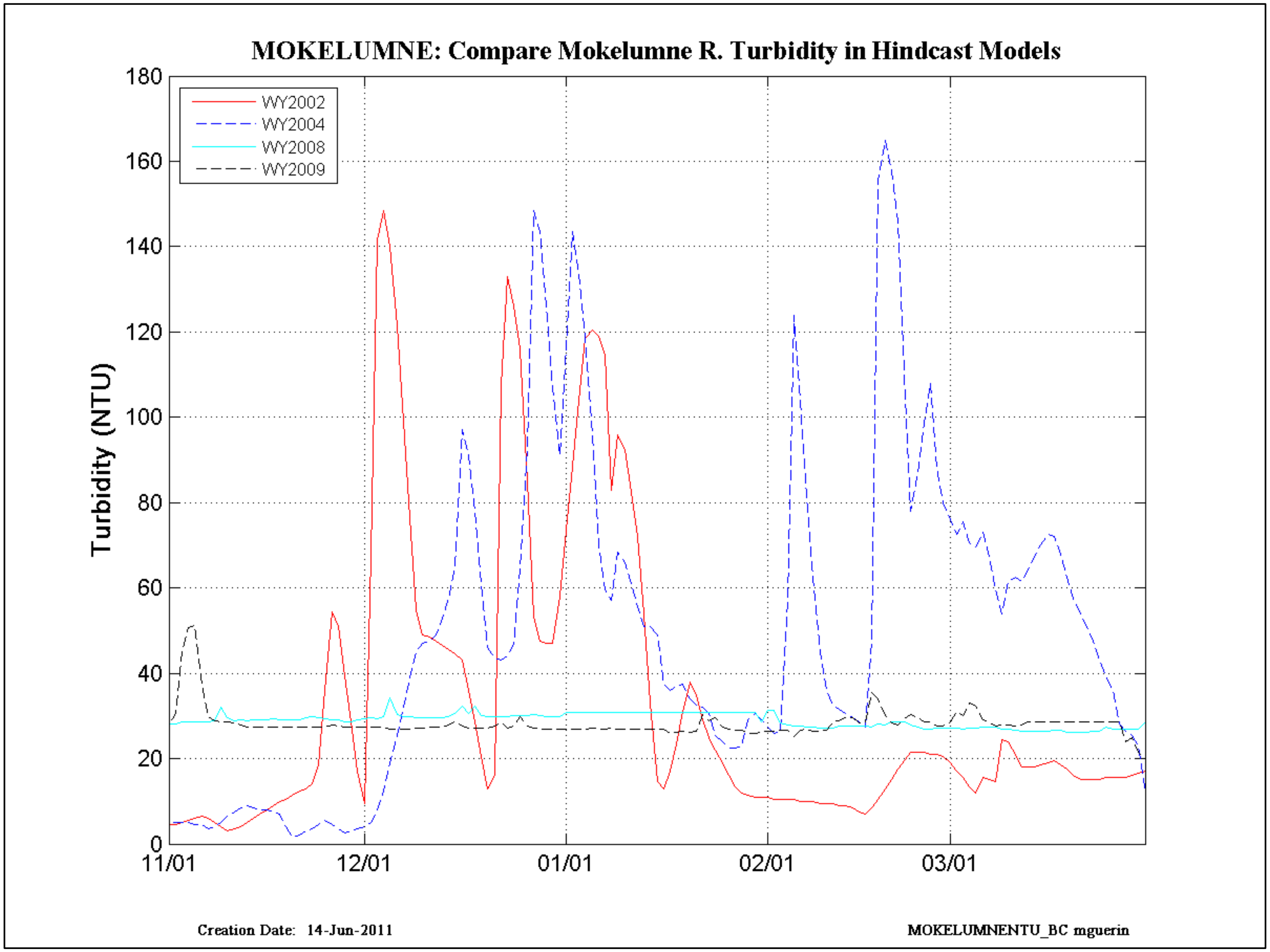

Figure 5-12 Comparison of Mokelumne River turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

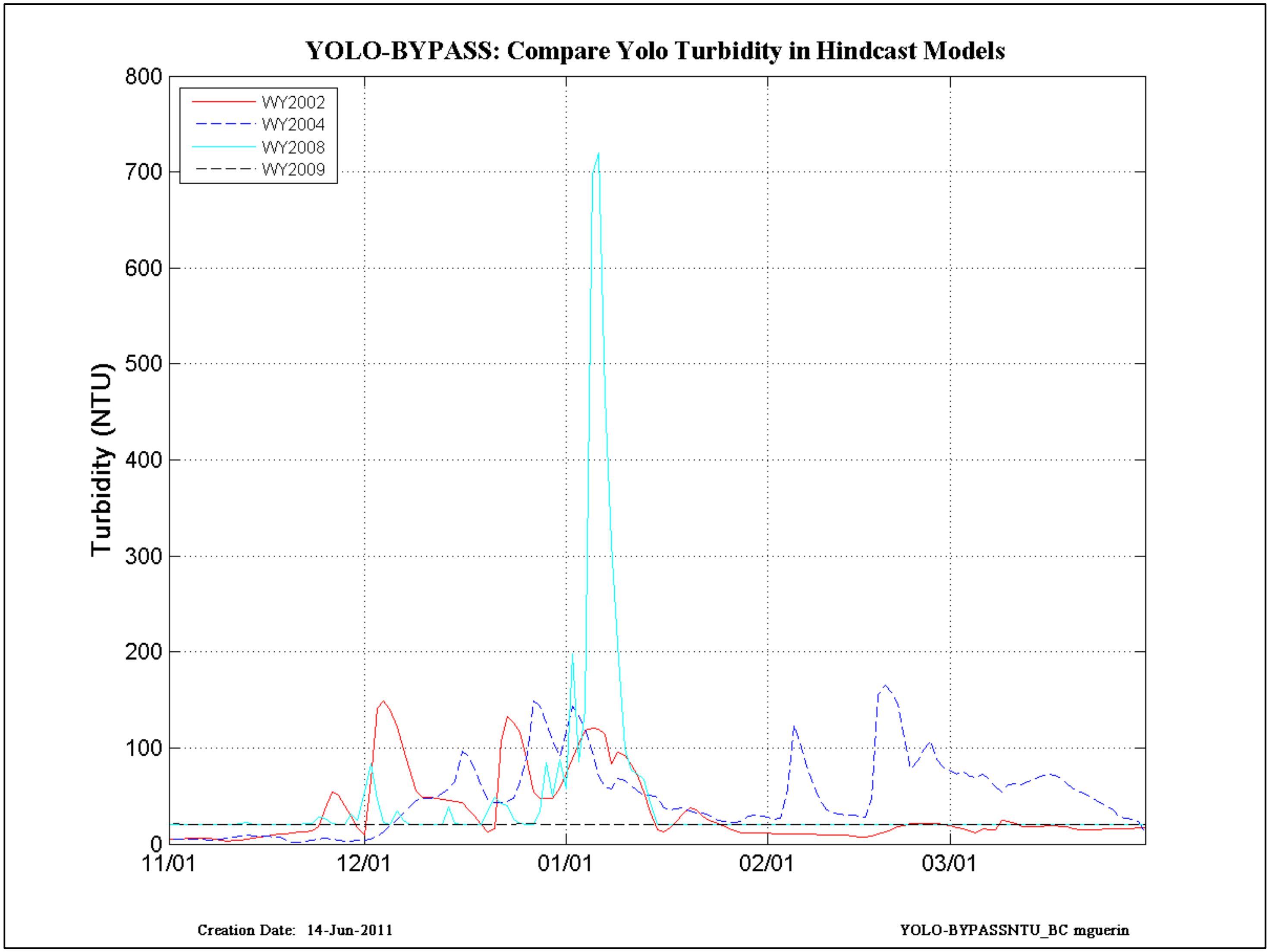

Figure 5-13 Comparison of Yolo Bypass turbidity for WY2002, WY2004, WY2008 and WY2009 simulation periods.

6. Modeling Results

The four simulation periods are treated differently for each analysis depending on the amount of turbidity data available for comparison in each WY and whether a turbidity model had been run with the previous one-parameter turbidity model. In WY2002 and WY2004, there is only one location with turbidity data in the Delta used for comparison, in Middle River – this is grab-sample data. In WY2008 and WY2009, there is measured turbidity data available at several locations in the Delta. WY2009 is the only simulation period in which the WY2010 model calibration is the sole model run. All of the simulations have results compared at a set of identical locations, but the WY2008 and WY2009 simulations illustrate additional locations where data was available. The most data was available in WY2009.

6.1. Turbidity model

6.1.1. WY2002 and WY2004

Figure 6-1 and Figure 6-2 illustrate a comparison of grab-sample turbidity data downloaded from BDAT (Dave Fullerton, MWD, pers. com.) in Middle River with simulation hindcast results for the WY2007 (one-parameter) and WY2010 (three-parameter) model calibrations for WY2002 and WY2004. The WY2007 calibration results are somewhat high, particularly at the peaks, while the WY2010 calibration results are somewhat low, particularly away from the peaks.

Figure 6-3 through Figure 6-9 illustrate a comparison of results using the WY2007 and WY2010 model calibrations at several locations in-Delta for WY2002. Recall, these models were run with identical flow and turbidity boundary conditions, but differ in decay parameters values (Figure 3-5) and in minor changes to the grid (Section 3.3.2). At locations with relatively short travel times from the boundaries (Hood ~Figure 6-6, Rio Vista ~Figure 6-8, Grant Line ~Figure 6-4), the differences in turbidity are minor. Near central Delta locations, however, the WY2010 calibration results are lower by nearly a factor of two (False River ~ Figure 6-3, Holland Cut ~Figure 6-5) due to decay rates which are more than double the original WY2007 decay rates.

The analysis of WY2004 results is similar (Figure 6-10 through Figure 6-16), with the two calibration results similar near the boundaries and differing by up to a factor of two in the central Delta.

6.1.2. WY2008

The analysis of WY2008 turbidity simulation results is similar to the analyses for WY2002 and WY2004 – the two models have similar magnitudes of turbidity near the boundaries but differ by up to a factor of two in the central Delta (Figure 6-17 through Figure 6-27). For WY 2008 there are several measurement sites in-Delta.

At some locations, the WY2007 calibration presents a better fit to the data (Figure 6-19), while at others the WY2010 calibration presents a better fit (Figure 6-23). The effects of wind on sediment re-suspension are seen at Holland Cut (Figure 6-28). In general, the WY2007 calibration results tended to overestimate the data at peaks, while the WY2010 calibration results tended to underestimate the data in general.

6.1.3. WY2009

Only the WY2010 model calibration simulation was run in WY2009. Modeled results are compared to data in Figure 6-29 through Figure 6-39.

WY2009 was different from the other simulation periods in that a flow-and-turbidity pulse was not observed until late February. Modeled results were lower than data before the turbidity pulse at many locations (Figure 6-38). Once the turbidity arrived, the model generally overestimated the data.

6.2. Adult delta smelt particle tracking model

Figure 6-40 through Figure 6-43 illustrate the count of adult delta smelt 'salvage' at the SWP and CVP export locations as well as the modeled count of particles removed from the model at the SWP and CVP locations out of 50,000 particles inserted in the Suisun Region near the Martinez boundary.

In WY2002, salvage numbers peaked in the first week of January (Figure 6-40 upper plot), mainly at the SWP location. In the particle tracking results (Figure 6-40 lower plot), the particles reached the export locations peaked about two weeks after the real salvage peak.

In WY2004, there were two flow and turbidity peaks on the Sacramento and San Joaquin Rivers (Figure 5-1, Figure 5-2, Figure 5-8, Figure 5-9), and two delta smelt salvage count peaks at the export locations (Figure 6-41, upper plot). In the particle tracking model, the count peaks mirror the actual peak salvage counts in timing. Note that, unlike the real salvage data (upper plot) the peak particle count (lower plot) in March is higher than the January counts – this high count is due in part to the high turbidity arriving from the San Joaquin River.

Figure 6-42 shows the adult delta smelt salvage numbers and the particle tracking model results for WY2008. In this WY, few delta smelt were salvaged at either export location. The particle tracking model results are generally late with respect to the salvage data, with particles reached the export locations in March 2009 from the San Joaquin River through the Head of Old River and from Old River through Franks Tract.

Figure 6-43 shows the adult delta smelt salvage numbers and the particle tracking model results for WY2009. In this WY, only a handful of adult delta smelt reached the export locations – the particle tracking model results are in general agreement, as no particles reached the SWP or the CVP export locations.

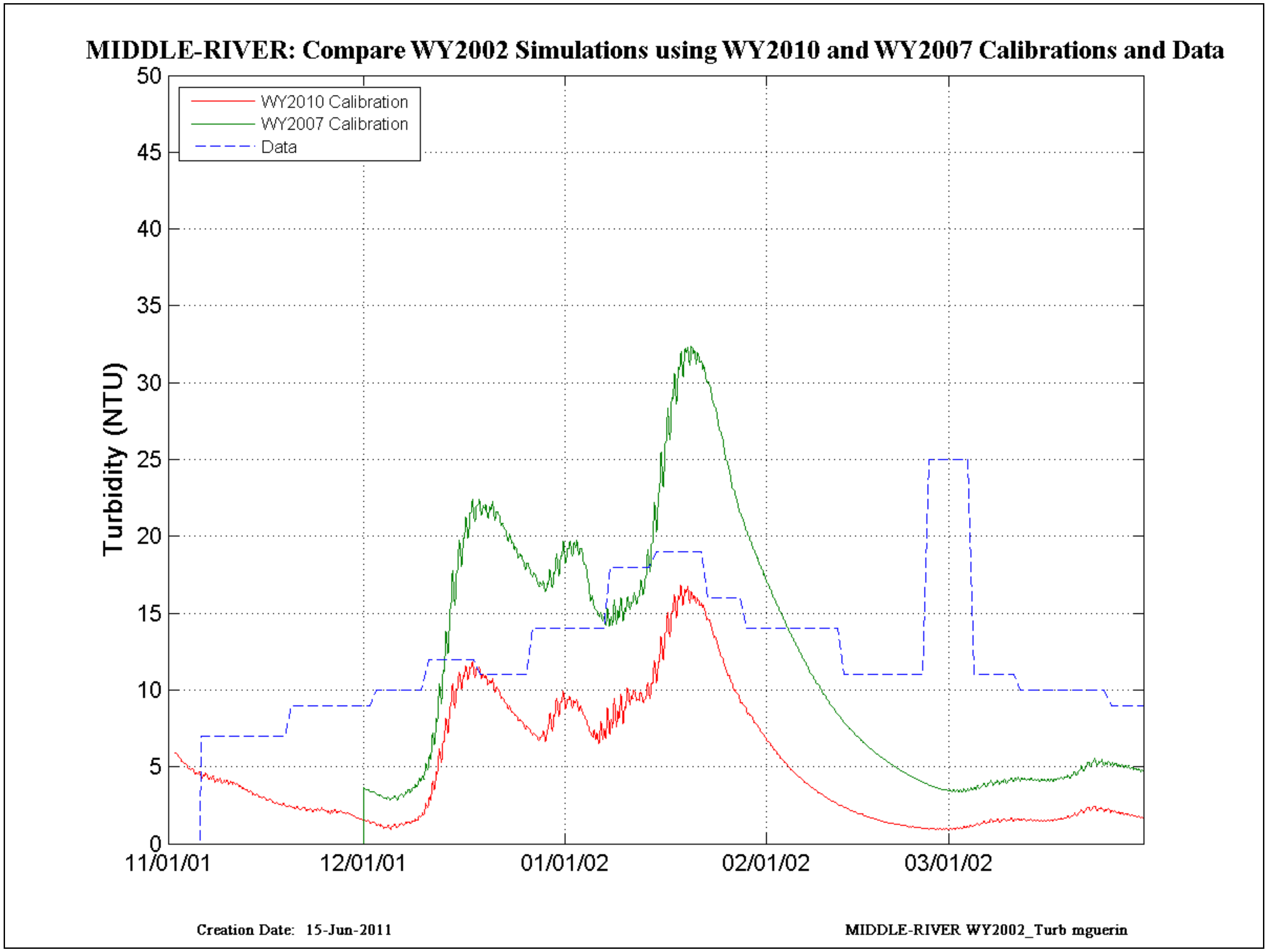

Figure 6-1 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations and data in Middle River.

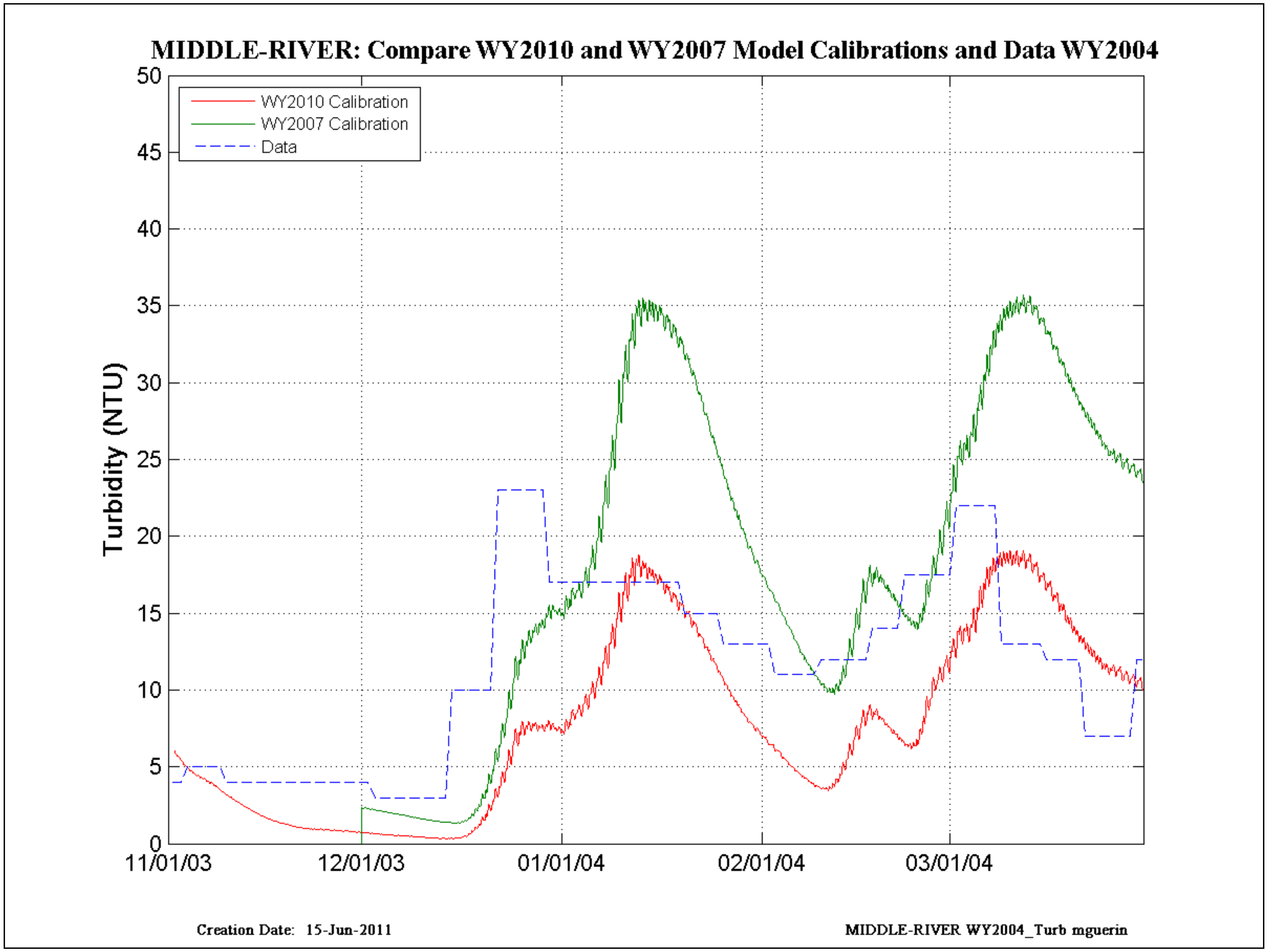

Figure 6-2 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations and data in Middle River.

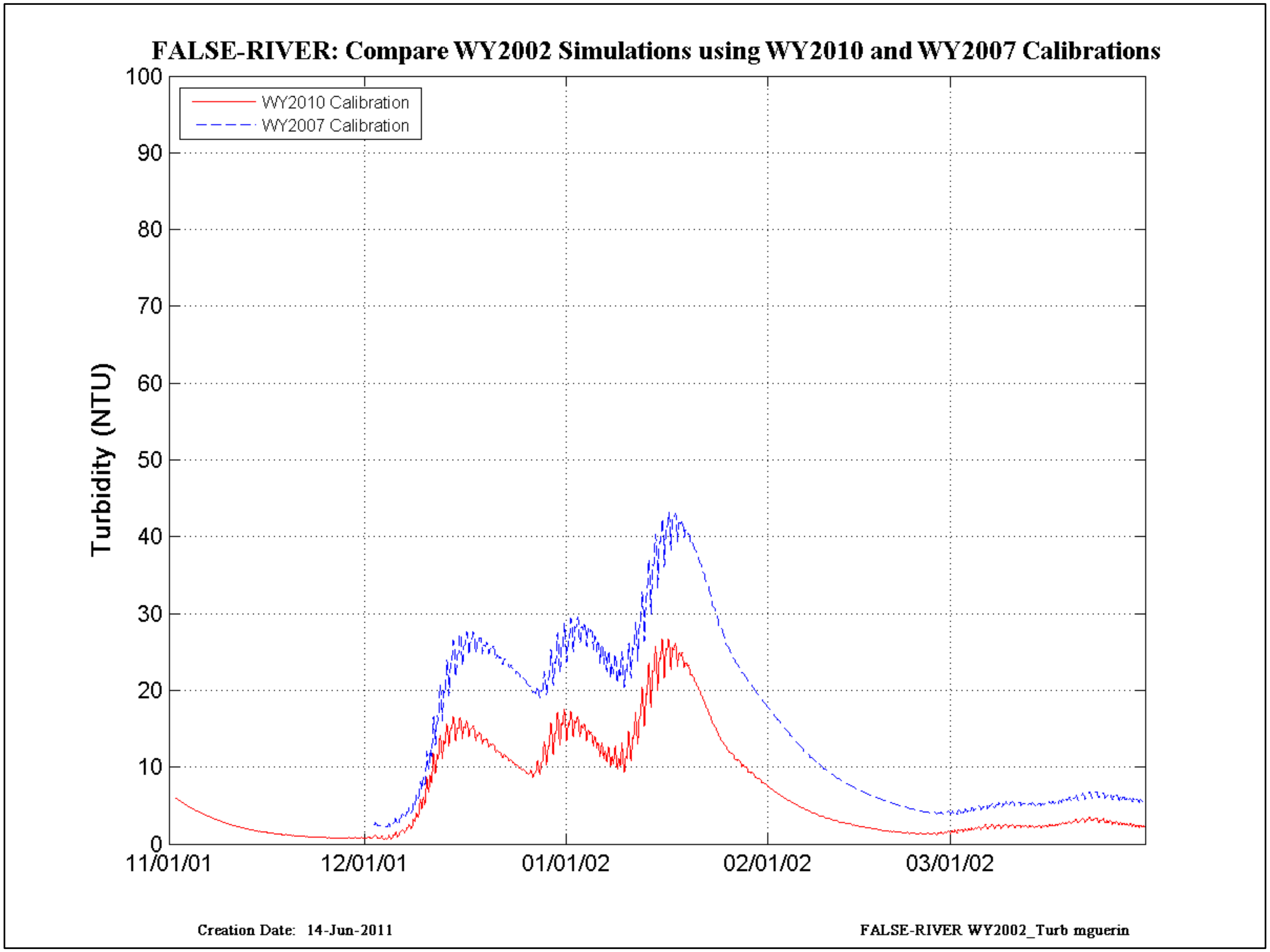

Figure 6-3 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at False River.

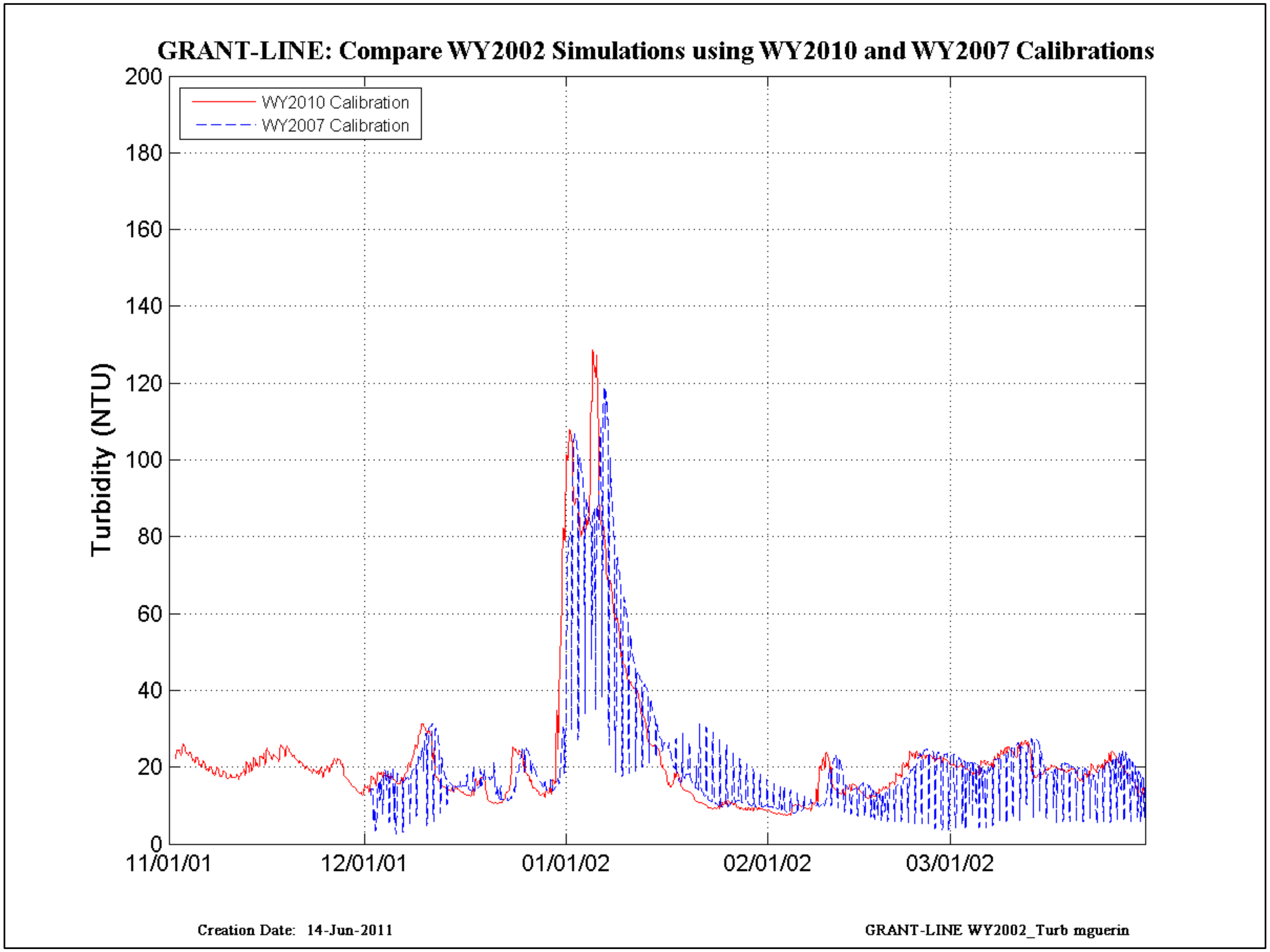

Figure 6-4 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Grant Line.

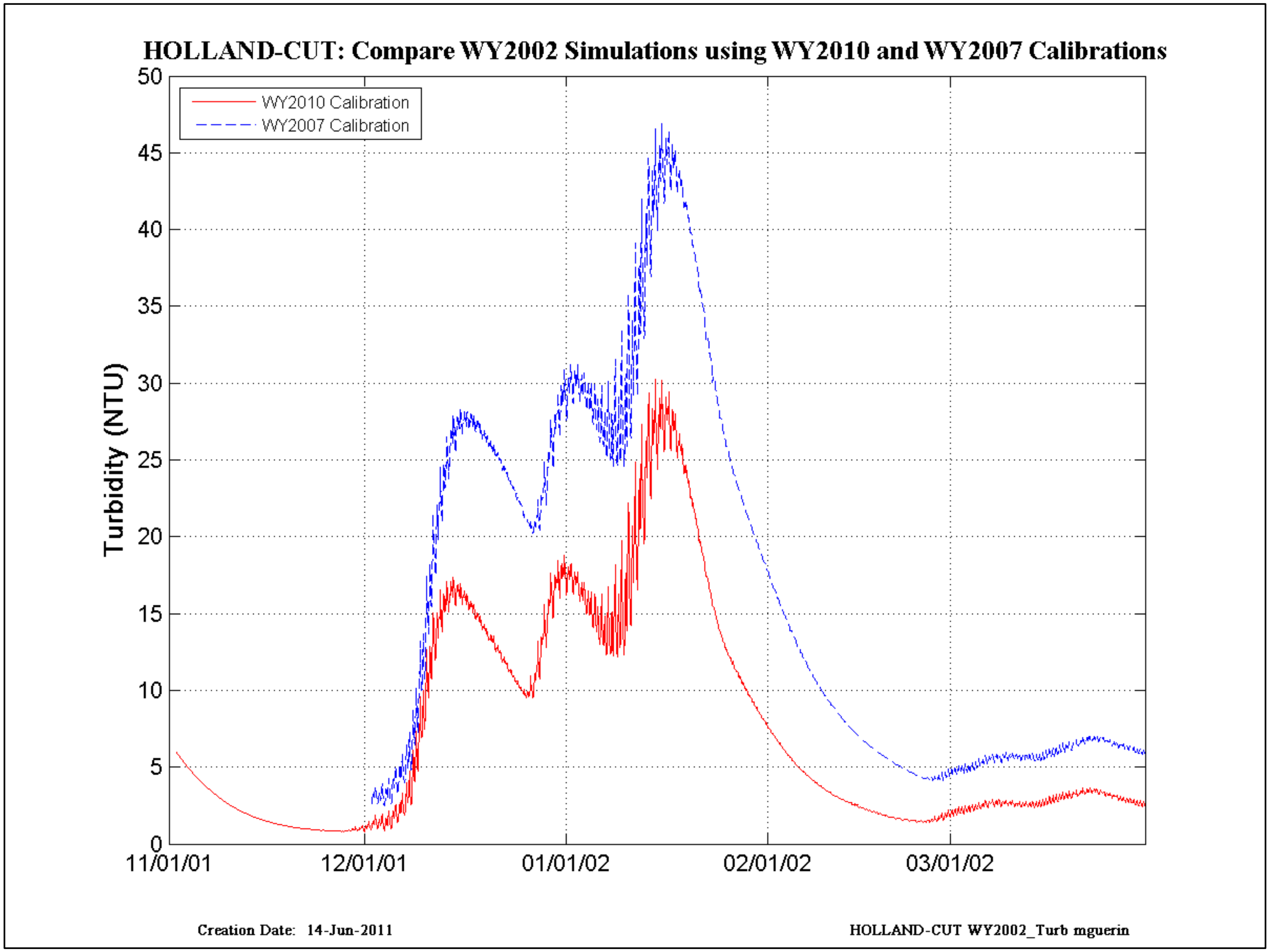

Figure 6-5 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Holland Cut.

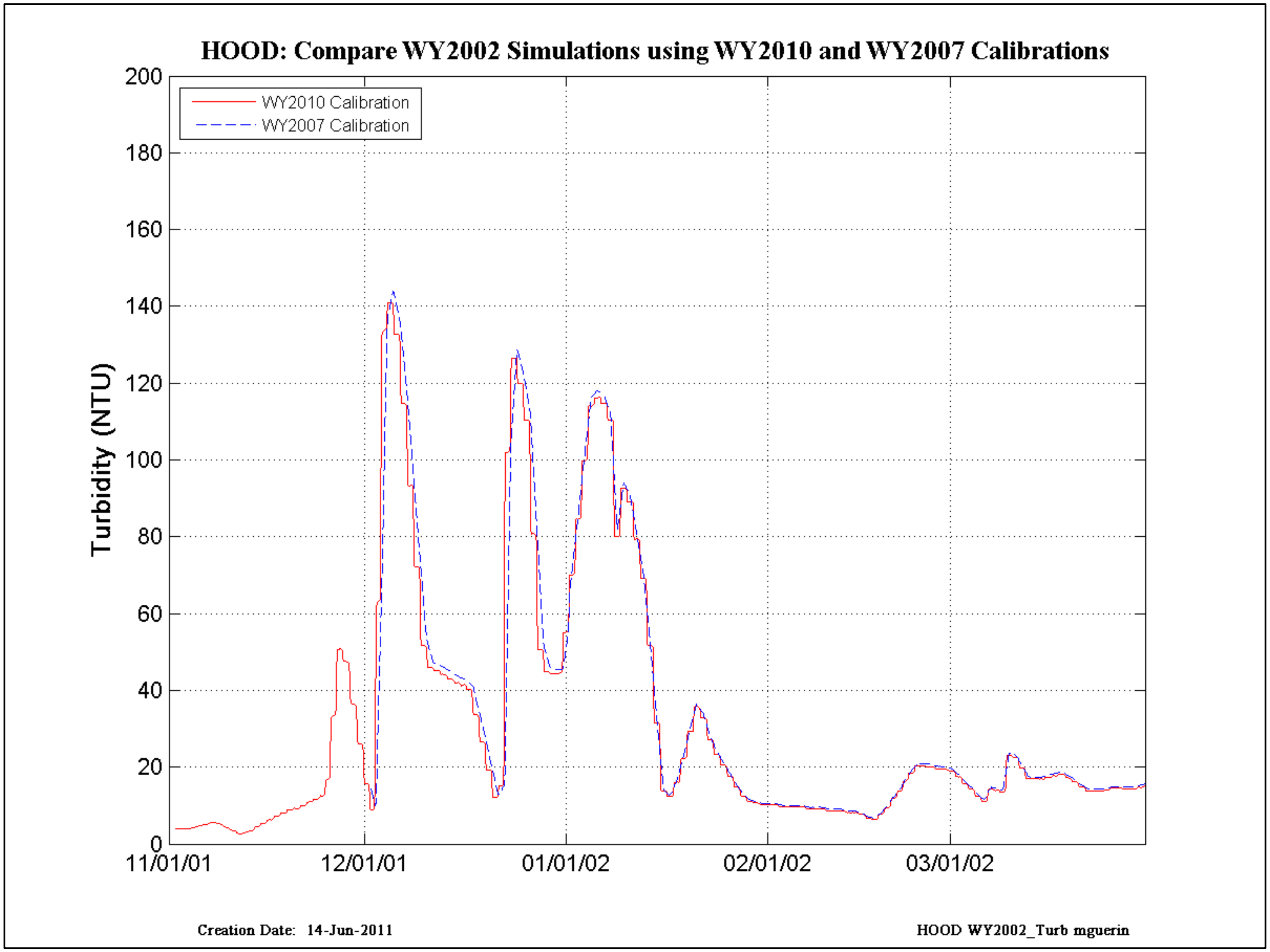

Figure 6-6 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Hood.

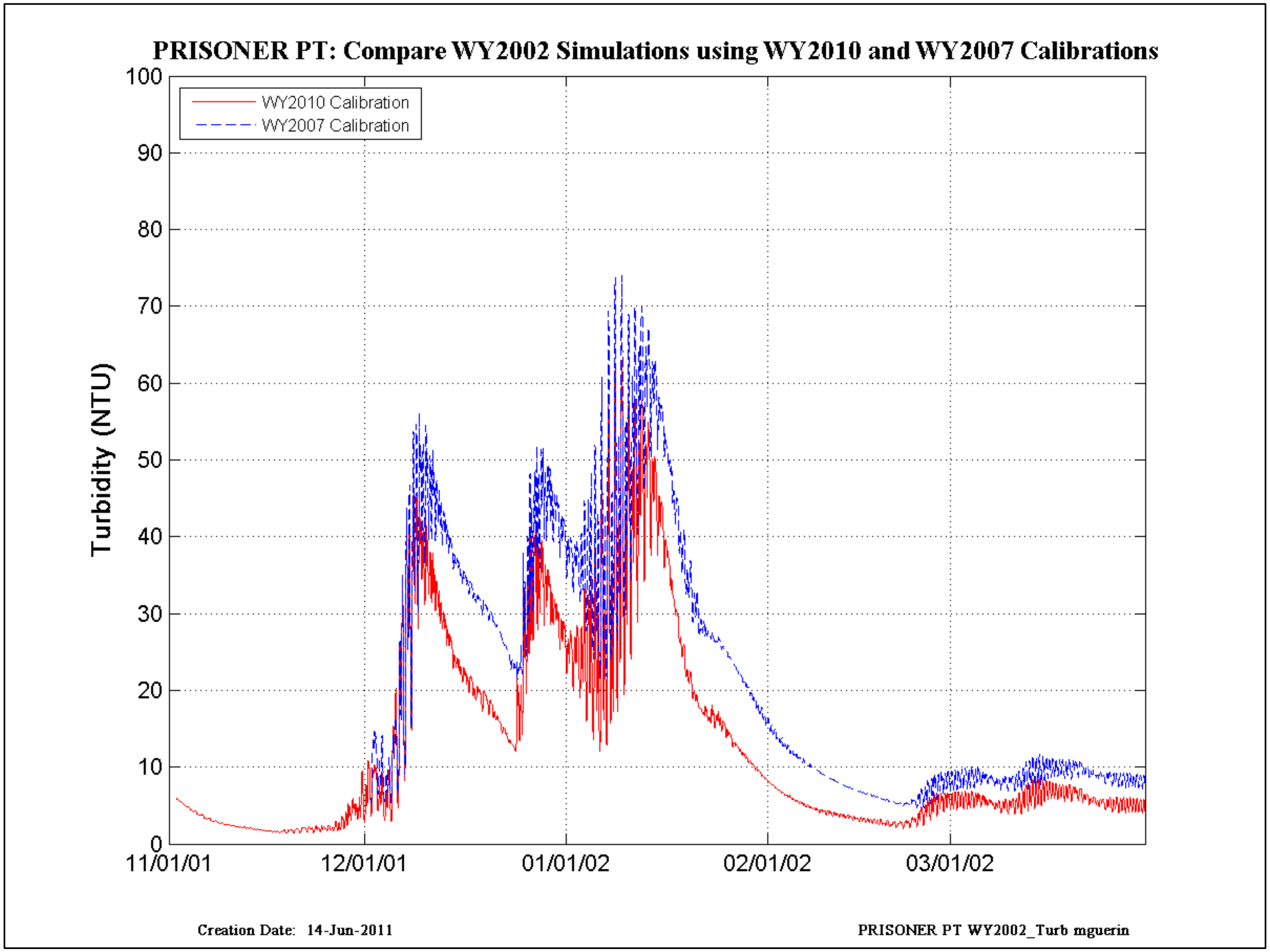

Figure 6-7 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Prisoner Point.

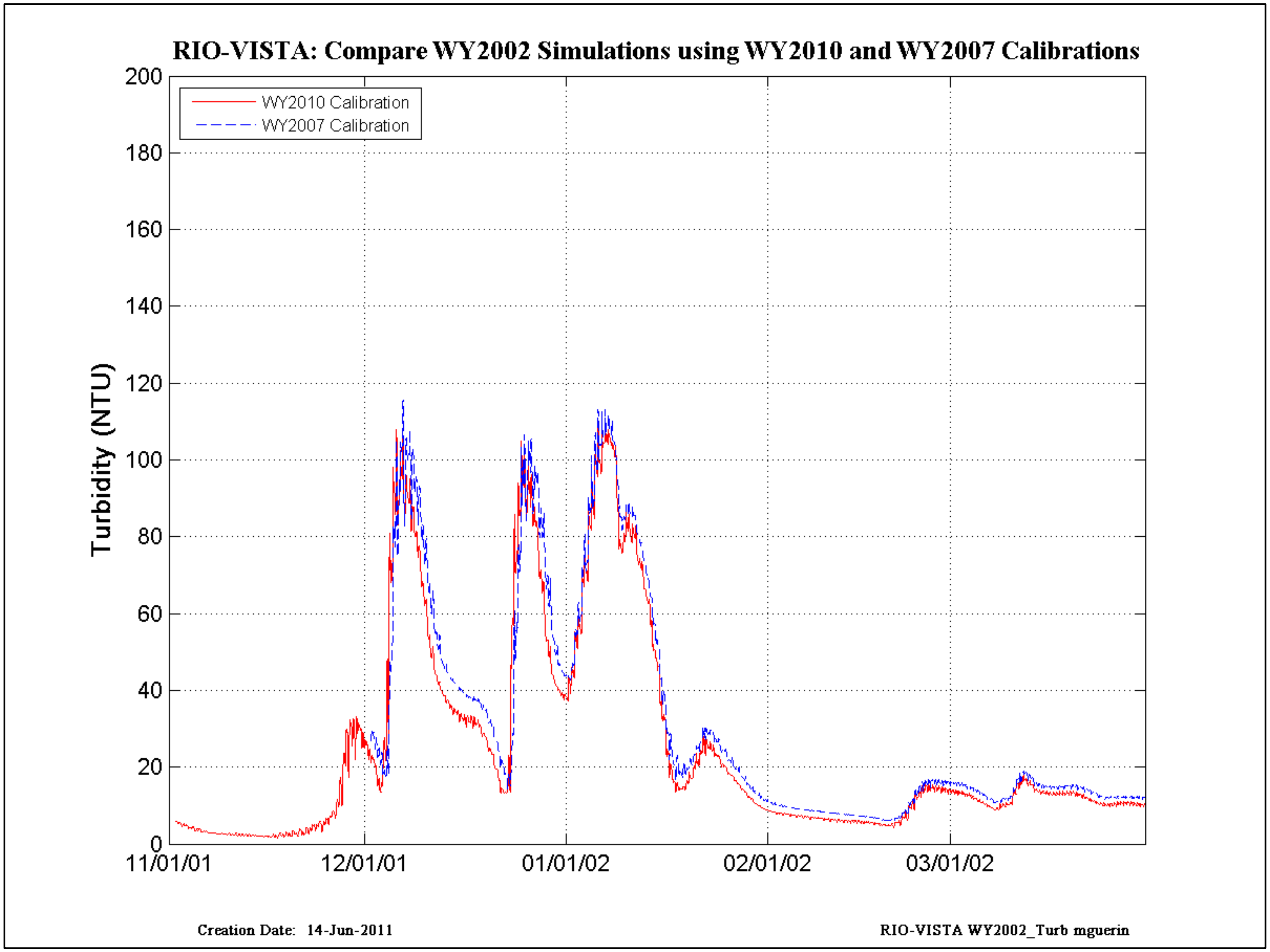

Figure 6-8 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Rio Vista.

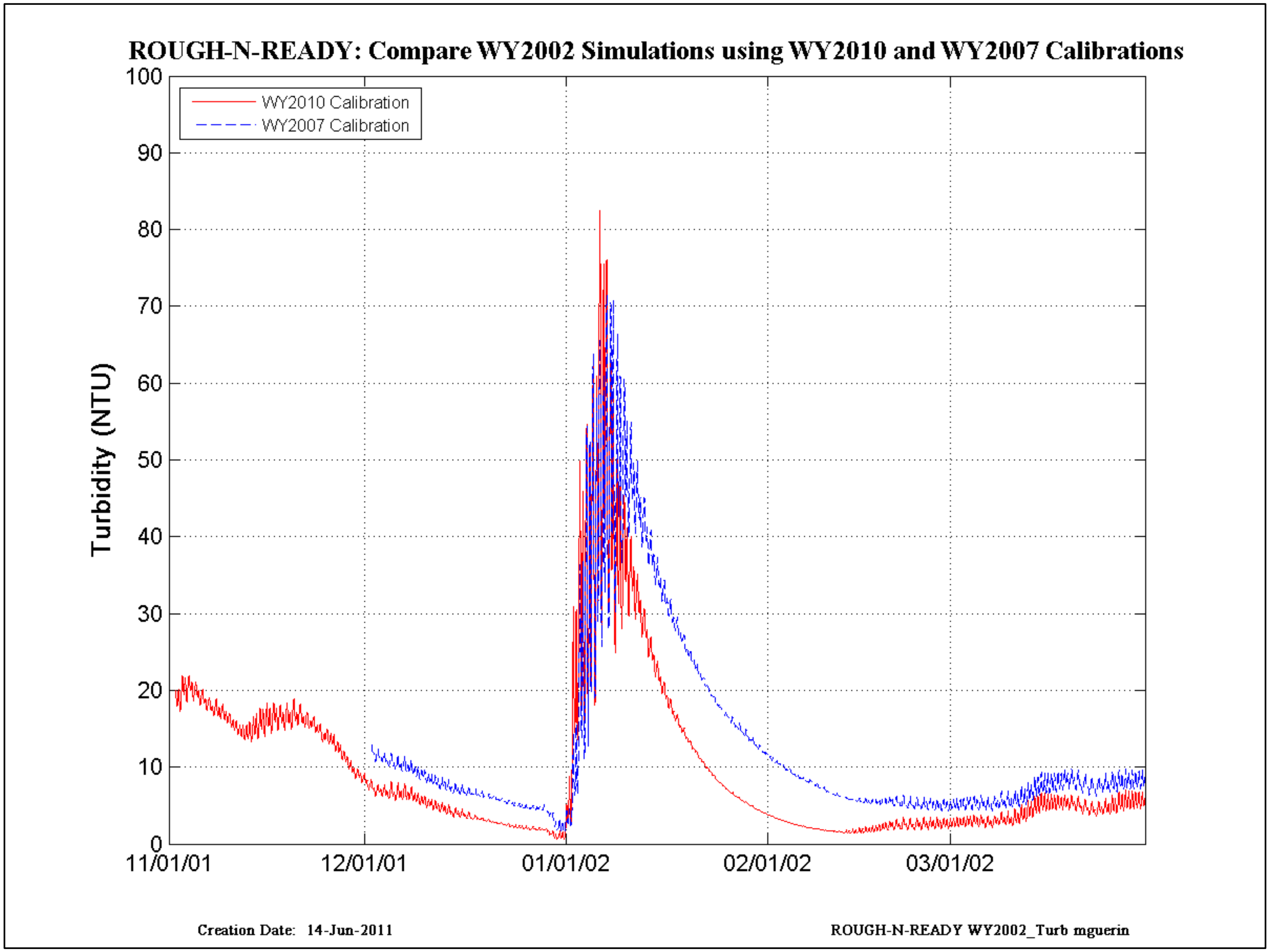

Figure 6-9 Comparison: WY2002 Turbidity simulations using WY2007 and WY2010 calibrations at Rough-N-Ready Island.

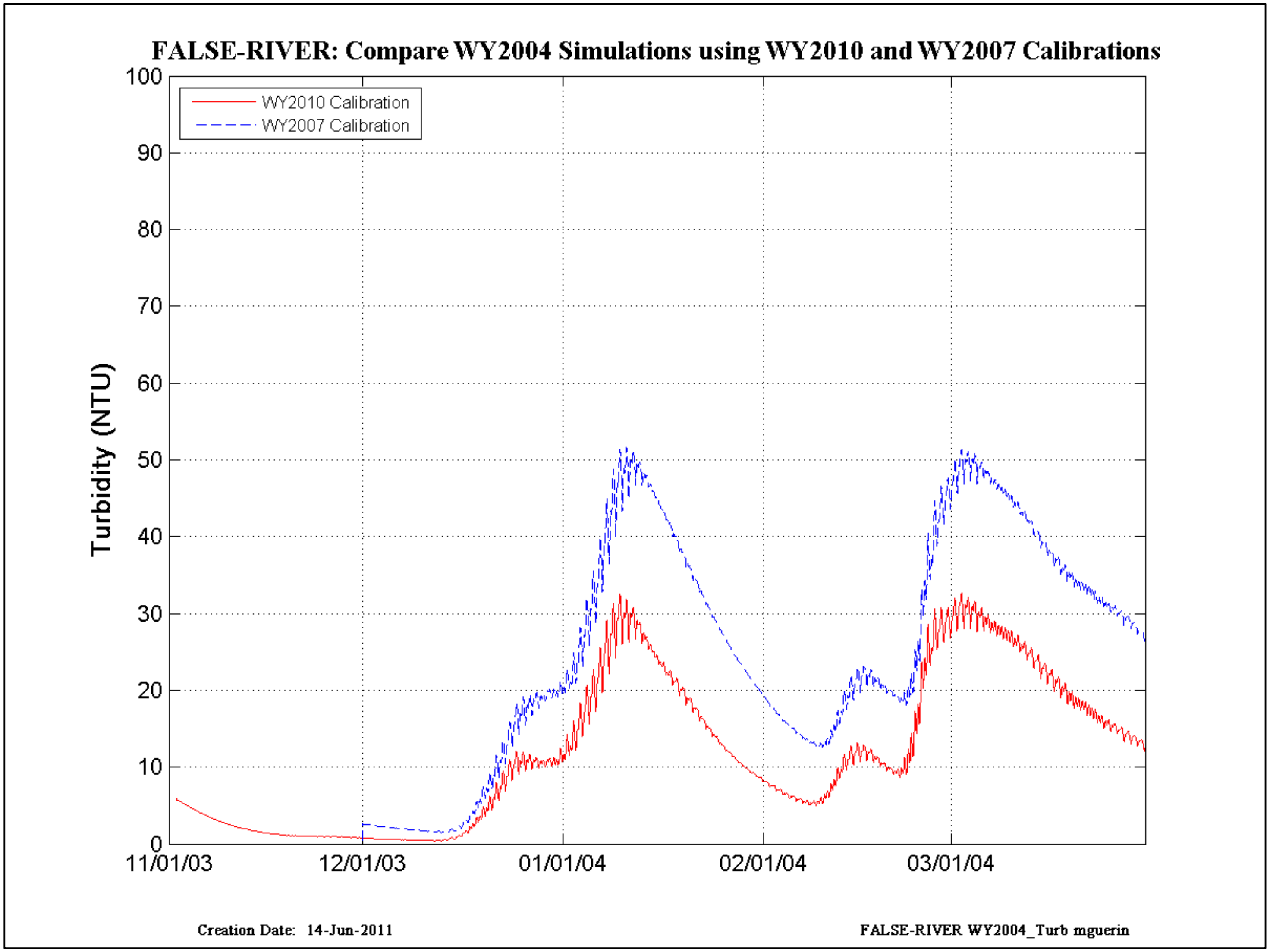

Figure 6-10 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at False River.

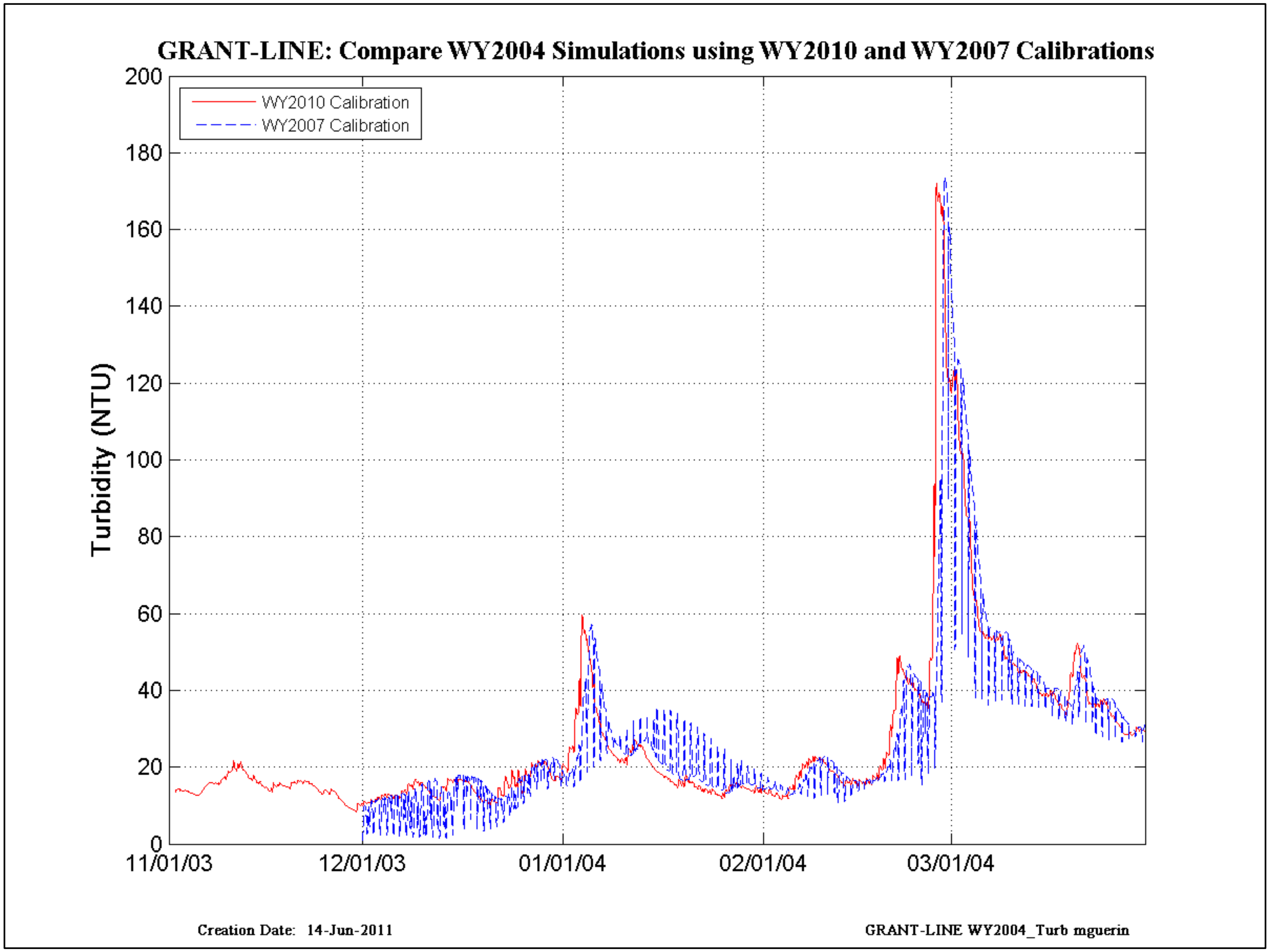

Figure 6-11 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Grant Line.

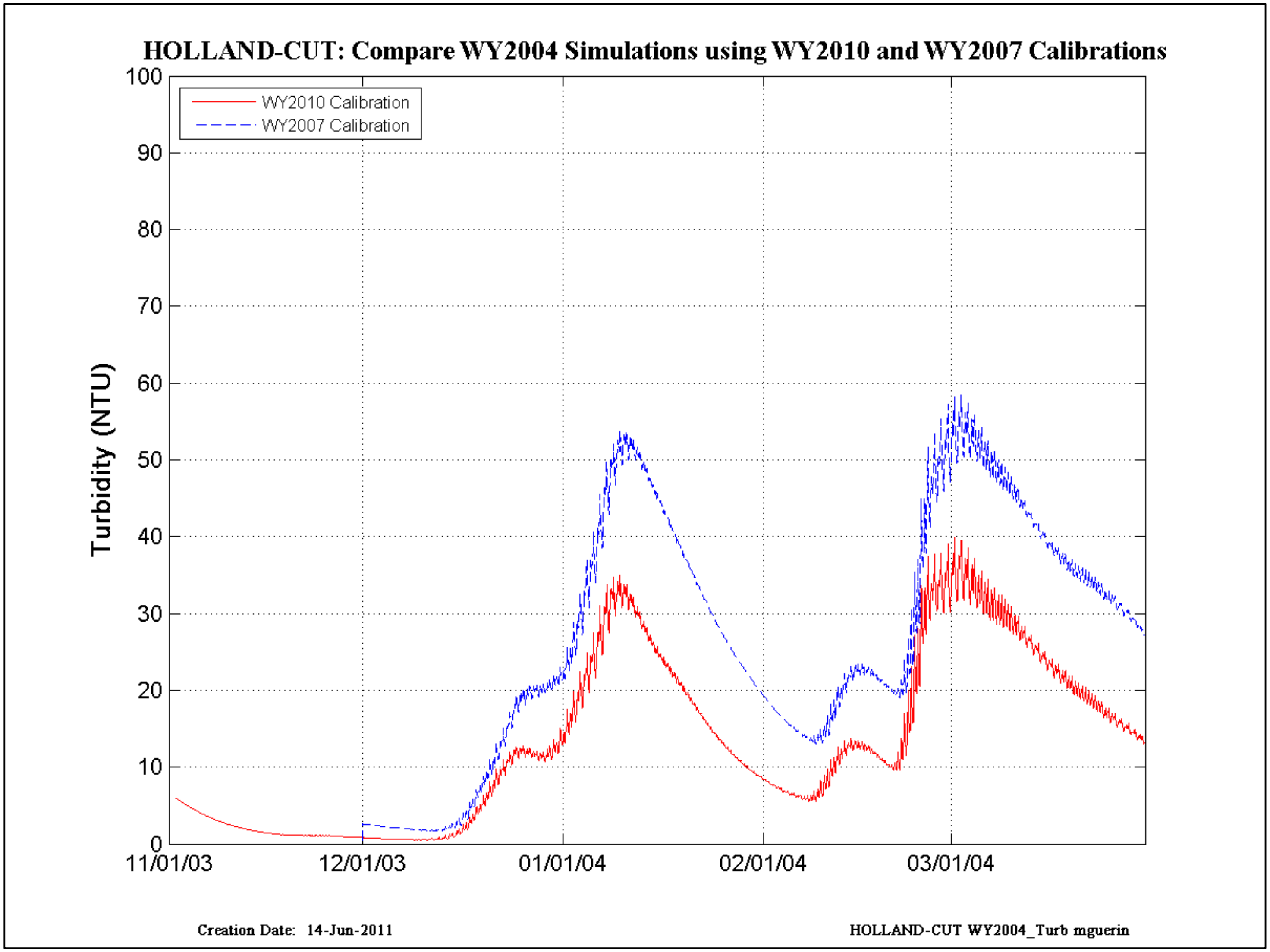

Figure 6-12 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Holland Cut.

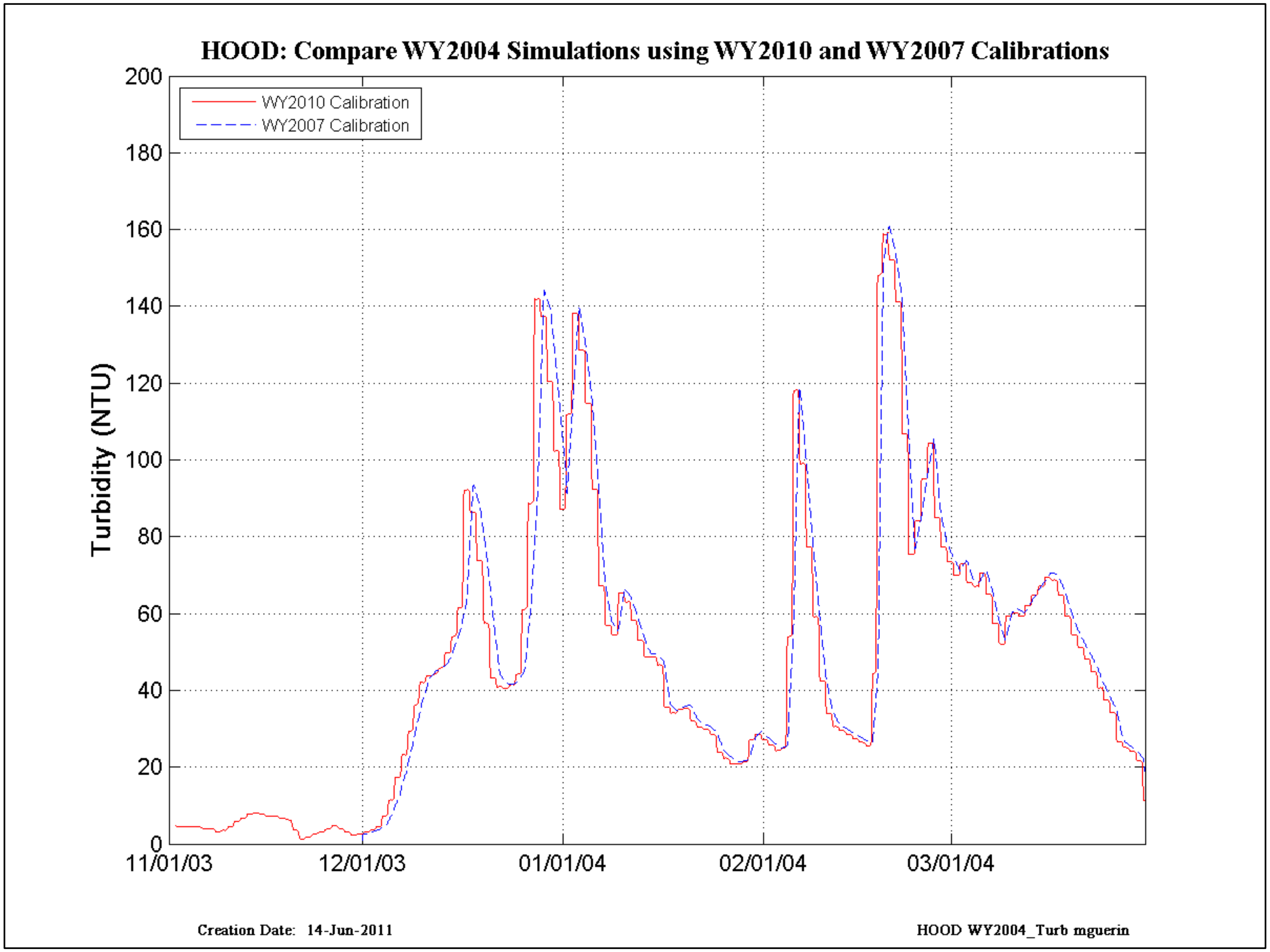

Figure 6-13 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Hood.

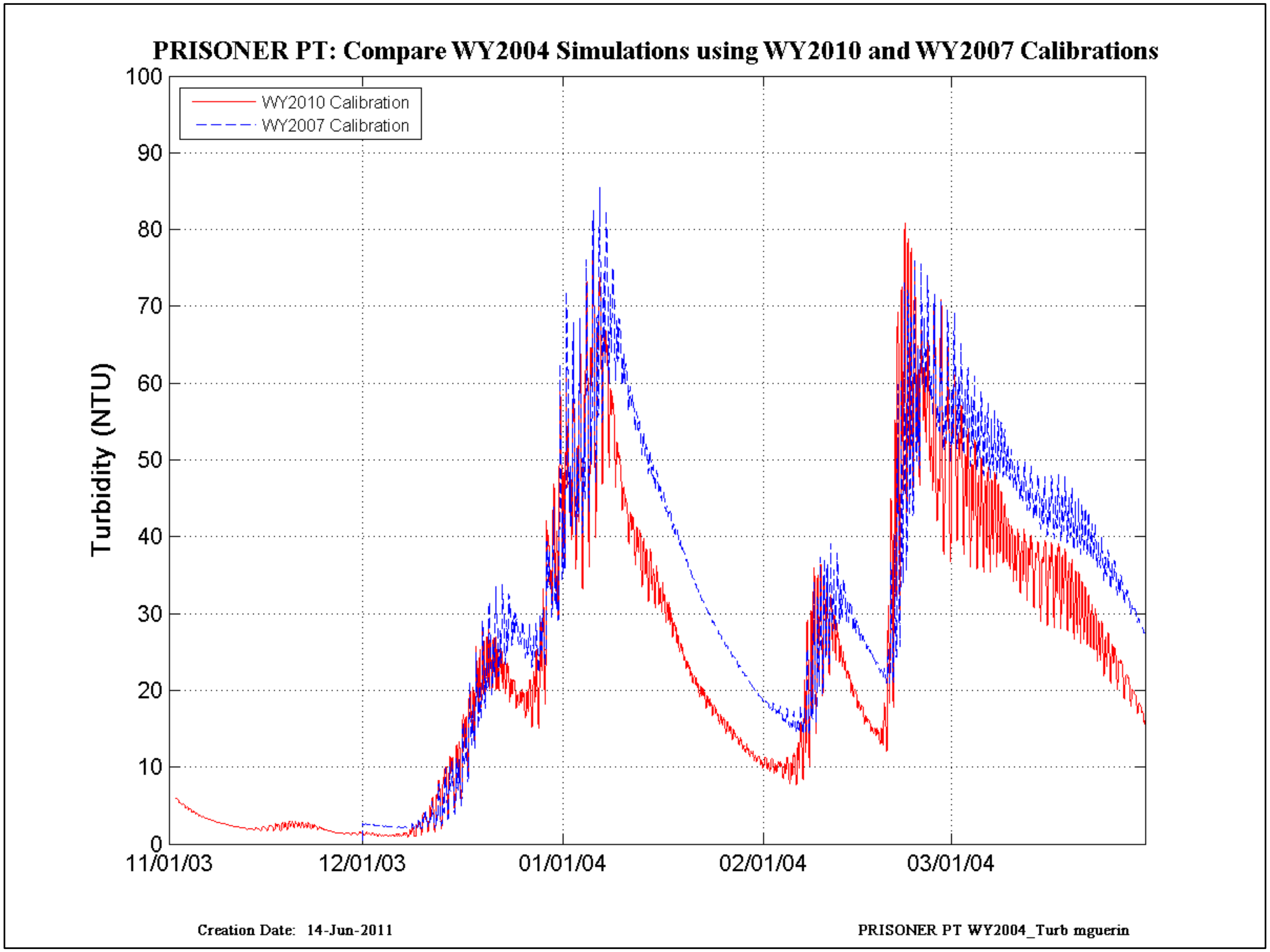

Figure 6-14 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Prisoner Point.

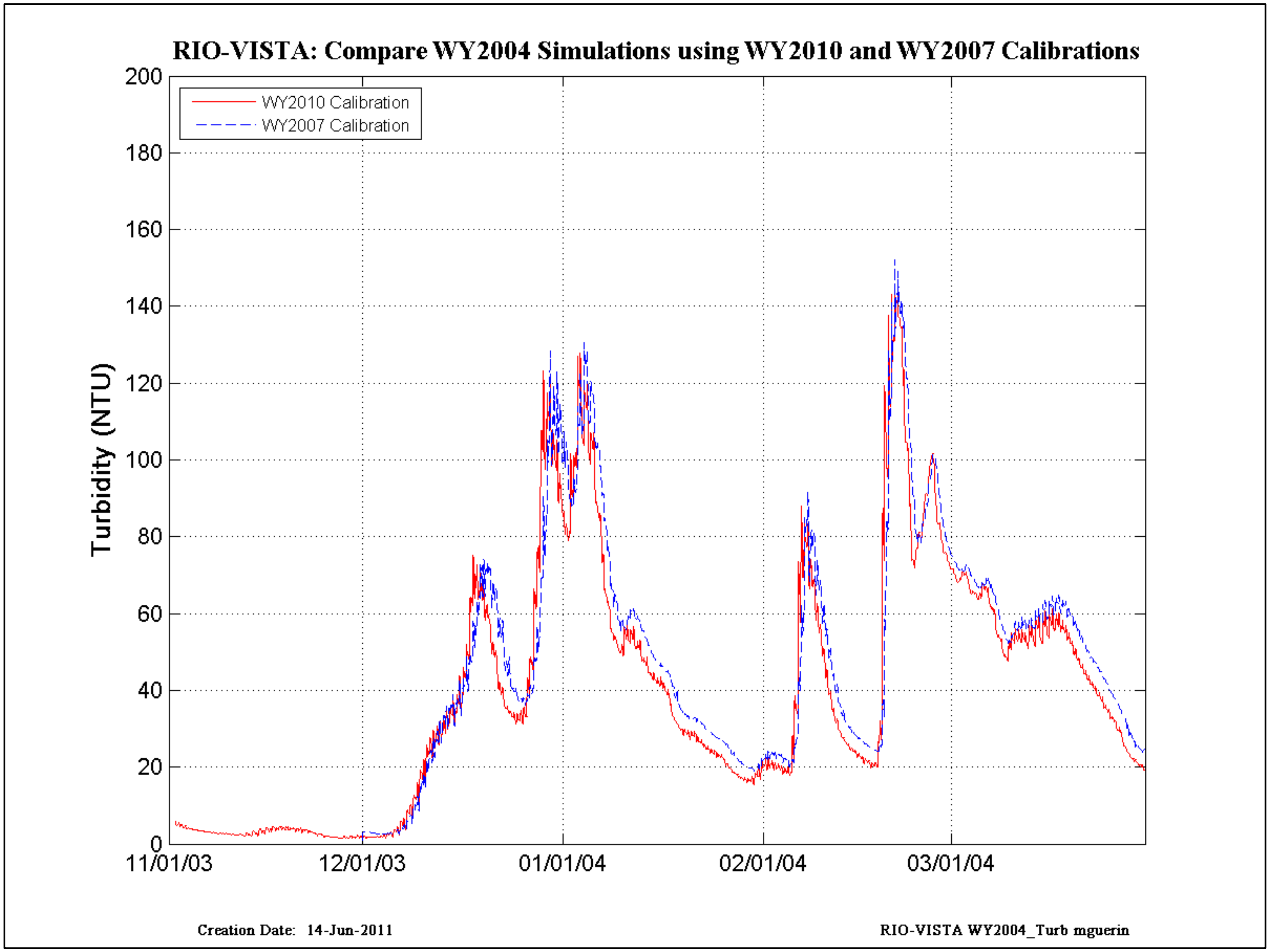

Figure 6-15 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Rio Vista.

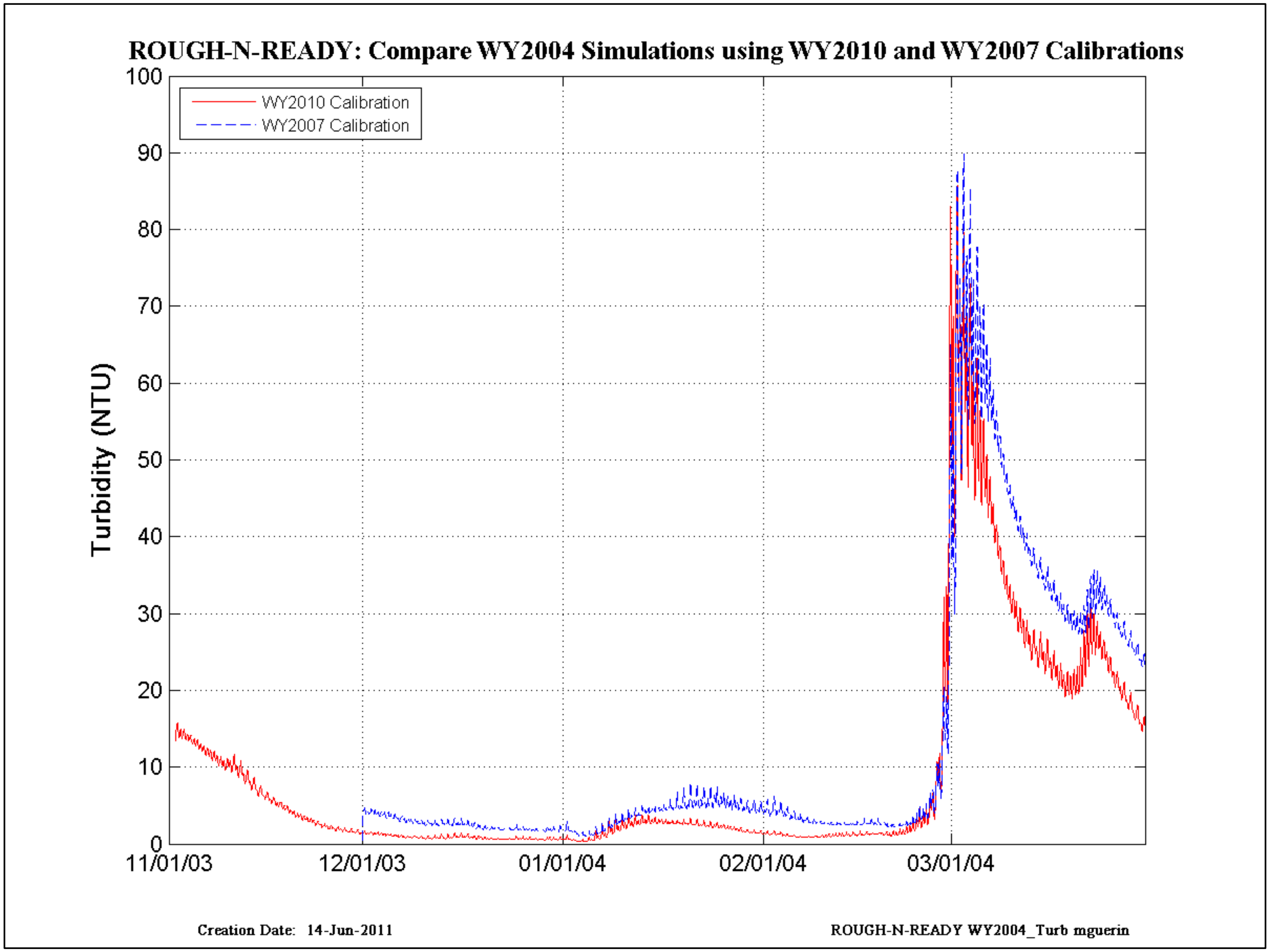

Figure 6-16 Comparison: WY2004 Turbidity simulations using WY2007 and WY2010 calibrations at Rough-N-Ready Island.

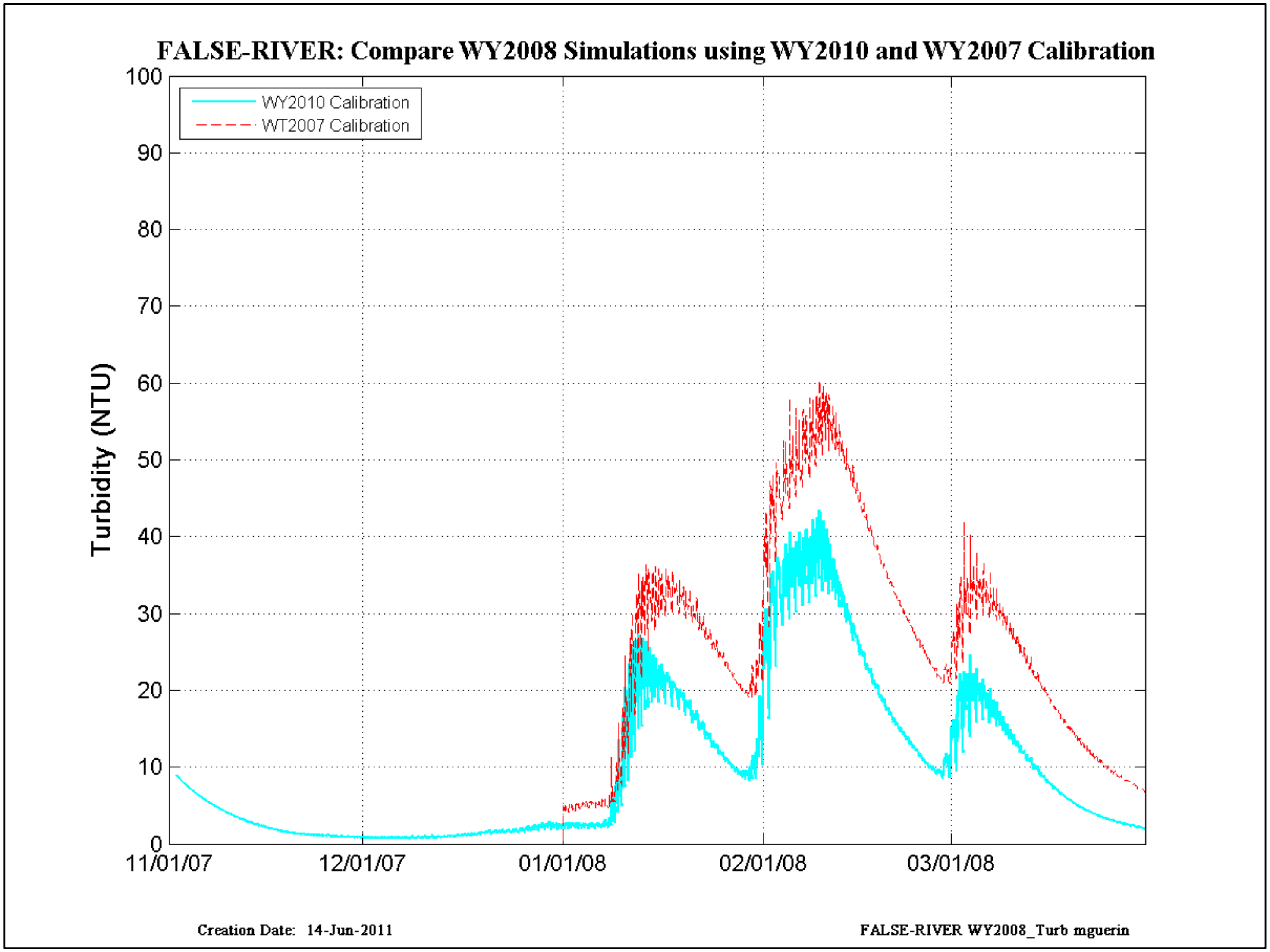

Figure 6-17 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations at False River.

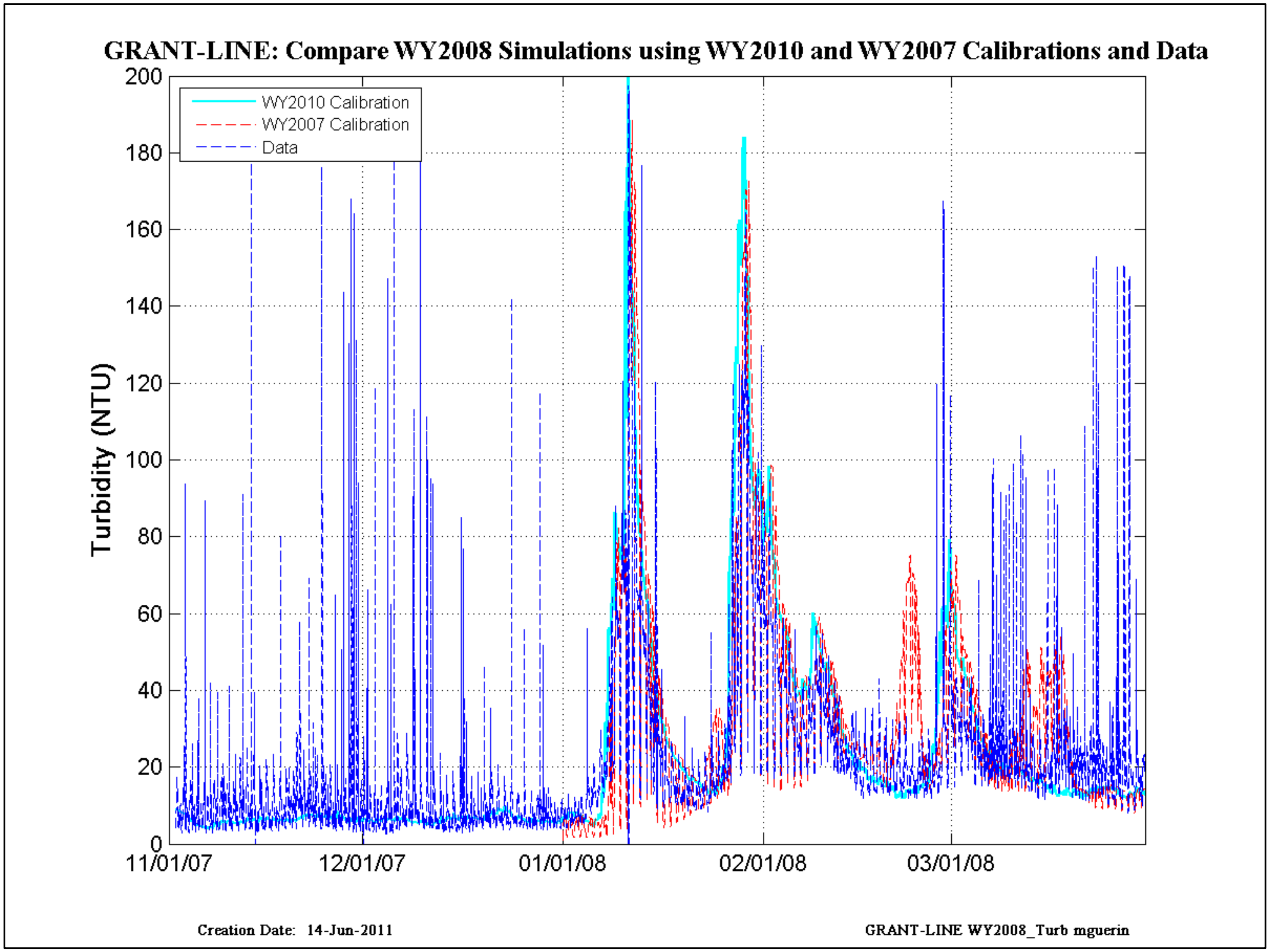

Figure 6-18 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Grant Line.

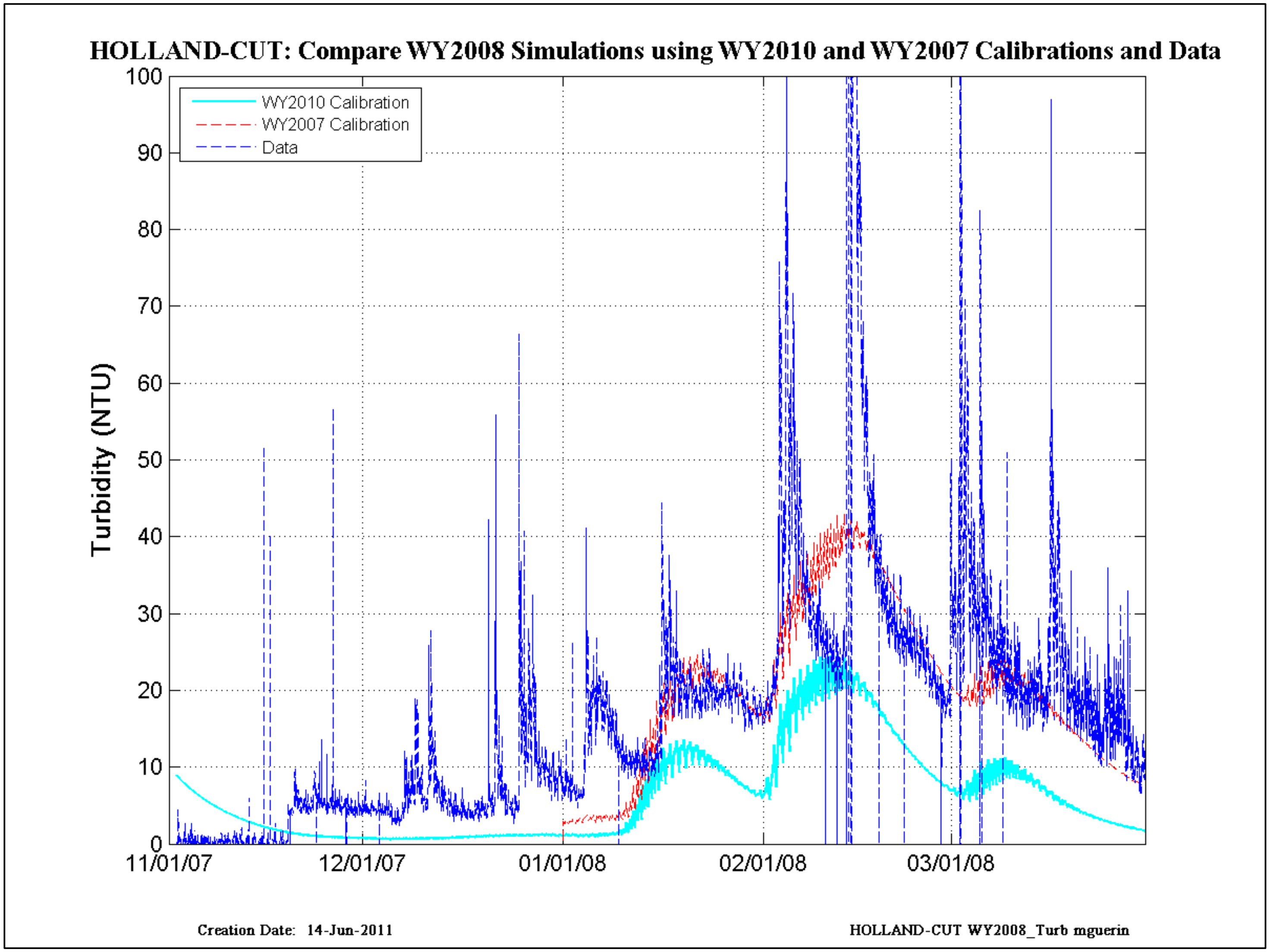

Figure 6-19 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Holland Cut.

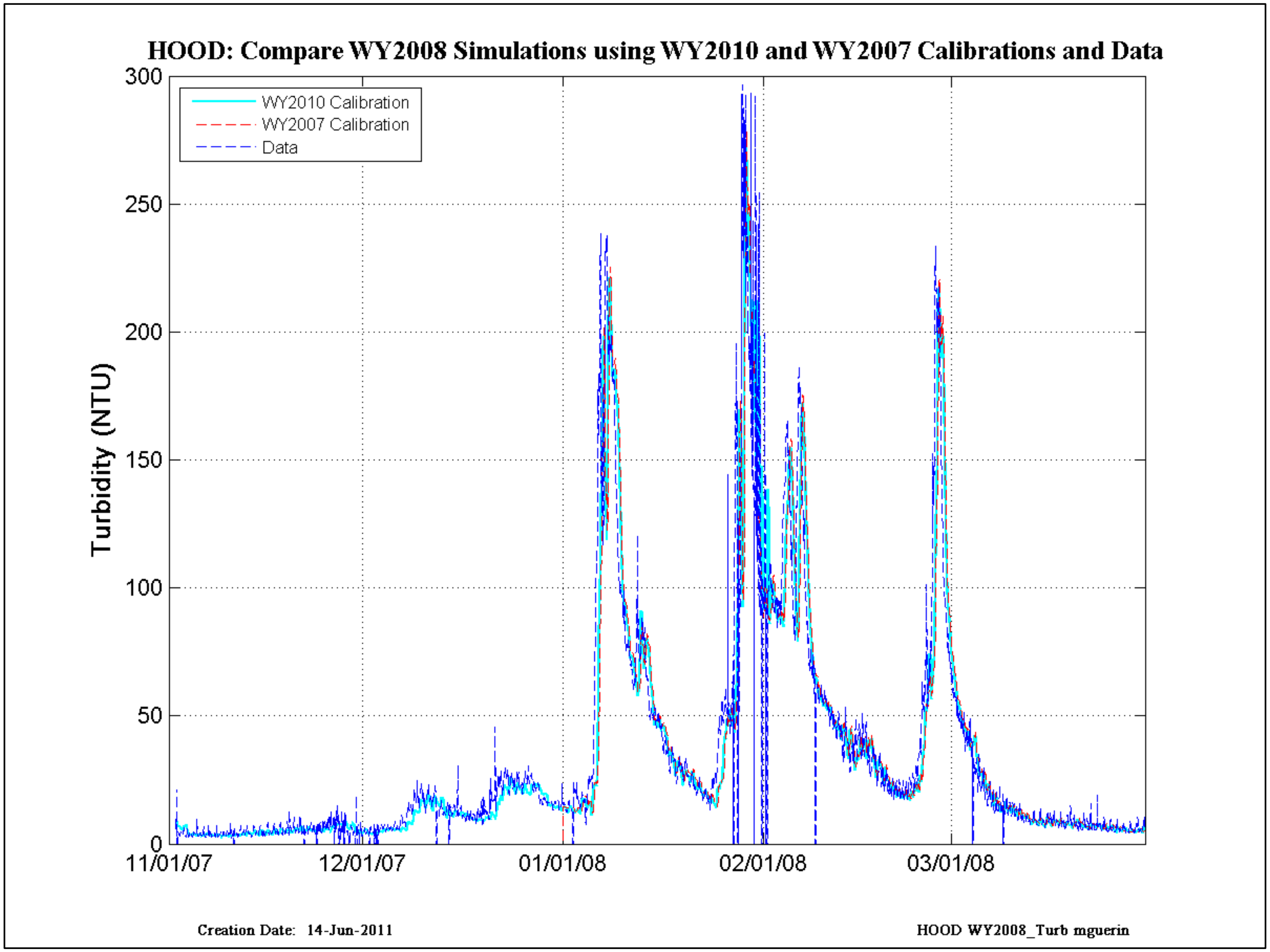

Figure 6-20 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Hood.

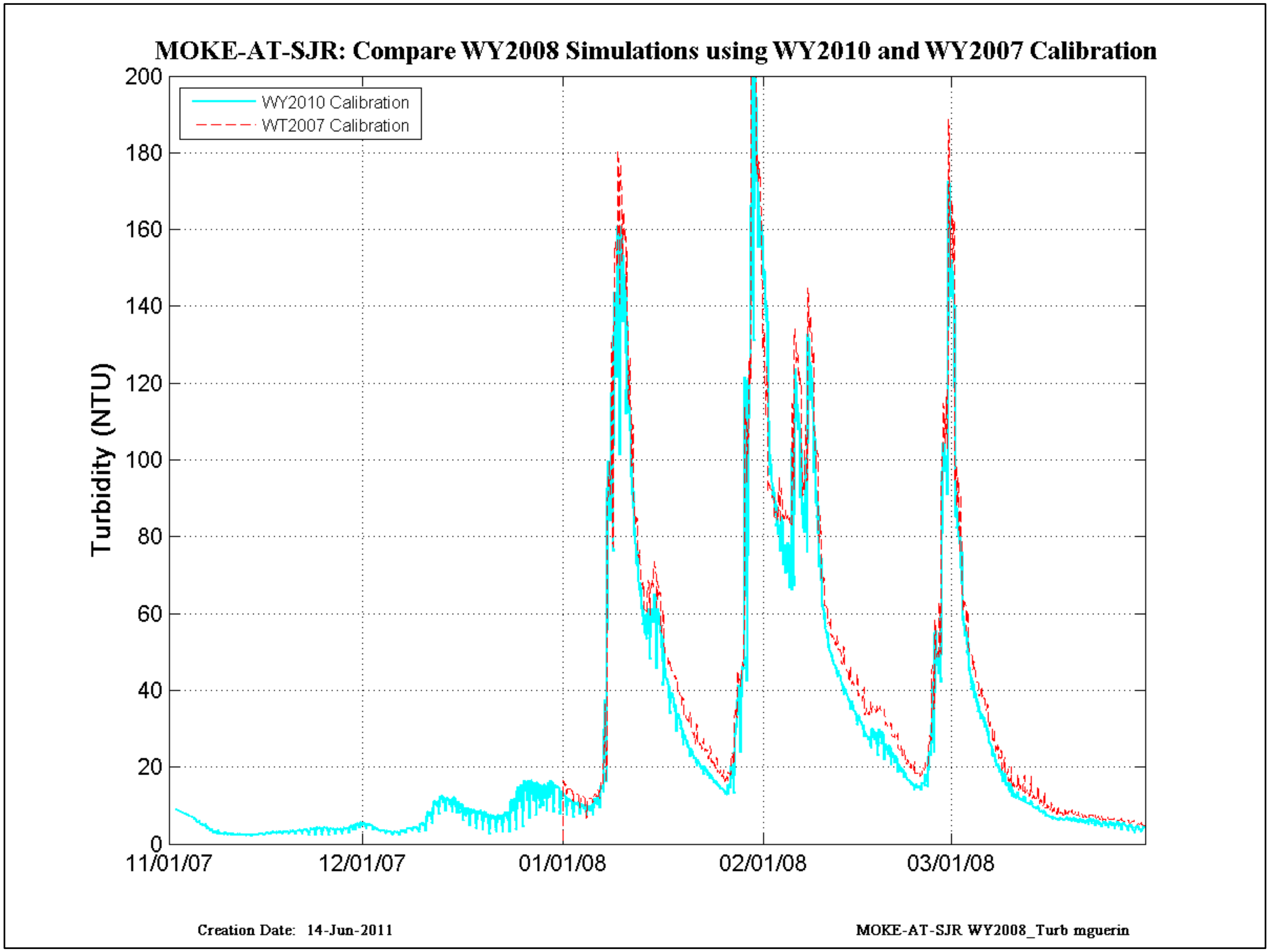

Figure 6-21 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations at Mokelumne-at-SJR.

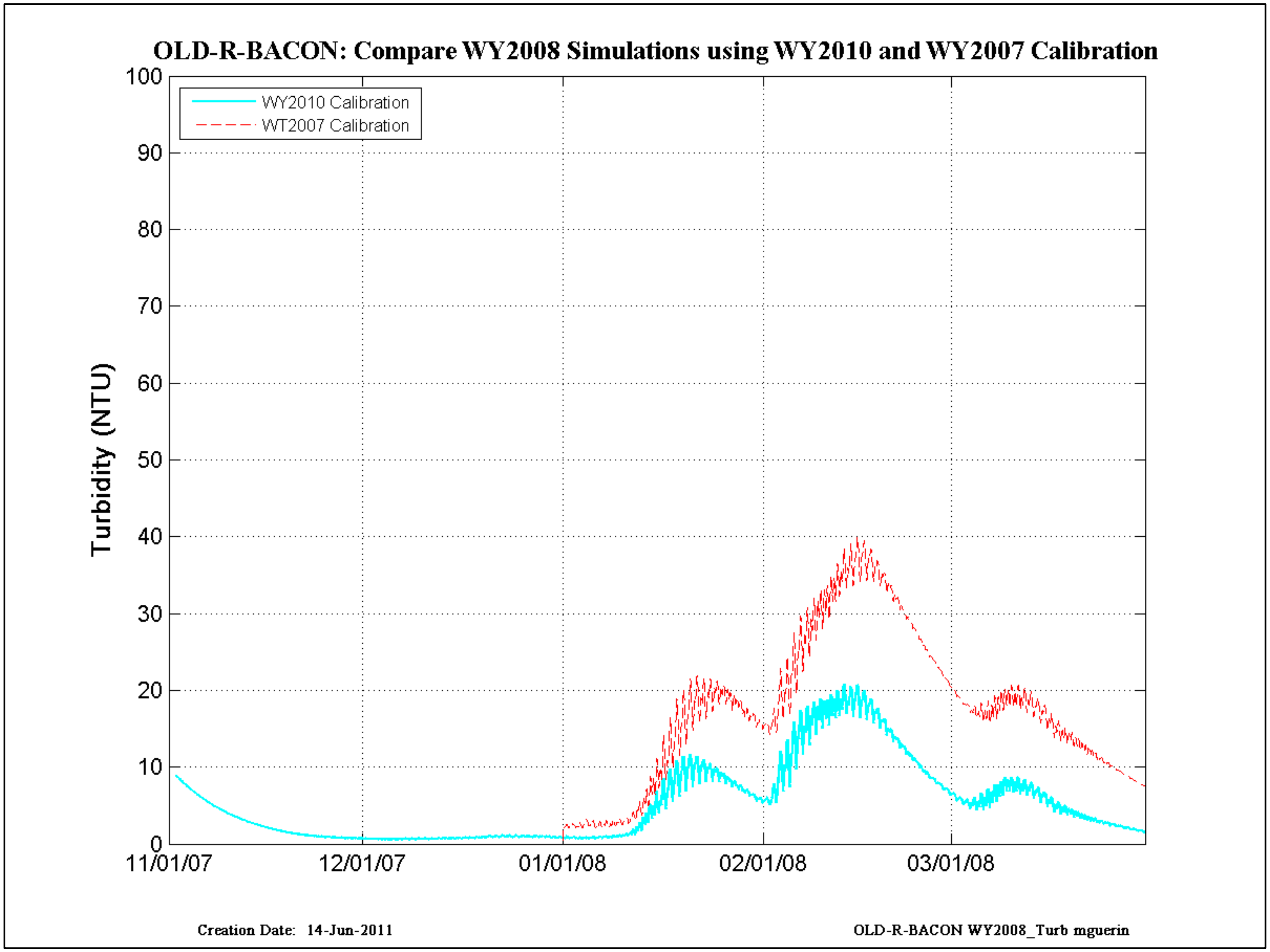

Figure 6-22 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations at Old-River-at-Bacon.

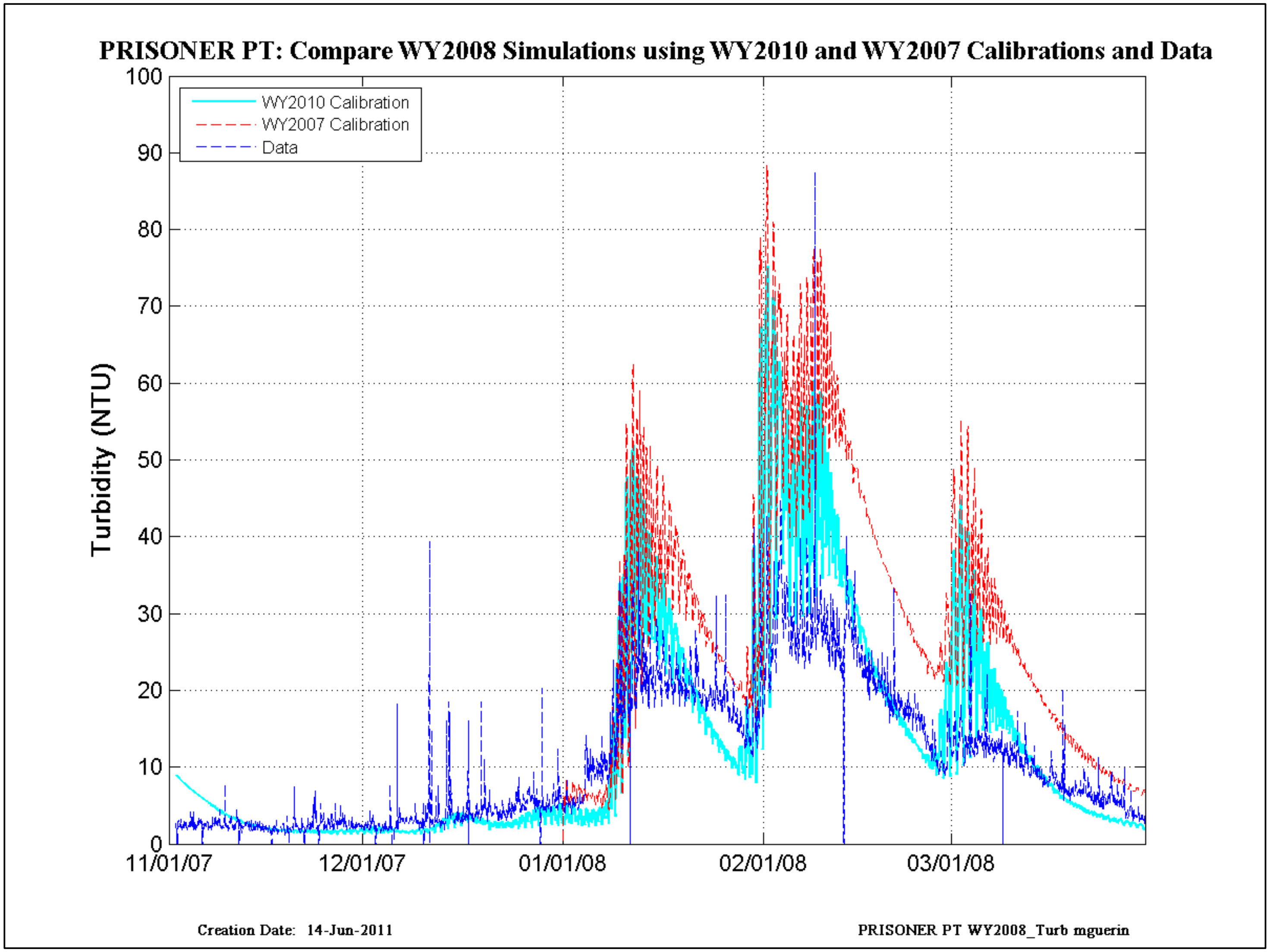

Figure 6-23 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Prisoner Point.

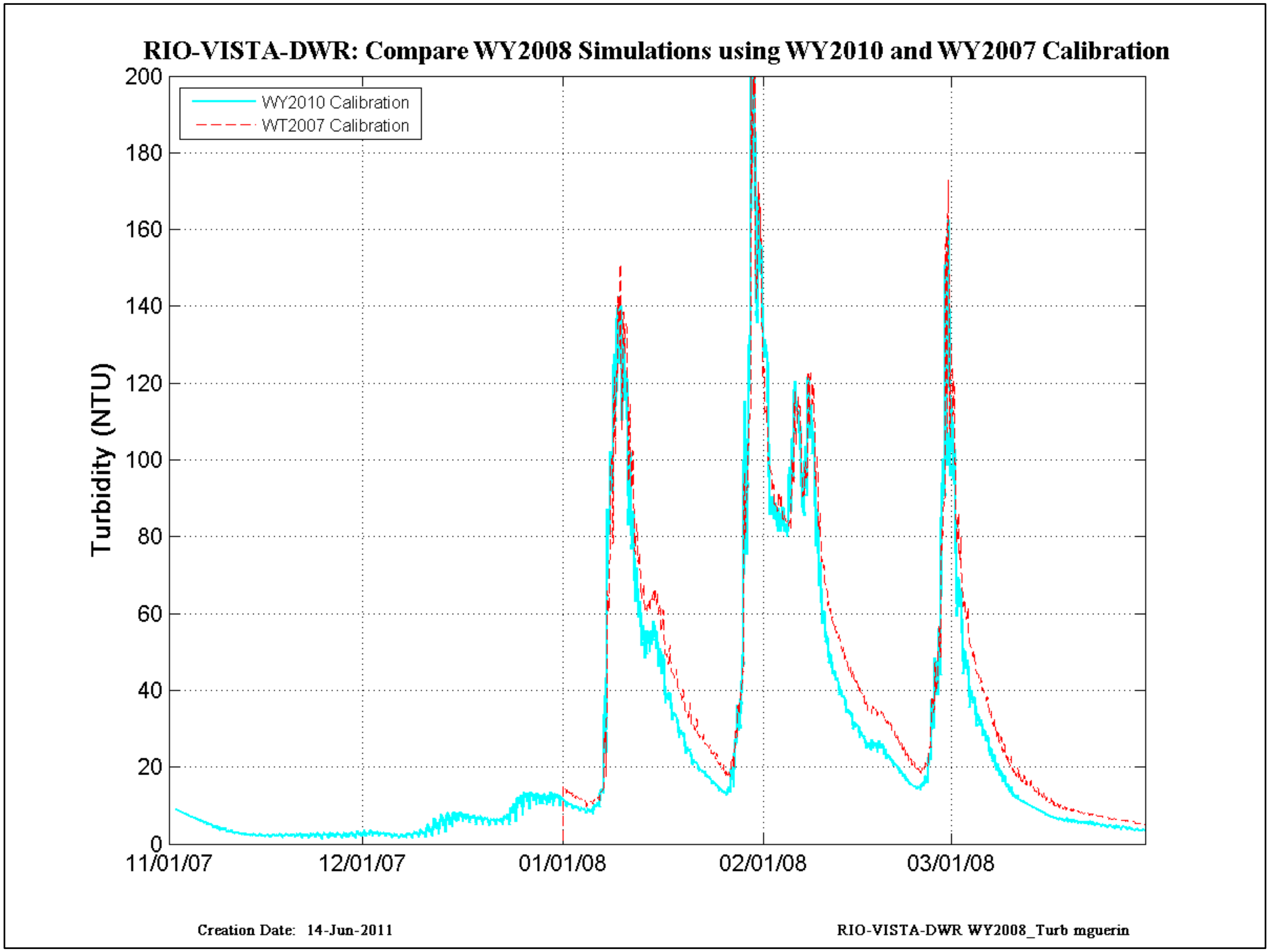

Figure 6-24 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations at Rio Vista.

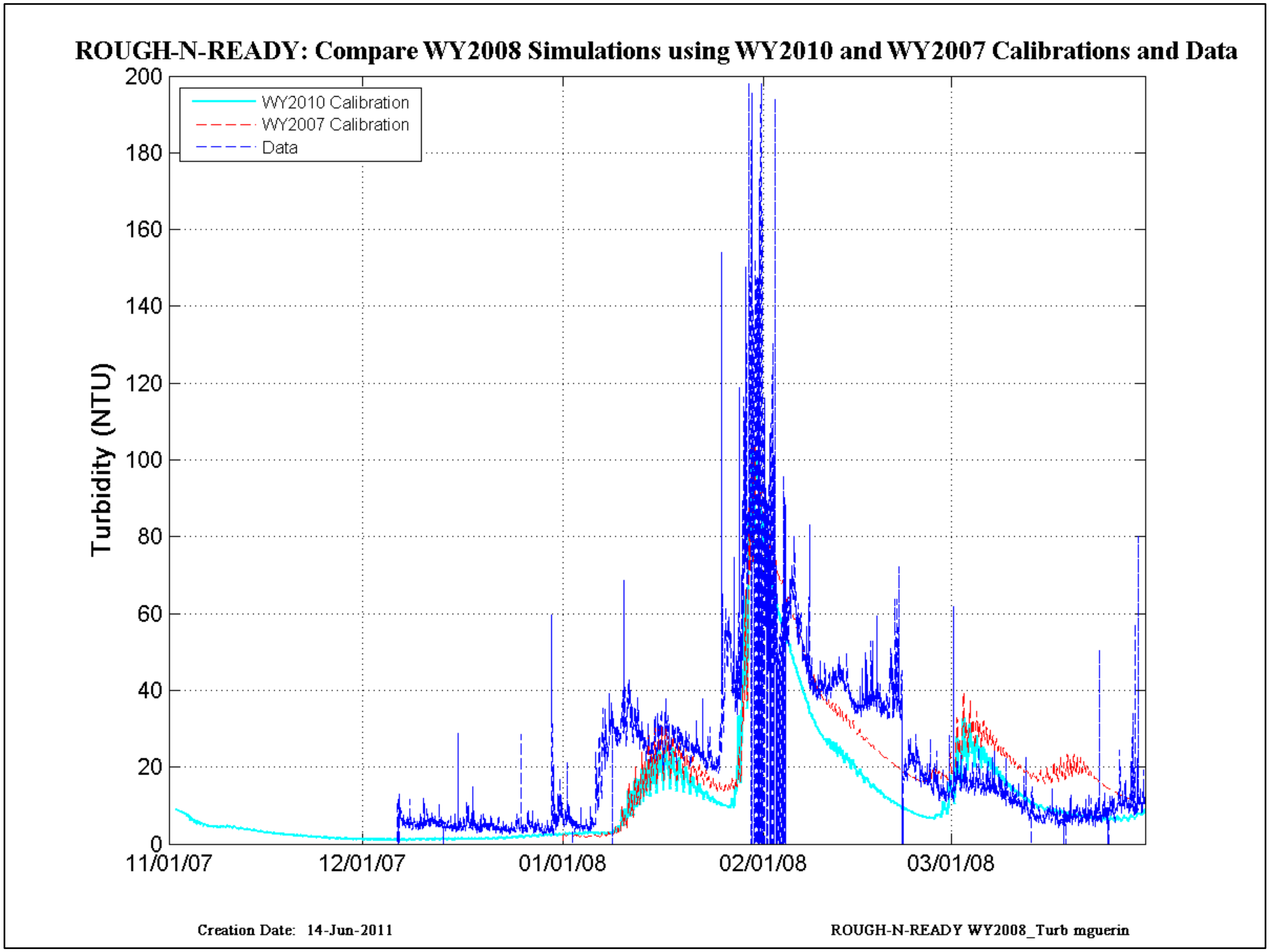

Figure 6-25 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Rough-N-Ready Island.

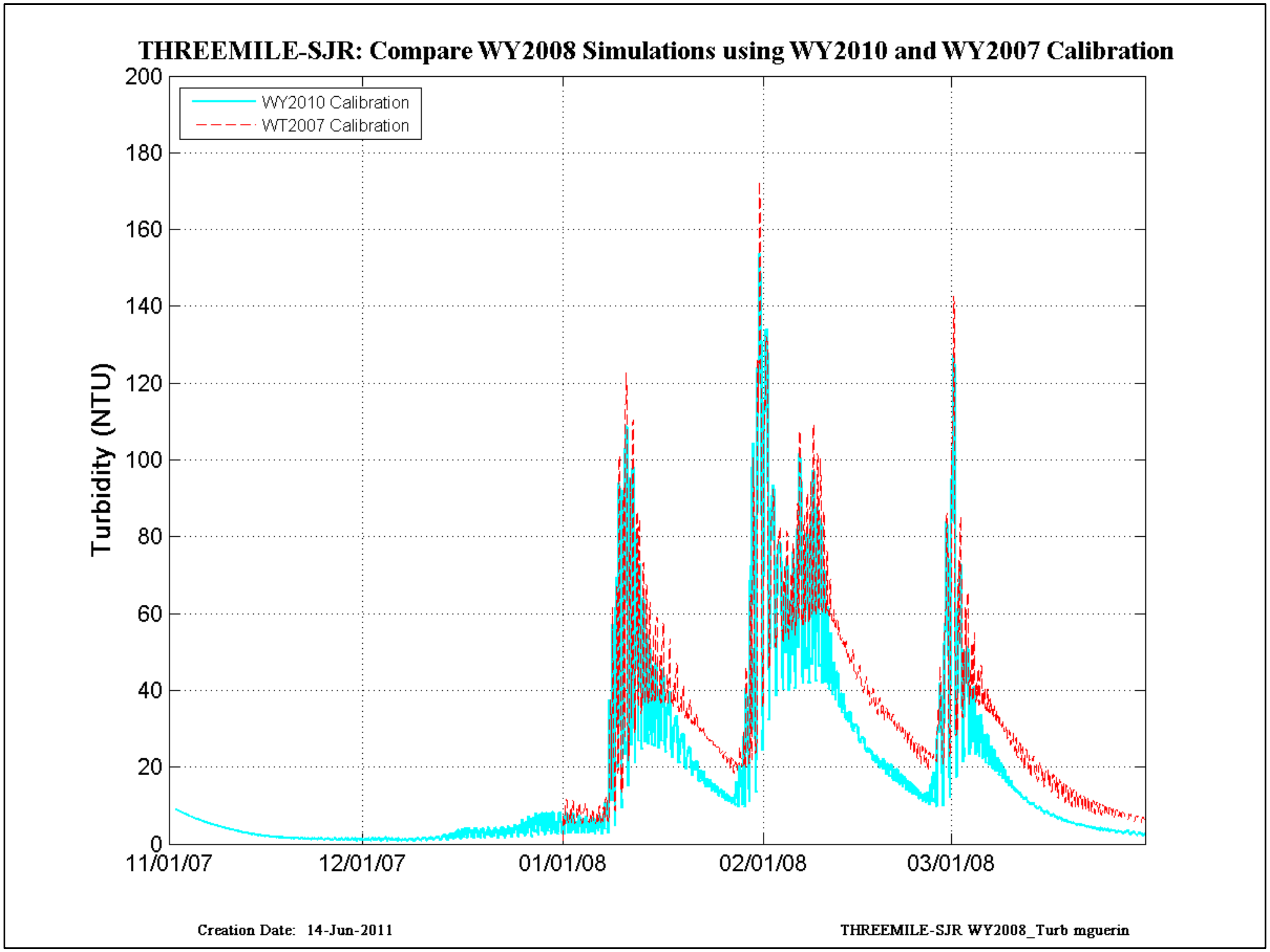

Figure 6-26 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations at Threemile-at-SJR.

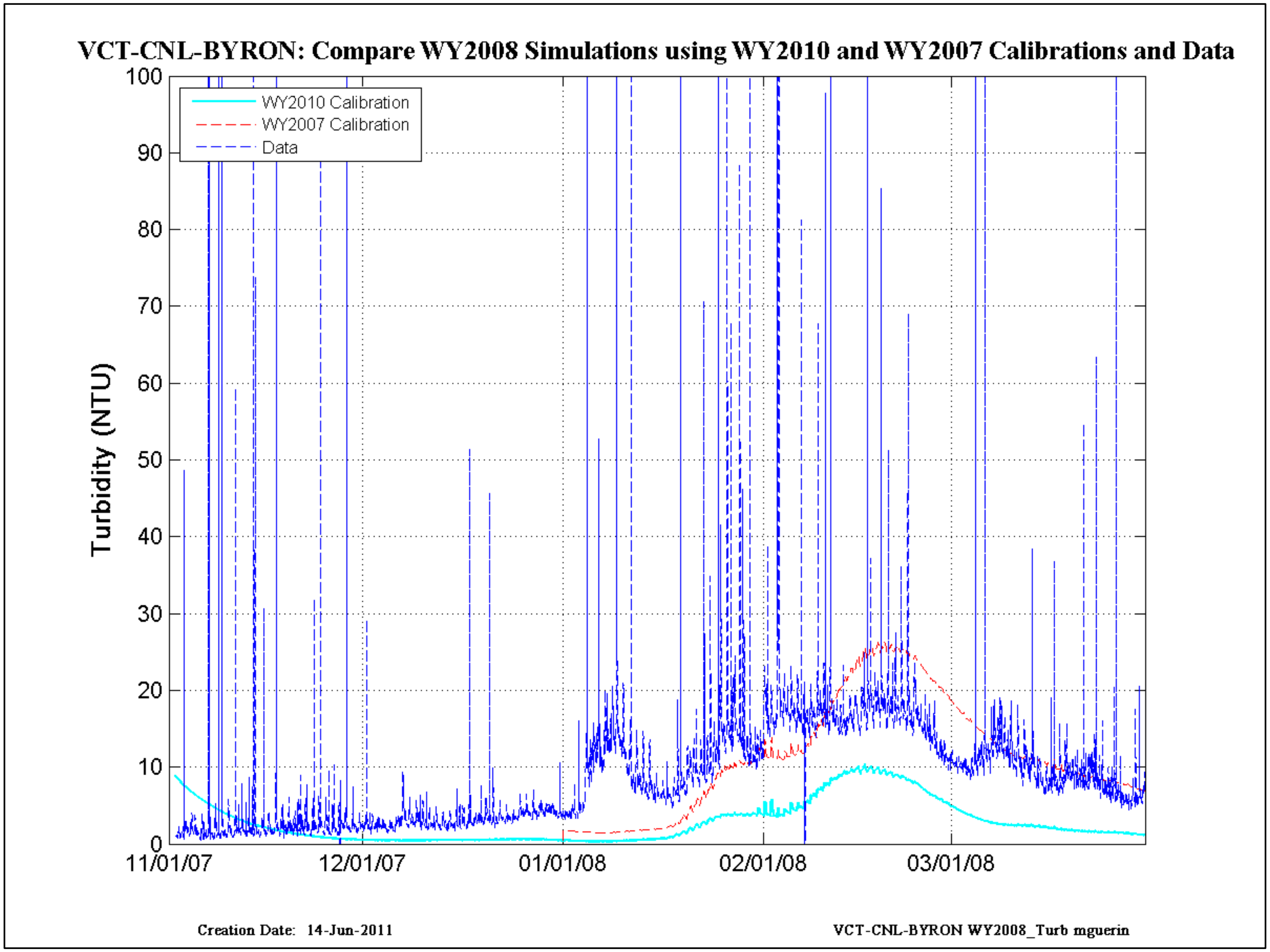

Figure 6-27 Comparison: WY2008 Turbidity simulations using WY2007 and WY2010 calibrations and data at Victoria-Canal-at-Byron.

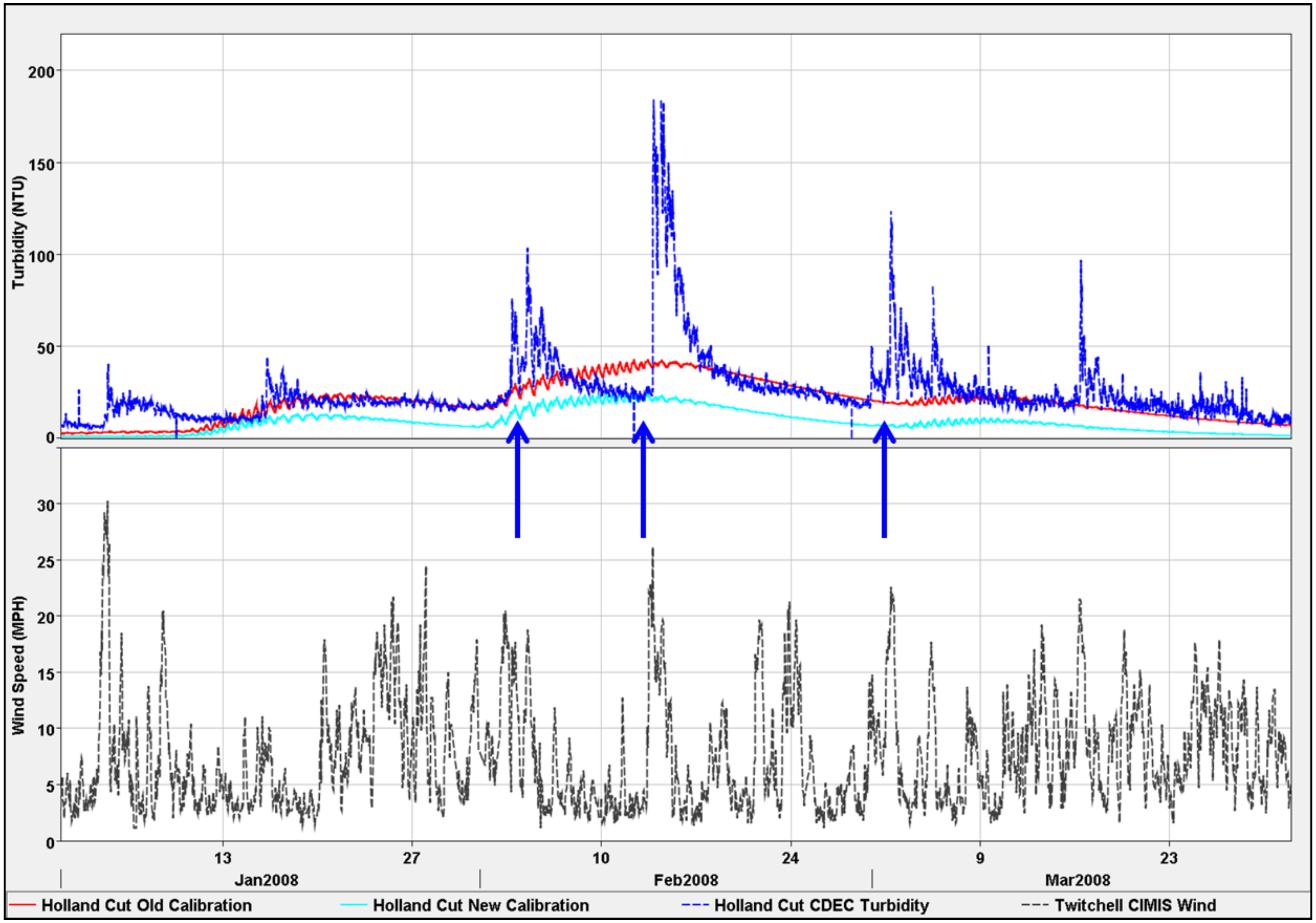

Figure 6-28 Wind effects (black dash, lower plot) can be seen in Holland Cut measurement data (blue dash, upper plot and blue arrows), but not in the model results. The WY2007 calibration simulation (red, upper) presents a better fit to data than the WY2010 calibration (cyan, upper) at Holland Cut.

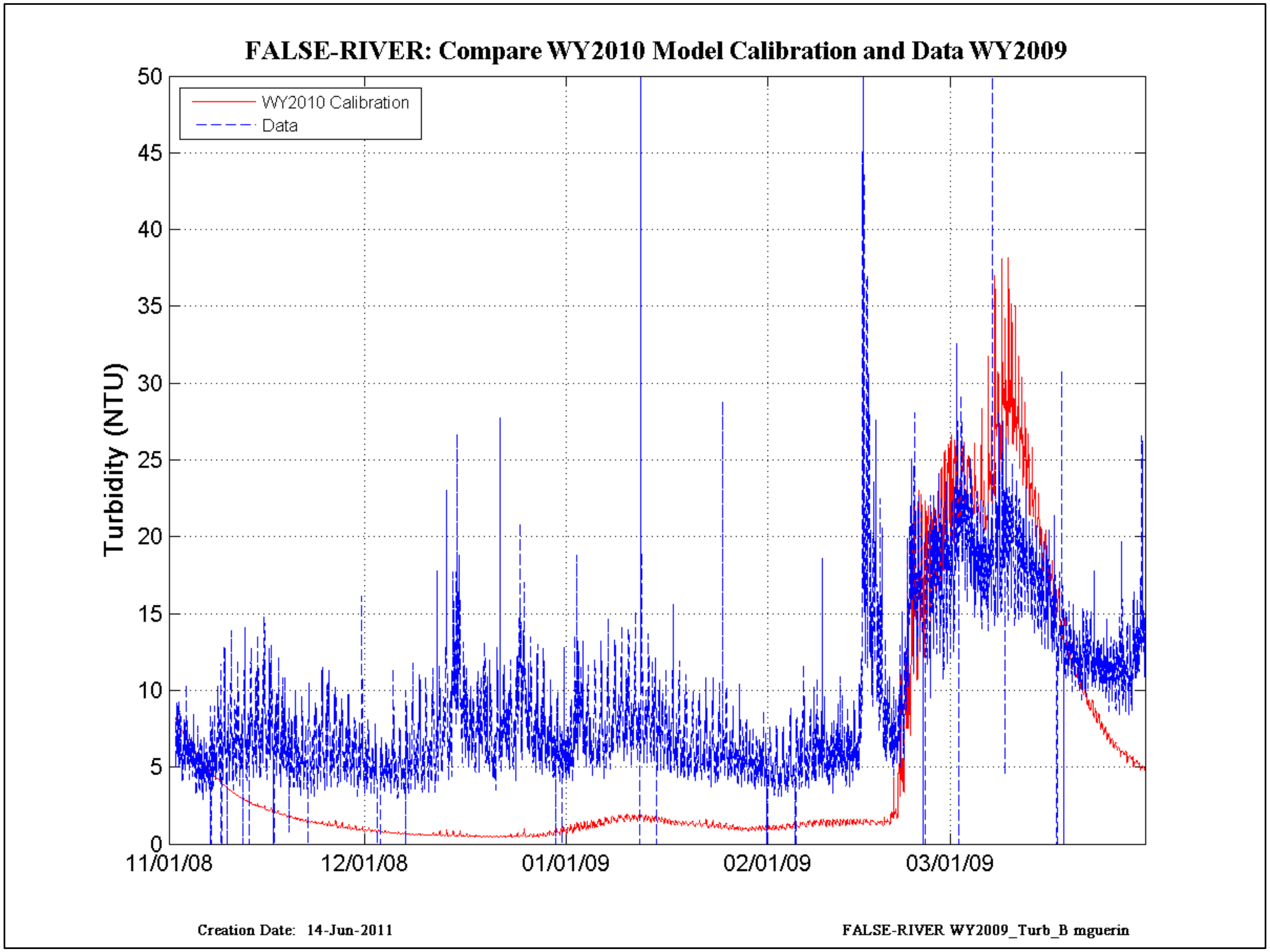

Figure 6-29 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at False River.

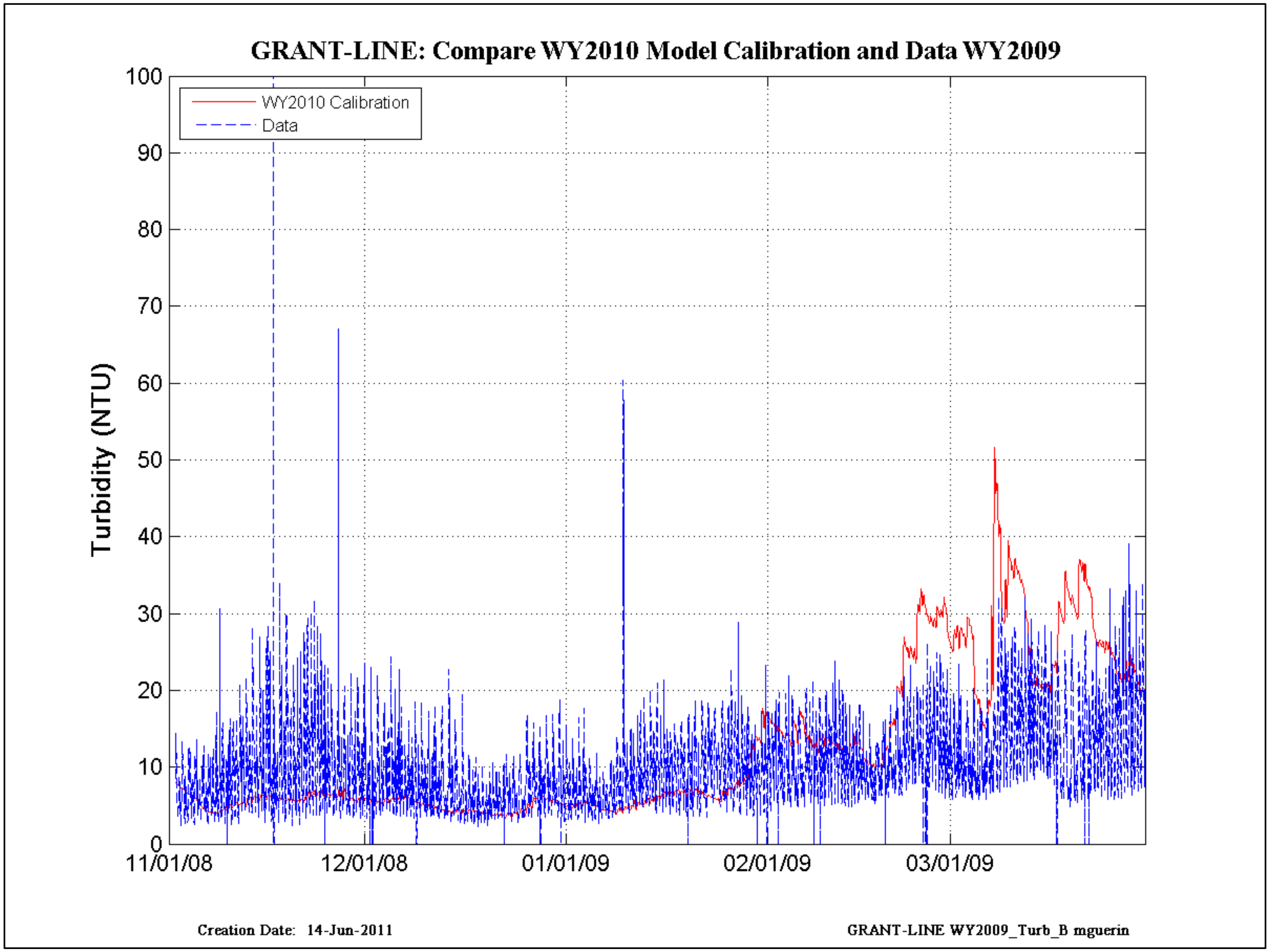

Figure 6-30 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Grant Line.

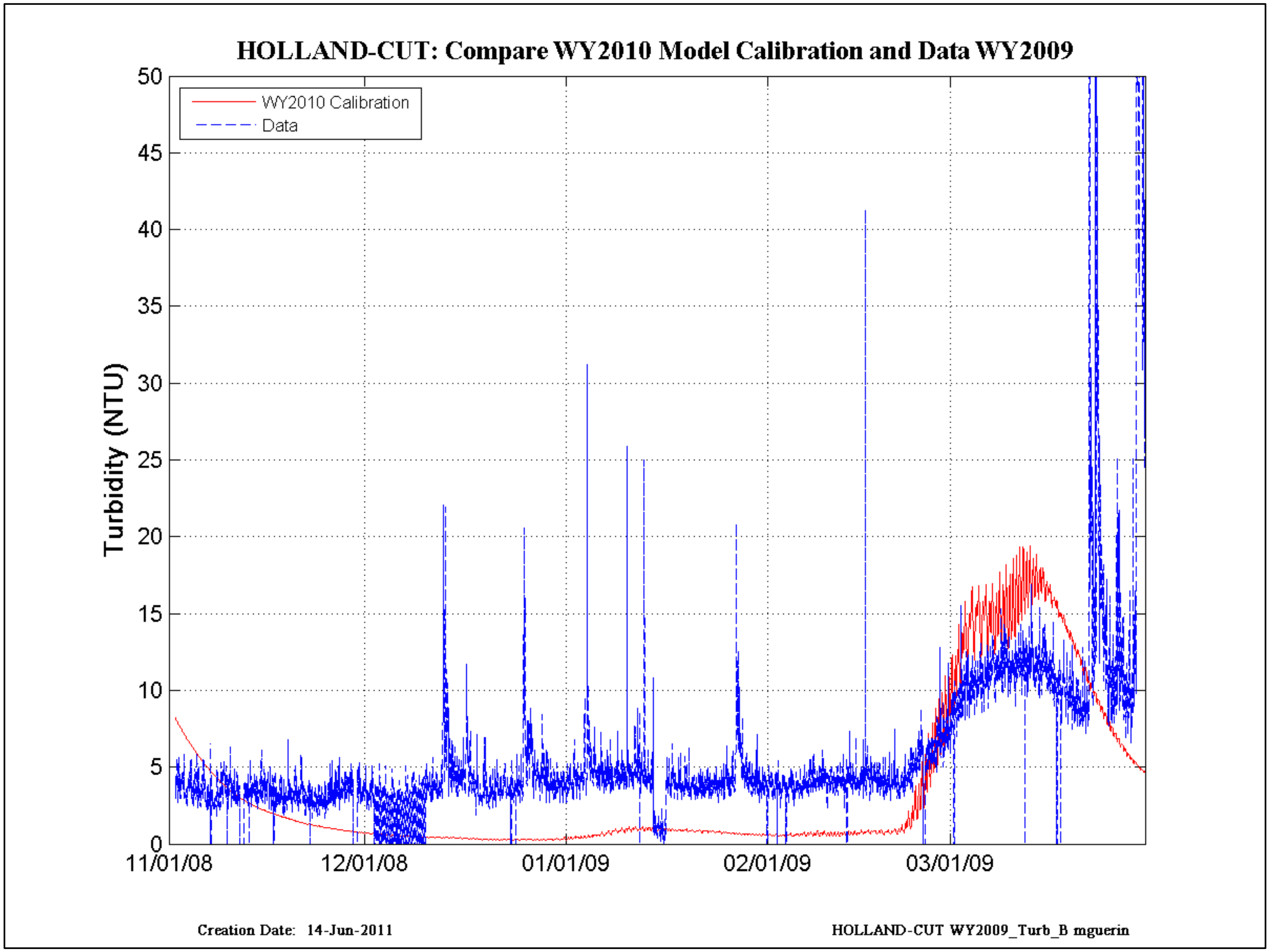

Figure 6-31 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Holland Cut.

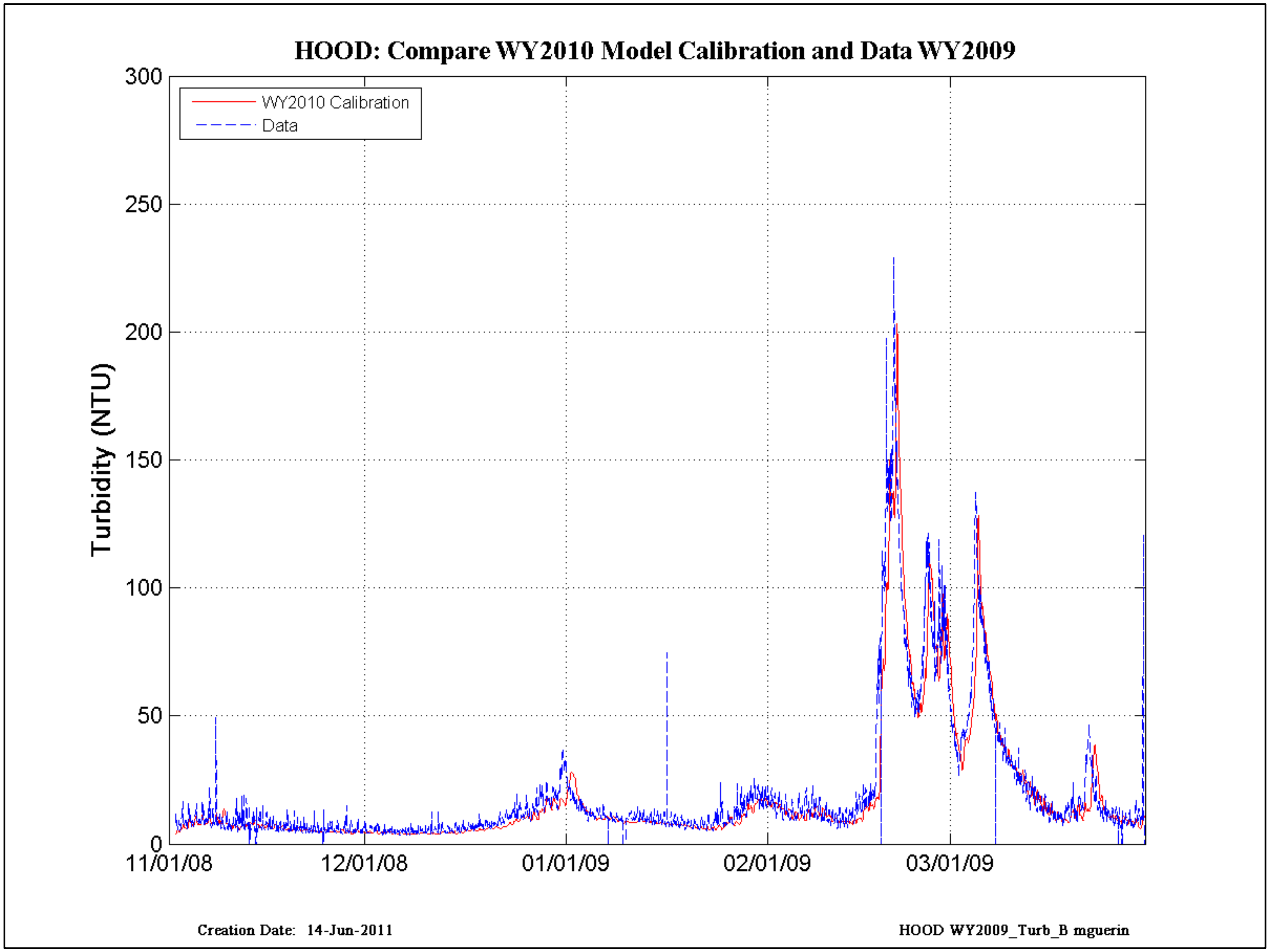

Figure 6-32 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Hood.

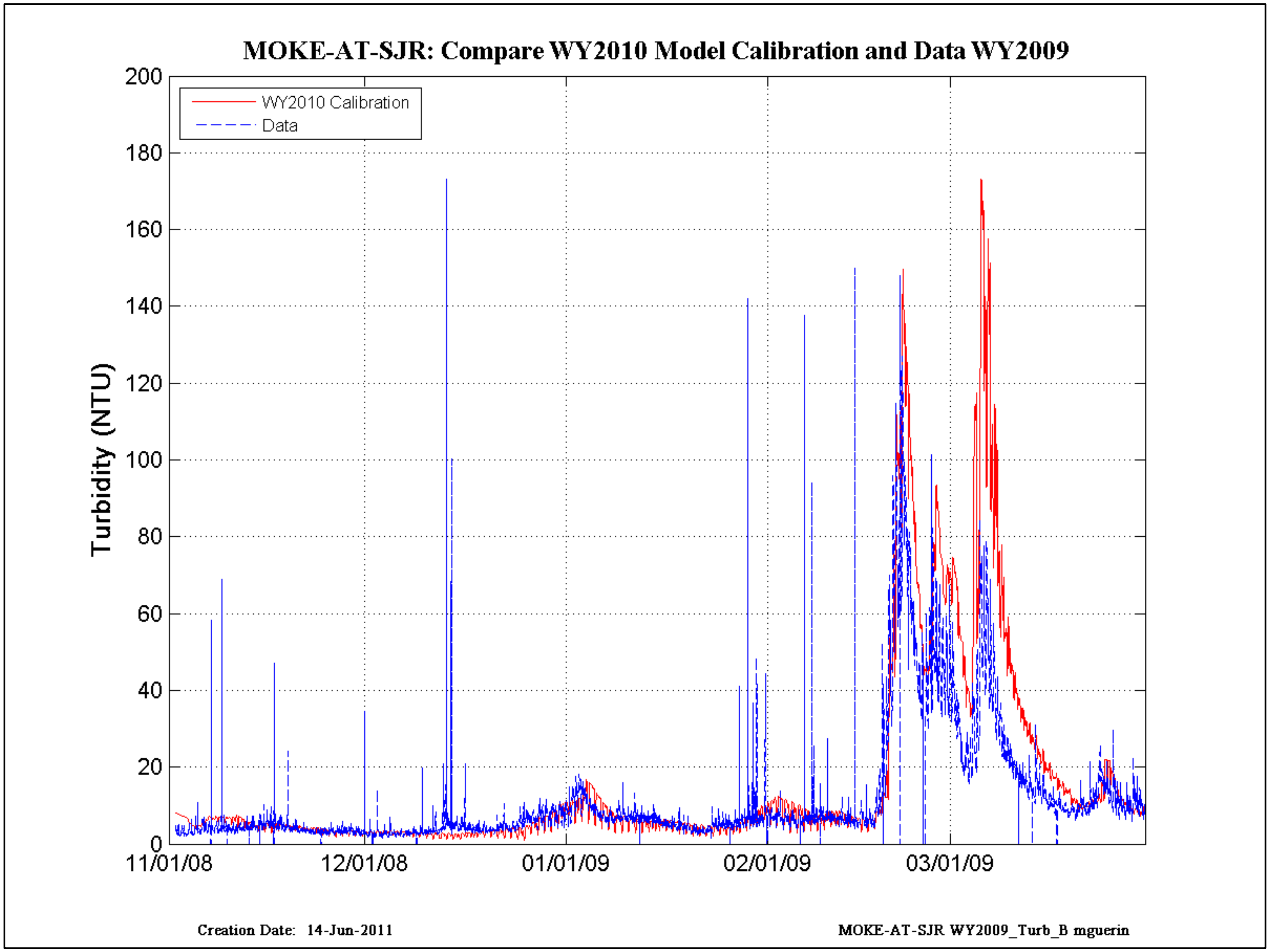

Figure 6-33 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Mokelumne-at-SJR.

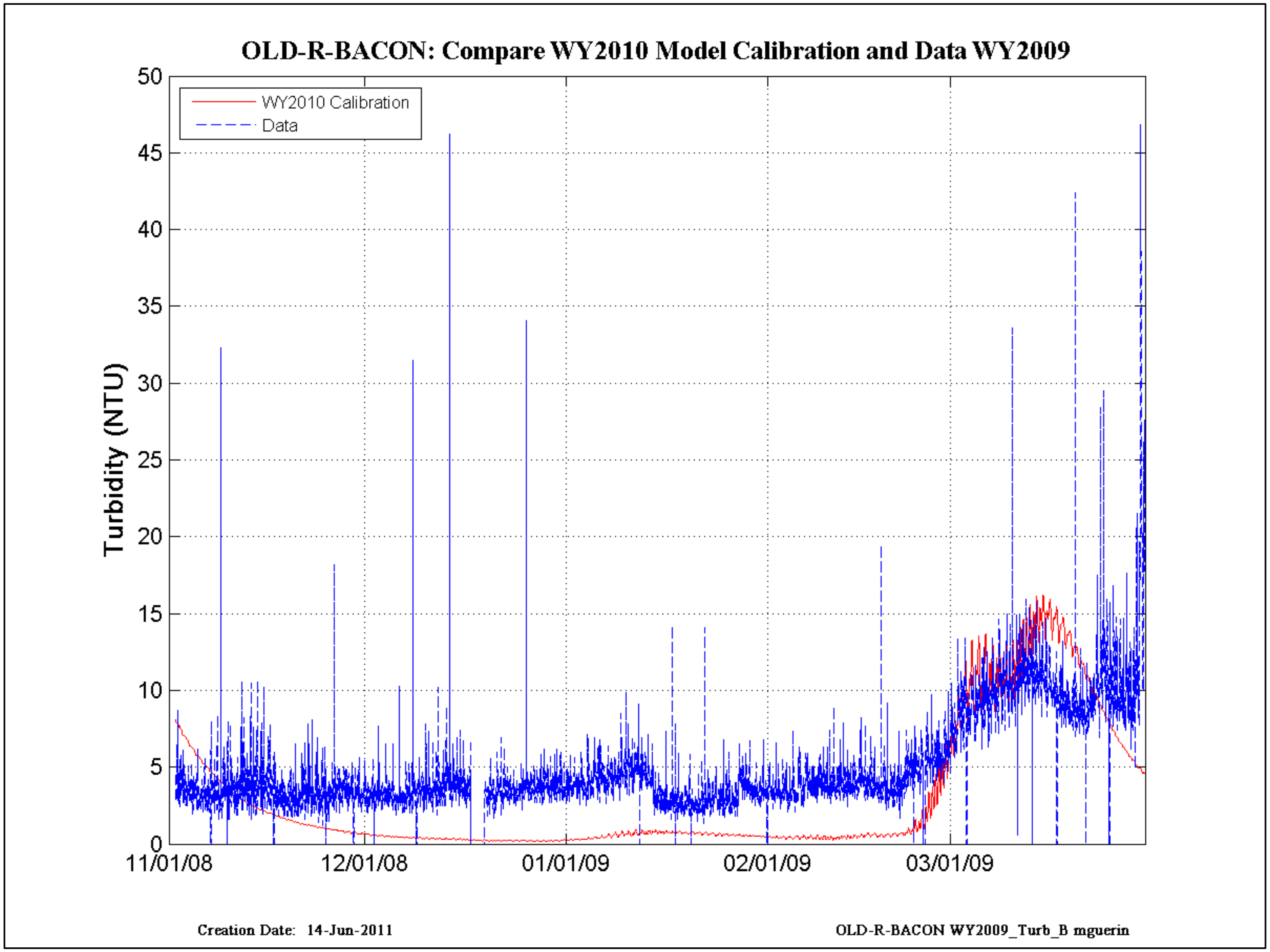

Figure 6-34 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Old-River-at-Bacon.

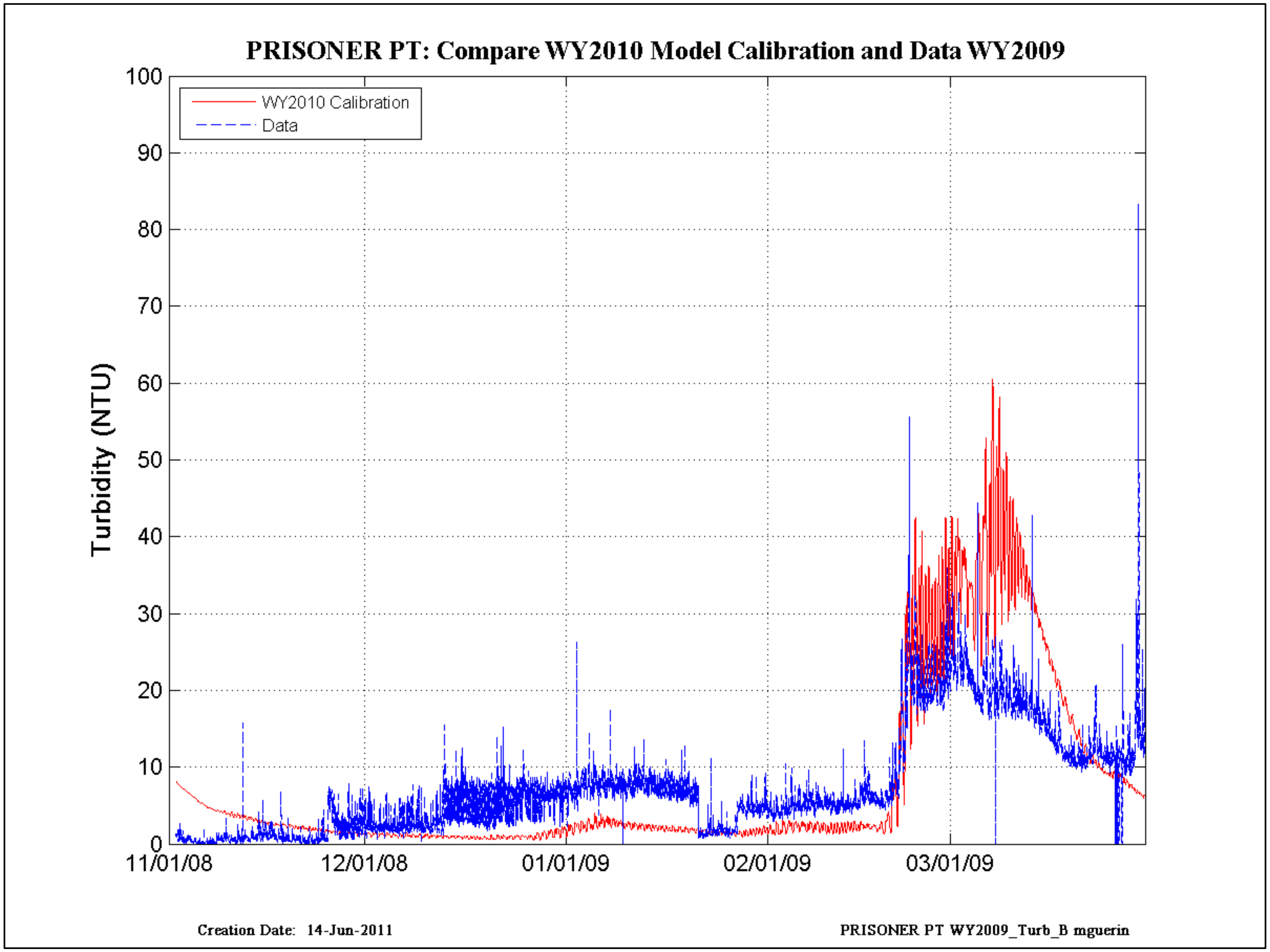

Figure 6-35 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Prisoner Point.

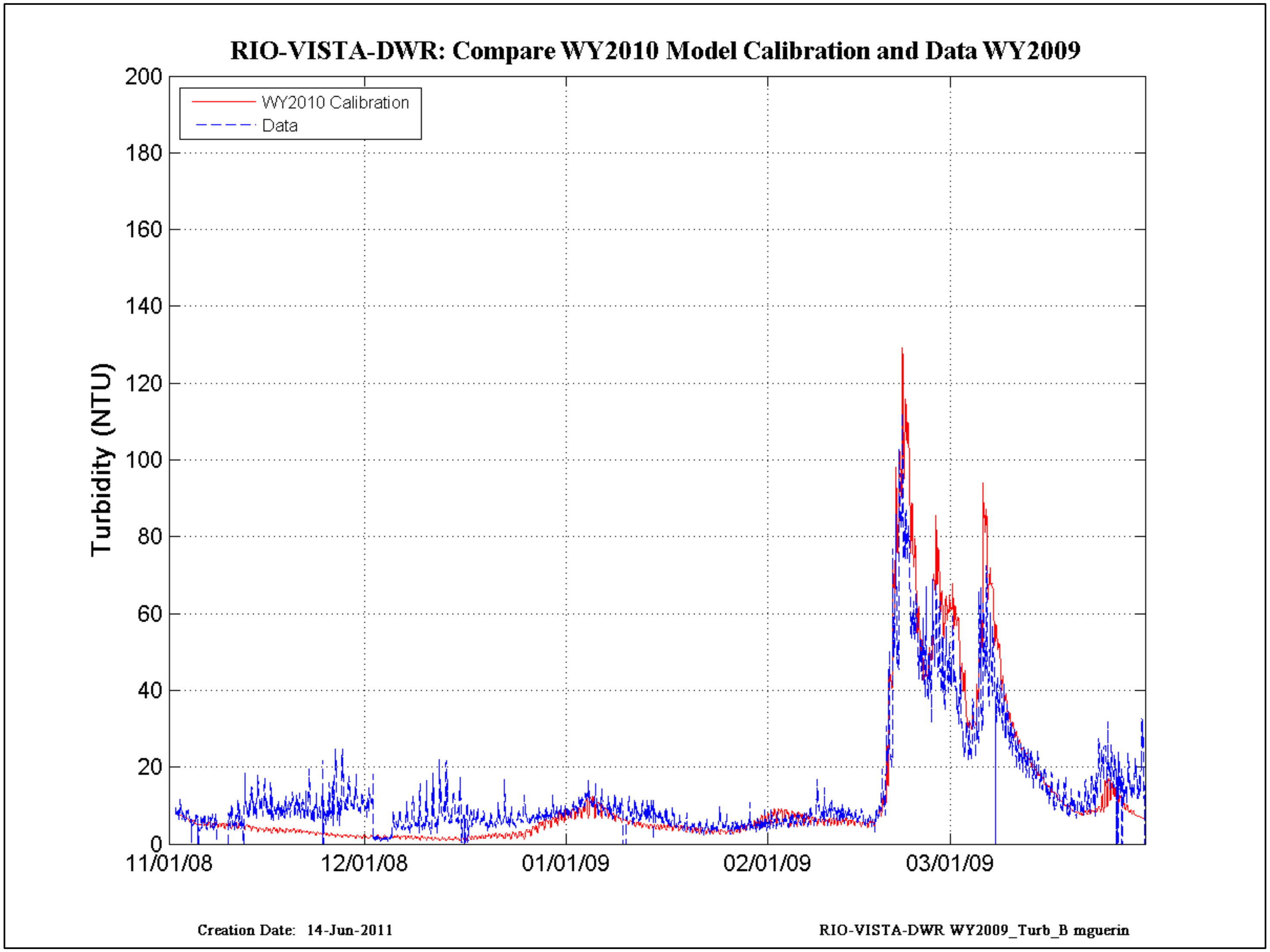

Figure 6-36 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Rio Vista.

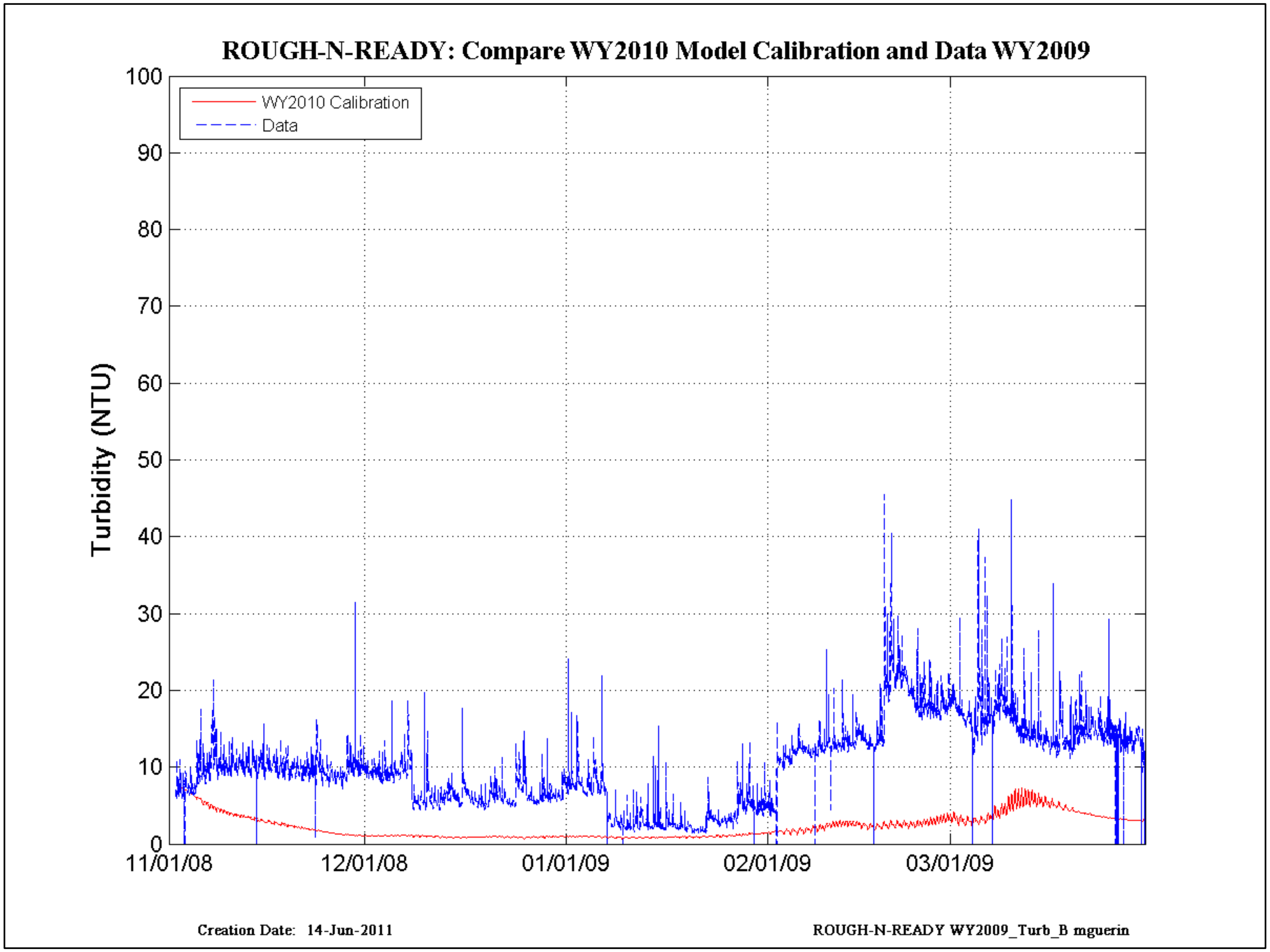

Figure 6-37 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Rough-N-Ready Island.

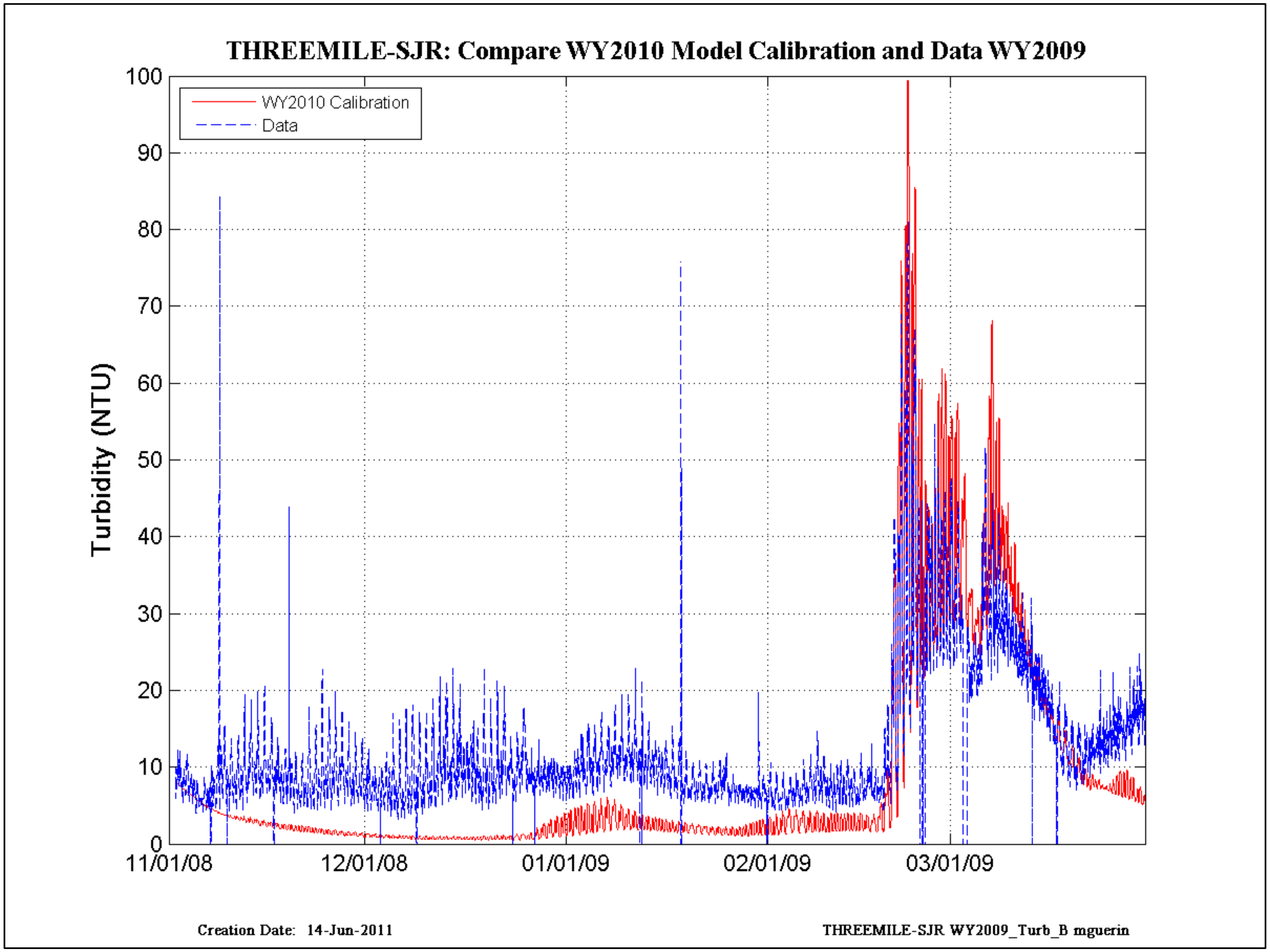

Figure 6-38 Comparison of WY2010 turbidity model calibration and data in WY2009 Hindcast at Threemile-at-SJR.

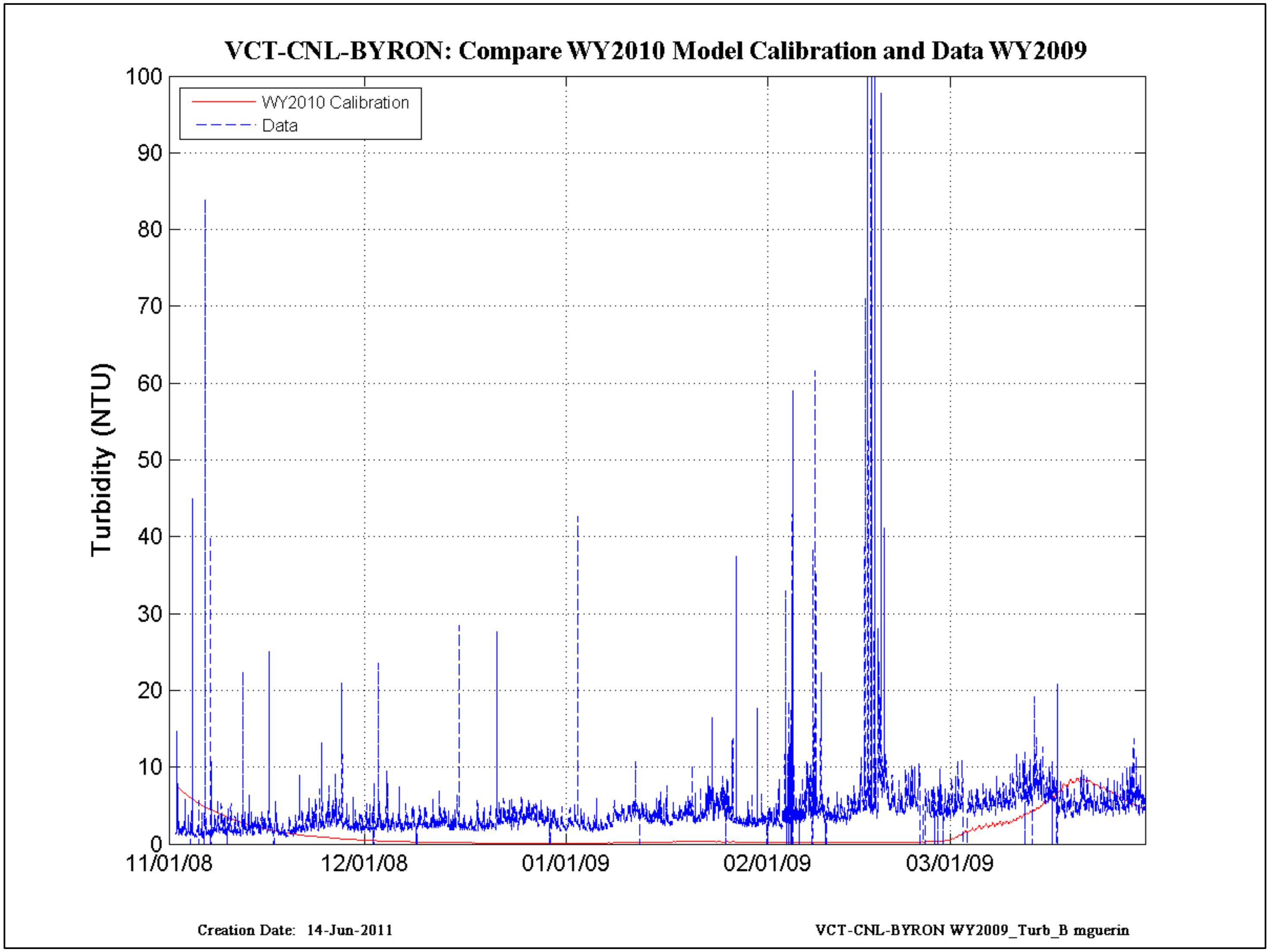

Figure 6-39 Comparison of WY2010 turbidity model calibration and data in WY2008 at Victoria-Canal-at-Byron.

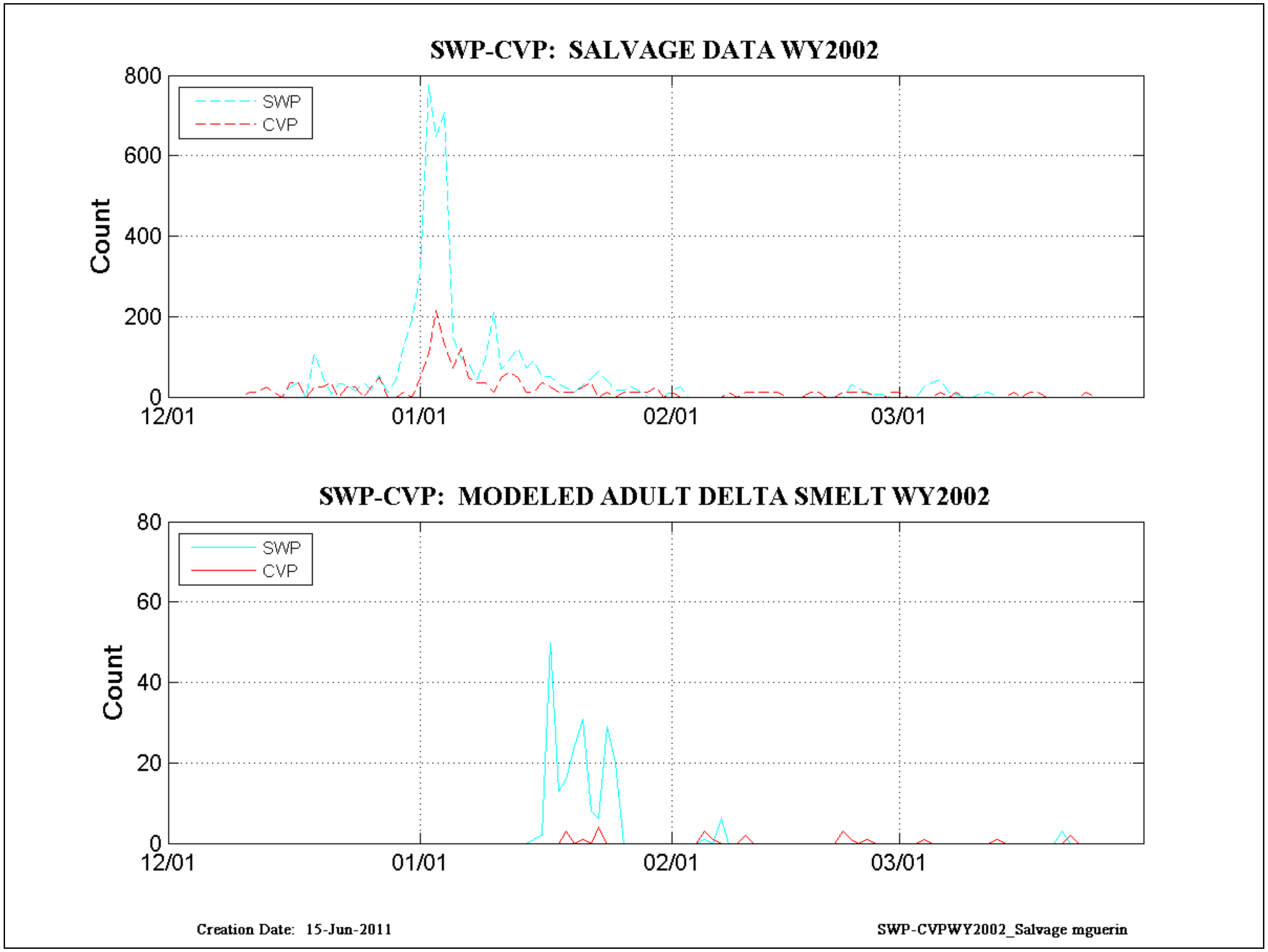

Figure 6-40 Upper plot shows the salvage count of adult delta smelt at the SWP and CVP exports locations in WY2002. Lower plot shows the modeled particle count out of 50,000 particles inserted.

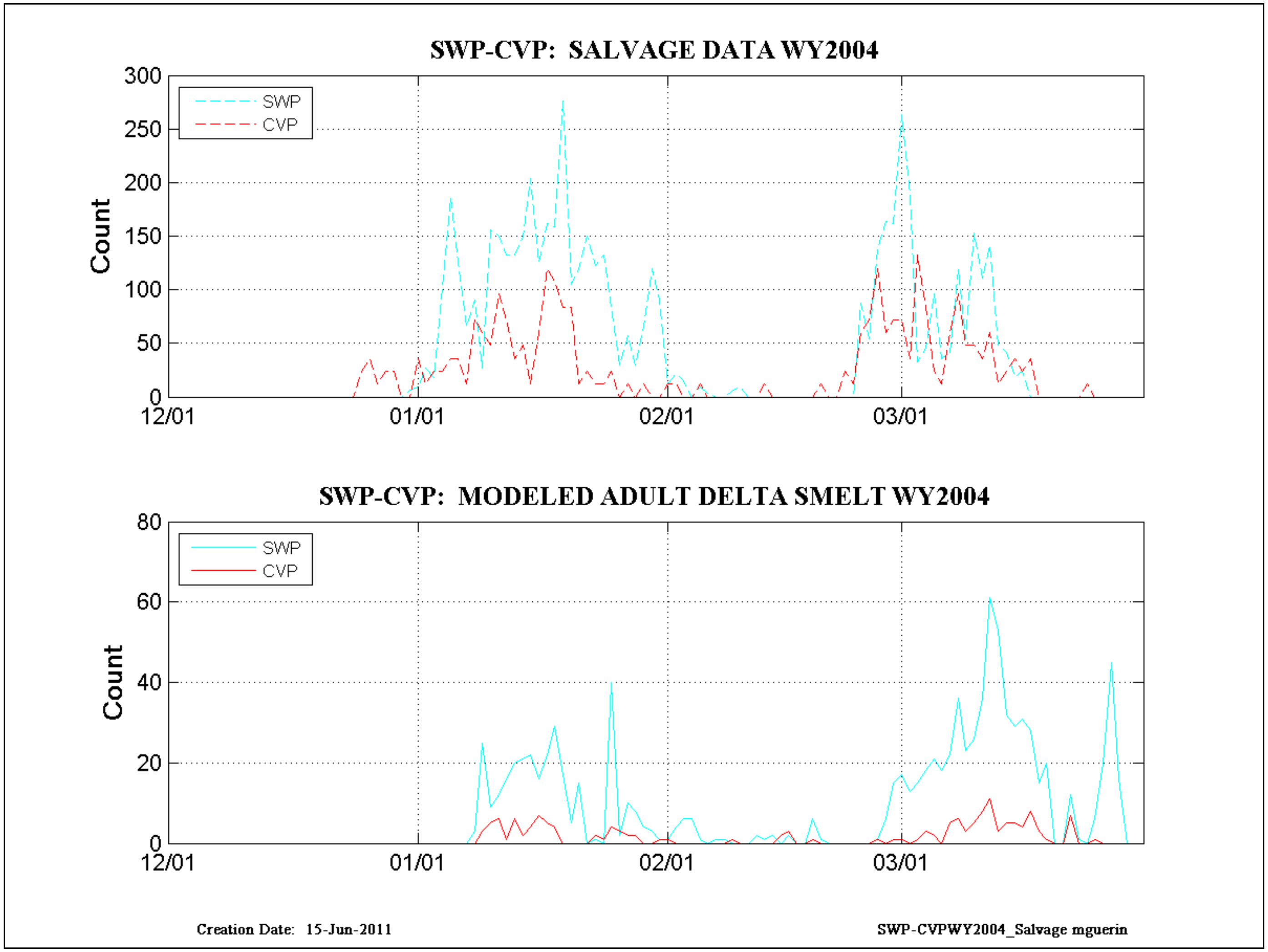

Figure 6-41 Upper plot shows the salvage count of adult delta smelt at the SWP and CVP exports locations in WY2004. Lower plot shows the modeled particle count out of 50,000 particles inserted.

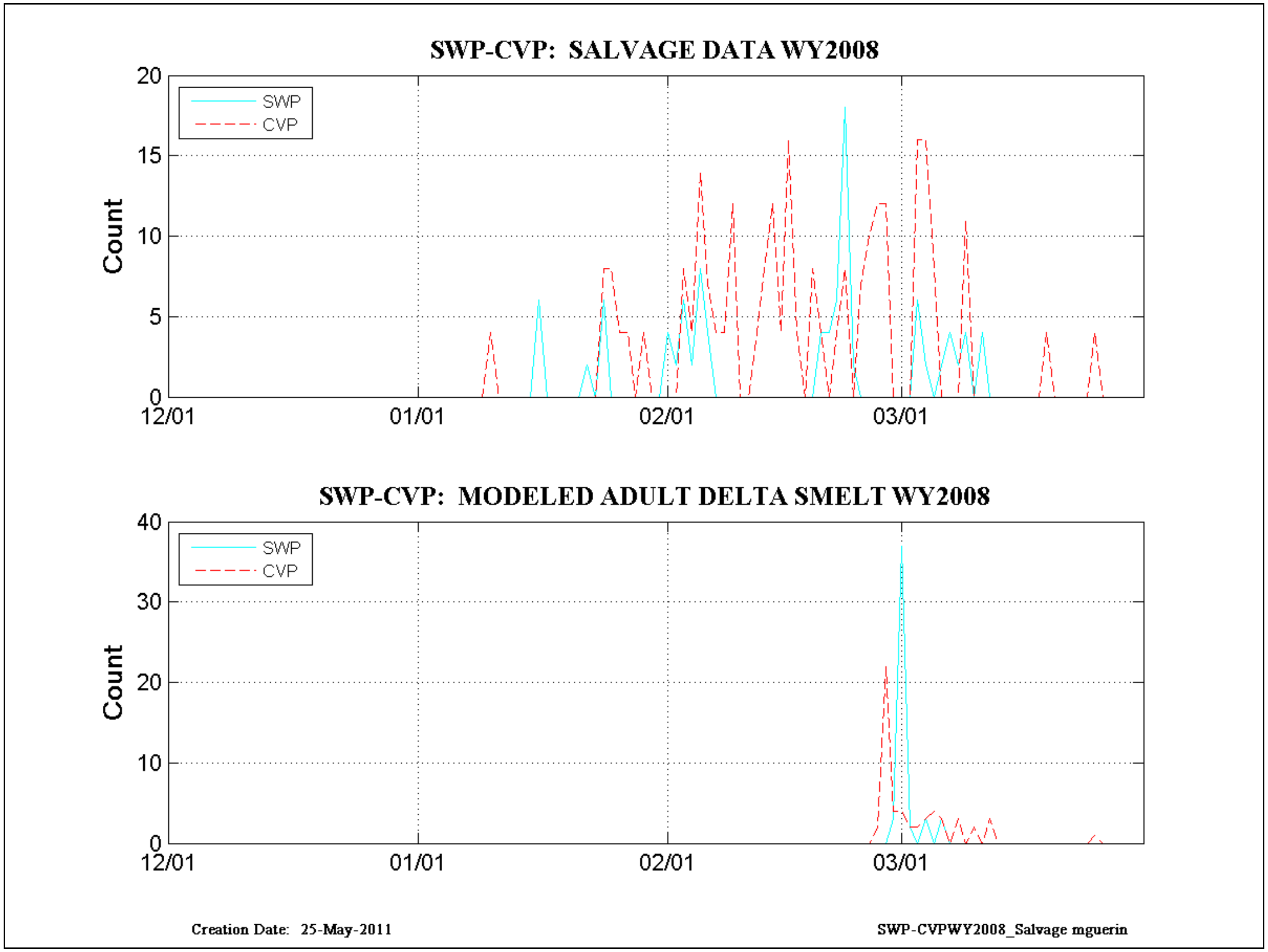

Figure 6-42 Upper plot shows the salvage count of adult delta smelt at the SWP and CVP exports locations in WY2008. Lower plot shows the modeled particle count out of 50,000 particles inserted.

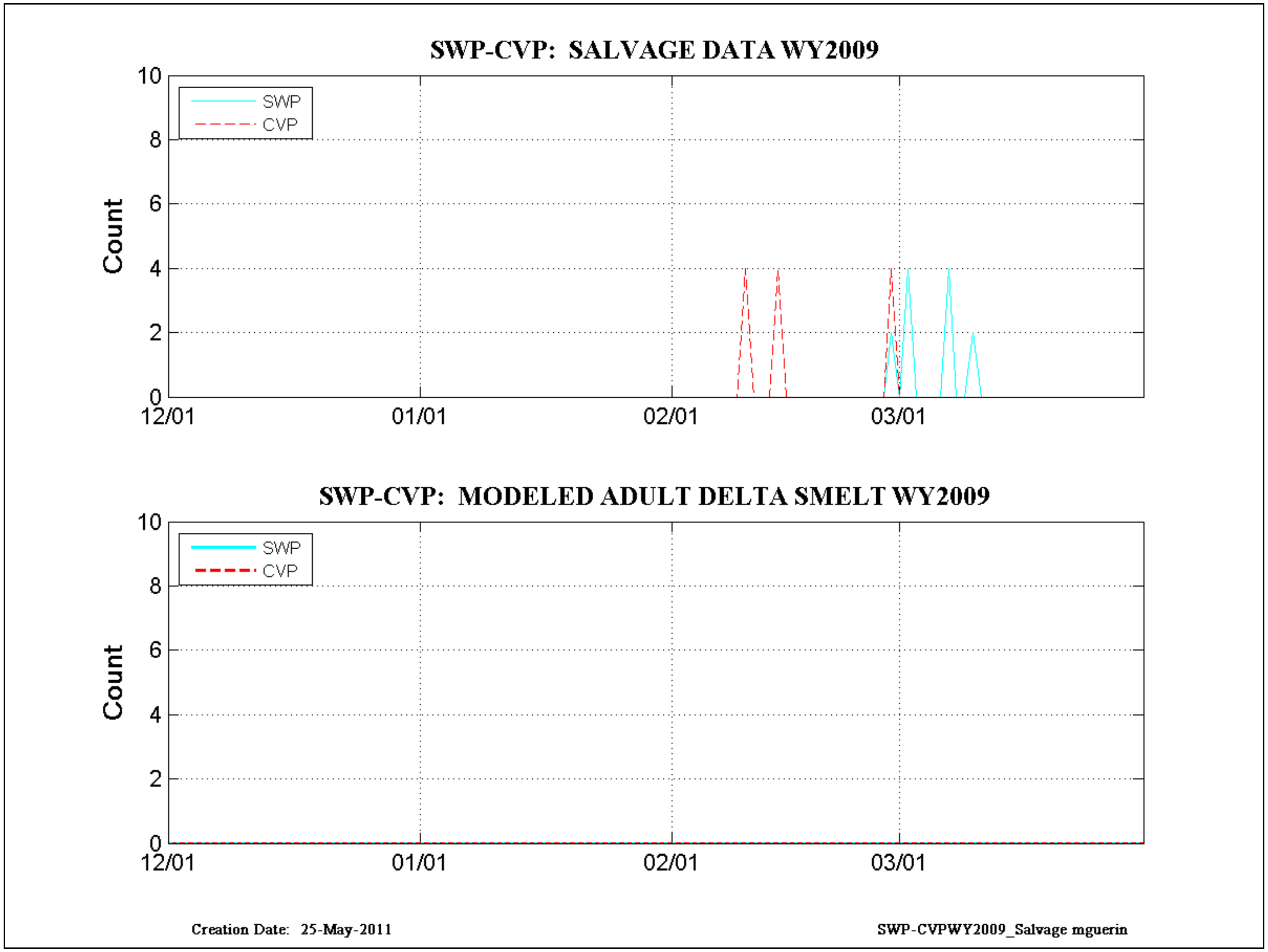

Figure 6-43 Upper plot shows the salvage count of adult delta smelt at the SWP and CVP exports locations in WY2009. Lower plot shows the modeled particle count out of 50,000 particles inserted.

7. Discussion

There were two objectives behind the work covered in this document – as an illustration of the WY2010 calibration of the RMA turbidity model in previous WYs and as a test of the adult delta smelt particle tracking model parameterization developed with the WY2007 turbidity calibration, but using the turbidity distributions calculated with the WY2010 calibration model for the simulations discussed in this document.

Four different simulation periods were run – the winter periods of WY2002, WY2004, WY2008 and WY2009 – with turbidity simulations implementing the WY2010 calibration. The WY2010 turbidity calibration has been implemented with variable results in four WYs, some of which are covered in separate documents (RMA2010b, 2011). The WY2002 and WY2004 hindcasts did not have turbidity available to specify the Sacramento and San Joaquin River boundary conditions. Of these four, the simulation period where turbidity model results were the poorest in comparison with data, WY2007, is also the year with the least data and where data quality was generally noisy. When also considering the recent WY2010 and WY2011 hindcasts, the simulation period where results were the best, WY2011, is also the year where there was the most data and data quality was generally very good, with few suspect measurement periods.

In comparing the model set-ups and simulation results using the WY2007 and WY2010 turbidity model calibrations in WY2002 and WY2004 where SSC was used to prepare the Sacramento and San Joaquin boundaries, we can see three areas where there is approximately a factor of two difference between quantities: the first is that turbidity was approximated as NTU=SSC*0.5 (originally suggested by D. Fullerton, MWD); the second is in the central Delta where the WY2007 model calibration turbidity results are nearly a factor of two higher than the WY2010 calibration results; and, the third is that the decay rates in the WY2010 calibration are about a factor of two higher than the WY2007 calibration rates throughout much of the Delta.

As mentioned in Section 5.4, on the Sacramento River boundary (Figure 5-8), it is notable that the measured turbidity values for WY2008 and WY2009 are nearly double the estimated turbidity *(i.e.*, as SSC*0.5) values used for WY2002 and WY2004 despite generally lower flows (Figure 5-1). The situation is similar on the San Joaquin River. This suggests that the original approximation of turbidity as SSC*0.5 on the Sacramento and San Joaquin River boundaries may well be too low, perhaps by up to a factor of two. If the estimates of turbidity at the Sacramento and San Joaquin River boundaries were increased by a factor of two, as NTU=SSC, then it is likely that the in-Delta turbidity results for the WY2007 and WY2010 model calibrations would be much closer in value and particle counts (using the WY2010 calibration simulation) would change.

In reviewing the literature (see Section 3.2), although it was generally found that there was a linear relationship between SSC and turbidity, that relationship could vary depending on various parameters such as location, depth of instrument and sensor type. Buchanan and Lionberger (2006) found that the relationship between turbidity and SSC could vary (approximately) from: NTU=SSC to: NTU=SSC*0.5. Thus, this relationship can vary by location and, at least at the model boundaries, it can also vary with flow volume. In investigating the relationship between SSC and flow on the Sacramento and San Joaquin Rivers (RMA 2010b), we observed that the relationship between SSC and flow was dependent on flow levels in the previous year (or more). Thus, the relationship between SSC and turbidity could also vary from year-to-year particularly at the upstream locations (*i.e.*, at the model boundaries). The implication is that the turbidity model calibration could also vary from year-to-year, as the characteristics of the SSC vary.

In WY2008, there were several wind events that the turbidity model could not reproduce (Figure 6-28) - it is known that tidally-induced current velocities and wind waves in shallow waters are capable of resuspending bottom sediments (Powell et al, 1989; Schoellhamer, 1996). In comparing turbidity data with meteorological data, it was apparent that wind, rain and/or runoff had influenced turbidity levels in various locations. Also, the noisy quality of the turbidity data suggests that the schedule for cleaning and maintaining sensors was not adequate, and that some of the measurement data is suspect. At low values of measured turbidity (~10 NTU and below), the WY2010 calibration generally underestimated turbidity in WY2008 and WY2009. More generally, the WY2010 calibration underestimated turbidity at most central Delta locations in WY2008, but tended to overestimate central Delta turbidity peaks in WY2009. The WY2007 turbidity model was not run in WY2009.

A test of the adult delta smelt model parameterization is best accomplished at times when a significant number of delta smelt are salvaged. Unfortunately, in the two periods where this occurred, WY2002 and WY2004, there were no turbidity boundary conditions available. Instead, SSC was used to estimate turbidity and the relationship, NTU=SSC*0.5, was essentially a 'best guess' based on little data (Dave Fullerton, MWD, pers. com.).

The results for the adult delta smelt particle tracking model in WY2002 and WY2004 in comparison with data should therefore be viewed with the understanding that the turbidity boundary conditions were developed using SSC. Despite this approximation, the general shape and timing of peak counts followed the trend of salvage data fairly well in WY2002 with a single peak of particles reaching the export location about two weeks after the real salvage peak. The comparison is better in WY2004, with the timing and relative CVP/SWP magnitudes of the particles mirroring the salvage data for both salvage events. Salvage numbers were low in WY2008 and extremely low in WY2009, and particle counts for the adult delta smelt particle tracking model followed this general trend.

The assumption that the relationship between turbidity and SSC is a single linear relationship at the boundaries across all flow conditions is very rough, as previous analyses (RMA 2010a) indicated that there can be a wide spread of turbidities within a single flow range at both the

Sacramento and San Joaquin River inflow boundaries. We examined the consequence of altering this assumption using a single test simulation in WY2004, in which the boundary conditions were increased by a factor of two, reflecting an assumption that NTU=SSC (instead of NTU=SSC*0.5) and using the WY2010 calibration. Figure 7-1 illustrates the results for adult delta smelt model at the SWP and CVP export locations in comparison with salvage data. The results are very similar to those for the original boundary condition assumption of NTU=SSC*0.5 (Compare with Figure 6-41), with minor increases in particle count as well as changes in the shape of the peaks. The timing of the particle pulses generally advanced, particularly for the March particle peak. Doubling the boundary condition turbidity results in a doubling of central Delta turbidity, as expected (not shown).

Figure 7-2 illustrates a comparison between WY2004 modeled turbidity for the WY2007 and WY2010 calibrations at two in-Delta locations. Doubling the boundary turbidity in the WY2010 calibration only increased the modeled turbidity about 25% at Holland Cut, while at Grant Line, the short travel time from the San Joaquin boundary resulted in a near-doubling of the turbidity. In comparison with the same locations shown in Figure 6-12 and Figure 6-11, respectively, using the WY2007 calibration simulated with the NTU=SSC*0.5, we see that doubling the turbidity with the WY2010 model has switched the relative magnitudes of the two simulations, and as expected the WY2010 model turbidity is now greater. However, the relative difference between the two simulations decreased at the Holland Cut location, and increased at Grant Line.

In summary, in testing the adult delta smelt particle tracking model parameterization using the WY2010 turbidity model calibration, it appears that the parameterization was capable of reproducing the general shape and timing of the delta smelt salvage data at the SWP and CVP locations during the salvage events in WY2002 and WY2004. The approximation of turbidity using SSC by assuming a linear relationship between them may result in distortion of the turbidity distribution in the Delta when using the RMA turbidity model either calibrated in WY2010 or calibrated in WY2007.

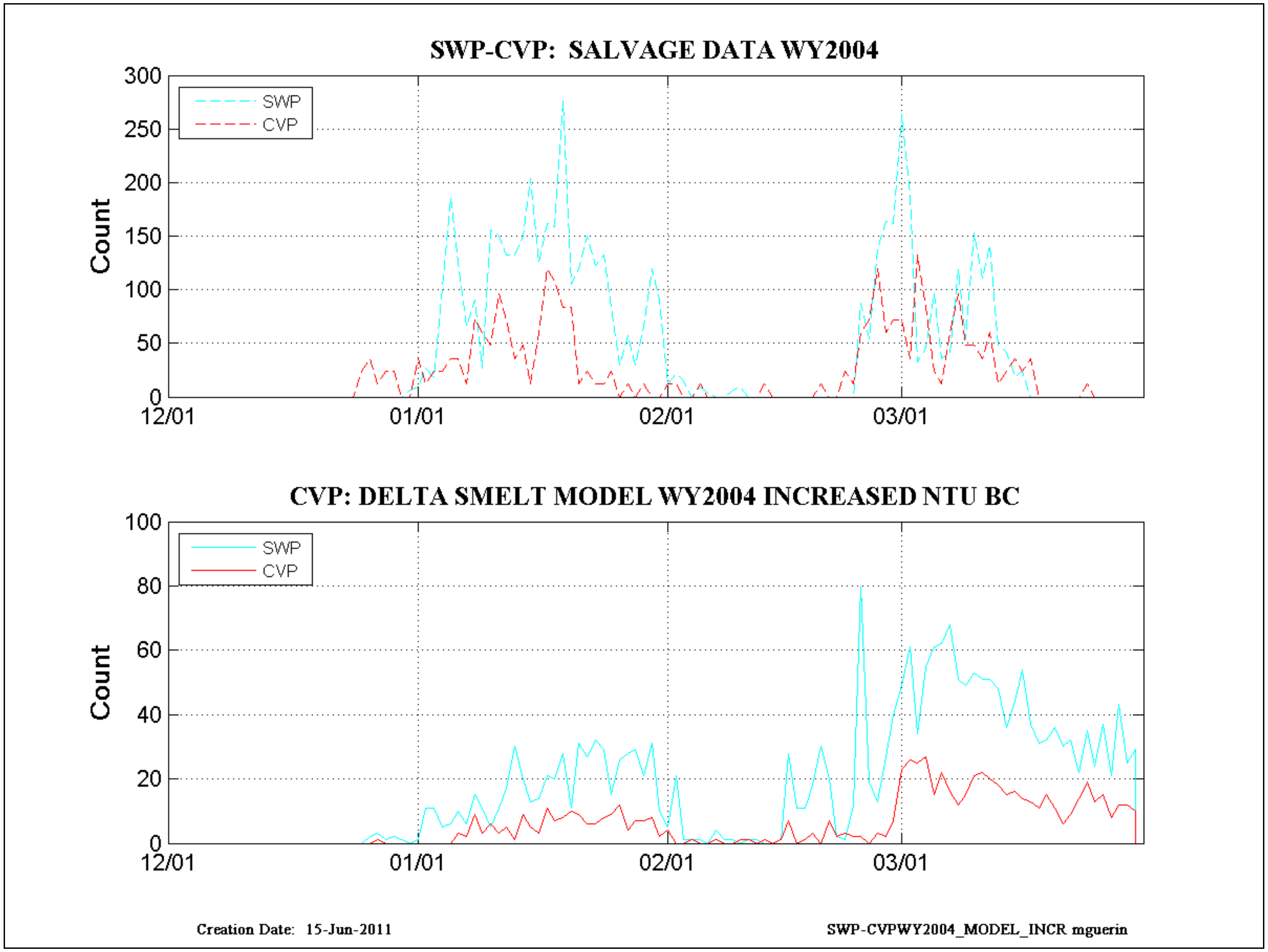

Figure 7-1 Upper plot shows the salvage count of adult delta smelt at the SWP and CVP exports locations in WY2004. Lower plot shows the modeled particle count out of 50,000 particles inserted using the WY2010 calibration, but with the WY2004 model boundarie0 doubled, i.e., using the approximation NTU=SSC. Compare with Figure 6-41.

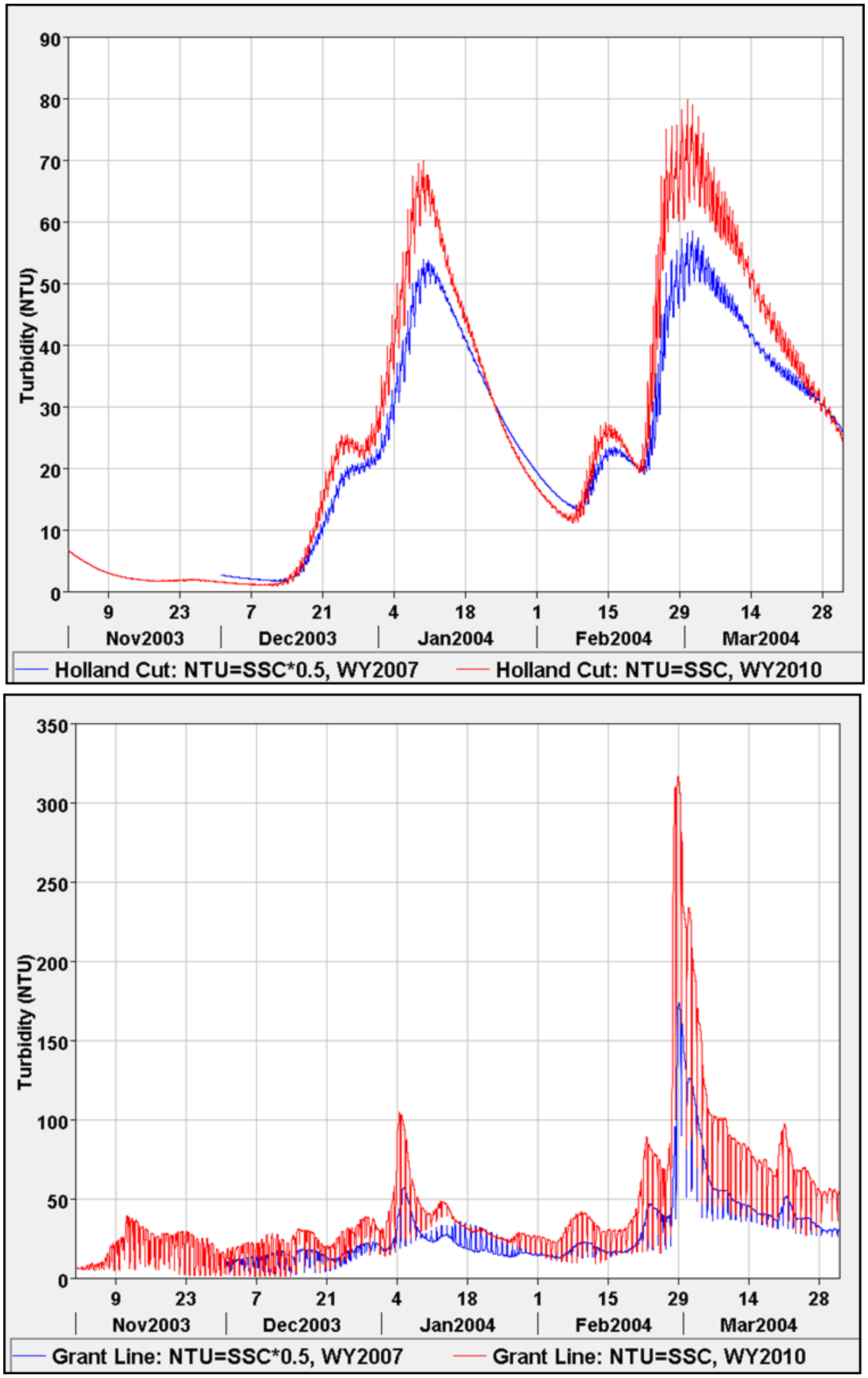

Figure 7-2 Comparison of WY2004 turbidity simulations with either NTU=SSC (red) with the WY2010 calibration and with NTU=SSC*0.5 (blue) and the WY2007 calibration at two central Delta locations, Holland Cut (upper) and Grant Line canal (lower). Compare with Figure 6-11 and Figure 6-12.

8. Conclusion and Suggestions

The modeling results presented herein illustrate the difficulties in several aspects of the turbidity/suspended sediment relationship: the relationship can vary by location, by the characteristics of upstream suspended sediment load, by the local characteristics of the underlying sediment, and by meteorological effects (wind, rain and run-off). As a consequence, it can be expected that any turbidity model calibration will work better in some years than others, and that unless decay coefficients are related to changes in bed sediment characteristics, the model will perform better at some locations than others. In the set of simulations discussed in this document, it was shown that the WY2010 turbidity model calibration performed differently in different years, with WY2009 results visibly better than WY2008 results. With the superior boundary conditions available in WY2011 (RMA 2011), the WY2010 turbidity calibration performed extremely well as demonstrated by the WY2011 hindcast.

The adult delta smelt particle tracking model parameterization was capable of reproducing the general shape and timing of the delta smelt salvage counts at the SWP and CVP export locations in WY2002 and WY2004. By moderating the linear relationship between SSC and turbidity, perhaps as NTU=SSC*0.8, the parameterization of the adult delta smelt might be improved somewhat to better represent the salvage trends. However, given the lack of turbidity data for comparison in the Delta during these WYs, any improvement would not necessarily be realized in future application of the turbidity model.

Overall, the move to a true suspended sediment model seems desirable, as some factors such as re-suspension due to wind and changes in SSC boundary conditions due to variation in particle size are better handled with a physically-based numerical model. However, since delta smelt apparently respond to turbidity (water clarity) not suspended sediment concentration, quantifying the relationship between suspended sediment and turbidity at the model boundaries and at numerous in-Delta locations needs to be considered concurrently. In addition, a methodology for calculating Delta-wide turbidity distributions from SSC-modeled distributions will need to be developed.

9. References

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