Memorandum

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DATE: January 7, 2011 PROJECT: 21865

TO: Jerry Schuster

AGENCY: City of Edmonds

FROM: Chris Long and Sam Gould

SUBJECT: Peer Review of Lake Ballinger Models

Lake Ballinger is a 100-acre lake located within the cities of Mountlake Terrace and Edmonds. The lake has been the focus of numerous studies in the last 30 years. These studies primarily addressed problems related to water quality and storm water runoff that can contribute to flooding and property damage.

Of late, the City of Edmonds is especially concerned with lake flooding of residences and desires to explore possible solutions. Before developing flood mitigation alternatives, the City wanted a review of the previous hydrologic and hydraulic modeling of lake levels. Northwest Hydraulic Consultants (NHC) was contracted by the City of Edmonds to provide a peer review of this prior modeling.

This memorandum briefly summarizes four hydrologic models that simulate Lake Ballinger water levels. This summary includes a short overview of each model and a review of the overall model approach, input variables, results, and conclusions. Recommendations on how the current models can be improved are also provided. It should be noted that because sufficient documentation for each model was not always available, a consistent evaluation of each model was not possible.

Overview of Models

To date, there have been four hydrologic models built that simulate water levels in Lake Ballinger. These are listed below in chronological order.

- Version 1, June 1999, Aqua Terra, *McAleer and Lyons Creeks Drainage Basin Study*
- Version 2, June 2008, Clear Creek Solutions, *Lake Ballinger Lake Level and Outlet Study*
- Version 3, January 2009, Clear Creek Solutions, *Greater Lake Ballinger / McAleer Creek Watershed Study*
- Version 4, December 2009, OTAK, *Flood Reduction Planning Study Lyon Creek and McAleer Creek Drainage Basins*

Some documentation for all four models was made available by the City of Edmonds. Based on the available data, a tabular summary identifying key components of the models was prepared.

A more detailed review was made of model Versions 2 and 4 because HSPF input files were available for these two versions and not the others.

In general, each successive model improved on the previous version. Improvements came in the form of delineation of contributing drainage basins, better land use data, more accurate information on underlying soils, refined effective impervious area assumptions, and FTABLE development. An exception to the general rule of successive improvement is model Version 4, which is an update of model Version 2. The hydrologic inputs and parameters for Versions 2 and 4 are identical; the only difference between these versions is a revised FTABLE for Lake Ballinger. As is discussed in more detail later, this is important because significant refinements to the model hydrology were made in Version 3 according to the study documentation.

Model Approach

Three of the Lake Ballinger models were built using the EPA's HSPF program. One model was built using WWHM3, a hydrologic model targeted for western Washington specifically, but which still uses HSPF as its computational engine.

Hydrologic Simulation Program FORTRAN (HSPF) is a sophisticated computer modeling program that simulates land surface and in-stream hydrologic processes on a continuous basis. The program is commonly used to transform long-time series of observed rainfall and evaporation data into concurrent time-series of streamflow data based on a continuous accounting of soil moisture levels. Continuous hydrologic modeling is of particular value in studying a watershed such as that draining to and from Lake Ballinger because it allows for an accurate representation of the relationship between historical rainfall and the resultant runoff to the lake and downstream peak flows. This generally provides a sound basis for computing stream or lake stage frequencies and durations.

Model Inputs

Inputs to an HSPF model include precipitation and evaporation data for the watershed, delineation of smaller subbasins within the watershed, soils and land use characteristics of the subbasins, and stage-area-storage-discharge relationships for routing flows through the system.

The precipitation and evaporation records used in all four models are listed in the model summary table (Table 1). Precipitation data for years prior to 1990 was provided by longstanding rain gages located in SeaTac or Everett, Washington. It is not documented if the rainfall was translated to the project site using multipliers based on annual rainfall totals. For more recent years, rainfall was obtained from one of three gages in the King County Hydrologic Monitoring Program, depending on the model version. The use of any of these rain gages is justifiable given their proximity to the basin. It is noted that in the summer of 2002 the precipitation record from the Boeing Creek rain gage used in Versions 2 and 4 was erroneously time-stamped as occurring 24 hours earlier than the actual rainfall. This does not have a significant effect on simulated lake levels, but correcting the precipitation record in future simulations would make comparing the simulated and observed lake levels more straightforward.

Pan evaporation data for the models were based on the Puyallup evaporation station at a daily interval. Pan constants of 0.75 and 0.76 were used to convert pan evaporation to potential evapotranspiration, depending on the version. These constants are reasonable values for the Lake Ballinger watershed.

Delineation of smaller modeling subbasins within the drainage basin can improve the timing of simulated flooding by allowing the user to provide more distinct and specific routing for each area and approximating more distributed soil-land use conditions. With the exception of model Version 3, drainage area that contributes runoff to Lake Ballinger is represented as a single upstream subbasin. Version 3 includes four subbasins upstream of Lake Ballinger. Two of these subbasins surround Echo Lake and Hall Lake specifically. It is noted that using a single upstream subbasin of approximately 3,500 acres provides a fairly coarse representation of runoff to Lake Ballinger, especially given the presence of smaller upstream lakes and drainage systems that may serve to attenuate storm hydrographs.

Soils and land use are input to the model to describe the physical characteristics of the subbasins. For model Version 1, soil type data was not available, so the estimates shown in Table 1 were made based on the consultant's previous modeling experience in south Snohomish County. However for Versions 2 and 4, soil types were determined using data available from the University of Washington. The source of the soil data for Version 3 was not clearly identified in the study documentation.

For Version 1, no basin-specific land use analysis was conducted. Instead, broad assumptions were made regarding land cover and associated effective impervious area. For model Versions 2 and 4, the land use analysis made use of the imagery available in Google Earth. It is not clearly documented how the land use analysis was carried out using Google Earth. The single upstream subbasin in both these versions was assigned an effective impervious area value of 39%. Land cover assumptions for Version 3 appear to be the most refined. The documentation indicates that this study accessed recent GIS layers from the Cities of Edmonds and Mountlake Terrace and performed an overlay analysis using geology and landuse layers to determine soil-land combinations.

HSPF models use a set of parameters to define the characteristics of a land surface's response to meteorologic inputs. These parameters represent the pseudo-physical characteristics, and can be adjusted (calibrated) as necessary to allow the model to better match observed flow data. The parameters used in model Versions 2 and 4 were developed by the USGS based on a regional study of a number of basins in the Puget Sound area (Dinicola, 1990). These regional parameters have been found by many users in western Washington to provide a good basis for model application in the absence of good calibration data. The documentation for model Versions 1 and 3 did not specify whether or not the regional parameters were used.

FTABLE development

HSPF uses user-defined stage-area-storage-discharge relationships, called FTABLEs, to simulate routing of runoff and estimate downstream flows. In general, FTABLEs are created for each subbasin to represent the dominant storage and drainage network features. In each of the four models, one FTABLE is used to describe the pivotal relationship between the lake level and the outlet discharge. As shown in Table 1, at least three different Lake Ballinger outlet FTABLEs have been developed. NHC only had access to the FTABLEs in model Versions 2 and 4, so only these will be discussed in more detail.

The stage-discharge relationship for model Version 2 was developed using a separate hydraulic model, HEC-RAS. In fact, three unique stage-discharge relationships were created because operation of the Lake Ballinger outlet structure is changed seasonally. These three are represented in the single FTABLE using seasonal routing. This seasonal operation of the outlet weir is based on Washington State court-adjudicated minimum lake levels. Without the HEC-RAS model, the development on the FTABLE could not be investigated further. The stage-area-volume relationship was developed using topographic contours surrounding the lake. Very little documentation was provided regarding how this overall FTABLE was developed.

Significantly more detail regarding the creation of the FTABLE in model Version 4 was available. Version 4 uses the same stage-area-volume relationship as Version 2. However, completely new stage-discharge relationships were developed using the hydraulic model XP-SWMM. Three XP-SWMM models were built to characterize unique relationships for each operational season; winter, summer, and spring/fall. The XP-SWMM models extend from Lake Ballinger to the downstream side of the culvert underneath Interstate-5.

Within the XP-SWMM models, the lake outlet structure is represented as two orifices and three weirs. The two orifices simulate the hypolimnetic withdrawal line, which is not currently operating, and the opening within the aluminum frame sitting on the weir sill. The three weirs simulate the top of the aluminum structure and the two abutting concrete walls. The three weir elevations in the model were coded according to as-built drawings and OTAK field observations. The weir elevations were also checked with field measurements and an RTK-based survey by NHC. The weir sill elevations in the three XP-SWMM models were set according to the minimum adjudicated Lake Ballinger water surface elevation for the respective season.

Three culverts are situated between the lake outlet structure and the culvert underneath Interstate-5. The diameter, length, and invert of the three culverts in the models match those shown on as-built drawings. Natural channel cross-sections between the culverts were built from a combination of an AutoCAD drawing provided by the City of Edmonds and LiDAR-based topography. The culvert spanning underneath Interstate-5 was coded into the model according to an unidentified WSDOT as-built plan. Roughness coefficients used in the natural channel cross-sections situated between the culverts include the following: stream channel – 0.03, overbanks - 0.05, and culvert – 0.024.

The FTABLE stage-discharge relationship was developed by running each operational season's XP-SWMM model with a continually increasing outlet discharge, spanning from 0 to 140 cfs. For a range of lake stages, the discharge exiting the culvert underneath I-5 was extracted. This stage and discharge data pair forms a rating curve

Figures 1 through 3 illustrate the FTABLE stage-discharge relationships represented in model Versions 2, 3, 4, and the outlet structure O&M manual. Figure 1 indicates that at a given lake level, the discharge from the lake according to the Version 4 FTABLE (blue line) is significantly lower than the discharge according to the O&M manual (purple line). Note that the stage-discharge relationship in the O&M manual does not account for the effects of partial submergence or the downstream culverts. For example, at lake stage 278 feet, under free flow conditions, the weir is theoretically capable of discharging approximately 60 cfs while the XP-SWMM model calculates the flow to be approximately 25 cfs. This difference in flow is even larger at higher lake stages. This indicates that one or more of the downstream culverts, and to a lesser extent the stream channel, are controlling the flow out of lake at the higher stages. Additional data collection and further refinement and interrogation of the model are needed to confirm this explanation.

Observed Lake Levels

The only data available to calibrate the models are observed lake levels. A continuous record of water surface elevations was provided by the City of Mountlake Terrace. The record spans from July 2001 to September 2010. This data were cleaned and reformatted in order to compare with the simulated lake levels from model Versions 2 and 4.

Results

Models were only available for model Versions 2 and 4. These models were re-run for their original period of record, October 1949 through August 2007. Plots comparing the computed lake stage from Versions 2 and 4 against observed lake levels for water years 2001 through 2007 are provided as Figures 4 through 27.

Both models simulate extremely similar lake levels during the wet months, approximately October through May. This is to be expected since these models have identical hydrologic inputs and stage-storage relationships, and their stage-discharge curves do not diverge until lake levels surpass 280 feet. Compared to the peaks in the observed record, the simulated data is consistently high. Comparing the simulated lake levels for the New Years Day 1997 storm, the Version 4 stage is closest to the observed peak of 282.47 recorded by Mountlake Terrace (Figure 28).

Conclusions

The overall approach of all four hydrologic models, using HSPF to continuously simulate inflows and lake levels, is reasonable. Model Versions 2 and 4, which were available to NHC for review, provide a reasonable representation of Lake Ballinger water levels. Of these two models, Version 4 provides the closest simulation to observed lake levels. However, based on the study documentation of model Version 3, a combination of Version 3 and Version 4 may produce a better model still. This model would use the refined hydrologic inputs developed in creation of Version 3 with the improved FTABLE created in Version 4.

All of the models reviewed by NHC consistently over-predict the peak stages in Lake Ballinger. This could be a result of one or more of the following factors:

- the volume of runoff entering the lake simulated by the models may simply be too high or the storage volume of the lake in the models may be too little,
- the upstream runoff simulated by the models may be too flashy due to lack of detention and routing in the upstream subbasin,
- the Lake Ballinger outlet FTABLE in the models may under-predict the outflow from the lake at higher stages, or
- regional groundwater routing simulated by the models may differ from surface runoff routing, and groundwater contributions to Lake Ballinger could be over-estimated.

The XP-SWMM model used to build the Version 4 FTABLE indicates that at high lake stages, the downstream culverts appear to be the controlling factor for lake outflow, and therefore lake level, rather than the outlet weir.

Recommendations

To improve the modeling, calibration to discharge measurements is critical. Comparing the model results to the lake stages is useful, but it is possible to get reasonable simulated stages for the wrong reasons. It would be simple to install a flow monitoring meter in one of the outlet culverts located in the golf course downstream of the outlet weir. In addition, an inactive flow monitor already exists at the mouth of Hall Creek. Calibrating to flow data at one or even both ends of the lake would be relatively simple and could significantly improve confidence in the hydrologic model.

In addition to recording actual discharges and using them to calibrate the model, several refinements could be made to the model. Some of these may have been made in Version 3, but it was unavailable for review. These refinements include the following:

- Delineation of multiple subbasins upstream of Lake Ballinger, especially encompassing Hall Lake, Echo Lake, and Chase Lake, to improve timing and account for flow routing, storage, and attenuation.
- Resurvey channel cross sections and culvert inverts downstream of the outlet structure to verify they are accurately represented in the FTABLE.

While the FTABLE in model Version 4 is likely the most accurate in all four models, a few deficiencies in its development are noted below.

- The weir sill elevations in the XP-SWMM model are set to the court-mandated lake water surface elevations instead of the actual weir elevations outlined in the O&M manual.
- The XP-SWMM model was run with a continually increasing outlet flow and was never allowed to reach a steady-state condition. However, FTABLEs should represent steady-state conditions. When developing the stage-discharge relationship, each point of the curve should be allowed to reach an equilibrium condition.
- The roughness coefficient of the overbanks, which should account for the dense vegetation along the top of banks, is too low.

In addition to the items noted above, it would be helpful to have more detailed documentation regarding the data sources and methods used to build the stage- area- volume relationship for Lake Ballinger. The study report for model Version 2 only shows topographic contours as low as elevation 280 feet. It is unclear how the storage relationship was developed for elevations below 280 feet.

After these recommendations are addressed, this model can be used to confirm that at higher lake stages, the downstream culverts are the controlling factor for lake outflow, and therefore lake level, rather than the outlet weir.

References

Flood Reduction Planning Study Lyon Creek/McAleer Creek Drainage Basins, 2009, prepared by Otak for the City of Lake Forest Park.

Greater Lake Ballinger/McAleer Creek Watershed Study Technical Memorandum #1, 2009, prepared by OTAK for the Staff Committee.

Lake Ballinger Lake Level and Outlet Study, 2008, prepared by Clear Creek Solutions Inc. for the City of Edmonds.

Lake Ballinger Restoration Project Operation and Maintenance Guide, 1984, prepared by KCM for the City of Mountlake Terrace.

Lake Forest Park Flood Reduction Study – Lake Ballinger Outlet Modeling, 2010, prepared by OTAK for the City of Lake Forest Park.

McAleer and Lyon Creeks Drainage Basin Study, 1999, prepared by Hammond, Collier & Wade Livingstone Associates and Aqua Terra Consultants for the City of Lake Forest Park.

Table 1 Model Summary

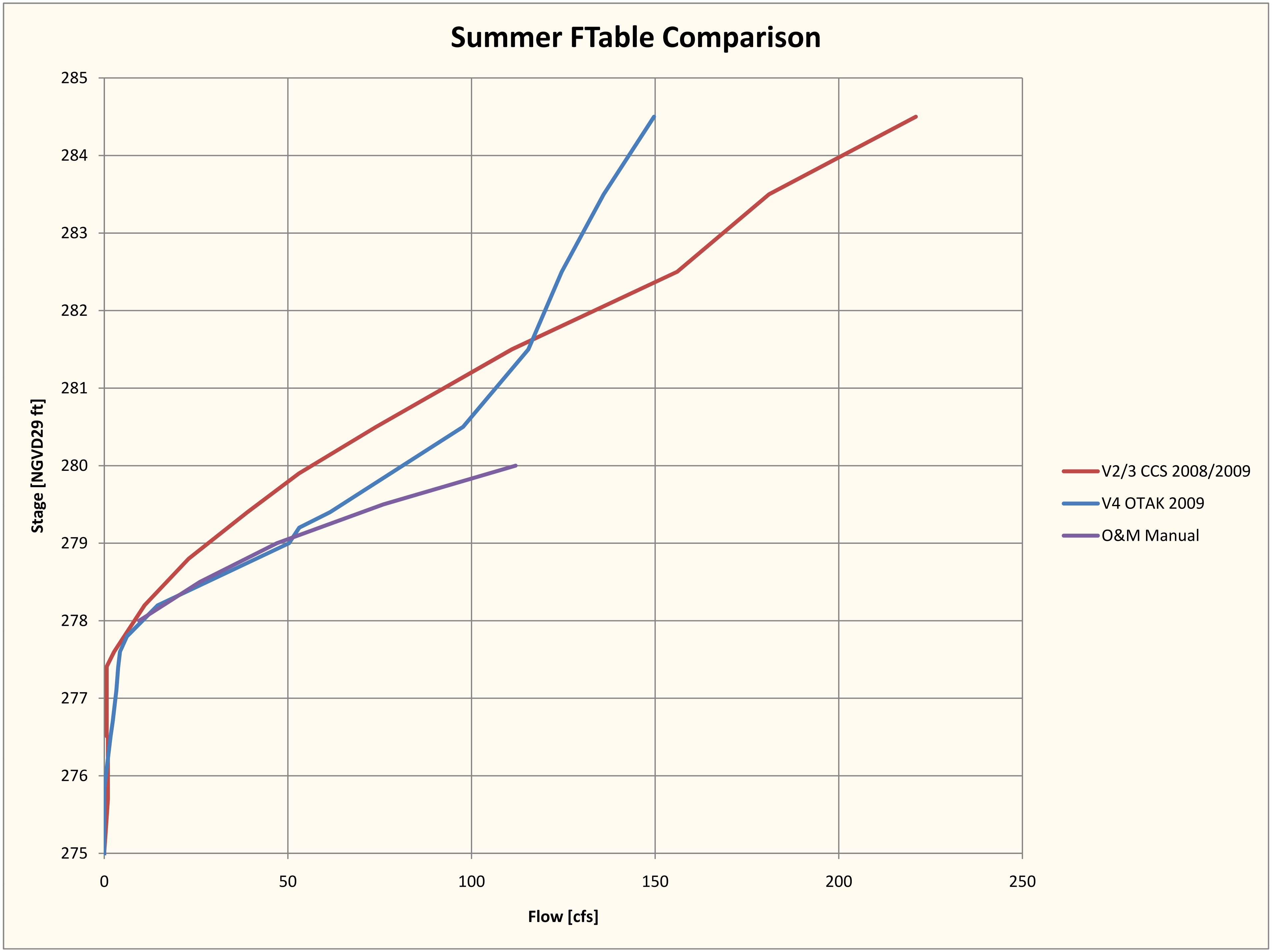
Model Version	Date	Author	Client	Study Name	Model Platform	Precipitation Source	Evaporation Source
1	Jun-99	Aqua Terra	City of Lake Forest Park	McAleer and Lyons Creeks Drainage Basin Study	HSPF	SeaTac 1949 - 1991 35U Brugger's Bog 1992 - 1997 Gage 51U for 24 Nov 1990 storm	Puyallup; 0.75
2	Jun-08	Clear Creek Solutions	City of Edmonds	Lake Ballinger Lake Level and Outlet Study	WWHM3	Everett Gage 1949 - 1989 35U Brugger's Bog 1990 - 2007 Filled with 04U Boeing Creek	Puyallup; 0.76
3	Jan-09	Clear Creek Solutions	McAleer Creek Forum	Greater Lake Ballinger/McAleer Creek Watershed Study	HSPF	Everett Gage 1949 - 1989 Gage 04U Boeing Creek 1990 - 2007	Puyallup; 0.76
4	Dec-09	OTAK	City of Lake Forest Park	Flood Reduction Planning Study Lyon Creek and McAleer Creek Drainage Basins	HSPF	Assume same as Version 2	Puyallup; 0.76

Table 1 Continued

Model Version	Land Use Source	Soil Type Source	Effective Impervious Area Assumptions	Topographic Source	Basin Area	Lake Outlet Ftable Source	Upstream Subbasins	Upstream Routing
1	No land use	No soil information available, estimate made 70% grass on till, moderate slopes (2261 ac)	No EIA information available, estimate made 30% or 969 acres	Unknown	3,230	Based on Calculations of Weir and Culvert Control	1	No
2	Google Earth	University of Washington	Unknown	10-meter DEM	3,457	HEC-RAS hydraulic model	1	No
3	"Updated" per technical memorandum	"Updated" per technical memorandum	Forest 0% Lawn 0% Roof 75% Roads 85%	"Updated" per technical memorandum	3,568	Unknown	4	Likely
4	Assume same as Version 2	Assume same as Version 2	Assume same as Version 2	Assume same as Version 2	3,457	XPSWMM hydraulic model	1	No

Winter FTable Comparison
Stage [NGVD29 ft]
285
284
283
282
281
280
279
278
277
276
275
0
50
100
150
200
250
Flow [cfs]
V2/3 CCS 2008/2009
V4 OTAK 2009
O&M Manual

Figure 1



Summer FTable Comparison
Stage [NGVD29 ft]
285
284
283
282
281
280
279
278
277
276
275
0
50
100
150
200
250
Flow [cfs]
V2/3 CCS 2008/2009
V4 OTAK 2009
O&M Manual

Figure 2

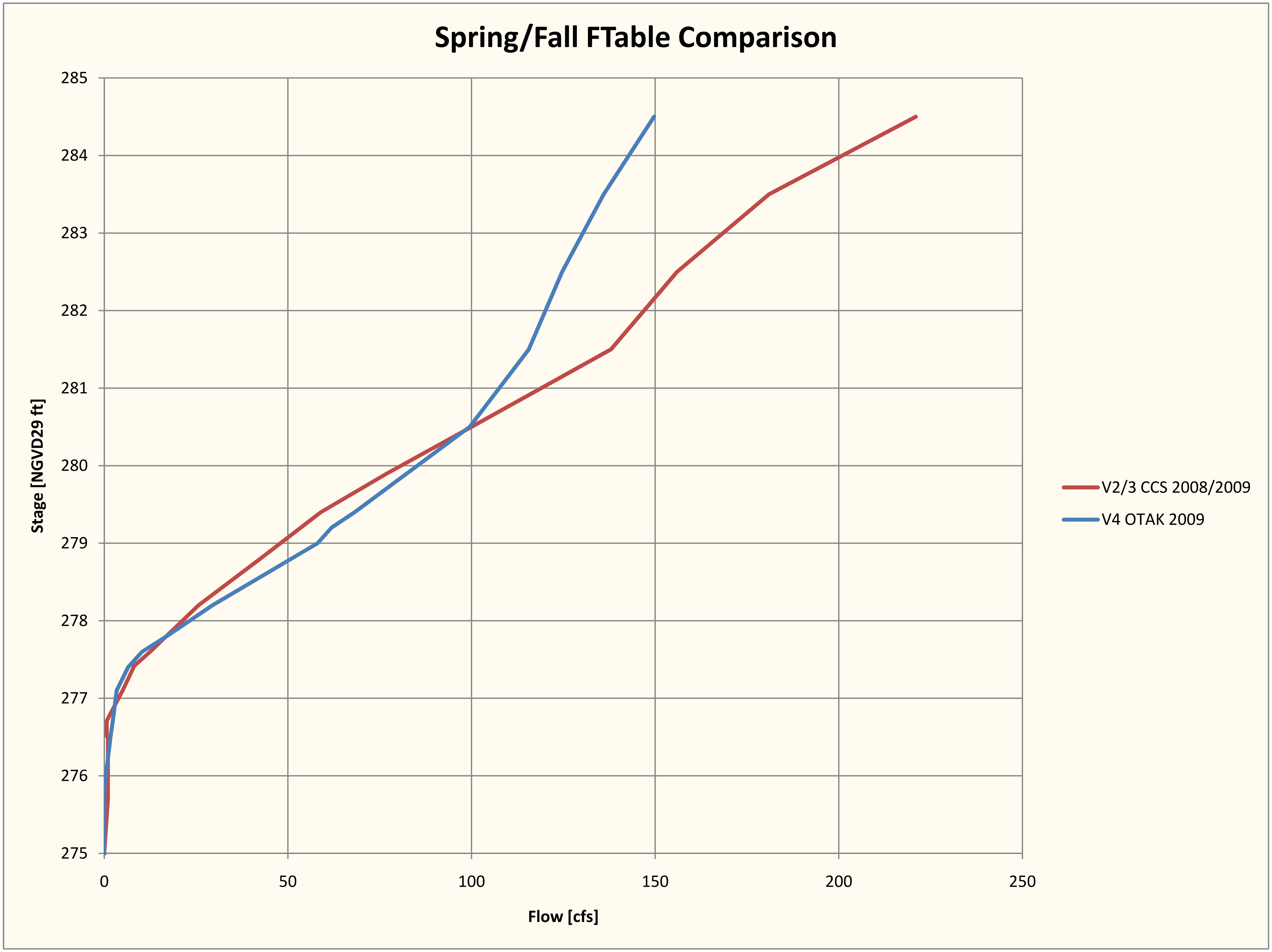
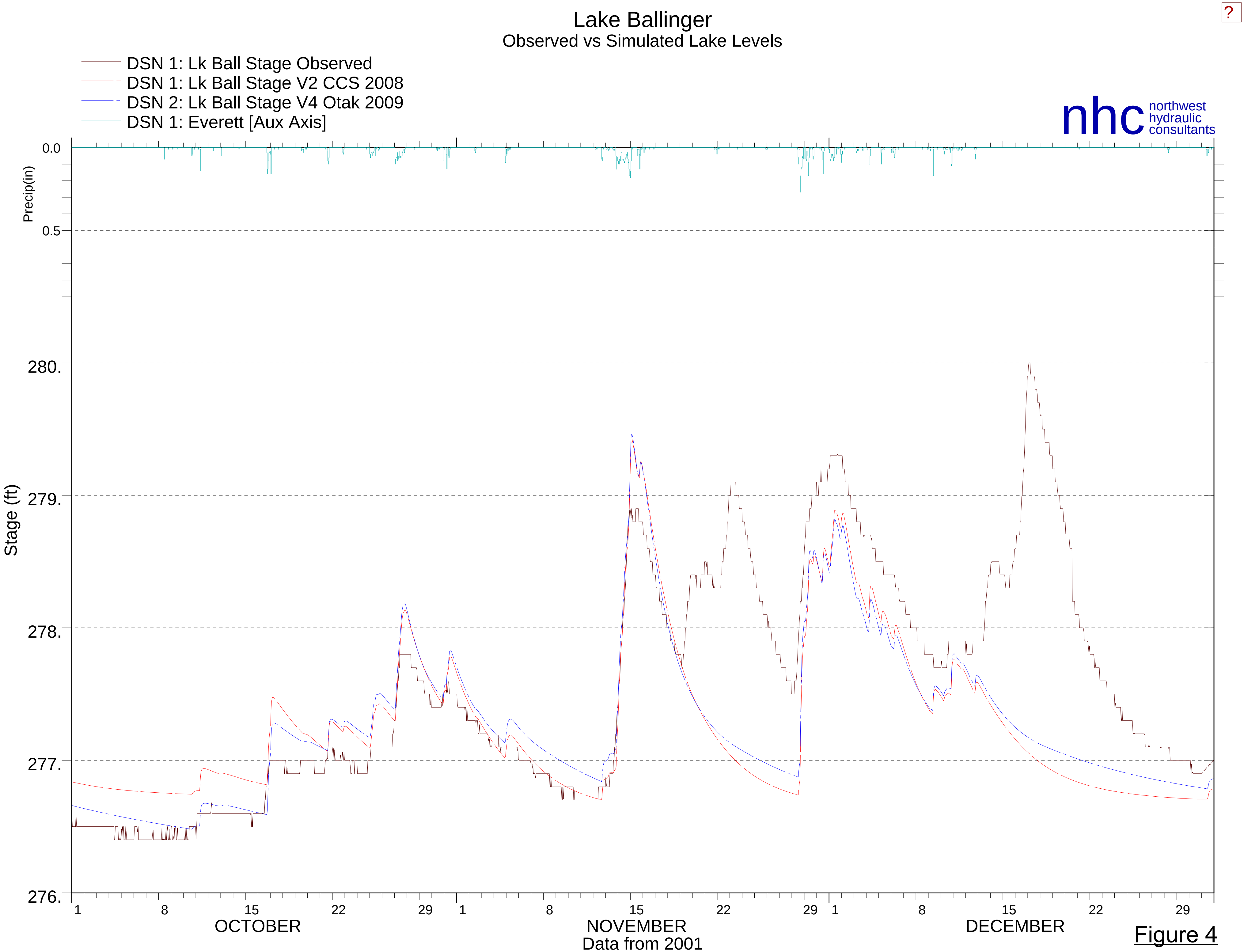

Spring/Fall FTable Comparison
Stage [NGVD29 ft]
285
284
283
282
281
280
279
278
277
276
275
0
50
100
150
200
250
Flow [cfs]
V2/3 CCS 2008/2009
V4 OTAK 2009

Figure 3


Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
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8
15
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1
8
15
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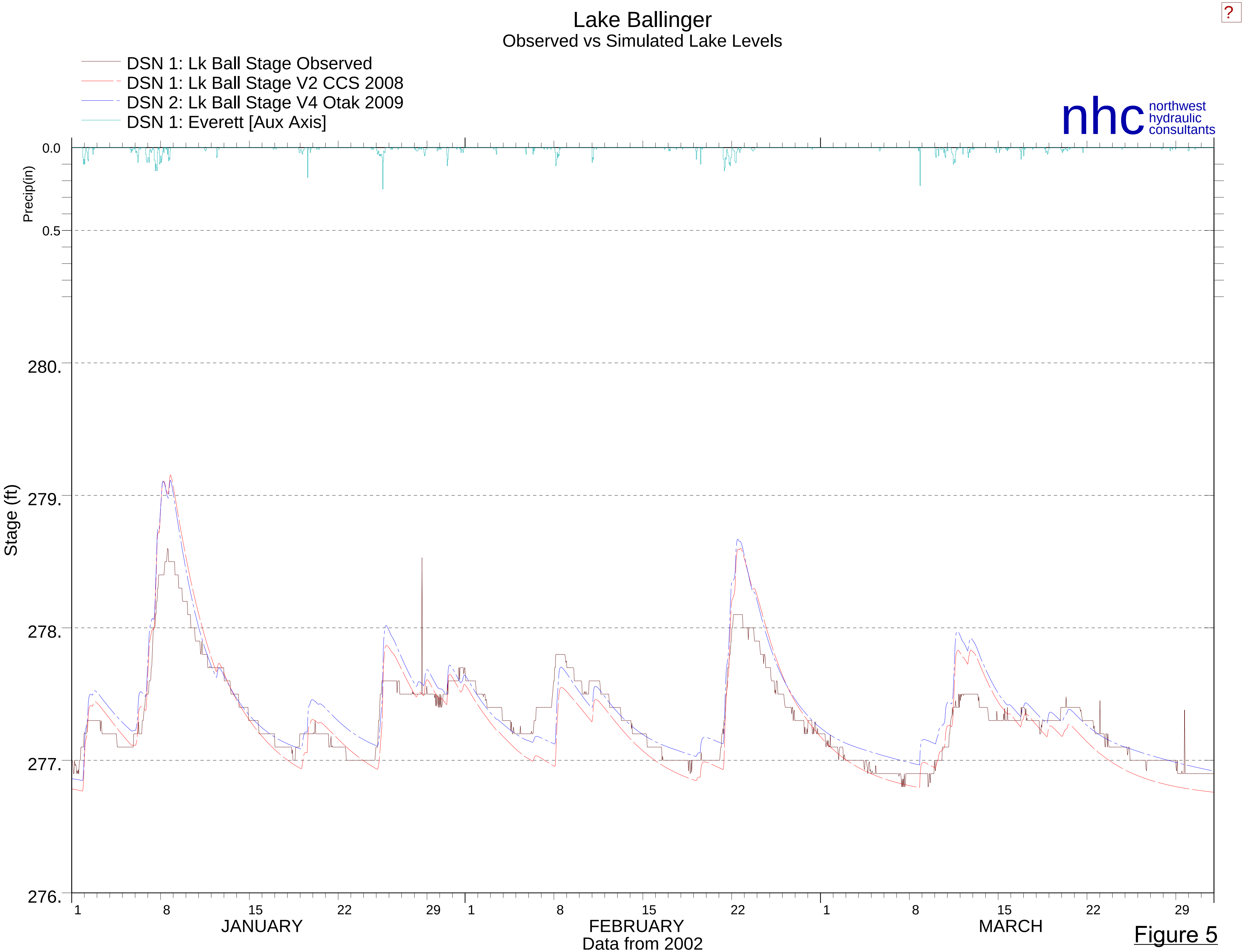
OCTOBER
NOVEMBER
DECEMBER
Data from 2001

Figure 4


Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
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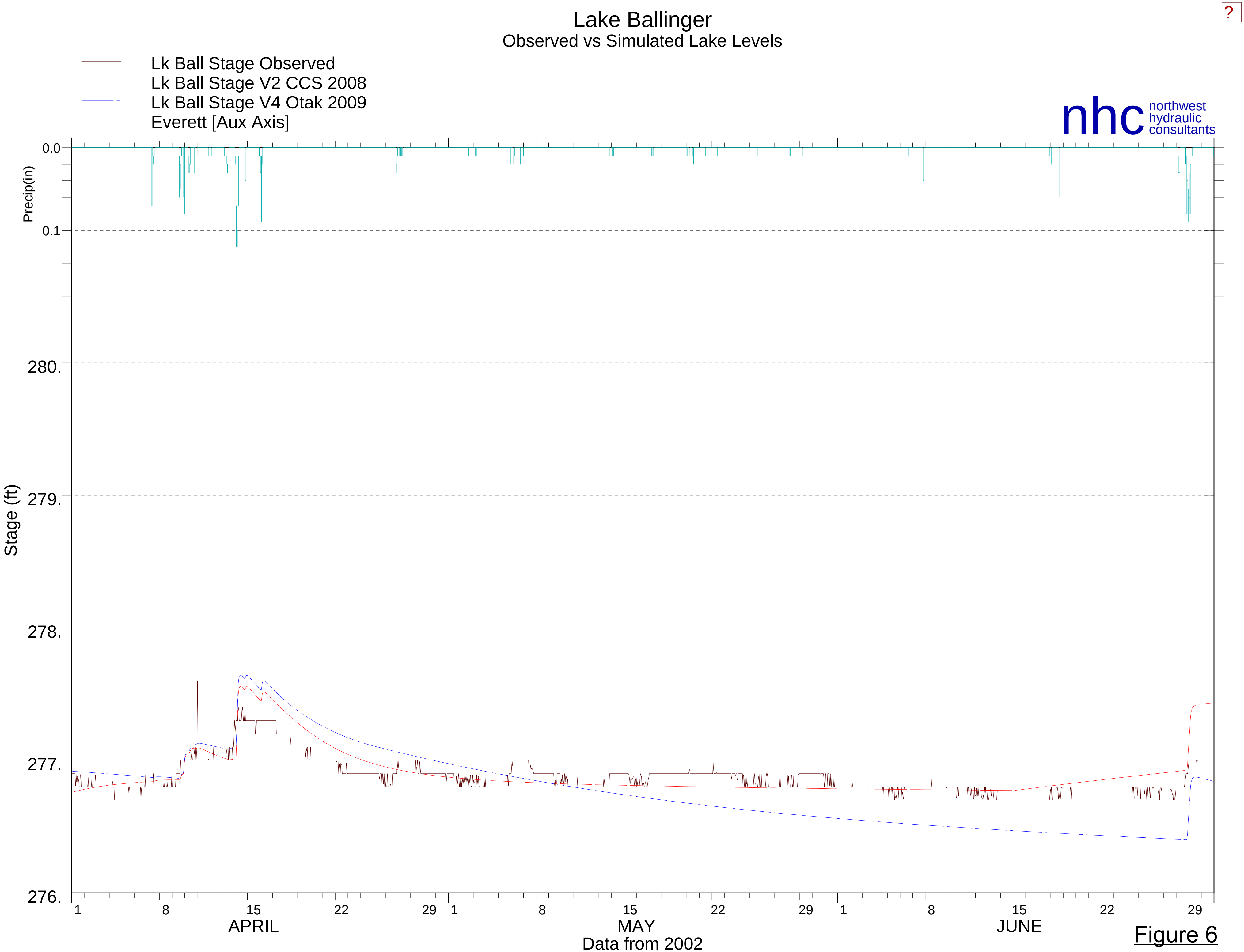
JANUARY
FEBRUARY
MARCH
Data from 2002

Figure 5


Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
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Stage (ft)
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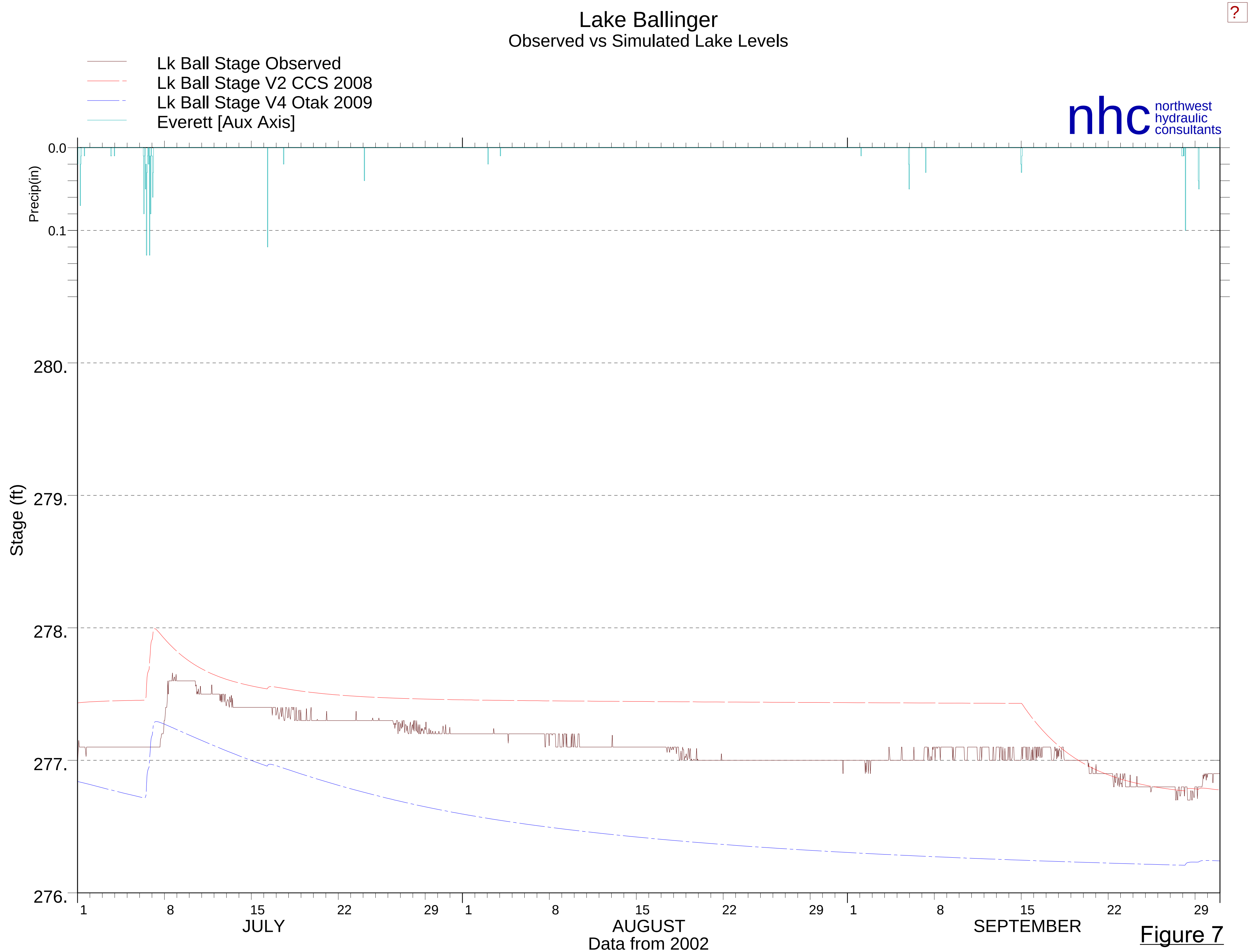
JUNE
Data from 2002

Figure 6



Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.1
Stage (ft)
280.
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276.
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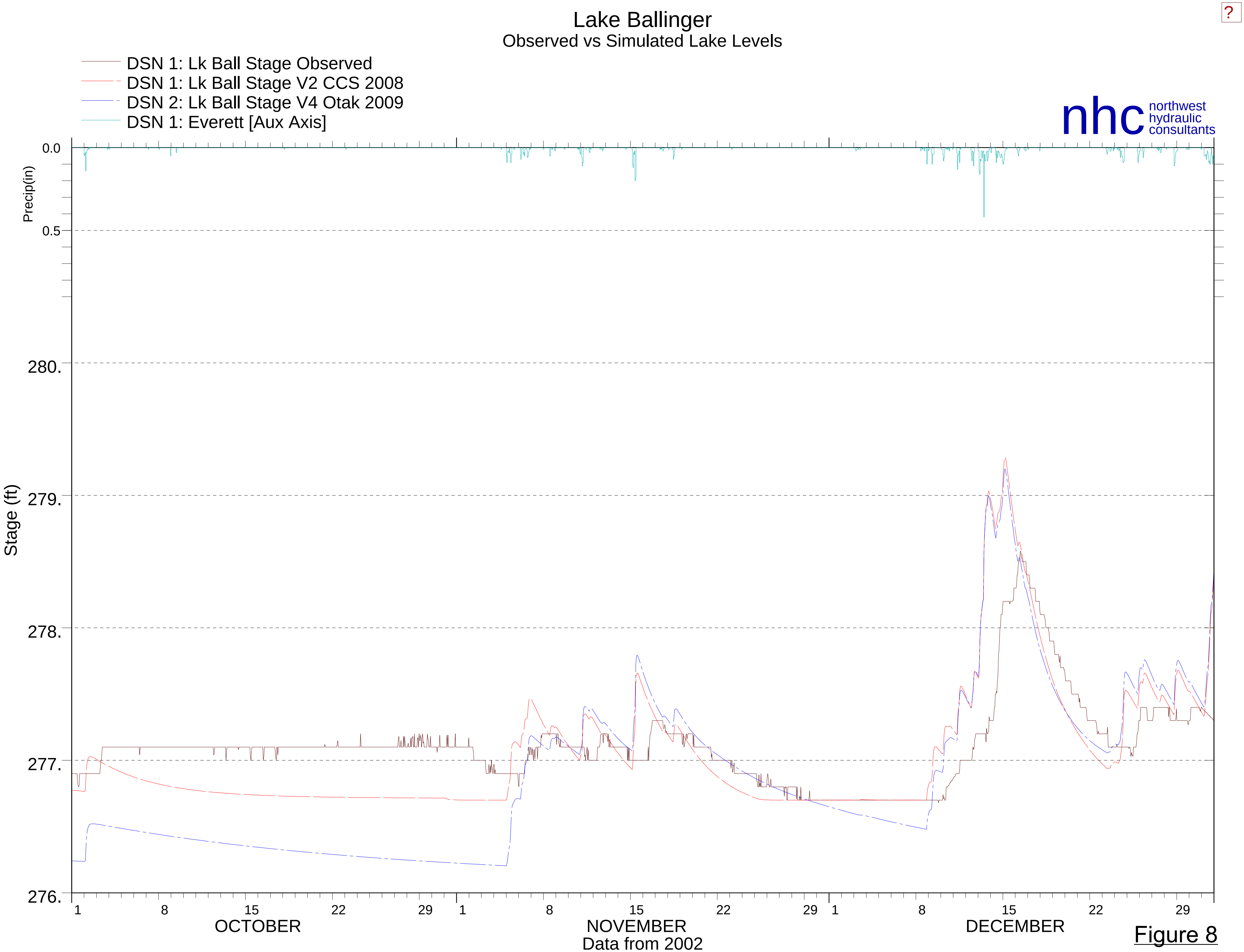
29
JULY
AUGUST
SEPTEMBER
Data from 2002

Figure 7



Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
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Stage (ft)
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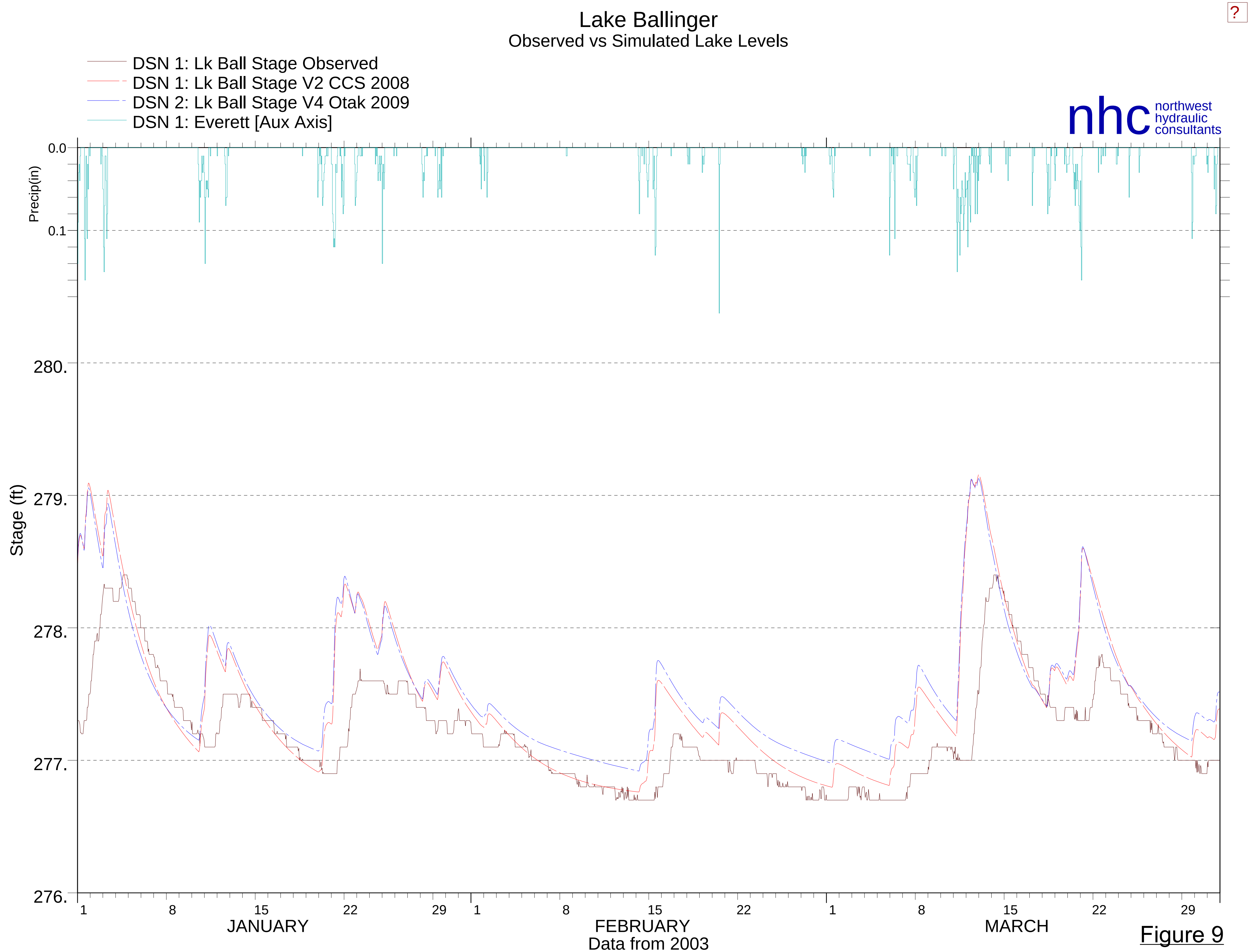
DECEMBER
Data from 2002

Figure 8


Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
northwest hydraulic consultants
Precip(in)
0.0
0.1
Stage (ft)
280.
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FEBRUARY
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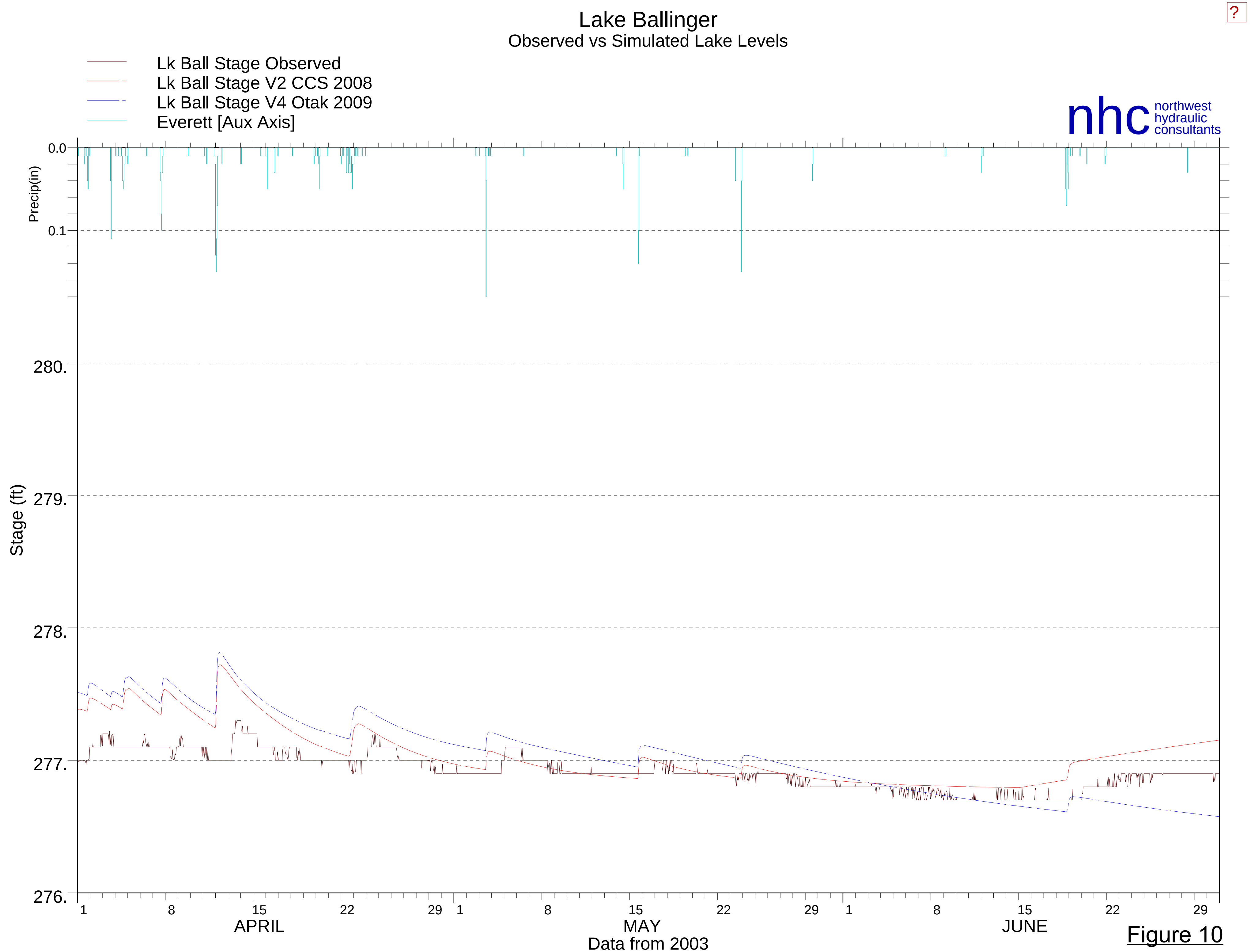
Data from 2003

Figure 9



Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc
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hydraulic
consultants
Precip(in)
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Stage (ft)
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MAY
JUNE
Data from 2003
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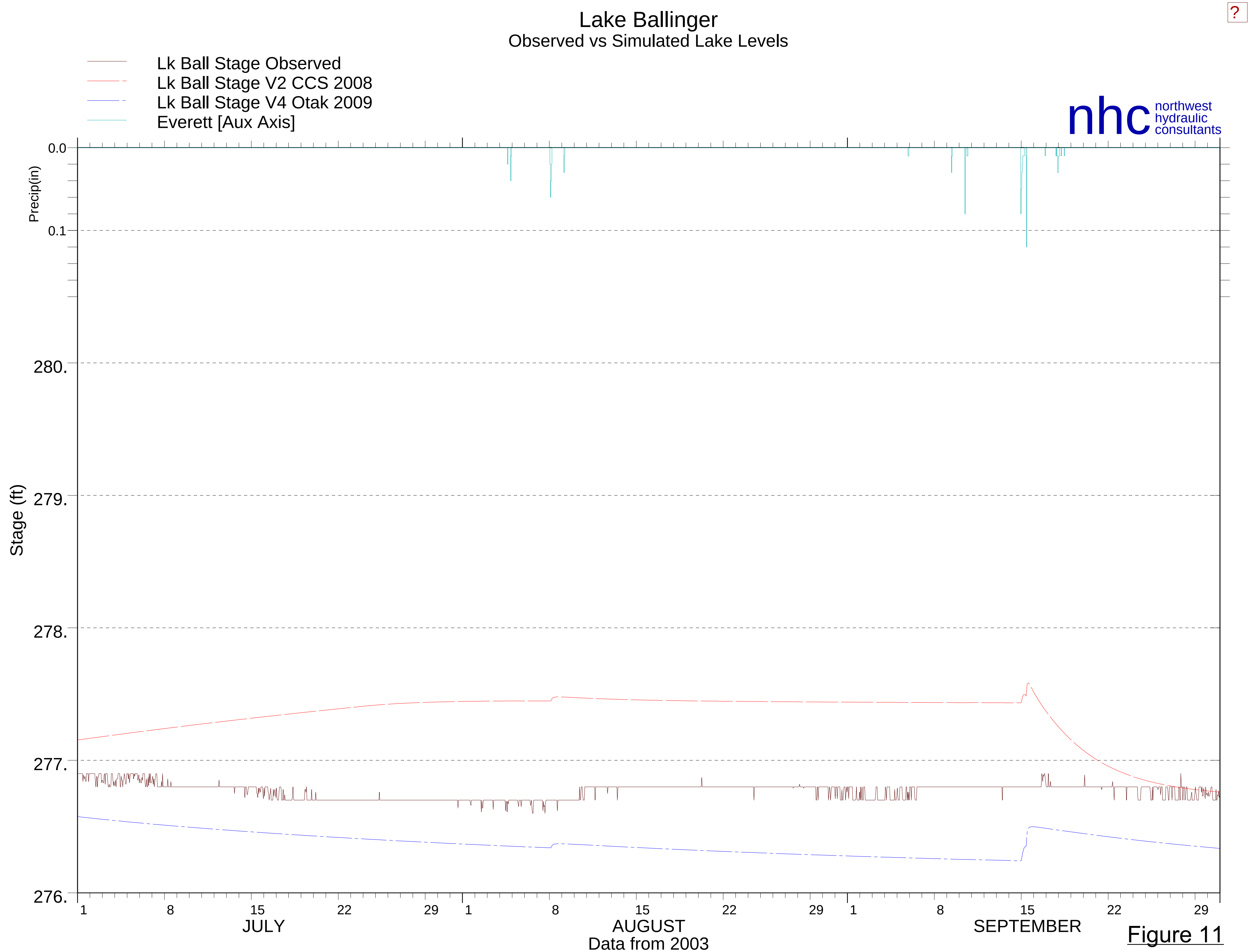
Figure 10



Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
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Stage (ft)
280.
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AUGUST
SEPTEMBER
Data from 2003

Figure 11

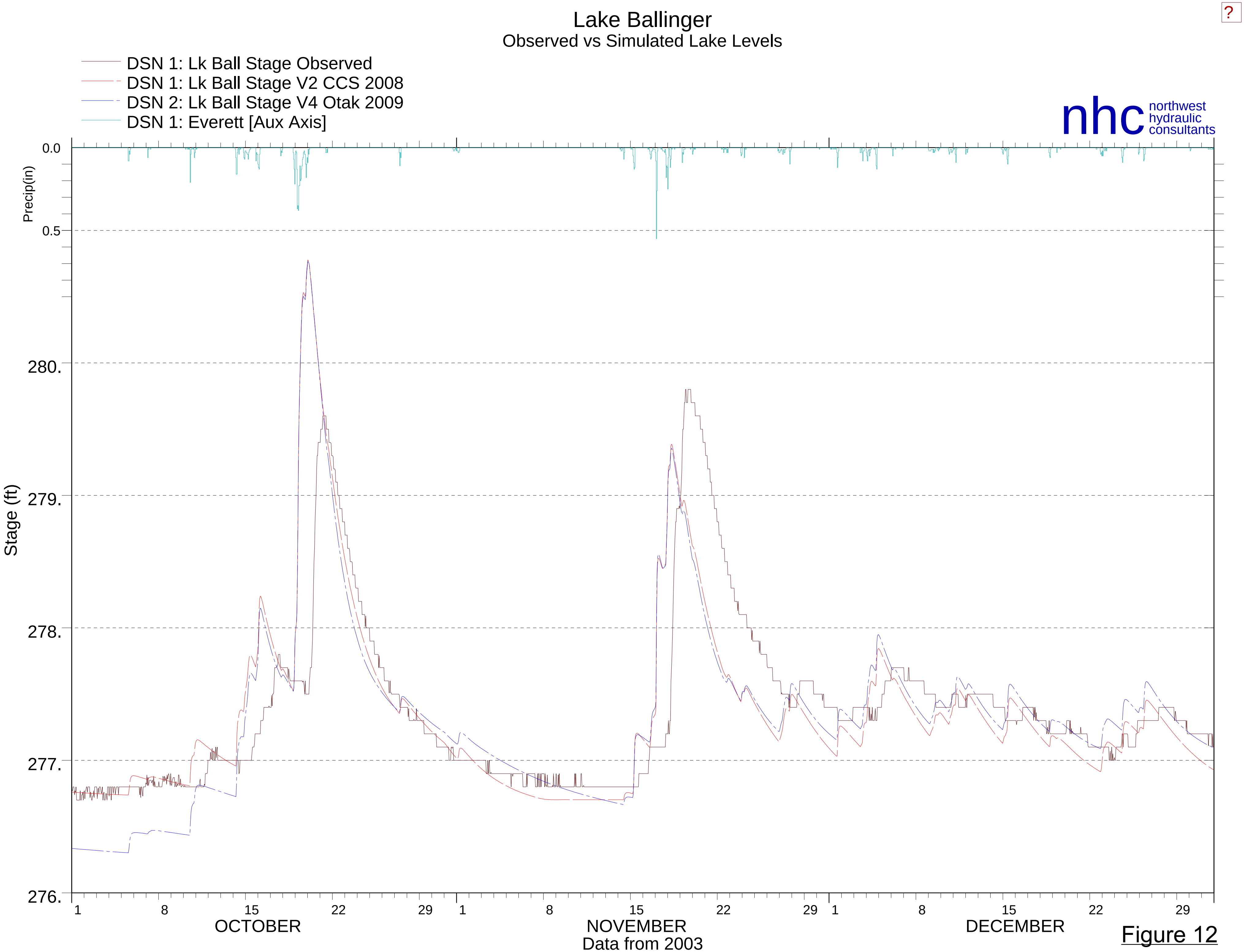

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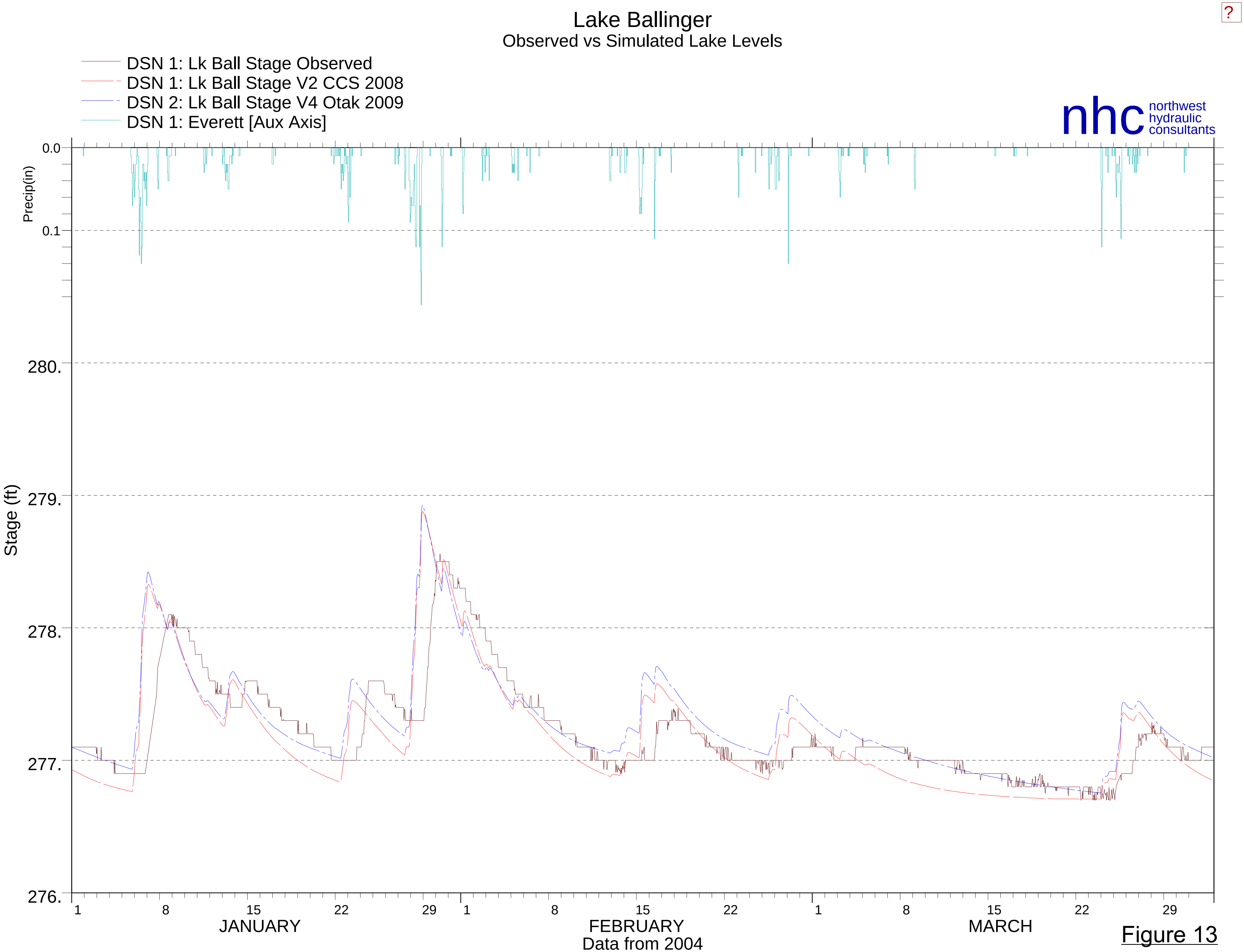
Figure 12



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DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
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Stage (ft)
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JANUARY
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MARCH
Data from 2004

Figure 13

Lake Ballinger

Observed vs Simulated Lake Levels

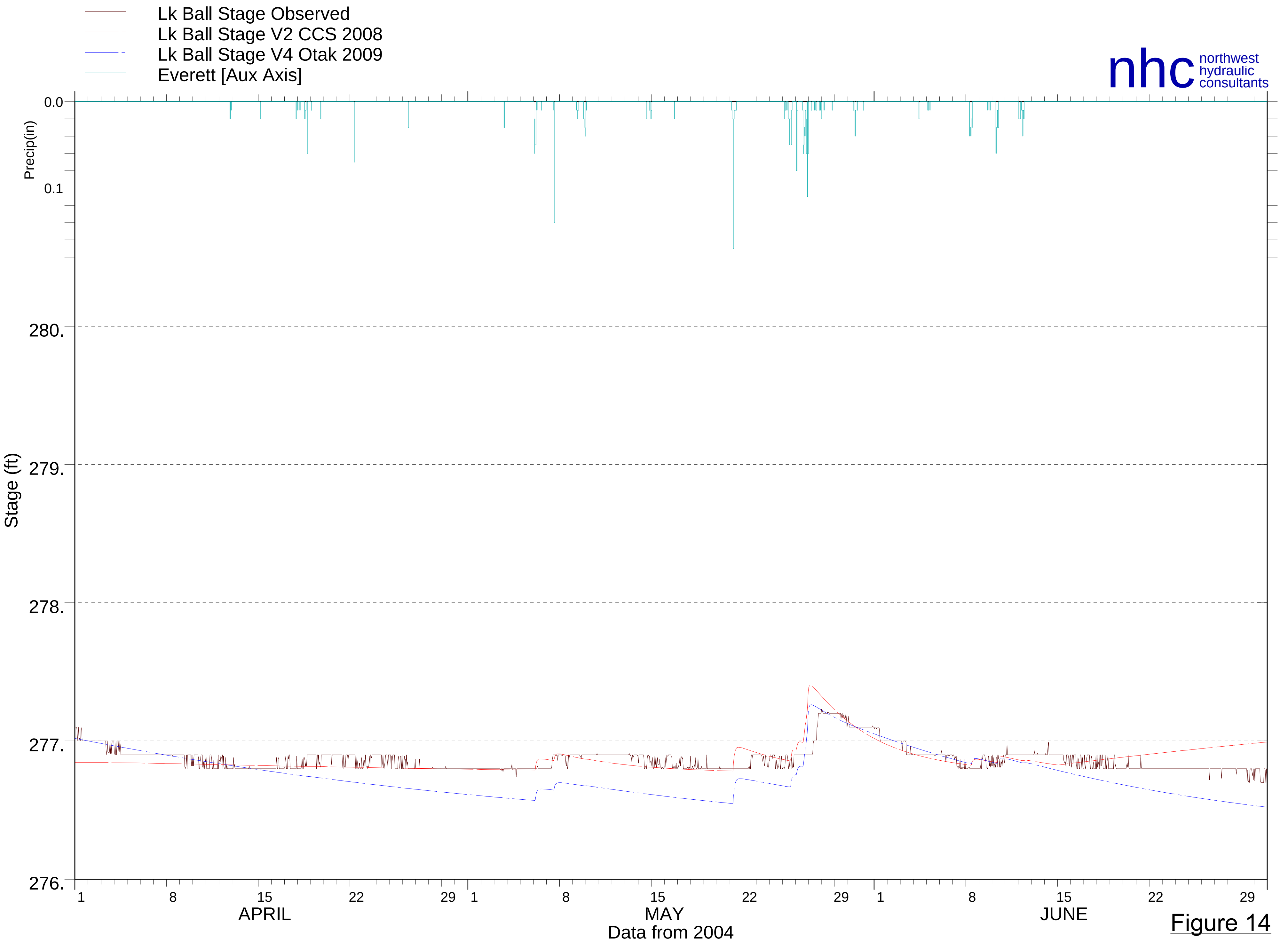
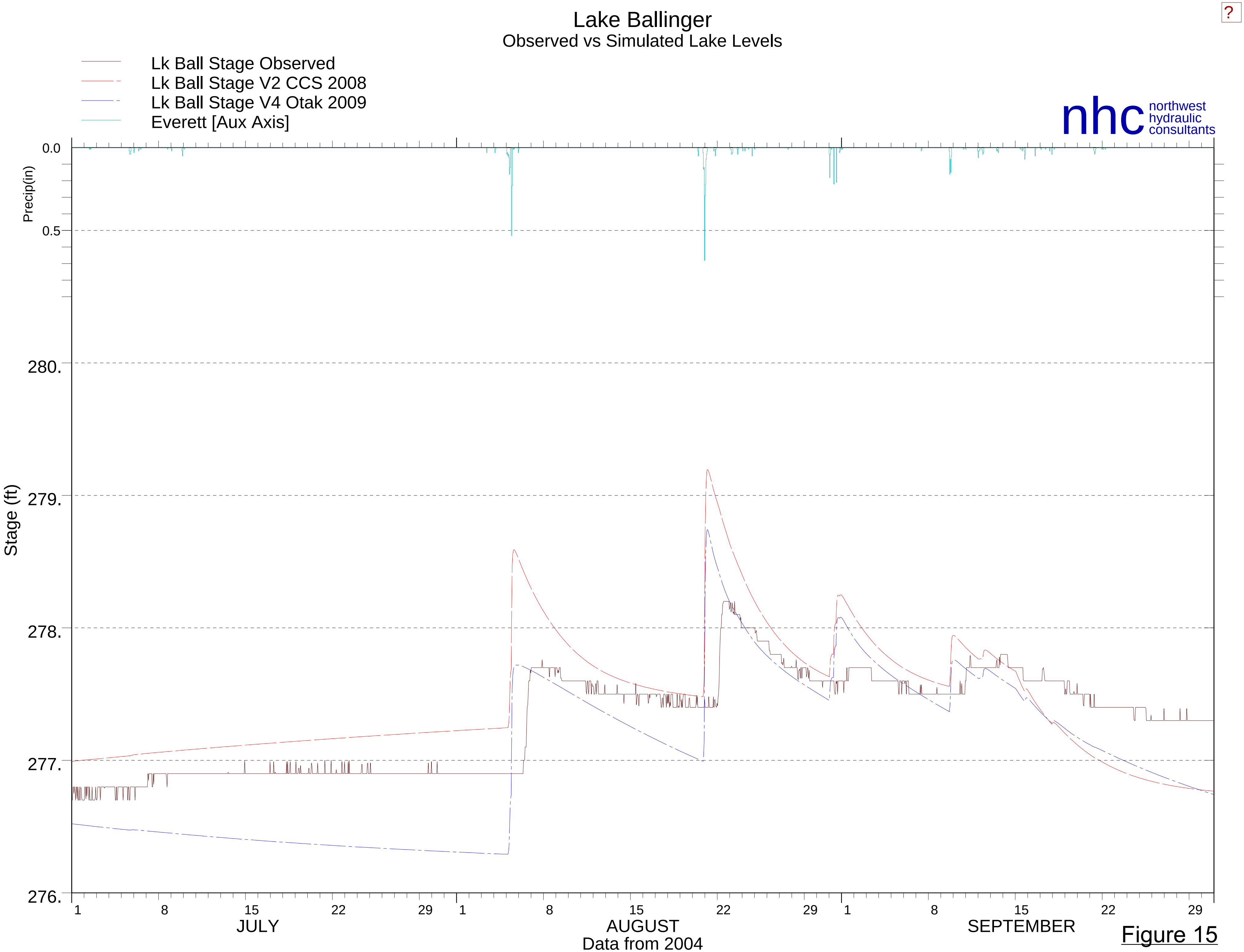


Figure 14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Stage (ft)
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JULY
AUGUST
SEPTEMBER
Data from 2004

Figure 15

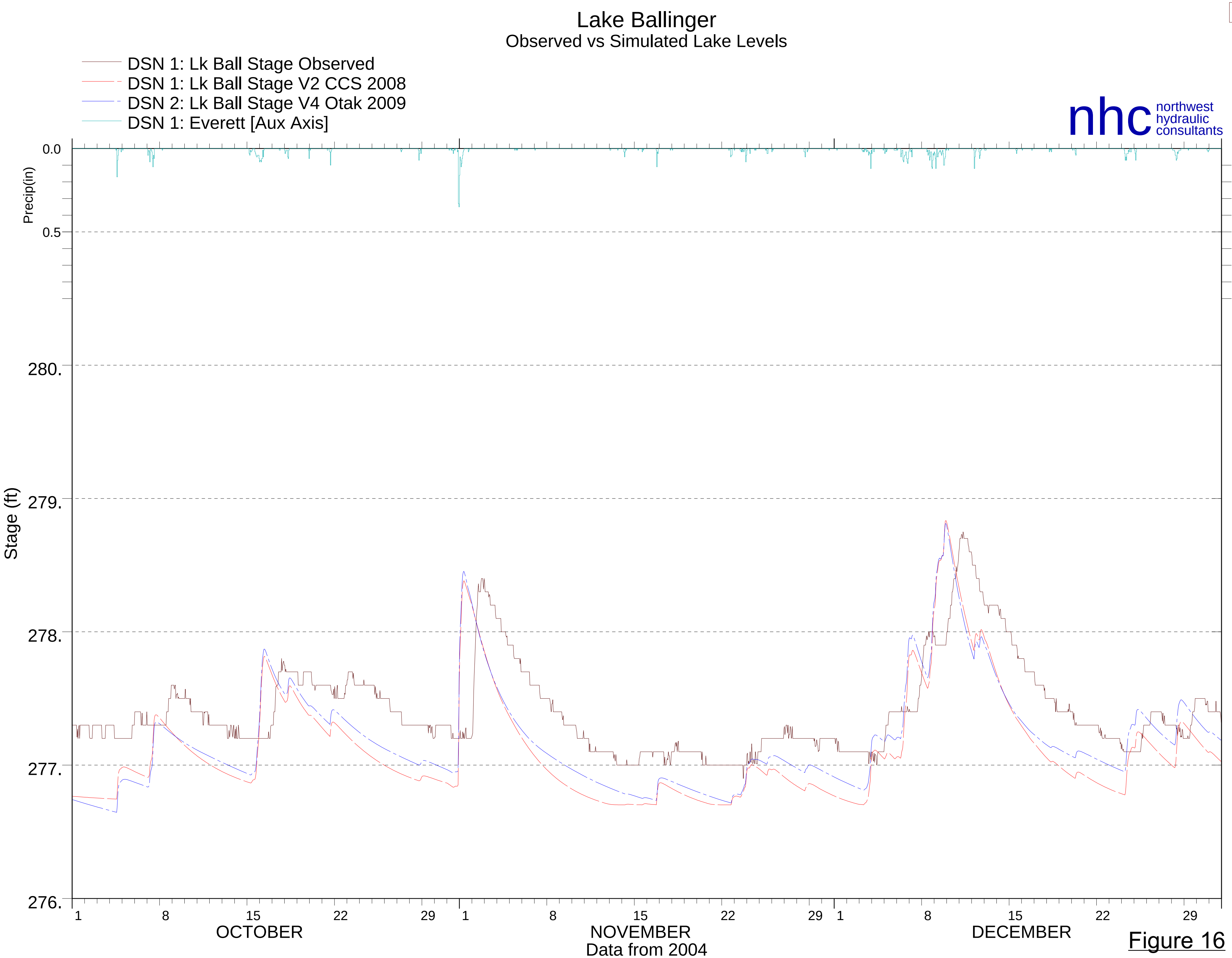

Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
OCTOBER
NOVEMBER
DECEMBER
Data from 2004

Figure 16

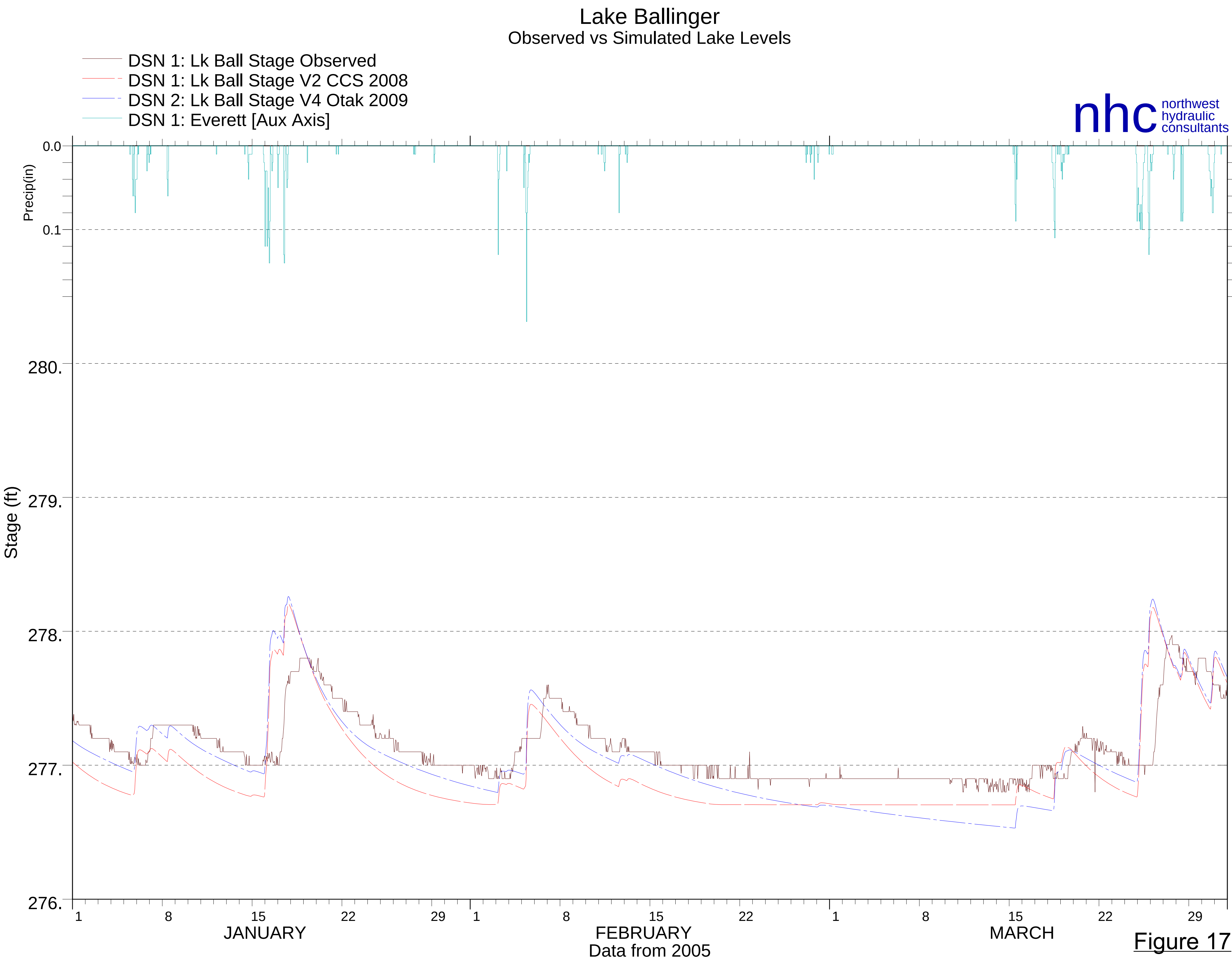
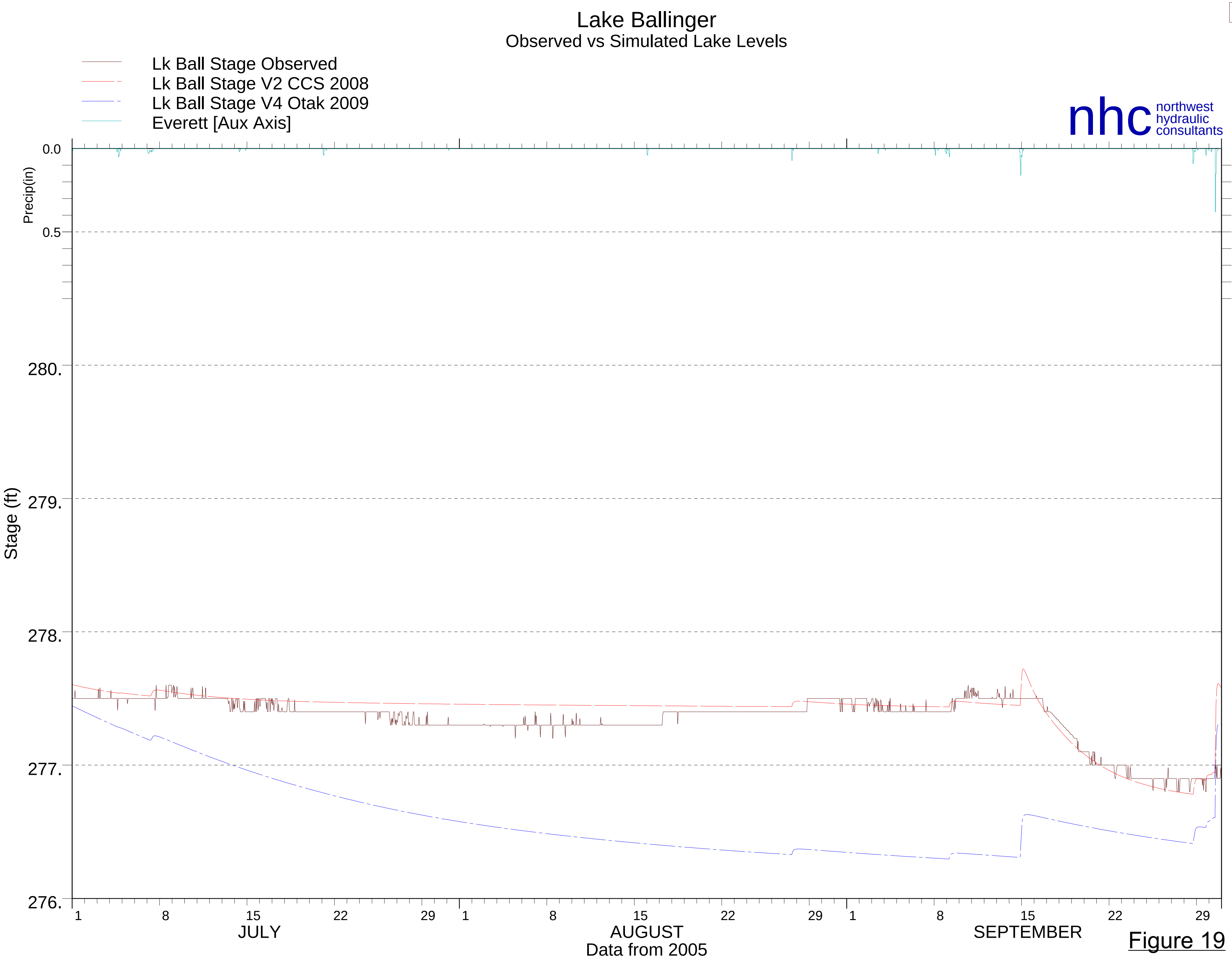

Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.1
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
1
8
15
22
1
8
15
22
29
JANUARY
FEBRUARY
MARCH
Data from 2005

Figure 17

Lake Ballinger
Observed vs Simulated Lake Levels

Figure 18



Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
1
8
15
22
29
1
8
15
22
29
JULY
AUGUST
SEPTEMBER
Data from 2005

Figure 19

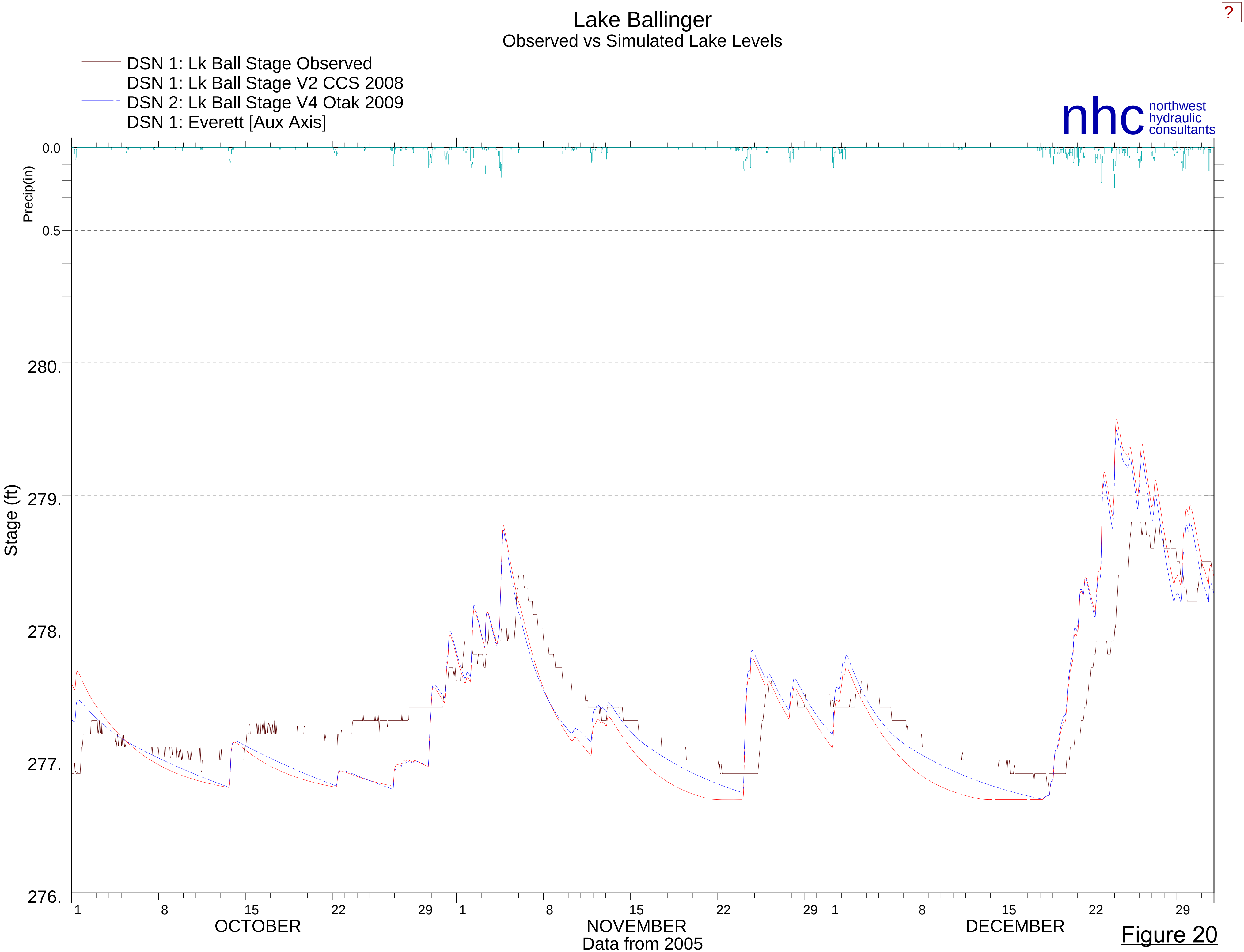

Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
OCTOBER
NOVEMBER
DECEMBER
Data from 2005

Figure 20

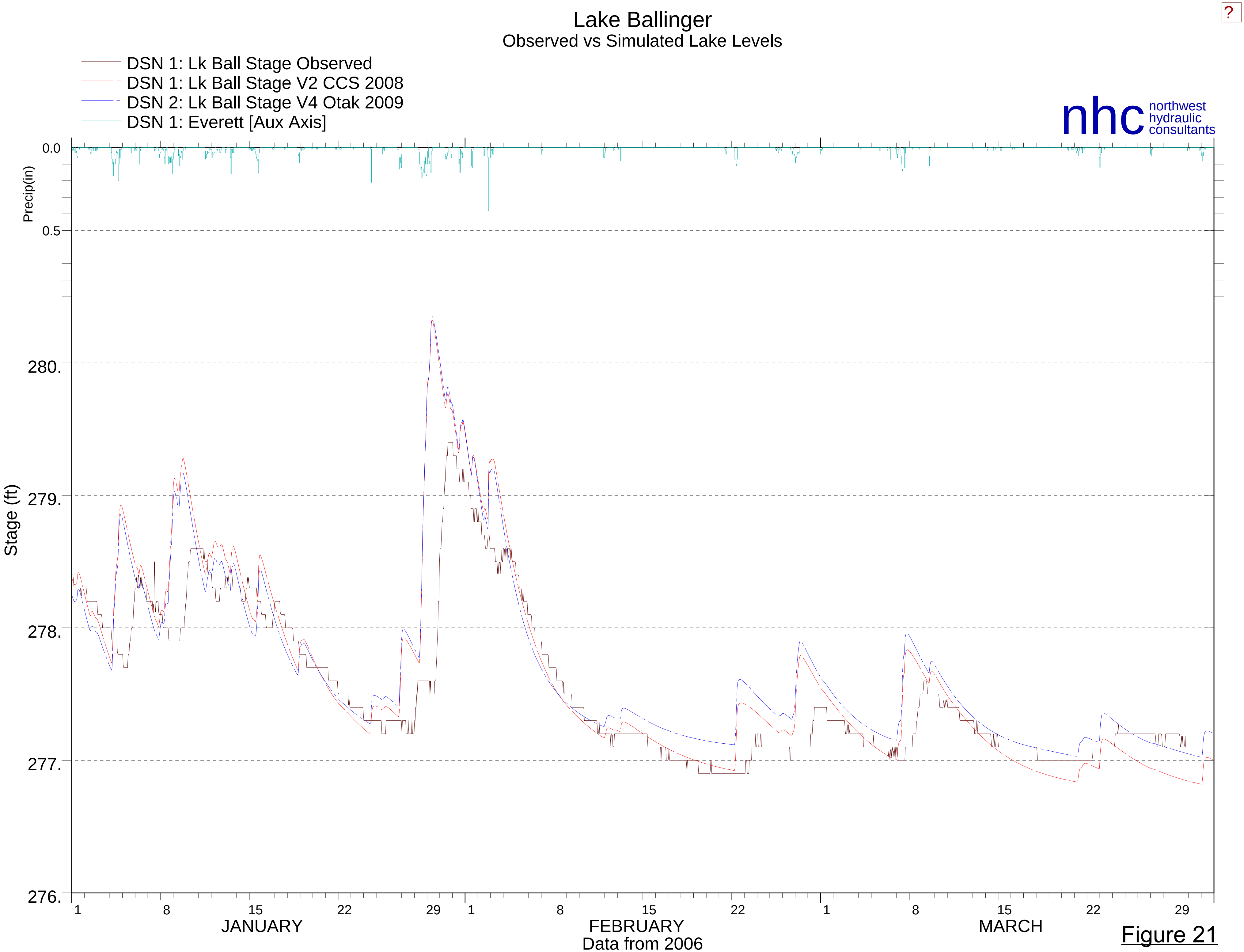

Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
JANUARY
FEBRUARY
MARCH
Data from 2006

Figure 21

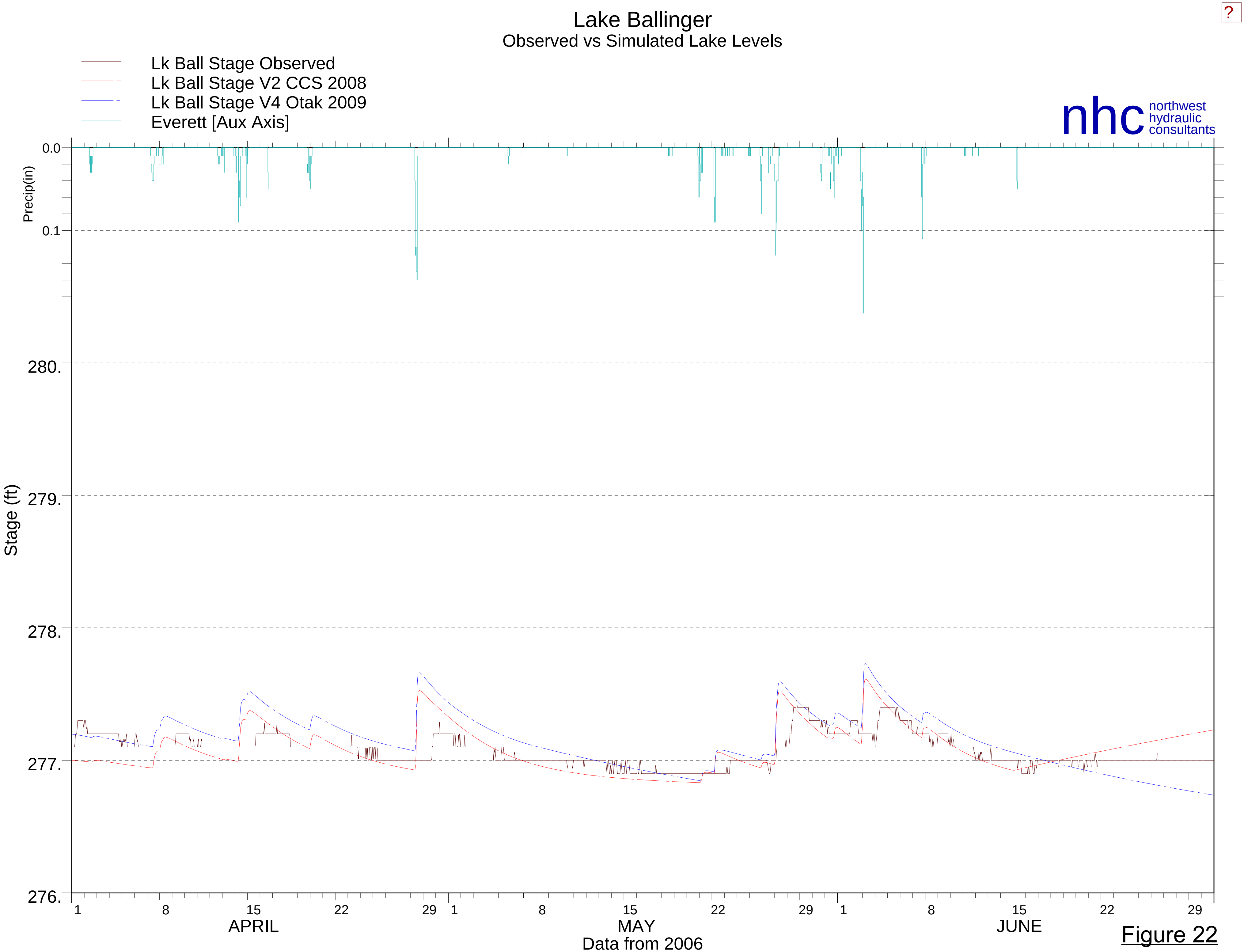

Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.1
Stage (ft)
280.
279.
278.
277.
276.
1 8 15 22 29 1 8 15 22 29 1 8 15 22 29
APRIL
MAY
JUNE
Data from 2006

Figure 22

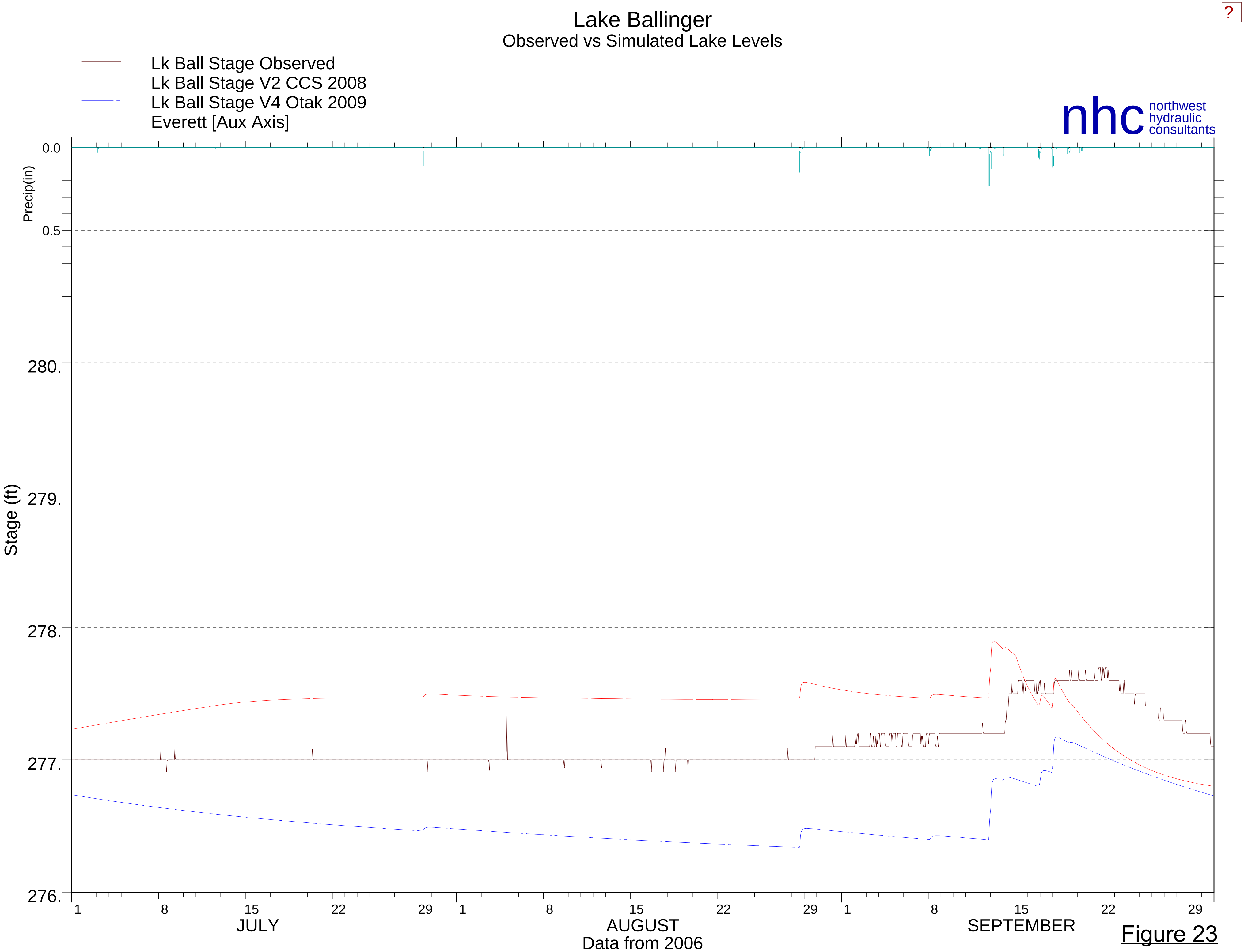
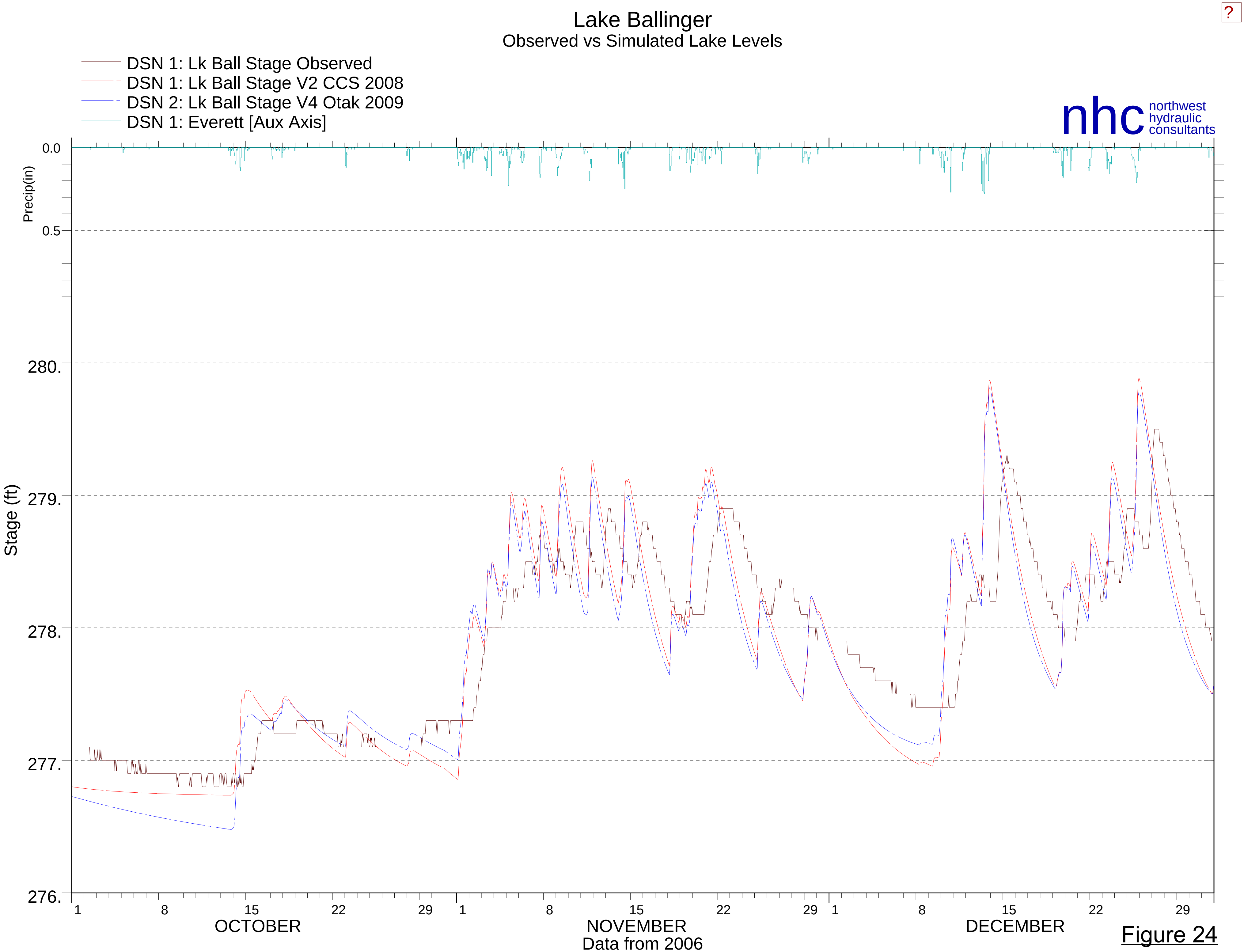
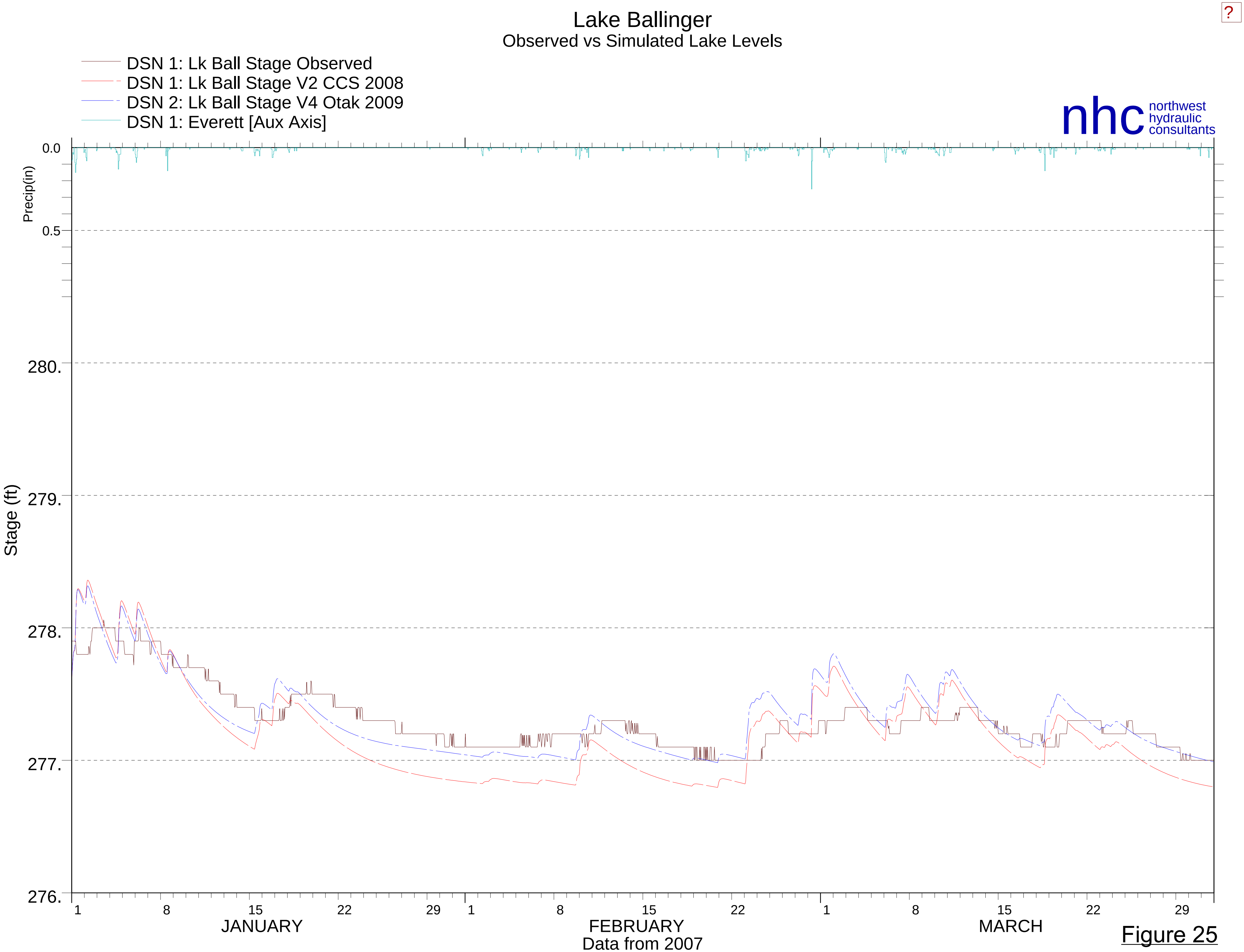

Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
1
8
15
22
29
1
8
15
22
29
JULY
AUGUST
SEPTEMBER
Data from 2006

Figure 23



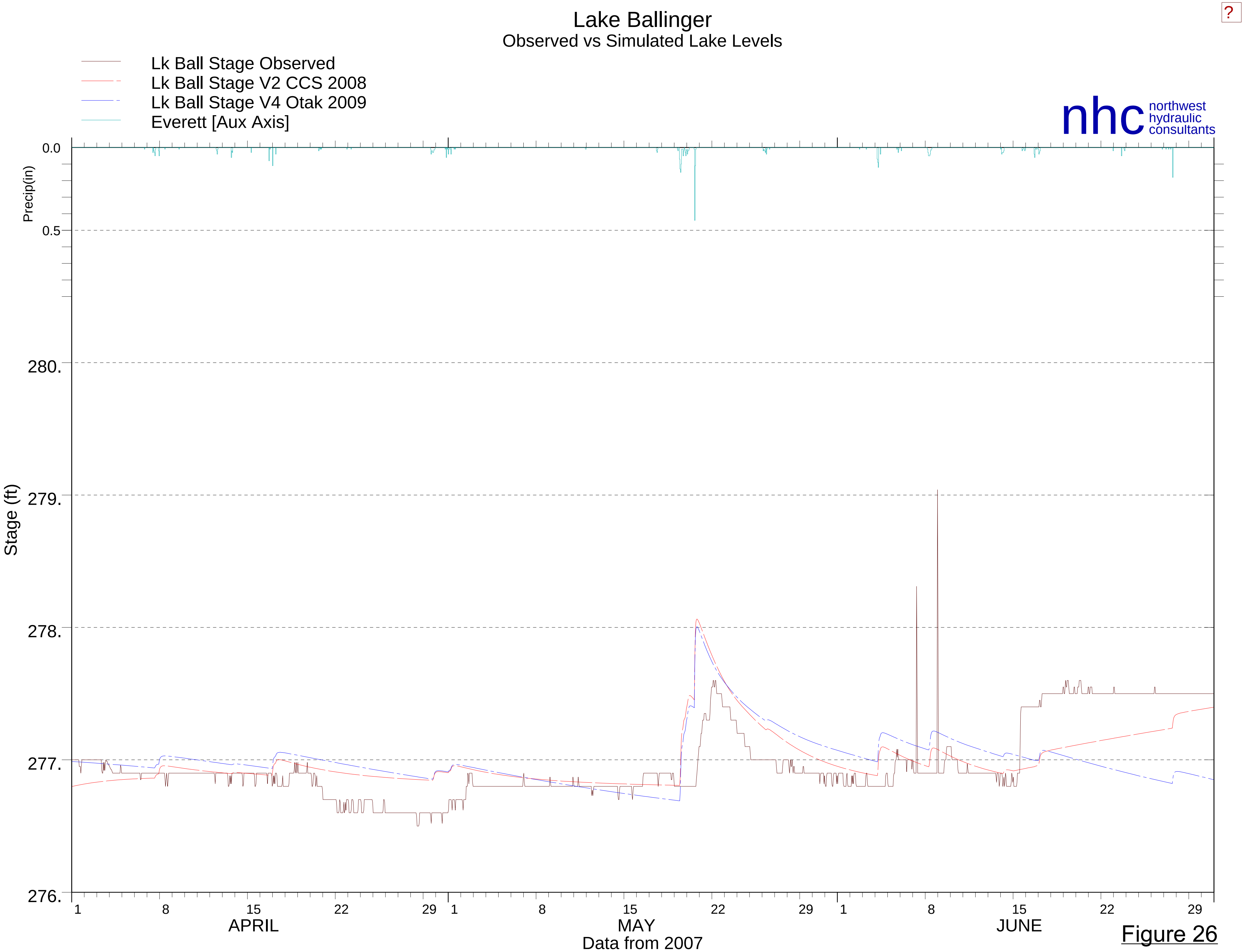
Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc
northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1 8 15 22 29
OCTOBER
1 8 15 22 29
NOVEMBER
1 8 15 22 29
DECEMBER
Data from 2006

Figure 24



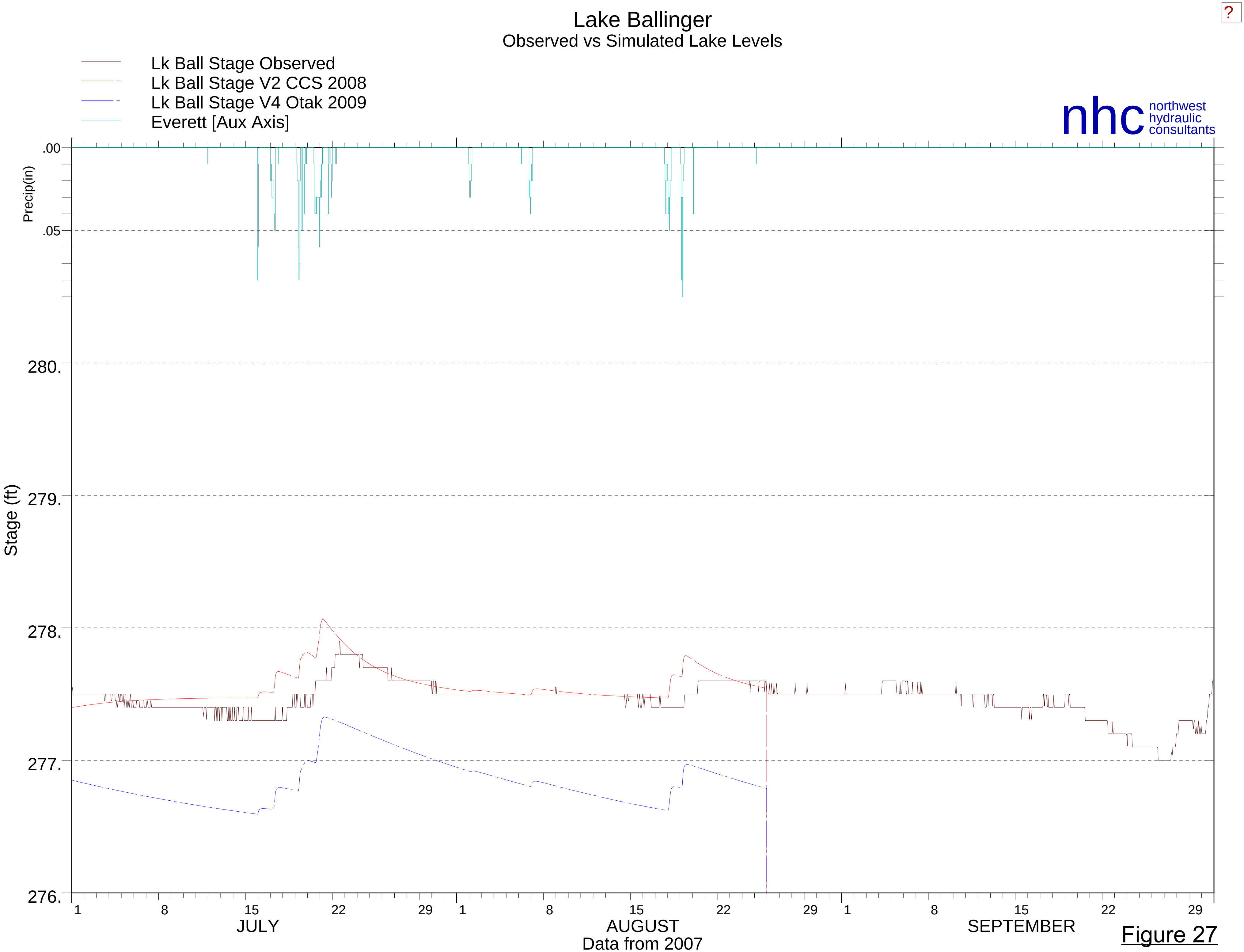
Lake Ballinger
Observed vs Simulated Lake Levels
DSN 1: Lk Ball Stage Observed
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
JANUARY
FEBRUARY
MARCH
Data from 2007

Figure 25



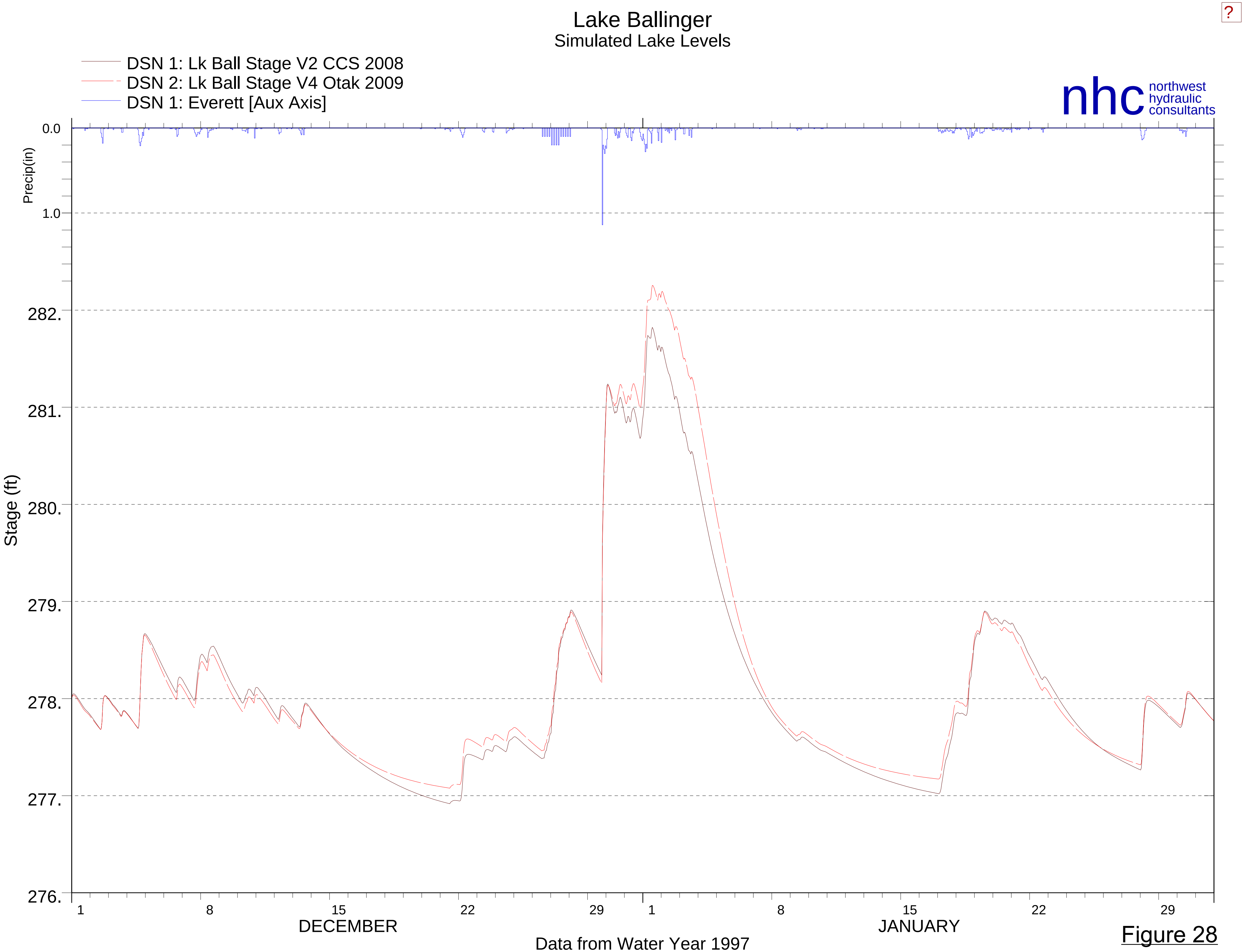
Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
0.5
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
1
8
15
22
29
1
8
15
22
29
APRIL
MAY
JUNE
Data from 2007

Figure 26



Lake Ballinger
Observed vs Simulated Lake Levels
Lk Ball Stage Observed
Lk Ball Stage V2 CCS 2008
Lk Ball Stage V4 Otak 2009
Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
.00
.05
Stage (ft)
280.
279.
278.
277.
276.
1
8
15
22
29
JULY
AUGUST
SEPTEMBER
Data from 2007

Figure 27



Lake Ballinger
Simulated Lake Levels
DSN 1: Lk Ball Stage V2 CCS 2008
DSN 2: Lk Ball Stage V4 Otak 2009
DSN 1: Everett [Aux Axis]
nhc northwest hydraulic consultants
Precip(in)
0.0
1.0
Stage (ft)
282.
281.
280.
279.
278.
277.
276.
1
8
15
22
29
1
8
15
22
29
DECEMBER
JANUARY
Data from Water Year 1997

Figure 28