Appendix D

Attachment 2 – TP Through Hoover Dam

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Memorandum

Date: 3/28/2006

Re: Phosphorus Load through Hoover Dam

Project No: S014004.1

Introduction

The purpose of this memorandum is to clarify and elaborate on results of the Lake Mead modeling with respect to predicted phosphorus loads through Hoover Dam. Much of the information presented here is also available in the Modeling Report ("Lake Mead ELCOM/CAEDYM Modeling", November 2005) that was prepared in relation to the Environmental Impact Statement (EIS).

Model and Data Validation

The Boulder Basin ELCOM/CAEDYM model is able to accurately model the Total Phosphorus (TP) concentrations passing through Hoover Dam, as illustrated by **Figure 1** (a similar figure appears as Figure 4.43 in the Modeling Report). **Figure 1** compares the measured and simulated TP concentrations over a four year period from 2000 to 2003, the period chosen for modeling as included in the Modeling Report. The agreement between the simulation and the measured United States Geological Survey (USGS) data is good, indicating the veracity of the model.

Other phosphorus data near Hoover Dam exist for the period after the modeling was completed (years 2004 and 2005) and are plotted in **Figure 2**. For this time period the data from all sources, other than the USGS, appear to have significant variability and indicate possibly higher TP concentrations than the 2000-2003 USGS data that were used to verify the model. However, these other data sets do not include the 2000 to 2003 modeling period and as such were not able to be directly used in the development of the model. Additionally, these other data sets have discrepancies and limitations as discussed below:

- All but two of the data points from the Southern Nevada Water Authority (SNWA) data set are below the detection limit, which is typically 10 µg/L. The second of the two data points that are above the detection limit, indicates a TP concentration of 30 µg/L on 9/21/05, but the same data set indicates an ortho-phosphorus concentration of 38 µg/L. Clearly there are inaccuracies in the measurements, since, by definition, TP must be greater than or equal to ortho-phosphorus.

- The United States Bureau of Reclamation (USBR) data were not measured at the dam outlets or downstream of the dam. The data were obtained from profile measurements at Station CR342.5, located approximately half a mile upstream of the dam in Black Canyon. The data are obtained from depths of approximately 70 m and 29 m, which are respectively chosen to approximately match the depths of the lower and upper Hoover Dam outlets. However, the TP concentrations measured half a mile upstream of the dam at the approximate depth of the outlets do not necessarily represent the flow passing through the dam. For example, when the lake is not stratified (as commonly occurs in the winter) water from *all depths* upstream, not just water at the depths of the outlets, will pass through the dam. When the lake is stratified, the withdrawal flow field will depend upon the strength of the stratification and the withdrawal flow rate (see, for example, the text "*Mixing in Inland and Coastal Waters*"). The approximation of water remaining confined to a relatively thin withdrawal layer only holds for strongly stratified reservoirs and low withdrawal flow rates. In addition, the empirical formulae used to estimate the vertical thickness of the withdrawal envelope are only valid in the steady-state, which may not be achieved given the high degree of daily variation in the dam flow rate. The situation is further complicated by the temporal flow reversals that can occur with depth in Black Canyon. Thus it can be concluded that much of the time the data measured half a mile upstream of Hoover Dam at the elevation of the outlets does not necessarily represent the quality of the water passing through the dam.

- Prior to September 2005, the USBR samples were not routinely collected at the 29 m depth (the approximate depth of the upper outlets), so that data collected before then would be biased toward values deeper in the hypolimnion.

- On certain instances in 2004 two USBR samples were collected. One of the samples was sent to the Denver Environmental Chemistry Lab (DECL) for separate analysis. The data points of the DECL laboratory results are plotted in **Figure 2** (pink points) and show clear discrepancies with the analysis results from the routine lab (blue points in **Figure 2**). Further comparisons indicate that the average of the absolute differences between the two laboratories is 7 µg/L (based upon the nine dates of dual lab analysis). In particular, on 3/16/04, the routine analysis indicates a TP concentration of 35 µg/L, while the DECL analysis indicates a concentration of only 4 µg/L. Such large discrepancies indicate one or more of the following with respect to the USBR measurements:
    - at least one, if not both, of the laboratory results is not accurate,
    - the samples are subject to contamination,
    - the samples are sensitive to the influence of discrete particulate matter, sometimes resulting in high, and not repeatable, apparent TP concentrations. Conversely, the USGS and SNWA data (from downstream of the dam) may have such particulate matter churned up and mixed by the turbines, and as such any samples may be more representative of the true average concentrations.

Additionally, it has been indicated that, due to some instrument problems in 2004 at the routinely used Boulder City Laboratory, the DECL results are likely to be more reliable than the routine laboratory results (Chris Holdren – personal communication, January 12, 2006). Therefore more confidence can be placed on the DECL data (which are comparable to the USGS data), than the routine data (which are generally higher in concentration).

Considering the discrepancies and limitations of the SNWA and USBR data, the TP concentrations at Hoover Dam were deemed to be best represented by the USGS data, which are at least consistent for the period 2000 through 2005.

In addition to the issues discussed above, and as documented in Section 2.5.3.7 of the Modeling Report, the wide variability of measured in-reservoir TP concentrations represented by the SNWA, USBR, and City of Las Vegas (COLV) data sets, is in part due to the detection limits of the various laboratory analyses being high relative to the low TP concentrations in Lake Mead. As a result of the uncertainty in TP concentrations, frozen samples collected in Boulder Basin between 2000 and 2002 (originally collected and analyzed by COLV) were re-analyzed using the more accurate Inductively Coupled Plasma -Mass Spectrometry (ICP-MS) technique. **Figure 3** (same figure appears as Figure 4.42 in the Modeling Report) plots these measured TP concentrations at Station CR346.4 (additional ICP-MS analysis was *not* conducted on samples collected at the Hoover Dam). Also plotted are the original measurements by COLV and other measurements by USBR and SNWA. Again, the data from different agencies shows wide variation. However, the agreement between the original COLV data and the re-analyzed ICP-MS data is reasonable (see also Figure 2.42 of the Modeling Report). Notably, the ICP-MS data have less variability than the other data sets and do not indicate the exceedingly high values that occur in other data sets. The prediction of the ELCOM/CAEDYM model is also plotted in **Figure 3**, and indicates reasonable agreement with the ICP-MS measurements (which appear to be the most accurate), particularly in the hypolimnion.

In addition to the ICP-MS analysis of the previously collected frozen samples, a special sampling of TP in Boulder Basin was undertaken in December 2002 and January 2003. Special care was taken during this sampling to avoid contamination. These samples were also analyzed using ICP-MS. As further discussed in Section 2.5.3.7 of the Modeling Report, TP concentrations from the special sampling are significantly lower than those obtained from other analyses. The differences are believed to be caused by contamination of the routinely collected data, which can have a major impact at the very low phosphorus levels. The data from the special sampling effort are believed to be more accurate since special precautions were taken during both the sampling and analysis to avoid any potential contamination. Thus, it is likely that the TP concentrations in Boulder Basin and through Hoover Dam are in fact lower than indicated by the routinely collected data. In particular, the TP concentrations in the hypolimnion at Hoover Dam range from 2.0 to 2.5 µg/L as measured by the special sampling, as compared to the 2000-2003 average of the USGS Hoover Dam data of 5.0 µg/L.

Since the special sampling only consisted of measurements on two days (one in December 2002 and one in January 2003) it is not appropriate to use these results for a four year (2000 through 2003) model calibration. Thus, the model was developed to match the most accurate data sets that were available over most or all of the four-year period; namely the ICP-MS data at Station CR346.4, and the USGS data at Hoover Dam. The agreement of the model with the most accurate TP measurements available over the four-year model period, both within Boulder Basin and at Hoover Dam, further validates the modeling.

Model Predictions for BI Alternative and Comparison to Historical Levels

As discussed in Section 2.2.2.6 of the final EIS, the phosphorus loading from the combined effluent discharges through the BI diffuser and into the Las Vegas Wash is not expected to exceed 334 lbs/day during ordinary conditions. The ELCOM/CAEDYM model predictions of flow weighted annual average TP concentrations through Hoover Dam for effluent TP loadings of 334 lbs/day are presented in **Table 1**. Modeling results for the BI Alternative (as well as the No Action [LVW] and LVB Alternatives) at initial water surface elevations (WSEL) of 1,178 ft and 1,000 ft are presented together with modeling results for the baseline year (2002), together with an extended baseline consisting of the average for years 1999 through 2003. It should be noted that the modeling results for the BI and LVB Alternatives are interpolated from simulations at 275 and 467 lbs/day. **Table 1** indicates that the BI Alternative results in predicted phosphorus levels through Hoover Dam that are similar to those that occurred over the extended baseline period of 1999 through 2003. While the levels for the BI Alternative are marginally higher than the single baseline year of 2002, the small difference of 1 μg/L is of the same order as the modeling errors.

Table 1. Lake Mead Modeling Results for Flow-Weighted Annual Average Total Phosphorus Concentrations through Hoover Dam

	Extended Baseline (average of 1999-2003)	Initial WSEL = 1,178 ft				Initial WSEL = 1,000 ft		
		Baseline (2002, 150 mgd, 292 lbs/day)	Effluent flow of 300 mgd, effluent TP = 334 lbs/day					
			No Action	Boulder Islands*	Las Vegas Bay*	No Action	Boulder Islands*	Las Vegas Bay*
Total Phosphorus (mg/L)	0.006	0.005	0.005	0.006	0.006	0.006	0.006	0.006

* Results for the Boulder Islands and Las Vegas Bay Alternatives are interpolated from simulations at effluent TP loadings of 275 and 467 lbs/day.

Figure 4 plots the modeled results for the Alternatives together with modeling results for the years 1999 through 2003. Again, it is clear that the BI Alternative is predicted to result in TP loads through Hoover Dam that are comparable to recent historical values. In particular, at a WSEL of 1,178 ft (which is comparable to recent historical years) the TP loads through the dam are predicted to

be less than three of the five modeled recent historical years, while at a WSEL of 1,000 ft (that is much lower than recent historical years) the load is predicted to be less than that experienced in year 2000.

Figure 5 plots the annual average TP concentration for water passing through Hoover Dam from USGS data extending back to 1974. It is apparent that the TP concentration through the Hoover Dam has historically been far higher than in recent years, apparently without negative consequences downstream. Clearly, the predicted TP concentrations through Hoover Dam for the BI Alternative are lower than historical levels over an extended period of time.

Variability of Measurements and Not-to-Exceed Water Quality Standards

As discussed previously, the TP measurements in Lake Mead and downstream of Hoover Dam have significant variability due to possible sample contamination, presence of discrete particulate phosphorus, and relatively high detection limits. Such data variability implies it may be unrealistic to attempt to maintain at all times a TP concentration at a not-to-exceed level of 10 µg/L for water leaving Hoover Dam.

To illustrate this, the USGS data, which shows the *least* variability of the Hoover Dam data plotted in **Figure 2**, is further analyzed. **Figure 6** plots the USGS data at Hoover Dam dating back to 1974. It is clear that the level of 10 µg/L was routinely exceeded prior to 1994, which is when the dischargers began to meet the waste load allocations limiting them to 334 lbs/day during the algal growing season (April through September). Even since 1994, there have been numerous exceedances of the 10 µg/L level. In fact, seven of the 68 measurements taken between 1994 and 2005 have been greater than 10 µg/L. This corresponds to exceedances for approximately 10 percent of the samples.

Since the large algal bloom of 2001 the dischargers have been removing more phosphorus during October through March. While the USGS data plotted in **Figure 6** do not indicate any exceedances of the 10 µg/L level since that time, statistical analysis of the data indicates exceedances would almost certainly occur during an extended period of time if the reservoir is continued to be operated as it has been since 2001. Assuming the USGS data TP concentrations at Hoover Dam between 2002 and 2005 to be log-normally distributed, then it is computed that there is a one percent probability that any single measurement will exceed 10 µg/L. While one percent is relatively small, over an extended period of time and many measurements the probability for exceedance becomes significant. For example, if it is assumed that TP measurements are made at the dam monthly then there are 12 measurements per year. The probability of at least one of these measurements exceeding 10 µg/L is then 11 percent ($1-[1-0.01]^{12} = 0.11$). Over 10 and 20 years, the probability increases to 70 and 91 percent, respectively.

It should be emphasized that the significant probability of exceeding 10 µg/L is a result of the variability of the measurement process (including sample contamination, presence of discrete particulate phosphorus, and high detection limits), rather than the real representative concentration

necessarily being greater than 10 µg/L. Additionally, the USGS data are the *least* variable of the Hoover Dam data plotted in **Figure 2**, and the probabilities of exceedance would be significantly higher if other data sets were used in the statistical analysis. Indeed, **Figure 2** indicates that both the SNWA and USBR data (which have significant discrepancies and limitations as discussed previously) exceed the 10 µg/L level on occasion in 2004 and 2005, even though the real representative concentration of TP in water through Hoover Dam (i.e., the USGS data) indicate that it is likely to be less than 10 µg/L.

Given the large variability in the measurement processes leading to a significant probability of exceedance of the 10 µg/L level, it is unrealistic to impose such a not-to-exceed criterion on future operations.

Additionally, it is the average TP concentration that is most relevant to downstream users concerned about algal blooms, since temporary and isolated peak TP concentrations will be mixed and diluted before reaching the photic zone of Lake Mohave. The seasonally uniform, cold inflow from the Lake Mead hypolimnetic Hoover Dam releases (approximately 12 °C year round) transits the Canyon Reach of the river with very little warming and enters the upper basins of Lake Mohave as an underflow through the spring, summer, and fall seasons (when algae growth in Lake Mohave may be of concern). This underflow becomes larger than the inflow from Lake Mead due to entrainment of epilimnetic water at the plunge point ("Lake Mohave Water Quality Model Project Report: Model Validation", October 27, 2003). This entrainment directly dilutes any parcels of water that may have higher than average phosphorus concentrations. In addition, the average residence time of Cottonwood Basin (the largest and furthest downstream portion of Lake Mohave) is 64 days ("Lake Mohave Water Quality Model Project Report: Model Validation", October 27, 2003). The time for the underflow to upwell and reach the surface in Lake Mohave would be smaller than, but of the same order as, the residence time. It would therefore take many days or weeks for any parcels of water with higher than average phosphorus concentrations to surface and reach the photic zone after entering Lake Mohave as an underflow. By this time, the higher phosphorus concentration will have been well mixed and diluted with ambient water and water entrained from the epilimnion. Thus, with respect to algal growth in Lake Mohave, the relevant phosphorus concentration leaving Hoover Dam is one that has been averaged over many days or weeks, rather than any instantaneous or maximum values.

Downstream Phosphorus Concentrations

The TP passing through Hoover Dam makes up only part of the TP concentrations downstream. **Figure 7** plots the TP concentrations through Hoover Dam (USGS data) together with Metropolitan Water District (MWD) data at inlets and outlets of Lakes Havasu and Mathews (downstream of Lake Mead), for the period 2000 through 2005. A similar plot with reduced range of vertical scale to enable more clarity is shown in **Figure 8**. The figures show that the TP concentrations in the downstream lakes are substantially higher than those that pass through Hoover Dam. This indicates that there are sources of phosphorus downstream of the dam that may be more significant than the phosphorus that passes through the dam. This is particularly evident in that none

of the large TP concentration peaks evident in the downstream lakes (particularly Lake Mathews) correlate with the TP concentration through Hoover Dam, which is devoid of large peaks.

Since there are more significant sources of phosphorus downstream of Hoover Dam, any modest changes to TP concentrations through the dam are likely to result in only very minor *relative* changes to the TP concentrations further downstream.

References

"Lake Mead ELCOM/CAEDYM Modeling" [Modeling Report], *Flow Science Incorporated*, November 17, 2005.

"Lake Mohave Water Quality Model Project Report: Model Validation", *J. E. Edinger Associates, Inc*., October 27, 2003.

"*Mixing in Inland and Coastal Waters*", H. B. Fischer, E. J. List, R. C. Y. Koh, J. Imberger, N. H. Brooks, *Academic Press*, 1979; Section 6.6.

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Data vs. Simulation for 2000-2003 at Hoover Dam Outlets

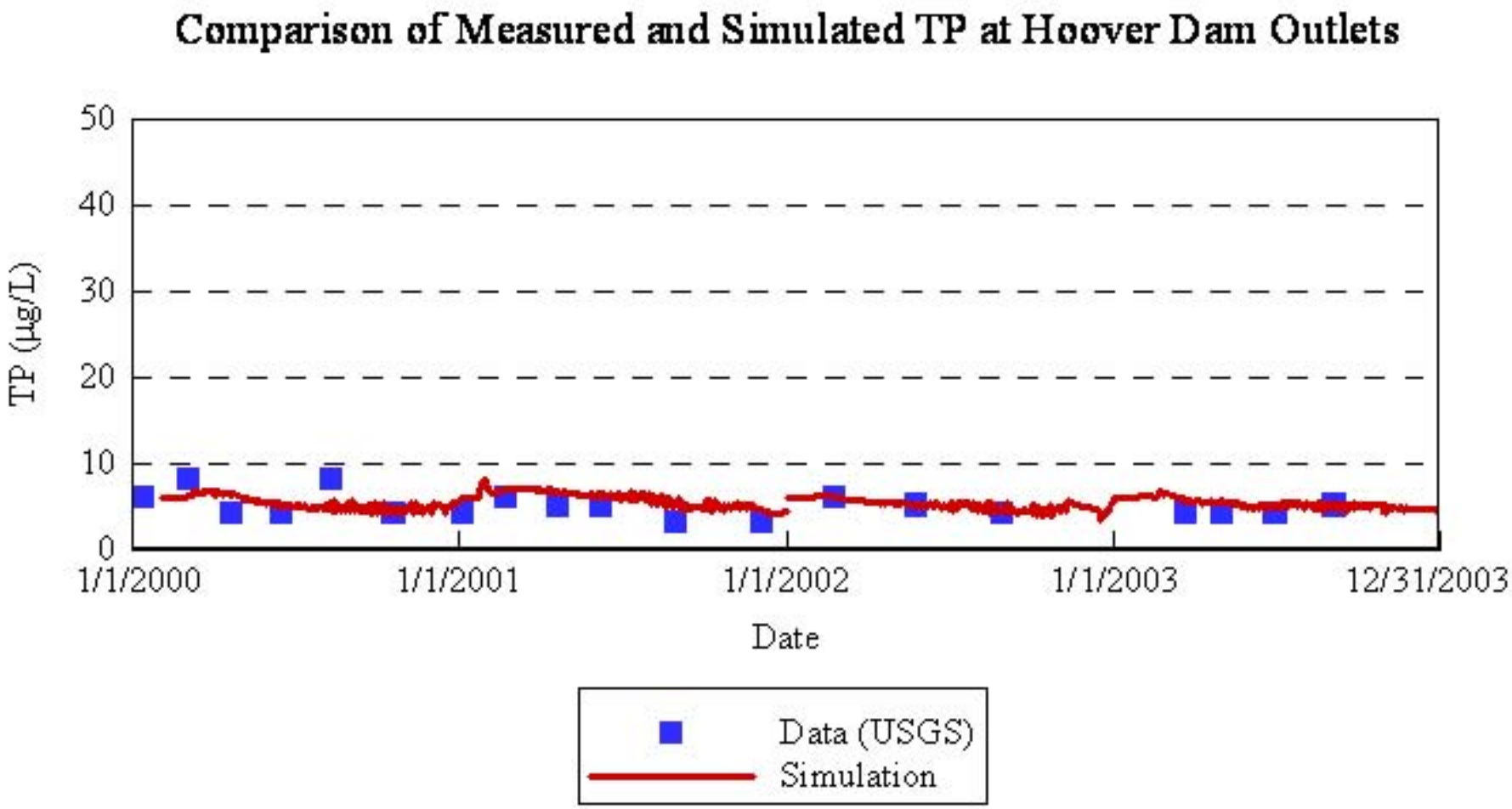

Figure 1

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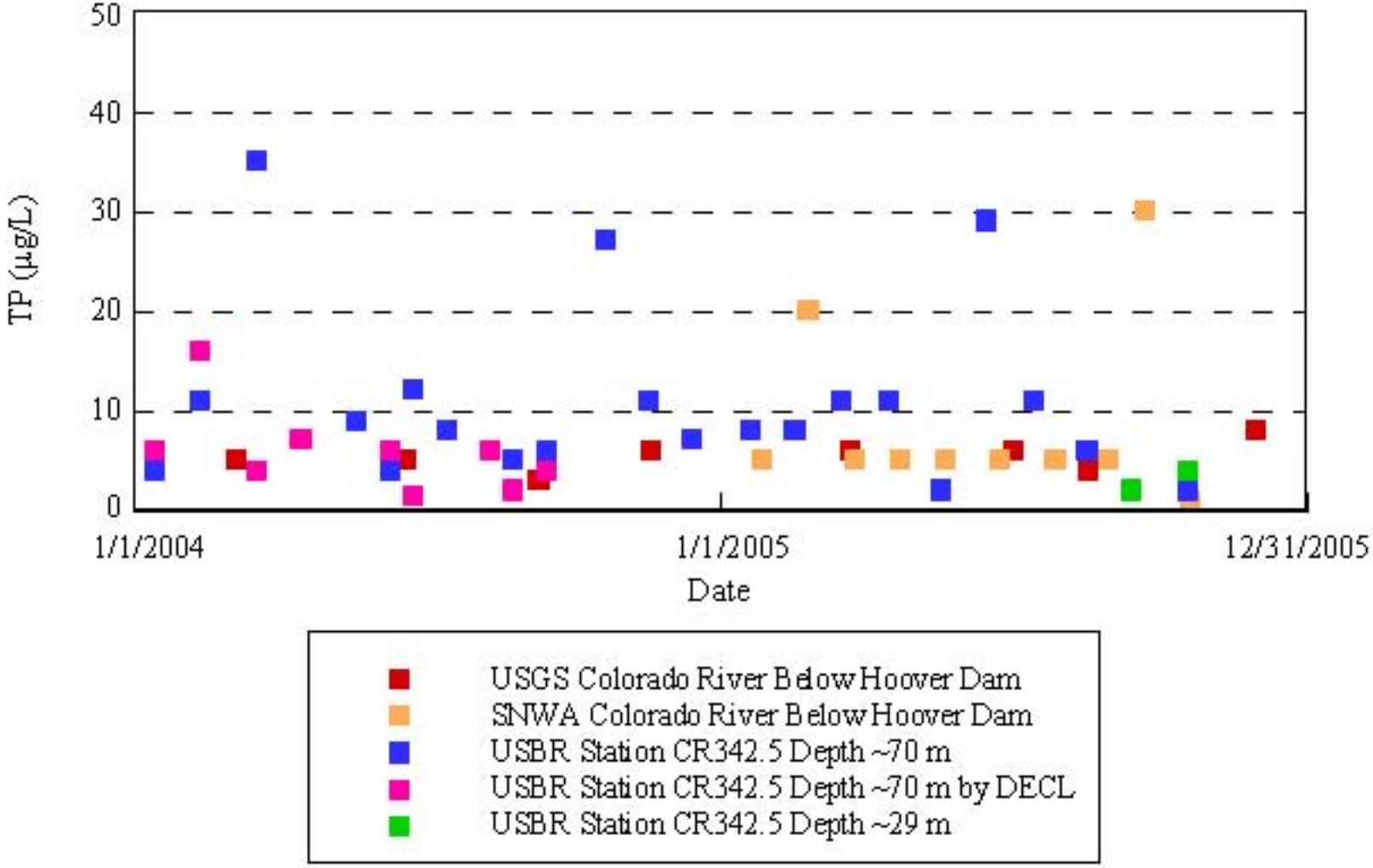
Measured Total Phosphorus at Hoover Dam



Note: Data reported as "not detected" and/or "less than" measured values were assumed to be equal to half of the detection limit.

Figure 2

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Data vs. Simulation for 2000-2003 at Station CR 346.4

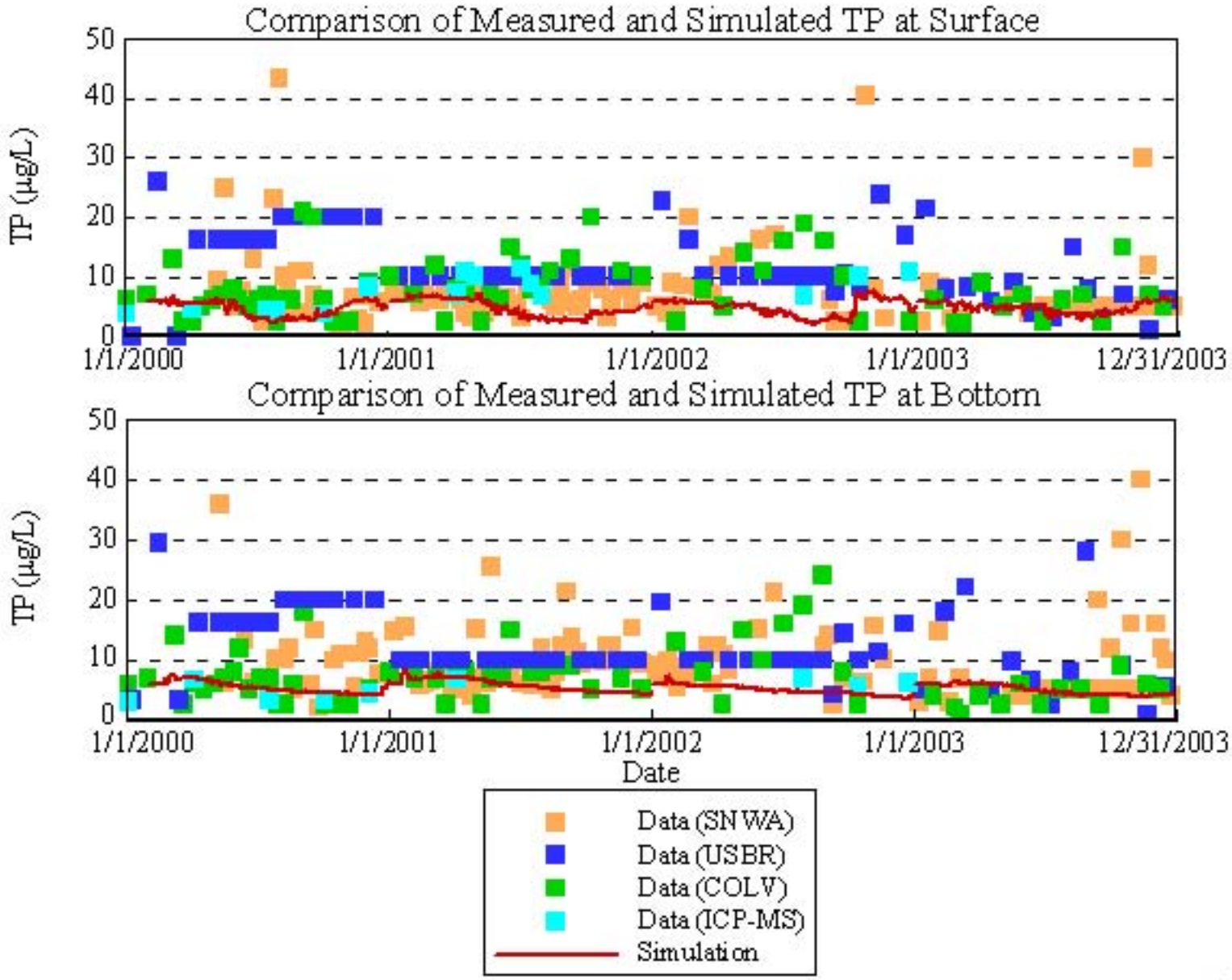

Figure 3

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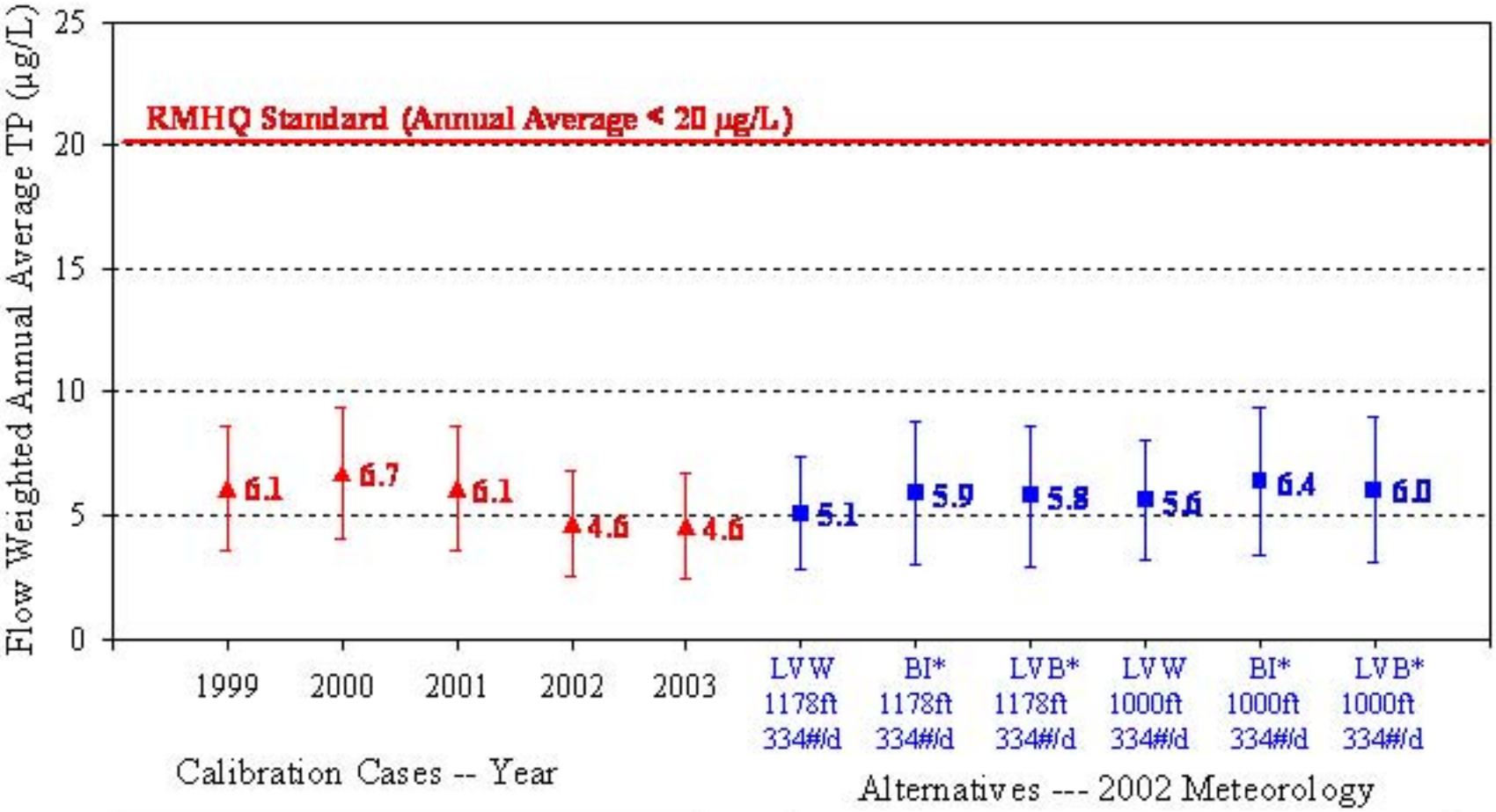
Total Phosphorus through Hoover Dam



Error bars are based upon ± 25% and ± 1 µg/L of TP through The Narrows.

■ Alternative cases ▲ Calibration Cases

* Results for BI and LVB are interpolated from 275 and 467 #/d simulations.

Figure 4

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Annual Average Total Phosphorus Concentration at Hoover Dam (USGS Data)

Data points below the detection limit of 10 µg/L (prior to year 1999) are assumed to be equal to half of the detection limit.

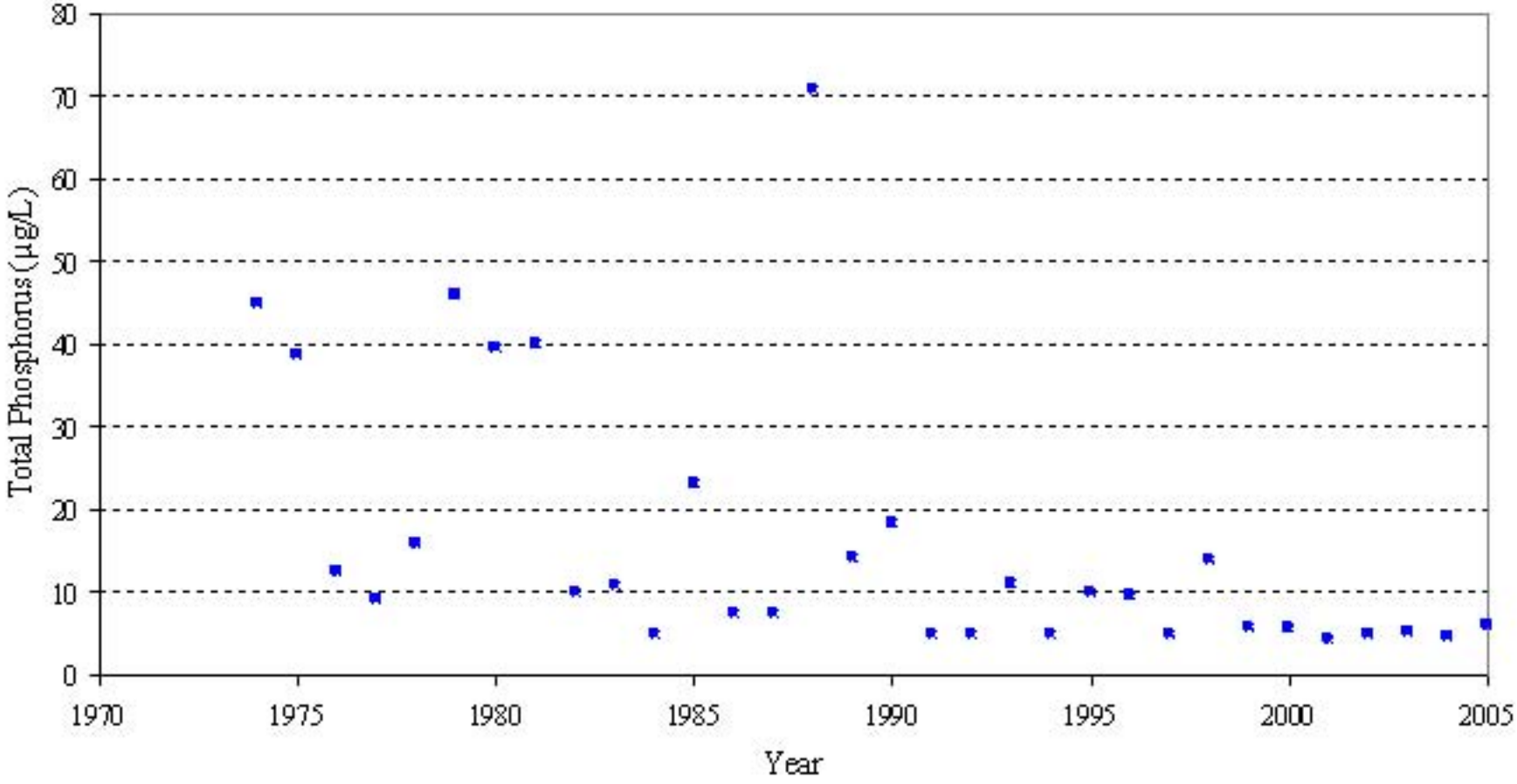

Figure 5

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Total Phosphorus at Hoover Dam (USGS Data)

Data points below the detection limit of 10 µg/L (prior to year 1999) are assumed to be equal to half of the detection limit.

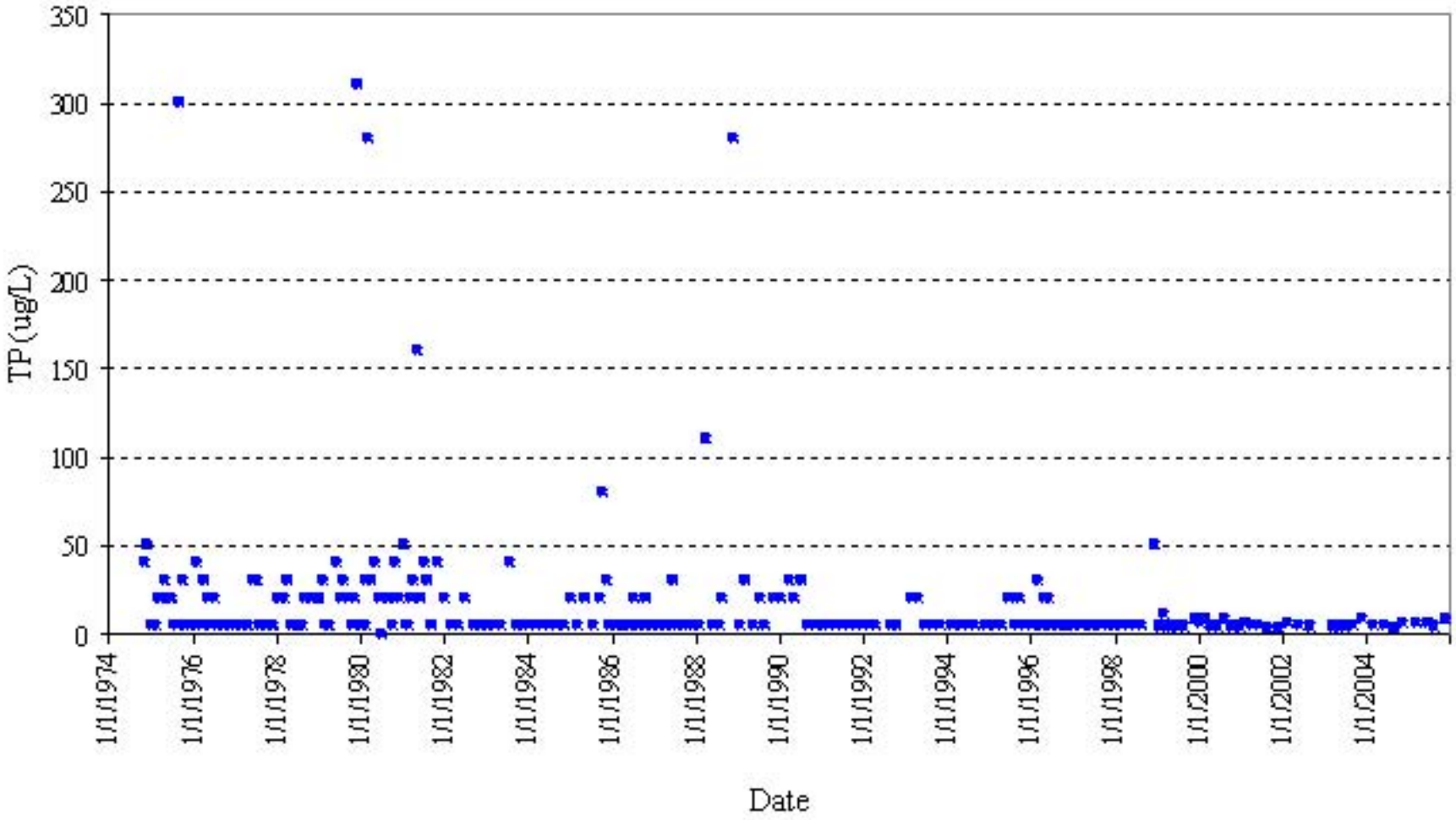

Figure 6

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Total Phosphorus Concentrations

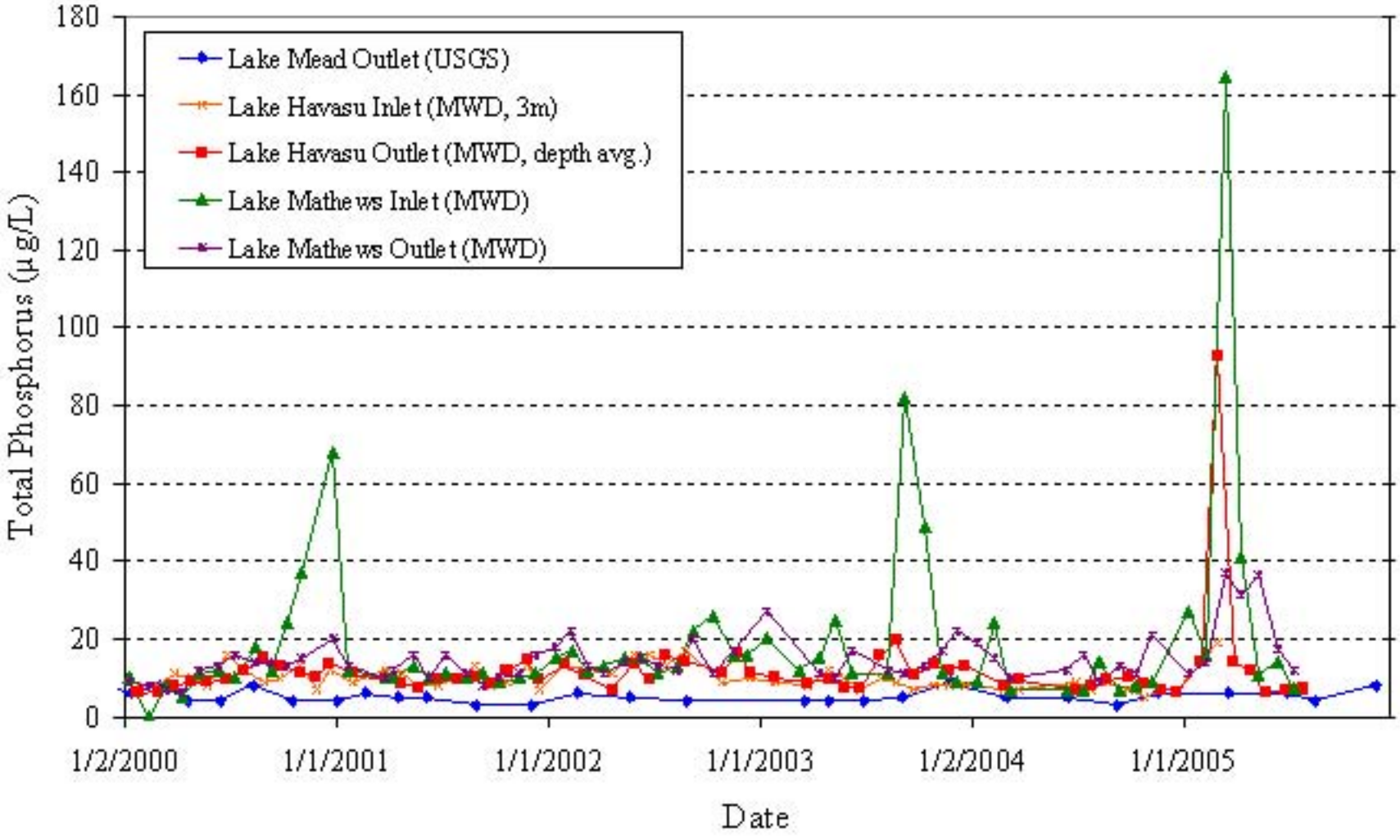

Figure 7

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Total Phosphorus Concentrations

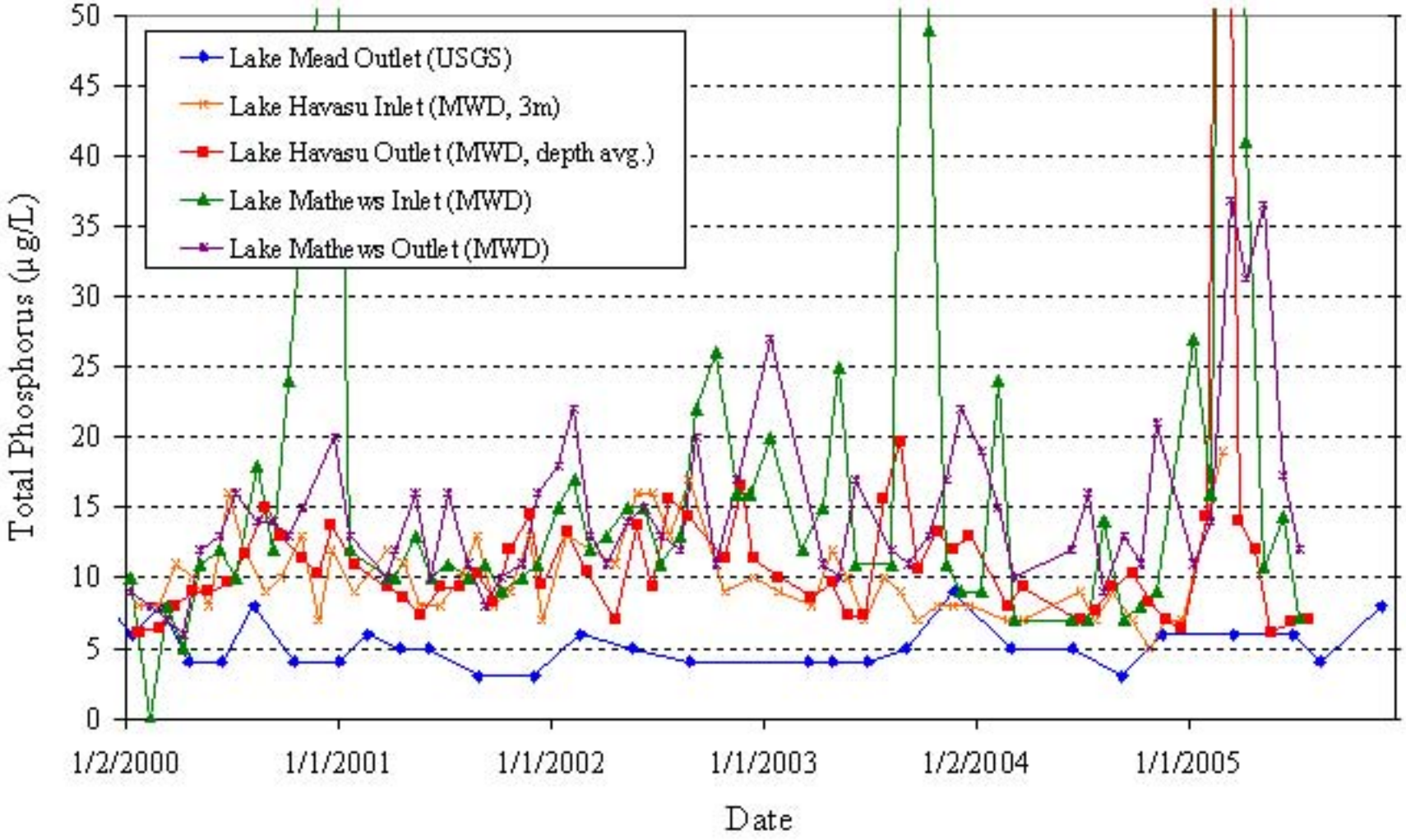

Figure 8

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