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Appendix J
Impacts of Increased Water Supply Storage on Water Quality

Impacts of Increased Water Supply Storage on Water Quality

Chatfield Reservoir Storage Reallocation Feasibility Study

Submitted to:
U.S. Army Corps of Engineers
Omaha District

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March 2013

Revised by:
U.S. Army Corps of Engineers
Omaha District

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1. PREFACE

This document is an evaluation of potential water quality impacts from the proposed reallocation of flood control storage at Chatfield Reservoir, Littleton, Colorado, and was prepared as a component of the Chatfield Storage Reallocation project.

In 2005, interested parties were invited to participate in a water quality workgroup to determine the scope of the water quality modeling necessary for the Feasibility Report-Environmental Impact Statement (FR-EIS). Participants included representatives from the Chatfield Watershed Authority, Colorado State Parks, Colorado Division of Wildlife, the water providers, the U.S. Army Corps of Engineers (Corps), and Tetra Tech (who assisted the Corps in preparing the FR-EIS). Four workgroup meetings were held between April and September 2005. The workgroup reviewed, evaluated, and considered scoping comments on water quality; identified the water quality parameters of greatest concern; and developed the approach for addressing water quality concerns associated with storage reallocation at Chatfield Reservoir. Appendix J of the FR/EIS documents the water quality analysis that was implemented under the direction of the water quality workgroup.

During the public comment period on the Draft FR/EIS, the U.S. Environmental Protection Agency (EPA) provided comments on water quality, including Appendix J. The Corps and Tetra Tech met with EPA to discuss the comments, and it was agreed that the analysis of phosphorus loading would be revised based on recent water quality data for Chatfield Reservoir. During discussions, EPA recommended incorporating recent data that were not included in the Draft FR/EIS and stressed the importance of utilizing a broad dataset to strengthen modeling for phosphorus and other parameters. Later discussions with EPA also lead to an agreement to further evaluate potential water quality impacts to the South Platte River immediately downstream of Chatfield Reservoir that could result from flow reductions. Thus Appendix J has been revised to include two parts: 1) assessment of potential impacts to the water quality of Chatfield Reservoir, and 2) assessment of potential impacts to the water quality of the South Platte River immediately downstream of Chatfield Reservoir.

EPA's comments on the Draft FR/EIS correctly identified a discrepancy in the water quality data initially used for water quality assessment and modeling. Water quality data collected by the Chatfield Watershed Authority (CWA) since 1983 were taken to represent historic water quality conditions in the deepwater, near-dam area of Chatfield Reservoir. Prior to 2009, these data were collected to a maximum depth of 10 meters and indicated the reservoir rarely (one occasion) exhibited hypoxic conditions (i.e. ≤ 2 mg/L dissolved oxygen) in the lower depths of the reservoir during the summer. The CWA and other local entities supported the conclusion that Chatfield Reservoir rarely experienced hypoxic conditions during the summer (CWA, 2008a). EPA correctly referenced post-2008 data that indicated Chatfield Reservoir was deeper than 10 meters and did regularly experience hypoxic conditions near the reservoir bottom. Further review of 2009 through 2012 water quality data, and more investigative review of historic Corps water quality data collected at Chatfield Reservoir, indicated that the CWA's historic water quality database was biased as pre-2009 profile measurements were only taken to a depth of 10 meters. The reasoning formulated for the bias was that the CWA may have only been trying to assess compliance with site-specific water quality standards criteria for Chatfield Reservoir (i.e. total phosphorus and chlorophyll *a*) that applied to the mixed layer during the summer. Given the identified discrepancy, it was concluded that the initial water quality assessment and modeling presented in the Draft FR/EIS needed to be revised to better represent the existing water quality conditions at Chatfield Reservoir as indicated by the more recent water quality data. Significant revisions were made to the water quality assessment and modeling included in Appendix J after the release of the Draft FR/EIS. It is noted that the original bathymetry used to model water quality in Chatfield Reservoir was correct. An error occurred when it was assumed the historic water quality profile data represented the entire water column in the deepest part of the reservoir.

2. CHATFIELD RESERVOIR

2.1 Background

2.1.1 Technical Approach

2.1.1.1 Initial Water Quality Assessment

Three broad categories of water quality parameters for Chatfield Reservoir were evaluated in the initial water quality assessment, based on recommendations from the project's water quality workgroup: nutrients, metals, and bacteria. Available physical, chemical, and biological data for the reservoir were evaluated, in conjunction with proposed changes in pool elevation from 5432 ft msl[1] (conservation pool, baseline) to 5444 ft msl (maximum proposed or "with-project" conditions). The initial water quality assessment provided a conservative analysis of water quality impacts for the Chatfield Storage Reallocation project using a simplified approach. It should be noted that uncertainty may be high when applying simplistic models, because simple models generally do not fully represent the dynamic, time-variable nature of a system. For that reason, the analysis included conservative assumptions. Simple analytical approaches like the one applied can be very useful analytical tools. Uncertainty may be reduced when using a complex analytical model; however, this greatly increases data and resource requirements. The water quality workgroup considered more complex, dynamic modeling approaches but ultimately determined that the approach of the initial water quality assessment was adequate and reasonable to evaluate the potential impacts associated with the proposed project.

The initial nutrient evaluation included two analyses, the first analysis used a simplistic but conservative regional nutrient loading model and the second analysis used a more detailed site-specific evaluation of nutrient loading to the Chatfield Reservoir. The first nutrient analysis used the EUTROMOD model to evaluate historical incoming total phosphorus loads, hydraulic residence time, and change in volume information to predict reservoir eutrophication potential and chlorophyll-a for the baseline and reservoir storage reallocation conditions. The second nutrient analysis was more site-specific and focused on the prediction of the change in hypolimnetic volume under the proposed reallocation condition and its impact on internal nutrient loading and reservoir nutrient concentrations. Oxygen demand in the quiescent hypolimnion can result in the development of hypoxic/anoxic conditions near the reservoir bottom. These conditions can limit aquatic life and mobilize constituents bound to reservoir sediments through oxidation-reduction. This is particularly true of sediment-bound nutrients such as phosphorus. An increased release of phosphorus has implications on the trophic nature of the reservoir.

An increased reservoir-bottom surface area may lead to an increased release of metals bound to bottom sediments. Thus, the metals evaluation involved prediction of metals release under the proposed condition and a comparison to baseline conditions. The diffusive flux was estimated for

[1] Note: MSL refers to Above Mean Sea Level

the entire lake bottom, and it was assumed to be equivalent for anaerobic and aerobic conditions for all metals evaluated. This assumption was necessary since no definitive aerobic versus anaerobic fluxes could be identified in the literature. The fluxes varied based on the environmental setting of the waterbody, were either positive or negative, and varied by orders of magnitude.

While evaluation of nutrients and metals involved reservoir-wide assessments, the bacteria evaluation focused on localized impacts around the swim beach. Changes in waterfowl and shorebird usage of the reservoir could occur if the reservoir's littoral area increased. Any increase in bird use would be accompanied by an increase in bacteria loading. An increase in bacteria loading could impact bacteria levels at the swim beach. Therefore, the analysis conducted focused on evaluating the potential for increased bacteria levels at the swim beach.

2.1.1.2 Revised Water Quality Assessment

As identified in the EPA's comments on the Draft FR/EIS, the initial water quality assessments of Chatfield Reservoir to evaluate potential impacts from reallocation were inadvertently based on incomplete water quality data, and the incorrect assumption that the reservoir rarely experienced hypoxic conditions during summer stratification. To address this deficiency an inventory of recent water quality data available for Chatfield Reservoir was conducted. The goal was to identify recent water quality data that could be used to assess existing water quality conditions in the reservoir; particularly regarding the occurrence and extent of hypoxic conditions in the reservoir throughout the summer stratification period. Two additional datasets were identified that partially met this need: 1) 2008 Colorado Division of Wildlife (CDOW) mercury methylation study, and 2) 2012 CWA water quality data. The 2008 CDOW data provided complete depth-profile temperature and dissolved oxygen (DO) measurements throughout the summer at the near-dam, deepwater area (Attachment 1). The 2012 CWA data also provided complete depth-profile temperature and DO measurements throughout the summer at the near-dam, deepwater area. In addition, the 2012 CWA data provided numerous other depth-discrete measurements of water quality conditions. The 2012 CWA data are available at the CWA's web site (http://www.chatfieldwatershedauthority.org/). No water quality data were discovered that monitored conditions throughout the water column in the deeper, mid-lake regions of the South Platte River and Plum Creek arms of the reservoir. This limited the spatial assessment of hypoxic conditions that occur throughout Chatfield Reservoir during the summer, and is a water quality data need that should be addressed with future water quality monitoring and/or modeling.

The application of the EUTROMOD model, that was part of the initial water quality assessment, was removed from the revised water quality assessment. EUTROMOD is a simplistic, regionalized water quality model that predicts annualized lake eutrophication metrics (i.e. phosphorus, chlorophyll-a, transparency, and trophic state). It doesn't allow for within-year, site-specific variation in limnological conditions. The revised water quality assessment included water quality modeling at a monthly scale, and allowed temporal variation in limnological conditions to be considered. Future application of dynamic water quality modeling at Chatfield Reservoir is identified in the Chatfield Reallocation Project Adaptive Management Plan (AMP). As such, it was determined that the EUTROMOD model had limited usefulness and was removed from the revised water quality assessment.

Subsequent to the evaluation of "with-project" water quality conditions and recognized uncertainties, water quality was included as an identified resource in the AMP. With regards to identified resources, the AMP identifies actions to:

- Reduce and/or address uncertainties associated with impact estimates and proposed mitigation,
- Provide contingent plans if needed for proposed mitigation and management,
- Serve as part of the feedback loop between mitigation monitoring and mitigation actions that will lead to appropriate adjustment, and
- Provide new and enhanced applications by learning through management and information from all sources as it becomes available.

In reviewing this technical report, it is important to consider that Chatfield Reservoir is not the originating source of phosphorus and would not be under the proposed reallocation project. Instead, phosphorus inputs from the watershed upstream of Chatfield Reservoir have been deposited in the reservoir and impact water quality. It has been estimated that 60 to 70% of the external phosphorus load annually delivered to Chatfield Reservoir is retained in the reservoir (CWA, 2008a). Changing the operation of Chatfield Reservoir could influence the reactivity and potential release of these minerals from bottom sediments. The applied model was used to simulate the effects of proposed operations on reservoir water quality.

2.1.2 Recent Changes in Water Quality Standards

This subsection describes recent changes in the water quality standards for phosphorus and chlorophyll-a at Chatfield Reservoir. The Colorado Water Quality Control Commission (CWQCC) implemented changes in these standards based on several factors related to existing water quality at Chatfield Reservoir. These factors are relevant to the discussion of the potential impacts of the proposed alternatives on water quality in this proposed reallocation project. For that reason, they are described in some detail below.

The technical analysis of the initial water quality assessment was completed prior to the 2008 rulemaking for the Upper South Platte Segment 6b (Chatfield Reservoir), which resulted in new standards for phosphorus and chlorophyll. Effective March 30, 2009, the CWQCC revised the site-specific phosphorus standard and changed the chlorophyll goal to a standard for Chatfield Reservoir (Regulation Number No. 38). They also revised the Chatfield Reservoir Control Regulation (Regulation No. 73) to be consistent with the revised standards.

The previous phosphorus standard of 0.027 milligrams per liter (mg/L) and chlorophyll-a goal of 17 micrograms per liter (µg/L) (both effective May 30, 1985) were referred to in the initial water quality assessment. As of March 2009, the standards are 0.030 mg/L for phosphorus and 10 µg/L for chlorophyll-a, measured through the collection of samples representative of the mixed layer during summer months (July, August, September). The maximum allowable exceedance frequency of these standards is once in five years. The assessment criterion used to determine whether Segment 6b is in attainment of the phosphorus standard is 0.035 mg/L, and the assessment criterion for chlorophyll is 11.2 µg/L. A distinction is made between the standard and an assessment threshold in Regulation No. 38, which states that these assessment thresholds shall be used when assessing whether Chatfield Reservoir is in attainment of the specified standards (for additional details see the "Development of Assessment Thresholds" paragraph below). The new allowable load of total phosphorus in Chatfield Reservoir is 19,600 pounds per year (lbs/yr) under a median inflow of 100,860 acre-feet per year (ac-ft/yr). According to Regulation No. 38, "The new allowable load better reflects the linkage between watershed total phosphorus load and the in-lake total phosphorus concentration."

A technical review of the scientific basis for the Chatfield Reservoir phosphorus standard resulted in the changes in standards. The CWQCC directed the Colorado Water Quality Control Division (CWQCD) to undertake the technical review for several reasons, as described in Regulation No. 38, including:

> The phosphorus standard has been exceeded in Chatfield Reservoir several times since approximately 1995, while the associated chlorophyll goal has not. The incongruity suggested that the original basis for linking chlorophyll and phosphorus concentrations in the lake should be revisited.

The following results of the technical review appear in Regulation No. 38. These are included here because they provide a context for the technical discussions presented in this water quality report.

Current Condition. Chatfield Reservoir presently has good water quality and uses are being attained. The Commission believes that good conditions have been maintained by having implemented effective phosphorus control strategies through adoption of Control Regulation No. 73. The data record amassed through more than 20 years of water quality monitoring shows that trophic condition has remained stable, and it provides a comprehensive basis for assessing the variability in those characteristics (chlorophyll and phosphorus) of trophic condition that are recommended as standards.

Characterizing Chlorophyll. Typical summer average chlorophyll is about 6 µg/l, and there has been no trend for increasing concentration over the 26-year period of study. Concentrations vary from year to year, but have exceeded 10 µg/l only 5 times in 24 years, and only twice since 1990.

Role of Phosphorus. The Commission believes that eutrophication of Chatfield Reservoir has been averted through the control of phosphorus loads from the watershed. Adoption of the control regulation made this possible by imposing concentration limits on point source discharges and by facilitating implementation of nonpoint source management. There has been no trend for increasing phosphorus in Plum Creek, where most of the development has occurred.

Characterizing Phosphorus. Typical summertime concentrations of phosphorus have been about 0.020 mg/L, and there has been no trend for increasing phosphorus in the lake. Summer median concentrations have exceeded 0.030 mg/L in only 3 of 24 years. It is appropriate to maintain phosphorus as a standard, rather than a goal, because of its importance in characterizing trophic condition, and because it is the direct link to the control regulation.

Old Relationship Between Chlorophyll and Phosphorus. At the time the technical review was conducted, the existing phosphorus standard was not consistent with the existing chlorophyll goal.

Phosphorus concentrations at or below the level of the standard have yielded chlorophyll much lower than the goal. The mismatch is the result of relying entirely on one year of data and assuming that all variation in chlorophyll is explained completely by the phosphorus concentration in the reservoir.

Defining a New Chlorophyll-Phosphorus Linkage. The conventional regression approach previously used to link chlorophyll and phosphorus in the context of trophic conditions has shown its weaknesses. The CWQCD believes a better linkage is based on the simple ratio of chlorophyll to phosphorus, which records the net responsiveness of the resident algal community to the amount of phosphorus present in the lake. It is a "net" value because it reflects the balance of growth (nutrients, light, temperature) and loss (grazing, washout, settling) processes. The measured ratios offer an empirical basis for defining expectations for chlorophyll given the available phosphorus.

Revised Water Quality Standards for Chatfield Reservoir. With the benefit of the lengthy historical record now available, the CWQCC believes it is appropriate to set chlorophyll and phosphorus standards consistent with the trophic condition that has been maintained. The CWQCC adopted a chlorophyll standard of 10 µg/L and a phosphorus standard of 0.030 mg/L to preserve the intended trophic condition and protect uses. Each standard is to be attained in four of five years.

Development of Assessment Thresholds. For Chatfield Reservoir, a distinction is made between the standard and an assessment threshold. The assessment threshold is designed to address the concern about the risk of incorrectly counting an exceedance when a high summer value is the result of natural variability, but does not indicate a substantive change in trophic condition. The approach is justified by the special nature of the pollutants (chlorophyll and phosphorus are not toxic) and the site-specific nature of the concern about false exceedances. Another reason for establishing an assessment threshold that is different than the standard is that the site-specific standard is derived from historical data, which creates the expectation that a number of exceedances will occur. Natural variability, especially for chlorophyll, is sufficient to produce much more uncertainty in the assessed value than in the standard, which was derived from the set of all summer averages. The CWQCC is establishing assessment thresholds for Chatfield Reservoir nutrient standards based on this unique combination of circumstances and does not intend this action to be a precedent for other standards and/or other segments.

These changes in standards do not affect the nutrient modeling presented in this technical report. Report figures show the current phosphorus and chlorophyll-a standards. Discussion of the model results includes references to both the previous and current standards.

2.2 Chatfield Reservoir Physical Evaluation

In order to evaluate potential impacts on nutrients, metals, and bacteria, the first step was to characterize the reservoir's physical nature. This involved collection and evaluation of available physical data, and prediction of changes in residence time.

2.2.1 Chatfield Dam Outlets

The outlet works at Chatfield Dam have five gates to withdraw water from Chatfield Reservoir:

- Two 6ft x 13.5ft hydraulic slide gates (elevation 5385.0 ft-msl) – primary release gates for high flows.
- Two 2ft x 2ft slide gates (elevation 5386.5 ft-msl) – primary release gates for low flows.
- One 6ft butterfly gate (elevation 5388.0 ft-msl) – control gate for ditch system.

2.2.2 Physical Data

To support an estimation of changes in residence time and potential impacts on water quality conditions in the reservoir, a number of physical data sets were accessed for Chatfield Reservoir. First, the 1998 Chatfield bathymetry developed by the U.S. Army Corps of Engineers (USACE) was obtained. Bathymetry was provided in an x-y-z file format, and the data were used to generate a TIN (Triangulated Irregular Network) surface in ArcGIS (Figure 2-1). There were no shoreline data associated with the bathymetry data, therefore an NHD (National Hydrography Dataset) shoreline was used in the analysis. The TIN surface was ultimately used to compute the bottom surface area below various elevations within the reservoir.

It should be noted that the elevations in the bathymetry data did not extend to the normal conservation pool elevation of 5432 ft msl. The maximum elevation in the x-y-z bathymetry file was 5421 ft msl which was below the normal pool elevation of 5432 ft msl. This was likely because the bathymetric collection period occurred during a dry year corresponding with a low reservoir level. This limitation did not detrimentally impact the analysis.

Figures 2-2 and 2-3 show surface area and storage capacity relationships provided by the USACE based on the 1998 survey of Chatfield Reservoir (USACE, 2001). These plots were used to extrapolate reservoir surface areas and capacities for elevations above the maximum elevation of 5421 ft msl from the bathymetric survey (i.e., estimate the volume and area for the conservation pool elevation and the proposed 12-ft rise above the conservation pool elevation – which are both above 5421 ft msl).

It can be seen from Figures 2-2 and 2-3 that at the conservation pool elevation of 5432 ft msl the surface area and volume are 1,429 acres and 27,428 acre-feet, respectively. The maximum proposed increase in the pool elevation is 12-ft (i.e., 5444 ft msl) and it corresponds to a surface area of 2,009 acres and a volume of 48,066 acre-feet. Daily water surface elevations for both the existing and maximum proposed project conditions were also obtained from the USACE (2006) to support the water quality analysis (Figure 2-4). Figure 2-4 shows the daily inter-year variability between the baseline and maximum proposed condition from 1942 to 2000. Based on USACE's modeled pool elevations for the maximum proposed condition, it was found that the 5444 ft msl elevation (greater than or equal to) occurs approximately 18 percent of the time (based on the daily values shown below from 1942 to 2000). The average increase in elevation during the summer period for the entire period of record was estimated to be 9.3 ft. This was computed based on an average value for the mean summer months (June, July and August) elevations for the period of 1942 to 2000. Hence, the water surface elevation data seem to suggest that the average summer increase of 9.3 ft is a more typical and likely case that can be expected during the critical summer period. In this report two

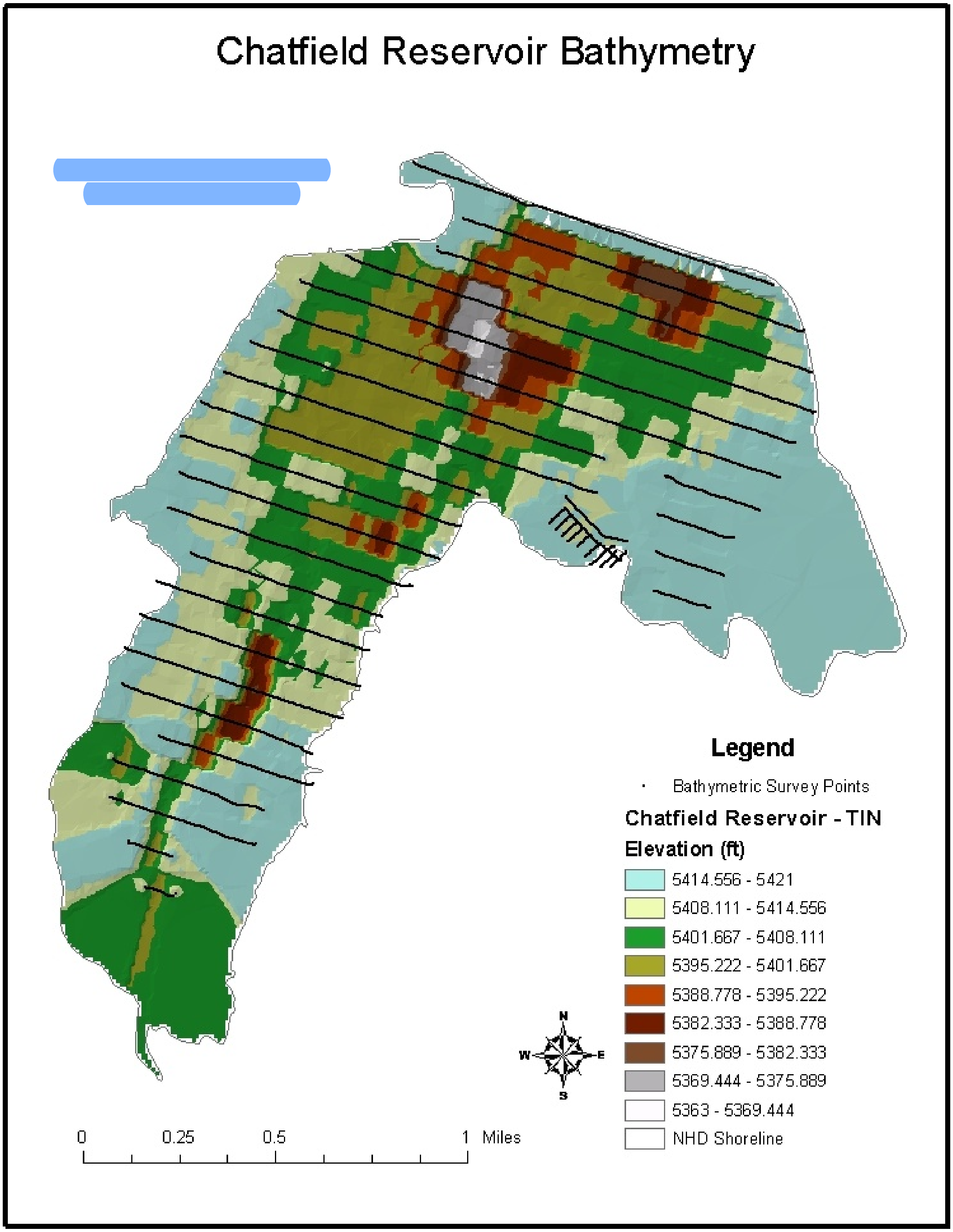


Figure 2-1. Chatfield Reservoir Bathymetry - 1998 Survey (Source: USACE, 2001).

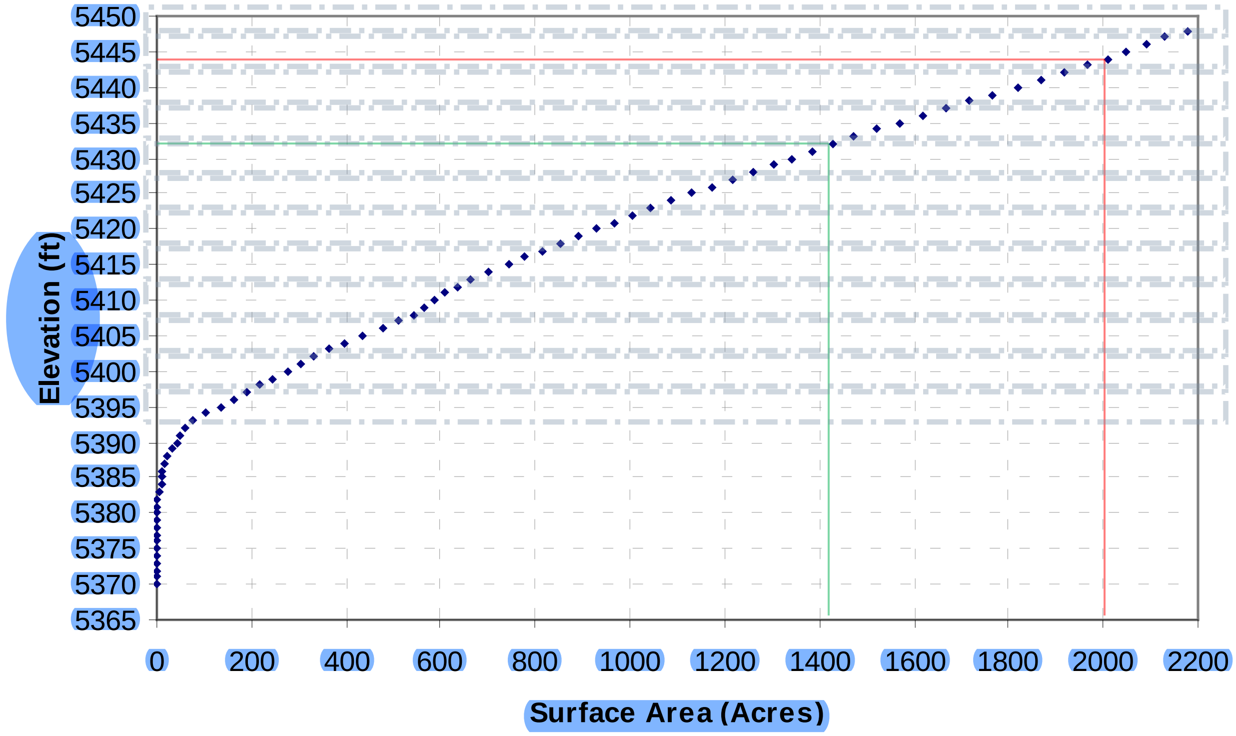


Figure 2-2. Elevation vs. Reservoir Surface Area (1998 Survey) (Source: USACE, 2001).

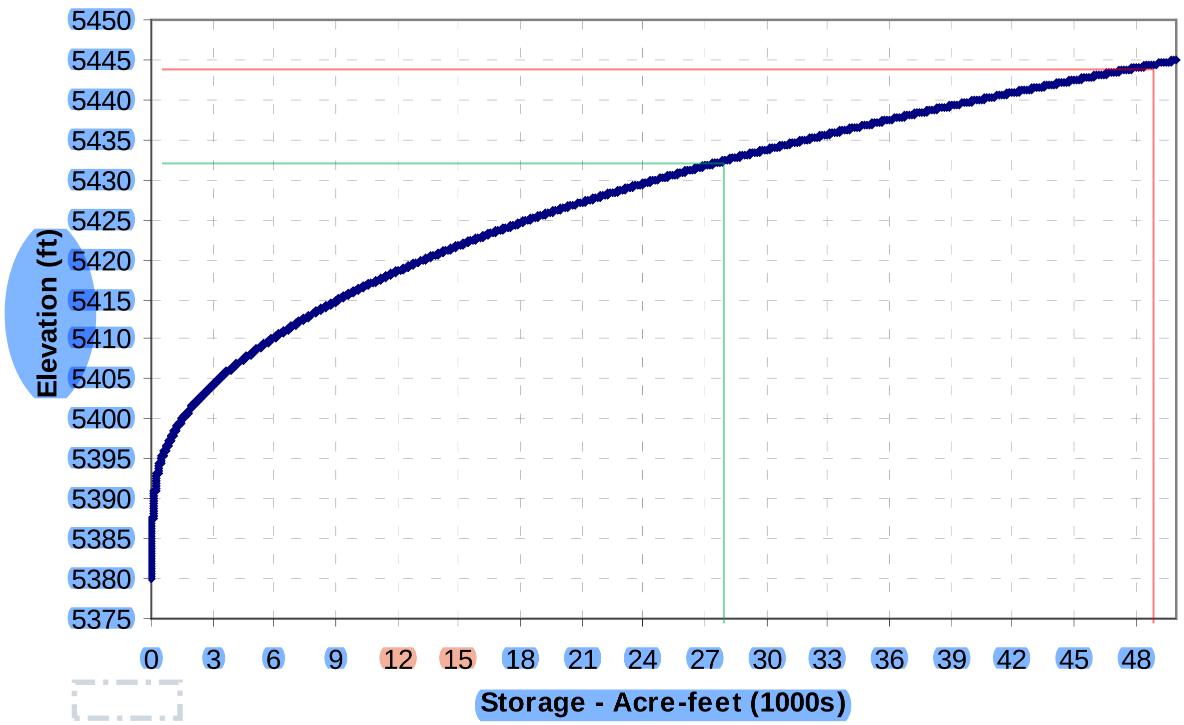


Figure 2-3. Elevation vs. Reservoir Capacity (1998 Survey) (Source: USACE, 2001).

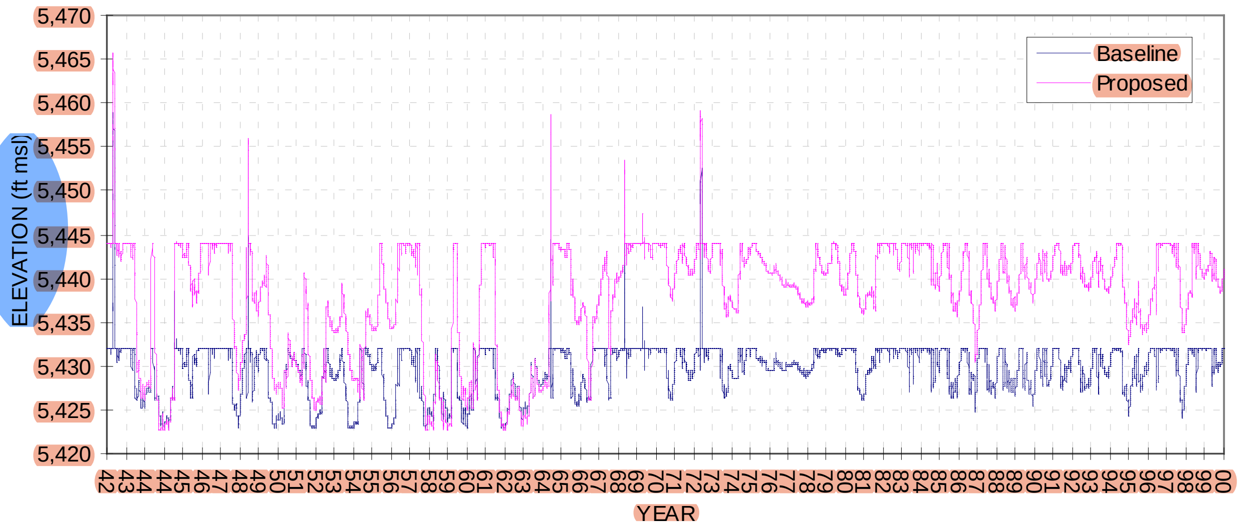


Figure 2-4. Chatfield Reservoir Daily Water Surface Elevations (1942 – 2000) (Source: USACE, 2006).

scenarios were evaluated: 1) a maximum increase (12-ft) in the hypolimnetic elevation from baseline, and 2) a mean monthly increase in the hypolimnetic elevation from baseline during summer months (May through September). This is discussed further in Section 2.3 under the scenarios evaluated.

2.2.3 Hydraulic Residence Time

In addition to an assessment of proposed volumetric and surface area changes, potential changes in reservoir residence time were also evaluated. This analysis consisted of computing historic residence time information and estimating residence times under the proposed operational regime to qualitatively assess impacts on water quality. Significantly longer or shorter residence times can have a significant impact upon the water quality of the reservoir in terms of hypolimnetic oxygen depletion, nutrient cycling and other parameters (Horne and Goldman, 1994).

The hydraulic residence time (HRT) is basically the amount of time that would be required for the outflow to replace the quantity of water in the reservoir. If the volume is large and the flow is small, the reservoir would have a large HRT (i.e., it would take longer for the reservoir to flush out). Alternatively, if the reservoir has a small volume and a high flow, it is considered a "fast flusher" (Chapra, 1997). It should be noted that the retention time of a nutrient is somewhat different from the hydraulic residence time, since sedimentation and recycling take place within a reservoir (Horne and Goldman, 1994).

The HRT can be determined as follows:

$$\mathrm{HRT} = \frac{V}{Q_{outflow} \times CF} \qquad [1]$$

where:
HRT = the hydraulic residence time (days)

V = the volume of the reservoir (acre-ft)
$Q_{outflow}$ = mean outflow (cfs)
CF = conversion factor = 1.983, if V is in acre-ft and $Q_{outflow}$ is in cfs

Daily baseline and proposed elevation data were available from the USACE (2006) for the period of 1942 to 2000. Annual average elevations were computed and their corresponding volume was estimated using the stage-storage relationship for the reservoir (as shown in Figure 2-3). Daily outflow data for the existing and proposed conditions were also available for the years 1942 to 2000 from the USACE (2006). Annual average outflows were computed for each year and the HRT was calculated for both the baseline and proposed conditions (using equation [1]). Figure 2-5 shows the annual HRT for 1942 to 2000. Figure 2-5 and Table 2-1 present the annual HRT for the baseline and proposed condition for each year based on annual average outflows and annual average volumes estimated using annual average elevations.

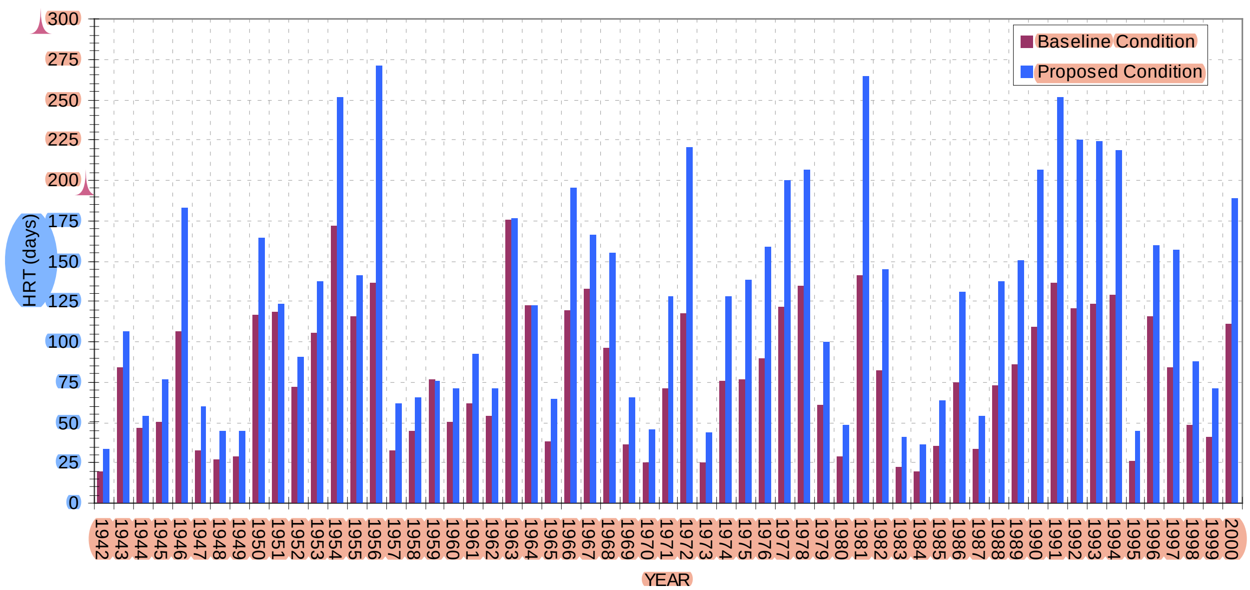


Figure 2-5. Baseline and Proposed Annual HRT from 1942 to 2000 for Chatfield Reservoir.

It can be seen that the outflow varies depending on the hydrologic regime for each year and that there is an increase in retention time irrespective of whether it is a dry year or a wet year (except for two years 1959 and 1964 which had a slight decrease in retention time). The HRT generally increases because the proposed project outflow does not increase proportionally with the increase in reservoir volume (the proposed project outflow actually decreases). However, it should be noted that HRT values could vary "daily" as significant inflow and outflow events occur. Hence, the results shown in Table 2-1 do not take into account the short term variations in HRT that can be expected due to changes in volume and outflow conditions. This could lead to an increase or decrease in HRT. As seen in Table 2-1, average annual outflow over the 1942 to 2000 period would have been reduced by 4.4 percent under the proposed conditions.

Table 2-1. Baseline and Proposed Annual HRT from 1942 to 2000 for Chatfield Reservoir.

Year	Average Baseline Conditions Outflow (cfs)	HRT – Baseline Conditions (days)	Average Proposed Conditions Outflow (cfs)	HRT – Proposed Conditions (days)
1942	780	20	759	34
1943	140	84	163	106
1944	223	47	219	54
1945	219	50	186	76
1946	119	106	115	183
1947	425	32	406	59
1948	437	27	439	45
1949	431	29	404	45
1950	96	117	98	165
1951	94	119	97	123
1952	151	72	143	91
1953	104	106	93	138
1954	62	172	60	252
1955	96	115	93	141
1956	82	137	67	271
1957	370	32	343	62
1958	248	45	264	66
1959	132	77	126	75
1960	203	51	188	71
1961	190	62	157	92
1962	207	54	229	71
1963	56	175	54	177
1964	87	123	84	122
1965	334	38	285	65
1966	99	120	104	195
1967	89	132	91	166
1968	135	96	125	155
1969	383	36	354	66
1970	553	25	528	46
1971	175	71	172	128
1972	108	118	100	221
1973	580	25	551	44
1974	163	76	164	128
1975	166	77	148	139
1976	146	89	143	159
1977	102	121	102	200
1978	91	134	91	206
1979	215	61	203	100
1980	465	29	448	48
1981	87	141	77	264
1982	155	82	140	145
1983	610	22	577	41

Year	Average Baseline Conditions Outflow (cfs)	HRT – Baseline Conditions (days)	Average Proposed Conditions Outflow (cfs)	HRT – Proposed Conditions (days)
1984	679	20	649	37
1985	367	36	352	64
1986	161	75	157	131
1987	369	33	356	54
1988	167	73	144	137
1989	139	86	135	151
1990	107	109	98	207
1991	91	136	85	252
1992	104	120	99	225
1993	99	123	96	225
1994	98	129	95	219
1995	471	26	454	45
1996	101	116	102	160
1997	160	84	135	157
1998	248	49	237	88
1999	325	41	296	71
2000	118	111	110	189
Average for Period of Record	227	80	217	126

2.2.4 Temperature and Dissolved Oxygen Conditions

2.2.4.1 Limnological Processes and Terms

The following overview of limnological processes and terms, regarding temperature and DO conditions in reservoirs, is provided as background information for interpreting the water quality modeling results that follow in this report.

The annual temperature distribution represents one of the most important limnological processes occurring within a reservoir. Thermal variation in a reservoir results in temperature-induced density stratification. Deeper, temperate-zone lakes (i.e. Chatfield Reservoir) typically completely mix from the surface to the bottom twice a year in the spring and fall (i.e., dimictic). Temperate-zone dimictic lakes exhibit thermally-induced density stratification in the summer and winter months that is separated by periods of "turnover" in the spring and fall. This stratification typically occurs through the interaction of wind and solar insolation at the lake surface and creates density gradients that can influence lake water quality. During the summer, solar insolation has its highest intensity and the reservoir becomes stratified into three zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion.

<u>Epilimnion</u>: The epilimnion is the upper zone that consists of the less dense, warmer water in the reservoir. It is fairly turbulent since its thickness is determined by the turbulent kinetic energy inputs, and a relatively uniform temperature distribution throughout this zone is maintained.

<u>Metalimnion</u>: The metalimnion is the middle zone that represents the transition from warm surface water to colder bottom water. There is a distinct temperature gradient through the metalimnion.

The metalimnion contains the thermocline that is the plane or surface of maximum temperature rate change.

Hypolimnion: The hypolimnion is the bottom zone of more dense, colder water that is relatively quiescent. Bottom withdrawal or fluctuating water levels in reservoirs, however, may significantly increase hypolimnetic mixing.

Oxygen is a fundamental chemical constituent of waterbodies that is essential to the survival of aquatic organisms, and is one of the most important indicators of reservoir water quality conditions. The distribution of DO in reservoirs is a result of dynamic transfer processes from the atmospheric and photosynthetic sources to consumptive uses by the aquatic biota. Two basic types of vertical DO distribution may occur in the water column of a reservoir: an orthograde and clinograde DO distribution (Figure 2-6). The orthograde distribution is representative of less productive, nutrient-poor reservoirs where DO concentration is primarily a function of temperature since DO consumption is limited. The clinograde DO profile is representative of more productive, nutrient-rich reservoirs where the hypolimnetic DO concentration progressively decreases during stratification and can occur during both summer and winter stratification periods. Recent depth-profile DO measurements of Chatfield Reservoir indicate a clinograde DO condition. The oxycline is defined as the narrow zone in the reservoir that exhibits a sharp gradient in the DO concentration. An oxycline is not present under orthograde conditions, and is usually close to the thermocline location under clinograde conditions.

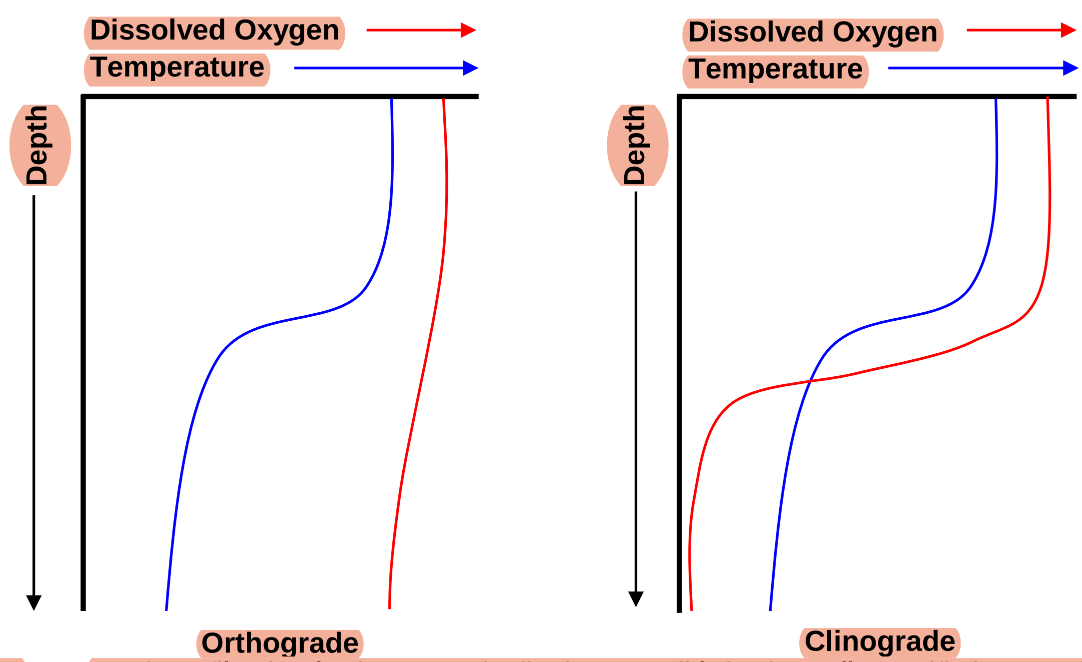


Figure 2-6. Depth-Profile Dissolved Oxygen Distributions Possible in Thermally Stratified Reservoirs.

When DO concentrations are reduced to approximately 2 to 3 mg/L, the oxygen regime is considered hypoxic. Anoxic conditions occur when there is a complete lack of oxygen. When hypoxic conditions occur in the hypolimnion, the oxygen regime at the sediment/water interface is generally considered anoxic, and anaerobic processes begin to occur in the sediment interstitial water. Anaerobic conditions are generally initiated at the sediment/water interface and gradually diffuse into the overlying water column. For use in this report, the term "**hypoxycline**" is defined as the 2 mg/L DO isopleth depth in Chatfield Reservoir. For application in this report, the term hypolimnion will be used to refer to the region of Chatfield Reservoir below the hypoxycline, and the term epilimnion will be used to refer to the region of the reservoir above the hypoxycline.

2.2.4.2 Existing Summer Temperature and Dissolved Oxygen Conditions in Chatfield Reservoir

Existing summer temperature and DO conditions in Chatfield Reservoir are represented by the 2008 depth-profile data collected by the CDOW and the 2012 depth-profile data collected by the CWA. These data represent the deepwater, near-dam area of the reservoir (Figure 2-1). Depth-profile temperature and DO measurements for other regions of the reservoir (i.e. South Platte River and Plum Creek arms) are not available. Future water quality monitoring of Chatfield Reservoir is recommended in the AMP that would extend the spatial coverage of water quality data. Figure 2-7 shows the summer temperature and DO conditions measured in Chatfield Reservoir during 2008. Figure 2-8 shows the summer temperature and DO conditions measured in Chatfield Reservoir during 2012. The summer temperature and DO conditions identified by the 2012 CWA data were used to define "baseline" conditions for water quality modeling application.

The hypoxycline separates the lower hypoxic/anaerobic region of the reservoir from the upper oxic/aerobic region of the reservoir. As previously mentioned for usage in this report, the term hypolimnion is used to refer to the anaerobic region below the hypoxycline, and the term epilimnion is used to refer to the aerobic region above the hypoxycline. As discussed in Section 2.2.3.1, this is not the standard usage of the terms hypolimnion and epilimnion, which is temperature dependent and defines a metalimnion region between the epilimnion and hypolimnion. Because of the clinograde DO distribution present in Chatfield Reservoir, the hypoxycline elevation in 2012 occurred in the region of the thermocline for all observations except 23-May and 24-July, when the hypoxycline was 1-meter outside of the measured thermocline region. Since the hypoxycline elevation was similar to the thermocline it also delineates the temperature-dependent density barrier to mixing within the reservoir water column. Thus, as used in this report, the epilimnion defines the aerobic upper region of mixing within Chatfield Reservoir, and the hypolimnion defines the anaerobic lower region of quiescence in the reservoir.

2.3 Nutrient Assessment

The analysis described in this section provides a detailed, localized analysis to address the uncertainty regarding possible increases in anaerobic and inundated vegetation nutrient fluxes due to phosphorus.

Water quality data collected at Chatfield Reservoir since 2009 indicate that historically collected depth-profile data measured only the upper 10 meters of the water column. At normal operating pools, the reservoir's maximum depth is 18 meters. Thus, the historic depth-profile data did not include measurements for the bottom 8 meters of water depth. This significantly impacted the utility of the initial water quality assessment and modeling results that were included in the Draft FR/EIS. To address this deficiency, the 2012 CWA data for Chatfield Reservoir were selected to

Chatfield Reservoir Depth Profile - 2008

Temperature (^{o}C)

Depth (m)	5/5/2008	5/22/2008	6/11/2008	6/24/2008	7/8/2008	7/22/2008	8/5/2008	8/20/2008	9/11/2008	9/23/2008
0	12.3	16.5	17.1	20.9	20.4	23.1	21.9	20.9	17.1	17.5
1	11.8	16.4	17.1	20.1	20.1	22.2	21.9	20.2	17.8	17.6
2	11.3	16.3	17.0	19.6	19.9	21.9	21.8	19.9	17.9	17.6
3	11.1	16.0	17.0	19.4	19.7	21.7	21.7	19.8	17.9	17.6
4	10.7	15.8	16.9	19.2	19.7	21.6	21.7	19.7	17.9	17.6
5	10.3	15.5	16.9	17.7	18.4	20.2	20.9	18.8	17.9	17.6
6	10.2	15.1	16.9	16.8	17.9	18.0	20.0	18.2	17.9	17.4
7	10.1	13.7	16.9	16.2	17.5	17.6	19.5	17.8	17.9	17.3
8	10.1	12.9	16.0	16.1	16.9	17.3	19.2	17.4	17.7	17.2
9	10.0	12.7	15.2	15.7	16.7	16.8	19.0	17.1	17.7	17.1
10	9.9	12.5	14.9	15.5	16.4	16.5	18.8	17.1	17.7	16.9
11	9.9	12.3	14.5	15.2	16.2	15.9	18.4	17.0	17.6	16.8
12	9.8	12.2	13.6	15.0	16.0	14.4	17.9	16.9	17.5	16.8
13	9.7	11.9	13.0	14.4	15.5	13.7	17.5	16.9	16.7	16.6
14	9.7	11.6	12.0	13.2	14.9	12.8	16.0	16.4	16.2	16.2
15	9.7	11.3	11.3	12.3	13.2	12.3	13.6	14.6	14.8	15.3
16		10.9	11.1	11.4	12.1	12.1	13.0	13.4	14.9	14.2
17				11.2		12.3	12.7	12.9		13.3
18								12.7		13.2

Thermocline

Chatfield Reservoir Depth Profile - 2008

Dissolved Oxygen (mg/L)

Depth (m)	5/5/2008	5/22/2008	6/11/2008	6/24/2008	7/8/2008	7/22/2008	8/5/2008	8/20/2008	9/11/2008	9/23/2008
0	9.1	8.7	7.6	8.3	7.7	7.4	7.2	8.0	6.5	7.3
1	9.0	8.6	7.2	8.3	7.5	7.5	7.3	8.4	6.6	7.4
2	9.1	8.6	7.4	8.6	7.6	7.4	7.1	8.1	6.8	7.5
3	9.2	8.6	7.5	8.6	7.5	7.3	7.2	7.5	6.7	7.4
4	8.6	8.4	7.3	8.1	7.2	7.2	7.1	7.2	6.7	7.4
5	8.3	8.2	7.2	8.0	6.7	6.5	4.9	5.5	6.8	7.3
6	8.1	8.1	7.1	7.4	6.4	4.7	4.8	5.5	6.7	7.1
7	8.0	7.5	7.2	7.2	6.0	3.8	3.9	6.2	6.6	6.9
8	7.9	7.0	5.5	6.8	5.2	3.0	3.2	6.0	5.3	6.3
9	8.0	6.8	5.4	6.1	4.9	2.1	3.1	6.3	5.3	6.0
10	7.8	6.4	4.8	5.4	4.3	1.6	2.2	6.3	5.2	5.4
11	8.0	6.3	4.3	5.2	4.1	0.9	1.6	6.1	4.7	4.8
12	7.9	6.1	3.7	4.9	3.6	0.2	1.0	6.3	3.8	4.6
13	7.9	5.8	3.3	4.7	2.8	0.2	0.7	5.7	0.3	4.4
14	7.9	5.4	2.2	2.2	2.3	0.1	0.2	3.4	0.3	3.4
15	7.8	4.9	0.6	0.8	0.3	0.1	0.2	0.3	0.2	1.1
16		4.4	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.4
17				0.2		0.1	0.2	0.2		0.2
18								0.2		0.3

Hypoxycline **Hypoxic (Anaerobic) Region**

Figure 2-7. Temperature and Dissolved Oxygen Conditions Measured in Chatfield Reservoir in the Deepwater, Near-Dam Area by the Colorado Division of Wildlife in 2008.

Chatfield Reservoir Depth Profile - 2012 Temperature (°C)										
Depth (m)	**4/25/2012**	**5/23/2012**	**6/19/2012**	**7/11/2012**	**7/24/2012**	**8/7/2012**	**8/22/2012**	**9/13/2012**	**9/26/2012**	**10/11/2012**
0	15.6	17.5	21.1	22.9	24.1	22.6	21.8	19.6	18.0	13.6
1	15.6	17.5	21.1	22.9	24.1	22.6	21.8	19.6	18.0	13.6
2	15.0	17.4	20.8	22.8	23.8	22.5	21.7	19.4	17.8	13.6
3	14.6	17.3	20.7	22.7	23.7	22.4	21.6	19.3	17.7	13.5
4	13.7	17.2	20.4	22.7	23.6	22.4	21.6	19.3	17.7	13.4
5	12.6	16.1	20.3	22.2	23.6	22.4	21.5	19.3	17.6	13.4
6	12.2	15.8	20.1	21.6	23.4	22.3	21.3	19.2	17.7	13.3
7	12.0	15.6	19.5	21.2	22.6	22.3	21.2	19.2	17.6	13.3
8	11.9	15.3	18.3	21.1	22.2	22.2	21.2	19.2	17.6	13.3
9	11.7	15.1	17.9	20.9	21.6	22.2	21.1	19.2	17.6	13.3
10	11.5	14.8	17.6	20.5	21.2	22.2	21.1	19.2	17.6	13.2
11	11.4	14.6	17.5	19.5	20.2	21.6	21.0	19.1	17.6	13.2
12	11.4	14.1	17.3	17.2	18.1	18.2	20.7	19.0	17.6	13.2
13	11.3	12.2	16.6	15.8	16.0	15.9	16.6	18.9	17.5	13.2
14	11.3	11.6	14.8	14.1	14.4	14.5	14.4	18.0	17.5	13.2
15	11.2	11.3	13.3	13.6	13.3	13.4	13.5	14.3	17.3	13.2
16		11.2	12.4	13.1	13.0	13.1	13.3		14.6	13.1
17					12.9					
18										

Thermocline **Hypoxycline Location (see below)**

Chatfield Reservoir Depth Profile - 2012 Dissolved Oxygen (mg/L)										
Depth (m)	**4/25/2012**	**5/23/2012**	**6/19/2012**	**7/11/2012**	**7/24/2012**	**8/7/2012**	**8/22/2012**	**9/13/2012**	**9/26/2012**	**10/11/2012**
0	9.1	9.2	7.7	8.3	7.8	7.0	7.5	8.3	7.4	8.7
1	9.1	9.2	7.7	8.3	7.8	7.0	7.5	8.3	7.4	8.7
2	9.5	9.0	7.6	8.2	7.8	6.6	7.4	7.9	7.1	8.4
3	9.8	9.0	7.4	8.1	7.6	6.5	7.2	7.6	7	8.3
4	10.0	8.9	7.4	8.0	7.4	6.4	7.1	7.4	7	8.3
5	9.9	8.6	7.3	7.6	7.0	6.4	7	7.3	7.1	8.1
6	8.9	8.1	7.0	4.0	6.9	6.2	6.9	7.2	7.1	8.2
7	8.7	7.6	5.8	3.9	4.1	6.1	6.8	7.2	7.1	8.2
8	8.3	6.5	3.4	3.7	2.6	5.9	6.3	7	7.1	8.1
9	7.9	5.9	2.6	3.4	1.5	5.8	6.2	6.8	7.1	8.0
10	7.8	5.4	2.3	2.2	0.6	5.6	6.1	5.6	7.1	8.0
11	7.4	5.2	2.4	1.3	0.5	3.5	5.9	5.6	7.1	8.0
12	7.2	4.4	2.6	0.5	0.5	0.5	4.2	6	7.1	8.0
13	7.1	3.3	2.8	0.5	0.5	0.5	0.5	4.2	7.1	7.9
14	7.1	2.6	1	0.5	0.5	0.5	0.5	1.2	7	7.8
15	7.0	1.3	0.5	0.5	0.5	0.5	0.5	0.9	3.7	7.7
16		0.6	0.5	0.5	0.5	0.5	0.5		1.4	7.6
17					0.5					
18										

Hypoxycline **Hypoxic (Anaerobic) Region**

Figure 2-8. Temperature and Dissolved Oxygen Conditions Measured in Chatfield Reservoir in the Deepwater, Near-Dam Area by the Chatfield Watershed Authority in 2012.

represent baseline water quality conditions in the reservoir. These data were used to reapply the "Localized Model" that was applied as part of the initial water quality assessment. The results from the reapplied model were then used to reassess the impact of the proposed Chatfield Reservoir Storage Reallocation Project on phosphorus loading and resultant water quality in Chatfield Reservoir. It is recognized that using one year of data to represent baseline water quality conditions leads to uncertainties regarding the appropriateness of the defined baseline conditions. The 2012 CWA data are comparable, regarding thermal stratification and hypoxia, to the 2008 CDOW water quality data. Also, the epilimnetic (i.e. 0 to 10 meter depth) conditions of the 2012 CWA data are comparable to the available historic data used in the initial water quality assessment. Available data are lacking for Chatfield Reservoir, other than the 2008 CDOW and 2012 CWA data, that describe thermal stratification and hypoxia throughout the reservoir. Because of this uncertainty, water quality is an identified resource in the AMP.

The model reapplication focused on reassessing the total phosphorus dynamics during the May through September summer stratification period of Chatfield Reservoir. Total phosphorus and the nutrient's impact on chlorophyll-a are regulated through site-specific, numeric water quality standards and a TMAL for the reservoir. Assessment of nitrogen (ammonia and nitrate-nitrite) was done as part of the initial water quality assessment, and was not identified as a water quality concern under upper bound scenario testing. Nitrogen assessment was not included as part of the revised water quality assessment and modeling. Future dynamic water quality modeling is identified for Chatfield Reservoir in the AMP, and will allow future assessment of nitrogen dynamics within the reservoir in regards to nutrient enrichment and possible ammonia toxicity.

An evaluation of the nutrient enrichment potential for Chatfield Reservoir was done by estimating total phosphorus loading within and to the reservoir for existing conditions and for the proposed increase in pool elevation. Nutrient sources that were quantified include release from reservoir-bottom sediments in both the aerobic and anaerobic zones, contributions from inundated plants and soil/sediment from the proposed increase in reservoir pool level, watershed contributions, and atmospheric deposition. These sources were quantified on a loading basis, and a separate mass balance was calculated for the reservoir in the epilimnion and the hypolimnion to estimate loads and concentrations in the reservoir for the existing and proposed scenarios. Figure 2-9 shows a schematic of phosphorus sources to the reservoir.

2.3.1 Application of the Localized Water Quality Model

The localized model was used to evaluate the scenarios by varying elevation conditions (under and including the 12-ft increase in pool elevation) (Table 2-2).

Baseline Case: The baseline case involved evaluating the reservoir for the critical summer period when it was stratified from May through September under the normal pool condition. The hypolimnion was defined based on observed DO data and number of 1-meter layers which showed hypoxia. The hypoxycline location was based on the 2012 DO profile data for each month from May through September (Figure 2-8).

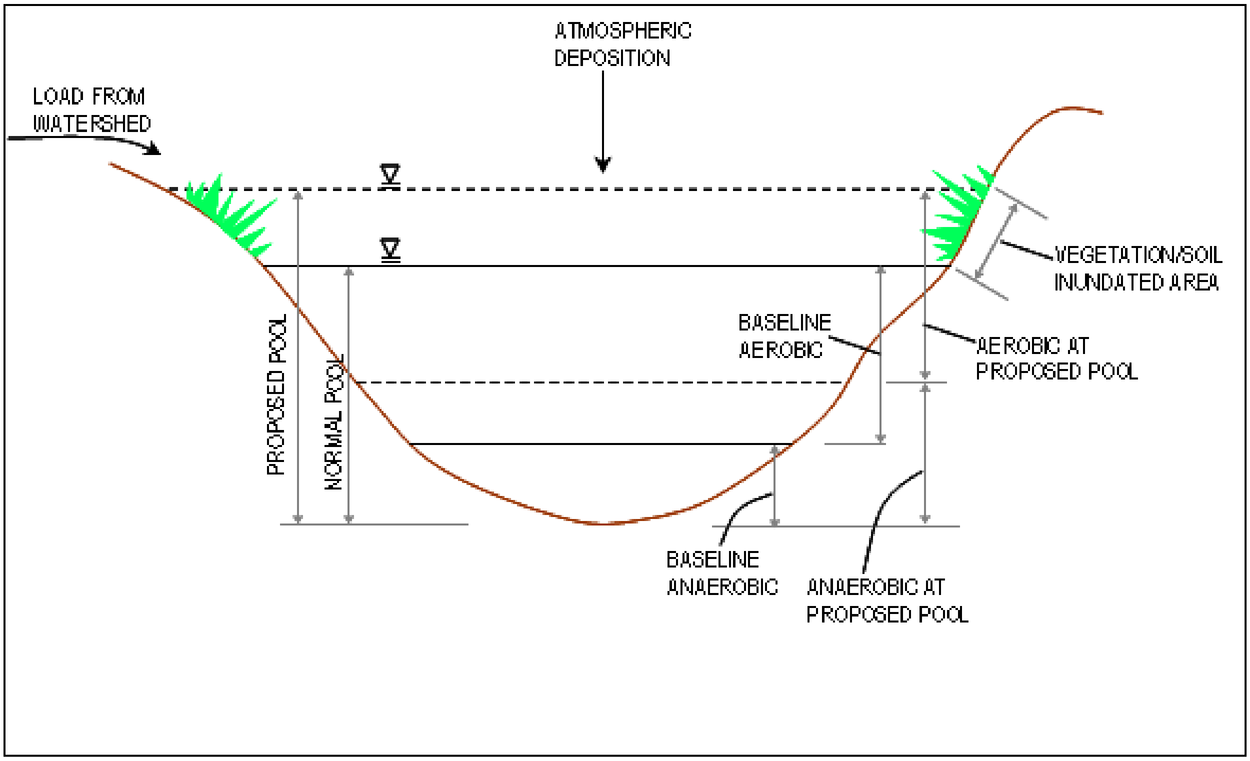


Figure 2-9. Phosphorus Sources to Chatfield Reservoir Represented in the Nutrient Analysis.

Table 2-2. Average Monthly Water Surface Elevation (based on USACE 1942 to 2000 data).

Month	Baseline Conditions - Average Elevation (ft)	Proposed Conditions - Average Elevation (ft)	Increase in Depth (ft)
Jan	5429	5437	7.72
Feb	5430	5438	7.81
Mar	5430	5438	8.05
Apr	5430	5439	8.43
May	5431	5440	9.00
Jun	5431	5440	9.61
Jul	5429	5439	9.31
Aug	5430	5438	8.88
Sep	5429	5437	8.47
Oct	5429	5437	7.96
Nov	5429	5437	7.79
Dec	5429	5437	7.72

Maximum Case – 12-ft increase in hypoxycline elevation: Increased reservoir volume was assumed to lead to an increased hypolimnetic volume and thermal stratification (inhibiting reservoir mixing) is maintained throughout the summer. It was assumed that the upper extent of the hypolimnion would increase by the same amount as the increase in pool elevation (12-ft). The baseline hypoxycline elevation was increased by 12-ft for this scenario. The assumption that the hypoxycline elevation would increase by the same amount as the increase in pool elevation cannot be fully evaluated without implementing a hydrodynamic and water quality model; however, it provides a conservative basis for evaluating potential impacts on reservoir nutrient levels (and the potential for eutrophication). For the proposed conditions, it was found that the 12-ft increase (which corresponds to 5444 ft msl) occurs approximately 18 percent of the time (based on the entire time period of the daily reservoir modeling results from 1942 to 2000) (Figure 2-4). Hence, the 12-ft increase in pool elevation provides a conservative estimate of the maximum increase in pool depth for the summer condition.

__Typical Case__ – Mean monthly increase in elevation from baseline to proposed condition: This scenario represents the most likely, typical summer critical condition. The USACE (2006) modeled and proposed water surface elevation data were used to derive average monthly water surface elevation data for the period 1942 to 2000. The mean monthly increase in elevation was computed for the baseline, and the "with-project" elevation was computed to estimate the increase in elevation for each month. The estimated mean monthly increase in elevation was always less than 12-ft (between the baseline and proposed conditions). The mean increase in elevation during the critical period from May through September ranged from 8.47 to 9.61 ft (Table 2-2). For this scenario, the hypoxycline elevation was varied by month from May through September.

The contributions from the submerged vegetation are expected to decrease substantially with time as the "trophic upsurge" subsides (Soballe, 2006). As the contributions due to the inundated vegetation subside, it is expected that the aerobic zone contributions would take over. A scenario after the pool increase, but without the contribution of the vegetation, was also evaluated for each of the two cases discussed above. For this case aerobic fluxes take over when no contribution from vegetation is present in the long-term. Table 2-3 shows the various nutrient scenarios evaluated.

Table 2-3. Nutrient Scenarios Matrix

Scenario	Description
BASELINE – Normal Pool	
BASE	Assumes anaerobic hypolimnion based on the number of hypoxic layers observed during the summer period.
MAXIMUM CASE – Assumes 12-ft increase (maximum proposed pool) in hypoxycline elevation from BASE	
MAXST	Considers contribution of phosphorus from inundated soil and vegetation (short-term impact)
MAXLT	Considers no phosphorus contribution from inundated soil and vegetation (long-term impact)
TYPICAL CASE – Assumes a monthly increase in hypoxycline elevation from BASE, based on depth computed from mean monthly baseline and proposed elevations	
AVGST	Considers contribution of phosphorus from inundated soil and vegetation (short-term impact)
AVGLT	Considers no phosphorus contribution from inundated soil and vegetation (long-term impact)

2.3.2 Determination of Hypolimnetic Volume and Anaerobic Bottom Area

The bathymetry data were analyzed in conjunction with 2012 CWA depth-profile water quality data to determine the hypoxycline and compute the corresponding reservoir bottom area and hypolimnetic volume. The 2012 depth-profile data show that the reservoir is 17 meters deep and stratified from May through September (Figure 2-8). This is corroborated by the 2008 CDOW data (Figure 2-7) which also indicates a period from mid-May through September as the critical summer stratified period. Weak temperature stratification appears in late-May at Chatfield Reservoir and strengthens into mid-summer as the thermal gradient between the reservoir surface and bottom intensifies. As temperatures cool in late summer, cooling at the reservoir surface leads to convective mixing of the reservoir and thermal stratification weakens. During this period the thermocline and hypoxycline are in close proximity and move down in the water column as the reservoir continues to cool. Fall turnover of Chatfield Reservoir occurs in September with the disappearance of the thermocline and hypoxycline and complete mixing and oxygenation of the water column occurs (Figure 2-8). Fall turnover leads to increased total phosphorus concentrations throughout the water column due to the mixing of accumulated phosphorus released from the anaerobic bottom sediment of the reservoir.

In this analysis it was assumed that increasing the reservoir volume can lead to an increased hypolimnetic volume and that the water depth would be sufficient for thermal stratification to be maintained throughout the summer critical period. It was assumed that the hypoxycline elevation would increase by the same amount as the increase in pool elevation (12-ft or the monthly average case). It should be noted that the actual change in thermocline and hypoxycline depth can only be rigorously evaluated with a hydrodynamic model. The 2012 CWA data were used to identify the hypoxycline elevation and the number of hypoxic 1-meter layers (Figure 2-8). The corresponding hypolimnetic volume and bottom area were estimated from the bathymetry for the baseline condition (Table 2-4). The hypoxycline elevations for the typical case and 12-ft scenario conditions were estimated by adding to the baseline elevations and then estimating the corresponding bottom area and volume for the scenarios. Figure 2-10 depicts the amount of anaerobic area present under baseline conditions and the typical case and 12-ft pool increase scenarios.

Table 2-4. Estimated Hypoxic Depth, Elevation, Hypolimnion Surface Area and Volume for Baseline and Scenarios (2012)

	Baseline				12-ft Increase			Typical Case - Mean Monthly Increase		
Date	No. of anaerobic layers	Elevation (ft)	SA (ac)	V (ft3)	Elevation (ft)	SA (ac)	V (ft3)	Elevation (ft)	SA (ac)	V (ft3)
5/23	2	5,392	81	34,636,063	5,404	389	139,789,870	5,401	247	84,544,961
6/19	3	5,395	115	47,172,988	5,407	573	205,813,795	5,405	389	139,789,870
7/11	6	5,405	485	159,542,530	5,417	1,061	550,180,769	5,414	868	424,008,340
7/24	9	5,415	929	463,147,630	5,427	1,215	906,701,400	5,424	1,087	770,663,520
8/7	5	5,402	313	108,964,169	5,414	868	424,008,340	5,411	685	288,619,686
8/22	4	5,398	177	66,072,107	5,410	685	288,619,686	5,407	531	181,772,268
9/13	2	5,392	81	34,636,063	5,404	389	139,789,870	5,400	247	84,544,961
9/26	1	5,388	64	22,180,790	5,400	247	84,544,961	5,396	131	52,553,496

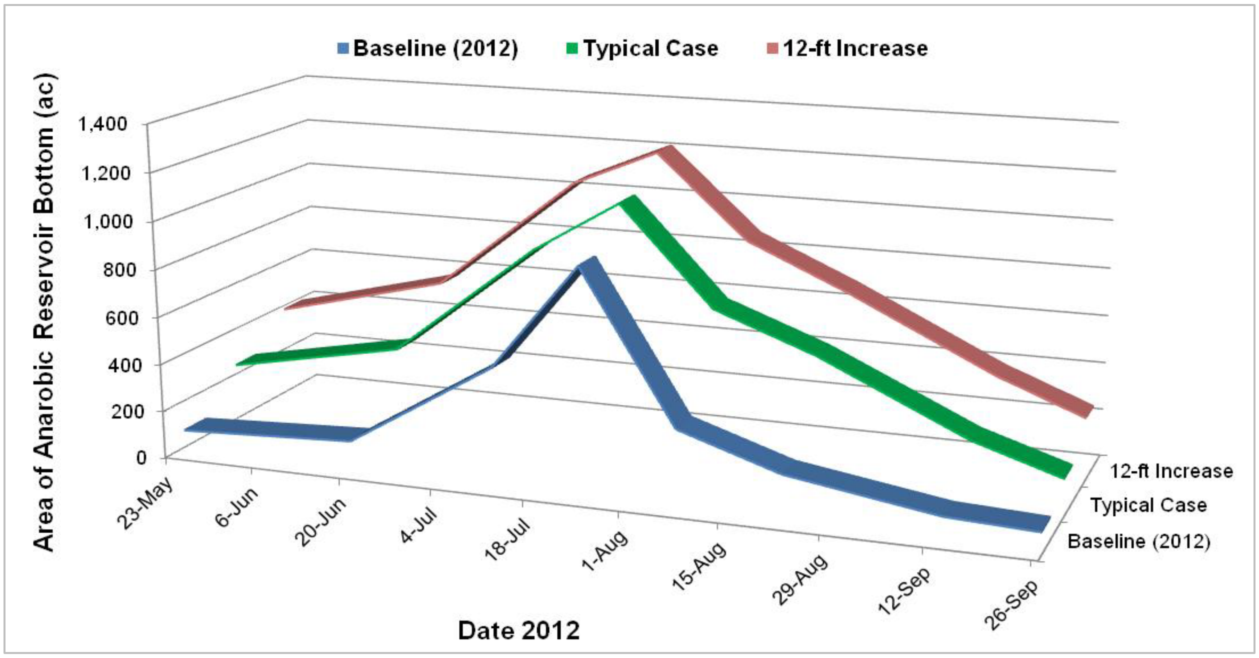


Figure 2-10. Bottom Area of Anaerobic Sediment in Chatfield Reservoir under 2012 Baseline and Proposed With-Project Conditions.

2.3.3 Estimating Phosphorus Loads

Sources of phosphorus loading to the Chatfield Reservoir were estimated to evaluate each of the scenarios mentioned in the previous section. Phosphorus loads were estimated from anaerobic and aerobic internal loading from the reservoir bottom, loading from inundated sediment and vegetation, watershed loading, and loading due to atmospheric deposition. Each of these sources is discussed in the following sections.

2.3.3.1 Loading from Reservoir Bottom Sediments

Estimates of phosphorus loading during anaerobic and aerobic conditions were computed. Fluxes of these nutrients were calculated from the anaerobic zone using 2012 CWA data collected at the bottom of the reservoir at the sediment water interface. Using observed data reduces uncertainty and increases confidence because site-specific nutrient fluxes are calculated. The CWA 2012 water quality data included observations at the bottom of the reservoir at the near-dam, deepwater location and were used in this analysis. The CDOW 2008 and CWA 2012 data indicate that the reservoir is stratified from mid-May through mid-September, with up to the lower 9 meters of depth exhibiting hypoxia (Figure 2-8). The 2012 CWA data measured total phosphorus and orthophosphorus concentrations during the critical summer months when hypoxic conditions were present in the reservoir, and the data included total organic carbon (TOC) analyses for the near-surface region of the reservoir.

Sediment phosphorus fluxes and sediment oxygen demand (SOD) were computed based on a sediment flux model developed by Di Toro (Chapra and Pelletier, 2003; Di Toro et al., 1991; Di Toro, 2001). The approach allows oxygen and nutrient sediment-water fluxes to be computed based on the downward flux of particulate organic matter from the overlying water. The sediments are divided into two layers: a thin (≅ 1 mm) surface aerobic layer underlain by a thicker (10 cm) lower anaerobic layer (default values specified in the model). Organic carbon and nutrients are delivered to the anaerobic sediments via the settling of particulate organic matter (i.e., plankton and detritus). There they are transformed by mineralization reactions into dissolved methane, ammonium, and inorganic phosphorus. These constituents are then transported to the aerobic layer where some of the methane and ammonium are oxidized. Oxidation reactions in the model become zero at low oxygen levels and denitrification becomes pronounced at low oxygen concentrations. The flux of oxygen from the water required for these oxidation reactions is the SOD predicted by the model.

The sediment flux (SedFlux) model computes sediment nutrient fluxes using specified fluxes for carbon (C), nitrogen (N), and phosphorus (P) (J_{Cin}, J_{Nin}, and J_{Pin}, respectively) and overlying nutrient, DO, and temperature concentrations in the water column. The model computes the SOD based on the input fluxes, and the resulting fluxes are calculated using the product of the concentration gradient between the sediment and the overlying water column and the mass transfer coefficient between water and the anaerobic sediments. The sediment flux model is a spreadsheet model and has the same algorithms (Di Toro, 2001) as the Qual2K model. For more details about the algorithms the reader is referred to Di Toro, 2001 and the Qual2K manual (Chapra and Pelletier, 2003).

The particulate carbon flux into the sediments (J_{Cin} $gO_2/m^2/d$) from settling organic carbon, includes plankton and detritus in oxygen equivalent units, and was computed using the observed TOC data. Since 2008, only surface TOC data were collected and reported by the CWA. Surface and bottom TOC data were collected in the past, from 2004 through 2007, and were used to estimate the bottom TOC concentrations for 2012. Ratios of coincident surface and bottom TOC data were calculated (n=43) and used to estimate the bottom TOC concentrations for 2012 using the observed surface TOC concentrations. The historical TOC data indicated that the surface and bottom TOC values were fairly similar with an overall bottom to surface ratio calculated as 1.07. This was used in the analysis to estimate bottom TOC concentrations for each month. The ratios observed during 2004, 2005, 2006 and 2007 were 1.16, 0.98, 1.14, and 1.10 respectively.

The particulate TOC was assumed to be 80 percent of the TOC and the other 20 percent was assumed to be the fast-reacting dissolved organic carbon and $CBOD_u$ (Carbonaceous Biochemical Oxygen Demand ultimate). The particulate carbon flux was estimated in oxygen equivalent units and input into the model ($gO_2/m^2/d$ L = $gC/m^2/d$ * 2.67 gO_2/gC*0.024 m/day *0.8). The fast reacting dissolved organic carbon and CBODu was also estimated in oxygen equivalent units and input into the model (mgO_2L=2.67*TOC mg/L*0.2).

The particulate phosphorus flux J_{Pin} was estimated using observed total phosphorus data in the bottom layer. For the first month, the initial phosphorus flux was calculated as the sum of the flux observed on 5/23/2012 and the flux observed on 4/25/2012. Thereafter, the phosphorus flux input value was calculated for each month by adding the observed phosphorus flux for the current month to the net phosphorus flux from the previous month, that is, the difference between the flux estimates for the previous month minus the estimated flux of phosphorus for the previous month. This methodology attempts to take into consideration the flux based on the particulate matter from prior months that may be available in the overlying water prior to stratification and during stratification when calculating the phosphorus fluxes. More refined results can only be obtained using a detailed dynamic water quality model, which includes sediment digenesis.

Other inputs specified for the water overlying the sediment were the DO, temperature, and soluble reactive phosphorus. The model also requires input of the total water depth overlying the sediment to compute the in-situ pressure when calculating the methane saturation concentration. The input data, along with the computed phosphorus fluxes using the SedFlux model in the anaerobic zone of the reservoir, are given below in Table 2-5.

Table 2-5. SedFlux Model Input Data and Computed Phosphorus Flux Output.

INPUT							OUTPUT	
Date	Particulate carbon flux (Jcin) (gO2/m^2/d)	Particulate phosphorus flux (Jpin) (gP/m^2/d)	Dissolved oxygen in water overlying the sediment (O20) (mgO2/L)	Temperature in water overlying the sediment (Tw) (deg C)	Soluble reactive P in water overlying the sediment (PO40) (mg P/L)	Dissolved Organic Carbon in the water overlying the sediment (CH40) (mgO2/L)	SOD (gO2/m^2/d)	Jpo4 (gP/m^2/d)
4/25/2012	0.2129	0.0004	7	11.2	0.006	1.943	0.270	0.00033
5/23/2012	0.2004	0.0010	0.6	11.2	0.012	1.828	0.545	0.00079
6/19/2012	0.2004	0.0018	0.5	12.4	0.053	1.828	0.522	0.00152
7/11/2012	0.1879	0.0024	0.5	13.1	0.04	1.714	0.508	0.00204
7/24/2012	0.2004	0.0042	0.5	12.9	0.113	1.828	0.527	0.00352
8/7/2012	0.2004	0.0049	0.5	13.1	0.132	1.828	0.529	0.00407
8/22/2012	0.1941	0.0046	0.5	13.3	0.133	1.771	0.520	0.00385
9/13/2012	0.1847	0.0029	0.9	14.3	0.04	1.686	0.601	0.00243
9/26/2012	0.1785	0.0025	1.4	14.6	0.03	1.628	0.575	0.00205
10/11/2012	0.2004	0.0015	7.6	13.1	0.004	1.828	0.244	0.00120

Note: Flux rates calculated from empirical observations available in the 2012 CWA data.

The computed phosphorus flux values (Jpo_4) are presented in Table 2-5. A phosphorus flux value was estimated for each day when a measurement of water quality was recorded at the bottom of the reservoir, thus giving a flux estimate for each month based on available water quality data in the sediment-water interface. Positive values indicate a source of the nutrient to the water column. The phosphorus fluxes during the hypoxic period range from 0.0008 to 0.00407 gP/m^2/day.

The phosphorus flux from the aerobic zone was taken as the mean of the flux estimated during the non-stratified months that is, from April and October, and was estimated to be 0.0008 gP/m2/day.

The phosphorus fluxes for each zone were multiplied by corresponding reservoir bottom surface areas (Table 2-4) to compute the amount of phosphorus released from the sediment for each month.

$$\text{Mass of nutrients released (lbs)} = A_c \times J \times n \qquad [7]$$

where:
A_c = reservoir bottom surface area assumed to be anoxic (m^2)
J = nutrient flux ($g/m^2/day$)
n = number of days in the month

Table 2-6 and Figure 2-11 shows the load for phosphorus from the anaerobic zone based on different anaerobic depth conditions.

Table 2-6. Mass of Phosphorus Released from the Bottom Sediments in the Anaerobic Zone.

Month	Number of days hypoxic	Baseline (lbs)	Typical Impact Case* (lbs)	Maximum Impact Case** (lbs)
May 15 to 30	15	8.6	26.2	41.3
June	30	47.1	158.8	233.7
July	31	905.2	1,059.7	1,184.5
August	31	352.5	772.0	978.2
September 1 to 15	15	26.3	80.2	126.6
TOTAL	122	1,339.7	2,096.9	2,564.3

* Based on modeled mean monthly baseline and proposed elevation.
** Based on 12-ft increase in proposed pool elevation.

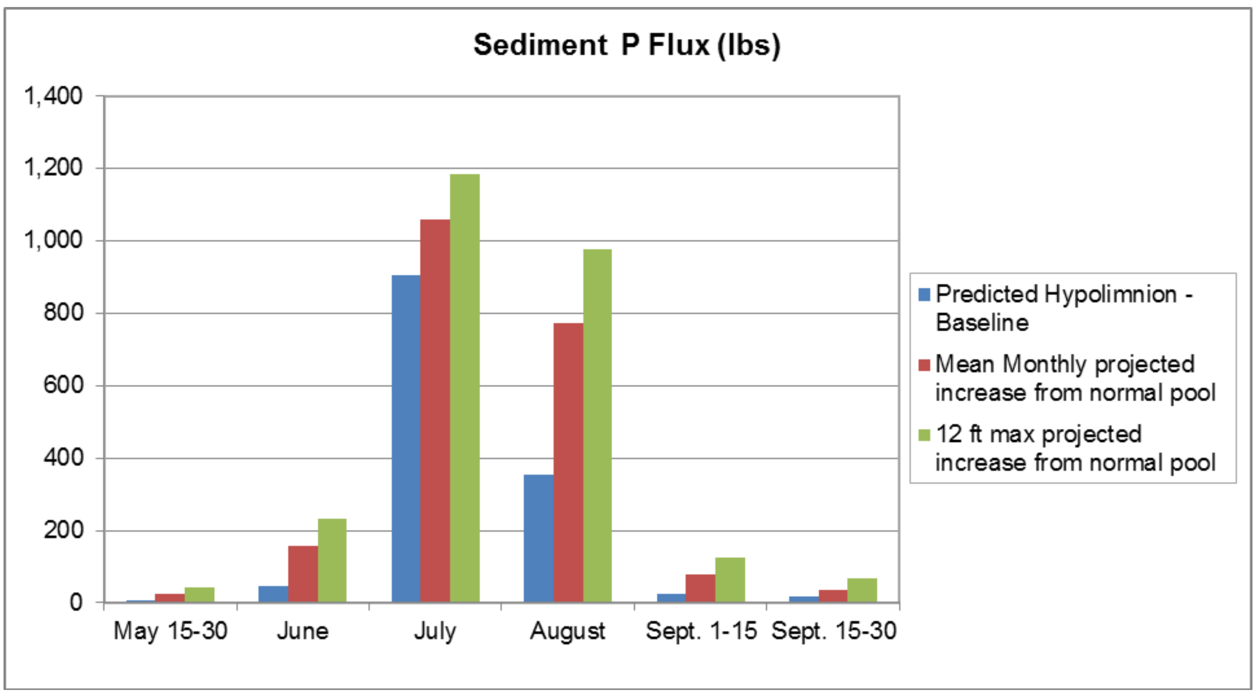


Figure 2-11. Monthly Estimates of Internal Phosphorus Loading from Bottom Sediment

2.3.3.2 Loading from Inundated Sediment and Vegetation

Soballe (2006) from the USACE's Engineer Research and Development Center (ERDC) Environmental Laboratory provided estimates of the magnitude of internal phosphorus loading from the inundated vegetation and soil/sediments due to the increase in pool elevation of Chatfield Reservoir. The report includes literature values for phosphorus content and grassland standing crop vegetation, expressed as phosphorus, in the area to be inundated and is reported to be ranging from 5 to 10 kg/ha. A value of 10 kg/ha was used in this analysis to be conservative. The report also notes that about 60 percent of phosphorus contained in the inundated vegetation is released in the first year and the remainder is released in the subsequent years. The short-term effect of inundated vegetation in the first year was evaluated. The inundated vegetation loading was calculated as:

$$Vegetation\ Phosphorus\ release\ after\ inundation\ (kg) \\ = Phosphorus\ Content\ (kgP/ha)\ x\ Area\ (ha)\ x\ (0.6\ (first\ year)\ /no.of\ days) \quad [8]$$

This assumption was also applied when estimating the load. In addition, a value of 0.05 kg/ha/day was used for estimating the inundated soils. The release of phosphorus from the inundated soil is calculated as the product of the release rate, the area inundated, and the period of inundation.

$$Sediment\ Phosphorus\ release\ after\ inundation\ (kg) = \\ Release\ Rate\ (kg/ha/day)\ x\ Area\ (ha)\ x\ Release\ Period\ (days) \quad [9]$$

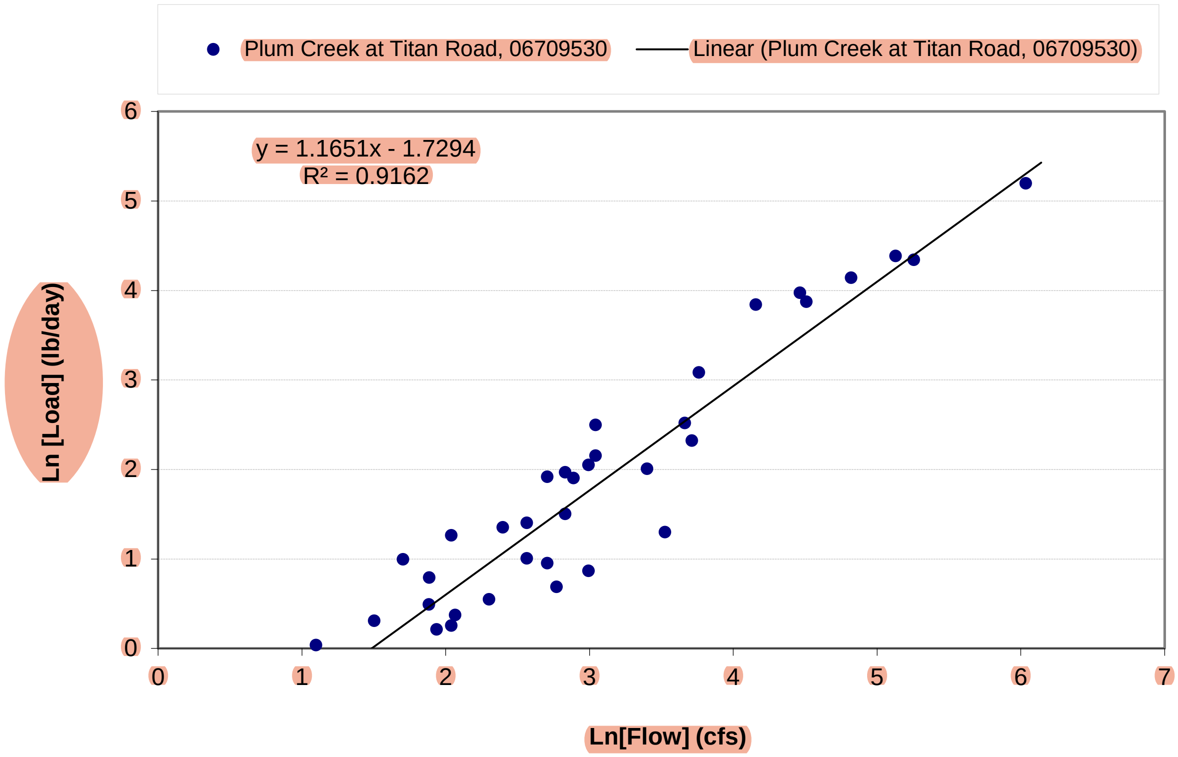
The inundated area for each scenario was calculated as the difference between the new pool elevation area and the normal pool elevation area (Table 2-7)

Table 2-7. Inundated Area Used in Calculations (acres)

Month	Inundated Area for Monthly Mean Increase in Depth Scenario (acres)	Inundated Area for 12-ft increase Scenario (acres)
May	389	580
June	441	580
July	441	580
August	389	580
September	389	580

2.3.3.3 Watershed Loading

Watershed nutrient loads were estimated from the observed total phosphorus data from Plum Creek and the South Platte River. Monthly observation data from both streams were available. Monthly flow and total phosphorus data for the period from 2009 through 2012 were used (n = 44) to compute an instantaneous load. The instantaneous flow and load were then converted to a log scale and regressed. R^2 values were approximately 0.9 for both Plum Creek and South Platte River. The relationships between phosphorus loading and instantaneous flow are shown in Figure 2-12.



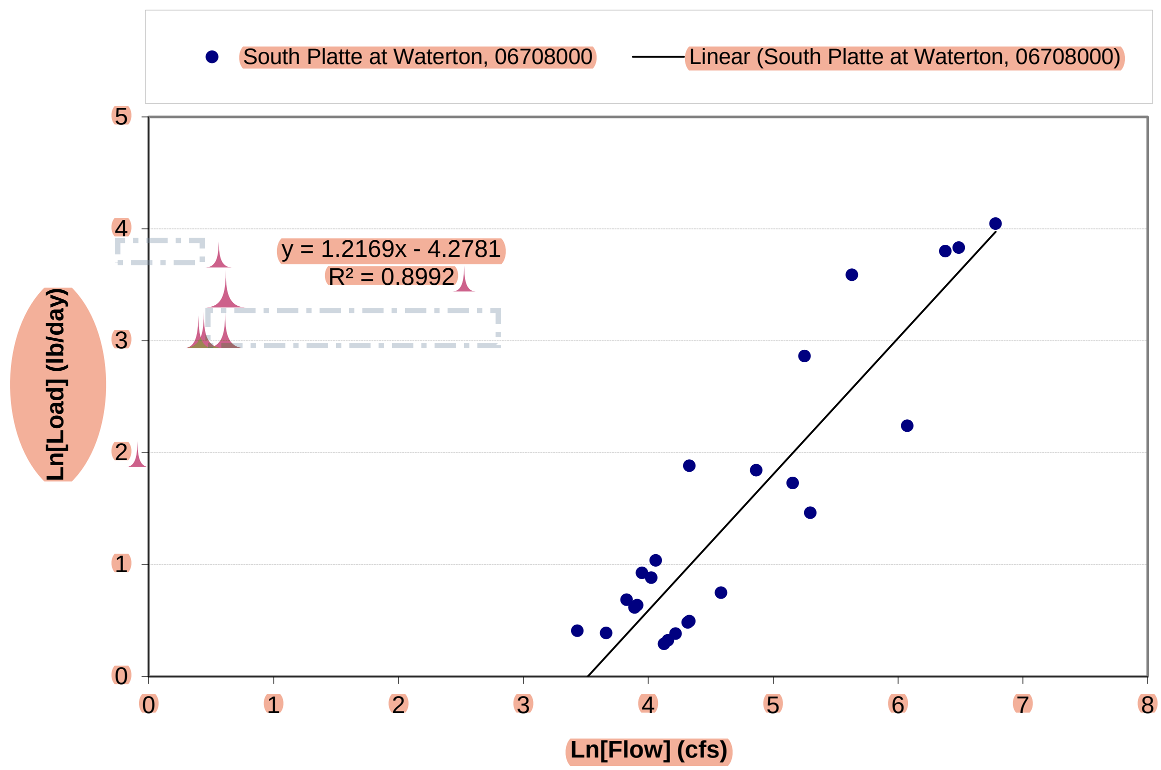


Figure 2-12. Total Phosphorus Load vs. Flow Relationship for the Period from 2009 through 2012.

The resulting relationship was used to generate a time-series of loading using daily flow data as given below:

$$PlumLoad = a\ Qplum^{\ b} \quad [10]$$

$$SPlatteLoad = c\ Qsplatte^{d} \quad [11]$$

where:

$Qplum$ =Flow in Plum Creek (cfs), $a = e^{-1.7294}$, b= 1.1651

$Qsplatte$ = Flow in South Platte River (cfs), $c = e^{-4.2781}$, d= 1.2169

Flow time series for the year 2012 from the USGS station 06709530 – Plum Creek at Titan Road and South Platte River at Waterton 0670800 (from the Colorado Division of Water Resources) were then used to compute a loading time-series based on the relationships developed for flow and load (Figure 2-13) . Monthly estimates of the total phosphorus loads were calculated for input into the model using these load estimates.

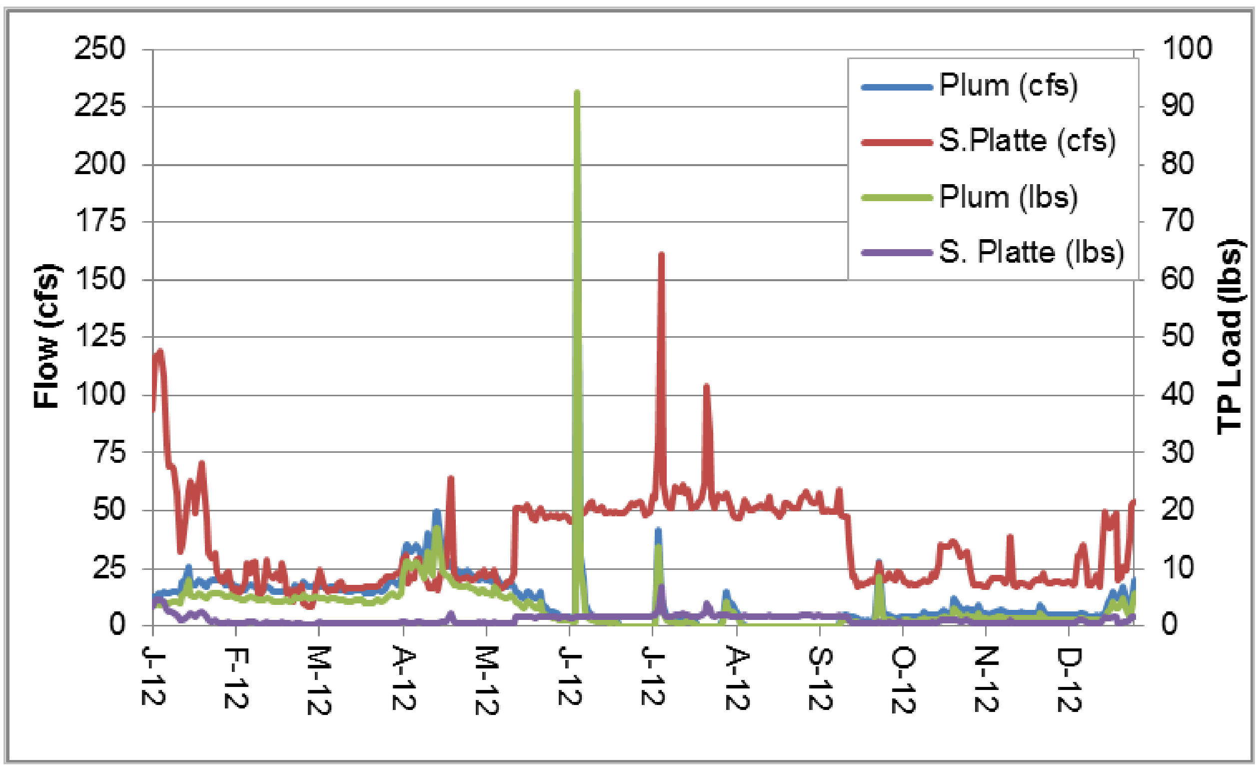


Figure 2-13. Observed Flows and Estimated Total Phosphorus Loads from the Watershed for 2012.

2.3.3.4 Atmospheric Deposition

Loading due to atmospheric deposition could not be considered. The National Atmospheric Deposition (NADP) network was queried for phosphorus deposition rates for stations in the vicinity of the Chatfield Reservoir. No phosphorus observations were available from any of the NADP network stations in Colorado. There are no available records of atmospherically deposited phosphorus, because soluble PO4 is rarely above detection limits (NADP, 1999), and total phosphorus is not measured (Baron et al., 2000). For this analysis, phosphorus from atmospheric deposition was assumed to be zero, however if site-specific data become available they could be incorporated into the analysis.

2.3.4 *Phosphorus Mass Balance Analysis*

This section presents the estimated phosphorus loads and presents phosphorus concentrations for each scenario.

2.3.4.1 Phosphorus Load Summary

Figure 2-14 shows the estimated total phosphorus loading from all sources feeding into the reservoir for the baseline, and the proposed condition scenarios - typical case and maximum pool increase. The analysis was conducted for all the scenarios shown under Table 2-3. The monthly watershed loads remain the same for all the scenarios. The two scenarios with increases in the hypolimnion show the sensitivity to the loading used in the analysis, with an overall increase due to increase in pool elevation. The hypoxycline elevation was assumed to increase by the same amount as the increase in the pool elevation, which results in increased hypoxic bottom surface area and a resulting increase in internal loading. The depth of the aerobic area in the epilimnion remains the same; however, there is an increase in surface area due to increase in pool elevation. This also leads to an increase in surface area available for aerobic fluxes.

The short term impacts due to trophic upsurge are expected to last for a year, after which they are expected to taper off (Soballe, 2006). As the phosphorus contributions due to the inundated vegetation and soil subside over time, it is expected that aerobic conditions would ultimately apply to the inundated zone. This would likely represent the long-term conditions in the reservoir after an increase in pool elevation. For the long-term scenario, the aerobic release was assumed to extend into the inundated areas, whereas for the short-term scenario the aerobic load calculation excluded the inundated areas. As can be seen in Figure 2-14, the aerobic load for the short-term impacts is less than the aerobic load when calculating the long-term impacts with no vegetation contribution.

2.3.4.2 Estimation of Phosphorus Concentrations in the Reservoir

A simple mass balance calculation was made to estimate monthly average phosphorus concentrations in the epilimnion and hypolimnion for all scenarios. A separate analysis of the epilimnion and hypolimnion was necessary since the reservoir is stratified during the summer period from May-September – phosphorus released from the anaerobic bottom sediment remains sequestered in the hypolimnion and will not mix and influence total phosphorus concentrations in the upper, mixed epilimnetic zone. From mid-May through mid-September, when the reservoir is stratified, the phosphorus released from the anaerobic bottom sediments was not made available to the upper mixed zone. After de-stratification or fall turnover occurs, the net total phosphorus load from the hypolimnion is made available for mixing throughout the entire water column. For this assessment the boundary between the epilimnion and hypolimnion was taken to be the hypoxycline elevation (discussed in Section 2.3.2 and Table 2-4). The total phosphorus mass balance analysis in the hypolimnion and epilimnion are discussed in the following sections.

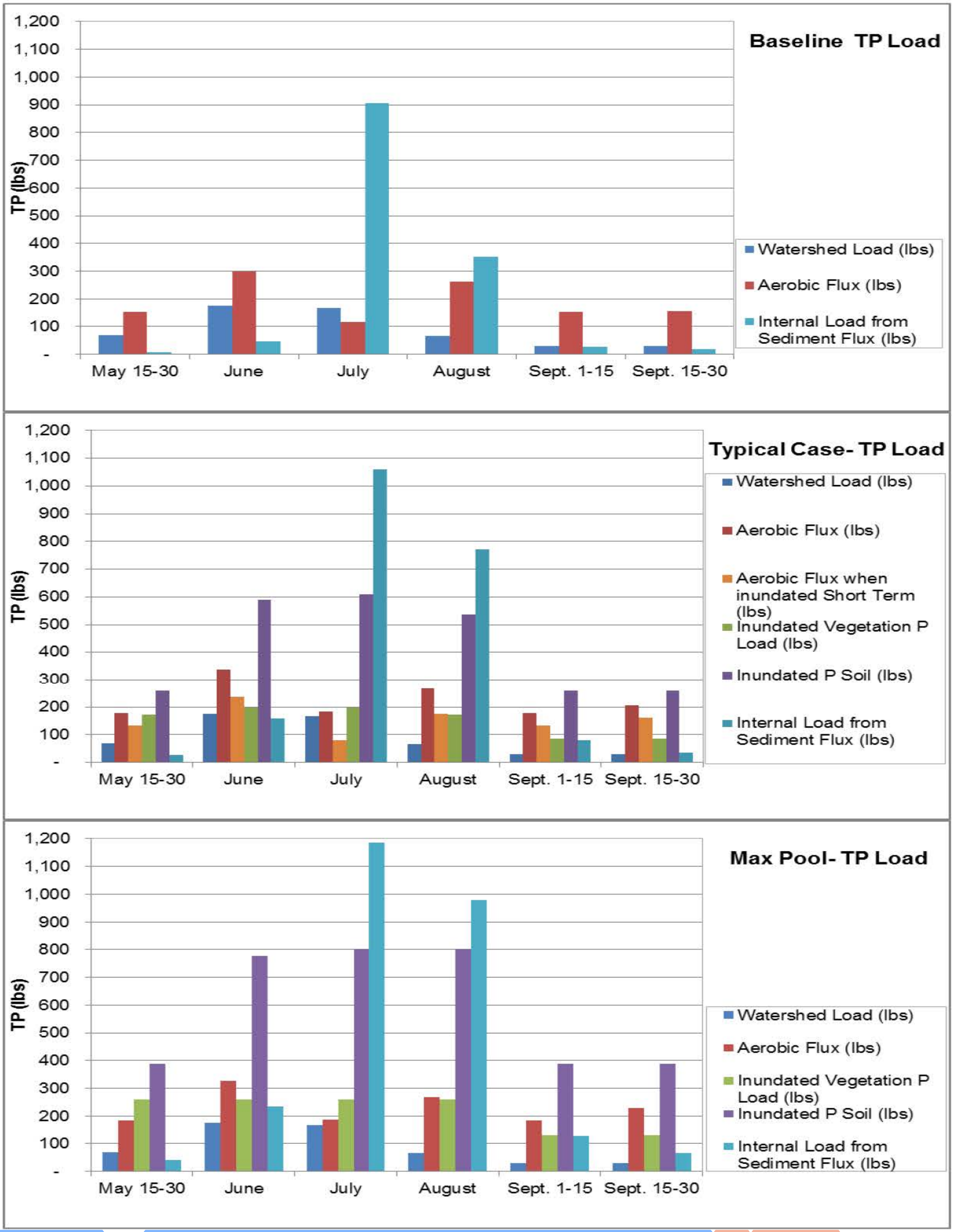


Figure 2-14. Total Phosphorus Loading from All Sources for Baseline, Typical and Max Pool.

2.3.4.3 Hypolimnion Load Estimation

A mass balance of the total phosphorus (TP) load in the hypolimnion was computed on a monthly basis. The calculation considered the TP concentration from the previous month. The equation below presents the various sources and sinks considered.

Mass of TP for current month = Initial TP concentration + Settling Load from Epilimnion + Bottom Sediment Flux – Loss from sediment

$$V\frac{dC}{dt} = V \cdot C_{t-1} + C_{epi} \cdot A \ \cdot v + J_p \cdot A - C_{hyp} \cdot A \cdot v \qquad [12]$$

where:

$\boldsymbol{V \cdot C_{t-1}}$ is the initial source load from the previous month based on the volume of the hypolimnion and the volume-weighted concentration in the hypolimnion from the previous month.

$\boldsymbol{C_{epi} \cdot A \ \cdot v}$ is the mass settling from the epilimnion into the hypolimnion for the current month based on the concentration at the interface of the hypolimnion from the previous month, surface area and settling velocity.

$\boldsymbol{J_p \cdot A}$ is the P flux that occurs at the bottom area and is based on the monthly estimated sediment flux value which considers the net flux that occurred in the previous months.

$\boldsymbol{C_{hyp} \cdot A \cdot v}$ is the loss due to settling based on the product of the concentration in the hypolimnion from the previous month, surface area and settling velocity.

The net TP loading in the hypolimnion was thus estimated by computing each term for the months May through September (and multiplying by the number of days). Table 2-8 presents the net TP load in the hypolimnion by month for each scenario evaluated. Figure 2-15 shows the computed loads in the hypolimnion from various sources and the final computed net load (in pink) for each month. As expected, the net load from the max pool case is the highest since the hypolimnion area is the greatest.

Table 2-8. Estimated Monthly Net TP Load in the Hypolimnion

Month	Baseline (lbs)	Typical Case Mean increase in pool (lbs)	Max Pool Increase (lbs)
May 15-30	41.02	105.31	172.25
June	116.51	362.53	533.98
July	1,862.73	2,840.33	3,213.67
August	612.41	1,538.72	2,184.07
Sept. 1-15	174.91	418.96	696.21
TOTAL	2,807.58	5,265.85	6,800.18

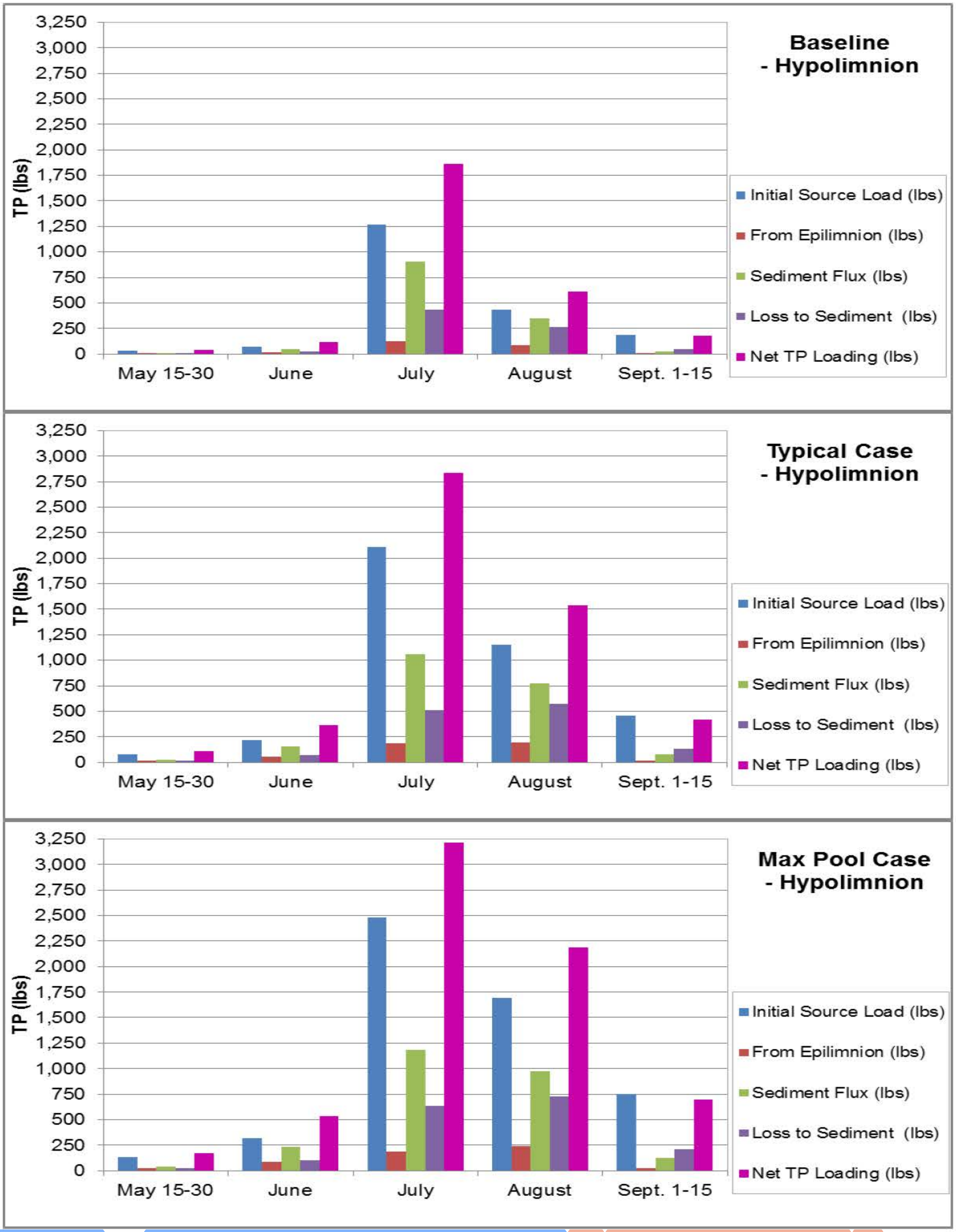


Figure 2-15. Estimated Net Total Phosphorus Load by month and Various Loading Sources in the Hypolimnion

In order to evaluate the predicted net TP load from the sediment, the net TP baseline load for each month was divided by the volume for the corresponding month to estimate a predicted TP concentration in the hypolimnion. The 2012 CWA data include TP concentrations measured at different depths in the hypolimnion. The observed TP concentrations were used to calculate a volume-weighted TP concentration for the hypolimnion. The volume-weighting was based on volume of water represented by the observed TP observation. Volumes were determined from the established elevation versus reservoir capacity table developed by the USACE (Figure 2-3). Figure 2-16 shows the monthly model predicted TP concentrations and observed 2012 hypolimnetic volume-weighted TP concentrations.

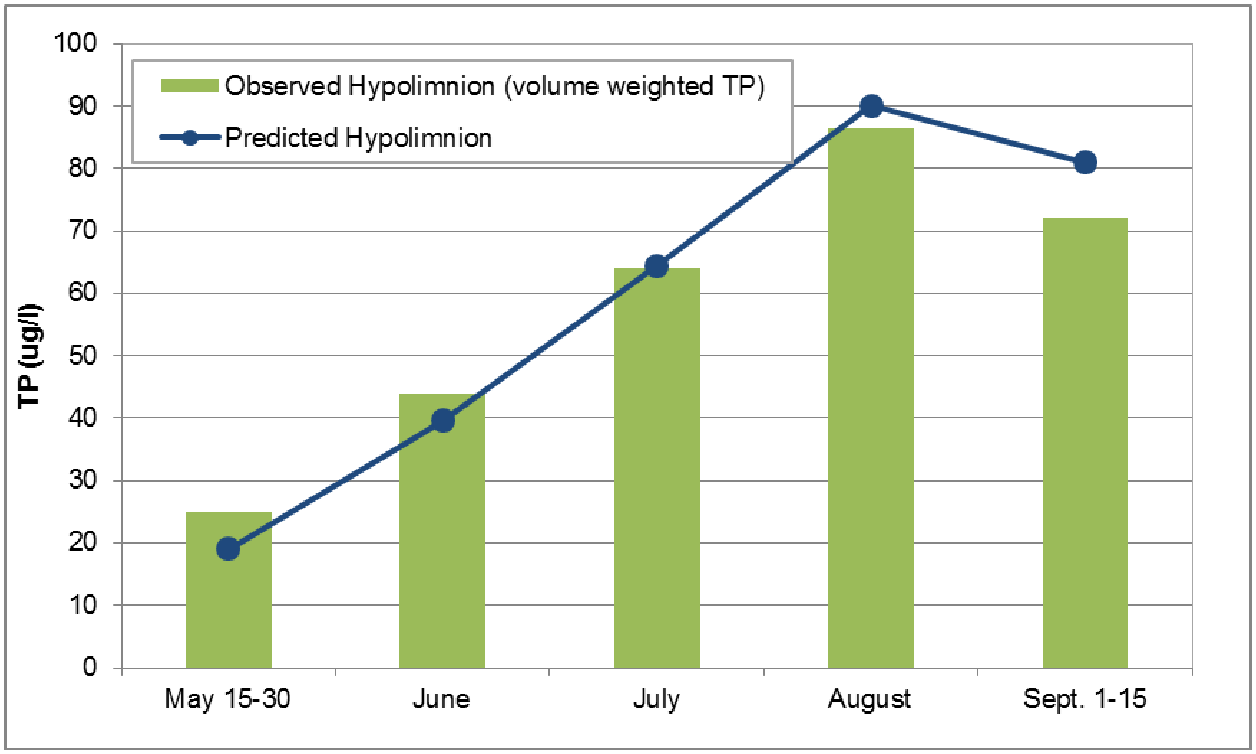


Figure 2-16. 2012 Observed and Predicted TP Concentrations in the Hypolimnion

The model predicted TP concentrations follow the overall trend of the 2012 observed TP data and are similar to the TP concentrations observed in the hypolimnion. No mixing of TP from the hypolimnion to the epilimnion was assumed during the period when the reservoir is stratified. The predicted net TP loads for the first half of the month of September were used in the calculation for the latter part of September, when the reservoir becomes de-stratified during fall turnover.

2.3.4.4 Epilimnion Concentration Estimation

The total phosphorus (TP) concentration in the epilimnion was estimated by assuming that the epilimnion is completely-mixed and at a steady-state condition.

To determine the reservoir TP concentration for each month, the following steady-state equation was used (Chapra, 1997) (by varying the total loading, outflow and loss predicted due to the fluctuation in the elevation/volume):

$$c = \frac{\sum W}{(Q + K_s \cdot V)} \qquad [13]$$

where:
c = steady state nutrient concentration
$\sum$ W = sum of all the loading into the system for each month
Q = monthly outflow
K_s = overall loss rate of the nutrient (Chapra, 1997)
V = reservoir volume in the epilimnion for the particular month

As can be seen in the steady state equation [13] the numerator includes all the sources to the system, whereas the denominator includes all the losses. The total load into the system was estimated as the sum of the watershed load and aerobic loads for each month. For the scenario conditions, in order to estimate the short-term effects, the load from vegetation and soil inundation was added to the watershed and aerobic load. During de-stratified conditions an additional net phosphorus load was also added due to the internal load from the bottom sediments (calculated using equation [12] discussed in section 2.3.3.1 for the period from 15 to 30 September).

Monthly outflow was computed for the year 2012 using data from the site South Platte River Below Chatfield Reservoir (PLACHACO) (collected by the Colorado Division of Water Resources). For each scenario the outflow was kept the same as baseline assuming similar reservoir operations. It should be noted that increasing or decreasing the outflows in the proposed condition will likely have an impact on the TP concentration. All other parameters remaining the same, a decrease in outflow along with increase in pool elevation will result in an increase in predicted TP concentrations and vice versa. This occurs because the localized model takes into account the increase in phosphorus flux due to the increased pool elevation. The increase in phosphorus flux in the localized model is more than the "dilution effect" due to increased pool elevation and due to increase in HRT (decrease in outflow).

As described in the above paragraph, Tetra Tech utilized the PLACHACO flow gage on the South Platte River to compute monthly outflow from Chatfield Reservoir. This gage site does represent the flow in the South Platte River immediately downstream of Chatfield Reservoir, but does not represent the actual outflow from the reservoir. The reason for the difference is that outflows at Chatfield Dam are routed through a "manifold" to service four diversions (City Ditch, Last Chance Ditch, Nevada Ditch, and CDOW Fish Hatchery) and the remaining water is discharged to the South Platte River (See Attachment 2). More outflow occurs from Chatfield Reservoir than is indicated by the PLACHACO gage (see Figure 3-3). As such, using the PLACHACO gage to define reservoir outflow likely underestimates the total phosphorus load released from the reservoir. Underestimating the total phosphorus load released by dam discharges will result in overestimating in-reservoir total phosphorus concentration based on inflow-outflow mass balance. Thus, the Tetra Tech analysis conservatively estimates impacts to in-reservoir total phosphorus concentrations based on mass balance calculations (i.e. in-reservoir total phosphorus concentrations could be lower).

The overall loss rate was used as a calibration parameter and was adjusted during calibration. The monthly volumes in the epilimnion were estimated based on the difference between the overall volume (normal pool, average pool increase, max pool increase) and the corresponding volume of the hypolimnion (see Table 2-4 for hypolimnion volumes and elevations) for the particular month. Table 2-9 shows the volumes used in the analysis to estimate the TP concentrations and the corresponding overall volumes that were used to estimate them. Note that the volumes for the period from mid to end of September are the same, since the reservoir is assumed to be de-stratified and the entire volume is made available.

Table 2-9. Volumes Used to Estimate Epilimnion Total Phosphorus Concentrations.

	Baseline Case		Typical Case		Maximum Case	
Month	Epilimnion (ac-ft)	Normal pool (ac-ft)	Epilimnion (ac-ft)	Average pool (ac-ft)	Epilimnion (ac-ft)	Maximum pool (ac-ft)
May 15-30	26,633	27,428	40,277	42,218	44,857	48,066
June	26,345	27,428	40,165	43,374	43,341	48,066
July	16,796	27,428	25,113	42,805	27,251	48,066
August	24,927	27,428	35,370	41,996	38,332	48,066
Sept. 1-15	26,633	27,428	39,299	41,240	44,857	48,066
Sept. 15-30	27,428	27,428	41,240	41,240	48,066	48,066

The resulting TP concentrations were compared to observed volume-weighted TP concentrations in the upper mixed zone during 2012 (Figure 2-17). The 2012 CWA data include TP concentrations measured at different depths in the epilimnion. The observed TP concentrations were used to calculate a volume-weighted TP concentration for the epilimnion. The volume-weighting was based on volume of water represented by the observed TP observation. Volumes were determined from the established elevation versus reservoir capacity table developed by the USACE (Figure 2-3). In general, the model predicted TP concentrations follow a similar trend to the 2012 observed data and the concentrations are within 3 µg/L. For the period when the reservoir is stratified no internal loading from the hypolimnion is allowed to mix with the epilimnion. The highest concentrations are observed during late September. This is primarily due to the influence of the internal hypolimnetic phosphorus load addition to the total epilimnetic phosphorus load when fall turnover occurs. In general, the differences in the 2012 observed versus predicted values can be expected due to the simplistic approach and attributed to several factors such as the simplistic steady state assumption, mixing effects, incoming watershed loading which was estimated based on regression, or due to errors in the flux estimates. The Chatfield Reservoir TP water quality standard applies to the upper mixed zone during the July through September period and is 30 µg/L. The Assessment criteria (used when assessing whether the waterbody is in attainment of the specified standard) is 35 µg/L as a summer (July through September) average with a one-in-five allowable exceedance frequency. Predicted averages from July through September 2012 were 23 µg/L for the modeled baseline period compared to the 2012 observed, volume-weighted TP concentration of 25.5 µg/L.

The under prediction of epilimnetic TP concentrations in July, August, and the first part of September may be attributed to the gradual erosion of the hypolimnion as the thermocline moves downward with reservoir cooling. As this occurs, TP in the upper hypolimnion will be released to the epilimnion as the thermocline gradual lowers. This gradual release of TP is not accounted for in the model as all the hypolimnetic phosphorus load is retained in the hypolimnion until mid-September when it is all released to the epilimnion. This may also account for the over prediction of the TP concentration in late September.

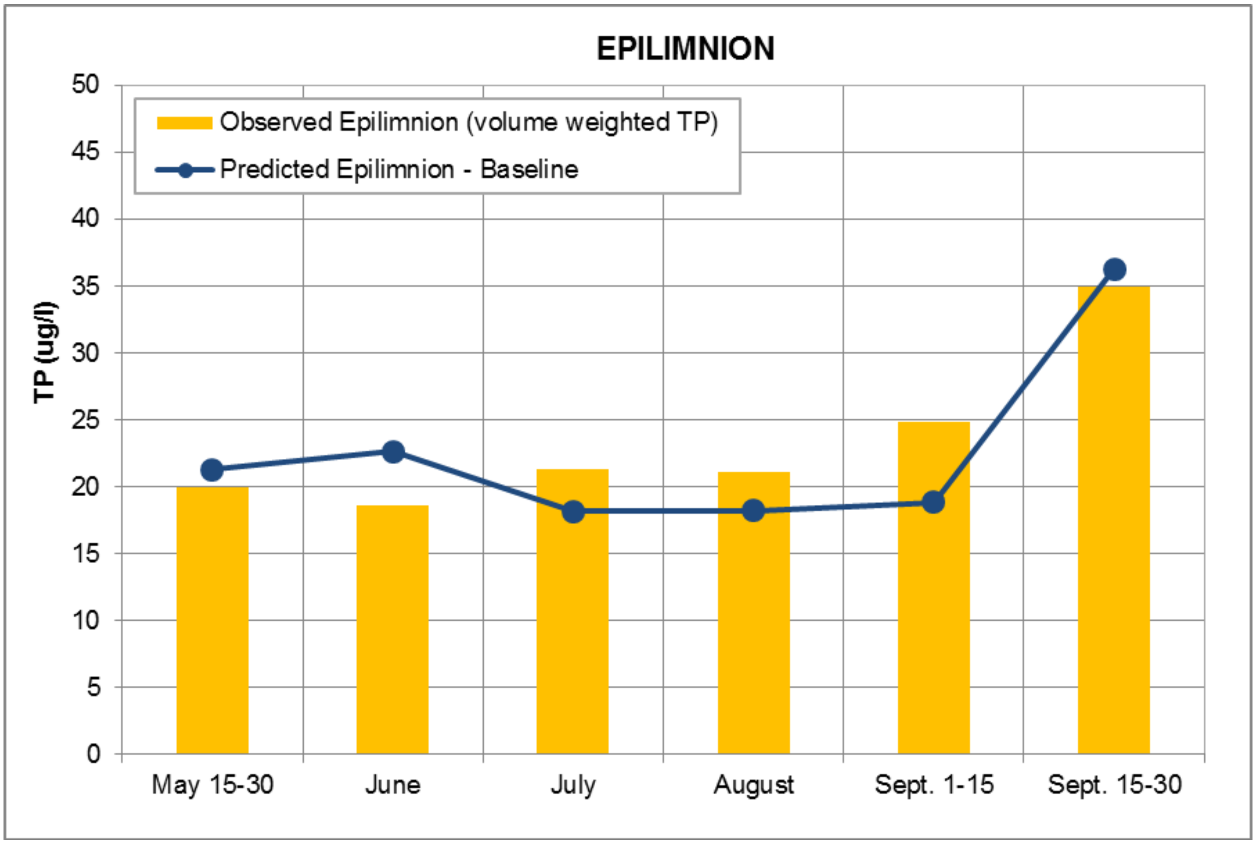


Figure 2-17. 2012 Observed and Predicted Baseline Total Phosphorus Concentrations in the Epilimnion.

The model was then used to simulate epilimnion TP concentrations, based on increase in pool elevation, for the defined nutrient scenarios (Table 2-3). The projected 12-ft increase and the typical case both show an overall decrease in the summer months when the reservoir is stratified (Figure 2-18). This is because of the increase in volume that is available for dilution and there is no mixing of the internal hypolimnetic phosphorus load to the upper mixed zone when the reservoir is stratified. This is not the case during fall turnover in the latter part of September when the reservoir becomes de-stratified. During fall when the reservoir turns over, and with the addition of the calculated internal hypolimnetic phosphorus load, higher TP concentrations result.

The extent of the hypolimnion has a significant impact on the concentration, and the predictions for the scenario switch during fall turnover showing maximum impact from the 12-ft maximum increase scenario. The TP results for the 12-ft increase scenario result in a higher concentration during this period compared to the typical case scenario since it has a greater assumed hypolimnion and hence greater calculated internal hypolimnetic phosphorus load that becomes available during late September.

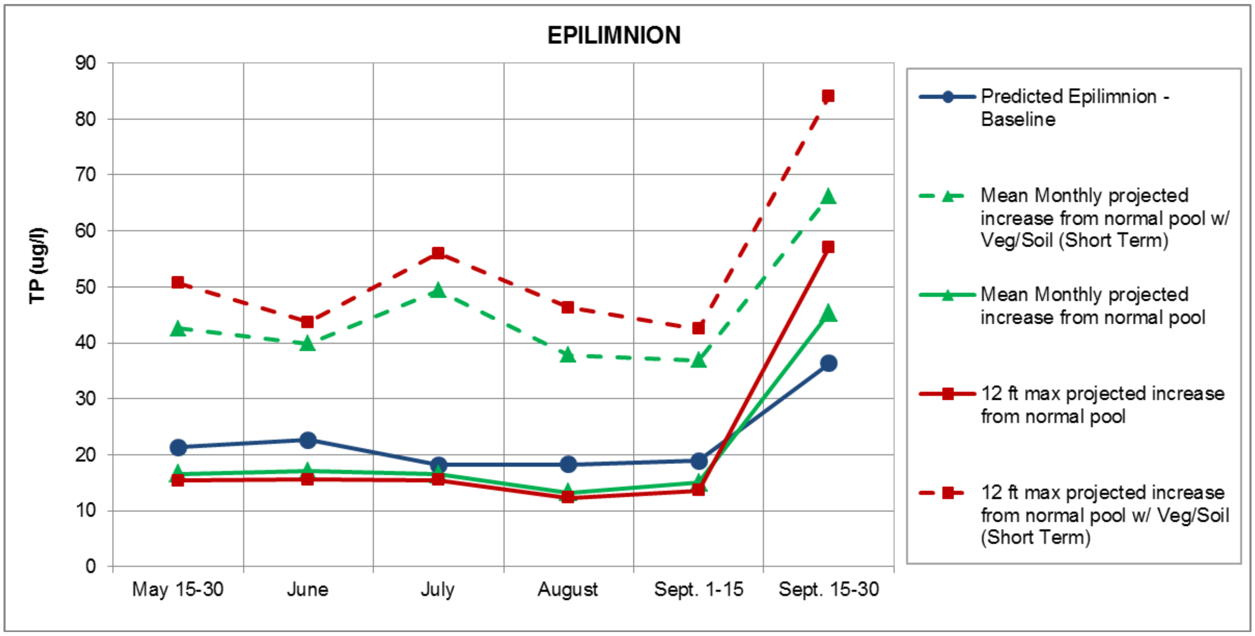


Figure 2-18. Predicted Monthly Epilimnion Total Phosphorus Concentrations for the Baseline and Proposed Scenarios.

The short-term effect of the increase in pool elevation indicates that the reservoir will experience increased TP concentrations due to loading from vegetation and inundated soils. The 12-ft maximum increase scenario shows the highest predicted concentrations since the inundated area is much more compared to the area inundated by the mean monthly projected increase scenarios. Figure 2-18 shows the predicted monthly TP concentration for each of the scenarios. The high TP concentrations are considered short-term, that is for about a year and in the subsequent years the contributions from inundated vegetation and soil should drop off substantially with time as the "trophic upsurge" subsides (Soballe, 2006).

Table 2-10 provides a range of estimated steady-state total phosphorus concentrations due to varying loading conditions in the reservoir for the summer period. The total phosphorus concentrations given in Table 2-10 are averages for the period from July through September that can be used to evaluate against the total phosphorus standard for the reservoir. The short-term scenarios have the greatest impact and exceed the reservoir standard of 30 µg/L and assessment criterion of 35 µg/L, with predicted concentrations being 57 µg/L and 48 µg/L for the maximum case and typical case, respectively. However, the same scenarios do not exceed standards when long-term impacts are considered, that is, no contribution from vegetation and inundated soils with predicted average concentrations of 25 µg/L and 23 µg/L, respectively.

Table 2-10. Mean Total Phosphorus Concentrations for Baseline and Increased Pool Conditions in the Epilimnion during July through September

Scenario	Description	Total Phosphorus (µg/L)
BASELINE – Normal Pool		
BASE	Assumes anaerobic hypolimnion based on the number of hypoxic layers observed during the summer period	23
MAXIMUM CASE – Assumes 12-ft increase (maximum proposed pool) in hypolimnetic elevation from BASE		
MAXST	Considers contribution of phosphorus from inundated soil and vegetation (short-term impact) in addition to watershed load and aerobic load	57
MAXLT	Considers watershed load and aerobic load. Does not consider phosphorus contribution from inundated soil and vegetation (long-term impact)	25
TYPICAL CASE – Assumes a monthly increase in hypolimnetic elevation from BASE, based on depth computed from mean monthly baseline and proposed elevations		
AVGST	Considers contribution of phosphorus from inundated soil and vegetation (short-term impact) in addition to watershed load and aerobic load	48
AVGLT	Considers watershed load and aerobic load. Does not consider phosphorus contribution from inundated soil and vegetation (long-term impact)	23

2.3.5 Recent Phosphorus and Chlorophyll Water Quality Trends

This section presents phosphorus and chlorophyll-a monitoring data collected since the initial modeling assessments were completed. These data, collected in 2008, 2009, and 2010, were obtained from the CWA (Chatfield Watershed Authority, 2008b, 2009, 2011a).

In 2008, the total phosphorus standard and chlorophyll goal were attained, and the phosphorus TMAL was met. The growing season (June through September) total phosphorus concentration of 19 µg/L was less than the 27 µg/L reservoir standard and the chlorophyll-a concentration of 4.9 µg/L was much less than the 17 µg/L goal to meet beneficial uses. The TMAL was met at 14,566 pounds with 117,631 acre feet (ac-ft) of flow.

The following year, Control Regulation No. 73 changed substantially, as discussed in the introductory section of this report. In 2009, the growing season (July through September) phosphorus concentration of 18.3 µg/L was less than the 30 µg/L reservoir standard and 35 µg/L assessment criterion. The TMAL was met at 11,049 pounds with 135,032 acre feet (ac-ft) of flow. The growing season chlorophyll-a concentration of 13.1 µg/L exceeded both the new 10 µg/L standard and the 11.2 µg/L attainment threshold, an increase from prior years. However, the one-in-five year exceedance criterion was attained.

Preliminary 2010 data include a phosphorus outlier of 1,100 µg/L from September 9, 2010. Including that value results in an average growing season phosphorus concentration of 198.2 µg/L. Excluding the outlier, the average appears to meet the phosphorus standard (Chatfield Watershed Authority 2011b). The growing season average chlorophyll-a concentration of 26.3 µg/L exceeds the standard. In meeting notes from November 16, 2010, the CWA suggests the possibility that a regional environmental issue may be affecting Chatfield Reservoir, noting that three nearby reservoirs recently have exceeded their phosphorus and chlorophyll-a standards.

The models in this technical report are based on phosphorus data collected from 1986 to 2012. As described in Regulation No. 38, typical summertime concentrations of phosphorus in Chatfield Reservoir have been about 0.020 mg/L, with no trend for increasing concentrations. Summer median concentrations have exceeded 0.030 mg/L in only 3 of 24 years. Typical summer average chlorophyll-a is about 6 µg/L, with no trend for increasing concentrations. Concentrations vary from year to year, but have exceeded 10 µg/l only 5 times in 24 years, and only twice since 1990. Despite the increase in chlorophyll-a during 2010, more recent data appear to fall within the historical range of variability of the data modeled in this technical report.

2.4 Metals Assessment

The potential for metals to be mobilized under hypoxic conditions was assessed for the baseline and proposed conditions. The concern with metals mobilization is the development of hypoxic conditions under summer thermal lake stratification. The mobilization and bioavailability of metals is a complex process and can be influenced by changes in pH, redox conditions, and organic complexation (Shipley, 2004). In anoxic sediments, sulfides are often believed to be the major solid phase regulating the mobility and bioavailability of metals (USEPA, 2000a; Shipley, 2004; Goossens and Zwolsman, 1996). This analysis does not simulate any of the complex interactions in the sediments but uses the flux of metals to estimate the loadings. For this analysis the following metals of concern were selected based on available sediment data – Copper (Cu), Lead (Pb), Mercury (Hg), Cadmium (Cd), Selenium (Se), and Arsenic (As).

Based on a literature review, it was found that fluxes of sediment-based metals to and from the water column exhibit a wide range of variability. They are dependent on the environmental setting and type of waterbody, vary by orders of magnitude, and can be both positive and negative (from and to the sediment). Of interest in this study are the characteristics of the identified metals under both anaerobic and aerobic conditions. Unfortunately, the literature reviewed was not definitive in identifying anaerobic versus aerobic flux rates.

For this analysis, it was assumed that flux rates are the same between the anaerobic and aerobic zones. Hence, evaluation of multiple scenarios for the anaerobic hypolimnion was not performed as was done in the nutrients analysis. The diffusive metal flux was calculated based on observed metals data from the sediment and water column and evaluated for the baseline and an average increase in pool. The maximum pool increase condition was taken as a 12-ft increase. The mean increase in depth during the summer period (June, July, and August) was estimated to be 9.3 ft (Table 2-2). The estimation of the metal fluxes may be updated in the future as additional literature is identified or sediment core sampling is conducted to estimate site-specific metal fluxes.

2.4.1 Estimation of Metals Flux from Sediment

For this study, observed metals data in the sediment and water column were used to estimate the diffusive flux of the metals. This method affords a way to quantify the internal loading using observed data for the relative comparison of the metals' internal loading at normal pool elevation and after the proposed elevation increase. It was assumed that the computed diffusive fluxes apply to the entire reservoir bottom surface area (both aerobic and anaerobic zones). The exchange of metals between interstitial pore-water and overlying water was determined using Fick's first law. This method calculates the flux of an element by molecular diffusion. The model is defined as follows:

$$J_z = -D\left(\frac{dc}{dz}\right) \qquad [14]$$

where:

J_z is the mass flux in the z direction

D is the molecular diffusion coefficient for the element in the sediment

dc/dz is the concentration gradient of the element across the sediment-water interface (Chapra, 1997; Naes et al., 2001; Balistrieri, 1995).

Equation 14 can be used to determine the mass of metal released per day and is written as follows:

$$A_c \cdot J_z = A_c \cdot v_d \cdot (c_2 - c_1) \qquad [15]$$

where:

c_2 is the metal concentration in the pore water of the sediment

c_1 is the observed concentration of the metal in the water overlying the sediment

A_c is the area of the interface between the two sides, i.e. the reservoir bottom surface area v_d is called a diffusion mass-transfer coefficient (D/z) and can be estimated from the empirically derived formula (Di Toro et al., 1981 as cited in Thomann and Mueller, 1987; Chapra, 1997):

$$v_d = 69.35 \cdot \phi \cdot M^{-2/3} \qquad [16]$$

v_d has units of m/yr, M = molecular weight of the compound, and ϕ is the sediment porosity (assumed to be 0.9).

The pore-water concentration of the metal in the sediment (c_2) in equation [15] was calculated using the observed sediment associated concentration (υ) and the sediment partition coefficient for the particular metal (K_d). This is given as follows (Chapra, 1997):

$$c_2 = \upsilon / K_d \qquad [17]$$

For the metals of concern, sediment data were collected for Cu, Hg, Pb, Cd, Se, and As. Therefore, these were the only metals evaluated. One value of sediment-associated metals fraction (mg/kg) was measured for each year from 1999 to 2004 (n = 6). Arsenic was the only exception, and it had data starting in 2001. For this analysis a median value for each metal was estimated and used. Table 2-11 shows observed concentrations of the metals sorbed to the sediment for each year and the median metals concentration. The sediment associated metals were measured during the month of August for each year.

Table 2-11. Concentration of Metal on Sediment in the Chatfield In-Reservoir, Near-Dam Station

Year	Total Copper mg/kg)	Total Mercury mg/kg)	Total Lead mg/kg)	Total Cadmium (mg/kg)	Total Selenium (mg/kg)	Total Arsenic (mg/kg)
1999	25.00	0.06	30.00	0.50	2.00	
2000	11.00	0.02	12.00	0.25	0.80	
2001	14.90	0.02	22.00	0.50	0.77	2.00
2002	14.90	0.05	22.00	1.00	3.10	79.00
2003	33.60	0.08	42.40	0.82	2.25	8.95
2004	27.20	0	36.20	0.99	2.00	4.30
Median	**19.95**	**0.04**	**26.00**	**0.66**	**2.00**	**6.63**

(Source: Chatfield Watershed Report, 2004)

The K_d values for each metal were determined from the literature (Allison et al., 2005). Allison et al. provides mean, minimum and maximum values of K_d for soil/soil water collected from various literature sources with a relative confidence flag for the K_d value for each metal. Table 2-12 shows all the observed data, coefficients and intermediate calculation values leading to the computation of the mass of metal released per day for normal pool elevation and the proposed 12-ft maximum and 9.3 ft mean increase in depth. It should be noted that the 12-ft increase is the maximum possible case but occurs infrequently (approximately 18 percent of the time based on daily data from 1942 to 2000) and that the mean case of 9.3 ft is the most likely typical condition that may occur under summer conditions.

It can be seen from Table 2-12 that the estimated flux values are positive (i.e., there is a positive flux or net source to the water column).

Table 2-12. Calculations for the Mass of Metals Released Per Day

Calculation	Cu	Hg	Pb	Cd	Se	As
Total Sediment Concentration *v* (mg/kg)	19.95	0.04	26.00	0.66	2.00	6.63
Dissolved Concentration (mg/L) *c1*	0.0027	0.00016	0.0011	0.0001	0.00000	0.0008
Molecular Weights	63.546	200.59	207.2	112.41	78.96	74.9216
Diffusion Mass-transfer Coefficient *vd* (m/yr)	4.20	1.82	1.78	2.68	3.39	3.51
Mean Values from Literature - Partition Coefficient [logKd] (L/kg)	2.70	2.30	4.10	3.25	5.70	3.50
Kd (L/kg)	501	200	12589	1778	501187	3162
Dissolved Metal Concentration (mg/L) *c2=v/kd*	0.040	0.00020	0.002	0.000	0.00000	0.002
Estimated Metal Flux Using Fick's First Law ($\mu g/cm^2/yr$)	15.60	0.008	0.172	0.073	0.001	0.442
At Conservation Pool Elevation (5432 ft)						
Mass of Metal Released per Day (lb/day) = *vd.Ac.(c2-c1)*	5.44	0.0027	0.060	0.025	0.0005	0.154
At 9.3ft increase (5441.3 ft)						
Mass of Metal Released per Day (lb/day) = *vd.Ac.(c2-c1)*	7.13	0.0035	0.079	0.033	0.0006	0.202
At 12ft increase (5444 ft)						
Mass of Metal Released per Day (lb/day) = *vd.Ac.(c2-c1)*	7.65	0.0038	0.084	0.036	0.0007	0.217

2.4.2 *Metals Source Comparison and Concentration Estimation*

Watershed loads for Cu, Hg, Pb, Cd, Se, and As were estimated from the observed 2004 metals data from Plum Creek and South Platte (Chatfield Watershed Report, 2004). Of the monthly data collected, no detectable levels of metals were observed for Plum Creek, however observed data from South Platte showed the presence of detectable levels of metals during certain sampling events.

A flow-weighted approach was used to estimate the loads from the watershed, since the regression between instantaneous load and flow did not show a good relationship for any of the metals. A flow-weighted concentration was computed for each observed value and the resulting concentration was multiplied by the average summer flow for 2004 to obtain a load. The relative contributions of the watershed loads, along with the internal loads for the two with-project pool level scenarios, are shown in Table 2-13.

Table 2-13. Watershed and In-Reservoir Metal Loadings

Loading Condition	Cu (lb/day)	Hg (lb/day)	Pb (lb/day)	Cd (lb/day)	Se (lb/day)	As (lb/day)
Watershed Loading	16.0	2.0	0.4	0.04	0.00	0.24
Internal Loading Normal Pool Elevation (5432 ft)	5.44	0.003	0.060	0.025	0.000	0.154
Internal Loading After 9.3 ft increase (5441.3 ft)	7.13	0.0035	0.079	0.033	0.0006	0.202
Internal Loading After 12-ft increase (5444 ft)	7.65	0.0038	0.084	0.036	0.0007	0.217

A simple mass balance calculation was also made to provide a relative comparison between overall reservoir impact for the current and proposed with-project conditions. A gross average reservoir concentration was calculated based on only the watershed and internal sources. This gross concentration assumes a completely-mixed reservoir, at steady-state, even though the calculations focus on the critical summer period exhibiting stratification. These values should only be used for relative comparison purposes as they only represent the diffusive fluxes from the sediment and do not represent detailed processes, such as the pH condition, redox conditions, organic complexation, and complex metal speciation dynamics in the sediment.

To estimate the gross reservoir concentration, the following steady-state equation was used (Chapra 1997):

$$c = \frac{\sum W}{(Q + K_s \cdot V)} \qquad [18]$$

where:

c = steady state metal concentration

$\sum$ W = sum of all the loading into the system (sum of the estimated watershed load and the internal load), Q = outflow during the summer critical period. Data from 1942 to 2000 (provided by USACE) were used to estimate the outflow during the critical summer period (June, July and August). The outflow was computed to be 439 cfs and 434 cfs for the baseline and proposed conditions. Note the outflow decreases for the proposed conditions, which would mean less flushing.

K_s = overall loss rate of the metal

V = reservoir volume. A baseline volume of 27,428 ac-ft at an elevation of 5432 ft msl;, and proposed volumes of 48,066 ac-ft at an elevation of 5444 ft (12-ft increase from baseline) and 42,729 ac-ft at an elevation of 5441.3 ft msl (9.3 ft increase from baseline).

The resulting estimates of metals concentrations are shown in Table 2-14. In general, the increase in volume is expected to provide sufficient dilution to offset the decreased outflow and amount of increased loading from the newly inundated areas. This results in an estimated decrease in metals concentrations in the reservoir for the increase in pool elevations.

Table 2-14. Estimated Steady State Metals Concentrations.

Scenario	Cu	Hg	Pb	Cd	Se	As
Assessed Water Quality Standard (in µg/L) based on a hardness value of 111 mg/L (Chatfield Watershed Authority 2005).	15.3	1.4	75	4.96	18.4	50
Range of Observed Data (µg/L)	0–10	0–0.9	0–2	0–0.1	0	0–1.7
Estimated Concentration at Conservation Pool (µg/L)	6.75	0.63	0.15	0.022	0.0005	0.123
Estimated Concentration (9.3 ft increase in Pool) (µg/L)	6.42	0.55	0.14	0.021	0.0004	0.121
Estimated Concentration (12-ft increase in Pool) (µg/L)	6.29	0.53	0.13	0.021	0.0004	0.120

Table 2-14 shows the estimated steady-state metal concentrations. None of the metals exceeded the water quality standards in the baseline and proposed condition. Hg is estimated to have the greatest percent decrease followed by Pb, Cu, Se, Cd, and As. The small increase in loading is offset by the increase in volume and results in a decrease in steady-state metal concentrations in the proposed alternative. It should be noted that this analysis only considers the diffusive flux due to the observed concentration gradient between the water and the sediment. It is possible that the metal concentrations might be higher in the hypolimnion due to the increased seasonal stratification and changes in the site-specific chemistry due to the increase in volume (larger anaerobic hypolimnion) for the proposed condition, resulting in greater internal loading due to release of metals. Site-specific metal release rates or a more detailed model would be necessary to confirm this hypothesis. In addition, the partition coefficients used in the analysis are based on mean values from literature and are also subject to uncertainty. Literature shows a wide range in the partition coefficients for the metals (Allison, 2005). The partition coefficient of a metal has the effect of increasing or decreasing the pore-water concentration of the metal in the sediment (c_2) (equation [17]). Based on sensitivity analysis (increasing and decreasing the partition coefficient by 1 L/Kg), a lower partition coefficient value could result in higher dissolved metal concentration from the sediment and potentially result in an increase in the estimated concentration for some metals. This is mainly due to an increased internal loading that would be predicted due to the higher dissolved metal concentration from the sediment. However, sensitivity analysis of the partition coefficients showed that the water quality standard (based on the specified hardness of 111 mg/L) would not be exceeded in any of the scenarios.

2.5 Bacteria Assessment

The water quality workgroup for the Chatfield project noted that if increasing the water surface elevation in Chatfield Reservoir increased the littoral area of the reservoir, it could attract more birds (e.g., waterfowl, shorebirds) to the reservoir and its shoreline areas. Increased usage by birds would result in a net increase in bacteria loading. The primary concern with this potential increase in bacteria loading is that conditions at the Chatfield swim beach could be detrimentally affected. Conversely, if the proposed recreation modifications do not increase the littoral area of the reservoir near the swim beach, then more birds would not be expected in this area and impacts to bacteria would not be anticipated.

The Chatfield State Park routinely monitors the swimming beach for *E. coli* bacteria during the swimming season from Memorial Day weekend through Labor Day weekend. The maximum observed *E. coli* concentrations at the swim beach based on data from the 2004 and 2005 swimming seasons ranged from 14 to 446 counts/100mL (Table 2-15) (Colorado State Parks, 2006a).

Table 2-15. Monthly Maximum Observed *E-coli* concentration (2004 to 2005) from the North and South sampling locations at the Chatfield Swim Beach (Source: Colorado State Parks, 2006a).

Month	North Station (Counts/100 mL)	South Station (Count/100 mL)
May	164	70
June	104	168
July	446	394
August	106	194
September	52	14

Based on stream classification and water quality standards for the Upper South Platte River, an *E. coli* concentration of 126 counts/100mL and a fecal coliform concentration of 200 counts/100mL have been set as targets for Chatfield Reservoir. In general, all months except September had maximum *E. coli* concentrations greater than 126 counts/100mL.

Under the proposed condition, the swim beach and nearby areas would be modified as described in the FR/EIS Appendix M. To meet the goal of replacing affected facilities and use areas “in-kind”, the relocation plan is based on maintaining current walking distances at the swim beach. Under this conceptual design, the beach area would be graded to minimize the distance between swim beach facilities and the water’s edge at low water conditions. As a result, the configuration of the shoreline near the beach area and the overall dimensions of the swim beach would be similar to current conditions. Given this proposed modification to the swim beach, changes in *E. coli* concentrations are not expected under the proposed condition.

2.6 Assumptions and Limitations

The following section provides the major assumptions and limitations that were used in the analysis of the different constituents regarding potential water quality impacts to Chatfield Reservoir. These assumptions and limitations were considered and documented during model development as part of the process of evaluating the predicted water quality impacts under each alternative.

- The load quantification process and concentration predictions do not consider the complex interactions among evaluated parameters and those not explicitly considered. Even with this limitation, the model does a fair job in matching the volume-weighted observed data. This model, like any other simple model, cannot be used to predict short-term lake response to inputs, spatial patterns (e.g., localized response) in nutrient concentration, or dynamic response (e.g., changes over time) to changes in nutrient inputs.

- The HRT results are annualized and do not take into account the short term variations in HRT that can be expected due to changes in volume and outflow conditions.

- None of the analyses take into account transport.

- For this study, the watershed outflow/operations were assumed to remain the same for both the normal pool and increase in pool elevation condition.

- South Platte and Plum Creek, which are the dominant inflows to the reservoir, were assumed to contribute the entire watershed loading to the reservoir.

- The year 2012 exhibited an extended hypoxic period within the reservoir hypolimnion and was assumed to provide representative conditions for the reservoir. It was assumed that increasing the reservoir volume would lead to an increased hypolimnetic volume by the same amount (i.e., 12-ft and/or the mean monthly increase in elevation between the baseline and projected), and that the lake depth is sufficient for thermal stratification to be maintained throughout the summer. Note that the metals analysis uses an average increase based on a summer depth average of 9.3-ft, since the analysis was not done on a month by month basis.

- The hypoxycline elevation was used to delineate the anaerobic hypolimnion and was determined by using a cutoff value of ≤ 2.0 mg/L DO based on observed 2012 data at the Chatfield Reservoir dam location. The number of hypoxic 1-meter layers defined the extent of the anaerobic hypolimnion.

- In determining the sediment flux, the total organic carbon (TOC) was assumed to be 80 percent particulate and 20 percent fast reacting dissolved. Bottom TOC values were assumed to be reasonably estimated using a bottom to surface TOC ratio based on historical data.

- The nutrient mass balance assumes a steady-state, completely-mixed condition for representative loadings in the hypolimnion and epilimnion that would occur during the summer stratified period. This was done to estimate monthly concentrations based on the quantified sources for varying levels of hypolimnion.

- For the metals analysis diffusive fluxes were assumed to apply, and the flux rates were assumed to be same between the anaerobic and aerobic zones.

- Diffusive fluxes were computed to estimate the amount of metals contributed by the reservoir sediment. Changes in the aquatic conditions and exposing the anoxic sediment to an oxic environment can cause sulfide to be re-oxidized and metals to be released. These diffusive fluxes do not represent the processes such as the overlying pH conditions, redox conditions, organic complexation, bioturbidation and complex metal speciation dynamics in the sediment. In order to predict a more accurate metals flux, additional sediment core sampling is required.

- The phosphorus released from the anoxic bottom sediments will not be available to the photic zone (algal growth) until the bottom hypolimnetic water can be mixed through the water column. This is assumed to occur during fall turnover in late September. It is possible that some internal phosphorus load is also released starting in late-July as the thermocline moves deeper, but the simplistic modeling analysis does not allow for representing this phenomenon.

3. SOUTH PLATE RIVER DOWNSTREAM OF CHATFIELD RESERVOIR

Comments on the Draft FR/EIS, and subsequent discussions with the EPA, identified the possible reduction of flows in the South Platte River downstream of Chatfield Dam as a water quality concern. As indicated in Table 2-1, average annual outflow from Chatfield Dam over the 1942 to 2000 period would have been reduced by 4.4 percent under the proposed conditions for storage reallocation. As noted in the FR/EIS, the Chatfield storage reallocation project would not result in the direct discharge of pollutants to the South Platte River. The project will likely reduce flows somewhat in the river downstream of Chatfield Dam. The reduction of flows could reduce the available pollution assimilative capacity of the South Platte River. Water Quality, TMDLs, and permitted dischargers could be adversely impacted by a reduced assimilative capacity to dilute pollutants discharged to the river downstream of Chatfield Dam during critical low flow periods. If water quality impacts were to occur, TMDLs and water quality-based permits may need to be recalculated. This concern is further evaluated in the following section.

3.1 Background

3.1.1 Colorado Water Quality Standards

3.1.1.1 South Platte River Segment Delineation and Classification

Colorado's water quality standards currently delineate two segments on the South Platte River in the metro Denver area downstream of Chatfield Dam: 1) Segment 14, mainstem of South Platte River from the outlet of Chatfield Reservoir to the Burlington Ditch diversion in Denver, CO; and 2) Segment 15, mainstem of the South Platte River from the Burlington Ditch diversion in Denver, CO to a point immediately below the confluence with Big Dry Creek (Regulation #38 Stream Classifications and Water Quality Standards, CWQCC, 2013a) . Figure 3-1 shows the location of Segments 14 and 15 in the metro Denver area. Colorado's water quality standards designate the uses of Primary Contact Recreation, Water Supply, Aquatic Life Warm 1, and Agriculture to Segment 14; and the uses of Primary Contact Recreation, Water Supply, Aquatic Life Warm 2, and Agriculture to Segment 15. Pursuant to Colorado's antidegradation rule, Segment 14 is afforded an intermediate level of water quality protection (i.e. reviewable), and Segment 15 is afforded minimum protection (i.e. use protected).

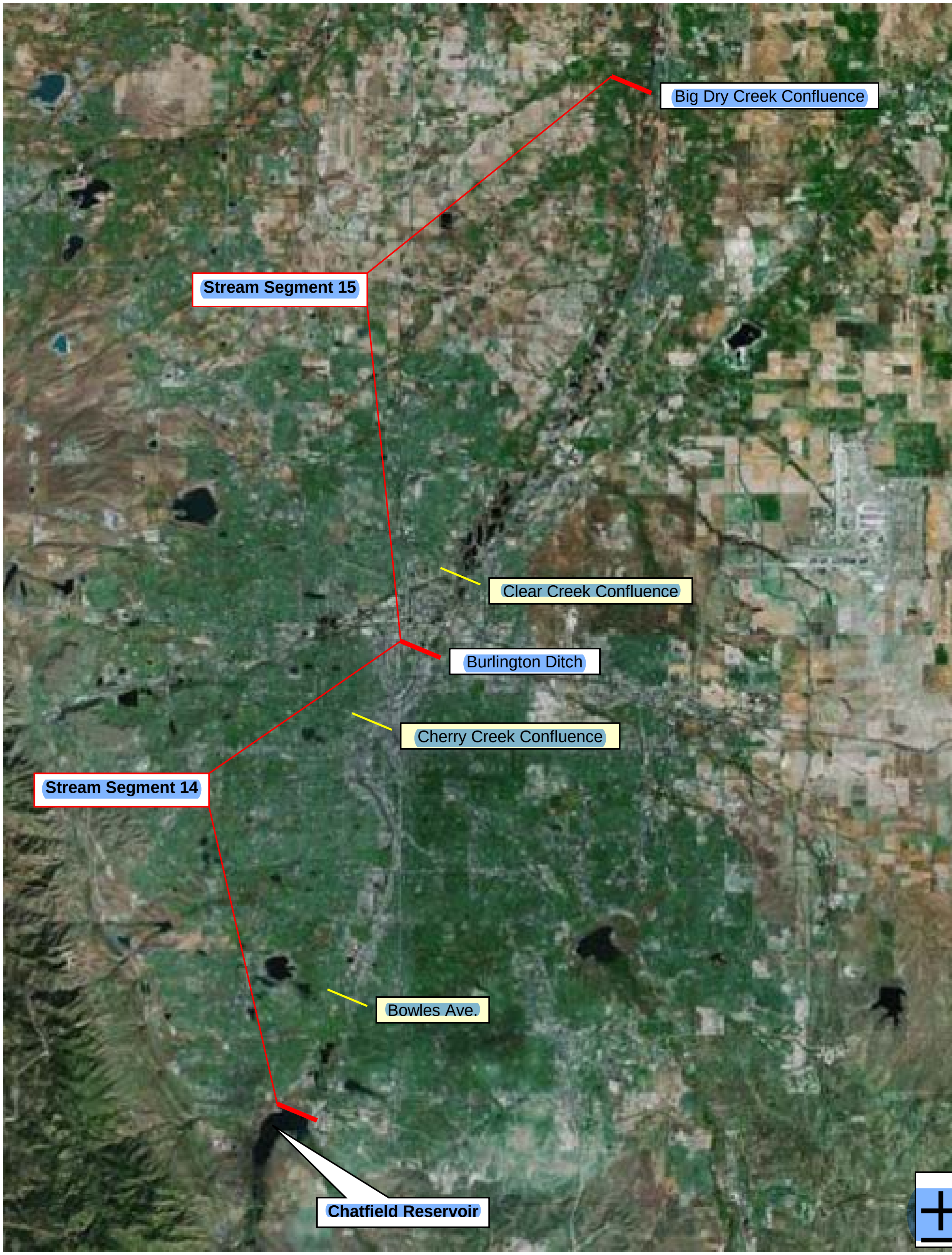


Figure 3-1. Locations of Delineated Stream Segments 14 and 15 of the South Platte River through the Metro Denver, CO area downstream of Chatfield Reservoir.

3.1.1.2 Flow Considerations

Colorado's water quality standards make exceptions regarding low flows and recognize the occurrence of effluent-dependent and effluent-dominated streams. Critical flows are used in the application of water quality standards regarding water quality-based permits and Total Maximum Daily Loads (TMDL).

3.1.2 Section 305(b) Water Quality Assessment and Section 303(d) Water Quality Impairment Listings

Table 3-1 provides the water quality assessment of Segments 14 and 15 as summarized in Colorado's 2012 Integrated Water Quality Monitoring and Assessment Report (CDPHE-WQCD, 2013). Both segments are identified as water quality impaired by Colorado's 2012 Section 303(d) list and given a high priority for the development of TMDLs (Regulation #93 – CWQCC, 2013b). Impaired waters refer to those waterbodies where it has been determined that technology-based effluent limitations required by Section 301 of the Federal Clean Water Act are not stringent enough to attain and maintain applicable water quality standards. Pursuant to Regulation #93, Stream Segment 14 is identified as impaired due to arsenic, and Segment 15 is identified as impaired due to *E. coli*.

Table 3-1. Water Quality Assessment of Delineated Stream Segments 14 and 15 on the South Platte River pursuant to the 2012 Colorado Integrated Water Quality Monitoring and Assessment Report.

ID 305(b)	Assessment Unit Name	Total Size (miles)	Designated Use Support	Causes	Sources	Integrated Report Category
COSPUS14_00	Mainstem of South Platte River	5.5	NS - P.C. Recreation NS - Aq. Life Warm 1 NS - Water Supply FS - Agriculture	Arsenic, *E. coli*	Unknown	5
COSPUS14_0500	South Platte River Bowles Ave. to Cherry Creek confluence	12.1	NS - P.C. Recreation NS - Aq. Life Warm 1 NS - Water Supply FS - Agriculture	Arsenic, *E. coli*	Unknown	5
COSPUS14_0600	South Platte River Cherry Creek confluence to the Burlington Ditch	3.63	NS - P.C. Recreation NS - Aq. Life Warm 1 NS - Water Supply FS - Agriculture	Arsenic, *E. coli*	Unknown	5
COSPUS15_0600	South Platte River Burlington Ditch to Clear Creek	3.7	NS - P.C. Recreation NS - Aq. Life Warm 2 FS - Water Supply FS - Agriculture	Ammonia, Cadmium, Nitrate/Nitrite, *E. Coli*	Contaminated Groundwater, Unknown	5
COSPUS_601	South Platte River Clear Creek to Big Dry Creek	23.2	NS - P.C. Recreation NS - Aq. Life Warm 2 FS - Water Supply FS - Agriculture	Ammonia, Cadmium, Nitrate/Nitrite, *E. Coli*	Contaminated Groundwater, Unknown	5

Legend: FS = Full Supporting, NS = Not Supporting.

3.1.3 *Total Maximum Daily Loads (TMDL) Developed for the South Platte River Immediately Downstream of Chatfield Reservoir.*

Tribes and States, as appropriate, are required to establish and implement TMDLs for waterbodies on their Section 303(d) lists. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards. For a water quality-limited segment that requires a TMDL, the State must quantify the pollutant sources and allocate allowable loads to contributing sources, both point and nonpoint, so that water quality standards can be attained for that segment. TMDL development is a rational method for weighing the competing pollution interests and developing an integrated pollution reduction strategy for point and nonpoint sources. TMDL development in Colorado includes five basic steps:

1) select the pollutant to consider;

2) estimate the waterbody assimilative capacity;

3) identify the contribution of that pollutant from all significant sources;

4) analyze information to determine the total allowable pollutant load; and

5) allocate (with a margin of safety), the allowable pollution among the sources so that water quality standards can be achieved.

A total of five TMDLs have been developed by the State of Colorado for Segments 14 and 15 of the South Platte River downstream of Chatfield Reservoir. TMDLs for *E.* coli and nitrate (NO_3^-) have been developed for Segment 14. TMDLs for dissolved oxygen and cadmium have been developed for Segment 15. An earlier TMDL for cadmium on Segment 15 was later revised. Table 3-2 summarizes the TMDLs developed for Segments 14 and 15 of the South Platte River.

3.1.3.1 E. coli TMDL – South Platte River Segment 14

The *E. coli* TMDL for Segment 14 of the South Platte River was approved by EPA Region 8 in October, 2007 (CDPHE, 2007). Segment 14 had been on the State of Colorado's 303(d) list of impaired waters since 1998 for fecal coliform and/or *E. coli*. Segment 14 is still identified on the 2012 303(d) list as impaired due to *E. coli*. *E. coli* are indicators of the possible presence of pathogenic organisms that may cause illness in those who come in contact with or ingest contaminated waters. The organismal contributions of *E. coli* in segment 14 are presently unconfirmed, i.e. wildlife, human, or domestic animal sources. However, more is known about how *E. coli* is conveyed to the South Platte River. Significant contributions of *E. coli* are conveyed to segment 14 through urban stormwater collection systems during storm events and dry weather conditions. Sanitary sewer seepage, cross connections, wildlife, and pets are all known sources of *E. coli* to storm sewer systems and expected contributors to segment 14 (CDPHE, 2007).

E. coli levels are measured as a density-based unit, i.e. a number of bacteria colony forming units ("cfu") per 100 milliliters ("ml") of water. *E. coli* sources are not additive due to death, reproduction, and diurnal fluctuations. Also, South Platte River flows in segment 14 fluctuate on a non-seasonal basis due to intensive water management. Therefore, the CDPHE-WQCD adopted a density based approach for this TMDL assessment, which allocates pollutant loads to sources based upon the *E. coli* water quality standard (CDPHE, 2007). As such, critical flows are not used to address *E. coli* contamination; instead the approach of the TMDL is to manage *E. coli* contamination by controlling it at its source.

Table 3-2. Summary of Total Maximum Daily Loads (TMDLs) that have been Developed by the State of Colorado for the South Platte River Downstream of Chatfield Reservoir in the Metro Denver area.

Segment	Pollutant/Condition Addressed	Water Quality Target	TMDL Goal
Segment 14: Mainstem of South Platte River from Bowles Avenue to Burlington Ditch Headgate	*E. coli* (protection of recreational uses)	Attainment of *E. coli* standard throughout segment	Protection of public health and recreational uses
	Nitrate (NO_3^-) (protection of water supply use)	Assure the nitrate concentrations at the points of attainment do not exceed 10 mg/L through implementation of controls on various nitrogen constituents	Attain Colorado water quality nitrate standards at the Allen Diversion and the Burlington Ditch Headgate points of attainment
Segment 15: Mainstem of South Platte River from the Burlington Ditch Headgate to the confluence with Big Dry Creek.	Dissolved Oxygen (protection of aquatic life)	Increase concentrations of dissolved oxygen in the stream through a combination of pollutant controls (primarily on ammonia discharge) and localized, physical improvements in the river channel	Achieve compliance with the Segment 15 dissolved oxygen standards
Segment 15: South Platte River between Burlington Ditch and Metro Wastewater Reclamation District discharge	Cadmium *(Revised and replaced by a new TMDL)*	Attainment of assigned numeric water quality standards for cadmium with the affected reach of Segment 15	Attainment of assigned aquatic life use designation
Segment 15: South Platte River between Burlington Ditch and the confluence with Clear Creek	Cadmium *(Replaced earlier TMDL)*	Chronic TVS = $[1.101672\text{-}(\ln(\text{hardness})\times(0.41838))*^{0.7998(\ln(\text{hardness}))-4.4451}]$ Acute TVS = $[1.136672\text{-}(\ln(\text{hardness})\times(0.41838))*^{0.9151(\ln(\text{hardness}))-3.1485}]$	Attainment of the assigned aquatic life use designation

3.1.3.2 Nitrate TMDL – South Platte River Segment 14

The nitrate TMDL for Segment 14 of the South Platte River was approved by EPA Region 8 in June, 2004 (CDPHE, 2004). Segment 14 of the South Platte River was identified as water-quality limited for nitrate based on predictive modeling. Low-flow modeling indicated that municipal wastewater treatment facilities are the primary point-source dischargers of nitrate to Segment 14. This TMDL derived wasteload allocations for nitrogen series pollutants that would ensure attainment of Colorado water quality standards for nitrate at the Allen Diversion and Burlington Ditch Headgate. Stormwater runoff from nonpoint sources does not contribute significantly to the nitrate impairment. Some localized groundwater may be affecting the overall water quality in the South Platte River. Water quality monitoring is necessary to verify that the TMDL requirements result in attainment of the standards. It is recommended that the TMDL should be reviewed when municipal dischargers propose plant expansions beyond the conditions utilized in the modeling effort, new wastewater treatment plants are proposed on the South Platte or its tributaries, or when assumptions included in the TMDL assessment are shown to be no longer appropriate (CDPHE, 2004).

Nitrate is a constituent of concern in the South Platte Urban Watershed. At low-flow conditions the concentrations of nitrate at the Burlington Ditch Headgate have exceeded the water quality standard. Predictive modeling identified nitrate standard exceedances at the Burlington Ditch Headgate under some low flow and high wastewater treatment plant ("WWTP") discharge scenarios. During high flow and even moderate flows, monitoring and modeling have shown that nitrate concentrations in the river are well below the nitrate standard; this includes both storm events and higher flows due to releases from the upstream reservoirs. During low flows, the nonpoint sources, groundwater seepage, and other ungaged water sources are not major contributors to the nitrate loading in this segment, but are significant in the dilution of nitrate from point-sources and must be considered in the low-flow modeling CDPHE, 2004).

The CDPHE-WQCD conducted low-flow modeling of the South Platte River to facilitate development of the Nitrate TMDL (CDPHE, 2003). Estimation of nitrate concentrations in Segment 14 under acute conditions required the determination of critical low flows (1E3) in the South Platte mainstem along the entire length of Segment 14 (CDPHE, 2003). Chronic low flows were not applicable to the nitrate standard. The acute low flows for the South Platte mainstem (1E3 values) were determined according to the policy for low-flow analysis that was adopted during early 2001 by the CDPHE-WQCD (see Section 3.1.1.2.1). The 10-year period 1-Oct-1999 through 30-Sep-2000 and DFLOW4 algorithm were used for the modeling. The low-flow analysis for acute conditions was developed at five key sites on Segment 14: South Platte River below Chatfield, South Platte River above Centennial effluent discharge, South Platte River above the Littleton/Englewood effluent discharge, South Platte River above the Xcel-Arapahoe power plant discharge, and South Platte River above the Xcel-Zuni power plant discharge (Table 3-3). For each of these sites, the monthly acute DFLOW values were obtained for the period 1-Oct-1990 to 30-Sep-2000 (water years 1991-2000) (CDPHE, 2003). The DFLOW algorithm calculates chronic low flows based on forward averaging (i.e., the flow for the nominal date plus 29 daily flows forward from the nominal date of the average). As a result, it is possible by use of this algorithm to obtain for any given month a chronic low flow that is lower than the acute low flow. For this reason, chronic low flows for all months were calculated for the five key sites mentioned above and, in cases where the chronic low flow was lower than the acute low flow, the chronic low flow was used as the acute low flow (CDPHE, 2003). Figure 3-2 shows the locations of the five key sites that low flow was calculated for the Nitrate TMDL on Segment 14 of the South Platte River.

Table 3-3. Acute (1-day) Low Flows (cfs) for the 10-year Period 1-Oct-1999 through 30-Sep-2000 for Selected Locations on Segment 14 of the South Platte River *(from CDPHE, 2003).*

Location	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Below Chatfield	0.2	0.3	0.4	0.7	5.3	2.0	0.2	0.6	0.2	0.1	0.1	0.2
Above Centennial	1.8	0.8	1.6	4.2	14.5	9.3	10.0	7.3	2.9	3.8	1.7	1.9
Above L/E Discharge	26.0	27.0	25.0	28.0	60.0	58.0	30.0	33.0	20.0	27.0	31.0	39.0
Above Xcel Arapahoe Discharge	59.0	60.0	64.0	59.0	95.0	102.0	67.0	71.0	55.3	63.0	67.0	74.0
Above Xcel Zuni Discharge	62.0	63.0	65.0	61.2	97.0	106.0	71.0	76.0	61.2	67.0	69.0	76.0

Figure 3-2. Locations of the Five Key Sites where Low-Flows were Calculated on the South Platte River for Development of the Nitrate TMDL on Segment 14 of the South Platte River.

3.1.3.3 Dissolved Oxygen TMDL – South Platte River Segment 15

The Dissolved Oxygen (DO) TMDL for Segment 15 of the South Platte River was approved by EPA Region 8 in July, 2000 (CDPHE, 2000). To assure meeting DO standards for Segment 15, the TMDL establishes requirements for ammonia discharge permit limits and requirements for physical improvements in the river channel. Implementation of these requirements will be through discharge permits for point source discharges. Non-point sources and stormwater discharges are not significant contributors to DO suppression and are not regulated under this TMDL. Because the size of discharges is expected to change in the future and because of potential changes in the river, continued monitoring is needed. It is recommended that the TMDL be reviewed at least every 5 years and revised when appropriate.

Based on field monitoring and modeling, Segment 15 of the South Platte River was identified on the Colorado's 1998 303(d) list as partially impaired for DO (CDPHE, 2000). However, more recent monitoring data suggested that Segment 15 complied with the aquatic life standard for DO, and the long-term monitoring record showed substantially improved DO conditions before the TMDL was implemented (CDPHE, 2000). Even though monitoring of Segment 15 showed compliance with DO standards, modeling showed that the segment would not be in compliance if all the point sources were running at capacity and all contained total ammonia matching permit limits (CDPHE, 2000). Thus, the DO TMDL was developed for Segment 15.

The flow in Segment 15 is largely controlled for agricultural and municipal uses of water. During the winter months, the entire upstream flow of the South Platte River is often diverted at the Burlington headgate for agricultural uses in Adams and Weld counties (CDPHE, 2000). At such times, over 90% of the flow in the river comes from wastewater treatment plant discharges, groundwater seepage, and very small ungaged tributaries (CDPHE, 2000). Over the next 50 years, much of the land along the downstream section of Segment 15 is expected to urbanize, and the flow regime in the river is also likely to change as agricultural uses of water are converted to municipal use (CDPPHE, 2000). There is potential for increased discharges of effluent to Segment 15 and potential for smaller volumes of water to be carried through Segment 15. Over time, these changes could affect DO in the segment, but the nature of the changes is difficult to predict.

The development of the DO TMDL for Segment 15 was facilitated by application of a water quality model by the CDPHE. Because the lowest concentrations of DO occur at low river flows, the model was used to represent low flow conditions (CDPHE, 2000). A DFLOW analysis was conducted for both acute and chronic low flows.

3.1.3.4 Cadmium TMDL – South Platte River Segment 15

A Cadmium TMDL for Segment 15 of the South Platte River was first approved by EPA Region 8 in September 2006 (CDPHE, 2006). The affected, upper portion of Segment 15 remained off Colorado's 303(d) list in 2006 and 2008; however, due to changes in water quality standards that were incorporated in the South Platte Basin in 2009, Segment 15 was again included on Colorado's 2010 303(d) list for exceeding aquatic life use-based chronic cadmium standard. A revised Cadmium TMDL was developed for Segment 15 and approved by EPA Region 8 in July, 2011 (CDPHE, 2011).

Aquatic life use-based water quality standards for cadmium are not attained in the portion of the South Platte River Segment 15 between the Burlington Ditch headgate and the confluence with Clear Creek (CDPHE, 2011). Surface and ground water data in this area indicate that groundwater plumes originating under or near the Globeville ASARCO Facility are the primary source of cadmium loading (CDPHE, 2011). Upstream cadmium concentrations and point source discharges do not cause or contribute significantly to the cadmium impairment (CDPHE, 2006). Remediation at the Globeville site is addressed in a Stipulated Agreement between ASARCO and the State of Colorado (CDPHE, 2011).

The revised Cadmium TMDL included an updated hydrological analysis of Segment 15. The following summarizes that analysis as documented in the revised Cadmium TMDL (CDPHE, 2011). The USGS operates a gaging station located on the South Platte River at 64th Avenue (Commerce City, USGS gage no. 06714215). Critical chronic (30E3) and acute (1E3) low flows were calculated at this site for the period 1997 through 2007 (Table 3-4). Much of the flow above Segment 15 is diverted at the Burlington Ditch. Seepage rates were estimated for the reach of the South Platte River between the USGS gages at Commerce City and Henderson (06720500) (Table 3-5).

Table 3-4. Chronic and Acute Low Flows (cfs) Determined for the South Platte River at USGS Station 06714215 over the Period 1997 through 2007 *(from CDPHE, 2011).*

Critical Low Flow	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
30E3	6.0	6.0	6.4	7.7	16.0	16.0	13.0	13.0	9.0	8.0	6.0	6.0
1E3	5.1	5.1	4.1	4.1	7.1	11.0	9.1	8.1	6.1	5.1	5.1	5.1

Table 3-5. Estimated monthly seepage rates (cfs per mile) for the South Platte River between Commerce City and Henderson, Colorado *(from CDPHE, 2011).*

Seepage Rate	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S. Platte River above Henderson	2.9	2.8	2.3	4.1	3.7	3.2	2.5	1.8	3.4	4.1	4.0	3.7

3.1.4 Technical Approach

Flows in the South Platte River downstream of Chatfield Reservoir are extensively impacted by diversions for water supply use (agriculture and public drinking water) and discharges from municipal and industrial facilities (wastewater treatment plants and power plants). A generalized schematic of the South Platte River diversions and discharges in the Metro Denver area is shown in Attachment 2.

It is important to note that the proposed Chatfield Reservoir reallocation will not directly introduce pollutants into the South Platte River downstream of Chatfield Dam. Ambient loadings of water quality constituents, some considered pollutants, flowing into Chatfield Reservoir will be passed through the reservoir and released to the South Platte River downstream of Chatfield Dam. If flow releases from Chatfield Dam are reduced with storage reallocation, ambient loadings of water quality constituents passed through Chatfield Dam to the start of Segment 14 could also be reduced. However, a reduction in the flow released to the South Platte River could also reduce the assimilative capacity of the river; especially if the reduced releases are a "higher quality" water than present further downstream in the river.

To assess the potential water quality impacts of reduced releases from Chatfield Reservoir that could possibly result from storage reallocation, the impact to critical low flows in the South Platte River was assessed. A significant reduction in the critical low flows of the South Platte River downstream of Chatfield Reservoir could reduce the assimilative capacity of Segments 14 and 15. If the assimilative capacity of the South Platte River were to decrease and pollutant loadings remained the same, pollutant concentrations in the river would increase. Assimilative capacity is accounted for in the development of TMDLs and any associated water quality-based discharge permit limits. The TMDL for *E. coli* for Segment 14 is density based and not dependent on flow conditions in the South Platte River. All of the other TMDLs (i.e. nitrate, DO, and cadmium) applicable to Segments 14 and 15 are based on meeting the appropriate water quality standards during critical low flow periods. Of these, the Nitrate TMDL for Segment 14 was deemed most sensitive to possible changes in critical low flows in the South Platte River downstream of Chatfield Reservoir. Possible water quality impacts to the South Platte River from storage reallocation were assessed by comparing existing and estimated "with-project" critical low flows conditions in the river immediately downstream Chatfield Dam. The water quality implications from any reduction in critical flows would then be assessed. It is noted that possible flow reductions in the South Platte River immediately downstream of Chatfield Dam from storage reallocation would not directly result in the discharge of pollutants to the river, and a possible reduction of the river's assimilative capacity is not regulated by Colorado's water quality standards.

3.2 Chatfield Dam Releases

3.2.1 Current Releases

Water released from Chatfield Dam can be routed in five directions: 1) diverted to the Last Chance Ditch, 2) diverted to the Nevada Ditch, 3) diverted to the City Ditch, 4) diverted to the Fish Hatchery, or 5) discharged to the South Platte River (Attachment 2). Figure 3-3 plots estimated 2012 mean daily total flow released from Chatfield Reservoir and the 2012 mean daily flow recorded at the Colorado Division of Water Resources PLACHACO gage on the South Platte River immediately downstream of Chatfield Dam (see Figure 3-5 for location of the PLACHACO gage). The difference in the two plots is taken to be the amount of the Chatfield Dam release that is diverted away from the South Platte River for off-stream use. The amount of water that is available for pollutant assimilation (i.e. assimilative capacity) in the South Platte River immediately downstream of Chatfield Dam is highly dependent upon the amount of water diverted away from the river at Chatfield Dam.

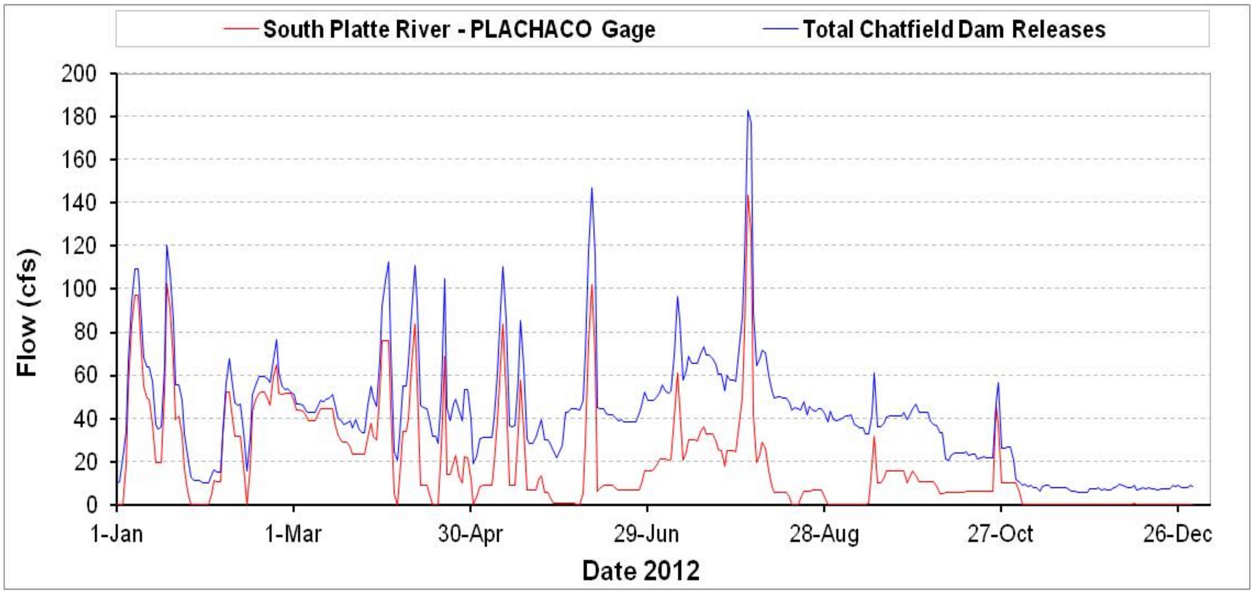


Figure 3-3. 2012 Mean Daily Releases from Chatfield Reservoir and Mean Daily Flows Measured in the South Platte River.

3.2.2 Estimated Chatfield Dam Releases with Chatfield Reservoir Storage Reallocation

Chapter 4 of the FR/EIS discusses the impacts of implementing the reallocation alternatives on the hydrological conditions on the South Platte River downstream of Chatfield Reservoir. As discussed in Chapter 4, the mean annual outflow from the reservoir into the South Platte River under Alternative 3 would range from 54.2 to 759.3 cfs. Of the alternatives, mean annual outflows into the South Platte River would be smallest under this alternative because more water would be maintained in the conservation pool to reach the targeted 5,444 feet msl pool elevation. The reduced flows in the South Platte River would be most noticeable in the months of May and June when incoming runoff is retained to fill the reservoir. Figure 3-4 (Figure 4-6 of Chapter 4 of the FR/EIS) shows the estimated mean annual outflows for each of the reallocation alternatives. As seen in Figure 3-4, Alternative 3 results in reduced lower quartile values in Feb, Mar, Apr, May, Jun, Nov, and Dec as compared to Alternatives 1 & 2. Minimum values indicate similar low releases for all alternatives.

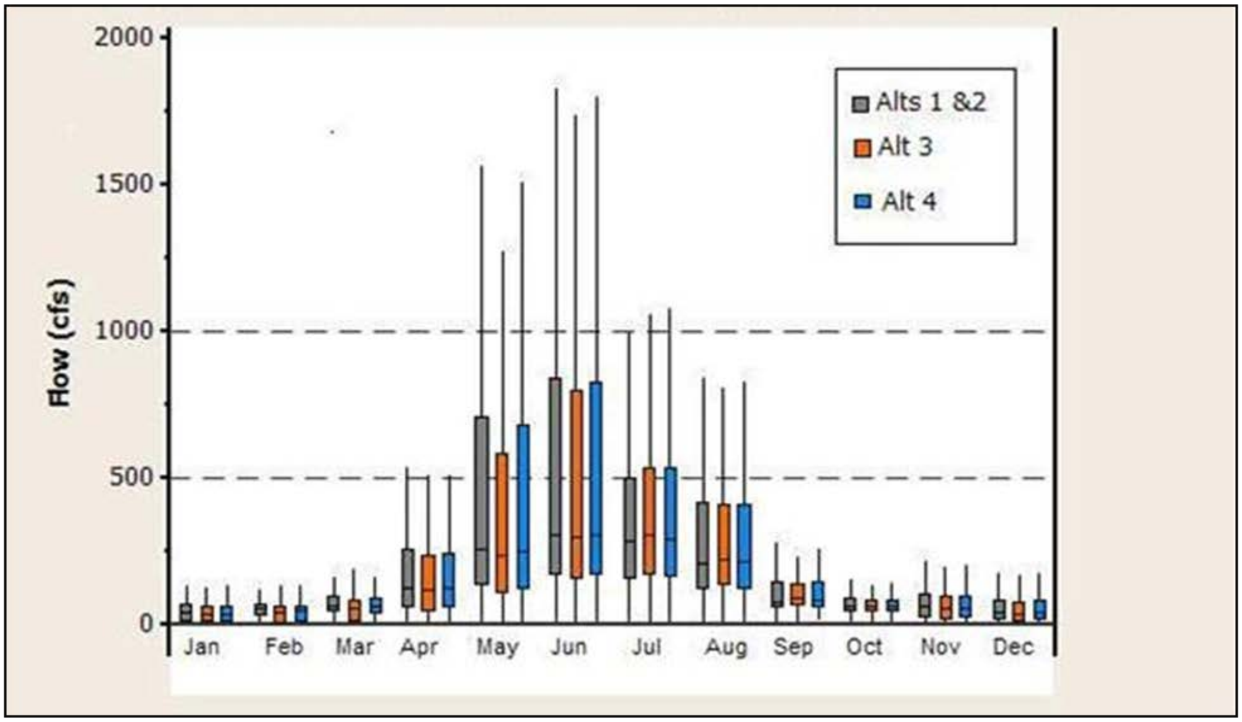


Figure 3-4. Comparison of Monthly Estimated Outflows for the Reallocation Alternatives (copy of Figure 4-6 of Chapter 4 of the FR/EIS).

3.3 Water Quality Critical Low Flow for the South Platte River Immediately Downstream of Chatfield Reservoir

3.3.1 Existing Critical Low Flows for Water Quality Management

The existing critical low flows for water quality management of the South Platte River immediately downstream from Chatfield Reservoir are taken to be the monthly acute low flows identified by modeling for the "Below Chatfield" site as part of the Nitrate TMDL developed for Segment 14 (Table 3-3).

3.3.2 Analysis of Chatfield Storage Reallocation Impact on Water Quality Critical Low Flows

The water quality critical low flows in the South Platte River immediately downstream of Chatfield Dam were computed using the DFLOW model and represent the minimum daily low flow that occurs on average once every three years and was based on the 10-year period of record from 1 October 1990 through 30 September 2000 (Table 3-3, "Below Chatfield" location). In order to determine the impacts of the storage reallocation on low flows downstream of Chatfield Dam, the modeled daily Chatfield releases from the HEC5 model for baseline and with-project conditions for the same period of record were used. Since the modeled Chatfield releases for baseline and with-project conditions include the diversions from the Chatfield outlet works, the historic diversions were estimated by subtracting the gaged flows at the PLACHACO gage from the total Chatfield Dam discharge recorded by the USACE. After the diversions were calculated, the 3-day average was computed and any negative values were set to zero. Next, the 3-day average outflows from the HEC5 simulation of baseline and with-project conditions were computed. The diversions were subtracted from the baseline and with-project flows and compared to the critical low flows shown in Table 3-3 for "Below Chatfield". During the 10-year period 1991 through 2000, there were 43 days that baseline flows were less than the identified critical low flow, an average of 4.3 days per year. For the with-project conditions, there were 210 days that flows were less than the critical low flows or an average of 21 days per year. Table 3-6 compares the monthly occurrence of flows below the identified critical low flows under baseline and with-project conditions. It should be noted that the HEC5 model was not configured to meet targeted low-flow requirements downstream from Chatfield Dam so during periods when there are no downstream demands and storage is available, the model can simulate zero releases. This occurs primarily in the winter months or early spring. Under baseline conditions, it would have required additional releases of an average 0.6 acre-feet per year for flows to equal or exceed the critical low flow, while for with-project conditions it would have taken additional releases of an average 19.6 acre-feet per year.

Table 3-6. Monthly Occurrence of Days below Water Quality Critical Low Flows in the South Platte River immediately downstream of Chatfield Dam during the 10-Year Period 1991 through 2000 under Baseline and With-Project (Alternative 3) Conditions..

Condition	Number of Days by Month												Total Days
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baseline	11	11	4	0	0	0	0	1	3	0	1	12	43
With-Project	32	42	64	38	5	2	1	2	6	0	11	7	210

3.3.3 Spatial Occurrence of Water Quality Critical Low Flows Immediately Downstream of Chatfield Reservoir

Figure 3-5 shows an aerial view of the region immediately downstream of Chatfield Dam and the locations of the "Below Chatfield" (PLACHACO gage) and "Above Centennial" locations where critical low flows were modeled for the Nitrate TMDL. The distance along the South Platte River from the Chatfield Dam outlet to the confluence of the Centennial WWTF discharge is approximately 1.2 miles (Figure 3-5). Table 3-7 gives the calculated critical low flows for the "Below Chatfield" and "Above Centennial" sites and the percent gain in the calculated critical low flow between the two sites. It is noted that the discharge from the CDOW's fish hatchery enters the South Platte River upstream of the "Above Centennial" site.

Table 3-7. Comparison of Water Quality Critical Low Flows Calculated at the Below Chatfield and Above Centennial Sites on the South Platte River.

Location	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Chatfield	0.2	0.3	0.4	0.7	5.3	2.0	0.2	0.6	0.2	0.1	0.1	0.2
Above Centennial	1.8	0.8	1.6	4.2	14.5	9.3	10.0	7.3	2.9	3.8	1.7	1.9
Percent Increase	800%	167%	300%	500%	174%	365%	4900%	1117%	1350%	3700%	1600%	850%

Figure 3-5. Locations of Water Quality Critical Low Flow Measurement Sites, Centennial WWTF, and Centennial WWTF Discharge Confluence with the South Platte River in the Area Immediately Downstream of Chatfield Reservoir.

3.4 Summary of Potential Downstream Water Quality Impacts to the South Platte River

The proposed Chatfield storage reallocation could potentially reduce critical low flows in the South Platte River immediately downstream of Chatfield Dam by storing an average of 19 acre-feet of water annually instead of releasing the water to the river during critical low flow periods. It may be possible to adjust the timing of Chatfield Dam releases in order to meet the currently identified critical low flows in the South Platte River immediately downstream of Chatfield Dam. Only about 1-mile of the South Platte River immediately downstream of the Chatfield Dam outlet would seemingly be impacted. Discharges from the CDOW's fish hatchery and the Centennial WWTF would "overwhelm" the possible with-project reductions in low flows.

As noted in the developed TMDLs, extensive land use changes are occurring along the South Platte River in the Metro Denver area. With this, the existing flow regime of the South Platte River will be impacted as agricultural uses of water are converted to municipal use and discharges from WWTFs increase as new facilities are built and existing facilities are expanded. The existing TMDLs will need to be reviewed as the flow regime in the South Platte River changes and the river's assimilative capacity is impacted. It is difficult to determine if an average annual reduction of 19 acre-feet of discharge from Chatfield Dam during critical low flow periods will have a significant adverse impact to water quality in the South Platte River immediately downstream of Chatfield Dam. As indicated in Table 3-3, calculated critical low flows in the South Platte River quickly increase in a short distance downstream of Chatfield Dam.

4. SUMMARY

The potential water quality impacts to Chatfield Reservoir, Littleton, Colorado due to the proposed reallocation of flood control storage from 5432 ft msl to 5444 ft msl in the reservoir were evaluated using a number of spreadsheet-based mass balance techniques. Gross water quality impacts were assessed for nutrients, metals, and bacteria. The load quantification process and concentration predictions do not consider the complex interactions among evaluated parameters and those not explicitly considered. This limitation was considered during model development as part of the process of evaluating the predicted water quality impacts under each alternative.

Nutrient analysis was conducted using recent data collected in 2012 to address the uncertainty regarding possible increases in anaerobic and inundated vegetation total phosphorus fluxes and internal phosphorus loading. Chatfield Watershed Authority DO and temperature profile data collected in 2012 indicated that the reservoir was stratified most of the summer period from May to September. The hypoxic volume also varied over the period from May-September – slowly building up to a maximum in July, thereafter decreasing through September. This analysis assumed that increased depth under increased storage maintained summer thermal stratification and resulted in increased hypoxic volume in the hypolimnion that would increase internal phosphorus loading from bottom sediments.

The Chatfield reservoir total phosphorus water quality standard applies to upper mixed zone during the July-September period. The localized model included separate mass balances for the epilimnion and hypolimnion. Monthly total phosphorus loads and concentrations were calculated for the critical period from May to September. Nutrient loads for total phosphorus from the watershed, atmospheric deposition, inundated soil and vegetation and internal load were evaluated for baseline and a series of hypothetical reservoir pool increase scenarios. The calculations in the epilimnion took into account that the phosphorus released from anoxic bottom sediments will not influence mixed zone total phosphorus until destratification occurs during fall turnover starting around mid-September.

The scenarios evaluated using this methodology included –a typical condition which includes an increase in hypolimnetic volume based on monthly summer increase in elevation (estimated from the modeled baseline and the proposed increase water surface elevation data (USACE, 2006), and a maximum impact condition which includes a 12-ft increase in hypolimnetic elevation based on the proposed increase in pool. A complete list of scenarios can be found in Section 2 under Table 2-3. The 12-ft increase in anaerobic hypolimnetic elevation condition provides an upper bound for the concentrations that can be expected, while the typical scenario provides an average typical summer condition case based on proposed pool elevation conditions.

Sediment nutrient fluxes were estimated using a sediment flux model (SedFlux) developed by Di Toro (Chapra and Pelletier, 2003; Di Toro et al., 1991; Di Toro, 2001). Since the amount of increase in the hypolimnetic depth for the proposed conditions is unknown, for the internal load analysis it was assumed that increasing the reservoir volume would lead to an increased anaerobic hypolimnetic volume by the same amount (i.e., 12-ft and average monthly increase). This conservative assumption was made because the actual change in hypolimnetic elevation can only be rigorously evaluated with a hydrodynamic water quality model.

Increasing the hypolimnetic elevation resulted in an overall decrease in the total phosphorus concentrations for most summer months compared to the baseline in the epilimnion. This occurred due to an increase in volume due to the pool elevation increase, which resulted in increased dilution for summer months when the reservoir was stratified and the phosphorus released from the bottom sediments was not available to be mixed. However, high total phosphorus concentrations were estimated during fall turnover due to mixing from the internal phosphorus from the bottom sediments. In addition, short-term impacts due to inundated vegetation and soils were also considered which always showed high total phosphorus concentrations for all the proposed project scenarios.

The average total phosphorus concentrations for the critical summer period (July through September) indicated that it is likely that the reservoir would experience an increase in total phosphorus concentrations from the baseline to the maximum possible increase condition (Table 2-10). For the maximum condition case the estimated total phosphorus concentrations increased from 23 µg/L to 25 µg/L (baseline to maximum pool, respectively), whereas, for the average pool increase condition typical case the total phosphorus concentration was very similar 23 (22.9) µg/L to 23 (22.5) µg/L (baseline to average pool, respectively). Although the July to September average total phosphorus concentrations increased for the proposed pool scenarios they were still under the 30 µg/L water quality standard and did not exceed the 35 µg/L assessment criterion for attainment of the water quality standard. However, average predicted total phosphorus results for the short-term impacts due to vegetation and inundated soils were 57 µg/L and 48 µg/L for the maximum case and the typical case respectively, and both exceeded the total phosphorus water quality standard and assessment criterion. The effects of the short-term scenario are expected to subside over subsequent years after inundation.

The nutrient analysis showed that there is uncertainty in the data available and the models used. The applied "Chatfield-derived" loading models, provides further insight into the possible water quality impacts of the proposed project. The analysis indicates that although the proposed project may improve or reduce the total phosphorus concentrations in the reservoir, the increased internal phosphorus loading from the anaerobic hypolimnion after fall turnover can result in high total phosphorus concentrations. However, July-September average total phosphorus concentrations were always lower than the total phosphorus assessment criterion and water quality standard. The contribution of total phosphorus from inundated vegetation and soil also has an impact in the near-term resulting in an increased total phosphorus concentration, which exceeds the total phosphorus assessment criterion and water quality standard. However the effect of this is expected to decrease substantially with time after approximately one year when the trophic upsurge subsides.

Adaptive management could address this uncertainty should the proposed Chatfield Reallocation Project be implemented (see the Adaptive Management Plan, Appendix GG of the FR/EIS).

Metal loads for Cu, Pb Hg, Cd, Se and As from the watershed and internal load were also evaluated. Diffusive fluxes were computed to estimate the amount of metals contributed by the reservoir sediment to the water column. These diffusive fluxes do not represent all processes such as the overlying pH conditions, redox conditions, organic complexation, bioturbidation and complex metal speciation dynamics in the sediment. In order to predict a more accurate metals flux, additional flux measurements from sediment core sampling are required.

The metals steady-state analysis resulted in an estimated decrease in metals concentrations in the reservoir for the proposed pool condition. The increase in volume provides sufficient dilution to offset the decreased outflow and amount of increased loading from the newly inundated areas. The analysis showed that the estimated concentrations of Cu, Hg, Pb, Cd, Se and As decreased from the baseline condition to the 12-ft and 9.3 ft increase in pool depth conditions. For the proposed condition, Hg had the greatest reduction in concentration, followed by Pb, Cu, Se, Cd, and As (Table 2-14). It should be noted that there is a level of uncertainty associated with these predictions. The estimated concentrations are estimates based on diffusive fluxes and could change if additional sediment core sampling is performed to more precisely estimate the site-specific sediment metal fluxes. An additional area of uncertainty can possibly occur due to the wide range of partition coefficients observed in the literature. However, results indicate that in all scenarios the concentrations never exceeded the metals' standard and were within the range of observed data.

The potential for increased bird (e.g., waterfowl, shorebirds) populations in the vicinity of the swim beach was evaluated to assess potential impacts on bacteria concentrations. The analysis focused on the shallow volume of water near the swim beach. Impacts due to an increased hypolimnetic volume were assumed to be negligible. To meet the goal of replacing affected facilities and use areas "in-kind" under the proposed condition, the configuration of the shoreline near the beach area and the overall dimensions of the swim beach would be similar to current conditions. Given this proposed modification to the swim beach, changes in E. coli concentrations are not expected.

Regarding reservoir water quality, all the parameters of concern quality can potentially be enhanced for given loadings, by timely managing water in storage and flushing times through the reservoir (residence time).

The proposed Chatfield storage reallocation could potentially reduce critical low flows in the South Platte River immediately downstream of Chatfield Dam by storing 19 acre-feet of water annually instead of releasing the water to the river during critical low flow periods. It may be possible to adjust the timing of Chatfield Dam releases in order to meet the currently identified critical low flows in the South Platte River immediately downstream of Chatfield Dam.   Only about 1-mile of the South Platte River immediately downstream of the Chatfield Dam outlet would seemingly be impacted.

Adaptive management could be used to test reasonable changes in reservoir operations to mitigate any water quality concerns that may arise through the increased storage of water in Chatfield Reservoir. Water quality is an identified resource in the AMP.

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ATTACHMENT 1.

Colorado Division of Wildlife 2008 Study of Mercury Methylation at Chatfield Reservoir

Synopsis of Chatfield Reservoir Sampling in 2008

In 2008, we observed high proportions of methylmercury to total mercury (approximately 40 – 70%) in zooplankton in Chatfield Reservoir. We also observed hypoxic conditions at depth in Chatfield Reservoir from June to September during routine sampling in 2008 (see attached data). Sampling occurred every two weeks during the months of May through September in the Platt River channel (UTM ~494400, 4378000).

Potential mechanisms for elevated methylmercury proportions in biota:
Anoxic conditions have been associated with high concentrations of Hg in water, zooplankton and fish (Driscoll et al. 1994; Slotton et al. 1995). Mercury is methylated (becoming bioavailable) under anoxic conditions by sulfate-reducing and iron-reducing bacteria as a byproduct of their energy sequestration pathway (Compeau and Bartha 1985; Fleming et al. 2006). These conditions have been associated with newly constructed reservoirs (Bodaly et al. 1984; Bodaly and Fudge 1999) and those that experience water level fluctuation (St. Louis et al. 2004). For example, Bodaly et al. (1984), and Bodaly and Fudge (1999) found that expanding impoundments increased methylmercury in fish (finescale dace, northern pike and walleye) following inundation. Similarly, water level fluctuation has been associated with increased methylmercury in walleye (Selch et al. 2007), and yellow perch (Sorenson et al. 2005).

The creation or expansion of reservoirs introduces additional organic matter (from shoreline vegetation) available for decomposition, which can increase anoxic conditions conducive to Hg methylation by microbes (Bodaly et al. 1984). Additionally, it was suggested that water level fluctuation causes rewetting and perturbation of dry soils which are relatively rich in sulfate, and mobilizes particles rich in mercury, stimulating population growth of sulfate-reducing bacteria and methylation rates (Sorenson et al. 2005; Selch et al. 2007). Plourde et al. (1997) linked the mobilization of suspended particles rich in Hg to wave action that is accentuated by changes in water level. Kim et al. (2008) focused directly on physical processes influencing Hg bioaccumulation and concluded that sediment resuspension may be important for introducing Hg into the water column, resulting in elevated bioaccumulation of Hg in benthic and pelagic organisms in systems experiencing high levels of water fluctuation.

In Chatfield Reservoir, the hypoxic conditions that were observed in 2008 would suggest that rates of mercury methylation could be elevated, and this supposition was supported by the high ratio of methyl to total mercury in zooplankton samples. The literature described above suggests that these conditions (low dissolved oxygen at depth from June to September and relatively elevated ratios of methyl to total mercury in zooplankton) could be exacerbated by reservoir expansion and/or increased water level fluctuation.

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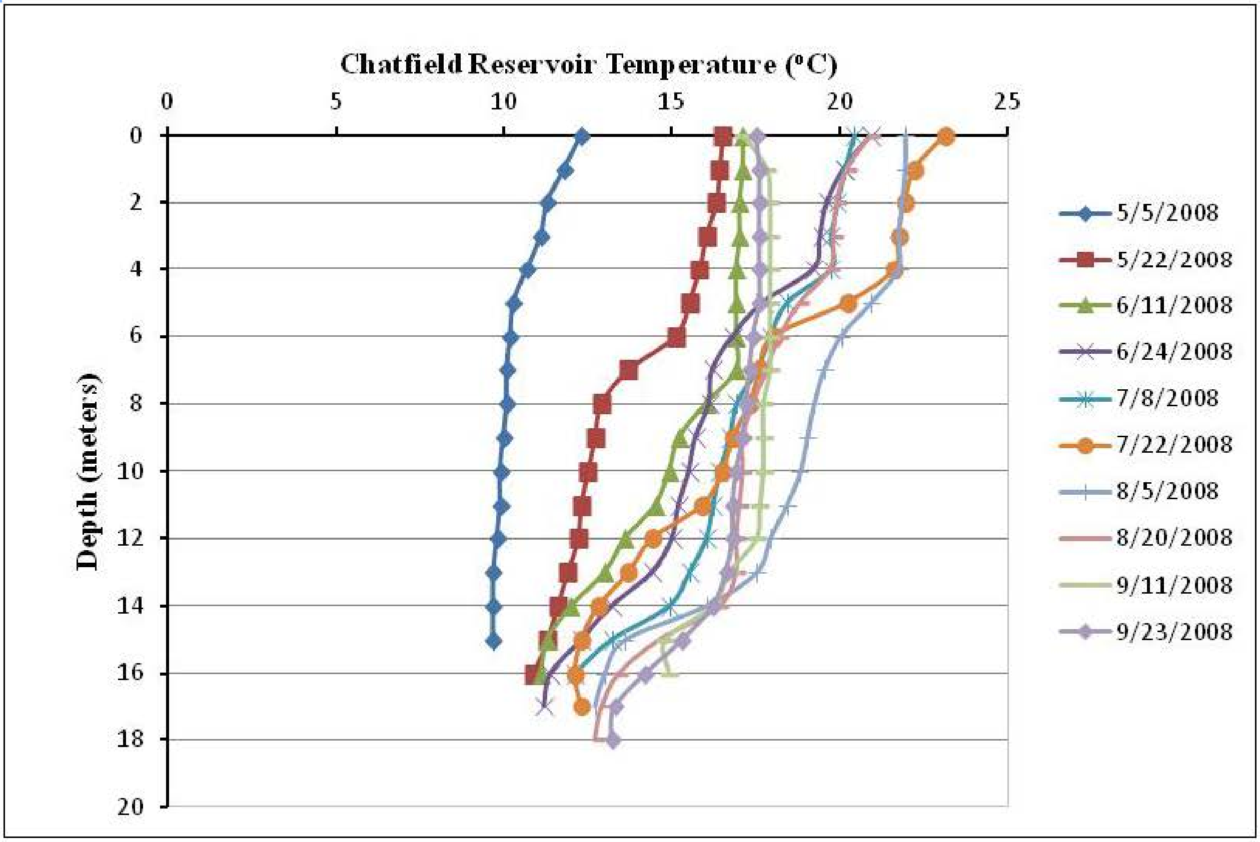
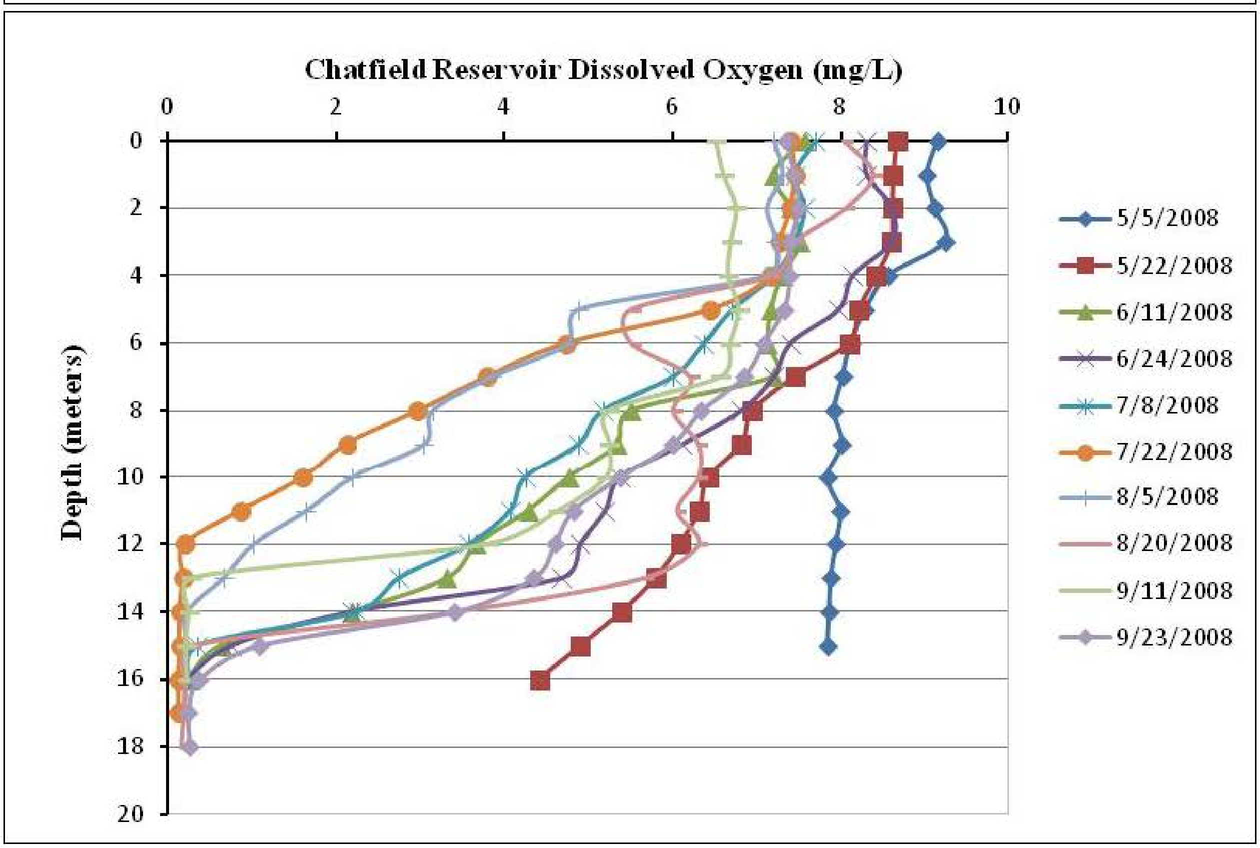

Chatfield Reservoir Temperature (°C)
0
5
10
15
20
25
Depth (meters)
0
2
4
6
8
10
12
14
16
18
20
5/5/2008
5/22/2008
6/11/2008
6/24/2008
7/8/2008
7/22/2008
8/5/2008
8/20/2008
9/11/2008
9/23/2008


Chatfield Reservoir Dissolved Oxygen (mg/L)
0
2
4
6
8
10
Depth (meters)
0
2
4
6
8
10
12
14
16
18
20
5/5/2008
5/22/2008
6/11/2008
6/24/2008
7/8/2008
7/22/2008
8/5/2008
8/20/2008
9/11/2008
9/23/2008

Chatfield Reservoir Temperature (°C)										
DEPTH (meters)	5/5/2008	5/22/2008	6/11/2008	6/24/2008	7/8/2008	7/22/2008	8/5/2008	8/20/2008	9/11/2008	9/23/2008
0	12.3	16.5	17.1	20.9	20.4	23.1	21.9	20.9	17.1	17.5
1	11.8	16.4	17.1	20.1	20.1	22.2	21.9	20.2	17.8	17.6
2	11.3	16.3	17	19.6	19.9	21.9	21.8	19.9	17.9	17.6
3	11.1	16	17	19.4	19.7	21.7	21.7	19.8	17.9	17.6
4	10.7	15.8	16.9	19.2	19.7	21.6	21.7	19.7	17.9	17.6
5	10.3	15.5	16.9	17.7	18.4	20.2	20.9	18.8	17.9	17.6
6	10.2	15.1	16.9	16.8	17.9	18	20	18.2	17.9	17.4
7	10.1	13.7	16.9	16.2	17.5	17.6	19.5	17.8	17.9	17.3
8	10.1	12.9	16	16.1	16.9	17.3	19.2	17.4	17.7	17.2
9	10	12.7	15.2	15.7	16.7	16.8	19	17.1	17.7	17.1
10	9.9	12.5	14.9	15.5	16.4	16.5	18.8	17.1	17.7	16.9
11	9.9	12.3	14.5	15.2	16.2	15.9	18.4	17	17.6	16.8
12	9.8	12.2	13.6	15	16	14.4	17.9	16.9	17.5	16.8
13	9.7	11.9	13	14.4	15.5	13.7	17.5	16.9	16.7	16.6
14	9.7	11.6	12	13.2	14.9	12.8	16	16.4	16.2	16.2
15	9.7	11.3	11.3	12.3	13.2	12.3	13.6	14.6	14.8	15.3
16		10.9	11.1	11.4	12.1	12.1	13	13.4	14.9	14.2
17				11.2		12.3	12.7	12.9		13.3
18								12.7		13.2

Chatfield Reservoir Dissolved Oxygen (mg/L)										
DEPTH (meters)	5/5/2008	5/22/2008	6/11/2008	6/24/2008	7/8/2008	7/22/2008	8/5/2008	8/20/2008	9/11/2008	9/23/2008
0	9.1	8.7	7.6	8.3	7.7	7.4	7.2	8.0	6.5	7.3
1	9.0	8.6	7.2	8.3	7.5	7.5	7.3	8.4	6.6	7.4
2	9.1	8.6	7.4	8.6	7.6	7.4	7.1	8.1	6.8	7.5
3	9.2	8.6	7.5	8.6	7.5	7.3	7.2	7.5	6.7	7.4
4	8.6	8.4	7.3	8.1	7.2	7.2	7.1	7.2	6.7	7.4
5	8.3	8.2	7.2	8.0	6.7	6.5	4.9	5.5	6.8	7.3
6	8.1	8.1	7.1	7.4	6.4	4.7	4.8	5.5	6.7	7.1
7	8.0	7.5	7.2	7.2	6.0	3.8	3.9	6.2	6.6	6.9
8	7.9	7.0	5.5	6.8	5.2	3.0	3.2	6.0	5.3	6.3
9	8.0	6.8	5.4	6.1	4.9	2.1	3.1	6.3	5.3	6.0
10	7.8	6.4	4.8	5.4	4.3	1.6	2.2	6.3	5.2	5.4
11	8.0	6.3	4.3	5.2	4.1	0.9	1.6	6.1	4.7	4.8
12	7.9	6.1	3.7	4.9	3.6	0.2	1.0	6.3	3.8	4.6
13	7.9	5.8	3.3	4.7	2.8	0.2	0.7	5.7	0.3	4.4
14	7.9	5.4	2.2	2.2	2.3	0.1	0.2	3.4	0.3	3.4
15	7.8	4.9	0.6	0.8	0.3	0.1	0.2	0.3	0.2	1.1
16		4.4	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.4
17				0.2		0.1	0.2	0.2		0.2
18								0.2		0.3

ATTACHMENT 2.

Metro Denver Area Water Diversion Schematic