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SOUTH PLATTE RIVER DIURNAL FLOW STUDY

DIURNAL FLOW MANAGEMENT OPTIONS IN THE SOUTH PLATTE RIVER FROM ROBERT W. HITE TREATMENT FACILITY DISCHARGE TO WESTERN MUTUAL DITCH

Prepared for:

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EXECUTIVE SUMMARY

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1.0 INTRODUCTION

On April 20, 2011, the City of Aurora, acting by and through its utility enterprise ("Aurora Water" or "Aurora"), the City of Thornton, and the Metro Wastewater Reclamation District ("Metro District") collectively referred to "Co-Applicants" filed an application with the District Court, Water Division No. 1, in Case No. 11CW74. The Co-Applicants in this case applied for the change of water rights to: 1) obtain approval of the relocation of the treatment and discharge of a portion of Thornton's effluent that is generated in Thornton and currently treated at the Metro District's Robert W. Hite Treatment Facility ("RWHTF" or "Hite Plant") to Metro District's proposed new Northern Treatment Plant ("NTP"), and 2) to obtain approval of a trade of effluent between Thornton and Aurora, referred to as the "Effluent Trade". During the course of negotiations to settle Case No. 11CW74, several Opposers to the application expressed concerns that the diurnal fluctuation of the South Platte River ("SPR") and the corresponding method of administration of water rights in Water District No. 2, caused a reduction in the amount of water delivered to various water rights located downstream of the effluent discharge point of the RWHTF. The diurnal fluctuation of the SPR downstream of RWHTF discharge is primarily due to the hourly variations in the plant's effluent discharge that largely mimic the typical fluctuating water use patterns of the municipalities it serves.

A stipulated settlement in this case was eventually achieved, which led to a Final Decree of the Court in Case No. 11CW74. As part of the stipulation between Co-Applicants and various Opposers, the Co-Applicants agreed to fund and oversee a study (not to exceed $100,000) of the diurnal flows discharged from the RWHTF, including the impacts and potential benefits of dampening those flows on the SPR. It was anticipated that funding of the study could be obtained from a grant by the Colorado Water Conservation Board (CWCB). The stipulation between the Opposers and the Co-Applicants specified that the study and the grant application would include:

- Defining the diurnal flow issues
- Identifying the water users likely affected by the diurnal flows and to what degree
- Identifying the potential benefits of mitigating or "dampening" the diurnal flows
- Identifying potential administrative or physical actions, including a flow equalization pond, that could provide those benefits
- Identifying the costs of providing potential administrative and physical benefits

In April of 2014, the Metro District received notice that the Water Supply Reserve Account (WSRA) grant application submitted to the CWCB for funding of the diurnal flow study was approved. The $100,000 grant was equally funded (i.e., $50,000 each) from the South Platte Basin Roundtable and the Metro Roundtable.

The scope of the study was cooperatively developed with Opposers and their consultants through a stakeholder process. All Opposers in Case No. 11CW74, including the State and Division Engineers, are considered stakeholders in the study process. In the development of the scope of the study, the stakeholders proposed several possible alternatives to address the diurnal flow fluctuation of the SPR. Possible solutions that have been proposed include:

A. Use of upstream storage at Chatfield Reservoir.

B. Use of an existing gravel pit reservoir between RWHTF and the Western Mutual Ditch headgate to dampen the diurnal fluctuation.

C. Construction of a new gravel pit storage reservoir downstream of RWHTF and upstream of the Western Ditch in order to dampen the diurnal fluctuation.

D. Use of storage at agreed upon locations, including agreed upon timed releases by parties using effluent discharged at RWHTF, to offset the diurnal fluctuation.

E. Construction of a storage reservoir near the headgate of the Western Mutual Ditch at the Gilcrest Reservoir site in order to dampen the impact of the diurnal fluctuation to the Western Ditch, which could benefit other water users that have been historically subject to calls by the Western Ditch. Investigation of a storage location between the RWHTF and the Western Mutual Ditch will not be limited to the Gilcrest Reservoir site. D&A will investigate storage locations near other ditch headgates on the South Platte River between RWHTF and the Western Mutual Ditch.

F. Use of existing or new river check dams that could be modified in order to regulate the diurnal fluctuation.

G. Utilize groundwater diversions for ditches to offset the diurnal fluctuation.

D&A conducted a screening analysis to evaluate the preliminary engineering feasibility of each of the above proposed mitigation alternatives. In addition to the analysis of engineering feasibility, this study identifies potential legal, institutional, and permitting issues associated with each alternative. Additional engineering, legal, and permitting research will be required to determine if any of the alternatives presented herein will be suitable for implementation.

2.0 STUDY REACH

The reach of the SPR that experiences the diurnal fluctuation created by the RWHTF effluent discharge is contained within Water District No. 2 ("District 2") of Water Division No. 1. The mainstem of District 2 is comprised of a 70 mile reach beginning upstream at the Denver Gage (PLADENCO) and ending immediately upstream of the Kersey Gage (PLAKERCO). Major surface inflows within District 2 include: Sand Creek, Clear Creek, Big Dry Creek, St. Vrain Creek, Big Thompson River and the Cache La Poudre River. Because the inflows from St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River are significant, the reach of District 2 most affected by the diurnal fluctuation is specifically the reach lying below the RWHTF outfall and above the confluence of St. Vrain Creek and the SPR. Based on discussions with the Division Engineer, Water Commissioner for District 2, other stakeholders and our own review of streamflow records, there is very little diurnal fluctuation downstream of the confluence of St. Vrain Creek and the SPR. Therefore, the reach of the SPR that is subject to this study (hereinafter the "Study Reach") is comprised of the mainstem of the SPR beginning upstream at the RWHTF outfall and terminating at the Jay Thomas Ditch headgate (see **Figure 1**).

The SPR flows at the upstream end of the Study Reach are largely dependent on Chatfield Reservoir, the Burlington Ditch operations and RWHTF discharges. For a large majority of the year, the Study Reach can be considered an effluent-dominated reach (i.e., the flow within the reach is largely comprised of RWHTF treated effluent). When not completely diverted by the upstream Burlington Ditch, effluent generated by other upstream municipal wastewater treatment plants (e.g., the Marcy Gulch Wastewater Treatment Plant and the Bi-City Wastewater Treatment Plant) does enter the Study Reach with its own inherent diurnal fluctuation. By examining the RWHTF discharges, the Henderson Gage records, and the Fulton and Brantner Ditch diversions for the period of June 2010 through 2014, D&A estimated the percentage of the SPR flows upstream of the Fulton Ditch headgate that were comprised of effluent from the RWHTF. On a daily basis during the period of 2010 through 2014, the percentage of the SPR comprised of RWHTF treated effluent, ranged from a maximum of 87 percent in the month of January to a minimum of 31 percent in the runoff influenced month of June. Individual monthly averages ranged from 99 percent in January 2012, to a low of 16 percent in June 2014 (See Table 1). On a daily basis, Metro District effluent comprised 55 percent of the flow in the upper segment of the Study Reach.

The Sand Creek and Clear Creek confluences with the SPR are located approximately 700 feet and 2 miles downstream of the upper terminus of the Study Reach, respectively. Surface diversions within the Study Reach are primarily made by the Fulton, Brantner, Brighton, Lupton Bottom, Platteville, Meadow Island No.1, Evans No.2, Meadow Island No.2/ Beeman, Farmers Independent, Western Mutual (aka Hewes & Cook) and the Jay Thomas ditches.

The SPR at Henderson (PLAHENCO) gage ("Henderson gage") is located approximately 10.6 miles downstream of the RWHTF outfall and provides a near continuous daily streamflow record beginning in May of 1926. The Henderson gage, as will be discussed in more detail later in this report, provides a useful record of the influence the RWHTF discharge on this reach of the SPR.

The adjacent lands on either side of the river within this reach have been heavily mined for sand and gravel. The reclaimed pits have been largely acquired by local municipalities and water providers for recapture and storage of reusable effluent supplies discharged at the RWHTF. The City of Thornton owns a large percentage of the reclaimed pits primarily made up of multi-cell complexes such as their East Gravel Lakes (aka, Tani Lakes Storage Complex), West Gravel Lakes, Cooley East, and Hammer facilities. Other owners of gravel pit storage in this reach include: South Adams County Water and Sanitation District (SACWSD), Denver Water Board, Aurora Water, the City of Arvada, and the City of Brighton. The NTP outfall will be located across the river from Aurora Water's Walker Reservoir (see **Figure 1**).

3.0 METRO WASTEWATER RECLAMATION DISTRICT BACKGROUND

3.1 Robert W. Hite Treatment Facility Background

The Metro Wastewater Reclamation District (Metro District) is the wastewater treatment authority for much of metropolitan Denver and its surrounding suburbs. The Metro District, originally the Metropolitan Denver Sewage Disposal District No.1, is a stand-alone special district formed by the Colorado legislature in 1961. Prior to 1966, wastewater from the Denver Metro area was treated at the Northside Wastewater Treatment Plant ("Northside") located upstream of the Burlington Ditch headgate. By 1966, Northside became inadequate due to population growth and higher health standards and therefore construction of the Metro District's first facility, Robert W. Hite Treatment Facility (RWHTF), began in 1964 and was completed in 1966. The Denver Northside Plant continued to operate and provide primary treatment for Denver and many small sanitation districts. In 1987, the Northside Plant was decommissioned.

The Metro District currently operates one wastewater treatment facility - the RWHTF, located at 6450 York Street, Denver, Colorado. The Metro District's service area is approximately 715 square miles and serves a population of approximately 1.7 million people. The Metro District customers include 60 local governments consisting of cities and sanitation districts. Large contributors of wastewater to the RWHTF include the cities of Thornton, Aurora, Denver, Lakewood, Westminster, and Arvada.

The RWHTF discharges treated effluent to the SPR approximately 700 feet upstream of the confluence of Sand Creek with the SPR and approximately 2 miles downstream of the Burlington Ditch headgate. The legal description of the RWHTF outfall is as follows: in the NW ¼ of Section 12, Township 3 South, Range 68 West, 6th P.M., Adams County, Colorado.

According to the Metro District, the RWHTF currently treats an average of approximately 140 million gallons (430 acre-feet) of wastewater per day. Effluent records examined for the years 2010 through 2014 indicate the average daily effluent discharge to the SPR for the same time period is 133 mgd, or 205 cfs (**Table 2**). Annual volumetric discharges for 2010 through 2014 averaged approximately 147,000 acre-feet (**Table 2**).

3.2 The Northern Treatment Plant (NTP)

The Metro District began construction of the Northern Treatment Plant in early 2013. It is generally located within the western half of Section 31, Township 1 North, Range 66 West, of the 6th P.M. The outfall of the NTP to the SPR is located near the intersection of WCR 2 (168th Ave.) and SH 85. The outfall is located approximately 6.8 miles downstream of the Henderson Gage or 2.75 miles downstream of the Brighton Ditch headgate.

The completion of the construction activities and the commissioning of the NTP are estimated to occur in 2016. The NTP is scheduled to be built in phases with an initial capacity (average daily annual flow) of 24 million gallons per day (mgd), expandable to 60 mgd at build-out. Upon startup in 2016, the new facility will be capable of serving approximately 300,000 people.

Ultimately, the facility could be expanded to be capable of serving approximately 750,000 people.

Several wastewater management facilities will be consolidated with the construction of the NTP. Numerous lift stations may be decommissioned or not constructed in the surrounding communities, as well as the eventual elimination of the need for the Brighton Wastewater Treatment Plant (within 20 years of the NTP becoming operational). NTP will offload flows from the District's RWHTF and eventually the South Adams County's Williams-Monaco Wastewater Treatment Plant. The Northern Treatment Plant will be capable of providing service for all or a portion of the City of Brighton (Brighton), South Adams County Water and Sanitation District (SACWSD), City of Thornton (Thornton), City of Aurora (Aurora), City and County of Denver (Denver), Adams County Regional Park, Hi-Land Acres Water and Sanitation District (Hi-Land Acres), and Todd Creek Metropolitan District (Todd Creek). Initially, flow is anticipated from portions of Thornton and Brighton and from the Adams County Regional Park. Hi-Land Acres and Todd Creek could send flow once Thornton constructs its Todd Creek Interceptor. Aurora, Denver, and SACWSD could convey flow after construction of a Second Creek Interceptor. Flows from SACWSD are not anticipated at the NTP prior to 2023.

Technologies that will be incorporated into the NTP include biological treatment and ultraviolet disinfection of the wastewater. An extended water channel at the end of the treatment process will add wetlands to the region and allow the treated effluent to cool naturally before it is discharged to the South Platte River.

Previous studies conducted by D&A in support of Case 11CW74, concluded that the introduction of the NTP's effluent discharge, including flows currently treated at RWHTF, to the SPR at the NTP outfall will not cause the low flow trough of the existing diurnal fluctuation present within the SPR to decrease and therefore will not trigger increased calls from water users downstream of the NTP outfall (D&A, 2012a).

4.0 PREVIOUS STUDIES

As far back as 1997, the Metro District has evaluated the concept of flow equalization for treated wastewater discharging to the SPR. The concept was not considered for the diurnal flow fluctuation's impact on downstream water users but rather the potential affect the daily flow variations had on aquatic life downstream of the RWHTF discharge. The Metro District provided two documents that addressed the flow equalization concept related to the Metro District's studies conducted in 2004 pursuant to the1997 Memorandum of Understanding (MOU) between the District, the Water Quality Control Division (WQCD), the EPA, and the Colorado Division of Wildlife (DOW). As part of the 1997 MOU, the District agreed to implement projects to provide a margin of safety for the dissolved oxygen standard adopted by the EPA and the WQCD. The proposed projects included the construction of instream reaeration structures, flow equalization facilities to stabilize the depth of flow and extent of the wetted river channel, and fish exclusion facilities to reduce fish loss (i.e., entrainment) in irrigation ditches. The following is a brief summary of the two documents related to the District's 2004 evaluation of flow equalization.

4.1 William M. Lewis, Jr. March 24, 2004 Letter

On March 24, 2004, Mr. William M. Lewis Jr., a professor and director of the Center of Limnology at the University of Colorado at Boulder, wrote a letter to Ms. Barbara Biggs, then the Governmental Affairs Officer for Metro, summarizing his opinion regarding the effectiveness of flow equalization of the RWHTF discharge on the environmental health of the South Platte River below Metro's discharge, as compared with other kinds of restoration activities requiring similar investment. Mr. Lewis's involvement was related to the previously mentioned MOU with the regulatory authorities. Mr. Lewis evaluated the effectiveness of the two identified advantages flow equalization may have on the reach of the South Platte River below the RWHTF discharge: 1) raising the mean and minimum dissolved oxygen concentrations below the discharge, and 2) increasing the abundance of aquatic life by removal of the oscillating water levels within the river.

Mr. Lewis's letter ultimately concludes that he believes the oscillating flow in the South Platte River "has a very small effect on oxygen concentrations, and that oxygen concentrations would be essentially as they are now if flow were equalized". Mr. Lewis also offered his opinion regarding the effect alternating wetting and drying of the South Platte River banks has on the aquatic life. Mr. Lewis concludes: "Given that the oscillations induced by Metro cause alternating wetting and drying of a relatively small portion of sandy sediment, and do not inundate or cut off true backwaters, I cannot find a good rationale for giving flow equalization a high priority." Mr. Lewis also believed that the oscillations in flow within this reach of the river "induced by other types of water management and by thunderstorms are quite substantial and are inevitably part of the environmental picture". Mr. Lewis closed the letter by stating "I do not believe "that flow equalization is an effective strategy for accomplishing [environmental] restoration.

4.2 Flow Equalization Summary Report

The Metro District provided D&A with a "Summary Report" titled: "Flow Equalization" dated July 12, 2004. The Summary Report documents the study and pilot demonstration level evaluations of flow equalization facilities at the RWHTF conducted by the Metro District pursuant to the 1997 MOU. As previously discussed, the flow equalization studies done pursuant to the MOU were conducted with a focus on the diurnal flow's effect on aquatic life.

The 1997 MOU assumed that an 18 million gallon (mg), 55 acre-feet, facility was required to provide flow equalization meeting the criteria of the MOU (i.e., achieve a daily variance of less than 10 percent of the average flow under normal discharge conditions). The MOU established the 10 percent variance goal for times when the RWHTF's discharge represents a large component of the South Platte River flows. Under high flows, flow equalization would not be needed as the RWHTF discharge has a lesser impact on stream depths under this condition. The MOU defines high South Platte River flows as those exceeding 1,000 cfs at the Henderson Gage.

The Metro District's analysis concluded there are numerous operational complexities associated with flow equalization, especially when trying to comply with the MOU variance criteria. The Summary Report stated "The diurnal flow patterns also include a rapid transition from deficit flow conditions to storage conditions. On many days, this transition takes less than one hour." The Summary Report also found that in addition to the rapid transitions, it is hard to predict the actual daily flow variability and therefore the actual daily storage requirement "will not be known until after the entire daily storage and discharge cycle has been completed". The Metro District found that in order to comply with the MOU variance standard 95 percent of the time, a storage volume in excess of 25 mg (77 acre-feet) was needed. This represented an approximate 35 percent increase in storage volume than originally conceived in 1997. At the time the study was completed, the Metro District estimated that an off-site 25 mg equalization facility would have a capital cost of approximately $19.5 million.

In addition to the operational complexities and capital costs associated with the flow equalization, the Metro District concluded that the facilities ability to reduce ammonia levels was costly and unreliable. Based on these findings, the Metro District concluded that "flow equalization is less viable than originally considered and has fewer treatment benefits than originally thought". The major findings of the Summary Report included:

- The storage volume required to achieve flow equalization is in excess of 77 acre-feet, which is approximately 35 percent greater than what was anticipated in 1997 (55 acre-feet) when the concept was first considered. The larger volume results from more detailed evaluations of flow patterns and operational strategies that would be necessary to meet the requirements of the MOU.

- The site area required for the flow equalization facilities was found to be much larger than was originally expected and would require the use of land already planned for future tertiary treatment facilities.

- Because flow equalization is operationally complex, uncertainty exists regarding the ability to equalize flows to meet the criteria set by the MOU.

- Little practical reduction in treatment process sizing at the RWHTF would be realized with flow equalization prior to secondary treatment.

- The ability to achieve additional treatment, e.g., ammonia removal, in the significantly enlarged equalization facilities was found to be costly and unreliable.

Based on the Metro District's studies, the construction of flow equalization or fish entrainment mitigation facilities would not ??? provide the environmental benefits originally anticipated. The Metro District concluded that both would be significantly more expensive to construct and operate than originally anticipated, and the flow equalization facility would be extremely difficult to operate in a manner that would achieve the purpose of its construction. Given these conclusions, the MOU was amended in 2004 (referred to as the "2004 Amendment"). In the 2004 Amendment, the District agreed to complete a comprehensive assessment to develop new recommendations on the best ways to protect and improve aquatic habitat in the South Platte River downstream of the RWHTF outfall.

5.0 DIURNAL FLOW FLUCTUATION

Typical diurnal variations in influent flow experienced by municipal wastewater treatment plants are generally characterized by two peaks resulting from morning and early evening water usage and decreasing flows late at night and early in the morning. The maximum flow of the diurnal flow period is defined as the "peak hourly flow" (U.S. EPA, 1981). Variations in the waveform of the diurnal fluctuation (e.g., amplitude or relationship of peak hourly flow to average) can be seen on a daily basis, with the largest variations occurring on weekends and holidays.

5.1 RWHTF Diurnal Fluctuation

The influent diurnal fluctuation of the RWHTF is typical of a wastewater treatment facility with both industrial and nonindustrial (i.e., municipal) contributions. The Hite Plant's effluent fluctuation is very similar to the influent fluctuation but slightly delayed due to the treatment processes. **Figure 3** illustrates the relationship between Hite's average hourly influent and effluent for the 2011 water year. By comparing the two lines, the trough of the influent and effluent are very similar in magnitude, with an approximate two hour delay between the trough entering the plant and exiting the plant. The peak of the effluent fluctuation is slightly reduced from the peak of the influent fluctuation, and again delayed by approximately two hours.

The peak effluent discharges from RWHTF occur at approximately 1:00 p.m. and 11:00 p.m., while the low flow discharge occurs at approximately 6:00 a.m. on average. Analysis of the average hourly effluent discharge at the RWHTF for the years 2001 through 2014 indicates that on a daily basis, the average discharge from this facility was 200 cfs. However, the discharge from the RWHTF varied on average from a low of about 99 cfs at 6:00 a.m. up to a high of 259 cfs at 1:00 p.m. (see **Figure 4**).

5.1.1 Average Daily Effluent Discharge

Metro's records of effluent discharge for the years of 2001 through 2014 indicate that the average hourly effluent discharge was 200 cfs (see **Figure 4**).

5.1.2 Average Daily Peak Flows

The average daily peak hourly flow was fairly consistent throughout the year, with a slight increase in the months of April through August (see **Table 4**). The month of May appears to have the highest average daily peak hourly flow of 280 cfs, whereas January had the lowest average daily peak hourly flow of 257 cfs.

5.1.3 Average Daily Minimum Flows

Average daily minimum hourly flows (i.e., lowest hourly discharge over the course of a day) followed a similar pattern of that of the peak flows (i.e., higher minimum flows within the spring and summer months) (see **Table 5**). For the period of 2001 through 2014, the month of March had the lowest minimum hourly flow of 83 cfs.

The difference between the peak hourly flow and the minimum hourly flow over the course of 24-hours represents the peak-to-peak amplitude of the daily diurnal flow waveform. At times the RWHTF discharge dominates the flow of the SPR downstream of the outfall, the difference between the peak hourly flow and the minimum hourly flow represents the approximate magnitude of the varying flows downstream irrigators may experience at their river headgate when diverting from the SPR. As shown in **Table 6**, the average daily peak-to-trough amplitude ranges from 181 cfs in April to 167 cfs in July.

The peaking factor of a plant's influent, a metric often used in the design of wastewater treatment facilities, represents the relationship of the peak hourly influent flow compared to the average daily flow. For the same period of 2001 through 2014, D&A calculated the peaking factor of the Hite Plant's *effluent* discharge. In the context of this study, the peaking factor of the effluent discharge is useful for the conceptual sizing and design of flow equalization facilities, especially when projecting maximum potential inflow rates based on future effluent discharges. As shown in **Table 7**, the average daily peaking factor of the Hite Plant's discharge is approximately 1.34. In other words, the peak hourly flow is, on average, 134 percent of the average hourly flow.

The "trough-to-average" factor, or the relationship of the minimum hourly flow compared to the average daily flow was also determined. This factor is also useful when projecting the expected magnitude of the minimum hourly flow, or trough, based on projected average effluent discharges. For the period of 2001 through 2014, the trough -o-average factor was calculated as 0.47, or the minimum hourly flow was 47 percent of the average daily flow. As shown in **Table 8**, this factor remained fairly constant through the course of a year, with a slight increase in trough-to-average factor in the months of June, July, and August, indicating in the context of this report, a slight improvement in the trough-to-average factor.

5.1.4 Volume of Fluctuation Above and Below the Average Daily Effluent Discharge

The volume of water above the average daily effluent discharge represents the volume that an equalization basin would be required to impound in order to maintain a constant discharge rate equal to the average daily flow rate. The average daily volume above the average hourly effluent discharge for the years of 2001 through 2014 is approximately 46 acre-feet (see **Figure 5**). However, while this is the average volume, there are days that the effluent discharge pattern varies from the average. Therefore, D&A calculated the volume of discharge in excess of the average daily flow rate for the years of 2001 through 2014 and performed an exceedance probability on the daily volumes. As shown in **Figure 6**, a volume in excess of 60 acre-feet is only exceeded 10 percent of the time. Similarly, a volume in excess of 63 acre-feet is exceeded 5 percent of the days. Therefore, an equalization basin of approximately 63 acre-feet would be capable of storing the daily volume of flow above the average daily flow rate 95 percent of the time.

The volumes above the average also represent the volume of water it would take to increase the trough up to the average. Therefore, a volume of 60 to 63 acre-feet would need to be released or pumped from an equalization basin on a daily basis to fill in the trough of the RWHTF discharge.

As discussed in Section 4.2 of this report, the Metro District's previous flow equalization study concluded after extensive modeling that equalization ponds need to be sized conservatively high to account for the fact that there are variations in the diurnal fluctuations that are not always known ahead of time. For example, the actual average daily flow rate is not known until after the day is completed. To account for these operational difficulties and inefficiencies, the Metro District study determined that 77 acre-feet was required to minimize large variances in discharges. The Metro District's study was based on the RWHTF's influent variations, whereas ours is based on the effluent diurnal fluctuation. However, both analyses show fairly consistent results and conclude that equalization of the RWHTF's diurnal fluctuation would require a 60-80 acre-foot equalization pond depending on the desired ability to equalize most or all diurnal variances.

5.2 South Platte River's Response to RWHTF Diurnal Fluctuation

When wastewater effluent flow rates are large compared to the receiving streams' base flow, the flow rate and pattern of the downstream reach of the receiving stream largely mimics that of the effluent discharge. This is the case with the SPR downstream of the RWHTF during the months not highly influenced by snowmelt runoff. As shown in **Table 1**, on a daily basis during the period of 2010 through 2014, the percentage of the SPR flow comprised of RWHTF treated effluent ranged from a maximum of 87 percent in the month of January to a minimum of 31 percent in the runoff influenced month of June. Individual monthly averages ranged from 99 percent in January 2012, to a low of 16 percent in June 2014. On an annual basis, Metro District effluent comprised 55 percent of the flow in the upper segment of the Study Reach. Because the RWHTF discharge constitutes such a large percentage of the SPR flow within the Study Reach, the hydrograph and flow pattern (i.e., hourly fluctuations) often mimic that of the RWHTF outfall.

5.2.1 Diurnal Fluctuation at Henderson Gage (PLAHENCO)

The South Platte River at Henderson (PLAHENCO) Gage ("Henderson Gage") is located approximately 10.6 miles downstream of the RWHTF outfall and provides a near continuous daily streamflow record beginning in May of 1926. If the flow rate in the SPR is not influenced by a recent storm or spring runoff, the flow rate and hourly flow rate variation at the Henderson Gage is largely influenced by the effluent discharge at the RWHTF. As an example, a two-day period during September 5th and 6th of 2011 is shown on **Figure 7**, which illustrates that the flow at this gage during this period fluctuated between approximately 170 cfs to as high as 330 cfs, and averaged approximately 250 cfs. By comparing the Henderson Gage hydrograph to the flow discharge at the RWHTF on this day, it is clear that the diurnal fluctuation at the Henderson Gage is strongly influenced by the diurnal fluctuation of the RWHTF effluent discharge.

The diurnal fluctuation of the RWHTF discharge and the diurnal fluctuation present at the Henderson Gage are similar; however, a slight attenuation (i.e., dampening) of the fluctuation occurs along that 10.6 mile stretch of the SPR. This occurs largely due to the effluent discharge combining with the base flow of the SPR above the RWHTF outfall, the influences of the Sand and Clear Creek inflows, and the irrigation diversions and return flows occurring within the reach.

As will be discussed in more detail later in Section 6.0 of this report, the Evans No. 2 1871 direct flow right is frequently subject to a bypass call. For comparison purposes, D&A examined the average daily hydrograph of the Henderson Gage on the days when the Evans No. 2 Ditch was subject to a bypass call. The SPR hydrograph on these days is representative of the conditions on the SPR at the Henderson Gage when the combination of the diurnal fluctuation and the bypass call was problematic for the District 2 irrigators. Average hourly discharge records for the Henderson Gage for the period of June 2010 through December 2014 were obtained from the Colorado Division of Water Resources website: *Colorado's Surface Water Conditions*[1]. **Figure 8** represents the average hourly flow and hydrograph of the Henderson Gage on days an Evans No. 2 priority was subject to a bypass call. Comparing this hydrograph to the average daily RWHTF discharge (**Figure 4**), one can see the attenuation that occurs in this reach. For example, the amplitude of the RWHTF effluent trough is 100 cfs, as compared to the average daily flow rate of the trough at the Henderson Gage of approximately 77 cfs. The delta of the peak flow rate to the average flow rate of the SPR at the Henderson Gage is 36 cfs, down from the 59 cfs at the RWHTF discharge. The peak-to-peak amplitude is 113 cfs, a reduction of 46 cfs.

Many of the potential mitigation alternatives presented herein propose to store the peak of the diurnal fluctuation after the RWHTF effluent has been discharged to the SPR. Therefore, similar to the analysis conducted to determine the storage required to regulate the RWHTF effluent prior to discharge to the SPR, D&A determined what the storage requirements would be for diverting and storing the peak of the SPR diurnal fluctuation at the Henderson Gage. This storage requirement would be for a gravel pit used to divert and store the peak or an on-channel reservoir created by on-channel check dams.

By examining the Henderson Gage hydrograph on days when the Evans No. 2 Ditch was subject to a bypass call, the average storage requirement was approximately 34 acre-feet. However, there are fairly significant variations from the average and therefore D&A conducted an exceedance analysis. The exceedance analysis (see **Figure 9**) indicated that to store 95 percent of the variations in the volume above the average daily flow, 70 acre-feet of storage is required. This storage amount is very similar to the storage requirement determined for the RWHTF effluent prior to discharge as well as what the Metro District's previous studies concluded. The attenuation of the RWHTF hydrograph that takes place between the RWHTF outfall and the Henderson Gage appears to reduce the magnitude of the peaks and troughs but the volume above the average appears to stay fairly consistent. For the purposes of sizing, cost estimates, and evaluating mitigation alternatives that rely on equalization storage, 70 acre-feet will be used herein for the storage requirement.

[1] Much of the South Platte River gage data relied on for this study, including streamflow data and ditch diversion data, was downloaded from the following Colorado Division of Water Resources website: http://www.dwr.state.co.us/SurfaceWater/data/division.aspx?div=1

5.2.2 Diurnal Fluctuation at Fort Lupton Gage (PLALUPCO)

The South Platte River at Fort Lupton, CO (PLALUPCO) Gage ("Fort Lupton Gage") is located approximately 28 miles downstream of the RWHTF outfall and 17 miles downstream of the Henderson Gage. The Fort Lupton Gage provides intermittent seasonal and monthly record beginning as early as 1906. However, a consistent daily record only exists from October 2003 to present. The Fort Lupton Gage is operated by the U.S. Geological Survey (USGS) in cooperation with the Metro District. Because it is located approximately 1 mile upstream of the Evans No. 2 river diversion, the flow data for this gage provides a record of the hourly fluctuations of the SPR present within the lower portions of the Study Reach and above one of the ditches most impacted by the diurnal fluctuation.

Similar to the Henderson Gage analysis, D&A examined the hourly flow data at the Fort Lupton Gage on days the Evans No. 2 Ditch is subject to a bypass call. As shown in **Figure 10**, the additional 17 miles along with the inflows and outflows occurring within the reach downstream of the Henderson Gage results in further attenuation of the diurnal fluctuation. For example, the amplitude of the trough compared to the average daily flow rate at the Fort Lupton Gage is approximately 39 cfs, compared to 77 cfs at the Henderson Gage and 100 cfs at the RWHTF discharge. The delta of the peak flow rate to the average at the Fort Lupton Gage is 22 cfs, compared to 36 cfs at the Henderson Gage and 59 cfs at the RWHTF discharge. The peak-to-peak amplitude is 61 cfs, compared to 113 cfs at the Henderson Gage and 159 cfs at the RWHTF discharge.

D&A understands that the Fort Lupton Gage is not as accurate as the Henderson Gage at low flow conditions due to the reduced frequency in which the USGS calibrates it. In addition, because the Henderson Gage is located higher within the study reach, D&A chose to use the 70 acre-feet calculated as the storage requirement at the Henderson Gage location for the equalization storage requirement for the alternative analyses involving equalization storage. The effects of attenuation within the SPR appear to reduce the peak-to-trough amplitudes but do little to reduce the peak volumes. Therefore, the farther downstream an equalization pond is implemented, the inflow and outflow capacities would likely be reduced but the total storage volume would be similar to the requirements of upstream locations.

5.2.3 Diurnal Fluctuation at Kersey Gage (PLAKERCO)

The South Plate River Near Kersey gage (PLAKERCO or the "Kersey Gage") is located downstream of the confluences of the St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River with the SPR and represents the downstream terminus of Water District 2 as shown on Figure 1. Because of the contributions of these inflows and the diversion of the majority of the SPR during the irrigation season by the ditches located at or above the Western Ditch, the Kersey Gage does not experience a diurnal fluctuation of a similar magnitude of the gages above the Western Ditch. For comparison purposes, D&A examined the Kersey Gage records on the days in which the Evans No. 2 ditch was subject to the bypass call and determined that the peak-to-trough amplitude for those days averaged only 8 cfs. Therefore, this analysis confirmed our previous understanding that the administration of the diurnal fluctuation results in the majority of the fluctuation being diverted and removed from the SPR at or above the Western Ditch headgate.

6.0 CURRENT RIVER ADMINSTRATION

The historical dry-up locations within District 2 generally occur below the Burlington Ditch, below the Farmers Independent Ditch, below the Jay Thomas Ditch, and at the Lower Latham Ditch (see **Figure 11** for dry-up locations). Recent changes in the operation of the Jay Thomas Ditch water rights (i.e., 100 percent owned by PSCo and used at PSCO's Fort St. Vrain and Cherokee stations) have caused the dry-up point that historically occurred below the Jay Thomas Ditch to occur below the Western Ditch (aka Hewes Cook) headgate. Historical administration affecting District 2 primarily consisted of bypass calls placed by the Jay Thomas Ditch and subsequent to PSCo's change of use of the Jay Thomas Ditch rights in 2006, the Western Ditch. A bypass call is the partial curtailment of a junior upstream right expressed as a call by the junior right bypassing to a named downstream senior right. For example, an 1885 Burlington direct flow bypass call to the 1871 Western Ditch water right will result in the total curtailment of rights upstream of the Western Ditch junior to 1885, and the Burlington bypassing or curtailing a portion of the 1885 water at its headgate as necessary to satisfy the downstream 1871 right at the Western Ditch. Recent call records indicate the most frequent bypass call is from the Burlington Ditch's 1885 and 1909 rights or the Evans No. 2 Ditch 1871 or 1909 priorities to the Western Ditch headgate. The same call records show an infrequent bypass call of short duration that affects the junior rights of the Fulton Ditch, Brantner Ditch and the Brighton Ditch placed by the Western Ditch necessary to satisfy its 8-10-1871 priority.

Through discussions with David Nettles, Division 1 Engineer, and William Schneider, District 2 Water Commissioner, D&A understands that the 1871 priority of the Western Ditch is the primary calling right of this reach of District 2 making the Western Ditch the "swing ditch" (i.e., the ditch that dictates the presence of a call). Furthermore, D&A understands that the Water Commissioner determines the need for a call in District 2, upstream of the Saint Vrain Creek confluence, by: 1) discussing the daily water needs of the Western Ditch with a ditch company representative, 2) examining the low flow "trough" of the daily hydrograph at the Henderson Gage, 3) examining gaged and known inflows within the reach upstream of the Western Ditch to determine their potential contribution to demand, and finally 4) distribution of the water to all in-priority water users, according to their demands, so that the Western's 1871 priority and all intervening water rights are satisfied when the trough of the diurnal flow reaches the Western headgate. If the Water Commissioner determines the Western's demand will not be completely satisfied, the Water Commissioner will place a bypass call within District 2. The bypass call allows the Water Commissioner to work with upstream junior users so that only a partial curtailment may be required to satisfy the Western Ditch's demands. D&A understands the Water Commissioner's goal when administering this typical bypass call is to fully satisfy the Western's calling right while avoiding any "spills" (i.e., flow over Western's check dam) to downstream reach.

6.1 Water District 2 Call Record Analysis

D&A completed an analysis of call records of District 2 for the period of 1992 through 2012. The analysis includes a tabulation of the various water rights that have placed a call during the study period, as well as the relative frequency of calls, including bypass calls, that affect each particular structure. The call record indicates which particular water users within District 2 were potentially affected by the diurnal flow administration.

6.1.1 Calling Structures

The following table displays the frequency in which a call, including bypass calls (i.e., water was being bypassed to the calling structure), was placed by a structure within the Study Reach. The table lists the number of calls for the entire period of 1992 through 2012 as well as those calls placed within the last eleven years of the study period (i.e., 2002 - 2012).

	1992 – 2012			2002 - 2012		
Calling Structure	**Total Days w/ Call**	**Average Days Per Year**	**% of Total Calls**	**Total Days w/ Call**	**Average Days Per Year**	**% of Total Calls**
Fulton	57	2.7	3.6%	-	-	-
Brantner	58	2.8	3.6%	-	-	-
Brighton	-	-	-	-	-	-
Lupton Bottom	6	0.3	0.38%	3	0.3	0.30%
Platteville	31	1.5	1.94%	-	-	-
Meadow Island No. 1	15	0.7	0.94%	-	-	-
Evans No. 2	138	6.6	8.65%	13	1.2	1.29%
Meadow Island No. 2	2	0.1	0.13%	1	0.1	0.10%
Farmers Independent	120	5.7	7.52%	82	7.5	11.90%
Western Mutual	674	32.1	42.26%	616	56	61.11%
Jay Thomas	494	23.5	30.97%	293	26.6	29.07%
TOTAL	**1,595**			**1,008**		

As indicated by the call tabulation, the primary calling structures since 1992 have been the Jay Thomas Ditch and Western Mutual Ditch. The Western Mutual Ditch represents approximately 61 percent of the calls placed above the St. Vrain Creek confluence since 2002. More recently and as previously mentioned, PSCos change of the Jay Thomas water in 2006 has increased the Western's share of the call as the Jay Thomas Ditch has not placed a call since 2006.

6.1.2 Structures Subject to a Bypass Call

As previously mentioned, a bypass call is the partial curtailment of a junior upstream right expressed as a call by the junior right bypassing to a named downstream senior right. The bypass call allows the Water Commissioner to work with upstream junior users so that only a partial curtailment may be required to satisfy the downstream senior right's demands. Recent administration of the District 2 call is primarily done utilizing a bypass call. As an example, of the 674 total calls the Western Mutual Ditch placed between 1992 and 2012, 547 of them, or 81 percent, were done by bypass call. Recent call records indicate the most frequent bypass call is from the Burlington Ditch's 1885 and 1909 rights or the Evans No. 2 Ditch 1871 or 1909 priorities to the Western Ditch headgate. The following is a table of how often a ditch system is subject to a bypass call for the period of 1992 through 2012.

Structure Subject of a Bypass Call	1992 – 2012		2002 - 2012	
	Total Bypass Days	Average Days Per Year	Total Bypass Days	Average Days Per Year
Burlington	386	18.4	265	24.1
Fulton	67	3.2	53	4.8
Brantner	51	2.4	48	4.4
Brighton	9	0.4	3	0.3
Lupton Bottom	26	1.2	14	1.3
Platteville	52	2.5	32	2.9
Meadow Island No. 1	41	2.0	40	3.6
Evans No. 2 (incl. Milton Reservoir)	500	23.8	447	40.6
Meadow Island No. 2	48	2.3	48	4.4
Farmers Independent	13	0.6	13	1.2
Western Mutual	43	2.0	43	3.9
Jay Thomas	-	-	-	-

The call record clearly indicates that the Evans No. 2 system is most frequently impacted by a bypass call. Of the total of 500 bypass calls affecting the Evans No. 2 and Milton Reservoir rights, 410 were to either the Jay Thomas Ditch or to the Western Mutual Ditch. These bypass call primarily occur during the months of July, August, and September.

7.0 IMPACT OF DIURNAL FLUCTUATION

Based on discussions with the Division Engineer, Water Commissioner for District 2, and other stakeholders, D&A understands that the diurnal fluctuation impacts the water users of District 2 in different ways. Impacts to District 2 include impacts to individual ditch systems, especially to those subject to a bypass call, and to the District as a whole in the form of inefficient water use and water lost to the lower reaches of the SPR downstream of the Western Mutual Ditch. D&A understands that the largest impacts as a result of the diurnal fluctuation are to those structures subject to a bypass call.

Based on current District 2 administrative practices, the ditch system subject to the bypass call is allowed to “chase the peak” of the diurnal fluctuation. This means that the Water Commissioner allows the bypassing structure to increase their diversion rates during the period in which the peak of the diurnal fluctuation is present at their headgate. Because the Water Commissioner has set the initial bypass amount based on the previously described “paper allocation” method (i.e., mathematical distribution of daily supply based on demand and minimum flow within the reach as defined by the trough present at Henderson Gage and corrected for known/assumed inflows and outflows), the Water Commissioner is assured that the calling ditch system will still be completely satisfied when the trough of the diurnal is present at the calling ditch’s headgate if the bypassing structure’s fluctuating diversions (i.e., chasing of the peak) does not reduce the flow in the river beyond the original amount used as the basis for the morning bypass. D&A understands that to accomplish this, the Water Commissioner and a representative of the bypassing ditch company remain in contact throughout the day and fairly late into the evening. The communication allows for the Water Commissioner to relay his approval to increase diversions or request to decrease diversions depending on any mid-day adjustments necessary or the Water Commissioner’s understanding of what limb of the peak (i.e., rising or falling) is present at the headgate.

The impact of chasing the peak of the diurnal fluctuation or the resulting variable diversion rates is felt by the ditch company, individual shareholders, and irrigators of the bypassing ditch. That is, the variable flow rates within the ditch over the course of the day create variable water stages and hydraulic heads that make it difficult for the ditch company to allocate water, for irrigators to adjust their farm headgates, and also for the setting of siphon tubes. For the purpose of this study, we are calling these impacts to the ditch downstream of the main headgate, “down-ditch impacts”. D&A understands that not only does the “diurnal fluctuation” within the ditch and the resulting down-ditch impacts require additional effort by the ditch company and its shareholders, it reduces the overall efficiency and utilization of the water by the ditch system.

7.1 Daily Flow Fluctuations at Measuring Structures

D&A examined the maximum daily fluctuation in hourly diversion rates for the ditch systems and stream gages within the Study Reach for the period of June 2010 through December 2014. The intent of the analysis was to identify the structures within the Study Reach with the largest daily fluctuation in diversion rates. It is important to note that daily flow fluctuations within an individual ditch system take place for many reasons beyond just the increasing or decreasing hydraulic head within the SPR as a result of the diurnal fluctuation. These reasons include but are not limited to: the ditch system's response to precipitation events that result in a shareholder reduction in demand, general increase or decrease in demand, irrigation cycles, response to river call administration, etc.

Also, some ditch systems have diversion structures and methods that better absorb river stage fluctuations than others. These systems include those with "feeder ditches" that divert off of the SPR a fair distance upstream of their measuring structures and waste back to the SPR flow in excess of their in-priority flow rates near the measuring structures. In these instances, the hydraulic head present at the controlling headgate is capable of being held at a more constant stage than those systems with headgates and measuring structures within a close proximity of the SPR. This analysis of hourly flow data provides insight as to the flow variations experienced by the ditch companies and their irrigators on a daily basis and the potential for down-ditch impacts.

Gage/ Structure/ Ditch System	Monthly Average of Daily Maximum Flow Fluctuation (2001 – 2014) (Maximum Daily Fluctuation = Hourly Maximum – Hourly Minimum)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SPR @ Denver Gage (PLADENCO)	39	53	46	94	233	185	372	128	179	76	43	40
SPR @ 64th Ave Gage (PLASIXCO)	Incomplete or Unreliable Data											
RWHTF Discharge	177	175	181	179	177	169	172	172	177	179	181	178
Fulton Ditch	-	-	5	9	19	16	17	12	13	5	1	-
Brantner Ditch	-	-	2	4	5	4	8	6	2	1	-	-
SPR@ Henderson Gage (PLAHENCO)	121	137	148	176	434	304	555	260	471	202	170	138
Brighton Ditch	-	-	1	2	3	3	3	2	2	1	-	-
Lupton Bottom Ditch	-	1	3	9	12	10	11	8	9	4	-	-
Platteville Ditch	2	3	2	8	6	6	11	9	9	4	-	-
SPR @ Fort Lupton Gage (PLALUPCO)	66	75	93	117	306	270	404	157	364	131	100	80
Meadow Island No. 1 Ditch	-	-	-	2	2	2	2	1	2	-	-	-
Evans No. 2 Ditch	10	17	24	30	25	30	45	31	29	13	3	7
Meadow Island No. 2 Ditch	-	-	3	3	4	8	9	8	4	1	-	-
Farmers Independent Ditch	1	1	2	5	7	6	7	5	6	3	1	-
Western Mutual Ditch	-	1	9	8	11	15	17	18	12	4	2	-

The table above indicates that the SPR above the Study Reach, as illustrated by the average daily fluctuations of the South Platte River at Denver, Co gage (PLADENCO), has fairly significant fluctuations during the runoff months and those months influenced by afternoon storms. These fluctuations along with the fluctuation of the RWHTF discharge result in the fluctuations witnessed at the Henderson Gage and District 2 headgates. The table also illustrates that the Evans No. 2 Ditch system generally experiences the largest flow fluctuations. The study period of June 2010 through December 2014 indicates that the Evans No. 2 experienced, on average, a daily fluctuation of 45 cfs during the month of July. While the Evans No. 2 system experiences the largest rate fluctuations, it is also one of the larger ditches within the Study Reach with relatively large diversions. Therefore, to normalize the flow fluctuations based on the magnitude of diversions, the table below presents the average daily flow fluctuations as a percentage of average daily diversions for the irrigation months of March through October.

Ditch System	Average Daily Flow Fluctuation as Percentage of Average Daily Flow (2001 – 2014)							
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Fulton	39%	21%	46%	22%	23%	15%	33%	30%
Brantner	19%	22%	17%	9%	18%	16%	9%	9%
Brighton	10%	10%	21%	14%	16%	9%	13%	7%
Lupton Bottom	28%	50%	49%	19%	22%	21%	44%	38%
Platteville	16%	27%	13%	10%	18%	19%	23%	38%
Meadow Island No. 1	9%	23%	13%	14%	9%	8%	15%	5%
Evans No. 2	25%	40%	39%	**45%**	**41%**	**33%**	39%	16%
Meadow Island No. 2	23%	10%	12%	21%	18%	25%	32%	6%
Farmers Independent	30%	14%	15%	9%	11%	8%	11%	13%
Western Mutual	52%	26%	26%	27%	29%	30%	30%	20%

While the table still indicates that the Evans No. 2 Ditch experiences the largest flow fluctuations, especially in the months most frequently influenced by a river call, it does illustrate that smaller magnitude fluctuations can represent a fairly significant percentage of the average daily flow. For example, the Brighton Ditch's average daily fluctuation is approximately 3 cfs for the month of May. A rate of 3 cfs represents approximately 21 percent of the average daily diversion by the Brighton Ditch in the month of May. Therefore, depending on the size and geometry of the ditch and the magnitude of diversions, smaller flow fluctuations can still impact the operations of the ditch.

7.2 Impact to Evans No.2 Ditch

Based our District 2 call record analysis described in Section 6.0 of this report and the flow fluctuation analysis presented above, it appears that the Evans No. 2 Ditch system is currently the system most impacted by the diurnal fluctuation both in terms of frequency and magnitude. This finding is consistent with the information D&A obtained during our discussions with the State and the stakeholders of this study.

As previously mentioned, the Evans No.2 Ditch is frequently subject to a bypass call placed in the months of July, August, and September. Typically, a portion of the 177 cfs, October 5, 1871 water right of the Evans No. 2 is bypassed to the Western's August 10, 1871 water right for 71 cfs. In general, the Evans No. 2 Ditch, aided by a SCADA controlled headgate, must start decreasing its diversions in 10 to 15 cfs increments each hour starting at about 3:00 p.m. to accommodate the Western's call for water while the flow of the SPR is decreasing due to the diurnal fluctuation. Typically, by 6:00 p.m., the trough of the diurnal fluctuation reaches the Evans No. 2 Ditch. By 10:00 p.m., the diversions will level off and they will then gradually open their headgate to chase the rising limb of the diurnal flow. According to Evans No. 2 Ditch representatives, the diurnal flow swing at their headgate is usually on the order of 60 to 80 cfs; however, their diversions can vary from 60 to 177 cfs during the course of a single day. D&A's analysis for the 2010 through 2014 study period indicated the average fluctuation in the month of July was 45 cfs; however, the diversion records did show individual daily fluctuations consistent with the statements provided by the Evans No. 2 Ditch representatives.

D&A understands that the Evans No. 2 Ditch is currently discussing the option of constructing an equalization pond on the ditch to regulate the diurnal fluctuations. The result of chasing the diurnal fluctuation during periods the ditch is subject to a bypass call causes additional effort by the ditch company, by the irrigators under the ditch and causes inefficiencies for the 110 headgates on the Evans No. 2 ditch.

7.3 Impact to Calling Structures

D&A understands that in addition to affecting the bypassing structures, the diurnal fluctuation can also impact the senior ditch placing the call based on information from Western Ditch representatives. The impacts to the senior calling ditch are a result of being shorted water at times over the course of the day. As previously mentioned, the Water Commissioner's goal when administering the bypass call is to fully satisfy the senior calling right, often the Western Mutual Ditch's August 10, 1871 right for 71.12 cfs, while only requiring a partial curtailment of the upstream junior users. Depending on how accurate the estimates of inflow, outflow, demands, etc. are when the Water Commissioner makes the morning paper allocation of supply, it is possible the calling right may be shorted if actual inflows to the SPR are less than estimated inflows. In these cases, due to inadequate flow data, the Water Commissioner may unknowingly allow the junior right to divert more water and release less to the SPR than what would be actually required to fully satisfy the senior calling right. D&A understands that once the Water Commissioner is made aware of any shortages, the Water Commissioner requires an increased curtailment of the junior right in order to satisfy the calling senior right.

7.4 Impact to Water District 2 Water Users

In addition to the impacts experienced by the individual ditch systems placing a call or subject to a bypass call, D&A understands that the diurnal fluctuation does, at times, result in water flowing over the Western Ditch check dam. As discussed above, the Water Commissioner's goal when administering the bypass call is to fully satisfy the Western's calling right while avoiding any spills (i.e., flow over Western's check dam) to the downstream reach. Depending on how accurate the estimates of inflow, outflow, demands, etc. are when the Water Commissioner makes the morning paper allocation of supply, D&A understands the flow over the Western check dam can be upwards of 10 cfs, plus or minus. The water flowing over the Western check dam would be water that would otherwise be available for diversion by the District 2 irrigators above the Western Ditch headgate. The amount of flow over the Western check dam is also dependent on the bypassing ditch's ability to efficiently and responsively chase the diurnal fluctuation.

No record is kept as to the amount of water flowing over the Western check dam. Generally, the presence of flow over the check dam is known only by visual inspection. According to multiple stakeholder statements, the District 2 water users believe the State's, and specifically District 2 Water Commissioner Bill Schneider's, methodology of estimating and administering for the diurnal fluctuation results in only limited spills. Bill Schneider did indicate in the same stakeholder meetings that improvements to stream gages as well as additional gages on tributary inflows could aid and improve his allocation of supplies and further limit spills from this reach.

More discussion regarding potential improvements to administration, including additional stream flow measurements, is found in Section 9.0 of this report.

8.0 STRUCTURAL MITIGATION ALTERNATIVES ANALYSIS

Several possible alternatives have been proposed to address the diurnal flow fluctuation and its impacts on District 2 water users. These alternatives were offered by various stakeholders during meetings held for the Effluent Trade case and early stakeholder meetings held in preparation of this study. The possible solutions proposed by the stakeholders include:

A. Use of upstream storage at Chatfield Reservoir.

B. Use of an existing gravel pit reservoir between RWHTF and the Western Mutual Ditch headgate to dampen the diurnal fluctuation.

C. Construction of a new gravel pit storage reservoir downstream of RWHTF and upstream of the Western Ditch in order to dampen the diurnal fluctuation.

D. Use of storage at agreed upon locations, including agreed upon timed releases by parties using effluent discharged at RWHTF, to offset the diurnal fluctuation.

E. Construction of a storage reservoir near the headgate of the Western Mutual Ditch at the Gilcrest Reservoir site in order to dampen the impact of the diurnal fluctuation to the Western Ditch, which could benefit other water users that have historically been subject to calls by the Western Ditch. Investigation of a storage location between the RWHTF and the Western Mutual Ditch will not be limited to the Gilcrest Reservoir site. D&A will investigate storage locations near other ditch headgates on the South Platte River between RWHTF and the Western Mutual Ditch.

F. Use of existing or new river check dams that could be modified in order to regulate the diurnal fluctuation.

G. Utilize groundwater diversions for ditches to offset the diurnal fluctuation.

8.1 Preliminary Screening Analysis

D&A conducted a screening analysis to evaluate the preliminary engineering feasibility of each of the above proposed mitigation alternatives. In addition to the analysis of engineering feasibility, this study identifies potential legal, institutional, and permitting issues associated with each alternative. Additional engineering, legal, and permitting research will be required to determine if any of the alternatives presented herein will be suitable for implementation.

8.1.1 Upstream Storage at Chatfield Reservoir

A mitigation alternative presented by the stakeholders involved the use of storage and releases from Chatfield Reservoir as a source of supplementing the flow in the SPR during the trough of the diurnal fluctuation. The Chatfield Reservoir is a 350,000 acre-foot on-channel reservoir located southwest of Denver, at the confluence of the SPR and Plum Creek within the South Platte River Basin. Chatfield Reservoir is primarily a flood control structure operated by the US Army Corps of Engineers (Corps); however, Denver Water does have a contract to store approximately 27,000 acre-feet of water within the conservation pool of the reservoir. There is currently a project underway (Chatfield Reservoir Reallocation Project) to reallocate approximately 20,600 acre-feet of the existing flood pool such that it can be utilized by municipal and agricultural water providers of the Front Range area. The Chatfield Reallocation Project is a partnership among nine water providers in the Denver metropolitan area. Each organization will receive a varying amount of storage space at Chatfield once the reallocation is complete. These organizations include: Castle Pines Metropolitan District, Cast Pines North Metropolitan District, Town of Castle Rock, Centennial Water & Sanitation District, Center of Colorado Water Conservancy District, and the Central Colorado Water Conservancy District.

In general, the Chatfield Reservoir mitigation alternative would conceptually use the storage and subsequent timed release of natural streamflow flowing into Chatfield Reservoir as a source of water to mitigate the trough of the diurnal fluctuation. Operations would include the timed release of all or a portion of the daily inflow to Chatfield Reservoir, subject to release for downstream purposes, such that when the storage release reaches the RWHTF outfall approximately 22 miles downstream, it would fill in or supplement the trough of the diurnal fluctuation. More specifically, the practice would involve varying the release out of Chatfield Reservoir on an hourly basis with gradually increasing and then decreasing release rates centered around an approximate 7 hour period (i.e., approximate length of trough of RWHTF diurnal fluctuation). The patterned release would likely be pre-determined based on recent RWHTF discharge information including the approximate timing and magnitude of the trough.

As D&A understands this concept, the peak of the SPR's diurnal fluctuation would only be slightly reduced as a result of storing the natural streamflow at Chatfield. While the concept would be to store water in Chatfield during the times the peak of the RWHTF discharge is entering the SPR, the magnitude of the daily peak of the SPR during the irrigation season is most generally a result of the RWHTF outfall and not the natural streamflow entering District 2. Therefore, this alternative would do very little to reduce the magnitude of the peak. However, the Chatfield Reservoir storage release would combine with the trough of the RWHTF discharge to increase the SPR trough and therefore reduce the variability between the daily peak and the daily troughs.

In terms of the potential storage space, Chatfield Reservoir would certainly have adequate daily storage capacity to store and retime normal daily inflows during the irrigation season for the purpose of potentially mitigating the trough of the diurnal fluctuation. From a water availability standpoint, D&A was unsure of the reliability of natural stream inflow into Chatfield Reservoir that could be stored and retimed for this mitigation purpose. Therefore, D&A examined the "Chatfield Checksheet" and the historical daily flows present at the South Platte River Below Chatfield Reservoir streamflow gage (PLACHACO). The Chatfield Checksheet is a jointly developed and maintained accounting form, mainly by Denver Water and the State, which accounts for, among other ancillary structures and inflows, the daily operations of the Strontia Springs and Chatfield reservoirs. One of the main metrics tracked by the Chatfield Checksheet is the daily required outlet release of Chatfield Reservoir, which is the amount of inflow into

Chatfield Reservoir not allocated for direct storage within the reservoir, outflow exchanges, or deliveries out of the manifold such as the deliveries to the fish hatchery, Last Chance Ditch, Nevada Ditch, City Ditch, etc. The calculated required outlet release is the daily amount of natural streamflow that should be available to meet downstream water requirements and is therefore used as the basis of determining the Chatfield Reservoir release rate. If the release requirement changes significantly from day to day, the SEO along with the Corps will make an adjustment to the gate such that the actual release is closer to the calculated release. Therefore, the daily flows at the streamflow gage located immediately below the Chatfield Reservoir outlet, PLACHACO, provide a good approximate record of the calculated required release from the Chatfield Reservoir on a daily basis and thereby the volume of water that could be stored and retimed for the purpose of mitigating the downstream diurnal fluctuation.

D&A analyzed the daily flow record provided by PLACHACO for the period of July 1986 through December of 2013 and found that the average volume of flow released from Chatfield Reservoir on a daily basis would be adequate, in most irrigation months and years, to offset the average 70 acre-foot trough of the RWHTF. As shown in **Table 9**, in all but the driest years (e.g., 2002 and 2012), the daily volume would be adequate (i.e., in excess of 70 acre-feet) in the irrigation months of April through August. The months of March, September and October are not as reliable but still average no less than 53 acre-feet of daily availability. Therefore, from examination of the streamflow releases from Chatfield Reservoir, it would appear that the availability of excess or unallocated natural streamflow present at Chatfield Reservoir would be adequate to fill-in the average trough of the diurnal fluctuation present at the RWHTF outfall if the storage and retiming of the streamflow could be done using the Chatfield Reservoir and its outlet infrastructure.

While water availability on a daily basis may be adequate to mitigate the trough, the necessity to vary the release rates out of Chatfield Reservoir on an hourly basis presents a fairly significant departure from the historical operations of the Chatfield outlet works D&A's research on this topic indicated that the operation of the Chatfield Reservoir outlet works is strictly managed by the Corps with input from the State Engineer's Office (SEO). When the stage of Chatfield Reservoir is within the normal "conservation pool", the SEO determines, using the previously mentioned Chatfield Checksheet, what daily river release rates are necessary to meet the downstream water requirements and will issue the necessary regulation release orders to the Corps. D&A understands that while these release rates can and are occasionally varied on a daily basis, the normal operation is to make gate adjustments less frequently. To use Chatfield Reservoir storage to offset the trough of the diurnal fluctuation, gate changes would be required on an hourly basis. By examination of multiple months and years of the Chatfield Checksheet, it appears gate changes are only made once a day, if at all. D&A is not aware of how the Chatfield Reservoir Reallocation Project will alter the normal operations of outlet works. However, given the current level of communication and coordination required for gate changes, hourly changes of releases from the Chatfield Reservoir outlet works would require a significant change in the water control plan currently instituted by the Corps.

D&A did not request a legal opinion on whether or not a decree would be necessary to temporarily store and retime the natural streamflow that flows into Chatfield Reservoir. Based on our understanding of how the reservoir outlets are operated, there is likely already some amount of temporary impounding taking place in between gate changes. A decree may be necessary and useful to provide terms and conditions for ushering these releases downstream to the Study Reach. These releases would have to flow past the Burlington Ditch headgate which is a historical dry-up location on the SPR.

D&A did not find any fatal flaws with the conceptual alternative of using Chatfield Reservoir storage and releases as a mitigation measure. However, it is D&A's opinion that the changes to the State's and Corps' operations of the Chatfield Reservoir outlet works necessary to make this alternative work involve both legal and institutional issues that may prove difficult and would require additional research beyond the scope of this study to determine if such changes would be feasible.

8.1.2 Use of Existing Gravel Pit for Flow Equalization Prior to Discharge

As previously mentioned, the adjacent lands on either side of the river within the Study Reach, especially upstream of Fort Lupton, CO, have been heavily mined for sand and gravel. The reclaimed pits that have been lined have been largely acquired by local municipalities and water providers for recapture and storage of reusable effluent supplies discharged at the RWHTF. **Figure No. 2** shows the location of the lined gravel pits and is color-coded by owner. As shown in these figures, the City of Thornton owns a large percentage of the reclaimed pits primarily made up of multi-cell complexes such as their East Gravel Lakes (aka, Tani Lakes Storage Complex), West Gravel Lakes, Cooley East, and Hammer facilities. Other owners of gravel pit storage in this reach include: South Adams County Water and Sanitation District (SACWSD), Denver Water Board, Aurora Water, the City of Arvada, and the City of Brighton.

During stakeholder meetings, discussions occurred regarding the potential use of an existing gravel pit that could be utilized to capture and equalize RWHTF effluent prior to its discharge to the river. An inherent requirement of this alternative would be the use of a gravel pit within close proximity to RWHTF to avoid lengthy and cost prohibitive pipelines and/or pump stations. By examining the location of existing gravel pits, the most likely candidates for use as an equalization structure would be Denver Water's Welby (a.k.a. Cat Lake) and/or Bambei-Walker (a.k.a. Miller Lake) pits based solely on their proximity to the existing RWHTF outfall. While these two pits are within 1,500 to 2,000 feet of the existing RWHTF outfall, a pipeline constructed to convey effluent to these pits would require a costly crossing of the SPR and/or Interstate 270.

D&A discussed the feasibility of this alternative from an institutional and legal standpoint with the Metro District and their legal counsel. The Metro District stated that their effluent discharge permit issued by the Colorado Department of Public Health and Environment (CDPHE) is for a specific location on the SPR. If the discharge were from an equalization pond different from the existing RWHTF discharge location, the Metro District stated that the permit amendment process of moving the discharge location would be lengthy and presents significant regulatory and legal hurdles. These hurdles would involve studying potential water quality impacts caused by the location of the equalization basin and outfall relocation and determining compliance with current permit and stream standards that are based on the location of the existing outfall. The Metro District indicated that water quality parameters potentially impacted by an equalization pond and/or outfall relocation include, but are not limited to, dissolved oxygen (DO) levels, reduced natural nutrient processing, selenium and cadmium levels, and increased water temperatures in the SPR reach above the new outfall.

In terms of legal hurdles, the Metro District believes that moving the discharge point will create very similar legal issues as those seen in Case No. 11CW74. That is, there are numerous water court decrees that identify the Metro District's current outfall location for exchanges, augmentation, and the point of municipal return flows. The movement of the outfall from its current location would create issues for the entities with such decrees. Therefore, the Metro District believes that a relocation of the existing outfall would ultimately involve significant added expense as well as litigation with numerous parties. Moreover, the Metro District does not believe that storing effluent to mitigate the diurnal flow is consistent with its statutory purpose of intercepting, receiving, transporting, treating, and disposal of the outfalls of member sewer systems (C.R.S. 32-4-506). The Metro District is also unsure of whether or not changing the timing of their discharge by storing and releasing the effluent at a more constant rate presents any legal issues as they do not own or exercise dominion or control over the water they treat. In general, the Metro District treats influent as it comes in and releases treated effluent in a similar pattern. Based on the institutional and legal opinions provided by the Metro District, it is D&A's opinion that the alternative of using an existing gravel pit for effluent equalization prior to discharge of the effluent to the SPR has potentially insurmountable legal and regulatory flaws that should effectively remove it from further consideration.

8.1.3 Use of Existing Gravel Pit between RWHTF and Western Mutual Ditch Headgate

An alternative concept developed by the stakeholders involves the use of an existing gravel pit storage reservoir located downstream of the RWHTF discharge for the purpose of mitigating the diurnal fluctuation. Conceptually, this alternative would use an existing gravel pit storage reservoir, and associated filling and discharging infrastructure, to divert the peak of the diurnal fluctuation off the SPR and release it during the following trough. This alternative would avoid the previously discussed legal and institutional issues regarding the retiming and relocating of the existing RHWTF discharge to the SPR as the effluent discharge would occur the same as it does today. The storing and retiming of the peak would be made by a diversion off of the SPR subsequent to the discharge of the RWHTF effluent to the SPR.

There are numerous lined gravel pit storage reservoirs and complexes, primarily owned and operated by municipal water providers, along the adjacent lands of the SPR within the Study Reach (see **Figure 2**). A majority of the gravel pits are filled via diversions of mostly reusable effluent supplies discharged to the SPR at the RWHTF outfall. The reusable effluent supplies are diverted at the headgates of District 2 irrigation ditches and conveyed to the gravel pits pursuant to contractual carriage agreements between the ditch companies and the municipalities. These carriage agreements usually specify the amount of the ditch capacity the municipal water provider can use for the purpose of conveying their supplies to their point of storage. The available capacity can be either the ditch's excess capacity (i.e., ditch's capacity in excess of that needed for ditch company's water rights) and/or additional constructed capacity whereby the ditch and infrastructure upstream of the gravel pit storage is improved to meet the simultaneous needs of both the ditch company and the water provider.

Based on the average peak of the diurnal fluctuation at the Henderson Gage compared to its average daily flow, a gravel pit would need to have an inflow capacity of approximately 40 cfs to completely divert the peak flow rate. These diversions would occur over approximately 14 hours and would utilize the gravel pit's existing filling structure and capacity or additional constructed capacity added for this purpose.

Due to the average depth of gravel deposits within this reach of the SPR (i.e., 30 to 50 feet below surface), a majority of the gravel pits require the use of a pump station to make releases to the SPR. Assuming that the release of the previously stored peak of the diurnal fluctuation during the time of the trough would require pumping, the pump station would be required to pump approximately 80 cfs to be capable of fully supplementing the minimum point of the trough.

The costs of this alternative could vary depending on what infrastructure upgrades would be required for the existing gravel pit storage reservoir in terms of inflow capacity and outflow capacity. The current owner of the storage reservoir would likely require payment for the use of the storage and, the purchase and development of lined storage ranges from $7,000 to $10,000 per acre-foot. If 70 acre-feet of equalization storage is required, the cost for storage would be approximately $490,000 to $700,000. If the construction of a pump station was required, an 80 cfs pump station including the pump(s), vault, inflow and outflow piping, controls, etc. could cost an estimated $8.3 million (see **Table 10**) or more depending on specific site conditions and required infrastructure.

In addition to the capital costs, the annual energy costs associated with operating the pump station are substantial. D&A estimated annual energy costs associated with operating the pump station to range from $41,000 to $44,000 (see **Table 11**) depending on the equalization pond's frequency and duration of use. That is, depending on the hydrologic and administrative conditions of the SPR (i.e., average, wet, dry), the reliance on the use of an equalization pond may vary. Annual energy costs were developed for an average and dry hydrologic year. As previously discussed, the diurnal fluctuation of the RWHTF discharge is not an issue for irrigators unless the SPR's flows get below a certain flow threshold (e.g., approximately 400 cfs). Below this flow rate, a bypass call is usually placed and the diurnal fluctuation creates the previously described down-ditch issues for the structure subject to the bypass call. Therefore, to estimate the duration of use of the equalization pond and pump station on an annual basis, D&A summarized the District 2 bypass calls for the years of 2000 through 2012. The following table summarizes the average annual number of bypass calls by month and the maximum for the study period which occurred in 2012.

Number of Bypass Calls Per Month

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Average	0	0	1	4	5	7	15	16	9	0	0	0	57
2012	0	0	7	6	14	23	20	25	23	2	0	0	120

The range of estimated annual energy costs were developed based on the pumping of the diurnal flow peak for approximately 60 days a year on average and for a maximum of 120 days.

There will likely be legal issues associated with the temporary diversion and storage of the peak flows of the SPR into an off-channel reservoir. The State generally allows for direct flow water rights to be temporarily detained for up to 72 hours in order to allow more efficient or effective beneficial use of the water. However, this alternative is essentially an off-channel gravel pit used to divert and temporarily store portions of the SPR flow made up of multiple entities' water rights, reusable supplies, and native flow. Downstream water users may be reluctant to have a portion of their water rights temporarily detained for this purpose without a court approved decree. Accordingly, it is likely a decree would be required to operate the off-channel equalization pond and the cooperation of the District 2 water users. Additional legal research and opinion would be required to identify all legal issues surrounding this alternative.

8.1.4 Construction of a New Gravel Pit

If storage within an existing gravel pit storage facility was not available or was thought to be problematic from a shared operating standpoint, a new gravel pit storage reservoir could be constructed for the purpose of flow equalization. Due to the relatively small amount of storage required for flow equalization (i.e., 70 acre-feet), it is likely the gravel pit constructed will be significantly larger based on the size of the majority of the existing gravel pits within the Study Reach. In this case, it may be again beneficial to share the storage capacity of the gravel pit with an entity with larger storage requirements. From a pumping cost standpoint, it is much more efficient to pump the flow equalization amounts from the "top" of the gravel pit rather than having to lift it from greater depths if the gravel pit is not kept near full.

This alternative may have added expenses over the use of an existing gravel pit and its associated infrastructure. If the new gravel pit did not have the ability to divert water from a nearby irrigation ditch or from an existing river diversion, a new river diversion would be required to divert the peak of the diurnal fluctuation. Given the current regulations and permitting requirements necessary to construct a new river diversion (e.g., Section 404 permitting), constructing a new river diversion would be cumbersome and expensive. Storage and pump station costs would be similar to those discussed above.

This alternative would have very similar legal issues to those discussed for the existing gravel pit reservoir. Because the gravel pit would require diverting and temporarily storing multiple entities' water rights, a water court decree and the cooperation of the District 2 water users will likely be required to do so.

8.1.5 Use of Storage and Timed Releases by Parties using RWHTF Effluent

Beyond what has been previously discussed regarding the use of gravel pit storage and timed releases of effluent to mitigate the diurnal fluctuation, an additional mitigation alternative was proposed that would involve a cooperative operating principle to be developed by the State and willing participants within the Study Reach, whereby the participants would agree to make strategically timed releases such that the augmentation and/or substitute supply releases would supplement the trough of the diurnal fluctuation when it is present at the outlet works of the storage structure. The participants of the operating principle or agreement would likely be those entities already relying on releases from gravel pit storage to augment depletions within the Study Reach or provide a substitute supply for an exchange originating within the Study Reach.

For example, rather than making an augmentation release of 20 acre-feet on an average basis over the course of a day (e.g., 10 cfs release), the augmenter would make a larger release over a shorter period of time. The timing of the release would be determined based on the timing of the trough within that reach. The increased rate or varied rate would be dependent on factors such as the capacities and limitations of the existing infrastructure (e.g., pump station, outlet pipe, etc.).

The effectiveness of this alternative to mitigate the diurnal fluctuation is dependent on the level of participation of the entities augmenting and/or exchanging within the reach, the participants' ability to increase their release rates during the time of the trough, and most importantly, the amount of consistent augmentation and/or substitute supply being released from gravel pit storage within the Study Reach. Given that exchanges within this reach generally rely on relatively large flow rates, releases of substitute supplies at downstream exchange termini are unlikely to occur during the times in which the diurnal fluctuation is problematic. Therefore, this alternative would likely rely heavily on augmentation releases. D&A was not able to quantify the existing or projected amounts of augmentation planned for the Study Reach, but understands that the majority of the augmentation currently taking place within the Study Reach is done using augmentation supplies that are left in the SPR after discharge from RWHTF. For example, Aurora Water's current augmentation of the Prairie Waters Project (PWP) well depletions is done almost exclusively using their reusable effluent supplies discharged at RWHTF. Therefore, Aurora does not currently make augmentation releases from their Walker Reservoir and/or Everist Reservoir on a consistent basis. However, as PWP depletions increase with the project's increased capacity and Aurora's increased reliance on it to meet an increasing municipal demand, Aurora expects to rely more regularly upon releases from their gravel pit storage for the purpose of augmenting PWP depletions.

D&A understands that Denver Water and Thornton largely use their gravel pit storage along this reach for exchange purposes and in Thornton's case, storage of Clear Creek water, Burlington-Wellington shares, and SPR raw water sources. Therefore, D&A does not believe that either Denver Water or Thornton currently have any significant or consistent augmentation occurring within the Study Reach.

This alternative may be feasible but its effectiveness may be limited, at least in the short term. As consistent augmentation via gravel pit releases increase with the reach, this alternative could help mitigate the diurnal fluctuation if augmenters are willing to participate and modify their operations with the goal of mitigating the diurnal fluctuation. This alternative could potentially help fill in the trough of the diurnal fluctuation but would not help reduce the peak flow. This alternative would likely require frequent communication between the Water Commissioner and the participants and likely increase the operating and maintenance expenses of the participants due to operating pumps and infrastructure at higher and possibly varying flow rates.

8.1.6 Storage Near Ditch Headgates

A majority of the alternatives presented by stakeholders and previously discussed herein are "regional" in nature, meaning that they are mitigation alternatives that would attempt to mitigate the diurnal fluctuation for the entire Study Reach or a large portion of it. However, this mitigation alternative looks to utilize individually owned and operated equalization ponds near river headgates in order to regulate the fluctuations delivered to shareholders. Therefore this alternative would not mitigate the diurnal fluctuation the SPR experiences but rather eliminate the large fluctuations and down-ditch problems on a ditch-by-ditch basis. This mitigation alternative also acknowledges that not all ditch systems are impacted equally by the diurnal fluctuation and therefore this alternative could be a more cost effective alternative than a regional fix.

The Western Mutual Ditch Company constructed the "Western Mutual Equalization Pond" in 2010 to help regulate flows and provide a more stable supply to its shareholders (White Sands Water Engineers, 2014). The clay lined, on-channel equalization pond has a capacity of 67 acre-feet and utilizes an Obermeyer Hydro, Inc. spillway gate with an inflatable air bladder to control and regulate the amount of water released to shareholders. D&A understands the equalization pond has been effective in regulating deliveries to Western's shareholders located downstream of the equalization pond. However, because it is located downstream of the river headgate, it has done nothing to regulate the fluctuating flows experienced at the river diversion.

D&A understands that the Evans No. 2 Ditch company is discussing and evaluating constructing their own equalization pond to dampen the variations in diversions they experience over the course of a day, especially during the bypass call. Similar to the analyses D&A performed for the RWHTF and Henderson Gage hydrographs to determine the approximate storage requirement for storing the peak of the diurnal fluctuation, D&A examined hourly diversion data for the Evans No. 2 ditch during days it was subject to a bypass call. The analysis indicated that the average volume of water in excess of the average daily flow, or conversely the volume of water required to fill in the trough of the fluctuation, is approximately10 acre-feet. While this is the average volume required, D&A performed an exceedance probability analysis to determine what the equalization volume would be required to store and regulate (i.e., release at constant flow rate) 95 percent of the daily fluctuations experienced by the Evans No. 2 Ditch. The results of the exceedance analysis indicate that a volume of approximately 35 acre-feet would be required to store and regulate 95 percent of the fluctuations.

This alternative is feasible, as evidenced by the Western Mutual Equalization Pond, and is effective in providing a more regular and stable supply to the Western Ditch shareholders. For other ditch systems, this alternative would require adequate land area along the ditch for construction of the pond and ideally a reach of the ditch with adequate fall necessary to create the required storage to dampen irregular diversion rates. D&A does not foresee any significant legal hurdles as the State generally allows for direct flow water rights to be temporarily detained for up to 72 hours in order to allow more efficient or effective beneficial use of the water.

8.1.7 Use of Existing or New River Check Dams

A mitigation alternative presented and discussed at the stakeholder meetings was utilizing an existing river check dam and modifying it to regulate the diurnal fluctuation. As D&A understands it, the concept would be to modify an existing river check dam, or construct a new one, so that the usually static (i.e., non-adjustable) check dam spill elevation could be varied by the use of an Obermeyer Hydro, Inc. inflatable dam (or equivalent). When the beginning of the peak of the diurnal fluctuation is present at the check dam, the inflatable dam would be raised so that it would only allow a predetermined average flow rate over the dam, and "store" the peak (i.e., the flow above the average daily flow rate) behind the dam. Therefore, the river and its banks become a temporary on-channel reservoir. As the diurnal fluctuation recedes such that "inflows" are lower than the average, the inflatable dam would lower and release the on-channel storage in order to maintain the flows within the SPR downstream of the check dam at a more constant average daily flow rate.

D&A analyzed the amount of storage potential available within the channel of the SPR at three different locations utilizing the U.S. Army Corps of Engineers (USACE) HEC-RAS model developed for the 2005 Adams County Flood Hazard Area Delineation for the South Platte River (CDM, 2005). The three locations selected for our analysis were 1) the Fulton Ditch check dam, 2) a location 8,750 feet downstream of the Brantner Ditch check dam, and 3) a location 4,800 feet upstream of the Brighton Ditch headgate (see **Figure 12**). The first location was selected based on it being an existing check dam located near the top of the Study Reach and the second and third locations were selected similar to how one would select a suitable location for an on-channel reservoir to maximize potential storage (i.e., a broad and flat reach). Due to limitations of the survey used to create cross sections at other existing check dams, D&A did not evaluate any other existing structures beyond the Fulton Ditch check dam. However, the three locations that were evaluated are representative of the channel geometry and the potential storage available within the Study Reach.

HEC-RAS is capable of calculating the volume of water between river cross-sections. Therefore, for each of the three scenarios, D&A incrementally increased the water surface elevation within the model at the cross-section representing the identified location. The rise in the water surface elevation simulates the stage of the river at the crest of the inflatable check dam. By comparing the volume upstream of the cross-section before and after the artificial water surface rise, we determined the amount of available storage upstream of the check dam created by the rise. The results of this analysis are summarized in the following table.

	Storage Behind Incremental Check Dam Rise, AF		
Rise In Stage (ft)	Fulton Ditch Check Dam	8,750 ft d/s of Brantner Ditch Check Dam	4,800 ft u/s of Brighton Ditch Check Dam
1	0.13	1.59	0.39
2	0.90	7.36	7.97
3	4.21	13.64	17.98
4	12.08	21.44	30.97
5	25.39	31.19	47.45
6	46.43	47.63	87.64
7	105.22	73.19	

As previously described, the volume necessary to store the peak of the diurnal fluctuation, or the amount of flow above the average daily discharge, is approximately 70 acre-feet. As shown in the table, a fairly significant rise in the water level of the SPR is required to gain enough volume to substantially store the peak of the diurnal fluctuation. For each of the three scenarios, to be able to fully store the peak volume of 70 acre-feet, a six to seven foot check is required.

This alternative presents the potential for significant flooding, riverbank destabilization, and adjacent land issues as a result of a rise and drop of the SPR river stage of this magnitude. The rapid rise and the decline of the river stage on daily basis would likely increase slumping and bank stabilization issues. Furthermore, the increased stage, even temporarily, could create high groundwater issues for neighboring properties. Using HEC-RAS, the flowrate corresponding to a rise of this magnitude ranges from approximately 3,400 to 4,200 cfs or approximately one-third the flow rate of a 10-year frequency storm.

A version of this alternative that would use more than one inflatable check dam could prove more feasible from a physical and engineering standpoint. The concept would be to use multiple inflatable check dams and therefore reduce the storage requirement and corresponding water rise requirement. However, using multiple dams may complicate operations and water rights issues. In addition, based on the three cross sections we analyzed, it would require three checks with a water level increase of slightly over 4 feet at each check dam to create the required 70 acre-feet of storage behind the check dams.

Because of the magnitude of the rise required to gain storage volumes necessary to fully or partially mitigate the diurnal fluctuation and the resulting flood and bank stability issues, this alternative is not likely as feasible as other alternatives presented in this report and therefore we did not fully investigate the costs associated with this alternative. However, based on D&A's experience, there are significant costs associated with inflatable check dams ranging in length from 150to 250 feet as well as the construction costs associated with retrofitting the inflatable check dam into one or more existing irrigation river diversions. In addition to these costs, significant bank stabilization work would be required on both sides of the SPR for approximately 5,000 to 6,000 feet upstream of the check dam.

There may also be legal issues associated with the temporary impoundment of water behind the check dams. As previously mentioned, the State generally allows for direct flow water rights to be temporarily detained for up to 72 hours in order to allow more efficient or effective beneficial use of the water. However, a check dam on the SPR would create a regional on-channel reservoir that would temporarily store multiple entities' water rights, reusable supplies, and native flow. D&A is unsure if a decree would be required to operate the variable check dam or if downstream water users would be reluctant to having a portion of their water supplies temporarily detained. Additional legal research would be required to identify all legal issues surrounding this alternative and to assess the feasibility of this alternative.

8.1.8 Utilization of Groundwater Diversions to Offset Diurnal Fluctuation

An alternative was presented by the group of stakeholders that involves the use of wells to supplement ditch diversions during the time of the trough. The conceptual idea involves pumping wells located near the ditch headgates and close to the SPR and discharging them into the ditch to help regulate the flows within the ditch when diversions decrease below a desired flow rate as a result of the trough. The depletions caused by the pumping of the well would be augmented by the ensuing peak of the diurnal fluctuation.

Alluvial wells that have been constructed along the river in this reach of the SPR generally yield between 1 and 2 cfs. Therefore, depending on the individual ditch system and their fluctuations, this alternative may require a significant number of wells. For example, on average the Evans No. 2 Ditch experiences a 24 cfs fluctuation below the average daily flow during the month of July. That means that during the trough of the diurnal fluctuations, their diversion rate is 24 cfs less than the average daily diversion rate. Therefore, to fully supplement the diversions during the trough, it would require approximately 12 wells assuming the upper range of the expected yields (i.e., 2 cfs). Not only are the capital and operational costs associated with this number of wells financially burdensome, the amount of real estate along the river necessary to construct a well field of this magnitude is sizeable. For example, Aurora's current PWP well field consists of 23 wells that stretch over approximately 2 miles of the western bank of the SPR. That being said, strictly from an engineering and physical feasibility standpoint, this alternative may be better suited for the ditch systems with smaller diversion rates and smaller negative departures from their desired daily average flow rate.

There are likely fairly significant legal issues associated with this alternative related to the operation of the wells. D&A understands that the original concept for this alternative was that the supplemental wells would operate as "headgate wells". That is, the wells would be located within close proximity of the SPR (e.g., less than 100 feet) and that their depletions to the river would be assumed to be instantaneous as if the pumping was an immediate diversion from the river. Therefore the pumping depletions would be replaced on the same day with the ditch company's direct flow water rights available within the SPR during the peak of the diurnal fluctuation. However, we understand that the State's position on the approval and administration of headgate wells has changed within the last 5 to 10 years. The State now requires a detailed groundwater modeling analysis that indicates that the wells have depletions within the same day as pumping. If the modeling doesn't support the same-day depletions, the State will require the wells' stream depletions be augmented pursuant to a decreed plan for augmentation. Current modeling methodologies and expert opinions regarding modeling input parameters results in very few wells being classified and administered as headgate wells. Therefore, this alternative would likely require the ditch company to obtain a decreed augmentation plan in order to operate the wells. The augmentation plan would require daily accounting, an augmentation station at the river headgate, and other administrative requirements that would complicate the operation of the supplemental wells.

Given the quantity and expense of the wells required to supplement the troughs of the ditch systems and the requirement, per current water law, of an augmentation plan, this alternative doesn't appear to be as feasible as others presented within this report.

9.0 REVISED ADMINSTRATIVE PROCEDURES

As previously discussed, the current District 2 Water Commissioner's administrative practice for determining the need for a call or bypass call upstream of the Saint Vrain Creek confluence is to: 1) discuss the daily water needs of the Western Ditch with a ditch company representative, since the Western Ditch is most often the swing ditch, 2) examine the low flow "trough" of the daily hydrograph at the Henderson Gage, 3) examine the gaged and known inflows within the reach upstream of the Western Ditch to determine their potential contribution to demand, and finally 4) to paper distribute the water to all in-priority water users, according to their demands. If the Water Commissioner determines the Western's demand will not be completely satisfied, the Water Commissioner will place a bypass call within District 2. The bypass call allows the Water Commissioner to work with upstream junior users so that only a partial curtailment may be required to satisfy the Western Ditch's demands.

As previously mentioned, the Water Commissioner's goal when administering the bypass call is to fully satisfy the Western's calling right while avoiding any spills (i.e., flow over Western's check dam) to the downstream reach. Depending on the accuracy of the estimates of inflow, outflow, demands, etc. when the Water Commissioner makes the morning paper allocation of supply, D&A understands the flow over the Western check dam can be upwards of 10 cfs, plus or minus. The flow over the Western check dam is also dependent on the bypassing ditch's ability to efficiently and responsively chase the diurnal fluctuation.

No record is kept as to the amount of water flowing over the Western check dam. Generally, the presence of flow over the check dam is known only by visual inspection. According to multiple stakeholder statements, the District 2 water users believe the State's, and specifically District 2 Water Commissioner Bill Schneider's, methodology of estimating and administering for the diurnal fluctuation results in only limited spills. Bill Schneider did indicate during stakeholder meetings as well as during the September 11, 2014 stakeholder field trip that improvements to stream gages as well as additional gages on tributary inflows could aid and improve his allocation of water supplies and further limit spills from this reach.

The following sections discuss the existing streamflow gages, methodology relied upon for administration of this reach, recommended improvements to existing infrastructure, and the potential benefits of gaging additional tributary inflows.

9.1 Current Mainstem Stream Flow Gages

The SPR mainstem gages that aid in the administration of the Study Reach include the South Platte River at 64th Ave. Commerce City, CO gage (PLASIXCO), the previously mentioned South Platte River at Henderson, CO gage (PLAHENCO), the previously mentioned South Platte River near Fort Lupton, Co gage (PLALUPCO), and to a lesser extent, the previously mentioned South Platte River near Kersey, CO gage (PLAKERCO). The 64th Ave. gage and the Fort Lupton gage are owned and maintained by the USGS whereas the Henderson and Kersey gages are owned and maintained by the Colorado Division of Water Resources.

Through discussions with David Nettles, Division 1 Engineer, and Bill Schneider, District 2 Water Commissioner, D&A understands that the State's ability to rely on USGS gages for allocation of flow, especially when the river is low, is difficult. Bill Schneider indicated that the USGS gages are rated and calibrated on 6 to 8 week intervals whereas the State hydrographers rate the Henderson Gage at least every 2 weeks and more frequently if a large storm event shifts the fairly sandy bed in the vicinity of the gage. Because the USGS gages are rated less frequently, Bill believes they are at times unreliable. For example, Bill's experience is that at low flows, the 64th Ave. gage can read high by up to 30 cfs, whereas the Fort Lupton Gage can underestimate the actual flow of the SPR by 40 to 50 cfs. These discrepancies make it difficult for the State to have sufficient data to fully evaluate the flow conditions at different locations within the Study Reach and allocate water to the District 2 ditches. Both Bill Schneider and David Nettles agreed that more frequent calibration of the USGS gages within this reach would aid the administration of the SPR within the Study Reach, especially in dry months and years when the diurnal fluctuation is problematic for District 2 irrigators.

9.1.1 Improving Existing Mainstem Gages

D&A contacted Mr. Greg Smith with the USGS to discuss the potential of increasing the frequency in which the USGS currently rates and calibrates the 64th Ave. gage and the Fort Lupton gage. Mr. Smith said that those two gages, which are already entirely funded by the Metro District, are currently rated __________. Mr. Smith mentioned that due to the relatively infrequent rating of these gages, he was not surprised the State did not find them to be accurate at low flow rates. Mr. Smith stated that to increase the rating frequency to a bi-weekly event, similar to the State's frequency, the annual cost increase would be approximately $4,000 per gage site.

9.2 Tributary Inflows

D&A understand that the tributary inflows that enter the SPR downstream of the Henderson Gage are of particular interest to the Water Commissioner Bill Schneider when making a paper allocation of supply during periods of low flow. Within the Study Reach, these tributary inflows include Big Dry Creek, Little Dry Creek, the Graflin Slough, the Lorentz Slough, and other minor drainages. Big Dry Creek is the only one of these tributary inflows that is gaged (BIGDAFCO). Therefore, most of tributary inflows are not measured, yet at times contribute measurable and meaningful flow rates to the SPR. Little Dry Creek and the Graflin Slough are downstream of the Evans No. 2 Ditch river headgate and therefore available for diversion at the Western Ditch headgate. Without gages, estimates of the inflows are made. If the estimate of these inflows is significantly different from actual flows, or they change significantly during the course of the day, this can result in either over-curtailment of the ditch subject to the bypass call and water being wasted over the Western check dam, or result in the Western Ditch being shorted.

Therefore, to aid with administration, Bill Schneider mentioned it would be useful to gage and instrument some of these larger tributary inflows. It was Bill's opinion that a gage on Little Dry Creek and the Graflin Slough would especially be useful in allocating the flow between the Evans No. 2 Ditch and the Western Ditch. Bill also mentioned that the gage on Big Dry Creek needed some improvements. D&A has since learned the State is the process of improving the Big Dry Creek gage.

D&A corresponded with Mr. Russell Stroud, Division 1 Lead Hydrographer, regarding the costs associated with construction of stream flow gages. Mr. Stroud provided us with very recent construction cost data for gages destroyed and replaced following the 2013 flood event. D&A reviewed the various projects and cost estimates and concluded that construction of a stream flow gage on a tributary drainage similar to Little Dry Creek it would cost between $20,000 and $45,000 depending on the selected grade control structure. Beyond construction costs, the $20,000 to $45,000 total includes material costs such as the shelter, stilling well, data logger, and the instrumentation and electronics required for the State's telemetry. It should be noted that these costs are based on State employees designing, bidding, and overseeing the construction of the gages. Costs would likely be higher if designed and constructed by a non-State entity. Mr. Stroud stated that the State's annual maintenance, calibration, and upkeep costs would be approximately $_________ per gage site.

9.3 Stage Recorder at Western Mutual Ditch River Check Dam

As previously mentioned, the amount of water flowing over the Western's check dam provides the Water Commissioner a visual idea of how closely the paper allocation of water supply is to meeting the irrigation demands based on actual river conditions. That is, if there is a consistent amount of water going over the Western check dam during the time there is a bypass call to the Western, the amount of curtailment occurring at the junior structure (e.g., Evans No. 2) could possibly be relaxed. Conversely, if there is no water flowing over the Western check dam and the Western is still not satisfied, the bypassing structure may need to further curtail its diversions. D&A understands that the State's ability to monitor the Western check dam and the amount of water flowing over it is by visual inspection. Therefore, it has been proposed that a stage recorder be installed at the Western check dam that continuously measures and reports the stage of the SPR at the check dam. Based on the known elevation of the Western check dam, the Water Commissioner could instantaneously monitor the depth of the water above or below the check dam. The State could develop a rating curve of approximate flow rates at given overtopping depths or simply develop operating rules based on the depth of flow over the dam.

Because there are approximately 9.5 miles between the Evans No. 2 and Western river headgates, there is travel time or a lag time between the two locations. D&A's estimate of the flow velocity of the SPR during the low flow periods suggests that the lag time between the two river headgates is approximately 5 to 6 hours. Because of this lag time, the Water Commissioner would not be able to make instantaneous decisions based on the stage recorder but rather take into account the duration of the excess flow over the dam or lack thereof before modifying the call or the bypass rates. Nevertheless, the stage recorder and the State's ability to monitor the amount of water leaving the Study Reach would be a useful tool to aid administration.

Using the same cost information provided by Russell Stroud, the materials and construction costs associated with the State installing a radar water level sensor (or equivalent) along with the necessary equipment to have the stage data remotely available (i.e., Satlink, telemetry, etc.)

would be in the $15,000 to $20,000 range. Annual maintenance costs would be approximately $________.

10.0 CONCLUSIONS

The diurnal fluctuation of the SPR downstream of RWHTF discharge is primarily due to the hourly variations in the plant's effluent discharge that largely mimics the typical fluctuating water use patterns of the municipalities it serves. Because the Study Reach can be considered an effluent-dominated reach for large parts of the year, the resulting diurnal fluctuation of the SPR impacts the water users of District 2. These impacts include down-ditch fluctuations as a result of chasing the peak, inefficient water use by shareholders, water lost to the lower reaches, and overall shortage of supply. D&A understands that a large majority of the impacts are experienced by the ditch systems subject to a bypass call. However, the administration of the bypass call, including the allocation of water supply, can lead to the senior calling structure being shorted over the course of the day.

The ditch systems that experience the largest impacts have either constructed an individual on-ditch equalization pond or have begun to discuss the need for one. The District 2 water users that were party to Case No. 11CW74 expressed a desire for a study to be conducted to determine, among other things, the feasibility of a more regional mitigation alternative capable of dampening the fluctuations caused by the RWHTF effluent discharge. D&A examined a series of stakeholder developed and proposed mitigation alternatives. A preliminary engineering feasibility analysis was conducted for each of the alternatives as well as the identification of potential legal, institutional, and permitting issues. In addition to the physical mitigation alternatives (e.g., equalization ponds), D&A researched improvements to streamflow gaging and infrastructure that could help with the water supply allocation and administration of the bypass call.

Based on the results of the various analyses and research conducted and described herein, the following conclusions have been developed:

10.1 Analysis of Diurnal Fluctuation Hydrology

1. The RWHTF effluent discharge constitutes a large percentage of the SPR flow downstream of the outfall. On an average annual basis, the effluent makes up approximately 55 percent of the flow at the Henderson Gage. This percentage varies from a maximum of 87 percent in the month of January, to a low of 31 percent in the runoff month of June (**Table 1**).

2. The Metro District's Northern Treatment Plant (NTP) will treat a portion the wastewater currently treated at the RWHTF. However, growth is expected to occur within the RWHTF service area so that projected effluent amounts at the RWHTF will be greater than current amounts (Table 3). The introduction of the NTP's effluent discharge to the Study Reach, approximately 6.8 miles downstream of the Henderson Gage, will not cause the low flow trough of the existing diurnal fluctuation to decrease and therefore will not trigger increased calls from water users downstream of the NTP outfall.

3. The Metro District's previous studies related to influent flow equalization concluded that flow equalization was not an effective strategy for accomplishing environmental restoration downstream of the outfall.

4. The Metro District's previous studies related to influent flow equalization concluded that approximately 77 acre-feet was required to regulate influent flow to within a daily variance of less than 10 percent of the average flow and that they did not possess adequate land area on their property to construct a flow equalization pond of this size.

5. The influent diurnal fluctuation experienced by the RWHTF is typical of a wastewater treatment facility with both industrial and nonindustrial (i.e., municipal) contributions.

6. For the years of 2001 through 2014, the average hourly effluent discharge from RWHTF was 200 cfs.

7. The average daily peaking factor of the RWHTF discharge is approximately 1.34. In other words, the peak hourly flow is on average 134 percent of the average hourly flow.

8. The average daily trough-to-average factor of the RWHTF discharge is approximately 0.47, or the minimum hourly flow is 47 percent of the average daily flow.

9. The average daily volume of RWHTF effluent discharge above the average daily flow is approximately 46 acre-feet. However, due to variations in water use patterns, a volume of approximately 63 acre-feet would be required to store 95 percent of the peaks of the diurnal fluctuations experienced at the RWHTF.

10. When not influenced by rapid snowmelt runoff or a storm event, the flow pattern (i.e., hydrograph) of the SPR downstream of the RWHTF is largely influenced by the RWHTF discharge (**Figure 7**).

11. A slight attenuation (i.e., dampening of the peaks and troughs) of the RWHTF hydrograph occurs within the SPR downstream of the outfall. However, while the peak-to-peak amplitude is reduced, the volume of water above the average daily flow is similar to that of the RWHTF hydrograph. Therefore, for alternatives looking to store the peak of the diurnal fluctuation downstream of the outfall, a similar amount of storage is required. D&A's exceedance analyses indicated that a storage volume of approximately 70 acre-feet is required to store the peak of the diurnal fluctuation present at the Henderson Gage during the times the diurnal fluctuation is problematic for water users.

12. Due to the contributions of flow from the St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River, there is little to no diurnal fluctuation at the downstream terminus of District 2 as evidenced by the streamflow record provided by the Kersey Gage (PLAKERCO).

10.2 Impact of Diurnal Fluctuation on Water Users

1. Until 2006, the historical administration affecting District 2 primarily consisted of bypass calls placed by the Jay Thomas Ditch. Subsequent to PSCo's change of use of the Jay Thomas Ditch rights in 2006, the Western Ditch is now considered the swing ditch.

2. A bypass call is the partial curtailment of a junior upstream right expressed as a call by the junior right bypassing to a named downstream senior right.

3. Recent call records indicate the most frequent bypass call is from the Burlington Ditch's 1885 and 1909 rights or the Evans No. 2 Ditch 1871 or 1909 priorities to the Western Ditch headgate. The same call records show an infrequent bypass call of short duration that affects the junior rights of the Fulton Ditch, Brantner Ditch and the Brighton Ditch placed by the Western Ditch necessary to satisfy its 8-10-1871 priority.

4. The Water Commissioner determines the need for a call in District 2, upstream of the Saint Vrain Creek confluence, by: 1) discussing the daily water needs of the Western Ditch with a ditch company representative, 2) examining the low flow "trough" of the daily hydrograph at the Henderson Gage, 3) examining gaged and known inflows within the reach upstream of the Western Ditch to determine their potential contribution to demand, and finally 4) distribution of the water to all in-priority water users, according to their demands, so that the Western's 1871 priority and all intervening water rights are satisfied when the trough of the diurnal flow reaches the Western headgate. If the Water Commissioner determines the Western's demand will not be completely satisfied, the Water Commissioner will place a bypass call within District 2.

5. The Water Commissioner's goal when administering this typical bypass call is to fully satisfy the Western's calling right while avoiding any "spills" (i.e., flow over Western's check dam) to downstream reach.

6. Examining the call record for the period of 1992 and 2012 indicates that the primary calling structures since 1992 have been the Jay Thomas Ditch and the Western Mutual Ditch. The Western Mutual Ditch represents approximately 61 percent of the calls placed above the St. Vrain Creek confluence since 2002.

7. The call record indicates that the Evans No. 2 system is most frequently impacted by a bypass call. Of the total of 500 bypass calls affecting the Evans No. 2 and Milton Reservoir rights, 410 were to either the Jay Thomas Ditch or to the Western Mutual Ditch. These bypass calls primarily occur during the months of July, August, and September.

8. The bypassing structure is allowed to chase the peak of the diurnal fluctuation. The impact of chasing the peak of the diurnal fluctuation is felt by the ditch company, individual shareholders, and irrigators of the bypassing ditch. That is, the variable flow rates within the ditch over the course of the day create variable water stages and

hydraulic heads that make it difficult for the ditch company to allocate water, for irrigators to adjust their farm headgates, and also for the setting of siphon tubes.

9. Not only does the "diurnal fluctuation" within the ditch and the resulting down-ditch impacts require additional effort by the ditch company and its shareholders, it reduces the overall efficiency and utilization of the water by the ditch system.

10. The Evans No. 2 Ditch system generally experiences the largest flow fluctuations (i.e., the difference between the maximum hourly diversion and the minimum hourly diversion on a given day). The study period of June 2010 through December 2014 indicates that the Evans No. 2 experienced, on average, a 45 cfs daily fluctuation during the month of July.

11. Other ditch systems in District 2 experience fairly significant daily fluctuations.

12. It is important to note that daily flow fluctuations within an individual ditch system take place for many reasons beyond just the increasing or decreasing hydraulic head within the SPR as a result of the diurnal fluctuation. These reasons include but are not limited to: the ditch system's response to precipitation events that result in a shareholder reduction in demand, general increase or decrease in demand, irrigation cycles, response to river call administration, etc.

13. The diurnal fluctuation impacts ditch systems other than just the structure subject to the bypass call. For example, depending on the accuracy the estimates of the inflows, outflows, demands, etc. used in the Water Commissioner's morning paper allocation, the diurnal fluctuation and the administration of the bypass call may result in the senior calling right being shorted over the course of a day.

14. Again depending on the accuracy of the paper allocation, the administration of the bypass call may result in water flowing over the Western river check dam. This inefficiency leads to water being lost from the reach that would have otherwise been available and diverted by the District 2 irrigators located above the Western Ditch headgate.

10.3 Preliminary Feasibility of Mitigation Alternatives

10.3.1 Upstream Storage at Chatfield Reservoir

1. D&A's research and engineering feasibility work related to the use of Chatfield Reservoir storage and releases as a mitigation measure did not find any fatal flaws. However, it is D&A's opinion that the changes to the State's and Corps' operation of the Chatfield Reservoir outlet works necessary to make this alternative work involve both legal and institutional issues that will be likely be difficult to overcome. Additional research beyond the scope of this study is required to determine if such changes in the operation of Chatfield Reservoir would be feasible.

10.3.2 Use of Existing Gravel Pit for Flow Equalization Prior to Discharge

2. Based on the institutional and legal opinions provided by the Metro District, it is D&A's opinion that the alternative of using an existing gravel pit for effluent equalization prior to discharge of the effluent from RWHTF to the SPR has potentially insurmountable legal and regulatory flaws that should effectively remove it from further consideration.

10.3.3 Use of Existing Gravel Pit between RWHTF and Western Mutual Ditch Headgate

3. The use of an existing gravel pit downstream of the RWHTF outfall to divert and regulate the diurnal fluctuation is a potentially feasible solution. There are sizable capital costs (e.g., $8.3 million) associated with this alternative related to the potential reimbursement of storage costs, construction of a pump station, and possible improvements to inflow infrastructure (e.g., adding constructed capacity to an existing ditch). In addition to capital costs, the estimated annual energy costs to operate a pump station to deliver temporarily stored water from the gravel pit to the SPR would be approximately $41,000 to $44,000.

4. Potential legal issues associated with the use of a gravel pit to divert the peak of the diurnal fluctuation off of the SPR for temporary storage and retiming include the need for a water court decree and likely the cooperation of the District 2 water users that would have a portion of their water rights temporarily detained by the upstream equalization pond.

10.3.4 Construction of a New Gravel Pit

5. The construction and use of a new gravel pit for the purpose of an equalization pond would have similar costs and legal issues associated with that of an existing gravel pit.

10.3.5 Use of Storage and Timed Releases by Parties using RWHTF Effluent

6. This alternative considers the use of storage and timed released by parties with gravel pit storage facilities who store and release augmentation water within the Study Reach to help offset the trough of the diurnal fluctuation. This alternative would involve participating augmenters and the State developing an operating procedure in which the augmenters would agree to make strategically timed releases during the trough. D&A's research of current augmentation amounts concluded that this alternative may be feasible but its effectiveness may be limited, at least in the short term due to the limited number of parties that store and release augmentation water in the Study Reach. If future operations increase the amounts and consistency of augmentation within this reach via gravel pit releases this alternative could be an effective mitigation alternative.

10.3.6 Storage Near Ditch Headgates

7. Constructing and utilizing an equalization pond downstream of ditch companies' river headgates is a proven method to better regulate deliveries to downstream shareholders as evidenced by the Western Mutual Equalization Pond. While these equalization ponds are

effective at regulating flows to shareholders, they do not mitigate the fluctuations experienced at the river headgates or reduce the potential of being shorted by upstream water users if over-diversion occurs during a bypass call.

10.3.7 Use of Existing or New River Check Dams

8. This alternative mitigation proposal would utilize an existing river check dam and modifying it to regulate the diurnal fluctuation indicated that a rise of 6 to 7 feet was necessary to create storage behind the check dams sufficient to regulate the diurnal fluctuation. This alternative presents the potential for significant flooding, riverbank destabilization, and adjacent land issues as a result of a rise and drop of the SPR river stage of this magnitude. Because of these issues, D&A did not fully investigate the costs associated with this alternative.

10.3.8 Utilization of Groundwater Diversions to Offset Diurnal Fluctuation

9. D&A conceptually examined the use of groundwater diversions (i.e., wells) to offset the diurnal fluctuation experienced by individual ditch systems. In our opinion, the legal issues surrounding the use of headgate wells would likely require the wells users to obtain a water court decreed plan for augmentation. Furthermore, based on the magnitude of the troughs experienced by the majority of the ditch companies, this alternative would likely only be feasible for a few ditch systems that have smaller fluctuations. Given the quantity and expense of the wells required to supplement the troughs of the ditch systems and the requirement, per current water law, of an augmentation plan, this alternative doesn't appear as feasible as others presented within this report.

10.3.9 Revised or Improved Administrative Procedures

10. Based on information gathered from discussions with the Division Engineer and District 2 Water Commissioner, there could be some improvements made to the administration of the Study Reach, especially during times of low flow when the diurnal fluctuation is problematic, with the enhancement of existing streamflow gages and the construction of gaging on currently un-gaged tributary inflows. The improvements to existing streamflow gages may include the more frequent calibration and rating of the two USGS gages within this reach (i.e., 64^{th} Ave. and Fort Lupton gages) such that they are more reliable in low flow conditions. In addition to improving existing gages, adding gaging instrumentation and infrastructure to currently un-gaged tributaries such as Little Dry Creek and the Graflin Slough would provide the Water Commissioner more definitive information as to the amount of water supply available for allocation. While this alternative will do nothing to mitigate the physical diurnal fluctuation, the improvements represent fairly low cost options to help reduce the impacts created by the diurnal fluctuation. The total cost of the recommended gage improvements ranges from $55,000 to $110,000. This costs includes constructing a streamflow gage on Little Dry Creek and the Graflin Slough and a river stage recorder on the Western check dam. The annual operations and maintenance costs associated with these gages is approximately_______.

The additional cost associated with funding the bi-weekly calibration of the USGS gages at 64th Avenue and Fort Lupton, CO would be $8,000.

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