To: Carl Brouwer, Northern Colorado Water Conservancy District

From: Howard Andrews & Chris Tadanier, Black & Veatch Corporation

Reviewed by: Klint Reedy, Black & Veatch Corporation

Subject: Total Organic Carbon Issues

1.0 Introduction

Under certain conditions, Northern Integrated Supply Project (NISP) operations could result in a different mix of water supplies being delivered to Horsetooth Reservoir than it has historically received. This is because the preferred NISP alternative would exchange Colorado-Big Thompson (C-BT) water with NISP water to achieve NISP objectives. The details of how these water exchanges would take place are presented in Section 2.

One important consideration to note is that, under certain conditions, Cache la Poudre River (Poudre River) water will be delivered to Horsetooth Reservoir in lieu of C-BT water. One of the primary concerns raised by the City of Fort Collins related to this operating condition is that levels of organic matter present in Poudre River water could increase the concentration of organic matter in Horsetooth Reservoir. Organic matter exists in all natural waters and is derived from the breakdown of plant and animal matter. This organic matter is a heterogeneous mixture of macromolecules with varying molecular size and chemical properties and is collectively termed natural organic matter (NOM). Because NOM does not have a unique chemical composition, it is typically quantified as total organic carbon (TOC).

NOM imparts color and sometimes off-tastes to water, and reacts with many drinking water treatment chemicals including coagulants, oxidants, and disinfectants. NOM in natural waters largely determines the coagulant demand during drinking water pre-treatment, and when combined with free-chlorine during disinfection produces regulated disinfection by-products (DBPs). NOM has also been shown to promote microbial re-growth in drinking water distribution systems.

For these reasons, the City is concerned that the potential for increased TOC concentrations could impact the operation of the Fort Collins Water Treatment Facility (FCWTF), which treats water stored in Horsetooth Reservoir to drinking water standards for distribution to City of Fort Collins customers.

Recognizing the City's concerns regarding TOC, there are several alternatives for addressing this issue including:

- Implementing a TOC monitoring program to determine if elevated TOC concentrations in Horsetooth Reservoir are a realistic concern.
- Strategically operating NISP to reduce the potential for elevated TOC concentrations in Horsetooth Reservoir.
- Treating for increased TOC concentrations at the FCWTF.

The following sections elaborate on these concepts.

2.0 Strategic Operation of NISP to Control TOC Concentrations

Several alternatives exist for controlling TOC concentrations in Glade and Horsetooth Reservoirs. These alternatives arise from operational flexibility that exists due to the ability to perform different types of water exchanges. Strategic use of these exchanges can accomplish the following.

- Identify NISP operating schemes that could minimize TOC concentrations in Glade Reservoir and Horsetooth Reservoir.
- Coordinate deliveries of water from Glade Reservoir to Horsetooth Reservoir with seasonal mixing patterns anticipated to occur in both reservoirs.
- Maximize the potential for TOC attenuation by achieving sufficient retention times in Glade Reservoir to allow for the potential settling and breakdown of TOC to occur.

2.1 Potential NISP – C-BT Exchanges

There are three basic ways that NISP water could be utilized in lieu of C-BT water to reduce required deliveries of C-BT water to Horsetooth Reservoir:

1. When there is a need to release C-BT water from Horsetooth Reservoir to the Poudre River while NISP also has priority to divert water from the Poudre River, NISP water could be left in the river to meet C-BT water demands.

2. When there is a need to release C-BT water from Horsetooth Reservoir to the Poudre River while NISP does not have priority to divert water from the Poudre River, NISP water could be released from Glade Reservoir into the Poudre River to meet C-BT water demands.

For items 1 and 2 above, the amounts of C-BT water not required to be released from Horsetooth Reservoir would also not be required to be delivered to Horsetooth Reservoir from Flatiron Reservoir. Consequently, this amount of water could be delivered from Flatiron Reservoir to Carter Lake for ultimate use by NISP Participants. See Figure TOC-1 for a graphical depiction of this concept.

3. In some water years (defined here as November through October), there may be insufficient opportunity for items 1 and 2 to fully achieve the objective of reducing Horsetooth Reservoir releases of C-BT water to the Poudre River in amounts equal to water not delivered from Flatiron Reservoir to Horsetooth Reservoir. When this occurs, NISP water could either be directly pumped from the Poudre River to Horsetooth Reservoir or could be transferred from Glade Reservoir to Horsetooth Reservoir to make up the difference.

The flexibility described above is feasible because the facility configuration shown on Figure TOC-1 will allow the Glade pumping station to operate under any of the following three conditions: 1) pump from Glade forebay to Glade Reservoir 2) pump from Glade forebay to Horsetooth reservoir 3) pump from Glade Reservoir to Horsetooth Reservoir.

2.2 Potential NISP Operating Schemes

The methods for exchanging NISP water for C-BT water described in the previous section could be utilized to achieve varying operational objectives. Analyses performed here focus on the following three operating schemes:

- Scheme 1 - Maximize exchange potentials while minimizing pumping into Glade Reservoir
- Scheme 2 - Minimize transfers from Glade Reservoir to Horsetooth Reservoir
- Scheme 3 - Eliminate transfers from Glade Reservoir to Horsetooth Reservoir

Descriptions of operating schemes 1, 2 and 3 are shown on Figures TOC-1, TOC-2, TOC-3, respectively. On each of these figures, numbers within circles represent locations where water would be released from Horsetooth Reservoir to the Poudre River without NISP, and numbers within squares represent potential exchanges of NISP water for C-BT water. These exchanges would have no net effect on flow in the Poudre River or water levels in Horsetooth Reservoir, thereby making it feasible to divert C-BT water from Flatiron Reservoir to Carter Lake for NISP participant use.

2.2.1 Operating Scheme 1

This operating scheme includes three methods for exchanging C-BT water for NISP water. The first method utilizes direct river exchanges (identified by rectangles 1 and 2 on Figure TOC-1). This means when there is a need to release C-BT water from Horsetooth Reservoir into the Poudre River <u>while NISP also has priority</u> to divert water from the Poudre River, NISP project water would be left in the river to meet C-BT water demands.

The second method utilizes Glade Reservoir to Poudre River exchanges (identified by rectangles 3 and 4 on Figure TOC-1). This means when there is a need to release C-BT water from Horsetooth Reservoir into the Poudre River <u>while NISP does not have priority</u> to divert water from the Poudre River, NISP project water could be released from Glade Reservoir into the Poudre River to meet C-BT water demands.

The third method (identified as rectangle 6 on Figure TOC-1) is only utilized in years when direct river exchanges and Glade Reservoir to Poudre River exchanges do not fully achieve the objective of no net impact on the storage volume in Horsetooth Reservoir. When this occurs, NISP water stored in Glade Reservoir would be directly transferred to Horsetooth Reservoir in the volume required to make up the difference.

2.2.2 Operating Scheme 2

This operating scheme includes four methods for exchanging C-BT water for NISP water. The first method utilizes direct river exchanges (identified by rectangles 1 and 2 on Figure TOC-2). The second method utilizes Glade Reservoir to Poudre River exchanges (identified by rectangles 3 and 4 on Figure TOC-2). These two methods are identical to the first two methods utilized in operating scheme 1.

The third method (identified as rectangle 5 on Figure TOC-2) includes diverting Poudre River water into the Glade forebay utilizing the Poudre Valley Canal and then pumping this Poudre River water directly into Horsetooth Reservoir. This condition would occur when the full potential to make exchanges with releases from Horsetooth Reservoir has been exhausted, but NISP still has priority to divert water from the Poudre River. Similar to the other available exchange methods, pumping Poudre River water diverted under a NISP water right directly into Horsetooth

Reservoir makes it feasible to divert an equal amount of C-BT water from Flatiron Reservoir to Carter Lake instead of sending that amount of water from Flatiron Reservoir to Horsetooth Reservoir. This operation would not occur in the month of May when TOC concentrations in the Poudre River are elevated.

The fourth method (identified as rectangle 7 on Figure TOC-2) is only utilized in years when the three previously discussed exchange opportunities do not fully achieve the objective of no net impact on the storage volume in Horsetooth Reservoir. When this occurs, NISP water stored in Glade Reservoir would be directly transferred to Horsetooth Reservoir in the volume required to make up the difference.

2.2.3 Operating Scheme 3

This operating scheme also includes four methods for exchanging C-BT water for NISP water. The first three methods are identical to the first three methods utilized in operating scheme 2. The fourth method (identified as rectangle 7 on Figure TOC-3) includes diverting Poudre River water during the winter months, even during times when NISP does not have priority to divert Poudre River Water, and pumping this water directly from Glade forebay to Horsetooth Reservoir.

This fourth method is only utilized when the first three exchange opportunities result in an insufficient amount of water exchanged into Horsetooth Reservoir to achieve no net impact on the storage volume in Horsetooth Reservoir. Pumping out of priority is accomplished by releasing water from Glade Reservoir to the Poudre River at a location directly downstream of the Poudre Valley Canal diversion and then making diversions in like amounts at the Poudre Valley Canal diversion. This method would only be utilized if Poudre River water is of better quality than the water stored in Glade Reservoir. This scheme entirely eliminates the need to transfer water directly from Glade Reservoir to Horsetooth Reservoir and also avoids pumping Poudre River water into Horsetooth Reservoir during times when TOC levels in the Poudre River are elevated.

2.3 Reservoir TOC Mass Balances

Time-series mass-balance analyses were conducted to estimate TOC concentrations in Glade and Horsetooth Reservoirs under the operating schemes outlined on Figures TOC-1 through TOC-3. In these analyses, TOC was considered a conservative constituent, with no degradation or buildup during reservoir storage. The analyses also assumed complete mixing due to thermally induced seasonal overturn and internal circulation was assumed for all water delivered to either reservoir. These assumptions conform with those used in previous evaluations of potential NISP impacts on TOC levels in Horsetooth Reservoir (CH2M HILL, 2006).

Northern Colorado Water Conservancy District (NCWCD) provided Black & Veatch with monthly diversion and exchange values for each of the three operating schemes evaluated. These values are based on MODSIM modeling, utilizing a 50-year reference hydrologic period between 1950 and 1999. Weekly TOC measurements collected from the Poudre River and Horsetooth Reservoir by Fort Collins Utilities between 1999 and 2008 were used to construct a 10-year record of monthly average TOC values, as shown on Figure TOC-4. Poudre River TOC concentrations shown on Figure TOC-4 are flow weighted monthly average values, calculate as follows:

$$FWMA = \frac{Average(c1 * f1, c2 * f2, c3 * f3, c4 * f4)}{Average(f1, f2, f3, f4)} \quad \text{Eq. TOC-1}$$

Where:

FWMA = Flow Weighted Monthly Average Value (mg/L)

$c1$ = Concentration of TOC (mg/L) in the Poudre River near the canyon mouth measured in week 1 of the month that the FWMA is being calculated. Concentrations c2, c3, and c4 are the concentrations measured during the other weeks of the month.

$f1$ = Flow (cfs) in the Poudre River near the canyon mouth on the same date that c1 was measured. Flow f2, f3, and f4 are the flows that occurred on the same dates that c2, c3, and c4 were measured.

The above combination of operational and water quality information was utilized to predict the water quality in Glade and Horsetooth Reservoirs. Modeled diversions of Poudre River water into Glade Reservoir and associated TOC of these waters are shown on Figure TOC-5, for each of the three operating schemes evaluated. The resulting TOC concentrations in Glade Reservoir typically varies between 5 mg/L and 6 mg/L, with occasional excursions slightly outside this range, as shown on Figure TOC-6. A similar range of predicted TOC values was reported in a previous evaluation of Glade Reservoir water quality using TOC data from different sources (CH2M HILL, 2006).

Modeled diversions of Poudre River water transferred/pumped directly into Horsetooth Reservoir and associated TOC of these waters are shown on Figure TOC-7. Note that Figure TOC-7 only includes water sent directly from the Poudre River to Horsetooth Reservoir and therefore does not include water diverted from the Poudre River, stored in Glade Reservoir, and then transferred to Horsetooth Reservoir. For this reason, Figure TOC-7 does not include data on operating scheme 1 because this scheme does not directly deliver water from the Poudre River to Horsetooth Reservoir.

Modeled transfers from Glade Reservoir to Horsetooth Reservoir and associated TOC of these waters are shown on Figure TOC-8. Note that Figure TOC-8 only includes water transferred from Glade Reservoir to Horsetooth Reservoir and therefore does not include direct deliveries from the Poudre River to Horsetooth Reservoir. For this reason, Figure TOC-8 does not include operating scheme 3 data because this scheme does not deliver water from Glade Reservoir to Horsetooth Reservoir.

Flow-weighted mass-balance TOC concentrations in Horsetooth Reservoir were first modeled assuming no degradation of TOC occurs in Glade or Horsetooth Reservoirs. Figure TOC-9 shows the predicted TOC concentrations in Horsetooth Reservoir for each of the three NISP operating schemes. Figure TOC-9 also includes the historical TOC concentration in Horsetooth Reservoir without NISP. As shown, Horsetooth Reservoir TOC concentrations are predicted to be between 2.5 mg/L and 3.5 mg/L with concentrations associated with NISP operations varying between several tenths of a mg/L higher to several tenths of a mg/L lower than the TOC concentrations without NISP. Figure TOC-10 shows that NISP operations are predicted to result in lower TOC concentrations in Horsetooth Reservoir 25 percent of the time, when compared to concentrations without NISP. Figure TOC-10 also shows that when making the conservative assumption that no degradation of TOC occurs during residence in Glade Reservoir, NISP operations would not increase TOC concentrations in Horsetooth Reservoir by more than 0.5 mg/L.

Secondly, flow-weighted mass-balance TOC concentrations in Horsetooth Reservoir were modeled assuming 25 percent TOC degradation does occur during residence in Glade Reservoir. This assumption lowered modeled TOC concentrations in Horsetooth Reservoir slightly for NISP operating schemes 1 and 2, as shown on Figure TOC-11. Because NISP operating scheme 3 does not transfer water from Glade Reservoir to Horsetooth Reservoir, predicted TOC concentrations in Horsetooth Reservoir remain unchanged for this operating scheme. Figure TOC-12 shows that all three NISP operating schemes would have little impact on TOC concentrations in Horsetooth Reservoir. Table TOC-1 provides a comparison of Horsetooth Reservoir TOC mass balance results for operating schemes evaluated.

Table TOC-1

Predicted TOC Concentrations in Horsetooth Reservoir for Several NISP Operating Schemes

Scheme	**Average for 50-Year Hydrologic Period from 1950 to 1999**			
	Poudre to Glade (AFY)	**Poudre to Horsetooth (AFY)**	**Glade to Horsetooth (AFY)**	**Horsetooth TOC Concentrations[1] (mg/L)**
Baseline Historical Value				
Without NISP	--	--	--	3.00
Assuming No TOC Degradation in Glade Reservoir				
1	2,226	0	267	3.16
2	2,533	443	36	3.10
3	2,533	480	0	3.07
Assuming 25 Percent TOC Degradation in Glade Reservoir				
1	2,226	0	267	3.10
2	2,533	443	36	3.09
3	2,533	480	0	3.07

Notes:
[1] Assumes full mixing in both Glade Reservoir and Horsetooth Reservoir.

3.0 Mixing Patterns and Fate of TOC in Reservoirs

Reservoir mixing and natural attenuation processes both impact organic matter concentrations in reservoirs. Organic matter in natural waters may be characterized in a variety of ways including its origin, chemical composition, and size distribution. Because organic matter in natural waters is a heterogeneous mixture it lacks a uniquely identifiable structure, and is therefore commonly quantified by its collective TOC content. TOC is frequently further classified into dissolved organic carbon (DOC) and particulate organic carbon (POC) based on its relative size.

3.1 Seasonal Reservoir Mixing

Detailed modeling of reservoir mixing is not required to understand that deep reservoirs located in this region of Colorado are governed by thermal conditions that result in "reservoir turnover" every spring and fall. This turnover results in mixing of the contents in the reservoir. Inflow into Glade Reservoir is anticipated to occur predominately in the spring and summer months and deliveries from Glade Reservoir to Horsetooth Reservoir are not anticipated until the winter months. Therefore, Glade Reservoir would have experienced full turnover during the fall, resulting in full mixing of the contents prior to deliveries to Horsetooth Reservoir.

3.2 Fate of TOC in Reservoirs

The fate of organic matter in Glade Reservoir and ultimately Horsetooth Reservoir will be influenced by physical, chemical, and biological processes to varying degrees. TOC entering Glade Reservoir from the Poudre River would consist predominantly of DOC and to a lesser extent POC. As shown on Figure TOC-13, the TOC content of the reservoir may be lowered by settling of POC, by photobleaching, and by microbial degradation of DOC.

3.2.1 TOC Introduced to Glade Reservoir

TOC loadings from Poudre River diversions would have the most immediate effect on TOC concentrations in Glade Reservoir. The United States Geological Survey (USGS) has conducted a National Water Quality Assessment (NAWQA) of the South Platte River Basin (Dennehy, 1998). This study included sampling of the Poudre River at the USGS flow monitoring station at the canyon mouth near Fort Collins (Station 06752000), which is in the vicinity of the Poudre Valley Canal turnout structure. Between April 1993 and August 1995, USGS sampled the river monthly a total of 32 times. DOC concentrations ranged from a maximum of 8.4 mg/L in June 1993 to a minimum of 1.5 mg/L in February 1995. POC concentrations ranged from a maximum of 2.1 mg/L in June 1995 to a minimum of 0.1 mg/L for numerous months. Over this monitoring period DOC was approximately 87 percent of TOC. This is approximately equal to the value of 90 percent DOC documented by CH2MHill (2006). Therefore, 10 percent reduction in TOC concentrations in Glade Reservoir could occur due to settling of POC in the supply water.

3.2.2 TOC Formation Within Glade Reservoir

Organic matter may be produced in the water column in the form of particulate algae cells or dissolved algal metabolites. However, because of low nutrient concentrations in the Poudre River, algal production in Glade Reservoir is expected to be very low (Lewis, 2003). Therefore, algae growth in the reservoir is not expected to significantly increase TOC.

3.2.3 TOC Attenuation in Glade Reservoir

Photobleaching is a natural process that occurs in aquatic systems and involves the break down of DOC by absorption of ultraviolet (UV) radiation. Photobleaching in Glade Reservoir is expected to be limited to the top 3 to 6 feet of the water column because of UV light attenuation. CH2MHill (2006) estimated that photobleaching could possibly reduce the TOC concentration in Horsetooth Reservoir by 4.5 to 7 percent. Based on proximity of the two reservoirs, this level of TOC degradation through photobleaching is also a reasonable estimate for Glade Reservoir.

Decomposition of DOC by bacteria is another process that could potentially reduce TOC in Glade Reservoir. Although there are numerous references in the scientific literature that document the degradation of DOC by bacteria, it is difficult to estimate the rate at which this process occurs in any given reservoir. However, CH2MHill (2006) conducted a mass balance of TOC in Horsetooth Reservoir, using 1995 to 1997 inlet concentrations from the Hansen Feeder Canal and outlet concentrations at Soldier Canyon Dam, near the diversion to Fort Collins Water Treatment Facility. TOC reductions ranged from 17 percent in 1995 to 26 percent in 1997. During these three years, the reservoir volume-weighted average reduction was 23 percent. This change could have been a combination of decomposition of DOC by bacteria, photobleaching, and settling of POC. Given the longer hydraulic retention time anticipated in Glade Reservoir, it is possible that similar or greater TOC reductions could occur.

3.2.4 TOC Introduced to Horsetooth Reservoir

The fate of TOC in water transferred from Glade Reservoir to Horsetooth Reservoir would depend in a complicated way on a variety of factors including, but not limited to; Horsetooth Reservoir water quality, temperature, and internal mixing; and the timing, quantities, and entrance location of water transferred. However, because transfers from Glade Reservoir would occur only during winter, substantial mixing due to seasonal overturn and internal circulation would limit the opportunity for short-circuiting in Horsetooth Reservoir.

4.0 TOC Removal During Drinking Water Treatment

Removal of natural organic matter (NOM) is one of the principle treatment objectives where surface waters are used as drinking water supplies. Because NOM does not have a unique chemical composition, it is typically quantified as total organic carbon in drinking water treatment practice.

4.1 TOC Removal Requirements

There are no regulatory maximum contaminant level (MCL) standards for NOM in finished drinking water. However, the Stage 1 Disinfection By-product Rule (Stage 1 DBPR) mandates a treatment technique for NOM removal in facilities that utilize conventional treatment of surface water, based on source water TOC and alkalinity concentrations, as indicated in Table TOC-2. Facilities that practice enhanced precipitative softening for hardness reduction are subject to additional treatment technique requirements based on TOC removal.

Table TOC-2

Percent TOC Removal Required by Enhanced Coagulation for Surface Water Systems Utilizing Conventional Treatment

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	≤ 60	>60 to 120	> 120
> 2.0 to 4.0	35	25	15
> 4.0 to 8.0	45	35	25
> 8.0	50	40	30

Alternative Compliance Criteria:
1. Source water TOC < 2.0 mg/L
2. Finished water TOC < 2.0 mg/L
3. Source water TOC < 4.0 mg/L, alkalinity > 60 mg/L, TTHM < 40 µg/L, and HAA < 30µg/L
4. TTHM < 40 µg/L and HAA < 30µg/L, only chlorine used for primary disinfection and residual
5. Source water specific UV absorbance (SUVA) prior to any treatment ≤ 2.0 L/mg·m
6. Treated water SUVA ≤ 2.0 L/mg·m

4.1.2 Alterative Compliance Criteria

There are six alternative compliance criteria for TOC removal from drinking water produced from surface water sources by conventional treatment, as listed in the footnotes to Table TOC-2. Any one of these alternative criteria may be applied to a given TOC monitoring result in lieu of the TOC removal percentages listed in the body of Table TOC-2 for the purpose of compliance calculations.

4.1.3 Compliance with TOC Removal Requirements

Compliance with the TOC removal requirements of the Stage 1 DBPR is based on the running annual average (RAA) of quarterly average calculations made using monthly monitoring data. Because the water quality in any given source may vary from month to month, there is no single TOC removal percentage in Table TOC-2 that universally applies for TOC removal compliance. Therefore, compliance is based on the TOC removal ratio (TOC_{RR}) calculated as follows:

$$TOC_{RR} = \frac{\Delta TOC_{Actual}}{\Delta TOC_{\mathrm{Re}quired}} \qquad \text{Eq. TOC-2}$$

where

ΔTOC_{Actual} = measured TOC removal percentage between raw and finished drinking water, and

$\Delta TOC_{Required}$ = required TOC removal percentage from Table TOC-2 based on source water alkalinity and TOC.

If the TOC_{RR} calculated in any month is less than 1.0 based on measured source water quality and treatment performance, but any one of the alternative compliance criteria is satisfied, a TOC_{RR} of 1.0 may be assigned for that month. Regulatory compliance is demonstrated if the RAA of the last 12 monthly TOC_{RR} values is greater than or equal to 1.0.

Continual reliance on alternative criteria to maintain compliance with Stage 1 DBPR TOC removal requirements may lead to a treatment technique violation based on poor TOC removal performance in a single month. For example, a drinking water provider that applies an alternative compliance criterion for 12 consecutive months would have a RAA TOC_{RR} value of exactly 1.0. If the TOC removal performance in the next month did not satisfy an alternative compliance criterion or meet the required removal based on source water TOC and alkalinity, the updated RAA TOC_{RR} value would be less than 1.0, resulting in a treatment technique violation. Thus, continual use of alternative compliance criteria does not allow a utility to balance slightly lower TOC removal performance in some months with slightly higher removal in other months.

4.2 TOC Removal at Fort Collins Water Treatment Facility

The Fort Collins Water Treatment Facility (FCWTF) uses a treatment process consisting of full conventional pre-treatment (coagulation, flocculation, and clarification) followed by granular media filtration. Pre-treatment takes place in four parallel treatment trains, with a total capacity of 87 mgd. Alum is used as the primary coagulant, with addition of a high molecular weight cationic polymer during flocculation to improve performance of subsequent particle separation processes. Clarification is assisted by either tube or lamella plate settlers. A filter aid polymer is added to settled water prior to dual-media constant-rate filtration.

FCWTF also has the capability to pre-condition raw water through chemical addition prior to coagulation. Facilities for lime slurry and carbon dioxide gas addition allow coagulation pH and alkalinity to be modified as necessary in response to seasonal variations in source water quality.

FCWTF has historically treated two water sources, the Cache la Poudre River and Horsetooth Reservoir, either singly or as a blended source. These water sources originate in separate basins within the Rocky Mountains and are generally of high quality. Due to elevated TOC and low alkalinity during annual spring snowmelt runoff, FCWTC has often blended Horsetooth Reservoir and Poudre River sources to partially offset higher pre-conditioning and pre-treatment chemical doses required for effective TOC and particulate removal. “However, with the completion in 2004 of a 67 mgd pipeline from the Poudre River to the FCWTF, the preference is to treat 100% Poudre River water during the runoff period due to water rights issues (Billica and Gertig, 2006).”

4.2.1 Characterization and Treatability of TOC in the Poudre River

Water quality in the Poudre River varies seasonally due to the impacts of snowmelt runoff in the spring and early summer. Between mid April and mid May, TOC in the Poudre River increases from a baseline value of approximately 2 mg/L to a typical peak value of 8 mg/L to 10 mg/L (occasionally as high as 13 mg/L), and then gradually decreases toward the baseline value throughout the remainder of May and June (Billica and Gertig, 2006). Typically, there is a two-month window in the spring during which TOC in the Poudre River is greater than 4 mg/L. Concurrent with elevated TOC levels, alkalinity in the Poudre River decreases from a baseline value of between 30 mg/L and 40 mg/L as $CaCO_3$ to 15 mg/L as $CaCO_3$ or less (Billica and Gertig, 2000).

The physicochemical properties of NOM in the Poudre River have been extensively characterized in previous studies by Fort Collins Utilities staff and others (Carlson, 1994; Billica and Gertig, 2000; Sharp, 2005, Sharp, 2005a; Sharp, 2005b). As is typically the case for pristine natural waters, NOM in the Poudre River is predominantly dissolved in character, with approximately 90 percent of TOC in the dissolved NOM fraction. Resin-based chemical fractionation of NOM present in the Poudre River during periods of snowmelt runoff has indicated that hydrophobic fractions predominate, constituting as much as 75 percent of NOM content (Sharp, 2005). It has long been recognized that certain properties of hydrophobic NOM fractions, especially ultraviolet light absorbance and molecular weight, are positively correlated with hydrophobic content (Collins, 1986; Edzwald, 1993). High performance size exclusion chromatography (HPSEC) UV absorbance analyses of NOM in the Poudre River have demonstrated that a large proportion of the increased TOC observed during snowmelt events is attributable to higher molecular weight hydrophobic NOM (Sharp, 2005).

Removal of NOM by coagulation during drinking water treatment has also been correlated to NOM physicochemical properties. Bench-scale and pilot-scale studies, as well as full-scale operational experience, have consistently shown that aluminum and iron coagulants preferentially remove higher molecular weight hydrophobic NOM fractions. Because physicochemical fractionation methods for NOM characterization are time consuming and labor intensive, they are not practical for routine evaluation of raw water treatability. However, specific UV absorbance (SUVA),

$$SUVA = \frac{100 \times UV_{254}}{TOC} \qquad \text{Eq. TOC-3}$$

where UV_{254} is absorbance of 254 nm UV light (cm^{-1}) and TOC is measured in mg/L, has been shown to be a useful surrogate parameter for monitoring NOM in an operational setting (Edzwald, 1985; Edzwald, 1993). General guidelines relating SUVA of aquatic NOM with physicochemical properties and treatability are listed in Table TOC-3. SUVA of NOM in the Poudre River during snowmelt runoff has been measured at between 3.0 L/mg·m and 3.5 L/mg·m (Billica and Gertig, 2006), which would correspond to an expected dissolved organic carbon (DOC) removal of 25 to 50 percent.

Table TOC-3

General Guidelines Relating SUVA of Aquatic NOM with Physicochemical Properties and Treatability[1]

SUVA	Composition	Coagulation	DOC Removal
> 4	Mostly humic matter, high hydrophobicity, high MW	NOM controls Good DOC removal	> 50% for alum > 50 % for ferric
2 to 4	Mixture of humic matter and other NOM, mixture of hydrophobic and hydrophilic NOM, wider range of MWs	NOM influences Moderate DOC removal	25 to 50 % for alum Slightly higher for ferric
< 2	Mostly non-humic matter, low hydrophobicity, low MW	NOM has little influence Poor DOC removal	< 25 % for alum Slightly higher for ferric

(1)Edzwald, 1999.

4.2.2 Coagulation Scheme for Treatment of Elevated TOC Waters at FCWTF

Over the past decade the City of Fort Collins Utilities has developed and implemented a coagulation scheme to effectively treat elevated TOC, low alkalinity source waters at FCWTF. Extensive bench-scale and pilot-scale testing was conducted at FCWTF during 1996 and 1997 using pH and alkalinity adjustment to pre-condition Poudre River water prior to coagulation (Billica and Gertig, 2000; Billica and Gertig, 2006). Pilot-scale experiments conducted in 2000 using this treatment approach demonstrated consistent TOC removal efficiency greater than 60 percent (Billica and Gertig, 2000), which would comply with Stage 1 DBPR removal requirements under all source water conditions (see Table TOC-2). Furthermore, particle removal was not compromised at these high TOC removal efficiencies.

4.2.3 Full-Scale Process Performance During the 2005 Snowmelt Runoff

Full-scale treatment of elevated-TOC, low-alkalinity Poudre River water was evaluated at FCWTF over a six-week period during May and June 2005, with average daily flows between 19 MGD and 43 MGD (Billica and Gertig, 2006). Pre-conditioning and coagulant chemical doses were adjusted to maintain post-coagulation target pH (6.5 to 6.8 s.u.), alkalinity (15 to 20 mg/L as $CaCO_3$), and zeta potential (± 3 mV) values. Under elevated TOC conditions during the full-scale evaluation period, TOC removal varied between 61 and 71 percent, and consistently exceeded Stage 1 DBPR required removal by 10 to 15 percent. Combined filter effluent turbidity was consistently less than 0.1 NTU while treatment was optimized.

Regulated DBP concentrations (total trihalomethanes (TTHM) and five haloacetic acids (HAA5)) in the distribution system during this evaluation period were not reported; however, TTHM concentrations entering the distribution system varied with residual TOC concentration. TTHM concentrations entering the distribution system were greater than 50 percent of the 80 μg/L MCL for approximately two weeks during the middle of the evaluation period, with a peak value at 68 percent of the MCL.

4.3 Potential Need for Additional NOM Removal at FCWTF Related to NISP

The City of Fort Collins Utilities staff have developed, demonstrated, and implemented a drinking water treatment strategy for use under challenging, elevated-TOC, low-alkalinity water quality conditions that successfully meets and typically exceeds TOC removal requirements, without compromising particulate removal. Therefore, the potential need for additional NOM removal at FCWTF appears not to be driven by TOC removal requirements per se, but rather by compliance with DBP standards. Average TTHM levels in the Fort Collins distribution system were reported as 28.3 μg/L in 2006 (Fort Collins Utilities, 2006), which is well below the 80 μg/L MCL.

The extent to which the NISP project would have any potential impact on the quality of drinking water delivered from FCWTF depends on the operational strategy

Fort Collins Utilities uses to select between Poudre River and Horsetooth Reservoir raw water sources. Because the FCWTF diversion from the Poudre River is upstream of both the proposed Glade Reservoir site and Horsetooth Reservoir, whenever FCWTF receives raw water exclusively from the Poudre River the NISP project would have no affect whatsoever on FCWTF operations or finished drinking water quality.

As previously described in Section 2, NISP operations have been predicted to increase TOC concentrations in Horsetooth Reservoir on average by approximately 0.1 mg/L to 0.2 mg/L (Table TOC-1). Because the ultimate source of this additional TOC in Horsetooth Reservoir is the Poudre River, it would have similar physicochemical characteristics such as high hydrophobic content and high molecular weight as the Poudre River water already treated by the FCWTF, and therefore be amenable to removal by the existing coagulation facilities.

Full-scale TOC removal evaluations conducted at FCWTF during 2005 demonstrated a strong linear relationship between optimal alum dose and raw water TOC concentration when treating Poudre River water during the snowmelt runoff season (Billica and Gertig, 2006). Alum doses ranged between 20 mg/L and 55 mg/L as TOC varied throughout this evaluation. Experimental data collected across the entire 2005 snowmelt event indicated that the optimal alum dose increased between 3 mg/L and 4 mg/L for each 1 mg/L increase in raw water TOC. Therefore, treating a blend of Poudre River and Horsetooth Reservoir waters at FCWTF would result in only marginal increases in optimal alum dose, on the order of a few mg/L.

Incremental differences in treatment costs associated with changes in Horsetooth Reservoir TOC levels related to NISP operations would depend on actual TOC levels and percentage of FCWTF demand met with Horsetooth Reservoir water in any given year. The potential influence of NISP operations on treatment costs at FCWTF was evaluated based on monthly raw water blends used in NCWCD MODSIM modeling, and assuming a forecast future demand of 29,000 acre-feet in 2010 per the Fort Collins Draft Water Conservation Plan (Fort Collins Utilities, 2007). The potential ranges of incremental treatment costs at FCWTF due to NISP operations were determined using predicted Horsetooth Reservoir TOC values (Figures TOC-9 through TOC-12), as shown on Figure TOC-14 assuming no TOC degradation during storage in Glade Reservoir, and on Figure TOC-15 assuming 25 percent TOC degradation during Glade Reservoir storage. Incremental cost data on Figures TOC-14 and TOC-15 indicate the average annual cost of additional treatment would be less than $3,500 assuming no TOC degradation during storage, and less than $2,000 assuming 25 percent TOC degradation during storage.

5.0 Conclusions

The following conclusions are drawn from the analyses and discussions presented in this memorandum:

- Long-term average TOC concentrations in Glade Reservoir due to diversion of Poudre River water under the operational schemes outlined here were predicted to be between 5 mg/L and 6 mg/L, assuming TOC behaves conservatively.

- Lower long-term average TOC concentrations could result from physical, chemical, and biological processes that would occur to some extent during detention in Glade Reservoir. TOC reductions between 17 percent and 26 percent have been observed during detention in the nearby Horsetooth Reservoir.

- Based on the projected timing of potential transfers to and withdrawals from Horsetooth Reservoir, substantial mixing due to seasonal overturn and internal circulation would be expected prior to NISP water use by FCWTF.

- As is typically the case for pristine natural waters, NOM in the Poudre River is predominantly dissolved in character, with approximately 90 percent of TOC in the dissolved NOM fraction, and hydrophobic fractions constituting as much as 75 percent of NOM content.

- Bench-scale and pilot-scale studies performed by Fort Collins Utilities, as well as full-scale operational experience, have consistently shown that aluminum and iron coagulants preferentially remove higher molecular weight hydrophobic NOM fractions typical of TOC in the Poudre River.

- Over the past decade, the City of Fort Collins Utilities has developed and implemented a coagulation scheme to effectively treat elevated TOC, low alkalinity source waters at FCWTF. This treatment scheme was successfully tested at full-scale over a six-week period during May and June 2005, during which TOC in the Poudre River peaked at approximately 13 mg/L.

- Treating blends of Poudre River and Horsetooth Reservoir waters at FCWTF would likely result in only marginal increases in optimal alum dose, on the order of a few mg/L.

- Projected incremental treatment cost data indicate the potential treatment cost increases would average less than $3,500 per year.

- Based on the analyses performed here, installation of additional TOC treatment processes at FCWTF would not be necessary to meet all applicable state and federal drinking water standards using currently available treatment processes and proven facility operating practices.

6.0 References

Billica, J. and K. Gertig (2000). *Optimization of a Coagulation Process to Treat High TOC, Low Alkalinity Water and its Impact on Filter Performance*, Proceedings of the 2000 AWWA Water Quality Technology Conference, Salt Lake City, Nov 5-9, 2000.

Billica, J. and K. Gertig (2006). *Use of Zeta Potential to Optimize Full-Scale Treatment of High TOC Water*, Proceedings of the 2006 AWWA Water Quality Technology Conference, Denver, Nov 5-9, 2006.

Carlson, K.H., Elmund, G.K., and K.R. Gertig (1994). *Getting a Jump on the Information Collection Rule: Plant Scale Characterization of NOM and the Relationship to DBP Formation*, Proceedings of the 1994 AWWA Water Quality Technology Conference, San Francisco, Nov 6-10, 1994.

CH2M HILL (2006). *Northern Integrated Supply Project: Glade Reservoir Water Quality Technical Memorandum*, September 5, 2006, CH2MHill.

Collins, M.R., Amy, G.L., and C. Steelink (1986). *Molecular weight distribution, carboxylic acidity, and humic substances content of aquatic organic matter. Implications for removal during water treatment,* Environ. Sci. Technol., 20, 1036-1032.

Dennehy, K.F, Litke, D.W., Tate, C.M., Qi, S.L., McMahon, P.B., Bruce, B.W., Kimbrough, K.A., and J.S. Heiny (1998). *Water Quality in the South Platte River Basin, Colorado, Nebraska, Wyoming, 1992–1995*, USGS Circular No. 1167.

Edzwald, J.K., Becker, W.C., and K.L. Wattier (1985). *Surrogate Parameters for Monitoring Organic Matter and THM Precursors*, Jour. AWWA, 77(4), 122-132.

Edzwald, J.K. (1993). *Coagulation in drinking water treatment: Particles, organics, and coagulants,* Wat. Sci. Technol., 27(11), 21-35.

Edzwald, J.K. and J.E. Tobiason (1999). *Enhanced coagulation: US requirements and a broader view*, Wat. Sci. Technol., 40(9), 63-70.

Fort Collins Utilities (2006). *Drinking Water Chemical Summary – 2006 Test Results*, accessed online on November 14, 2008, http://fcgov.org/water/pdf/dw-chemicals.pdf.

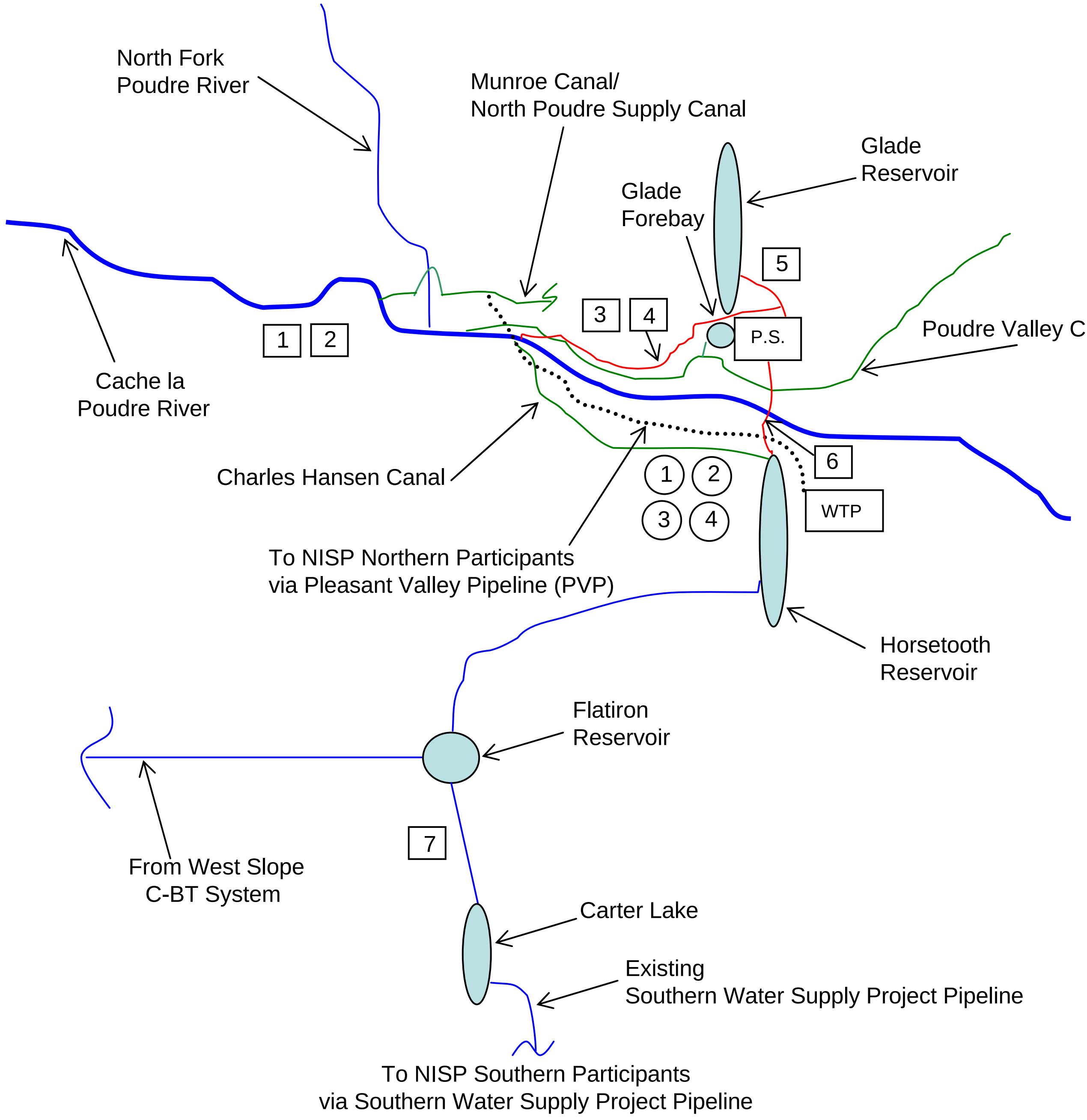
Fort Collins Utilities (2007). *Water Conservation Plan – Draft October 8, 2007*, accessed online on November 14, 2008, http://fcgov.org/water/pdf/conservation-plan-20071004.pdf.

Lewis, W.M. (2003). *Water Quality Considerations for the Proposed Glade Reservoir*, William M. Lewis, Jr., Novemeber 18, 2003.

Sharp, E.L. (2005). *Natural Organic Matter Coagulation*, Ph.D. Disseration, Cranfield University, School of Water Sciences.

Sharp, E.L., Banks J., Billica, J.A., Gertig, K.R., Henderson, R., Parsons, S.A., Wilson, D., and B. Jefferson (2005a). *Application of zeta potential measurements for coagulation control: pilot-plant experiences from UK and US waters with elevated organics*, Wat. Sci. Technol.: Water Supply, 5(5), 49-56.

Sharp, E.L., Parsons, S.A., and B. Jefferson (2005b). *Coagulation of NOM: linking character to treatment*, Wat. Sci. Technol., 53(7), 67-76.

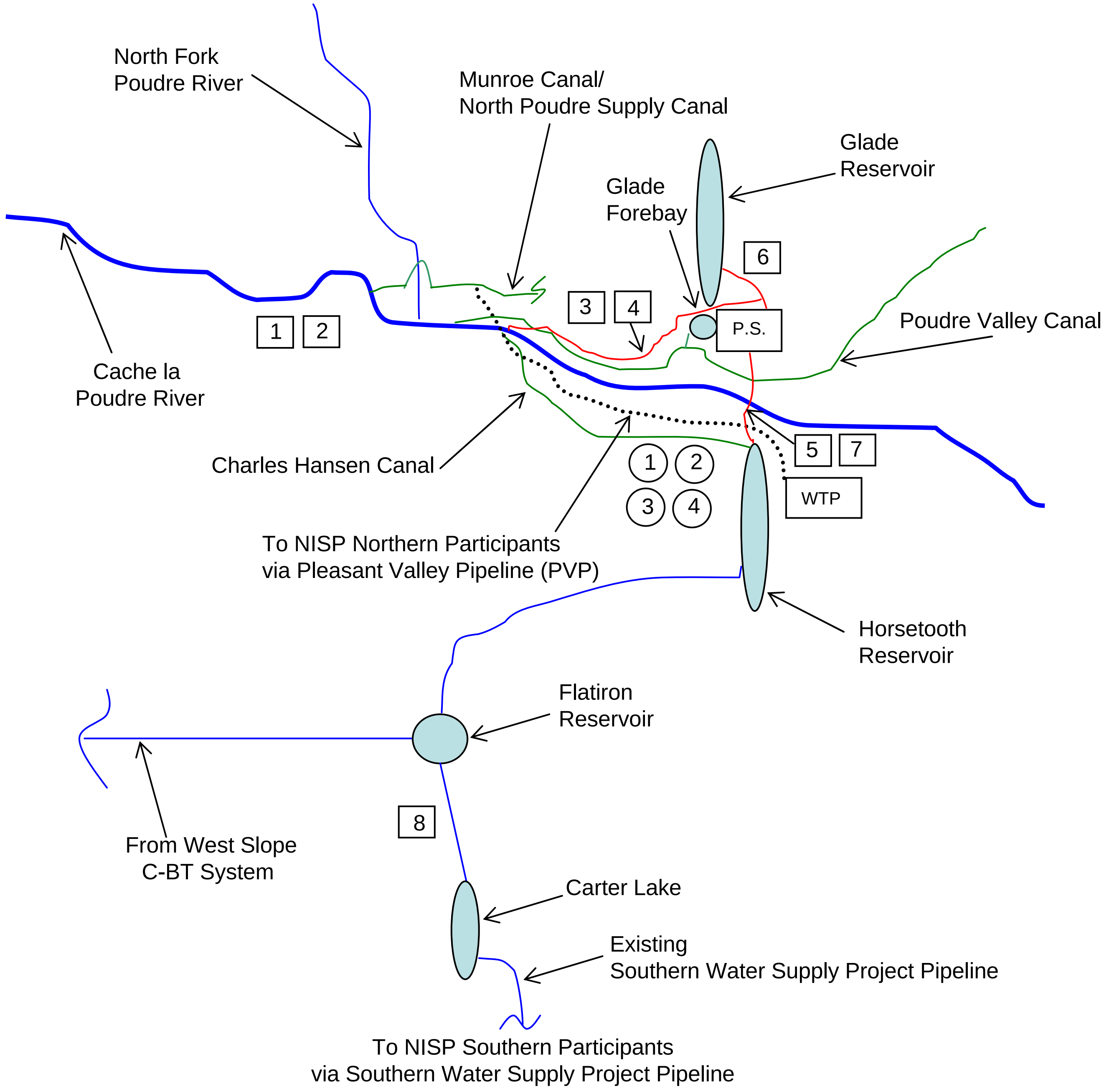


Without NISP		With NISP	
Item	**Action**	**Item**	**Action**
①	HT releases C-BT water to river for downstream diverters.	1	When NISP water rights are in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be left in the river for either items 1 or 2 and used instead of C-BT Water.
②	HT releases C-BT water to river allowing diversion into the PVP.	2	
③	HT releases C-BT water to river for downstream diverters.	3	When NISP water rights are not in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be delivered from Glade Reservoir to the river for either items 3 or 4 and used instead of C-BT Water.
④	HT releases C-BT water to river allowing diversion into the PVP.	4	
N/A	Not Applicable.	5	When the amount of water available to NISP is greater than available C-BT exchanges, this water would be diverted into the Poudre Valley Canal and transferred into Glade Reservoir for later use.
N/A	Not Applicable.	6	At the end of the water year, if there has been an insufficient amount of water exchanged into HT to achieve NISP objectives, water could be transferred via pipeline from Glade Reservoir to HT over the winter months. This operation would continue until sufficient water has been delivered to HT from Glade to make up for any shortfalls that occurred in the prior year.
N/A	Not Applicable.	7	Items 1,2,3,4 reduce the amount of C-BT water released from HT. When required, Item 6 provides an alternate water supply into HT. The combination of releasing less water from HT and supplemental supplies into HT allows for reduced deliveries of C-BT water into HT. Instead, this water can be sent from Flatiron Reservoir to Carter Lake for NISP participant use.

Northern Integrated Supply Project

Operating Scheme 1
Minimum NISP Pumping

Figure
TOC-1



Without NISP		With NISP	
Item	**Action**	**Item**	**Action**
①	HT releases C-BT water to river for downstream diverters.	1	When NISP water rights are in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be left in the river for either items 1 or 2 and used instead of C-BT Water.
②	HT releases C-BT water to river allowing diversion into the PVP.	2	
③	HT releases C-BT water to river for downstream diverters.	3	When NISP water rights are not in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be delivered from Glade Reservoir to the river for either items 3 or 4 and used instead of C-BT Water.
④	HT releases C-BT water to river allowing diversion into the PVP.	4	
N/A	Not Applicable.	5	When NISP water rights are in priority, but the full potential to make exchanges has been exhausted, NISP water can be diverted and pumped directly to HT. This operation would not occur in the month of May when TOC concentrations in the Poudre are elevated.
N/A	Not Applicable.	6	When the amount of water available to NISP is greater than the available C-BT exchanges or greater than the pumping capacity to HT, NISP water would be diverted and transferred into Glade Reservoir for later use.
N/A	Not Applicable.	7	At the end of the water year, if there has been an insufficient amount of water exchanged or pumped into HT to achieve NISP objectives, water could be transferred via pipeline from Glade Reservoir to HT over the winter months. This operation would continue until sufficient water has been delivered to HT from Glade to make up for any shortfalls that occurred in the prior year.
N/A	Not Applicable.	8	Items 1,2,3,4 reduce the amount of C-BT water released from HT. Item 5 transfers low concentration TOC water from the Poudre to HT. When required, Item 7 delivers water directly from Glade to HT. The combination of releasing less water from HT and supplemental supplies into HT allows for reduced deliveries of C-BT water into HT. Instead, this water can be sent from Flatiron Reservoir to Carter Lake for NISP participant use.

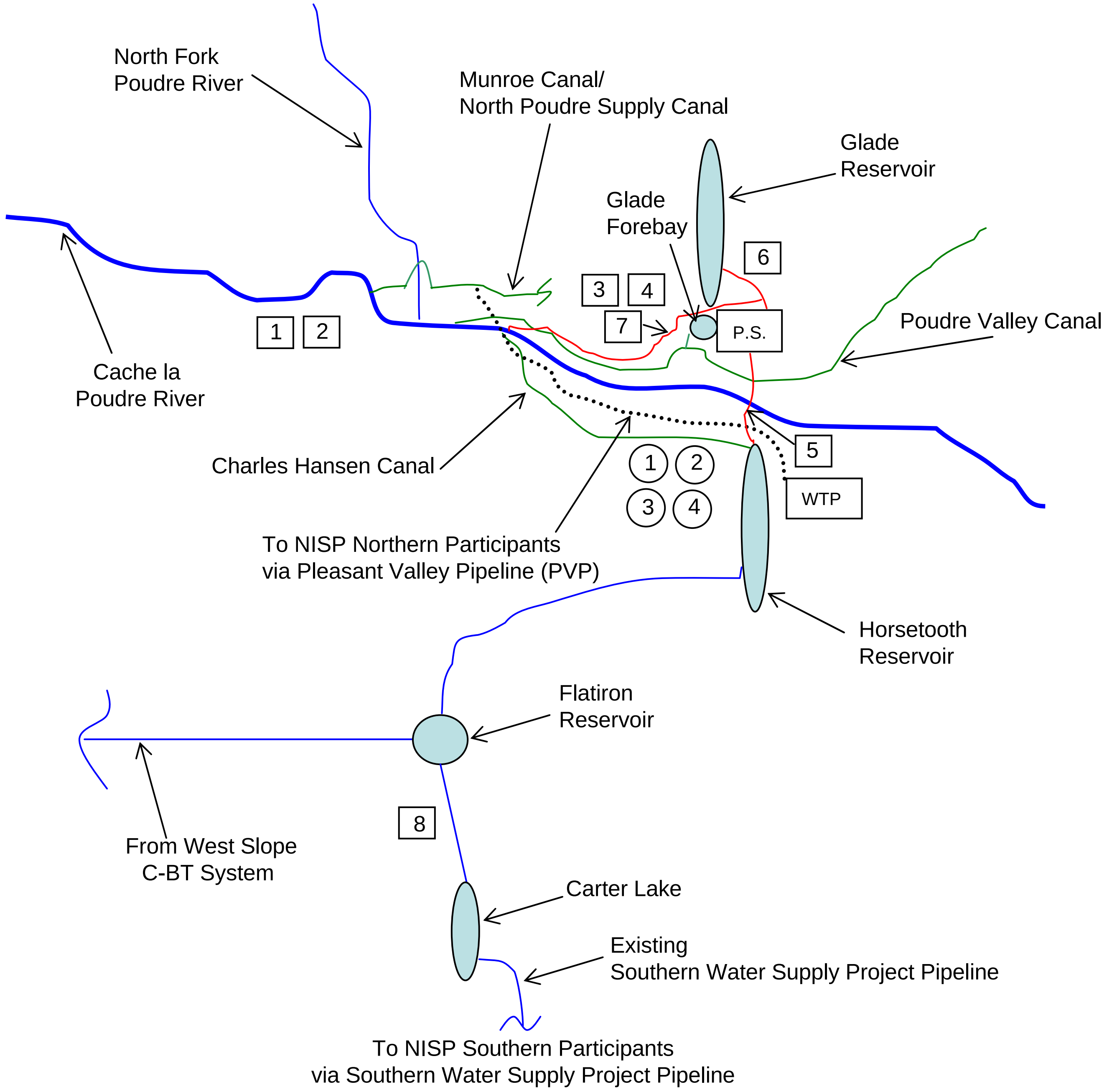
Northern Integrated Supply Project

Operating Scheme 2

Minimum Transfer of Water from Glade Reservoir to Horsetooth Reservoir

Figure

TOC-2



Without NISP		With NISP	
Item	**Action**	**Item**	**Action**
①	HT releases C-BT water to river for downstream diverters.	1	When NISP water rights are in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be left in the river for either items 1 or 2 and used instead of C-BT Water.
②	HT releases C-BT water to river allowing diversion into the PVP.	2	
③	HT releases C-BT water to river for downstream diverters.	3	When NISP water rights are not in priority and when HT would be releasing C-BT water to the Poudre, NISP water can be delivered from Glade Reservoir to the river for either items 3 or 4 and used instead of C-BT Water.
④	HT releases C-BT water to river allowing diversion into the PVP.	4	
N/A	Not Applicable.	5	When NISP water rights are in priority, but the full potential to make exchanges has been exhausted, NISP water can be diverted and pumped directly to HT. This operation would not occur in the month of May when TOC concentrations in the Poudre are elevated.
N/A	Not Applicable.	6	When the amount of water available to NISP is greater than the available C-BT exchanges or greater than the pumping capacity to HT, NISP water would be diverted and transferred into Glade Reservoir for later use.
N/A	Not Applicable.	7	At the end of the water year, if there has been an insufficient amount of water exchanged or pumped into HT to achieve NISP objectives, water could be released from Glade Reservoir to a location directly downstream of the NISP diversion and Poudre water with low TOC concentrations can be diverted and pumped into HT over the winter months. This operation would continue until sufficient water has been delivered to HT from Glade to make up for any shortfalls that occurred in the prior year.
N/A	Not Applicable.	8	Items 1,2,3,4 reduce the amount of C-BT water released from HT. Item 5 transfers low concentration TOC water from the Poudre to HT. When required, Item 7 delivers water directly from Glade to HT. The combination of releasing less water from HT and supplemental supplies into HT allows for reduced deliveries of C-BT water into HT. Instead, this water can be sent from Flatiron Reservoir to Carter Lake for NISP participant use.

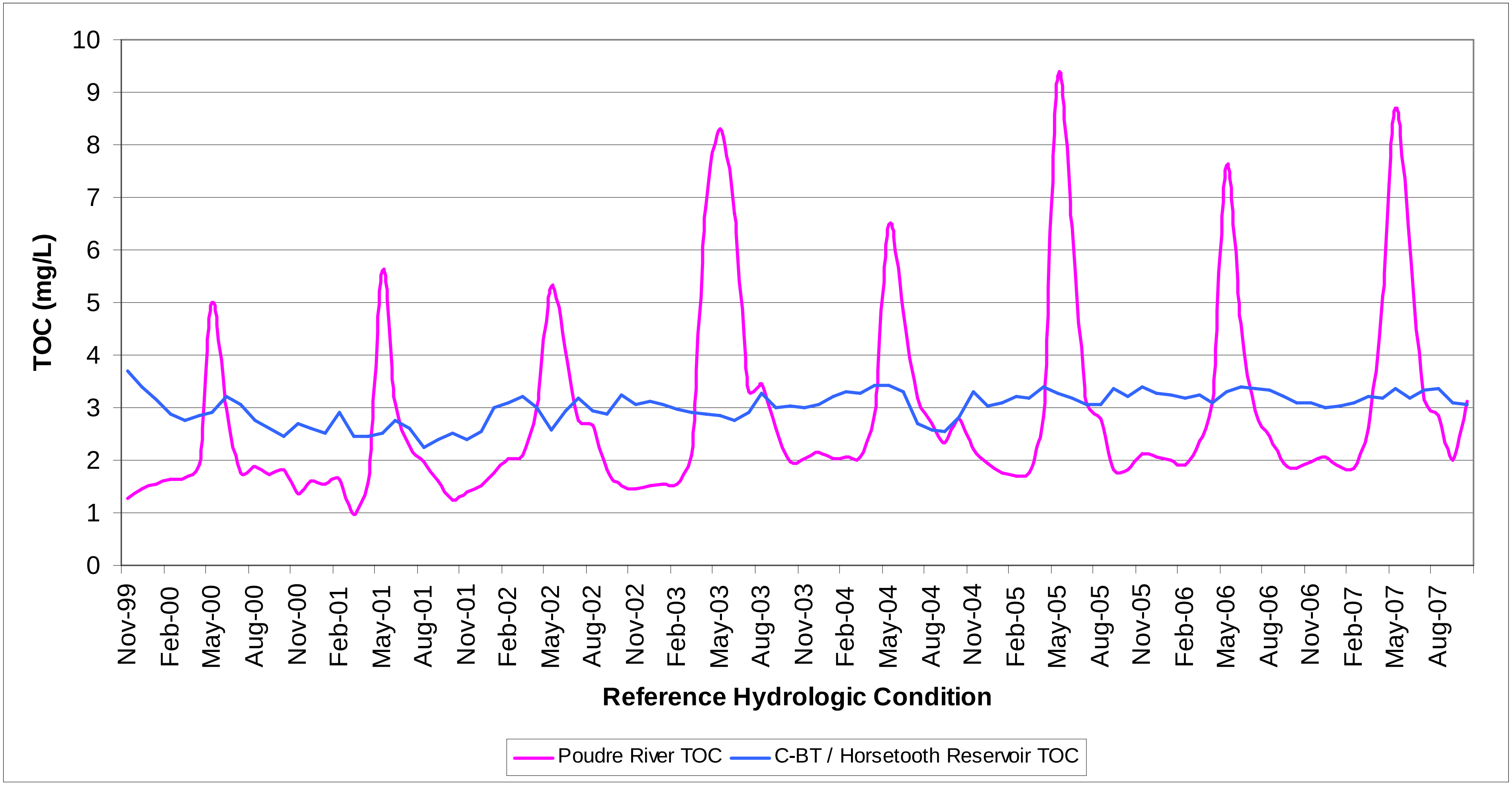
Northern Integrated Supply Project

Operating Scheme 3

No Transfers of Glade Reservoir Water into Horsetooth Reservoir

Figure

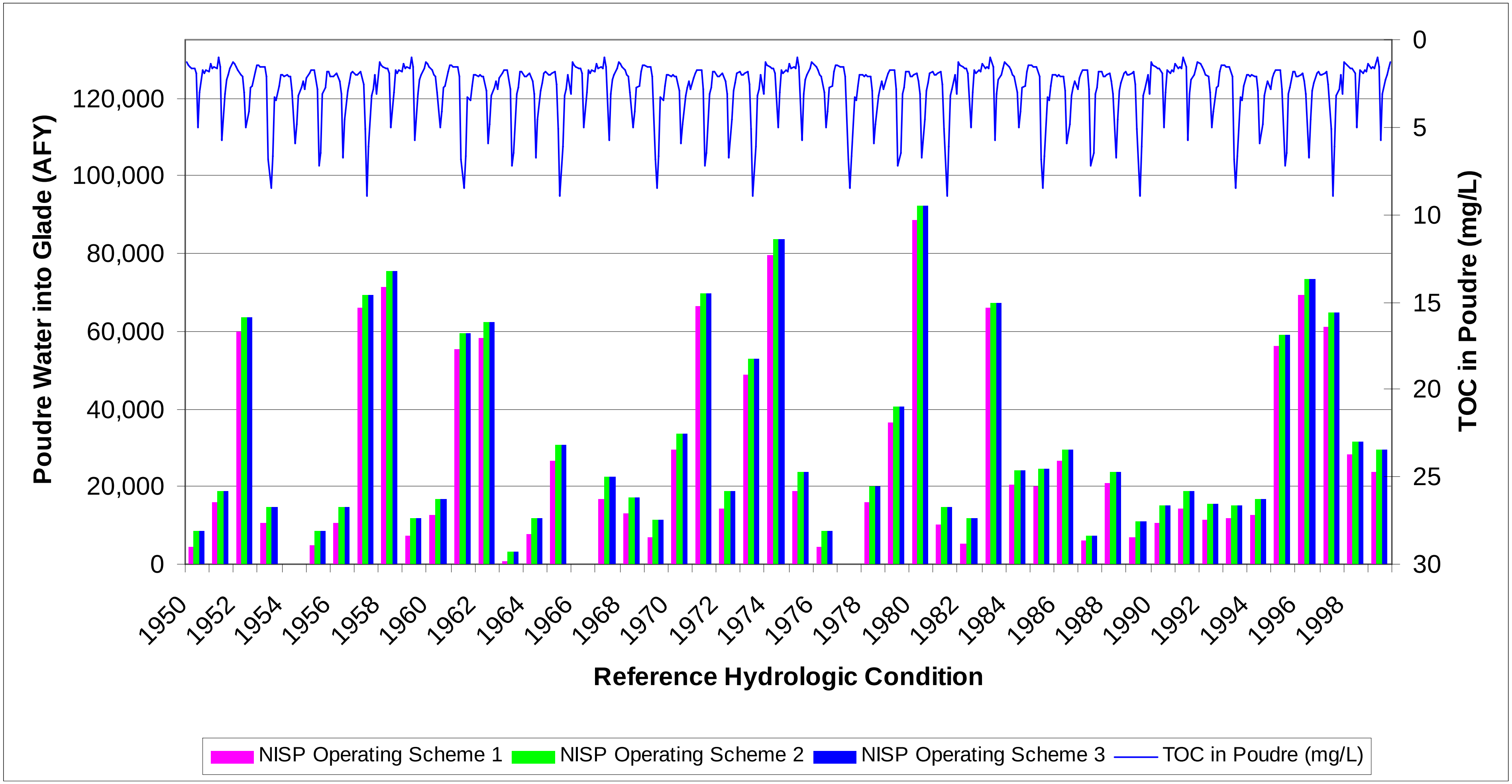
TOC-3



Source: Poudre River TOC values are flow weighted monthly average values based on TOC concentrations collected by the City of Fort Collins and flow rates measured at USGS gage station 06754000, located near the Poudre Canyon mouth.

Horsetooth Reservoir TOC values are average monthly TOC concentrations in the reservoir based data collected by the City of Fort Collins.

NISP Northern Integrated Supply Project	**Northern Integrated Supply Project** **Historical Values Used in Reservoir TOC Mass-Balance Analyses**	**Figure** **TOC-4**



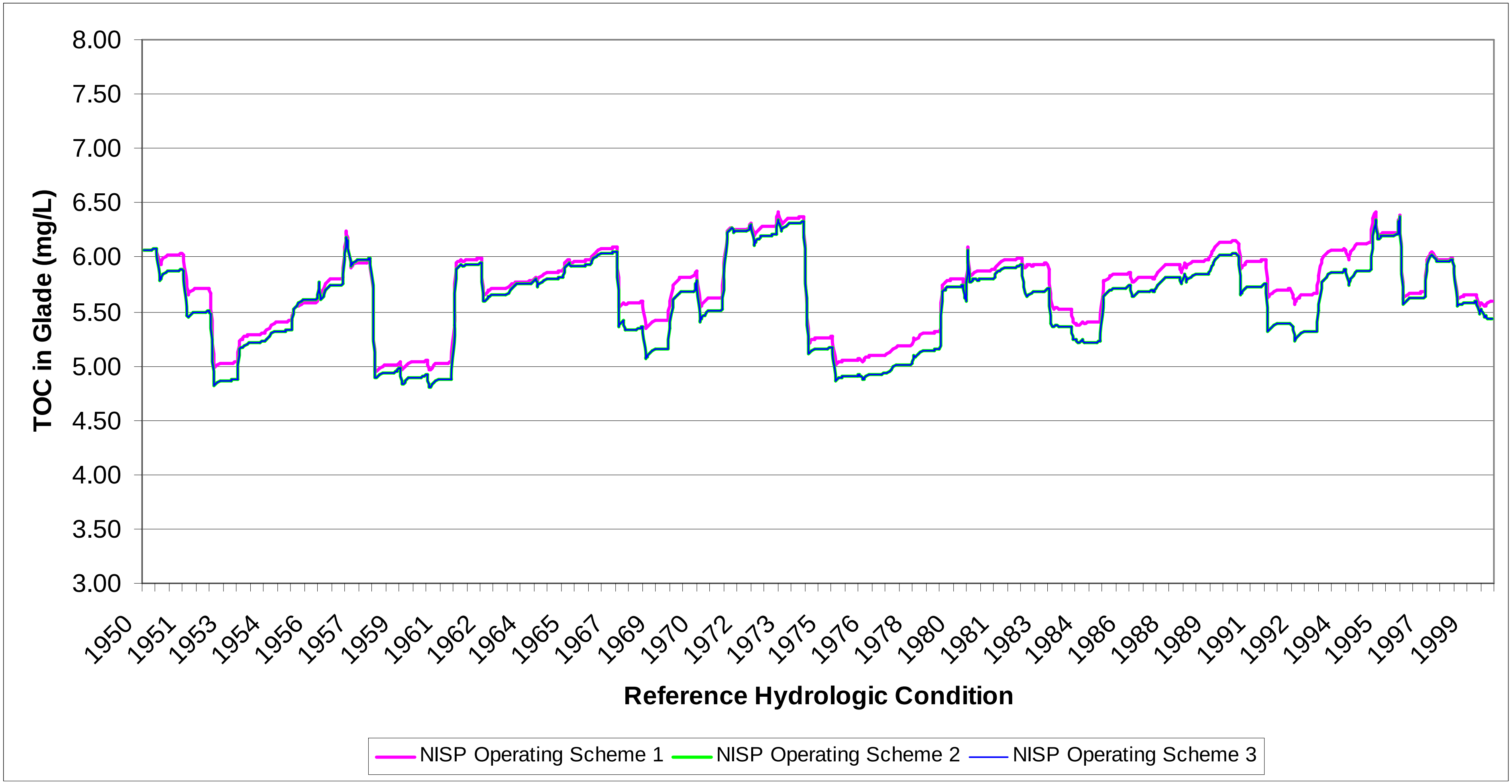
Source: TOC values are flow-weighted mean values for each month based on Fort Collins data collected between 1999 and 2008.

Northern Integrated Supply Project

Modeled Diversion of Poudre River Water into Glade Reservoir

Figure

TOC-5

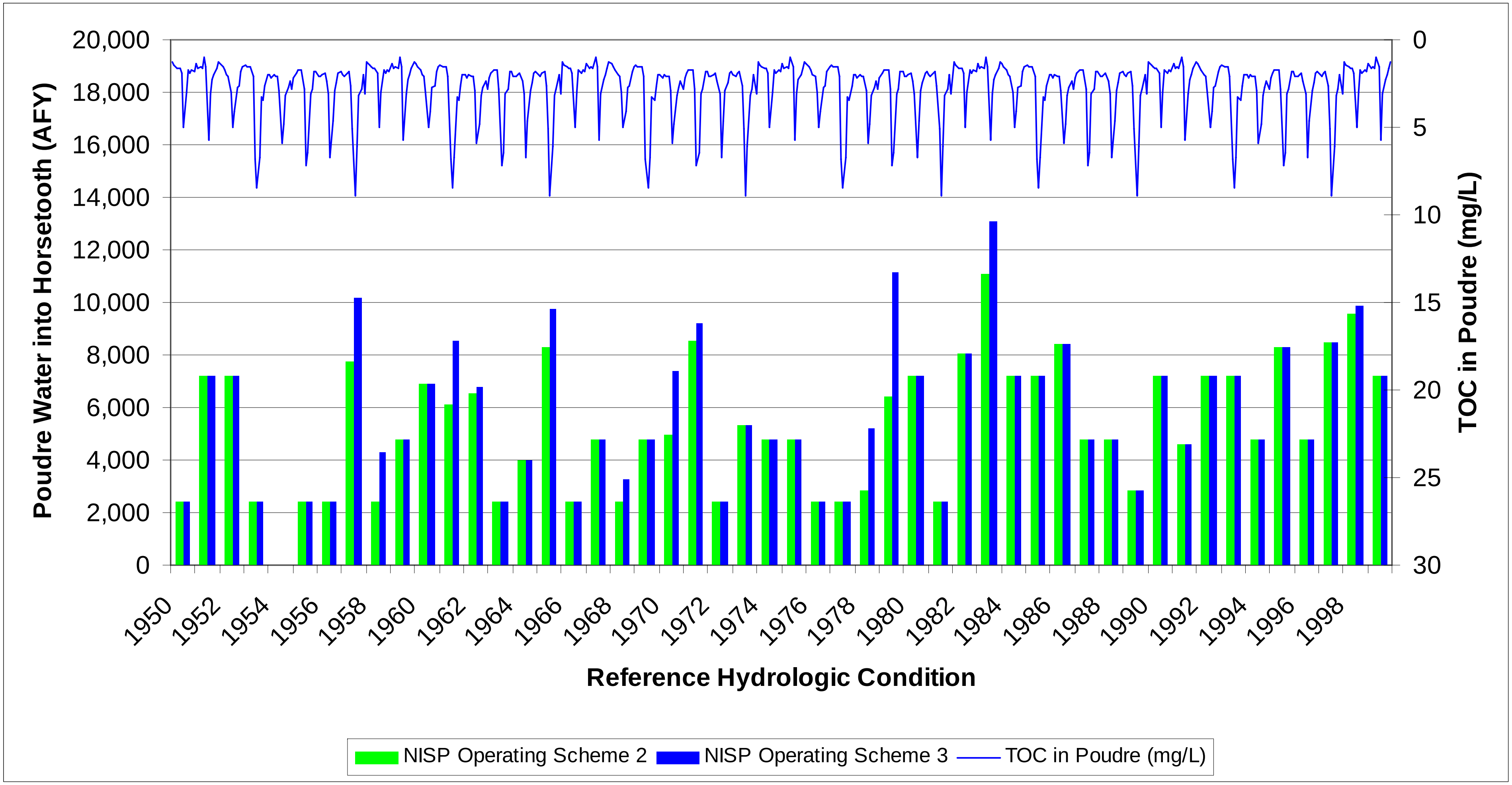


Northern Integrated Supply Project

Predicted TOC Concentrations in Glade Reservoir

Figure

TOC-6

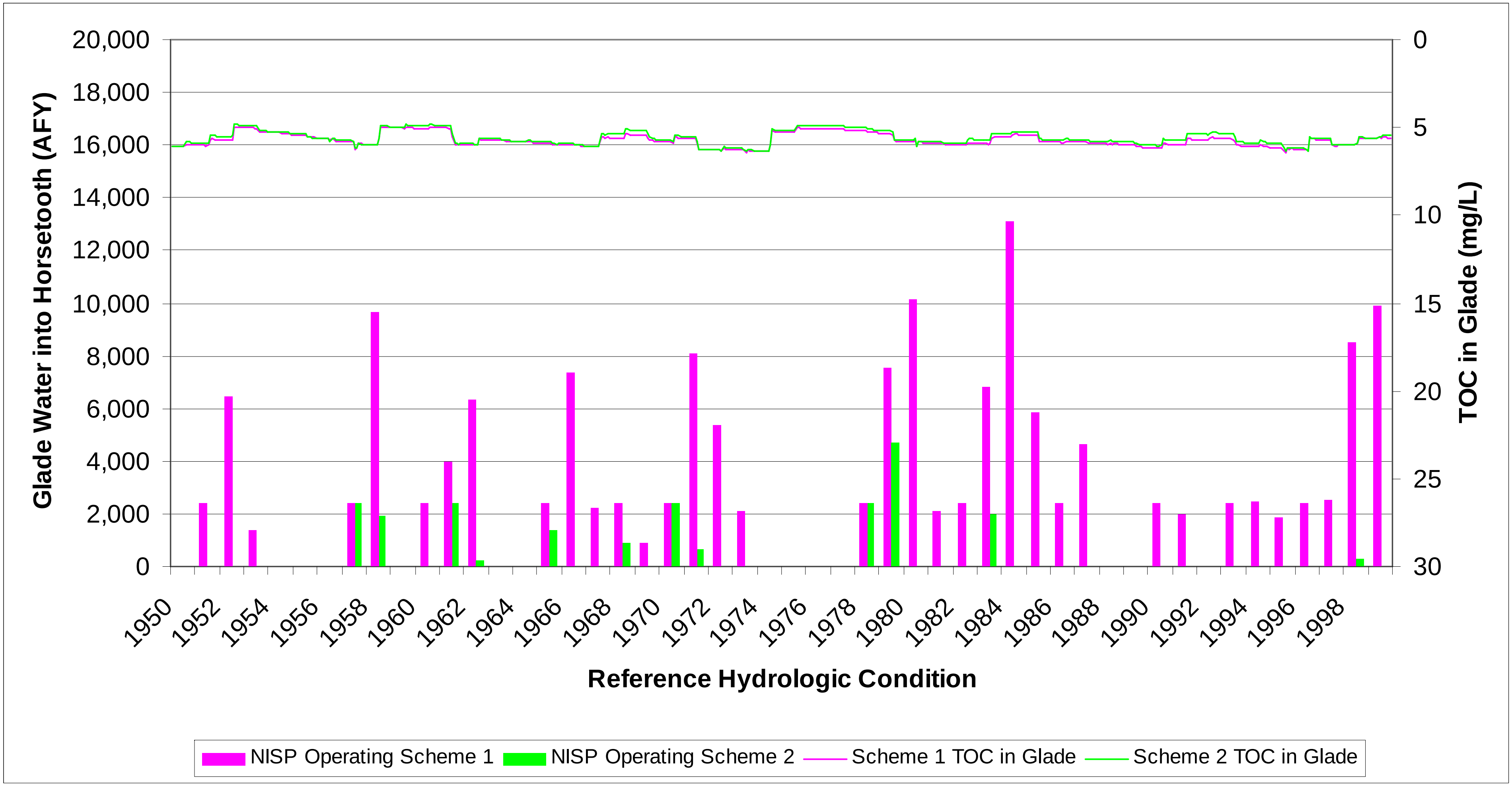


Northern Integrated Supply Project

Modeled Poudre River DIversions Directly into Horsetooth Reservoir

Figure

TOC-7

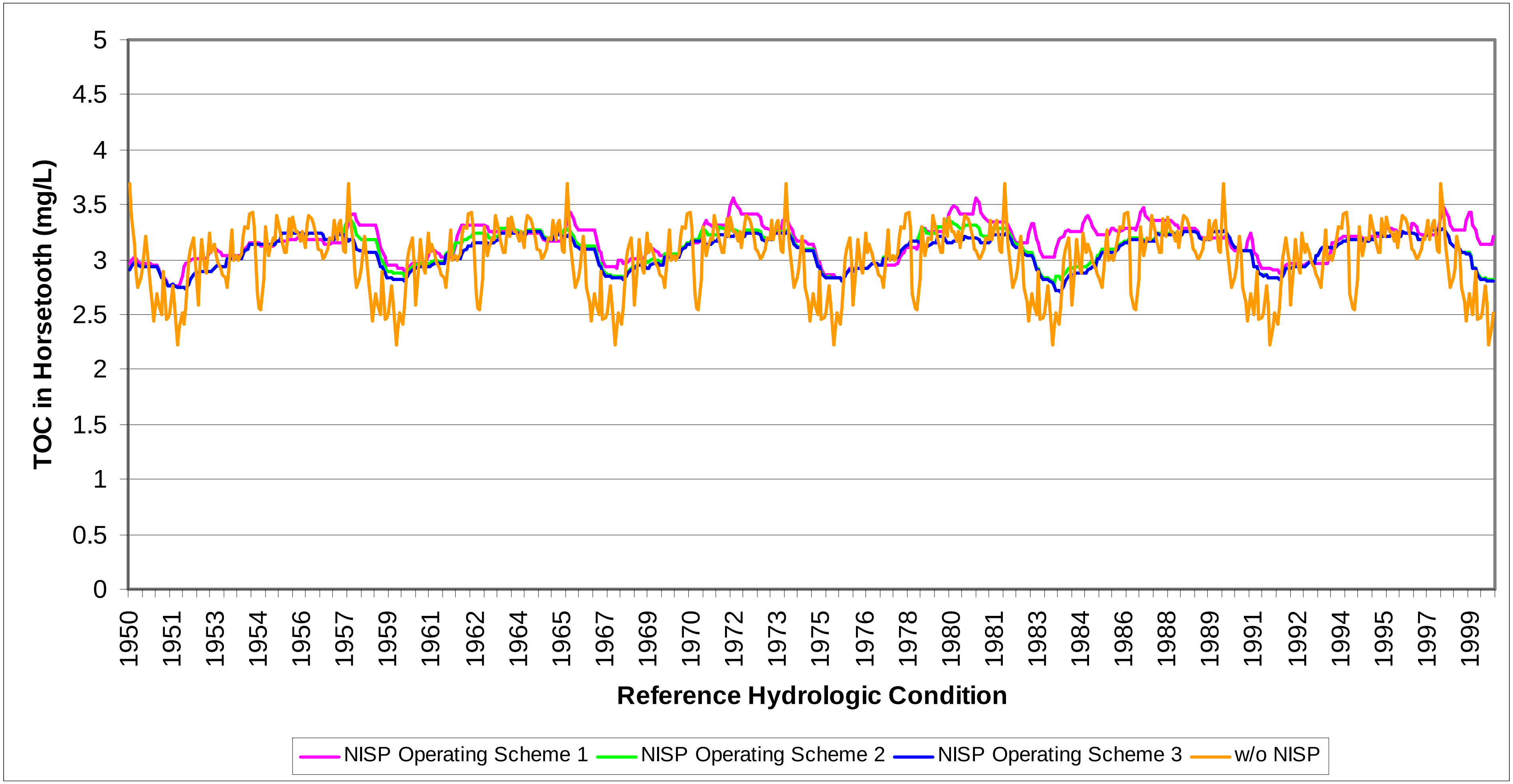


Northern Integrated Supply Project

Modeled Glade Reservoir Transfers Directly into Horsetooth Reservoir

Figure

TOC-8

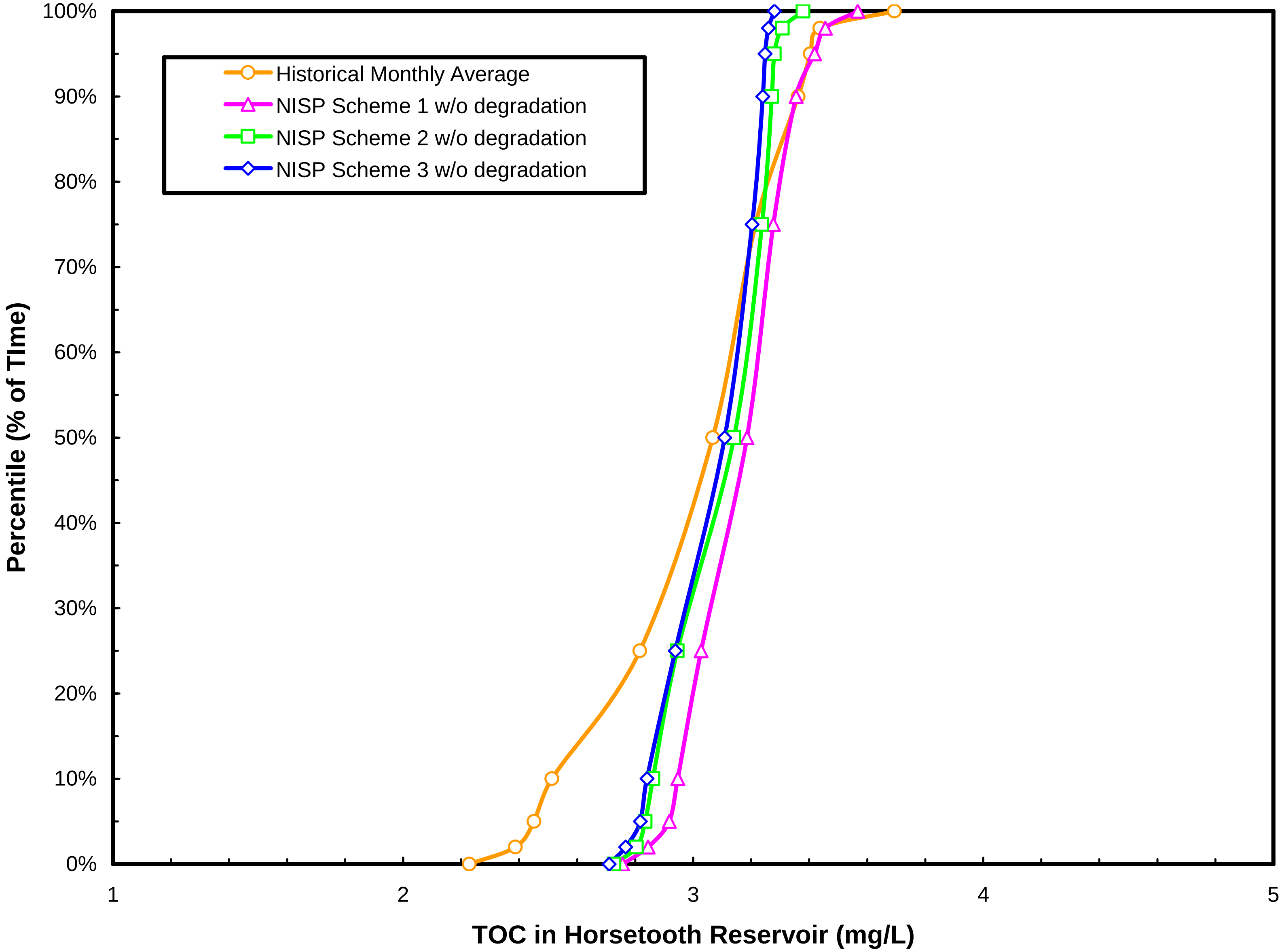


Northern Integrated Supply Project

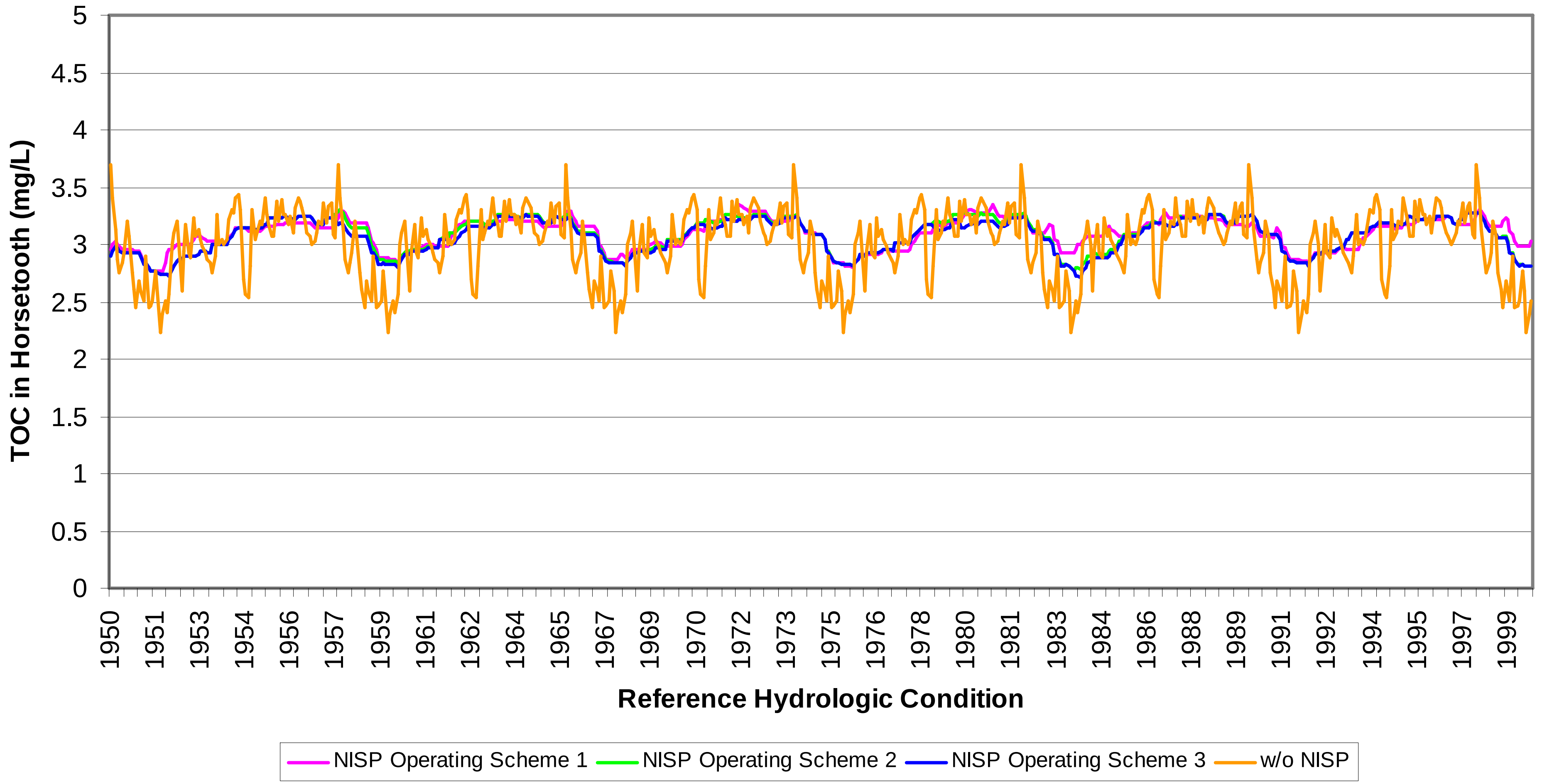
TOC Concentrations in Horsetooth Reservoir Resulting from NISP Operations (Assuming No TOC Degradation in Glade Reservoir)

Figure

TOC-9



Northern Integrated Supply Project	Figure TOC-10
Potential Impact of NISP Operations on TOC Concentrations in Horsetooth (Assuming No Degradation of TOC Occurs in Glade Reservoir)	

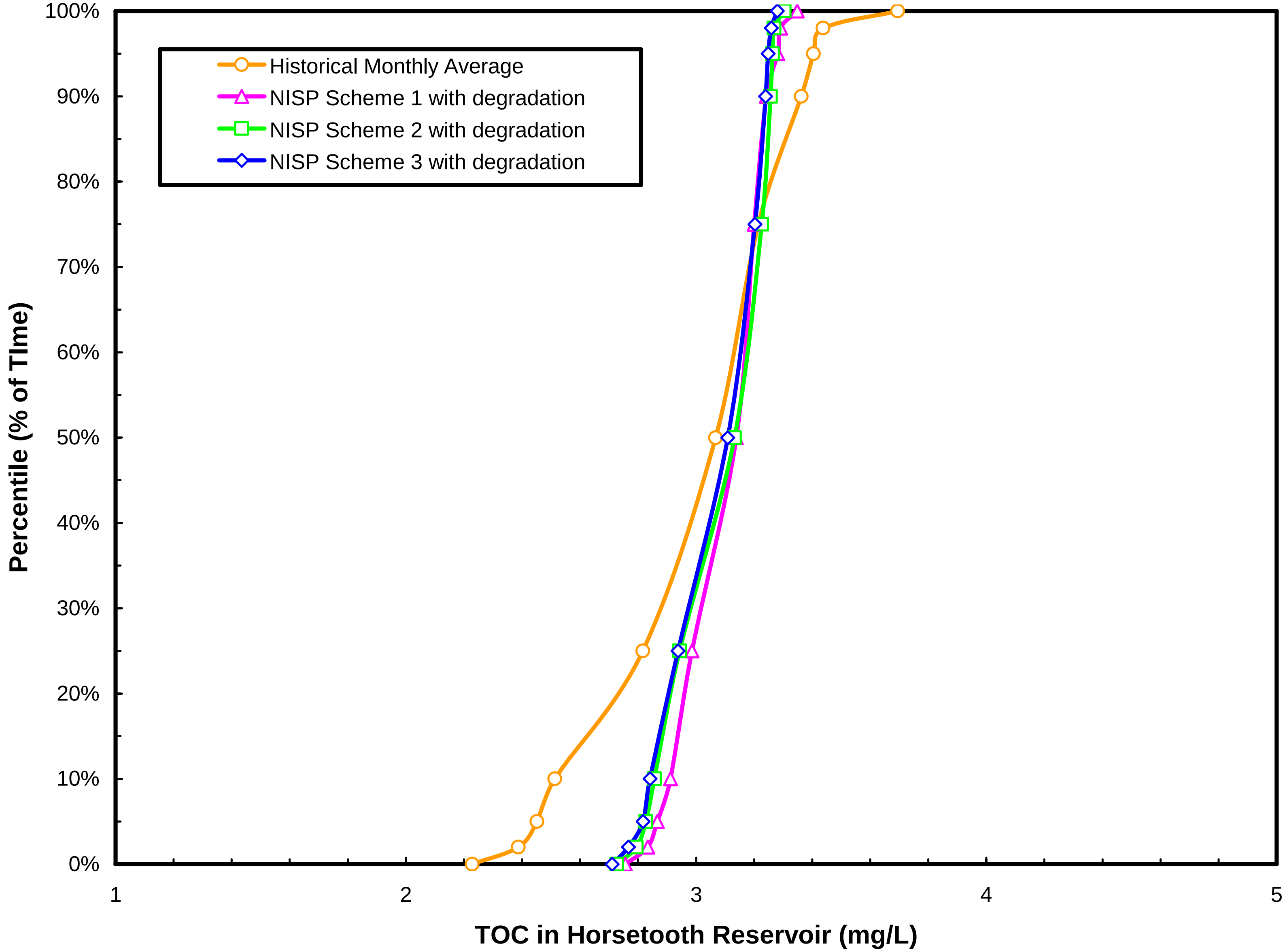


Northern Integrated Supply Project

TOC Concentrations in Horsetooth Reservoir Resulting from NISP Operations
(Assuming 25 Percent TOC Degradation in Glade Reservoir)

Figure

TOC-11

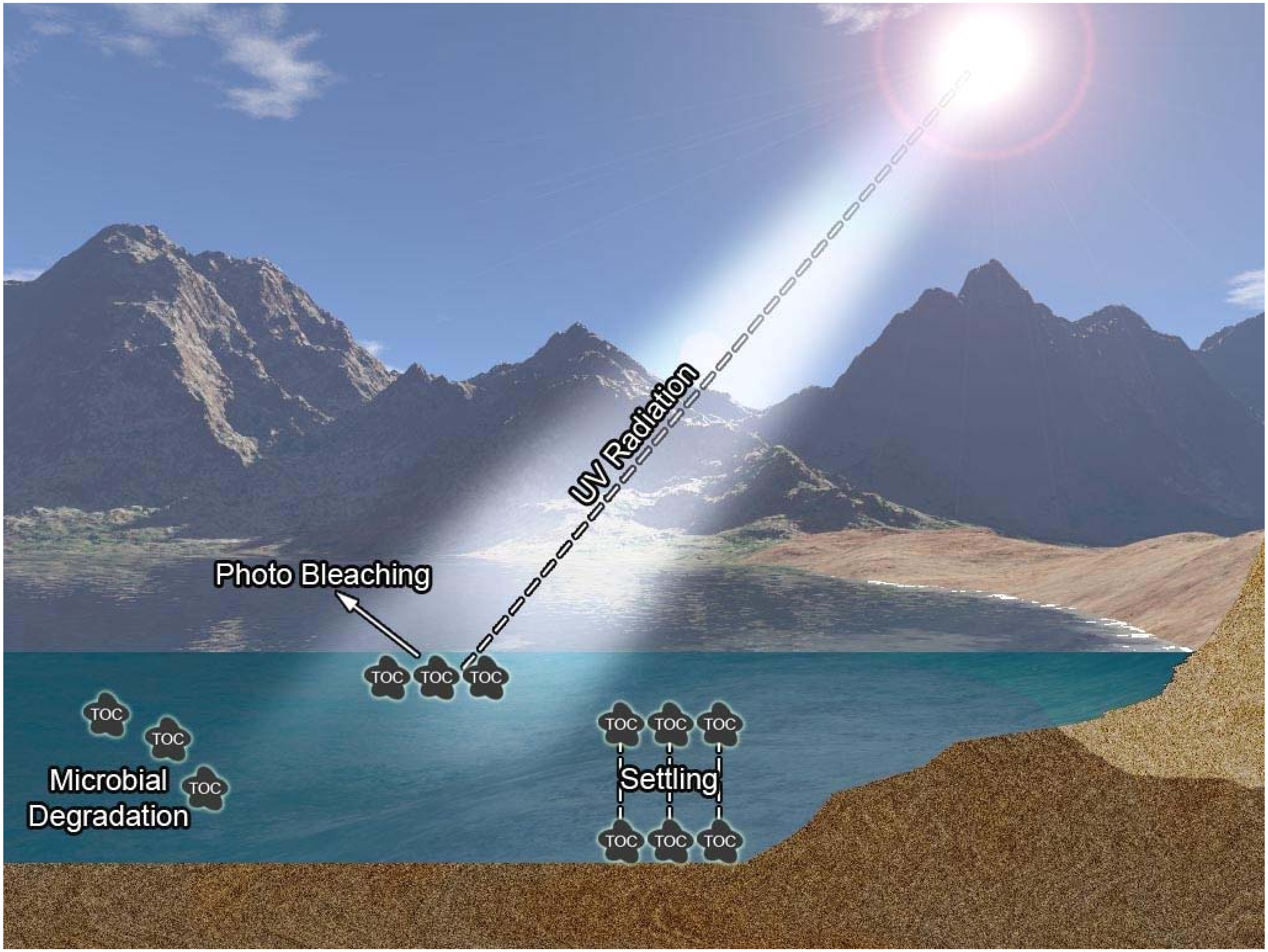


Northern Integrated Supply Project

Potential Impact of NISP Operations on TOC Concentrations in Horsetooth (Assuming 25% Degradation of TOC Occurs in Glade Reservoir)

Figure

TOC-12



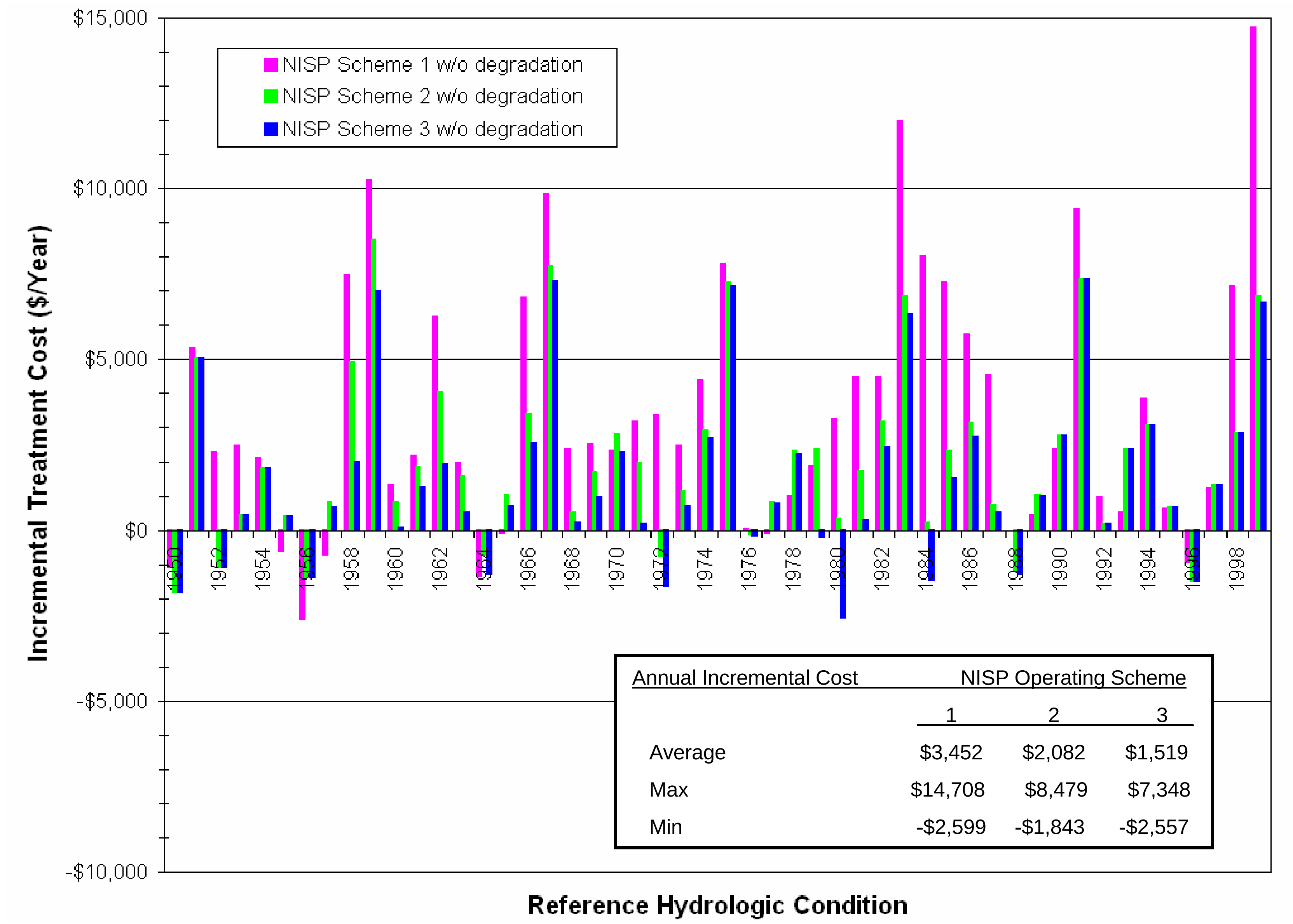
NISP

Northern Integrated Supply Project

Potential TOC Degradation in Glade and Horsetooth Reservoirs

Figure

TOC-13



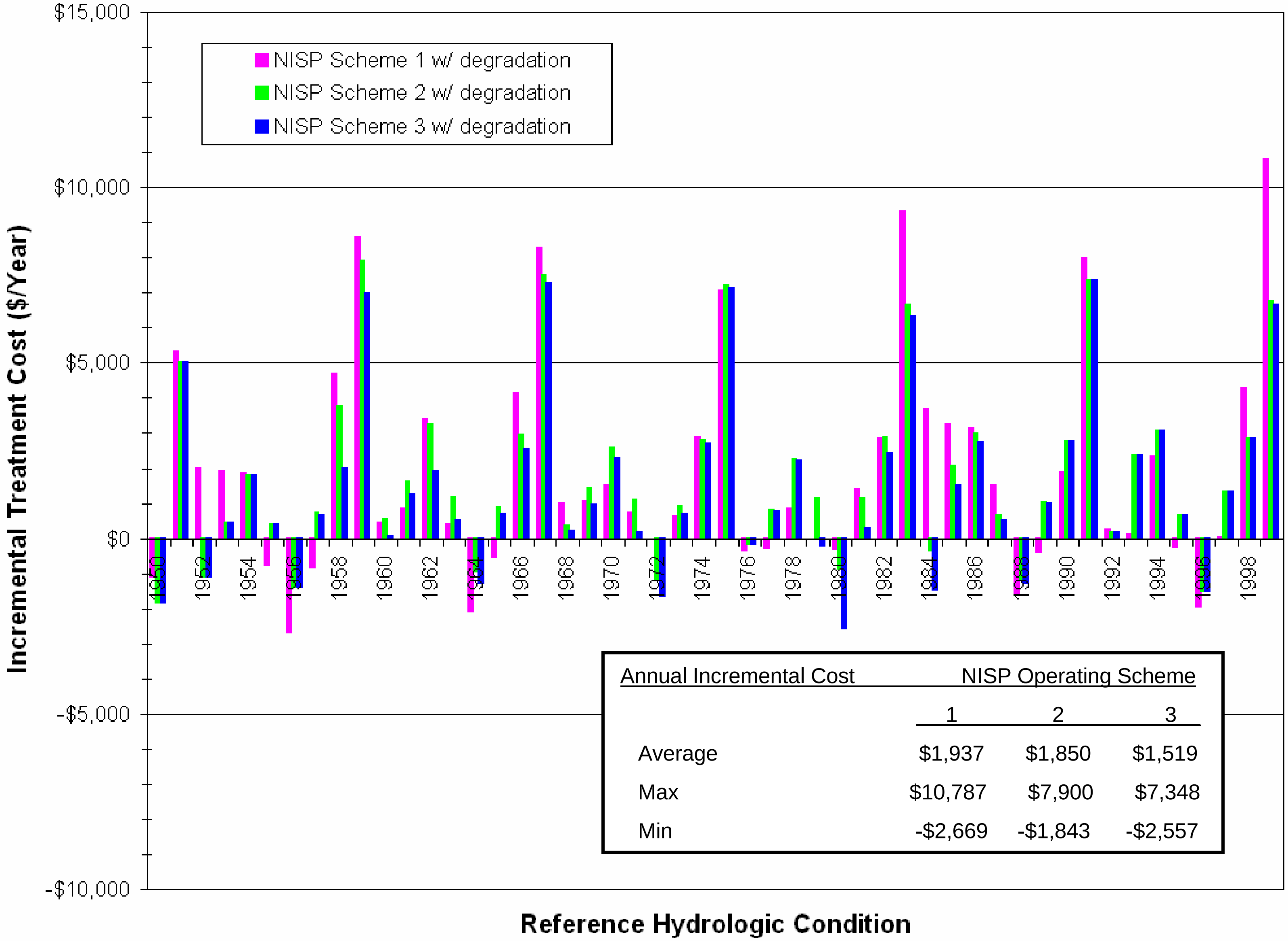
Annual Incremental Cost	NISP Operating Scheme		
	1	2	3
Average	$3,452	$2,082	$1,519
Max	$14,708	$8,479	$7,348
Min	-$2,599	-$1,843	-$2,557

Northern Integrated Supply Project

Incremental Treatment Cost at FCWTF due to NISP Operations (Assuming No Degradation of TOC Occurs in Glade Reservoir)

Figure

TOC-14



Annual Incremental Cost	NISP Operating Scheme		
	1	2	3
Average	$1,937	$1,850	$1,519
Max	$10,787	$7,900	$7,348
Min	-$2,669	-$1,843	-$2,557

Northern Integrated Supply Project

Incremental Treatment Cost at FCWTF due to NISP Operations (Assuming 25% Degradation of TOC Occurs in Glade Reservoir)

Figure

TOC-15