Analysis of Total Maximum Daily Load (TMDL) for Nitrate in the Urban Region of the South Platte River, with Emphasis on Segment 14

Prepared for: Colorado Department of Public Health and Environment
Water Quality Control Division

Prepared by: William M. Lewis, Jr.
James F. Saunders, III.

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Introduction

This report summarizes the results of an analysis of nitrate concentrations in the South Platte River between Chatfield Dam and the Burlington Ditch headgate (Upper South Platte Segments 6c and 14: Figure 1). The analysis is applicable to present and future conditions. Because the context for the analysis is a TMDL for nitrate, all influences on loads and concentrations of nitrate are taken into account as fully as possible on the basis of monitoring data, effluent characteristics, or other pertinent information. The focus of the analysis is on low-flow conditions because critical concentrations of nitrate coincide with minimum availability of dilution for point-source discharges. For this reason, identification of critical low flows is a major component of the analysis. The ultimate goal of the analysis is to identify limits for nitrate in point-source discharges that would be consistent with the stream standard for nitrate in Segment 14 (acute, 10 mg/L $NO_3\Gamma$-N; drinking water supply).

Because the estimation of appropriate effluent limits for point sources involves the simultaneous consideration of numerous factors, a model is used in making estimates. The model is designated here as the Segment 14 Nitrate TMDL Model. The design of the model as well as its calibration and validation are explained in this report.

Ungaged Flows

Ungaged flows entering the South Platte River contribute significantly to the dilution of point-source discharges. Thus it is important to take ungaged flows into

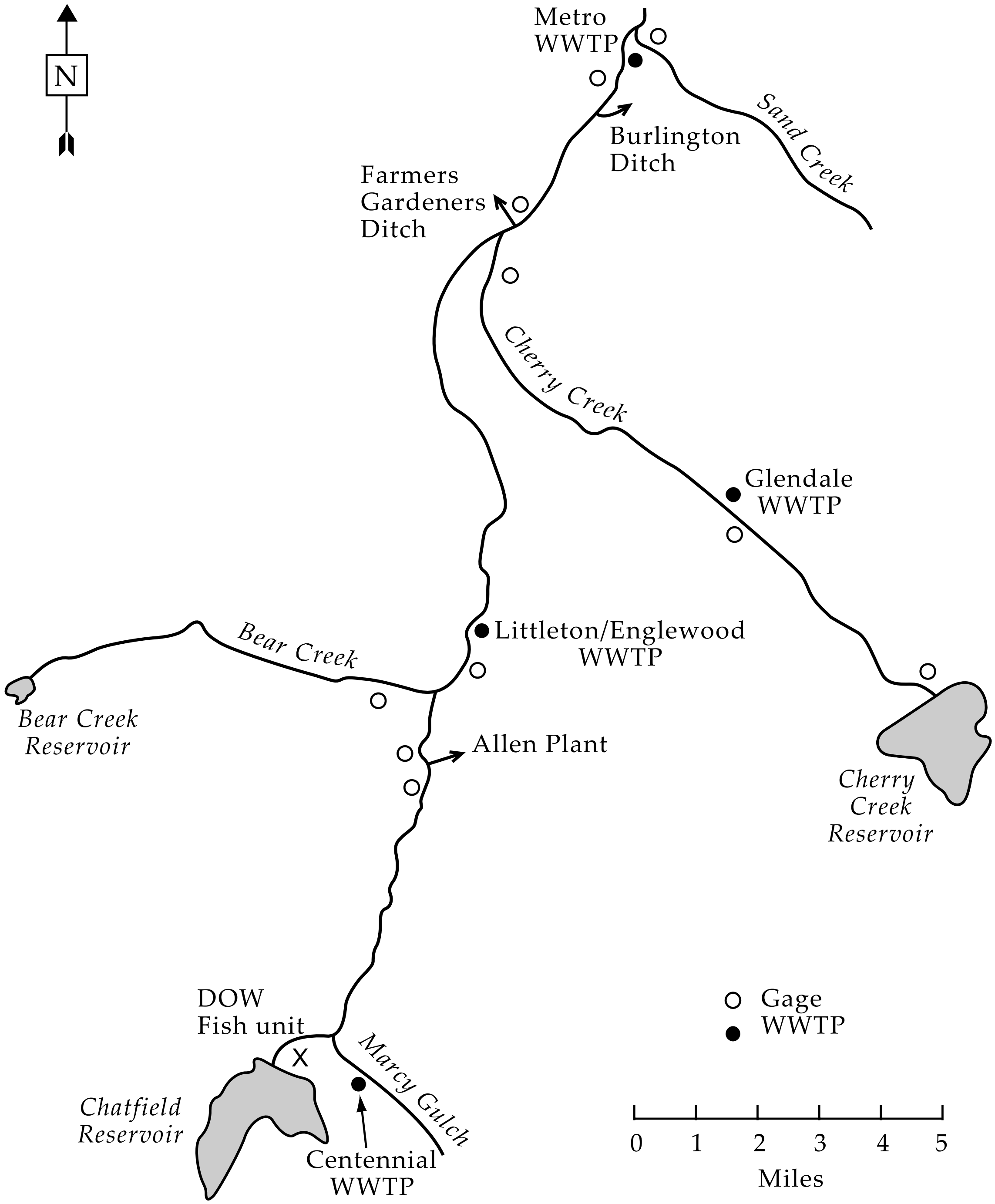


Figure 1. Map of Segment 6c and 14 of the upper South Platte River indicating tributaries, points of effluent discharge, and points of withdrawal.

account in modelling, especially under low-flow conditions.

The ungaged flows for Segments 6c and 14 of the South Platte had not been estimated from field data prior to the current TMDL study for nitrate. Ungaged flows consist of a dry-weather surface component and a seepage (subsurface) component. For previous TMDL modelling, the seepage component was assumed to be identical to that of the upstream end of Segment 15. The dry-weather surface component was measured in the field, and a relationship was developed between this component of ungaged flow and the drainage area contributing to individual ungaged flows (gulches, small tributaries, etc.). For the present phase of TMDL modelling, direct estimates were made of ungaged flows to Segments 6c and 14 of the South Platte (as described below), and the relationship between area and dry-weather surface flows as developed previously was used to estimate the surface component of total ungaged flows. Any ungaged flows not attributable to surface sources were assumed to be from seepage (groundwater entering the channel).

The ideal information for estimation of ungaged flows is a long-term record of flow for a pair of gages several miles apart over a reach of river without any intervening tributaries, diversions, or other complicating factors. This ideal situation does not exist in Segments 6c and 14, but reasonable estimates are possible because there are several pairs of gages from which multiple estimates can be made, and because daily records are available for major tributaries, point source additions, and diversions.

Data for eight gages (five for the main stem) and two tributary reservoir releases were used in the analysis of ungaged flows. These are listed in Table 1. The five main stem gages were paired in five different ways to give all useful pairwise combinations for which simultaneous daily readings were available at an upstream and a downstream gage, and for which diversions and tributary flows were known on a daily basis. The five reaches are listed in Table 2.

For the South Platte, the daily flow records were compiled from the upstream and

Flow Records	Miles Below Dam	Gage Number
South Platte		
Below Chatfield (PLACHACO gage)	0	SEO Records
Above Union Avenue (Above Allen Plant)	6.79	06710245
Below Union Avenue (Below Allen Plant)	6.88	06710247
Englewood (Above L/E WWTP)	9.73	06711565
Denver (Above Burlington)	17.51	06714000
Cherry Creek		
Reservoir Release	0	USACE Records
Glendale	5.87	06713300
Denver (Mouth)	10.87	06713500
Bear Creek		
Reservoir Release	0	USACE Records
Sheridan (Mouth)	5.00	06711500

Table 1. Gages used in the analysis of ungaged flows for Segments 6c and 14 (see Figure 1 for locations).

downstream records for each of the five reaches listed in Table 2. The same was done for the two tributaries. Records then were assembled for intervening flows and diversions over each reach. These include tributary flows, diversion records, and point-source discharges. For each reach, the period of overlap for the upstream gage, downstream gage, and all intervening flows was determined; this period of overlap was the basis for the analysis of the reach.

Reach Number	Reach Boundaries	Length of Reach (miles)	Length of Record	Intervening Flows and Diversions	Flow Threshold (cfs)
Main Stem					
1	Chatfield to above Union	6.79	4/12/89-2/5/96	Fish Hatchery, Ensor Wellfield	200
2	Chatfield to below Union	6.88	2/7/96-9/30/2000	Fish Hatchery, Ensor Wellfield, Allen Filter Plant	120
3	Above Union to Englewood	3.08	2/1/83-2/5/96	Allen Filter Plant, Bear Creek, Little Dry Creek	400
4	Below Union to Englewood	2.87	2/7/96-9/30/2000	Bear Creek, Little Dry Creek	200
5	Englewood to Denver	7.78	1/1/91-9/30/2000	L/E Discharge, Xcel Arapahoe and Zuni, Cherry Cr., Farmers and Gardeners Ditch	400
Tributaries					
Cherry Creek					
1	Reservoir to Glendale	5.87	1/1/85-7/31/2000	None	70
2	Glendale to Mouth	5.00	12/30/90-9/3/2000	Glendale WWTP	70
Bear Creek					
1	Dam to Sheridan	5.00	1/1/86-9/30/2000	None	100

Table 2. Reaches used in the residual flow analysis leading to estimates of ungaged flows in Segments 6c and 14 (see Figure 1 for gage locations). See the text for explanation of the flow theshold.

For each reach, a residual was calculated for each day as follows:

Residual = Downstream Flow - Tributary Flow - Effluent Flow + Ditch Withdrawals -

Upstream Flow. This residual is the daily estimate of ungaged flow, including both surface flow and seepage.

The next stage in the analysis involved construction of plots relating the residual for each day to the flow for the same day. The purpose of these plots was to allow inspection of the residuals in relation to discharge. The focus of the analysis is on low flows; the plots allowed selection of an appropriate range of discharges to be used in estimating ungaged flow at times of low flow. Figure 2 shows an example of such a plot.

As shown by Figure 2, estimates of ungaged flow as shown by residuals have very low scatter over a range of low discharges, and then begin to show high scatter beyond some threshold. The threshold varies from one reach to another. The reason for higher scatter at high discharges is that all of the individual contributions to discharge are known with less precision at high discharge; thus, the absolute magnitude of error at high discharge tend to be greater than at low discharge.   For this reason, high discharges are not well suited for estimation of ungaged flows. This does not present a problem, given that the emphasis for the TMDL modelling is on ungaged flow under low-flow conditions in the South Platte. A flow threshold was selected for each reach for division of the higher flows with high scatter from the lower flows that provided the basis for the estimate of ungaged flow. The thresholds, which were obtained by inspection of plots such as the one shown in Figure 2, are listed in Table 2.

Following selection of the discharge thresholds for all reaches, the data for dates falling below the threshold were clustered by month for the period of record in each reach, and the median value of the residual was taken for each month. This median value, expressed as cfs, was then divided by the length of the reach in miles to give

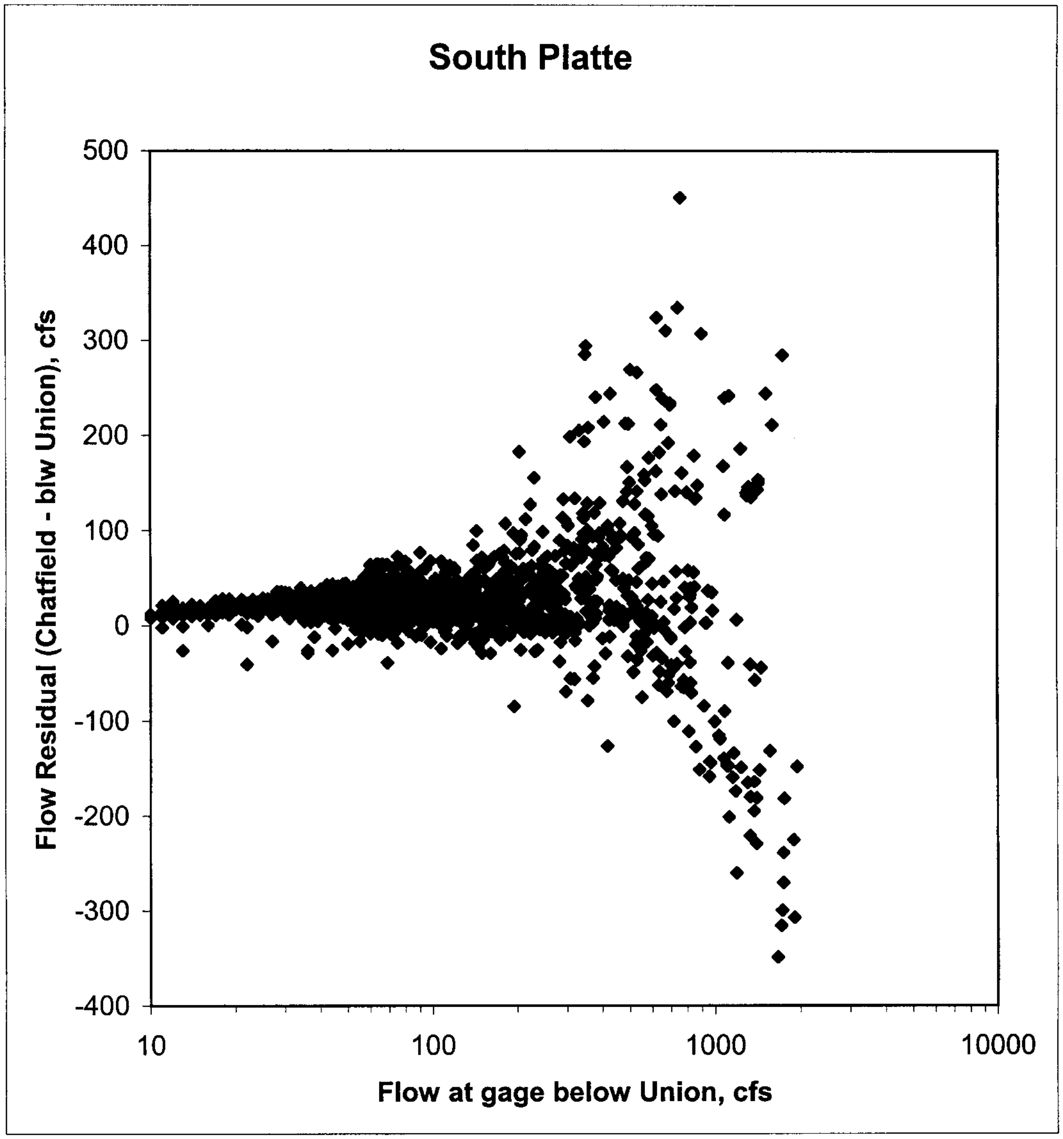


Figure 2. Relationship of residuals (downstream minus upstream) for daily flows at a pair of gages on the South Platte main stem.

ungaged flow as cfs per mile. The results of this calculation are summarized in Table 3.

Reaches 1 and 2 (which differ only slightly in length, due to movement of a gage) were combined in deriving characteristic ungaged flows between Chatfield Dam and Union Avenue. The average of the median ungaged flows, as cfs/mile, were obtained month by month for the two reaches. A 3-point moving average was then calculated across months. The results are reported in Table 4. Seepage rates between Union

	Reach Number				
Month	1	2	3	4	5
Jan	2.62	1.89	2.26	5.23	1.62
Feb	2.49	1.84	2.26	4.18	2.17
Mar	1.44	1.67	3.24	3.83	1.30
Apr	2.69	2.50	0.28	7.32	1.10
May	3.30	1.81	1.93	8.01	2.73
June	4.00	3.29	5.24	-2.79	2.15
July	3.71	3.12	3.90	1.83	3.03
Aug	4.26	3.37	0.08	4.36	3.42
Sep	4.40	4.19	2.41	5.57	3.24
Oct	3.31	4.02	3.44	5.57	2.01
Nov	2.65	3.33	5.70	4.88	2.18
Dec	2.48	2.75	4.03	5.75	1.15

Table 3. Median cfs/mile for ungaged flows in each of five reaches within Segment 14, as estimated by residual analysis at low flow.

Avenue and Englewood (reaches 3 and 4) were combined in the same way as those between Chatfield and Englewood (Table 4), and the three-month moving average of reach 5 provided the estimate for the reach between Englewood and the Burlington Ditch headgate.

Ungaged flows also were estimated for Cherry Creek. These estimates were necessary because the influence of Glendale WWTP, which discharges to Cherry Creek, cannot be modeled accurately without knowledge of ungaged flows over the 5-mile reach that separates it from the South Platte main stem.

There are three flow records on Cherry Creek: the USACE release record for the dam, a record for the gage just above the Glendale WWTP, and a record for the gage located about 1/2 mile above the mouth of Cherry Creek. A residual analysis following the pattern that was used on Segments 6c and 14 was applied to the two reaches that are bracketed by these three records, except that the monthly data were not smoothed by 3-point averaging (there was no apparent need for smoothing). The results are summarized in Table 4. Ungaged flows are assumed to be seepage, except for the influence of Goldsmith Gulch (1.74 cfs), which is the only identifiable dry weather surface flow.

An estimate of ungaged flow was also obtained for Bear Creek below Bear Creek Reservoir. Table 4 shows the median monthly values for residuals between the dam and Sheridan (near the mouth of Bear Creek), as obtained by procedures identical to those used for Cherry Creek. The ungaged flows are comparable to those of the lower portion of Cherry Creek.

Month	South Platte Main Stem A Chatfield to Union Ave.	South Platte Main Stem B Union Ave. to Englewood	South Platte Main Stem C Englewood to Burlington	Cherry Creek A Dam to Glendale	Cherry Creek B Glendale to Mouth	Bear Creek A Dam to Sheridan
Jan	2.34	3.95	1.65	0.73	1.00	1.40
Feb	1.99	3.50	1.70	0.34	0.78	1.40
Mar	2.10	3.52	1.53	0.34	0.74	1.20
Apr	2.24	4.10	1.71	0.85	1.57	1.40
May	2.93	3.33	1.99	1.61	1.47	0.80
Jun	3.21	3.02	2.64	2.39	1.28	1.00
Jul	3.62	2.10	2.87	2.21	1.34	1.00
Aug	3.84	3.02	3.23	1.87	1.31	1.40
Sep	3.92	3.57	2.89	2.21	1.48	1.60
Oct	3.65	4.60	2.48	1.45	1.62	1.80
Nov	3.09	4.90	1.78	1.10	1.14	1.60
Dec	2.62	4.64	1.65	0.68	1.10	1.40

Table 4. Ungaged flows (cfs/mile) in Segments 6 and 14, as estimated by the method of residuals. On the main stem, dry weather surface flow components are approximately (cfs/mile): 1.78 for A, 1.07 for B, and 1.66 for C. On Cherry Creek, 0.3 cfs/mile is surface flow (Goldsmith Gulch) for reach A, and 0 cfs/mile for reach B. On Bear Creek, 0.34 cfs/mile is the estimated dry-weather surface flow.

Low-Flow Analysis

Estimation of nitrate concentrations in Segment 14 under acute conditions requires the determination of critical low flows (1E3) in the South Platte main stem along the entire length of Segment 14. Chronic low flows are not applicable to the nitrate standard.

The acute low flows for the South Platte main stem (1E3 values) were determined according to a policy for low-flow analysis that was adopted during early 2001 by the CDPHE Water Quality Control Division. This policy includes the following elements: (1) Use of the most recent 10-year block of discharge data that is readily available for gaged flows on any stream reach where water management has a strong influence on flows, (2) use of provisional gage data in the absence of any evidence that such data would include significant errors, and (3) use of the DFLOW4 algorithm and other conventions that are used by the State presently for the preparation of NPDES permits.

The low-flow analysis for acute conditions was developed first for four key locations on Segment 14: South Platte below Chatfield, South Platte above the Littleton/Englewood effluent discharge, South Platte above the Xcel Arapahoe discharge, and South Platte above the Xcel Zuni discharge (Table 5). For each of these locations, the monthly acute DFLOW values were obtained for the interval 1 October 1990 to 30 September 2000 (water years 1991-2000).

Flows in the South Platte below Chatfield were obtained from the State Engineer's Office (PLACHACO gage). The daily flows in the South Platte just above the

Centennial wastewater treatment plant outfall were set equal to the flows below Chatfield plus flows for the DOW fish unit (obtained as described below), and a small amount of ungaged flow (as estimated for a distance of one mile from Table 4). Daily flows in the South Platte above the Littleton/Englewood effluent discharge were estimated from the daily data for the Englewood gage, Xcel diversion, and ungaged flows (these particular values were obtained and analyzed for low flow by the WQCD Assessment Unit; no new calculations were made as part of the modelling work reported here). Flows in the South Platte above the Xcel Arapahoe discharge (which is very close to the Littleton/Englewood discharge) were set equal to the flows of the South Platte above Littleton/Englewood plus the daily discharge of Littleton/Englewood effluent over the period of record. The flows above Xcel Arapahoe, plus the recorded daily releases from the Xcel Arapahoe discharge point and ungaged flows estimated from Table 4, were used as daily flows for the South Platte above Xcel Zuni.

The DFLOW algorithm calculates chronic low flows based on forward averaging (i.e., the flow for the nominal date plus 29 daily flows forward from the nominal date of the average). As a result, it is possible by use of this algorithm to obtain for any given month a chronic low flow that is lower than the acute low flow. For this reason, chronic low flows for all months were calculated for the five key locations mentioned above and, in cases where the chronic low flow was lower than the acute low flow, the chronic low flow was used as the acute low flow.

Modelling of low-flow conditions at all points in the South Platte main stem between Chatfield Dam and the Burlington Ditch headgate requires monthly low flows for all intervening points of withdrawal (diversions) and non-effluent additions. Low-flow values for withdrawals and additions could be obtained by application of the DFLOW algorithm to the daily estimates of flow for each withdrawal or addition. This

	Month											
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South Platte Low Flows (from DFLOW)												
Below Chatfield	0.2	0.3	0.4	0.7	5.3	2.0	0.2	0.6	0.2	0.1	0.1	0.2
Above Centennial	1.8	0.8	1.6	4.2	14.5	9.3	10.0	7.3	2.9	3.8	1.7	1.9
Above L/E Discharge	26.0	27.0	25.0	28.0	60.0	58.0	30.0	33.0	20.0	27.0	31.0	39.0
Above Xcel Arapahoe Discharge	59.0	60.0	64.0	59.0	95.0	102.0	67.0	71.0	55.3	63.0	67.0	74.0
Above Xcel Zuni Discharge	62.0	63.0	65.0	61.2	97.0	106.0	71.0	76.0	61.2	67.0	69.0	76.0
Reservoir Release Low Flows (By Difference)												
Bear Creek Res. Release	12.0	10.8	9.0	10.7	24.0	8.0	2.0	3.0	4.2	8.9	10.6	17.5
Cherry Cr. Res. Release	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Additions and Withdrawals at Low Flow (By Difference)												
Hatchery Release	1.0	0.3	0.9	3.0	8.0	5.9	8.0	4.6	0.6	1.8	0.3	0.9
Allen Plant Withdrawal	7.4	7.7	8.3	9.0	17.0	14.0	21.0	12.0	8.0	7.6	6.0	8.0
Bear Creek at Mouth	19.0	17.8	15.0	17.7	28.0	13.0	7.0	10.0	12.2	17.9	18.6	24.6
Cherry Creek at Mouth	10.9	8.2	8.2	8.0	21.0	13.0	13.0	13.0	11.0	12.0	8.0	11.0
Farmers & Gardeners	13.5	13.5	16.6	13.8	13.7	14.0	13.0	11.0	7.0	7.0	11.0	12.4

Table 5. Acute (1-day) low flows for selected locations on Segment 14 (cfs).

approach would produce an unrealistic view of actual 1E3 conditions in the main stem, however, in that extreme flows for diversions and additions do not necessarily occur at the same times as extreme flows on the South Platte main stem. For this reason, the flows coinciding with low flow conditions on the South Platte main stem were obtained by difference. For example, the appropriate low-flow withdrawals for the Farmers and Gardeners Ditch were obtained by use of a DFLOW-derived value on the main stem both above and below the Farmers and Gardeners Ditch. The subtraction of the low flow value on the main stem below the Farmers and Gardeners Ditch from the low flow value on the main stem above the Farmers and Gardeners Ditch for the same period of record thus produced a withdrawal value for each month that would be internally consistent with low flows on the South Platte main stem as determined by the DFLOW algorithm. The construction of a set of daily flows both above and below any given diversion or addition of water typically involved use of gage records plus ungaged flows and measured flows for additions and withdrawals between the nearest gage and the point of interest either above or below a given withdrawal or addition. Low-flow values that were obtained by the method of differences are shown in Table 5 for the five points of withdrawal or addition. Internally consistent flows also were calculated by the same methods for the two tributary reservoir releases (Bear Creek Reservoir, Cherry Creek Reservoir; Table 5). For main stem modelling, however, low flows at the mouths of these two tributaries, as obtained by the method of differences, were used.

Modelling requires assumptions about effluent flows under critical conditions. As is standard practice for NPDES permitting, all modelling of future conditions was done with the assumption that point sources would be operating at capacity. The capacity flows are shown in Table 6.

Capacity flows originating at any given wastewater discharge may be carried downstream according to either of two assumptions. The simplest assumption is that all of the capacity discharges will be occurring simultaneously and will not be removed from the stream, i.e., there will be a downstream accumulation of the capacity flows. This assumption may be unrealistic if capacity flows do not occur simultaneously, and if some or all additional effluent flow in the river is removed in accordance with water rights.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wastewater Treatment Plants (sources of ammonia and nitrate)												
Centennial	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Littleton/Englewood*	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3
Glendale (Cherry Cr.)	2	2	2	2	2	2	2	2	2	2	2	2
Other Discharges (cooling water)												
Xcel Arapahoe	1	1	1	1	1	1	1	1	1	1	1	1
Xcel Zuni**	42	42	42	42	42	42	42	42	42	42	42	42

* A design capacity of 50 mgd also has been modeled.
**Zuni uses water for pass-through cooling that does not deplete water flow.

Table 6. Capacity flows for discharges (mgd), as set for TMDL modelling.

A second possible assumption is that the flows upstream of any given point of wastewater discharge will be similar to the historical low flows observed above that point of discharge over the last ten years. In order for the model to incorporate such a condition but still operate on the assumption that dischargers are releasing effluent at their full hydraulic capacity, it must incorporate a flow reset that comes into play just above each wastewater discharge. The purpose of the flow reset (designated here as "reset") is to remove, just above the next point of addition, that component of the flow that is equal to the difference between the historical effluent discharge rates and the capacity discharge rate for any upstream effluent discharge.

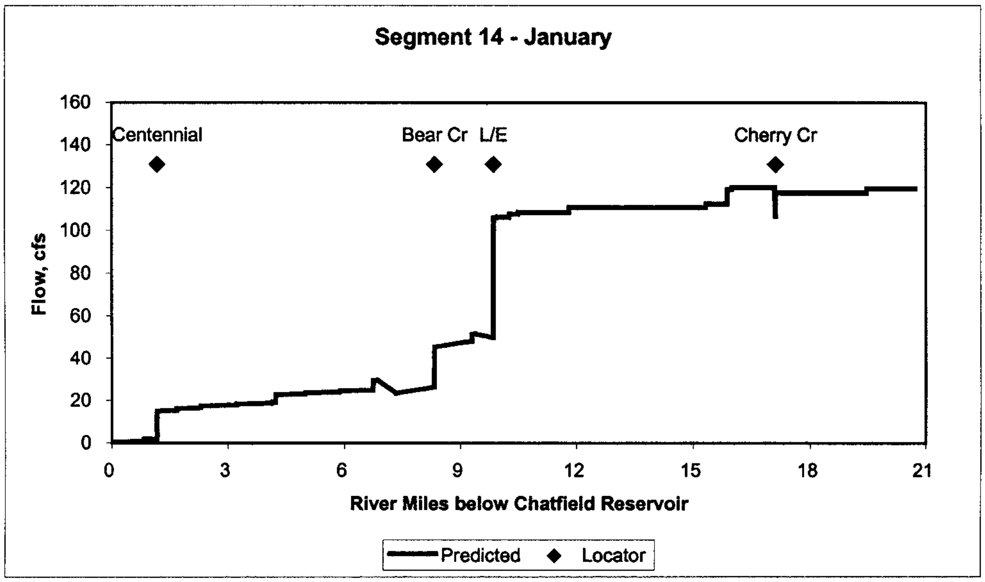
The model was operated first with reset in place (locations of reset: above Littleton/Englewood WWTP, above Xcel Arapahoe, above Xcel Zuni). As a means of exploring the possibility that capacity flows would actually accumulate progressively in the main stem and occur simultaneously, the model allows the reset to be turned off, thus producing an alternate set of values to be compared with those obtained with the reset in place. The final results of modelling to be reported here give an accounting of these two alternate assumptions concerning capacity effluent flows.

Figures 3 through 6 show the critical low flow conditions on Segment 14 with and without the hydrologic resets for four months of the year (January, March, July, October).

Chemistry of Ungaged Flows

Ungaged flows, which consist of small surface flows that are sustained under low-flow conditions as well as seepage water that enters the channel below the surface, are a consideration in water quality modelling for Segment 14. The amounts of ungaged flow and the partitioning between surface and seepage flows were quantified as explained in a previous section of this report (Table 4). Concentrations of ammonia and nitrate must be attached to these flows before they can be used in modelling.

Concentrations of ammonia in seepage water generally are assumed to be about 0.1 mg/L along the main stem of the South Platte because ground water in this vicinity



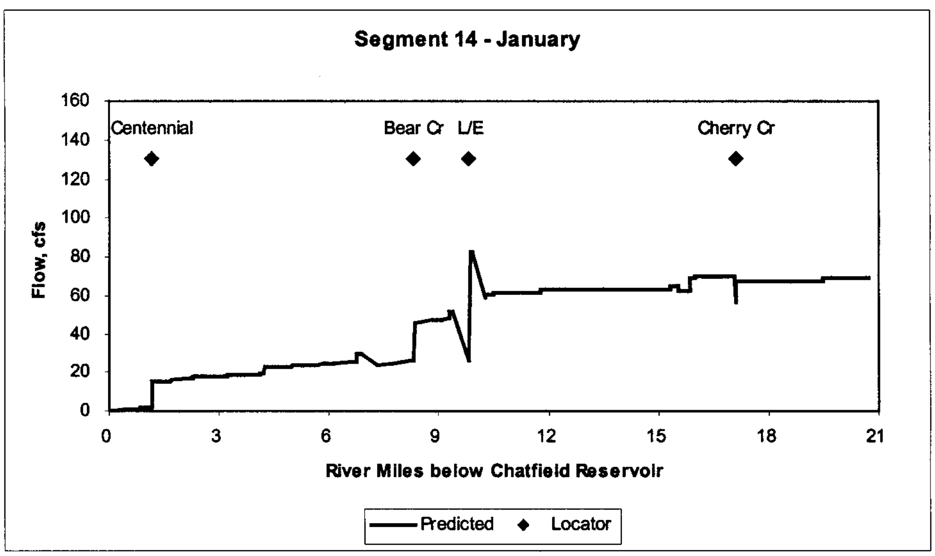
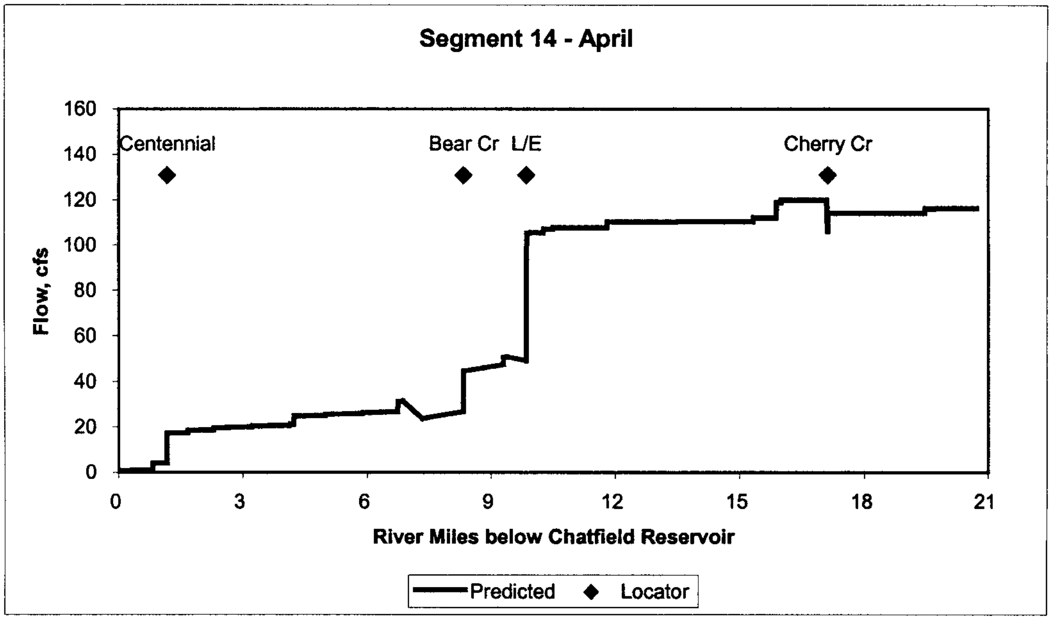


Figure 3. Acute low flows in Segments 6c and 14 for the month of January. The top panel shows flows without a flow reset applied and the bottom panel shows the flows with the application of the reset.



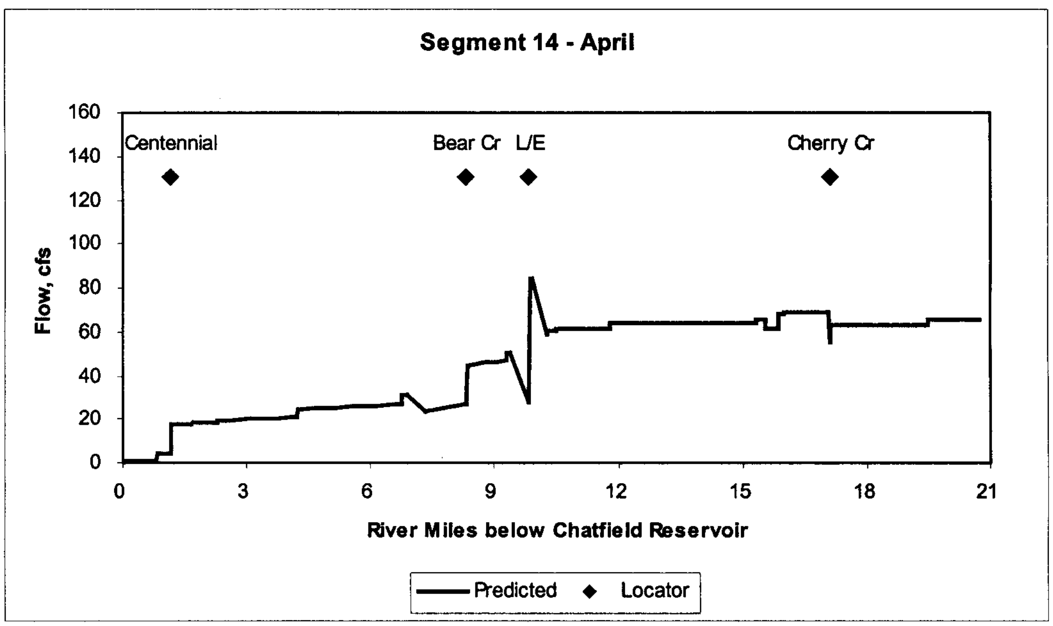


Figure 4. Acute low flows in Segments 6c and 14 for the month of April. The top panel shows flows without a flow reset applied and the bottom panel shows the flows with the application of the reset.

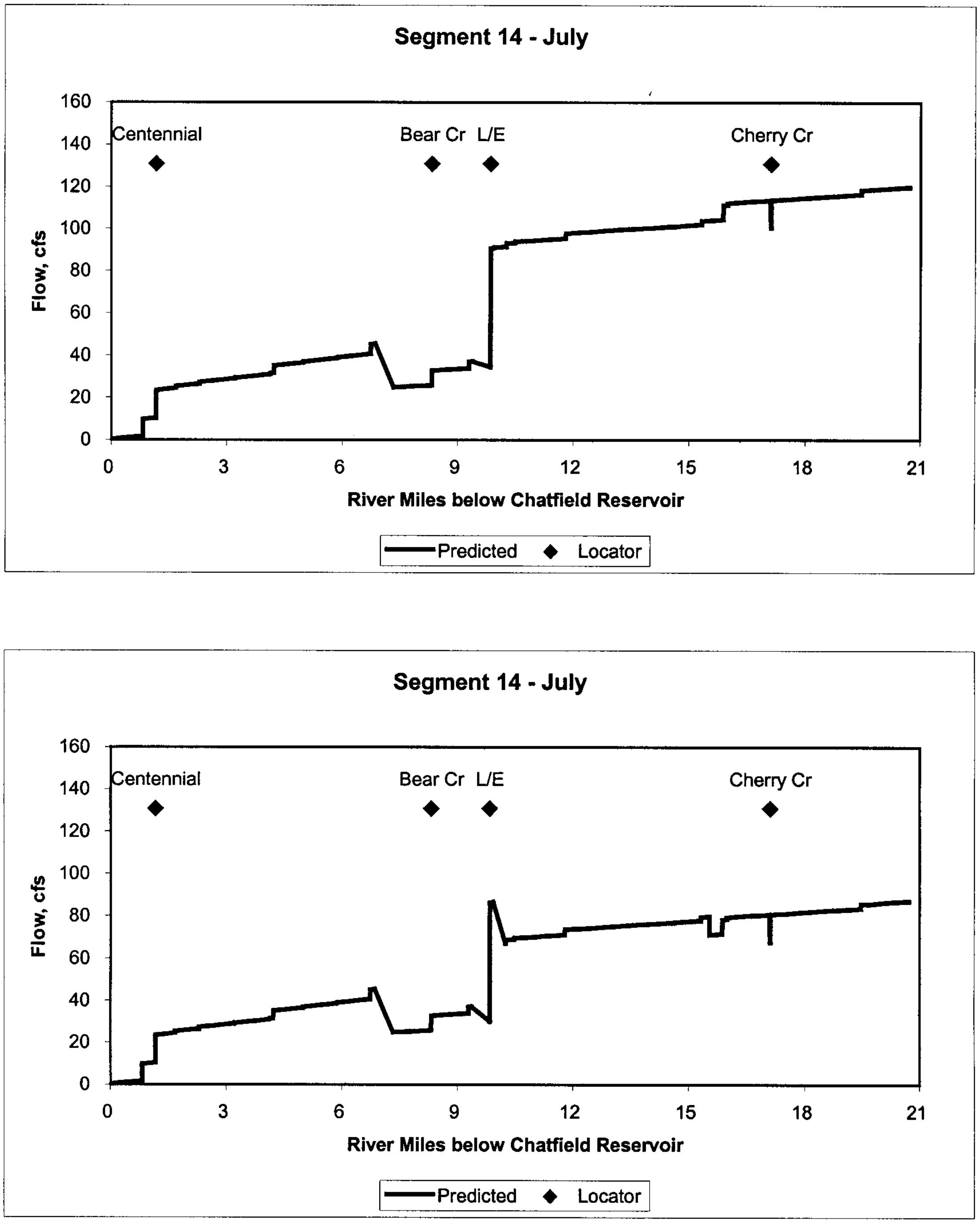
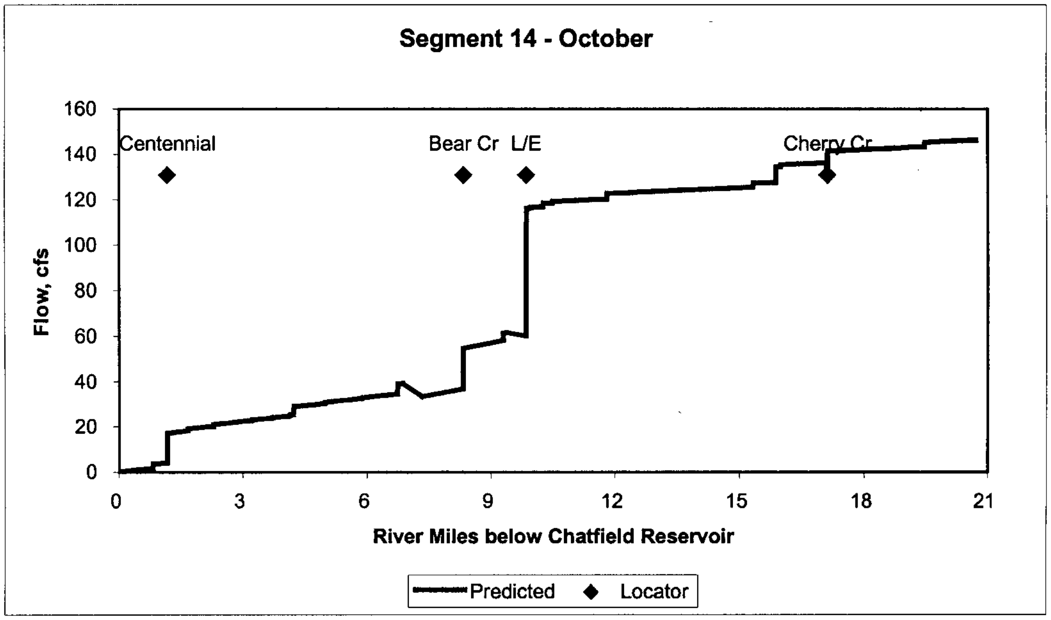


Figure 5. Acute low flows in Segments 6c and 14 for the month of July. The top panel shows flows without a flow reset applied and the bottom panel shows the flows with the application of the reset.



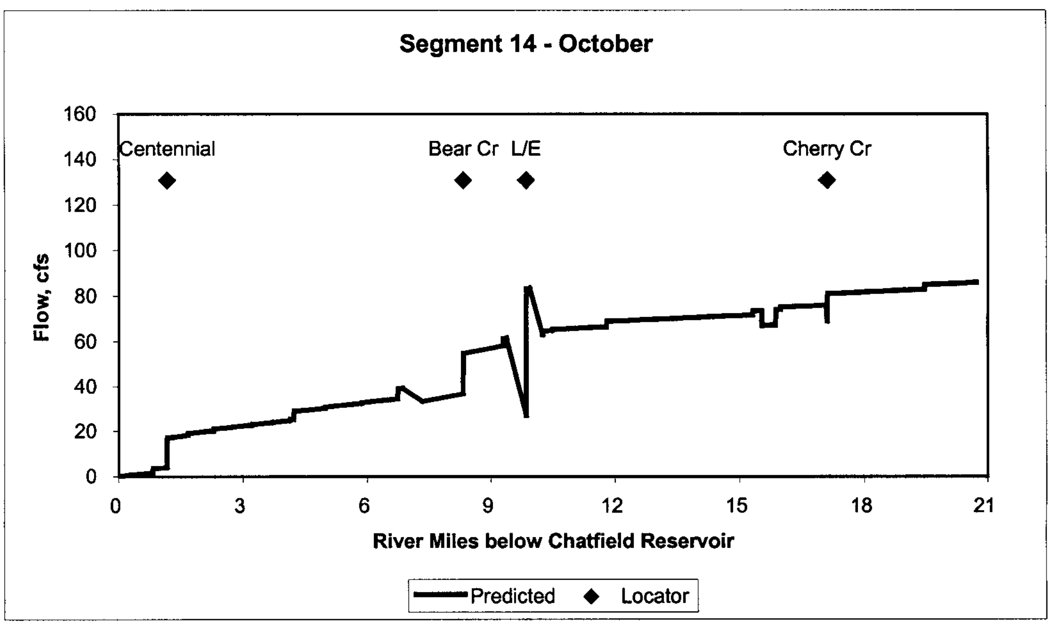


Figure 6. Acute low flows in Segments 6c and 14 for the month of October. The top panel shows flows without a flow reset applied and the bottom panel shows the flows with the application of the reset.

often shows concentrations of ammonia below the detection limit. Seepage water entering through the bottom and sides of the channel is likely to experience an increase in concentrations of ammonia, however, as a result of decomposition processes that lead to ammonification (release of ammonia caused by microbially-mediated decay of organic matter). There are no independent estimates of ammonification, but such estimates can be estimated roughly from measurements of community respiration. Community respiration in Segment 15, which is just downstream of Segment 14, has a median value close to 0.2 moles of $O_2/m^2/d$. Assuming that half or more of the community respiration is bacterial, this rate of respiration corresponds to approximately 1 mg/L of ammonia at low flow. Therefore, ammonia concentrations of seepage water along Segment 14 are set at 1 mg/L, which incorporates the ambient concentration of ground water (about 0.1 mg/L) plus a substantial contribution from ammonification. The ammonia concentration of seepage along Cherry Creek is set to the same value because Cherry Creek also receives effluent, which would stimulate ammonification (0.9 mg/L). The ammonia concentration of seepage along Bear Creek is set to the background value of 0.1 mg/L because it receives no effluent discharge and thus has a lower organic load than the other locations.

For nitrate, samples taken as part of the NAWQA urban land use study by the USGS in 1993 indicate higher variable concentrations in the Denver area. In general, nitrate concentrations along the South Platte main stem were 0-5 mg/L, and there was no apparent spatial pattern to the concentrations. According to the NAWQUA data, concentrations in the lower part of Segment 14 are not consistently higher than those in the upper part. Therefore, a concentration of 1.5 mg/L, which is near the median of values along the main stem, is applied to both reaches.

A different approach was taken with Bear Creek, where nitrate concentrations are measured routinely in the stream. For dates when release from the reservoir was minimal (< 10 cfs) and denitrification rates were minimal (winter months), the resulting data set should be a good indication of the contribution from seepage. Under those conditions, nitrate concentrations were typically 1-1.5 mg/L; a value of 1.5 mg/L is used in modelling.

For seepage along Cherry Creek, the few samples from the NAWQA study support use of 3 mg/L nitrate N.

Concentrations of ammonia and nitrate in seepage water are not necessarily the same as those of ungaged dry weather surface flows. Fortunately, ungaged surface flows were sampled during early TMDL model development. Over 90 samples were

Location	Discharge cfs	Ammonia N mg/L	Nitrate N mg/L
Big Dry Creek[1]	4.5	-	-
Little Dry Creek[1]	3.1	-	-
Harvard Gulch	0.6	0.016	0.13
Sanderson Gulch	2.4	0.027	1.94
Lakewood Gulch	6.7	0.051	1.17
West Harvard Gulch	0.3	0.014	2.55
All Others[2]	17.3	0.025	1.69

[1]Monthly values for chemistry are from SP CURE; dates as shown in Table 9.
[2]Thirteen additional sites (sum for discharge, median for concentration).

Table 7. Ungaged surface-water sources for Segment 14. Flows for the four largest discharges are based on four dry-weather measurements (average); flow for West Harvard is based on one measurement, and all others are based on an empirical relationship between drainage area and dry-weather surface flow.

taken during two periods of low flow. The amount of flow and the ammonia and nitrate concentrations were measured at each of the sampling locations. Results are summarized in Table 7.

The TMDL model contains concentration and flow data that are site-specific for five of the largest ungaged tributaries (Table 7). The other flows (13) are treated as having uniform chemistry (median of observed values among sites in dry weather) and individual flows based on the empirical relationship of flow to drainage area, as described in the section on ungaged flows.

A few ungaged flows in Denver have received special attention. Monitoring of ungaged small tributary flows (including pipes, drains, etc.) by the Denver Department of Environmental Health has shown that some flows downstream from contaminated sites (e.g., Superfund sites) carry concentrations of nitrate that are well above the median measured during the general sampling of dry weather flows. Flows in these reaches are assigned the median monitoring value obtained by the Denver Department of Environmental Health. Two modelling reaches are involved: Reach 1, downstream of Harvard Gulch (10.49 - 10.89 miles below Chatfield = 10.25 mg/L nitrate N, 2.34 acre-feet/day; and Reach 2, upstream of Mississippi Avenue (12.31 - 12.42 miles below Chatfield = 17.6 mg/L nitrate N, 0.64 acre-feet/day). Monthly seepage rates were applied to these reaches, and it was assumed that concentrations are constant.

Ammonia and Nitrate Content of Other Water Sources

Aside from effluents and ungaged flows, there are six water sources for Segment

14, as shown in Table 8. Table 8 includes Big Dry Creek and Little Dry Creek, which are ungaged flows, but the chemistry of these ungaged flows is available month by month through the SP CURE program, which is the reason for their inclusion in Table 8.

Table 8 shows median ammonia and nitrate concentrations month by month for each water source. Data for the South Platte below Chatfield originated from the SP CURE data set (45 dates, September 1998 through June 2000). Data on Big Dry Creek

	Ammonia-Nitrogen mg/L											
Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S. Platte below Chatfield[1]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Big Dry Creek	0.12	0.26	0.21	0.16	0.15	0.19	0.17	0.24	0.12	0.13	0.12	0.14
Bear Creek Res.	0.08	0.12	0.08	0.10	0.03	0.01	0.03	0.05	0.06	0.16	0.11	0.05
Bear Creek at Mouth	0.22	0.18	0.12	0.16	0.20	0.31	0.14	0.33	0.17	0.15	0.11	0.14
Little Dry Creek	0.15	0.18	0.24	0.24	0.23	0.30	0.19	0.25	0.20	0.16	0.13	0.13
Cherry Creek Res.	0.04	0.04	0.04	0.05	0.05	0.05	0.12	0.12	0.12	0.02	0.02	0.02

	Nitrate-Nitrogen mg/L											
Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S. Platte below Chatfield	0.10	0.09	0.02	0.01	0.12	0.07	0.01	0.03	0.03	0.00	0.00	0.04
Big Dry Creek	3.64	3.32	2.87	2.95	3.23	2.89	2.55	2.32	2.62	2.30	2.67	3.16
Bear Creek Res.	0.92	0.88	0.51	0.55	0.50	0.18	0.26	0.44	0.17	0.48	0.64	0.95
Bear Creek at Mouth	1.25	1.28	1.33	0.89	0.73	0.46	0.36	0.33	0.52	1.04	1.13	0.94
Little Dry Creek	1.78	1.35	1.10	1.10	1.04	1.08	0.95	1.07	1.24	1.33	1.69	1.65
Cherry Creek Res.	0.05	0.05	0.05	0.01	0.01	0.01	0.05	0.05	0.05	0.80	0.80	0.80

[1]Also used for DOW fish unit.

Table 8. Ammonia and nitrate in water sources reaching Segment 14.

and Little Dry Creek also are from SP CURE, but for different ranges of dates (Big Dry Creek for 1999 through 2002 and Little Dry Creek from 1998 through 2002). For Bear Creek Reservoir, the data are from lake monitoring programs as derived the STORET data base, and are relevant only for perspective in that the concentrations directly relevant to monitoring are for the mouth of Bear Creek (SP CURE data set, 1998-2000). For

Cherry Creek Reservoir, monitoring data from the mouth cannot be used because water at the mouth is influenced by effluent discharge from Glendale. Computation of the source chemistry for Cherry Creek is obtained from data on the Cherry Creek Reservoir discharge (as obtained from STORET, but minimally relevant because of the low flows from the reservoir) and the information on the chemistry of ungaged flows, as described above. All the sources shown in Table 8 have low to very low concentrations of nitrate and ammonia, as expected.

Use of Data for Calibration and Validation

Data on water temperature, ammonia, and nitrate in the South Platte main stem and effluents reaching the main stem were taken from the SP CURE monitoring program for use in calibration and validation. The SP CURE data set is well suited for calibration (which involves determination of rate constants) and validation because it is based on coordinated sampling of the South Platte main stem, effluent flows, and tributary flows. The data set that was used includes 45 sampling dates extending from September 1998 to June 2000 plus data for 2002, when flows were unusually low (24 sampling dates; Table 9).

For calibration and validation of the TMDL Model, the main stem was divided into two reaches. The upper reach extends from Chatfield Dam to Dartmouth Avenue (just above the Littleton/Englewood discharge) and the lower reach extends from Dartmouth Avenue to the Burlington Ditch headgate. Relevant sampling points for SP CURE on the upper reach included the South Platte above Centennial, Centennial

		Ammonia Loss Rate*	Nitrate Loss Rate	
Date	Data Set	Lower ***	Upper **	Lower ***
09/03/98	1	-	-	-
09/16/98	2	5.60	-	1.31
10/07/98	3	V	V	V
10/21/98	4	2.05	0.00	1.99
11/04/98	5	5.75	-	1.79
11/18/98	6	11.30	1.17	1.38
12/02/98	7	V	V	V
12/16/98	8	11.60	1.01	0.55
01/06/99	9	4.95	0.60	0.77
01/20/99	10	7.90	0.32	0.70
02/03/99	11	7.60	0.00	0.77
02/17/99	12	5.70	1.16	0.60
03/03/99	13	9.00	0.38	6.16
03/17/99	14	5.95	1.79	0.00
04/07/99	15	-	0.00	-
04/21/99	16	2.60	0.00	0.76
05/05/99	17	34.00	-	7.83
05/19/99	18	10.00	-	3.10
06/02/99	19	17.50	0.00	2.85
06/16/99	20	-	5.00	-
06/22/99	21	-	-	-
07/07/99	22	V	V	V
07/21/99	23	12.50	0.48	3.12
08/04/99	24	V	V	V
08/18/99	25	7.20	-	2.33
09/01/99	26	V	V	V
09/15/99	27	8.10	-	2.07
10/06/99	28	10.40	-	1.86
10/20/99	29	10.30	1.14	1.71
11/03/99	30	7.45	0.41	1.99
11/17/99	31	11.81	1.72	1.57
12/01/99	32	10.40	1.74	2.37
12/15/99	33	V	V	V
01/05/00	34	19.05	0.00	1.60
01/19/00	35	V	V	V
02/02/00	36	7.05	1.15	1.11
02/16/00	37	12.10	4.24	2.22
03/01/00	38	V	V	V
03/15/00	39	4.55	-	1.50
04/05/00	40	V	V	V
04/19/00	41	-	-	-
05/03/00	42	9.70	-	2.41
05/17/00	43	-	-	-
06/07/00	44	V	V	V
06/21/00	45	-	-	-
01/02/02	46	2.75	1.28	0.12
01/16/02	47	-	1.29	-
02/06/02	48	7.20	2.35	0.85
02/20/02	49	-	0.15	-
03/06/02	50	9.80	1.45	2.14
03/20/02	51	-	2.30	-
04/03/02	52	4.10	1.40	1.70
04/17/02	53	-	1.55	-

Table 9, continued on next page.

		Ammonia Loss Rate *	Nitrate Loss Rate	
Date	Data Set	Lower ***	Upper **	Lower ***
05/01/02	54	3.30	2.30	0.11
05/15/02	55	-	2.95	-
06/05/02	56	6.00	3.85	3.08
06/19/02	57	-	2.75	-
07/03/02	58	3.00	4.80	0.95
07/17/02	59	-	1.97	-
08/07/02	60	1.72	2.25	1.48
08/21/02	61	-	1.83	-
09/04/02	62	3.20	1.86	1.60
09/18/02	63	-	-	-
10/02/02	64	-	-	-
10/16/02	65	-	1.72	-
11/06/02	66	2.30	0.12	0.00
11/20/02	67	-	0.00	-
12/04/02	68	3.80	2.10	1.51
12/18/02	69	-	0.90	-

* Set to 6, d^{-1} in the upper reach. See text for explanation.
** Chatfield to Dartmouth.
*** Dartmouth to Burlington headgate.

Table 9. Sampling dates for SP CURE. Dates marked "V" were reserved for validation. Dash indicates excessive missing data or hydrologic inconsistencies. Numbers indicate rates used in calibration (first order, base e, adjusted to 20^{o}C).

effluent, the mouth of Bear Creek, the mouth of Little Dry Creek, and the mouth of Big Dry Creek. The relevant SP CURE sampling sites for the lower reach included the South Platte above the Littleton/Englewood treatment plant, the Littleton/Englewood treatment plant effluent, the Xcel Arapahoe discharge, and the mouth of Cherry Creek (now sampled by DDEH), as well as the South Platte near the Burlington Ditch headgate. Routine monitoring by DDEH in 2002 added four sites on the main stem in the lower reach (below PSCO dam, above Cherry Creek confluence, near 31st Street, and downstream of I-70). Data for the South Platte at Dartmouth were used to define the upstream conditions for the lower reach. In this sense, the calibration and validation procedures were independent for the upper and lower reaches of the main stem.

The 69 data sets (1998-2000 and year 2002) from SP CURE were screened for adequacy in estimating rate constants. Absence of ammonia data at key points precluded calculation of loss rates for either ammonia or nitrate. When information was available for ammonia, but not for nitrate, it was still possible to calculate the ammonia loss rate.

For the upper reach, the absence of information on concentrations of ammonia or nitrate for Centennial effluent or for the South Platte at Dartmouth led to the exclusion of data sets 1, 21, 39, 40, 41, and 43 through 45. Information on nitrate concentration was missing for the Centennial effluent on data set 12, but the data set was used with the assumption that the nitrate concentration in the effluent was the average of the concentrations from sampling sets 11 and 13.

Analysis of the data for the upper reach provided little information on ammonia removal rates because the concentrations of ammonia in the upper reach were so small that rates could not be estimated. Following the policies of the Colorado Department of Public Health and Environment Water Quality Control Division, ammonia loss rates were set at 6 d^{-1} for the upper reach in the absence of any sound basis for direct estimation of rates.

For the lower reach, absence of information on nitrate or ammonia for the Littleton/Englewood effluent or the South Platte above the Burlington Ditch led to the exclusion of data sets 1, 15, 20, 21, and 45. Also, data set 44 was excluded due to lack of information on concentrations of ammonia and nitrogen at the Burlington Ditch headgate.

Data sets also were screened with respect to the adequacy of data on flow. Any dates requiring more than 10 cfs per mile of unexplained flow to balance flow between gages were excluded. For the upper reach this meant excluding data sets 1, 2, 3, 5, 17, 18, 24 to 28, and 40 to 44. For the lower reach, data sets 24 and 43 were excluded. In addition, data sets were omitted when the unexplained residual flow at any gage was greater than 10% of the flow at the gage. This led to the exclusion of set 45 from the upper reach and sets 1, 41, and 44 for the lower reach. Data sets with large unexplained residuals were associated with high flows in the river, at which time augmentation of small tributary flows by storm water often leads to unexplained residuals between gages. Because low-flow conditions are the focus of the analysis, exclusion of data sets representing high flow conditions is appropriate.

Data sets retained for analysis in some cases were missing information for one or more variables at a particular location. Information on temperature often was missing for samples taken at Union Avenue and at the Xcel Arapahoe discharge. Temperatures for these locations were estimated on the basis of regression analysis from data for adjacent stations or through interpolation across dates. Information on concentrations of ammonia was missing in several instances for the Xcel Arapahoe discharge. These concentrations were set equal to the concentrations for the South Platte at Dartmouth based on the similarity of concentrations for these two points as indicated by the days for which all information was available. Nitrate data were missing on several dates for Xcel Arapahoe discharge and for the mouth of Little Dry Creek. This information was filled in on the basis of concentrations for other dates for which information was available. Because the contributions of these two sources to total load is small, errors in the substitutions are unlikely to introduce significant bias in the outcome of calibration or modelling. Big Dry Creek was first sampled in August 1999. For earlier dates (sets 1-23), the nitrate concentration at the mouth of Big Dry Creek was set equal to the median of the other dates (periods 24-45).

The SP CURE data for 1998-2000 was divided into two sets of dates. One set of dates was used for calibration and the second was used for validation. The validation data set consisted of 10 dates selected by use of a random number generator from the full set of 45 dates (Table 9). These 10 dates were not used in the calibration process. All of the remaining sampling dates, except those that were excluded through screening, were used in calibration. Temperature data at main stem sampling sites provided the basis for longitudinal representation of temperature change in the model.

The 2002 data are especially valuable for testing relationships between flow and conversion rates for nitrate and ammonia, as explained below, and thus were added to the calibration. The SP CURE sampling program for 2002 yielded 24 data sets. Specific problems with the data sets and actions taken to resolve those problems are outlined in Table 10. One general problem for the lower reach was the monthly sampling frequency for the South Platte at the Burlington headgate. Although the Metro District sampled the Burlington on a biweekly basis, concerns about the relevance of the sampling location and the timing of sample collection relative to other SP CURE data precluded use of the Metro data. The remaining monthly data sets had the additional advantage of including four sites monitored by DDEH between the Littleton-Englewood outfall and the Burlington. These sites, which were not available routinely in the original data sets for 1998-2000, make it possible to set removal rates for the lower reach by means of a least-squares approach rather than by exclusive reliance on concentrations at the terminal station.

Estimation of Transformation Rates for Ammonia and Nitrate

Transformation rates (loss rates) for ammonia and nitrate were estimated from the calibration data sets. For each estimation, the seepage rate was adjusted until the flow

Site	Date	Variable	Problem	Resolution
Cent-Eff	2/20/02	Ammonia	<det. lim.	Set to detection limit
Cent-Eff	3/6/02	Ammonia	<det. lim.	Set to detection limit
Cent-Eff	3/20/02	Ammonia	<det. lim.	Set to detection limit
Cent-Eff	6/19/02	Flow	Missing	Average of adjacent dates
Cent-Eff	10/16/02	Ammonia, nitrate	Missing	Omit
Cent-Eff	11/6/02	All	Missing	Omit
Cent-Eff	11/20/02	All	Missing	Omit
Cent-Eff	12/4/02	All	Missing	Omit
Cent-Eff	12/18/02	All	Missing	Omit
Cent-Up	Various	Nitrate	<det. lim.	Set to detection limit
Cent-Up	Various	Ammonia	<det. lim.	Set to detection limit
Cent-Up	10/16/02	Ammonia, nitrate	Missing	Ignore
Cent-Up	11/6/02	All	Missing	Ignore
Cent-Up	11/20/02	All	Missing	Ignore
Cent-Up	12/4/02	All	Missing	Ignore
Cent-Up	12/18/02	All	Missing	Ignore
Excel diversion	All	Flow	Not available	Set to 1 cfs on all dates
F&G Ditch	Nov-Dec	Flow	Missing	Monthly medians from POR
Glen-CC	All even sets	All	Missing	Average adjacent dates
Glen-CC	Most odd sets	Ammonia	<det. lim.	Set to detection limit
LE-BDC	3/6/02	Nitrate	3x adjacent values	Average adjacent dates
LE-Bear	All even sets	All	Missing	Average adjacent dates, except 24
LE-Eff	2/20/02	Ammonia, nitrate	See note below	Omit
LE-Eff	10/16/02	Ammonia, nitrate	See note below	Omit
LE-EGC	All	All	Missing	Delete connection to temperature data
LE-LDC	11/6/02	All	Missing	Average of adjacent dates
LE-PSC out	1/2/02	Ammonia	Missing	Average of adjacent dates
LE-PSC out	6/5/02	All	Missing	Average of adjacent dates
LE-PSC out	11/6/02	All	Missing	Average of adjacent dates
SP@BC	All even sets	All	Not sampled	Omit
SP@BC	4/3/02	Ammonia	10x adjacent values	Omit

Table 10. Catalog of problems encountered with the SPCURE data sets for 2002, and steps taken to resolve those problems. Two sampling sets were taken in each month, but some stations were sampled only on the first date in each month. The group of sampling sets taken first in each month are referred to as "odd" and the other as "even."

residual was zero as a means of minimizing the influence of flow estimation errors on the estimation of rates. When such a procedure called for adjustments implying seepage rates below zero, the adjustment was set to be consistent with seepage rates of zero.

Transformation rates for ammonia were estimated first. Given the flows and concentrations that were recorded for each date in the calibration set for either of the two reaches on the main stem, a first-order ammonia transformation rate was used in adjusting the predicted downstream concentrations to match the observed downstream concentrations. After the appropriate ammonia transformation rate was obtained for a given date and reach, a first-order nitrate transformation rate was estimated with the assumption that the disappearance of ammonia as represented by the ammonia transformation rate was matched stoichiometrically by the appearance of nitrate at the same rate.

The calibration procedure for ammonia was based on the assumption that nitrification (conversion of ammonia to nitrate by nitrifying bacteria) is the main process accounting for the disappearance of ammonia. Other processes are known to contribute to the disappearance of ammonia. These include inorganic adsorption of the ammonium ion, volatilization of ammonia, and uptake of ammonium ions by autotrophs or bacteria. If any of these processes were occurring at rates constituting a significant percentage of the total transformation rate for ammonia, they could contribute to an overestimation of the nitrification rate.

Except at extremely low concentrations of ammonia, significant immobilization of the ammonium ion through adsorption is not possible. At the moderate pH values that are observed in Segment 14, volatilization losses of ammonia would be very minor. Rates of photosynthesis in Segment 14 are unknown, but are probably near those of Segment 15 (ca. 1g C/m^2/d). At such rates, autotrophic assimilation could account for about 100 kg/d of N transformation, as compared with a nitrate transport rate of about 4500 kg/d below Littleton/Englewood. Heterotrophic assimilation is less likely than autotrophic assimilation, given the presence of N-rich organic matter.

Ammonia concentrations also are affected by mineralization of organic nitrogen (ammonification). Respiration rates, which are an indicator of the potential for mineralization of organic nitrogen, have not been estimated for Segment 14, but have been estimated for Segment 15, which is similar in chemistry, hydrology, and substrate characteristics, as about 5 g C/m^2/d. This rate of respiration corresponds roughly to the allowance that is made for ammonification through adjustment of seepage water concentrations (see section on seepage water chemistry).

Nitrate transformation (loss) is assumed to be explained by denitrification. Denitrification has been measured at other locations on the South Platte main stem, and is known to contribute to the disappearance of significant amounts of nitrate. The mechanism for denitrification in the South Platte includes penetration of channel waters into the alluvium (hyporheic zone), where anoxic conditions develop due to microbial respiration. Anoxic conditions lead to the use of nitrate as an electron acceptor by microbes, which under these conditions convert nitrate primarily to N_2 gas.

Factors other than denitrification can affect nitrate concentrations. Nitrification of ammonia produces nitrate, but this process is taken into account through the estimation of nitrification rates. Nitrate can be taken up as a nitrogen source by autotrophs or even by heterotrophs for the synthesis of organic matter. Significant loss of nitrate in this way is unlikely in the South Platte River because ammonia is the preferred nitrogen source for organisms needing inorganic nitrogen for purposes of organic synthesis. Thus in the presence of even relatively low (e.g., 0.2 mg/L) concentrations of ammonia, nitrate typically remains unassimilated by living organisms, except under anoxic conditions, when it is used readily by microbes to produce energy through denitrification.

The identity of the processes underlying the transformations of ammonia and nitrate may be irrelevant, provided that the rates of these processes can be reasonably extrapolated to future conditions involving higher effluent flows. The extent of extrapolation is minor in terms of ecosystem function, as it does not involve large changes in the concentrations of nitrogen substrates or major changes in physical conditions that might influence individual processes in a differential way.

Results of Calibration

Table 11 shows the results of model calibration. The rate at 20^{o}C for each reach and each of the two transformations (ammonia loss, nitrate loss) is shown at the bottom of the table along with its standard error. The rate at 20^{o}C for a given reach and process is the median of all individual rates that were estimated during the calibration process (Table 9). The value shown for theta at the bottom of the table was used in correcting the rates at 20^{o}C to the relevant environmental temperatures, which are shown in Table 11 for each of the two reaches.

Ammonia concentrations in the upper reach frequently were very low or undetectable. High concentrations are desirable for studies of removal rate because the difference in concentrations between two fixed points will be maximized when concentrations are high, given first-order kinetics. If the upstream concentration is near the detection limit, there is little precision in estimates of change over distance. It is not even possible to say with certainty whether the rate is low or high, although it may be low because the microbial community has little exposure to ammonia.

The WQCD has used the default ammonia removal rate (6 d^{-1}) in the Colorado Ammonia Model for the purpose of setting effluent limits at the Centennial facility. In the absence of direct measures of the rate, this default rate is applied in modelling of the entire upper reach.

	Chatfield-Englewood Loss Rates[2]			Englewood-Burlington Loss Rates		
Month	Temperature[1]	Ammonia	Nitrate	Temperature[1]	Ammonia	Nitrate
Jan	4.5	1.82	0.65	2.5	1.55	0.60
Feb	4.8	1.86	0.66	2.5	1.55	0.60
Mar	7.5	2.29	0.74	6.2	2.07	0.71
Apr	11.2	3.05	0.88	8.6	2.49	0.79
May	14.8	4.02	1.03	12.5	3.36	0.94
Jun	15.5	4.24	1.06	14.5	3.91	1.02
Jul	20.6	6.28	1.32	18.5	5.33	1.22
Aug	20.1	6.05	1.30	19.0	5.53	1.25
Sep	18.9	5.51	1.23	17.3	4.86	1.16
Oct	13.6	3.67	0.97	10.5	2.88	0.86
Nov	9.5	2.67	0.81	7.1	2.21	0.74
Dec	4.5	1.82	0.65	3.5	1.68	0.63
Rate at 20EC		6.00	1.29		5.98[3]	1.30[3]
Theta		1.08	1.045		1.08	1.045

[1]Temperatures shown here are for the upper end of each reach.
[2]These rates also were applied to Cherry Creek and Bear Creek.
[3]Using a flow of 120 cfs at the Denver gage.

Table 11. Empirically determined rates (day^{-1}, base e, first order) of ammonia loss and nitrate loss for the South Platte River between Chatfield Reservoir and the Burlington Ditch headgate, as determined by model calibration. Rates for the lower reach are flow-dependent.

Estimations of the ammonia removal rate for the lower reach were hampered by the high frequency of concentrations below the detection limit at the terminal point (Burlington headgate). The terminal concentration on such dates was set equal to the detection limit (0.05 mg/L) to permit a calculation of the removal rate. Because the actual concentration was less than the detection limit, the removal rate was larger than the number that is calculated. The analysis is thus conservative with respect to removal rate, and the effect applies equally to the nitrate removal rate, which is influenced by nitrate produced through nitrification.

Flow Dependence of Removal Rates

Addition of the 2002 data sets the association between flow and removal rates. On most of the sampling dates in 2002, flow at the Denver gage was less than it had been on any sampling dates in the original calibration set (1998-2000). The relationship between flow and the nitrate removal rate shown in Figure 7 is strong enough to warrant

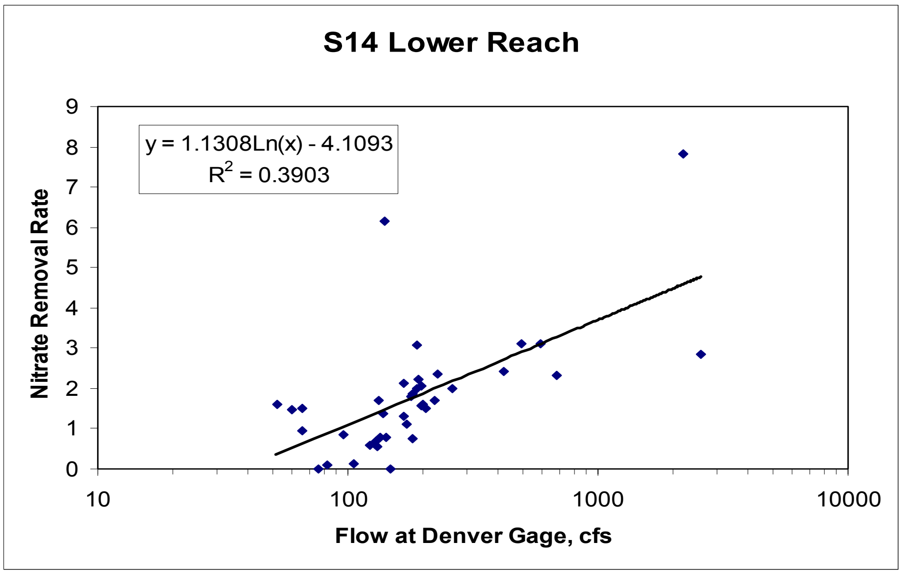


Figure 7. The relationship between the nitrate removal rate in the lower reach of Segment 14 and flow at the Denver gage. One outlier (6.2, 140) has a strong influence on R^2, but exerts little influence on the slope of the line; if it were removed, R^2 would be increased to 0.55.

inclusion in the TMDL model.

The existence of a relationship between flow and the nitrate removal rate suggests the possibility of a similar relationship for the ammonia removal rate in the lower reach and the nitrate removal rate in the upper reach. The ammonia removal rate in the lower reach showed a significant dependence on flow (Figure 8), and this is incorporated in the model. There was no association between flow and the nitrate removal rate in the upper reach. It was not possible to examine the connection between flow and the ammonia removal rate in the upper reach because that rate was set to a constant value, for reasons described above.

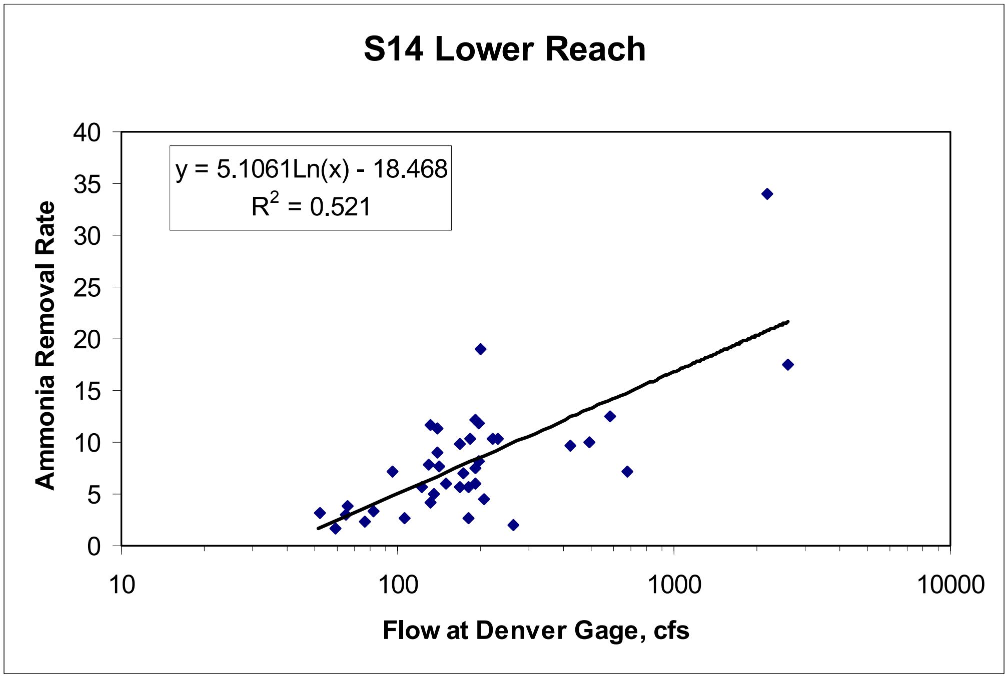


Figure 8. The relationship between ammonia removal rate in the lower reach of Segment 14 and flow at the Denver gage.

Validation of the Model

The ten data sets that were excluded from model calibration were used for validation. The first step in the validation sequence was to use screening criteria identical to those used on the calibration data set as a means of eliminating data for dates and reaches that were too incompletely documented to support the estimation of rates. Table12 summarizes the results of the screening. The second step was to obtain all of the appropriate flow data for each date and reach, including actual effluent flows as well as main stream tributary and ungaged flows. The transformation rates that were developed from the calibration data set then were inserted into the model, and the model was run for each date. Nitrate concentrations for each model run were obtained at the lower end of the upper reach (Dartmouth Avenue) and lower end of the lower reach (Burlington Ditch headgate). The differences between the observed and predicted values for each of these two locations on each date were recorded as residuals. The median residuals, which

	Nitrification		Denitrification	
Data Set[1]	Upper	Lower	Upper	Lower
3	-	√	-	√
7	√	√	√	√
22	√	√	√	√
24	-	-	-	-
26	-	√	-	√
33	√	√	√	√
35	√	√	√	√
38	√	√	√	√
40	-	√	-	√
44	-	-	-	-
Total Sets	5	8	5	8

[1]For dates, see Table 9.

Table 12. Results of screening for validation data sets (v = data sufficient for modelling; - = insufficient data for modelling).

would be 0.00 in the case of a perfect match between calibration and validation data, are reported in Table 13 along with their standard errors. Figure 9 gives a graphical presentation.

Location	Median Residual	Number of Cases Available	Standard Error Residual
Ammonia Loss Rate			
Upper	0.01	5	0.04
Lower	-0.05	8	0.06
Nitrate Loss Rate			
Upper	-0.10	5	0.10
Lower	0.44	8	0.27

Table 13. Statistics on residuals. Residuals are observed minus predicted nitrate N as mg/L at Dartmouth Avenue ("upper") and the Burlington Ditch headgate ("lower"), mg/L.

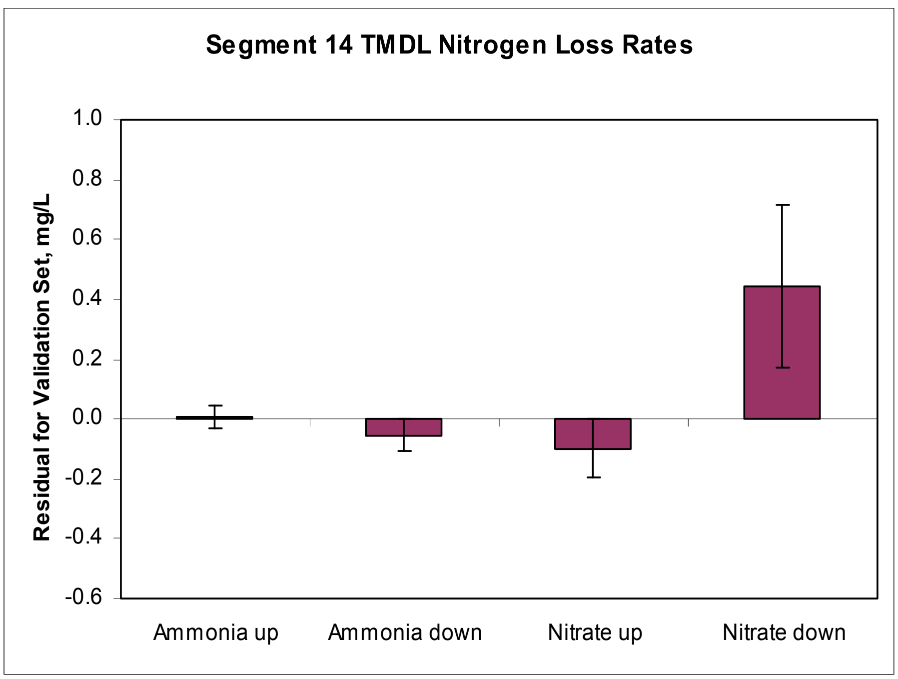


Figure 9. Results of model validation for nitrogen removal rates in the upper ("up") and lower ("down") reaches of Segment 14. The height of each bar represents the median of residuals (observed - predicted) from the validation sets (N=5 for the upper reach and N=8 for the lower reach), and error bars show one standard error unit on either side of the median.

The rates show a mixture of positive and negative biases in the validation data as compared with the calibration data, but the magnitude of the biases is small (less than 0.44 mg/L in the most extreme case). The standard errors in all cases are less than 5% of the nitrate standard on Segment 14 (10 mg/L).

Use of the TMDL Model to Estimate Permit Limits

Once calibrated with the information mentioned in the foregoing sections, the TMDL model can be used in estimating permit limits for individual dischargers consistent with points of compliance for the nitrate standard on Segment 14 of the South Platte River. Points of compliance are the Allen Filter Plant and the Burlington Ditch headgate, both of which are shown in Figure 1.

The discharge of the Glendale WWTP is situated over five miles from the South Platte main stem. The discharge is sufficiently small that it is subject to considerable dilution by seepage before reaching the mouth of Cherry Creek, even under acute low flow conditions. A key question in establishing an acceptable range of permit limits for nitrate for Glendale is whether the nitrate concentration at the downstream compliance point for nitrate (Burlington Ditch headgate) is sensitive to changes in the nitrate content of Glendale WWTP effluent. This issue can be resolved by modelling.

For testing of the effects of the Glendale effluent, the nitrate concentrations at Centennial WWTP were set arbitrarily at 20 mg/L nitrate-nitrogen and 7.8 mg/L ammonia-nitrogen. Littleton/Englewood was set arbitrarily to 20 mg/L nitrate-nitrogen and 8 mg/L ammonia nitrogen. The concentration of nitrate in the Glendale effluent was then adjusted in increments of 5 mg/L from 10 to 30 mg/L, and the effect on concentration of nitrate-nitrogen at the Burlington Ditch Headgate was noted. The results are given in Figure 10 (for February, during the season of highest concentrations).

As shown by Figure 10, adjustment of nitrate concentration in the Glendale effluent over a wide range has little effect (about 5%) on the concentration of nitrate at the Burlington Ditch headgate. Because of the small size of the discharge, even at design capacity, and the substantial distance from the discharge to the South Platte main stem, the Glendale WWTP discharge can be considered essentially disjunct from the other wastewater treatment plant discharges with respect to nitrate permitting.

The Effect of Centennial Wastewater Discharge Plant on the Littleton/Englewood Wastewater Discharge

A second possibility for interaction is between the Centennial and Littleton/Englewood WWTPs. For the purpose of exploring this interaction, it is possible to fix the concentrations of ammonia and nitrogen in the Littleton/Englewood effluent and allow the concentrations in the Centennial effluent to vary. The effect of this variation at Centennial on the nitrate concentration at the compliance point (Burlington Ditch headgate) will then indicate the degree to which the Littleton/Englewood permit limits might need to take into account limits set for Centennial WWTP. For modelling purposes, the Littleton/Englewood WWTP effluent was set to 20 mg/L $NO_3\Gamma$-N and 8 mg/L ammonia nitrogen; Glendale was set to 25 mg/L $NO_3\Gamma$-N and 15 mg/L ammonia-N; Centennial was variable for $NO_3\Gamma$-N (12 to 20 mg/L) and set to 7.8 mg/L ammonia N.

Modeling Scenario 1

Initial conditions
February
L/E Flow = 36.3 mgd
Centennial NO3 = 20 mg/L; NH4 = 7.8
L/E NO3 = 20 mg/L; NH4 = 8
Glendale NH4 = 15
Vary Glendale NO3

	10	15	20	25	30
Burlington	9.4	9.5	9.6	9.7	9.8
Cherry Cr mouth	6.2	7.6	8.9	10.2	11.6

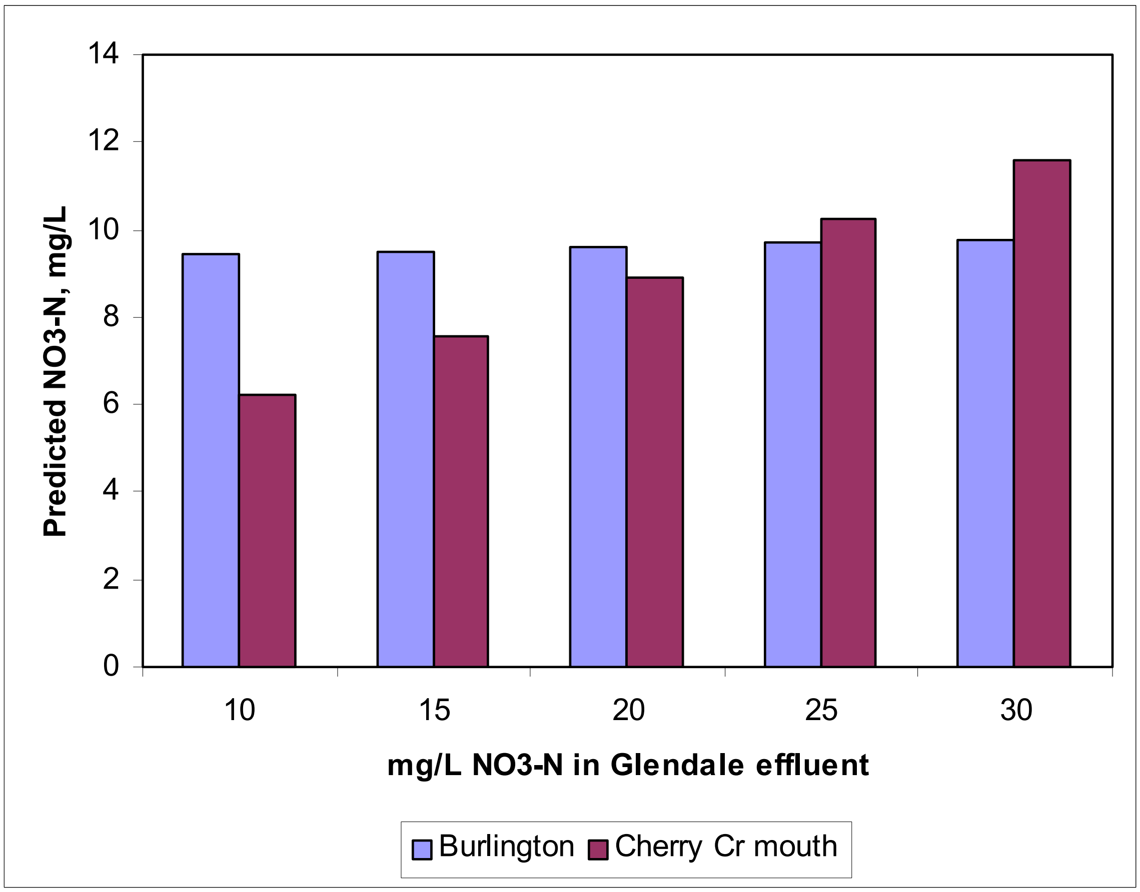


Figure 10. Summary of model runs showing the sensitivity of nitrate concentrations at the Burlington Ditch headgate to concentrations of nitrate and effluent from Glendale Wastewater Treatment Plant.

Figure 11 shows the result of the modelling. The concentration of nitrate at the

Allen Filter Plant (above Littleton/Englewood) is affected but nitrate at the Burlington Ditch headgate is very little affected by changes in nitrate at the Centennial WWTP. Therefore, concentrations of nitrate in the effluent from Centennial are not a major consideration in setting permit numbers for the Littleton/Englewood effluent.

Littleton/Englewood Wastewater Treatment Plant: Relationship of Nitrate and Ammonia

Given that the modelling incorporates a substantial nitrification rate for the reach of Segment 14 extending downstream from Littleton/Englewood WWTP discharge, the potential effects of ammonia on the nitrate concentrations at the point of compliance (Burlington Ditch headgate) must be considered.

The role of ammonia can be explored through model runs that fix the nitrate content of the Littleton/Englewood discharge but allow the total ammonia concentrations to vary. For modelling purposes, total ammonia was allowed to vary between 6 and 14 mg/L, while nitrate nitrogen was held constant at 15 mg/L. The results are shown in Figure 12.

The modelling shows that ammonia in the Littleton/Englewood discharge has a significant influence on the concentration of nitrate at the Burlington Ditch headgate. The explanation lies in the high nitrification rate for the reach of Segment 14 below the Littleton/Englewood discharge. Because of this high rate, much of the ammonia is converted in transit to nitrate over the time of travel between the effluent discharge and the Burlington Ditch headgate at low flow.

The implication of the modelling runs summarized in Figure 11 is that control of nitrate at the Burlington Ditch headgate requires a limit on both ammonia and nitrate.

Modeling Scenario 2

Initial conditions
February
L/E Flow = 36.3 mgd
L/E NO3 = 20 mg/L; NH4 = 8.0
Glendale NO3 = 25 mg/L; NH4 = 15
Centennial NH4 = 7.8
Vary Centennial NO3

	12	14	16	18	20
Burlington	9.5	9.5	9.6	9.6	9.7
Allen Plant intake	7.3	7.9	8.5	9.2	9.8

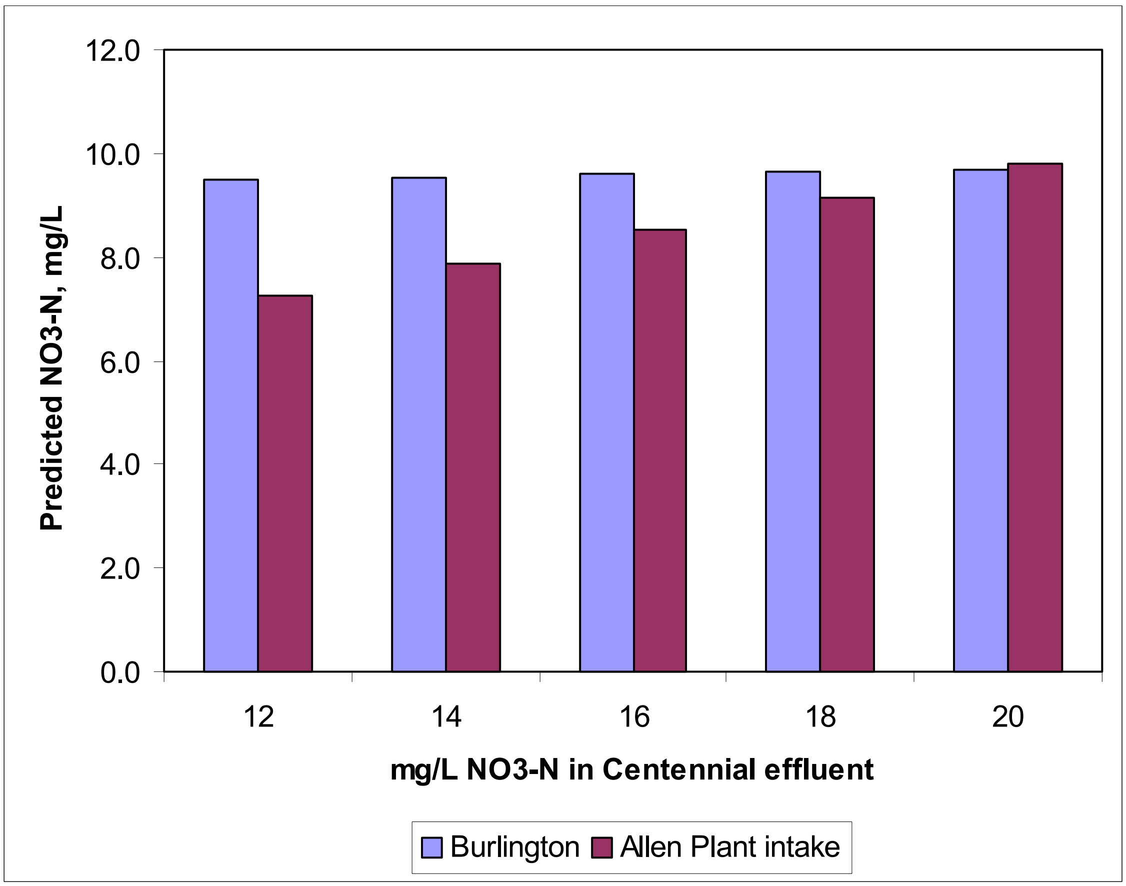


Figure 11. Summary of model runs showing sensitivity of the nitrate concentrations at the Allen Filter Plant intake and Burlington Ditch headgate to amount of nitrate in effluent from Centennial Wastewater Treatment Plant.

Modeling Scenario 3

Initial conditions
February
L/E Flow = 36.3 mgd
Centennial NO3 = 20 mg/L; NH4 = 7.8
Glendale NO3 = 25 mg/L; NH4 = 15
L/E NO3 = 15 mg/L
Vary L/E ammonia-N

	6	8	10	12	14
Burlington	7.8	8.3	8.8	9.3	9.8

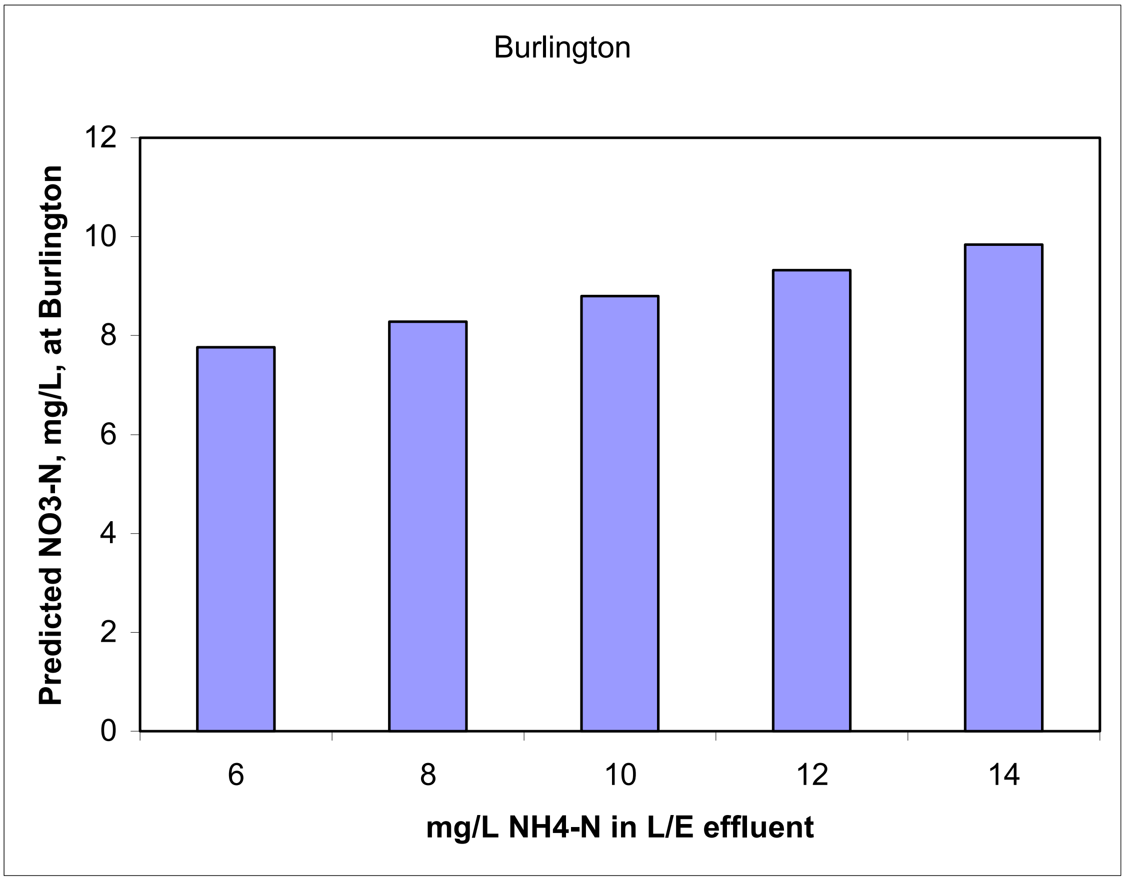


Figure 12. Summary of model runs showing the sensitivity of nitrate concentrations at the Burlington Ditch headgate to amount of ammonia in the Littleton/Englewood effluent.

Use of the TMDL Model to Set Limits

The TMDL model, calibrated as explained in foregoing sections of this report, was used in determining limits on the concentration of nitrate in effluent that would be consistent with the nitrate standard at compliance points on Segment 14. Effluent limits for ammonia must be set concurrently with nitrate limits because nitrification adds to the amount of nitrate present in the stream. The requirement to determine the two sets of limits simultaneously creates a practical problem in that there is no constraint on the number of combinations of nitrate and ammonia limits that could meet the stream standard. The problem can be resolved by fixing the limit for one constituent and then adjusting the other to a concentration at which compliance with the nitrate standard is assured.

The proposal of the CDPHE, based on discussions with the dischargers, involves setting ammonia limits at 15 mg/L (except where the acute limit is less), and adjusting nitrate limits until the compliance objective is met. The initial values for ammonia limits are shown in Table 14. An additional constraint was necessary for the Glendale effluent: the total inorganic nitrogen (TIN) concentration, which is the sum of ammonia and nitrate, cannot exceed 40 mg/L.

Target concentrations are different for the two compliance points in Segment 14. At the intake to the Allen Filter Plant, a target of 9.8 mg/L was used in modeling because of the direct connection to the treatment facility. A target of 10 mg/L was used at the Burlington headgate, where the concentration is indirect.

Month	Centennial	Littleton-Englewood	Glendale
Jan	15.0	15.0	14.3
Feb	12.6	15.0	15.0
Mar	8.5	15.0	10.2
Apr	8.2	15.0	15.0
May	15.0	15.0	15.0
Jun	15.0	15.0	15.0
Jul	15.0	15.0	15.0
Aug	15.0	15.0	15.0
Sep	15.0	15.0	15.0
Oct	15.0	15.0	15.0
Nov	15.0	15.0	15.0
Dec	15.0	15.0	15.0

Table 14. Acute limits for total ammonia, provided by CDPHE, as suggested by the dischargers. The nominal value of 15 mg/L is superseded by the acute limit when the acute limit is less than 15 mg/L.

Nitrate limits for the three dischargers are shown in Table 15. These limits are based on the assumption that flow resets are not applied, and that Littleton-Englewood has a design capacity of 36.3 mgd. Three other operating scenarios must be examined, taking into account a different design capacity (50 mgd) for Littleton-Englewood, and exploring outcomes if flow resets are applied with either design capacity. These scenarios, which affect nitrate limits for Littleton-Englewood, but not the other dischargers, are shown in Table 16. In almost all months, the most restrictive conditions occur at a design capacity of 50 mgd when flows are reset (Figure 13). In general, limits are lower when resets are used, and limits decrease as design capacity increase.

Month	Centennial	Littleton-Englewood	Glendale
Jan	15.5	16.2	25.7
Feb	15.2	14.5	25.0
Mar	20.7	13.6	29.8
Apr	24.2	17.2	25.0
May	31.5	28.7	25.0
Jun	28.4	27.2	25.0
Jul	33.3	28.0	25.0
Aug	31.7	36.0	25.0
Sep	27.1	32.4	25.0
Oct	25.6	25.9	25.0
Nov	20.5	19.6	25.0
Dec	17.4	18.9	25.0

Table 15. Nitrate limits for dischargers to Segment 14. These limits were determined for the scenario in which flow resets are not applied, and Littleton-Englewood has a design capacity of 36.3 mgd.

	Design Capacity: 36.3 mgd		Design Capacity: 50 mgd	
Month	No Reset	With Reset	No Reset	With Reset
Jan	16.2	12.4	12.7	10.7
Feb	14.5	11.6	11.5	9.9
Mar	13.6	10.4	10.8	8.9
Apr	17.2	12.9	17.2	11.0
May	28.7	28.6	22.0	22.8
Jun	27.2	30.6	21.6	24.6
Jul	28.0	25.1	23.2	21.5
Aug	36.0	29.7	29.0	25.3
Sep	32.4	20.2	26.0	17.9
Oct	25.9	17.9	20.4	15.4
Nov	19.6	13.2	15.5	11.1
Dec	18.9	14.9	14.8	12.3

Table 16. Nitrate limits for Littleton-Englewood for design capacities of 36.3 and 50 mgd, with and without flow resets.

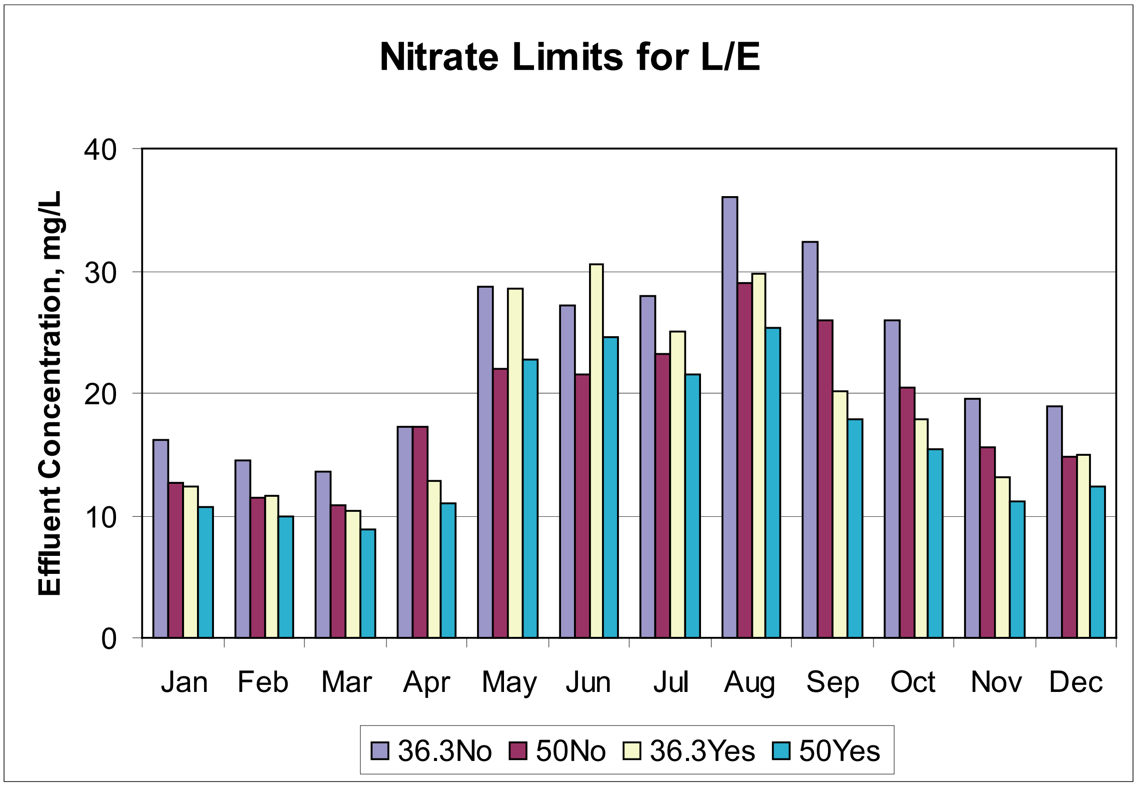


Figure 13. Nitrate limits for the Littleton-Englewood WWTP under four modelling scenarios. Design capacity for the facility is set at 36.3 or 50 mgd, and the model is run without ("No") or with ("Yes") use of flow resets, as described in the text.

Overview of the TMDL

Tables 17a and 17b (with resets in place) and 18a and 18b (with no flow resets), give a comprehensive picture of acute low flow discharges, concentrations, and loads that are consistent with the nitrate standard on Segment 14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge, cfs												
Chatfield	0	0	0	1	5	2	0	1	0	0	0	0
DOW	1	0	1	3	8	6	8	5	1	2	0	1
SP abv Centennial	2	1	2	4	15	10	10	8	3	4	2	2
Centennial	13	13	13	13	13	13	13	13	13	13	13	13
SP abv Allen Plant	30	27	28	31	46	42	45	44	40	39	34	31
SP abv Bear Creek	26	22	23	27	32	31	26	35	36	37	33	29
Bear Creek mouth	19	18	15	18	28	13	7	10	12	18	19	25
SP abv L/E	26	27	25	28	60	58	30	33	20	27	31	39
L/E at 36.3 mgd	56	56	56	56	56	56	56	56	56	56	56	56
Denver Sites	0	0	0	0	0	0	1	1	1	0	0	0
SP abv Cherry Cr	70	71	73	69	105	115	81	86	71	76	77	84
Cherry Cr abv Glendale	5	2	2	6	11	17	16	13	16	10	8	5
Glendale	3	3	3	3	3	3	3	3	3	3	3	3
Cherry Cr mouth	11	8	8	8	21	13	13	13	11	12	8	11
Burlington	69	68	66	65	116	120	87	96	81	86	76	84
Concentration, mg/L												
Chatfield	0	0	0	0	0	0	0	0	0	0	0	0
DOW	0	0	0	0	0	0	0	0	0	0	0	0
SP abv Centennial	1	1	0	0	0	0	0	1	1	1	1	1
Centennial	16	15	21	24	32	28	33	32	27	26	21	17
SP abv Allen Plant	10	10	10	10	10	10	10	10	10	10	10	10
SP abv Bear Creek	8	8	8	8	9	9	9	9	9	8	8	8
Bear Creek mouth	1	1	1	1	1	0	0	0	1	1	1	1
SP abv L/E	5	4	4	4	4	5	5	5	5	5	5	4
L/E at 36.3 mgd	12	12	10	13	29	31	25	30	20	18	13	15
Denver Sites	-	12	-	12	12	12	12	12	12	12	12	-
SP abv Cherry Cr	11	10	10	11	13	13	13	14	13	12	11	11
Cherry Cr abv Glendale	2	2	2	2	3	3	3	3	3	3	3	2
Glendale	26	25	30	25	25	25	25	25	25	25	25	25
Cherry Cr mouth	8	10	11	7	6	6	6	6	6	6	7	8
Burlington	10	10	10	10	10	10	10	10	10	10	10	10
Load, kg/d												
Chatfield	0	0	0	0	2	0	0	0	0	0	0	0
DOW	0	0	0	0	2	1	0	0	0	0	0	0
SP abv Centennial	3	1	2	2	9	8	9	10	10	9	6	4
Centennial	499	489	666	779	1014	914	1071	1020	872	824	660	560
SP abv Allen Plant	707	634	670	750	1095	1009	1087	1049	958	939	812	750
SP abv Bear Creek	532	449	467	532	678	660	558	735	746	751	666	562
Bear Creek mouth	58	56	49	39	50	15	6	8	16	46	51	56
SP abv L/E	287	283	274	294	628	729	390	432	254	326	353	389
L/E at 36.3 mgd	1704	1594	1429	1773	3930	4205	3449	4081	2776	2460	1814	2047
Denver Sites	0	1	0	1	5	14	18	23	18	12	2	0
SP abv Cherry Cr	1827	1773	1791	1819	3281	3655	2648	2877	2229	2261	2061	2214
Cherry Cr abv Glendale	29	9	9	35	75	116	107	89	107	67	49	27
Glendale	195	189	226	189	189	189	189	189	189	189	189	189
Cherry Cr mouth	216	205	223	138	314	176	179	189	150	180	139	218
Burlington	1688	1650	1619	1597	2831	2929	2124	2343	1986	2101	1862	2058

Table 17a. Summary of acute low flows, nitrate-nitrogen concentrations and loads with Littleton-Englewood at a design capacity of 36.3 mgd, and with flow resets applied.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge, cfs												
Chatfield	0	0	0	1	5	2	0	1	0	0	0	0
DOW	1	0	1	3	8	6	8	5	1	2	0	1
SP abv Centennial	2	1	2	4	15	10	10	8	3	4	2	2
Centennial	13	13	13	13	13	13	13	13	13	13	13	13
SP abv Allen Plant	30	27	28	31	46	42	45	44	40	39	34	31
SP abv Bear Creek	26	22	23	27	32	31	26	35	36	37	33	29
Bear Creek mouth	19	18	15	18	28	13	7	10	12	18	19	25
SP abv L/E	26	27	25	28	60	58	30	33	20	27	31	39
L/E at 50 mgd	77	77	77	77	77	77	77	77	77	77	77	77
Denver Sites	0	0	0	0	0	0	1	1	1	0	0	0
SP abv Cherry Cr	70	71	73	69	105	115	81	86	71	76	77	84
Cherry Cr abv Glendale	5	2	2	6	11	17	16	13	16	10	8	5
Glendale	3	3	3	3	3	3	3	3	3	3	3	3
Cherry Cr mouth	11	8	8	8	21	13	13	13	11	12	8	11
Burlington	69	68	66	65	116	120	87	96	81	86	76	84
Concentration, mg/L												
Chatfield	0	0	0	0	0	0	0	0	0	0	0	0
DOW	0	0	0	0	0	0	0	0	0	0	0	0
SP abv Centennial	1	1	0	0	0	0	0	1	1	1	1	1
Centennial	16	15	21	24	32	28	33	32	27	26	21	17
SP abv Allen Plant	10	10	10	10	10	10	10	10	10	10	10	10
SP abv Bear Creek	8	8	8	8	9	9	9	9	9	8	8	8
Bear Creek mouth	1	1	1	1	1	0	0	0	1	1	1	1
SP abv L/E	5	4	4	4	4	5	5	5	5	5	5	4
L/E at 50 mgd	11	10	9	11	23	25	22	25	18	15	11	12
Denver Sites	-	12	-	12	12	12	12	12	12	12	12	-
SP abv Cherry Cr	11	10	10	11	13	13	13	14	13	12	11	11
Cherry Cr abv Glendale	2	2	2	2	3	3	3	3	3	3	3	2
Glendale	26	25	30	25	25	25	25	25	25	25	25	25
Cherry Cr mouth	8	10	11	7	6	6	6	6	6	6	7	8
Burlington	10	10	10	10	10	10	10	10	10	10	10	10
Load, kg/d												
Chatfield	0	0	0	0	2	0	0	0	0	0	0	0
DOW	0	0	0	0	2	1	0	0	0	0	0	0
SP abv Centennial	3	1	2	2	9	8	9	10	10	9	6	4
Centennial	499	489	666	779	1014	914	1071	1020	872	824	660	560
SP abv Allen Plant	707	634	670	750	1095	1009	1087	1049	958	939	812	750
SP abv Bear Creek	532	449	467	532	678	660	558	735	746	751	666	562
Bear Creek mouth	58	56	49	39	50	15	6	8	16	46	51	56
SP abv L/E	287	283	274	294	628	729	390	432	254	326	353	389
L/E at 50 mgd	2025	1874	1684	2082	4315	4656	4069	4788	3388	2915	2101	2328
Denver Sites	0	1	0	1	5	14	18	23	18	12	2	0
SP abv Cherry Cr	1819	1763	1779	1806	3261	3636	2645	2867	2227	2254	2057	2208
Cherry Cr abv Glendale	29	9	9	35	75	116	107	89	107	67	49	27
Glendale	195	189	226	189	189	189	189	189	189	189	189	189
Cherry Cr mouth	216	205	223	138	314	176	179	189	150	180	139	218
Burlington	1687	1650	1618	1596	2829	2927	2128	2341	1988	2098	1865	2061

Table 17b. Summary of acute low flows, nitrate-nitrogen concentrations and loads with Littleton-Englewood at a design capacity of 50 mgd, and with flow resets applied.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge, cfs												
Chatfield	0	0	0	1	5	2	0	1	0	0	0	0
DOW	1	0	1	3	8	6	8	5	1	2	0	1
SP abv Centennial	2	1	2	4	15	10	10	8	3	4	2	2
Centennial	13	13	13	13	13	13	13	13	13	13	13	13
SP abv Allen Plant	30	27	28	31	46	42	45	44	40	39	34	31
SP abv Bear Creek	26	22	23	27	32	31	26	35	36	37	33	29
Bear Creek mouth	19	18	15	18	28	13	7	10	12	18	19	25
SP abv L/E	50	44	42	49	63	47	34	48	52	60	58	59
L/E at 36.3 mgd	56	56	56	56	56	56	56	56	56	56	56	56
Denver Sites	0	0	0	0	0	0	1	1	1	0	0	0
SP abv Cherry Cr	120	115	112	120	136	124	114	129	131	136	129	129
Cherry Cr abv Glendale	5	2	2	6	11	17	16	13	16	10	8	5
Glendale	3	3	3	3	3	3	3	3	3	3	3	3
Cherry Cr mouth	11	8	8	8	21	13	13	13	11	12	8	11
Burlington	120	111	106	116	147	129	120	139	141	146	129	130
Concentration, mg/L												
Chatfield	0	0	0	0	0	0	0	0	0	0	0	0
DOW	0	0	0	0	0	0	0	0	0	0	0	0
SP abv Centennial	1	1	0	0	0	0	0	1	1	1	1	1
Centennial	16	15	21	24	32	28	33	32	27	26	21	17
SP abv Allen Plant	10	10	10	10	10	10	10	10	10	10	10	10
SP abv Bear Creek	8	8	8	8	9	9	9	9	9	8	8	8
Bear Creek mouth	1	1	1	1	1	0	0	0	1	1	1	1
SP abv L/E	5	4	4	4	4	5	5	5	5	5	5	4
L/E at 36.3 mgd	16	15	14	17	29	27	28	36	32	26	20	19
Denver Sites	-	12	-	12	12	12	12	12	12	12	12	-
SP abv Cherry Cr	11	11	11	11	13	13	13	13	13	12	11	11
Cherry Cr abv Glendale	2	2	2	2	3	3	3	3	3	3	3	2
Glendale	26	25	30	25	25	25	25	25	25	25	25	25
Cherry Cr mouth	8	10	11	7	6	6	6	6	6	6	7	8
Burlington	10	10	10	10	10	10	10	10	10	10	10	10
Load, kg/d												
Chatfield	0	0	0	0	2	0	0	0	0	0	0	0
DOW	0	0	0	0	2	1	0	0	0	0	0	0
SP abv Centennial	3	1	2	2	9	8	9	10	10	9	6	4
Centennial	499	489	666	779	1014	914	1071	1020	872	824	660	560
SP abv Allen Plant	707	634	670	750	1095	1009	1087	1049	958	939	812	750
SP abv Bear Creek	532	449	467	532	678	660	558	735	746	751	666	562
Bear Creek mouth	58	56	49	39	50	15	6	8	16	46	51	56
SP abv L/E	549	460	461	516	664	590	448	624	657	726	660	584
L/E at 36.3 mgd	2226	1992	1869	2363	3944	3737	3847	4947	4452	3559	2693	2597
Denver Sites	0	1	0	1	5	14	18	23	18	12	2	0
SP abv Cherry Cr	3187	2966	2890	3260	4169	3932	3721	4261	4170	4016	3546	3453
Cherry Cr abv Glendale	29	9	9	35	75	116	107	89	107	67	49	27
Glendale	195	189	226	189	189	189	189	189	189	189	189	189
Cherry Cr mouth	216	205	223	138	314	176	179	189	150	180	139	218
Burlington	2920	2722	2589	2840	3585	3156	2934	3399	3459	3580	3142	3164

Table 18a. Summary of acute low flows, nitrate-nitrogen concentrations and loads with Littleton-Englewood at a design capacity of 36.3 mgd, and without flow resets.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge, cfs												
Chatfield	0	0	0	1	5	2	0	1	0	0	0	0
DOW	1	0	1	3	8	6	8	5	1	2	0	1
SP abv Centennial	2	1	2	4	15	10	10	8	3	4	2	2
Centennial	13	13	13	13	13	13	13	13	13	13	13	13
SP abv Allen Plant	30	27	28	31	46	42	45	44	40	39	34	31
SP abv Bear Creek	26	22	23	27	32	31	26	35	36	37	33	29
Bear Creek mouth	19	18	15	18	28	13	7	10	12	18	19	25
SP abv L/E	50	44	42	49	63	47	34	48	52	60	58	59
L/E at 50 mgd	77	77	77	77	77	77	77	77	77	77	77	77
Denver Sites	0	0	0	0	0	0	1	1	1	0	0	0
SP abv Cherry Cr	141	136	134	141	157	146	135	151	152	158	150	150
Cherry Cr abv Glendale	5	2	2	6	11	17	16	13	16	10	8	5
Glendale	3	3	3	3	3	3	3	3	3	3	3	3
Cherry Cr mouth	11	8	8	8	21	13	13	13	11	12	8	11
Burlington	141	133	127	137	168	150	141	160	163	167	150	151
Concentration, mg/L												
Chatfield	0	0	0	0	0	0	0	0	0	0	0	0
DOW	0	0	0	0	0	0	0	0	0	0	0	0
SP abv Centennial	1	1	0	0	0	0	0	1	1	1	1	1
Centennial	16	15	21	24	32	28	33	32	27	26	21	17
SP abv Allen Plant	10	10	10	10	10	10	10	10	10	10	10	10
SP abv Bear Creek	8	8	8	8	9	9	9	9	9	8	8	8
Bear Creek mouth	1	1	1	1	1	0	0	0	1	1	1	1
SP abv L/E	5	4	4	4	4	5	5	5	5	5	5	4
L/E at 50 mgd	13	12	11	17	22	22	23	29	26	20	16	15
Denver Sites	-	12	-	12	12	12	12	12	12	12	12	-
SP abv Cherry Cr	11	11	11	12	12	13	13	13	13	12	11	11
Cherry Cr abv Glendale	2	2	2	2	3	3	3	3	3	3	3	2
Glendale	26	25	30	25	25	25	25	25	25	25	25	25
Cherry Cr mouth	8	10	11	7	6	6	6	6	6	6	7	8
Burlington	10	10	10	11	10	10	10	10	10	10	10	10
Load, kg/d												
Chatfield	0	0	0	0	2	0	0	0	0	0	0	0
DOW	0	0	0	0	2	1	0	0	0	0	0	0
SP abv Centennial	3	1	2	2	9	8	9	10	10	9	6	4
Centennial	499	489	666	779	1014	914	1071	1020	872	824	660	560
SP abv Allen Plant	707	634	670	750	1095	1009	1087	1049	958	939	812	750
SP abv Bear Creek	532	449	467	532	678	660	558	735	746	751	666	562
Bear Creek mouth	58	56	49	39	50	15	6	8	16	46	51	56
SP abv L/E	549	460	461	516	664	590	448	624	657	726	660	584
L/E at 50 mgd	2404	2177	2044	3255	4164	4088	4391	5489	4921	3861	2934	2801
Denver Sites	0	1	0	1	5	14	18	23	18	12	2	0
SP abv Cherry Cr	3731	3520	3440	4276	4746	4550	4389	4923	4822	4614	4125	4012
Cherry Cr abv Glendale	29	9	9	35	75	116	107	89	107	67	49	27
Glendale	195	189	226	189	189	189	189	189	189	189	189	189
Cherry Cr mouth	216	205	223	138	314	176	179	189	150	180	139	218
Burlington	3435	3242	3102	3712	4101	3672	3452	3918	3973	4097	3661	3686

Table 18b. Summary of acute low flows, nitrate-nitrogen concentrations and loads with Littleton-Englewood at a design capacity of 50 mgd, and without flow resets.

Appendix I

Locations of Landmarks in Segments 6c and 14, Upper South Platte River

Distance from Chatfield Release, miles	Landmark Name
0.00	Chatfield Release
0.82	DOW Trout Unit
1.17	Centennial WWTP/Marcy Gulch
2.60	Mineral Avenue
5.13	Bowles Avenue
6.74	Big Dry Creek
6.86	Allen Plant Intake
7.78	Oxford Avenue
8.33	Bear Creek
8.81	Hampden Avenue
9.30	Little Dry Creek
9.38	Dartmouth
9.85	Littleton/Englewood WWTP
9.93	West Harvard Gulch
10.26	Xcel - Arapahoe
10.48	Harvard Gulch
10.89	West Evans
11.74	West Florida
11.80	Sanderson Gulch
13.55	West Alameda
15.55	Xcel - Zuni
15.87	Lakewood Gulch
15.98	West Colfax Avenue
17.02	Speer Boulevard
17.09	Farmers and Gardeners
17.11	Cherry Creek
17.51	South Platte River at Denver Gage
19.67	I - 70
20.72	Burlington Ditch