EXTERNAL MEMORANDUM

To: Cherry Creek Basin Water Quality Authority
Modeling Sub-committee

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Date: January 22, 2024

Subject: Additional Watershed Model Scenarios and Scenario Approaches

Two additional watershed scenarios were completed using the Cherry Creek 2030 Future Development HSPF model:

1. Reduced WWTF TN concentration (Scenario 12).
2. Scenario 12 plus improved water quality treatment for all developed areas (Scenario 13).

Scenarios 8 through 13 were also rerun using an alternative approach where water quality efficiencies were adjusted using the flow efficiency. For the scenarios represented, flow, sediment, and nutrients were being adjusted. With small flow adjustments, changes in concentrations of parameters that are not intentionally being adjusted with each scenario (such as BOD and dissolved oxygen) are not obvious. However, the larger the flow adjustments become, the more the scenario concentrations of those parameters that are not intentionally being adjusted show up. Therefore, in the most recent run of scenarios, where flow adjustments were as large as 40%, the increases in concentrations of parameters such as BOD and dissolved oxygen were becoming apparent, and an alternative methodology was incorporated to also adjust the loads of all parameters based on the changes in flow. Details regarding the additional scenarios and the alternative efficiency factor methodology are provided in the following sections. Results are briefly described in this memo with the full results provided in Appendix A.

ADDITIONAL SCENARIOS

Scenario 12 was developed using Scenario 11 (full 2030 buildout) as the base model. The WWTF TN concentrations were capped at 6 mg/l during the summer (April – September) and 8 mg/l during the winter (October – March). The Pinery, Parker, and Stonegate facilities exceed the seasonal limits 100%, 58%, and 23% of the simulation time-period, respectively. During these periods, the total nitrate-nitrite concentrations were reduced until there were no more

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exceedances. The Arapaho County Water and Wastewater Authority (ACWWA) facility never exceeded the seasonal TN limits, so those associated time series remained unchanged.

Relative to Scenario 11, the inflow TN loads and concentrations to Cherry Creek Reservoir for Scenario 12 were reduced by 5% and 3%, respectively. The TN load is still 51% higher than the base model, but the concentration is 1% lower. Inflow volume, TSS, and TP remained the same as Scenario 11.

Scenario 13 was developed using Scenario 12 as the base model. Efficiency factors for flow (0.4), TSS (0.5), TN (0.1), and TP (0.25) that were applied to new development in Scenarios 10 – 12 were applied to all developed model landuse categories.

As expected, Scenario 13 resulted in a reduction in inflow volume and water quality loads to the reservoir relative to Scenarios 11 and 12. However, there was a 10% and 15% increase in inflow TP and TN concentrations, respectively, relative to Scenario 11. These modeled increases are likely due to the modeled enrichment that occurs in the model when the flow efficiency change is larger than water quality efficiencies change (e.g., when more volume than load is removed at the edge of the stream, an increase in inflow concentration is expected). The results generated using the original methodology show the effects of changes in loads but do not maintain the original concentrations of the modeled constituents. Although applying the efficiencies directly to loads is an acceptable method to model load changes, our goal with this additional modeling is to use concentrations as the basis for projections related to the effects of improved water quality treatment for all developed areas. Thus, the alternative efficiency factor approach is provided for this purpose.

ALTERNATIVE EFFICIENCY FACTOR APPROACH

The equation below was used to adjust the water quality efficiency factors as a function of the flow efficiency factor for Scenarios 8 – 13.

$$NewEff_{WQ} = (1 - Eff_{Flow}) \times OriEff_{WQ} + Eff_{Flow}$$

where:

$NewEff_{WQ} = adjusted\ water\ quality\ efficiency\ factor$
$Eff_{Flow} = efficiency\ factor\ for\ flow$
$OriEff_{WQ} = original\ water\ qualtiy\ efficiency\ factor$

This methodology prevents enrichment in water quality pollutants when the flow efficiency is higher than a water quality efficiency. It also preserves runoff concentrations for parameters that have zero efficiency by setting the efficiency to that of flow. For example, the efficiency for BOD was zero, so the concentrations in runoff actually increased using original method even though the load remained the same. The original and new efficiency factors are summarized in Table 1.

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Table 1. Summary of Original and New Efficiency Factors.

Parameter	Original Efficiency Scen 8 – 9	New Efficiency Scen 8 – 9	Original Efficiency Scen 10 – 13	New Efficiency Scen 10 – 13
Flow	0.20	0.20	0.40	0.40
TSS	0.50	0.60	0.50	0.70
TP	0.25	0.40	0.25	0.55
TN	0.10	0.28	0.10	0.46
Temperature	0.00	0.20	0.00	0.40
DO	0.00	0.20	0.00	0.40
BOD	0.00	0.20	0.00	0.40
Carbon	0.00	0.20	0.00	0.40

The new methodology resulted in more accurate estimates of future loads and concentrations. Overall, the narrative remains the same regarding inflow to the reservoir where TSS, TP, and TN loads are still substantially larger than the base condition for Scenarios 8-12. Scenario 13 resulted in no change in TP load and slight increase in TSS and TN load relative to the base condition. Furthermore, all inflow concentrations for Scenario 13 were lower than the base results. A legend for the various scenarios is presented in Table 2. Presented in Figures 1-7 are graphic representations of the results of the alternative model runs.

Table 2 – Scenarios Legend

Scenario	Description	Representative Icons	Color
Base	Baseline Model	None	
4	2030 Level of Development Only		
5	2030 WWTF Flows Only		
6	2030 Level of Development and WWTF Flows Only		
7	2030 Level of Development, WWTF Flows, and PRFs		
8	2030 Level of Development, WWTF Flows, PRFs, and LID		
9	2030 Level of Development and LID only		
10	2030 Level of Development, WWTF Flows, PRFs, and LID at 40% Volume Reduction	+ 20% Added Volume Reduction	
11	Scenario 10 with Parker Wastewater Flows from Future Development diverted to Rueter-Hess Reservoir	plus future additional Parker WW to Rueter Hess Reservoir	
12	Scenario 11 with WWTF TN in Discharges Limited to 6 mg/l Summer, 8 mg/l Winter	plus future additional Parker WW to Rueter Hess Reservoir and reduced TN from WWTF	
13	Scenario 12 with Improved Water Quality Treatment for all Developed Areas	plus future additional Parker WW to Rueter Hess Reservoir, reduced TN, and improved WQ for all development	

Figure 1 - Modeled Flow

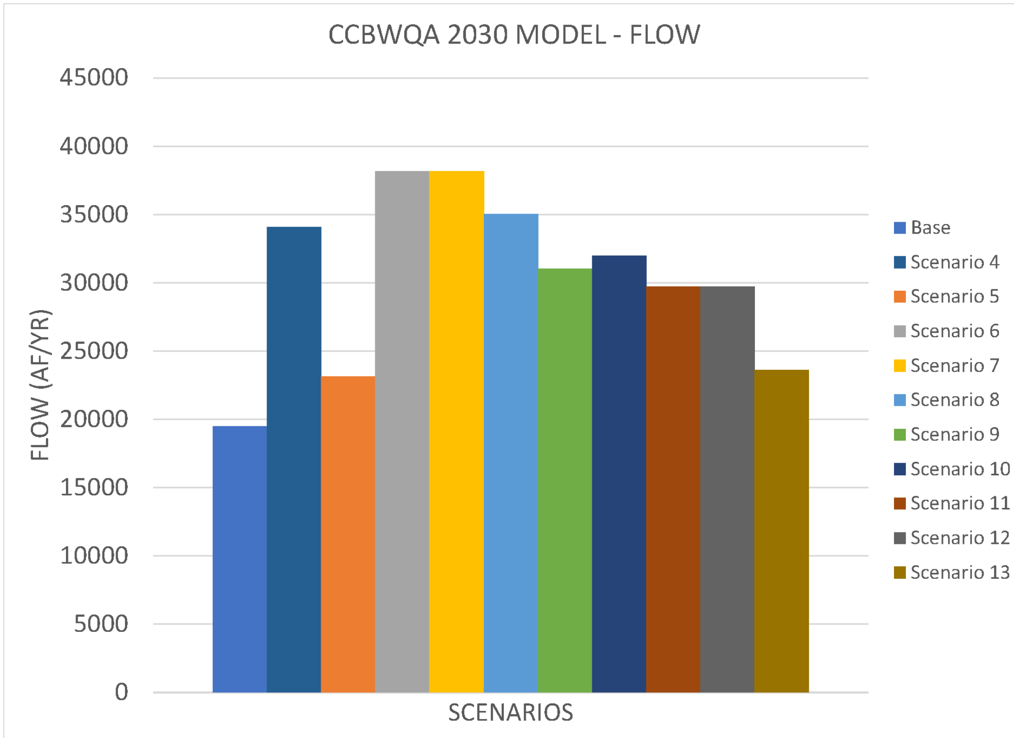


Figure 2 - Modeled TP Load

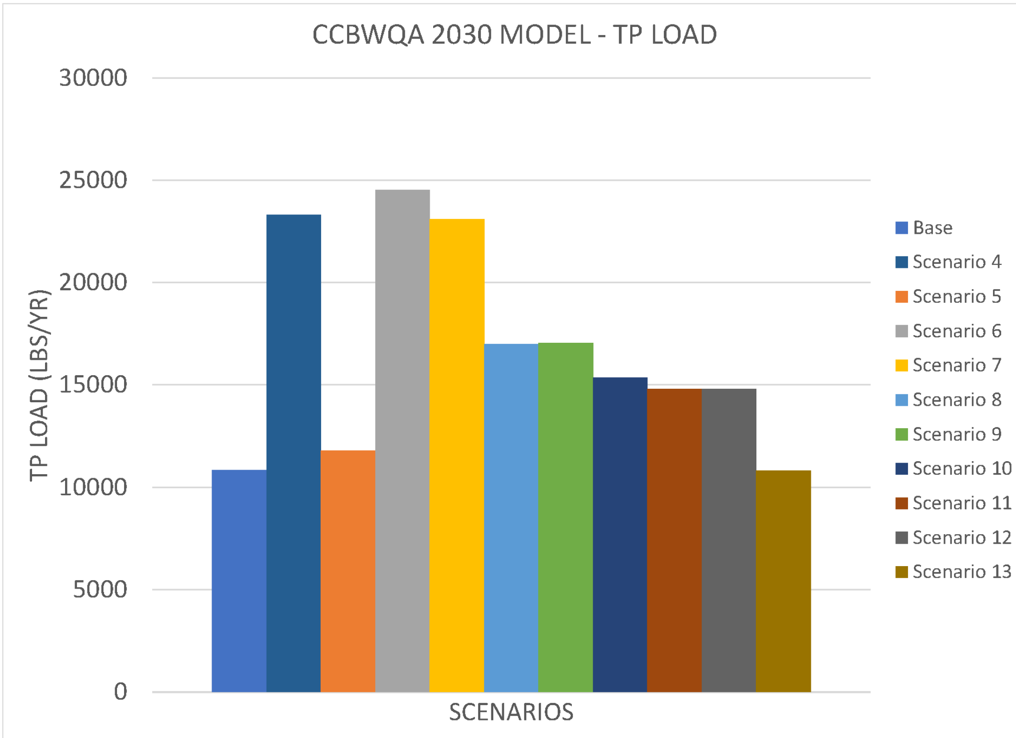


Figure 3 - Modeled TP Concentration

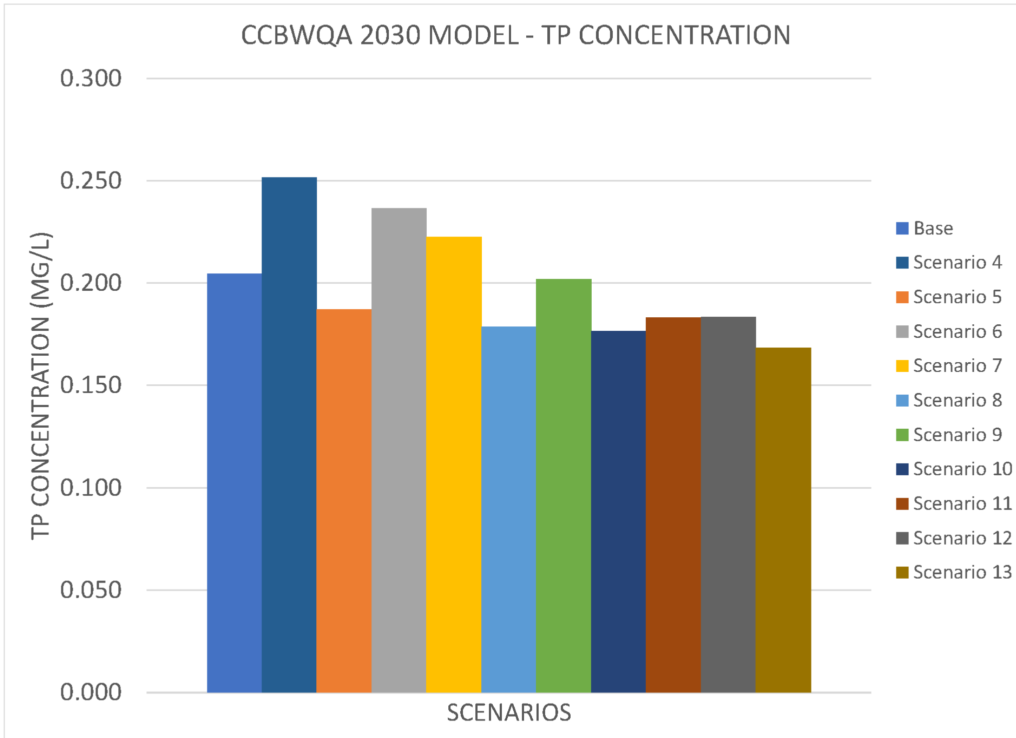


Figure 4 - Modeled TN Load

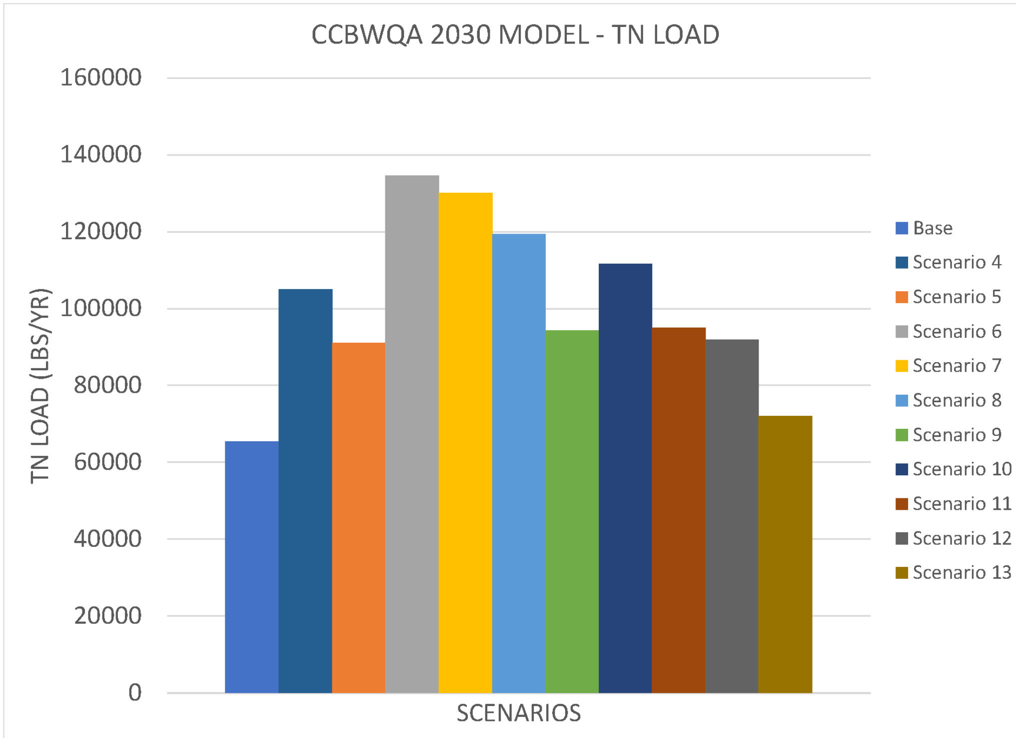


Figure 5 - Modeled TN Concentration

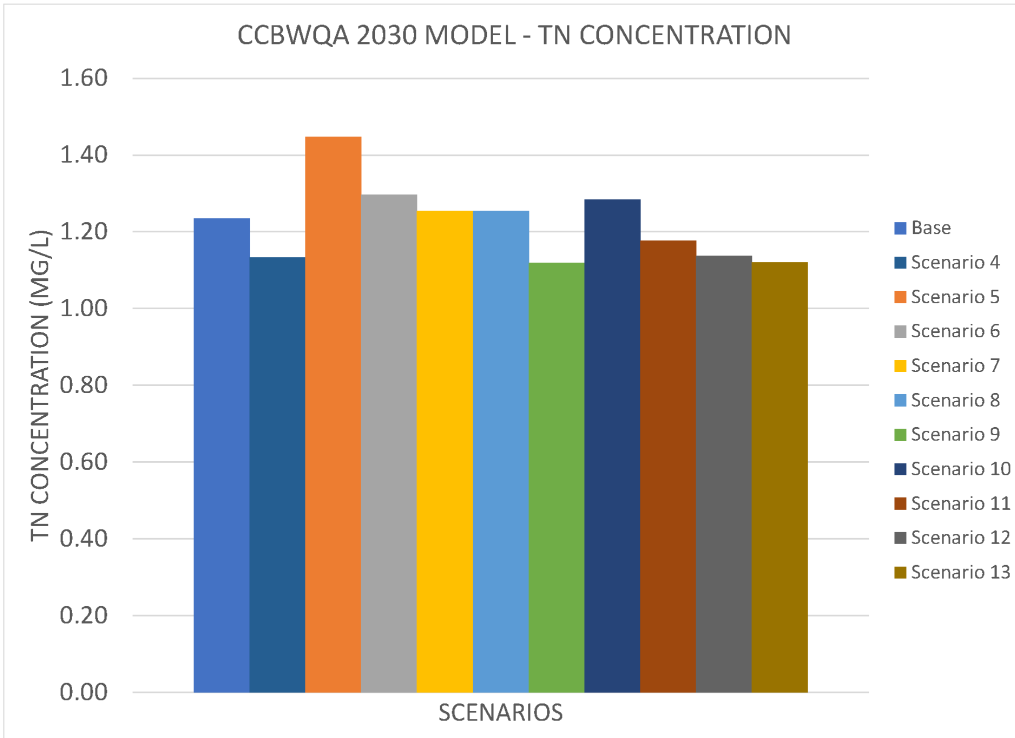


Figure 6 - Modeled TSS Load

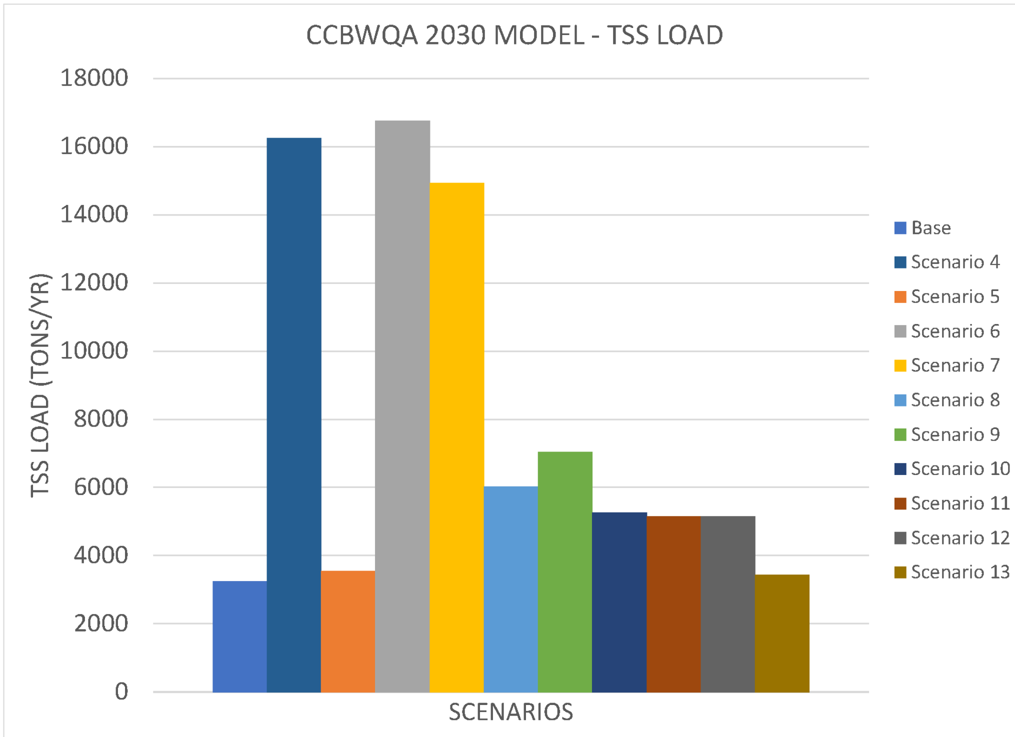
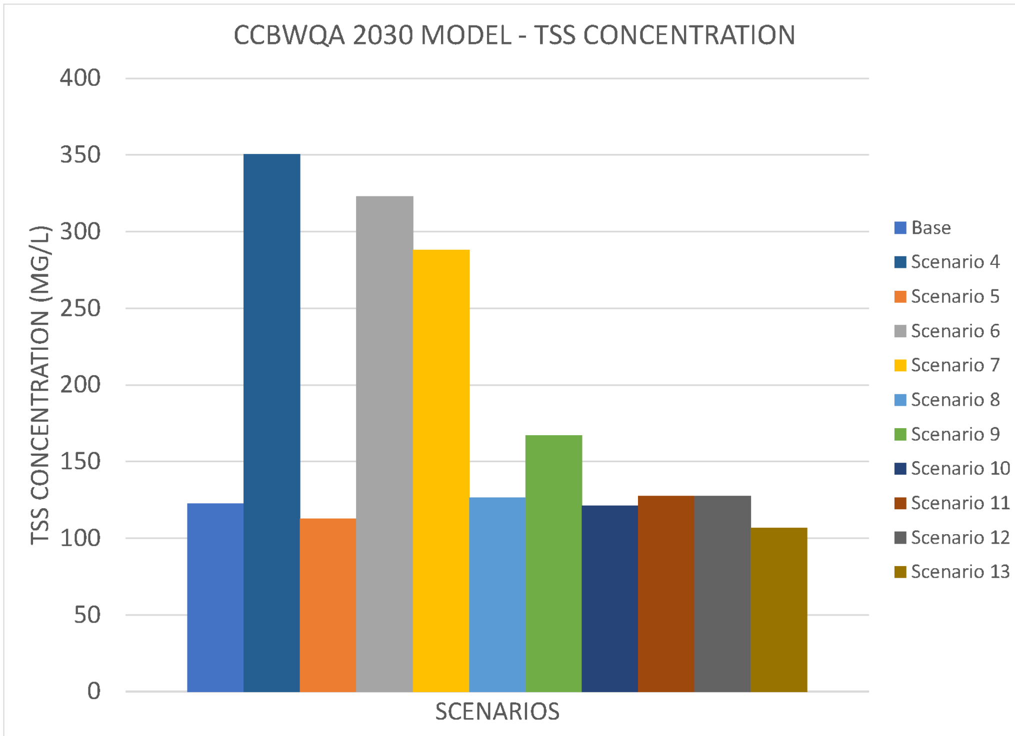


Figure 7 - Modeled TSS Concentration



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APPENDIX A

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Load and Concentration Results	Base_v2 Model				Scen004 Model				Scen005 Model				Scen006 Model				Scen007 Model			
Loadings	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN
Source	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR
Cherry Creek Surface Flow	14473	2845	9447	43356	27991	15730	21495	80410	17815	3146	10367	65972	31706	16238	22682	106792	31706	14413	21252	102499
Cottonwood Creek Surface Flow	4340	280	839	18568	5195	395	1132	20374	4647	281	853	21561	5503	396	1147	23377	5503	396	1136	23280
Other Surface Inflow	679	122	560	3520	903	123	685	4260	679	122	561	3525	935	123	703	4367	935	123	703	4367
Total Inflow	19491	3247	10846	65444	34090	16249	23312	105043	23141	3549	11781	91058	38144	16757	24532	134535	38144	14932	23092	130146
FWMC	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L
Cherry Creek Surface Flow	20.0	145	0.240	1.10	38.7	413	0.282	1.06	24.6	130	0.214	1.36	43.80	377	0.263	1.24	43.80	334	0.246	1.19
Cottonwood Creek Surface Flow	5.99	47.4	0.071	1.57	7.18	55.9	0.080	1.44	6.42	44.4	0.068	1.71	7.60	53	0.077	1.56	7.60	53	0.076	1.56
Other Surface Inflow	0.937	133	0.303	1.91	1.248	100	0.279	1.73	0.937	133	0.304	1.91	1.29	97	0.277	1.72	1.29	97	0.277	1.72
Total Inflow	26.9	123	0.205	1.23	47.1	351	0.251	1.13	32.0	113	0.187	1.45	53	323.1	0.237	1.30	53	287.9	0.223	1.25

Load and Concentration Results	Scen008 Model				Scen009 Model				Scen010 Model				Scen011 Model				Scen012 Model				Scen013 Model			
Loadings	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN
Source	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR	AF/YR	TON/YR	LB/YR	LB/YR
Cherry Creek Surface Flow	28756	5552	15261	92211	25101	6570	15323	70119	25929	4805	13694	84859	23680	4697	13141	68397	23680	4697	13141	68397	19173	3278	9967	49777
Cottonwood Creek Surface Flow	5353	346	1053	22956	5046	345	1049	20050	5203	334	1007	22651	5203	334	1007	22651	5203	334	1007	22651	4034	112	537	20224
Other Surface Inflow	906	123	687	4273	873	123	668	4159	852	123	657	4094	830	123	645	4020	830	123	645	4020	422	42	310	2000
Total Inflow	35015	6022	17001	119440	31019	7039	17040	94328	31984	5262	15358	111604	29713	5155	14793	95068	29713	5155	14793	95068	23629	3432	10815	72001
FWMC	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L	cfs	mg/L	mg/L	mg/L
Cherry Creek Surface Flow	39.72	142	0.195	1.18	34.67	193	0.224	1.03	35.81	136	0.194	1.20	32.71	146	0.204	1.06	32.71	146	0.204	1.01	26.48	126	0.191	0.95
Cottonwood Creek Surface Flow	7.39	48	0.072	1.58	6.97	50	0.076	1.46	7.19	47	0.071	1.60	7.19	47	0.071	1.60	7.19	47	0.071	1.60	5.57	20	0.049	1.84
Other Surface Inflow	1.25	100	0.279	1.73	1.21	104	0.281	1.75	1.18	106	0.284	1.77	1.15	109	0.286	1.78	1.15	109	0.286	1.78	0.58	73	0.271	1.74
Total Inflow	48	126.5	0.179	1.25	43	166.9	0.202	1.12	44	121.0	0.177	1.28	41	127.6	0.183	1.18	41	127.6	0.183	1.14	33	106.8	0.168	1.12

Change Relative to Base_v2	Scen004 - SCH only				Scen005 - WWTF only				Scen006 - SCH & WWTF				Scen007 - SCH, WWTF, & PRF				Scen008 - SCH, WWTF, PRF, & LID			
Loadings	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN
Source	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
Cherry Creek Surface Flow	93	453	128	85	23	11	10	52	119	471	140	146	119	407	125	136	99	95	62	113
Cottonwood Creek Surface Flow	20	41	35	10	7	0	2	16	27	42	37	26	27	42	35	25	23	24	25	24
Other Surface Inflow	33	1	22	21	0	0	0	0	38	1	26	24	38	1	26	24	34	1	23	21
Total Inflow	75	400	115	61	19	9	9	39	96	416	126	106	96	360	113	99	80	85	57	83
FWMC	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
Cherry Creek Surface Flow	93	186	18	-4	23	-10	-11	24	119	161	10	12	119	131	3	8	99	-2	-19	7
Cottonwood Creek Surface Flow	20	18	13	-8	7	-6	-5	8	27	12	8	-1	27	12	7	-1	23	0	2	0
Other Surface Inflow	33	-24	-8	-9	0	0	0	0	38	-27	-9	-10	38	-27	-9	-10	34	-25	-8	-9
Total Inflow	75	186	23	-8	19	-8	-9	17	96	164	16	5	96	135	9	2	80	3	-13	2

Change Relative to Base_v2	Scen009 - SCH & LID				Scen010 - 008 with Flow eff X 2				Scen011 - 010 w/ Base Parker WWTF				Scen012 - 011 w/ WWTF TN Capped				Scen013 - 012 w/ Eff Fac on all Dev			
Loadings	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN	Flow	TSS	TP	TN
Source	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
Cherry Creek Surface Flow	73	131	62	62	79	69	45	96	64	65	39	58	64	65	39	58	32	15	6	15
Cottonwood Creek Surface Flow	16	23	25	8	20	19	20	22	20	19	20	22	20	19	20	22	-7	-60	-36	9
Other Surface Inflow	29	1	19	18	26	1	17	16	22	1	15	14	22	1	15	14	-38	-66	-45	-43
Total Inflow	59	117	57	44	64	62	42	71	52	59	36	45	52	59	36	45	21	6	0	10
FWMC	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
Cherry Creek Surface Flow	73	33	-6	-7	79	-6	-19	9	64	1	-15	-4	64	1	-15	-8	32	-13	-20	-13
Cottonwood Creek Surface Flow	16	6	7	-7	20	0	0	2	20	0	0	2	20	0	0	2	-7	-57	-31	17
Other Surface Inflow	29	-22	-7	-8	26	-20	-6	-7	22	-18	-6	-7	22	-18	-6	-7	-38	-45	-11	-9
Total Inflow	59	36	-1	-9	64	-1	-14	4	52	4	-11	-5	52	4	-10	-8	21	-13	-18	-9