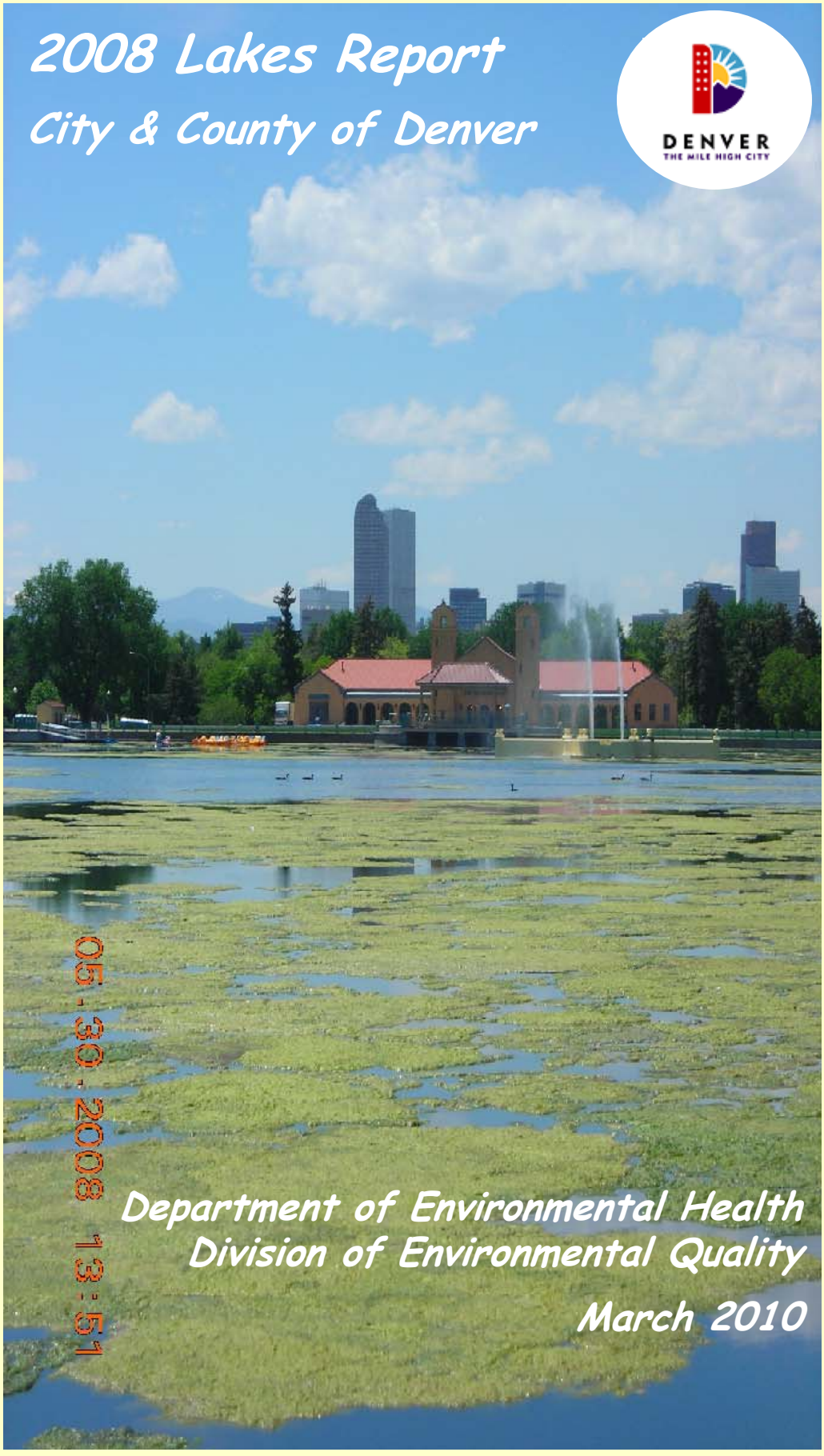
2008 Lakes Report

City & County of Denver



Ferril Lake May 2008

Department of Environmental Health
Division of Environmental Quality

March 2010

2008 Lake Report

City & County of Denver

Department of Environmental Health - Environmental Quality Division

(March 2010)

2008 Lake Report
City and County of Denver
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Abstract

This report summarizes findings based on the Denver Department of Environmental Health's Environmental Quality Division's (EQD) 2008 annual summer lake sampling effort. Unlike previous reports, the 2008 version has limited discussion and text, focusing on a highlight of issues in each lake, with brief discussion of the foremost recommended action(s) for each lake. The findings are presented in one table to simplify use for readers. A more thorough discussion of recommendations was provided in the 2007 Annual Report, and will be re-visited in the 2009 Annual Report.

The highlighted issues ranged from limited water clarity to fish consumption advisories for two lakes. The majority of issues are related with high nutrient levels and excessive growth of algae and/or vegetation. These factors can result in high pH (photosynthesis drives pH levels up), extreme values for dissolved oxygen (D.O.; photosynthesis increases D.O. while algae decomposition decreases it), and elevated copper levels (algae chemical control applications). Lakes with excessive algae-driven productivity typically exhibit high chlorophyll-a levels, which is a measure of phytoplankton (algae suspended within the water column) activity in the water column. The City Ditch Lakes are good examples exhibiting many of these conditions. Lakes in Denver with elevated pH and highly variable D.O. combined with ***low*** chlorophyll-a typically have excessive amounts of submerged-rooted vegetation and/or macro-filamentous algae (e.g., Parkfield-vegetation; Ferril-macro-algae).

Elevated metals concentrations were found in the water column of a few lakes (arsenic-Berkeley, iron-Sloans and Harvey, selenium-Lollipop). Elevated metals have also been identified in lake sediments, most notably in Vanderbilt which had served as an industrial holding pond for a few decades up until early 1990's. ***Please see Table 4 for specific information on lakes of interest***.

All data from the 2008 mid-summer trend sampling visits is provided in the appendix. Long term data is available through the EQD. Requests for data and comments regarding this report and how the EQD can better meet your needs regarding lake monitoring can be made by contacting the Department of Environmental Health's EQD at 720-865-5480.

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2008 Annual Lake Report

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List of Acronyms & Abbreviations

AD – Agricultural Ditch
BMP – best management practice
CCD – City and County of Denver
CD – City Ditch
CDPHE – Colorado Department of Public Health and Environment
DEH – Denver Department of Environmental Health
DEQ – Division of Environmental Quality (within the DEH)
DI – de-ionized water
DPR – Denver Department of Parks and Recreation
DPW – Denver Department of Public Works
DWD – Denver Water Department
DWMD –Denver Wastewater Management Division (within the DPW)
DOC – dissolved organic carbon
DO – dissolved oxygen
E. coli – Escherichia coli
OP - orthophosphate
PAH – polycyclic aromatic hydrocarbon
PEC – probable effect concentration
RMD – Rocky Mountain Ditch
SP – South Platte River
STL – Severn Trent Laboratory, Inc.
TDP – temperature/dissolved oxygen profile
TDS – total dissolved solids
TIN – total inorganic nitrogen
TKN – total kjeldahl nitrogen
Total-P – total phosphorus
TP – total phosphorus
TREX – Transportation Expansion Project on Interstate-25
TSI – Carlson's trophic status index
TSS – total suspended solids
UDFCD – Urban Drainage and Flood Control District
USEPA – United States Environmental Protection Agency
VOC – volatile organic compound

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I. INTRODUCTION

The Denver Department of Environmental Health's (DEH) Environmental Quality Division (EQD) monitors the quality of the City and County of Denver's (CCD) lakes. The core of the EQD lake monitoring effort is the mid-summer sampling of CCD's lakes, the goal of which is to assess their status in terms of public and environmental health. In 2008, this entailed the sampling of 16 CCD Lakes (**Table 1**, **Fig 1**). Additional sampling efforts address issues of specific concern (e.g., change in water supply source, seasonal changes in plankton productivity). Annual sampling allows the CCD to:

- assess the long term status of lake water and sediment quality;
- determine trends;
- assess management actions; and
- provide recommendations for future actions that will benefit water quality, aquatic and riparian habitat, and recreational opportunities.

This report summarizes findings from the 2008 sampling year.

Unlike previous reports, the 2008 report is meant to provide a succinct coverage of the primary issues for each of the lakes covered in the monitoring program. Field and laboratory procedures will not be provided in this report but are available from: (1) previous Lakes Reports (DEH 2005 and 2006, respectively); (2) the DEH *TTQuality Assurance Project Plan (QAPP) and Sampling and Analysis Plan* (SAP) (DEH 2006), or (3) the EQD upon request. Information concerning data management and quality assurance/quality control (QA/QC) is also provided in more detail in the DEH QAPP-SAP.

Section 2 presents the 2008 results in a table format with a summary of noteworthy findings and highlights based on the 2008 monitoring. The table is organized by lake groups which are based on the primary water source during the summer irrigation season (**Table 1**). These groups include Rocky Mountain Ditch, City Ditch, Agricultural Ditch (Salisbury Lateral), South Platte River; urban runoff, and groundwater.

Tables and a figure within Section 1 provide additional background information regarding the CCD Lakes and the monitoring program. **Table 1** and **Figure 1** provide basic characteristics of the lakes that are routinely monitored and their location within the CCD, respectively; **Table 2** provides 2008 sample dates; and **Table 3** provides a list of parameters typically assessed during the mid-summer sample visits.

The appendices include data summaries from 2008, details on QA/QC samples, references, and a glossary of water quality terms.

Table 1. Lake groups based on the primary water source within the City and County of Denver.

Subsidy Source / Lake	Surface AcresPP[1/]	Acre Feet[2/]	Perimeter (ft)	Primary Water Source Origin
Rocky Mountain Ditch				Clear Creek in Golden
Berkeley	36	235	4,810	
Rocky Mountain	24	250	4,870	
Sloans	176	790	14,780	
City Ditch				Recycled water from Denver Water
Grasmere	16	85	4,350	
Smith	18	115	3,230	
Ferril	24	120	4,590	
Duck Pond	5	24	1,935	
Agricultural Ditch (Salisbury Lateral)				Clear Creek in Golden
Harvey	5	26	2,030	
Garfield	5	35	2,820	
Huston	14	40	3,190	
South Platte River				South Platte River @ Florida Ave., Denver
Overland Pond	2	8	1,060	
AquaGolf	11	27	2,740	
Groundwater				
Vanderbilt	4	26	1,710	Possibly groundwater
Lollipop	4	18	2,210	Groundwater from north side of Garland Park
Urban Runoff[3/]				
Barnum	4	17	2,320	Weir Gulch – urban runoff
Parkfield	10	25	4,860	Storm runoff

1/ Both acreage and perimeter only include surface water acreage, does not include islands
2/ This is an estimate based on bank full conditions and limited bathymetric measurements
3/ While all lakes receive some amount of urban runoff, it is the primary water subsidy year round for these lakes

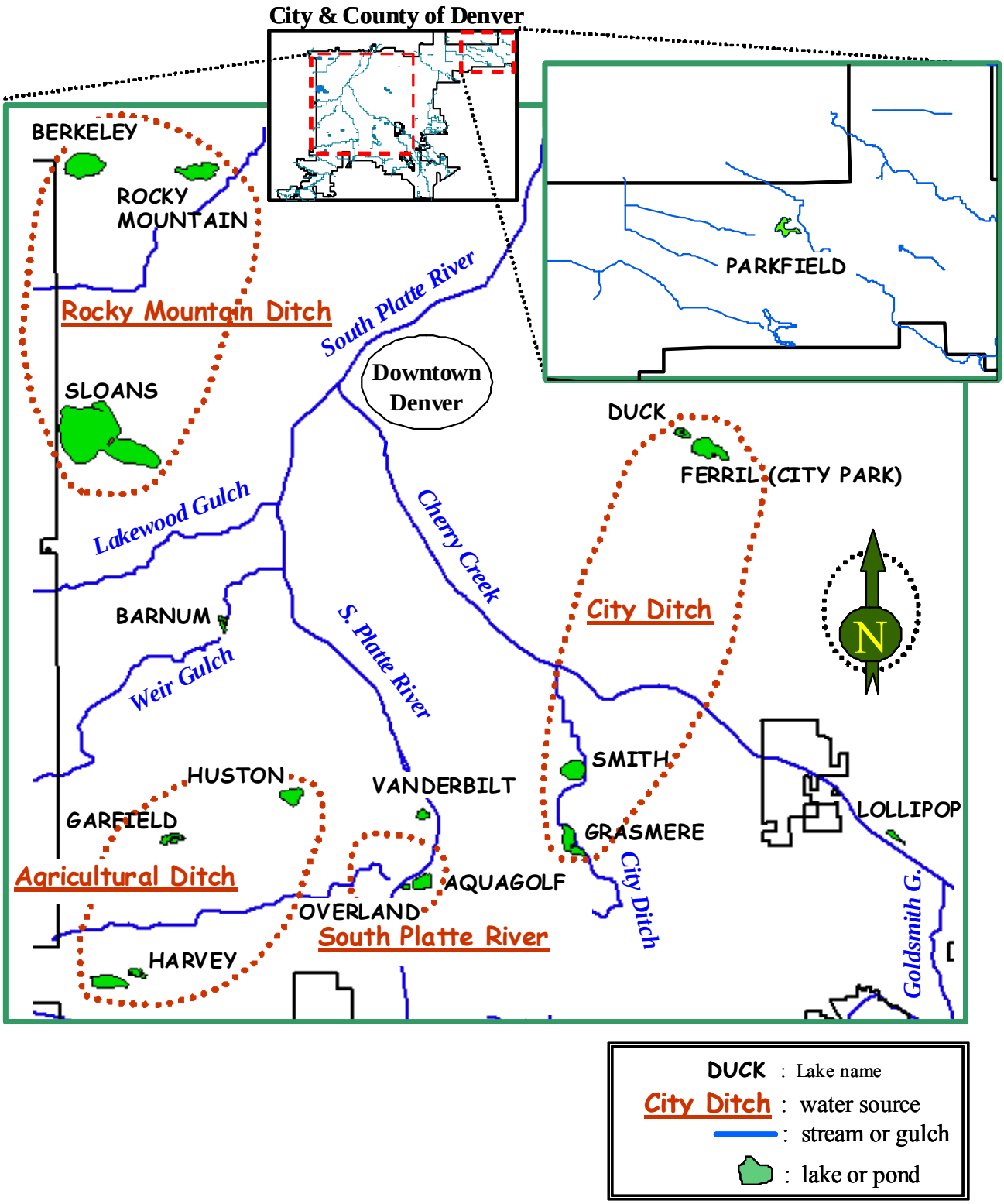

Figure 1. Regularly sampled lakes within the City and County of Denver's summer monitoring program.

Table 2. **Denver lakes sampling dates in 2008**. Seventeen "lakes" were sampled at least once in 2008 to assess mid-summer conditions. Because of its relatively high recreational use, Sloans Lake bacteria concentrations were sampled weekly from May 23rd through September 12th.

Subsidy Source / Lake	Sample Date	Additional Sample Visits in 2008
Rocky Mountain Ditch		
Berkeley	July 22	None
Rocky Mountain	July 22	None
Sloans	July 24	4/17/08, 10/16/08
City Ditch		
Grasmere	August 5	10/10/08
Smith	August 5	10/10/08
Ferril	August 7	3/10/08, 6/24/08, 8/19/08, 10/20/08
Duck Pond	August 7	None
Agricultural Ditch		
Harvey	July 29	None
Garfield	July 29	None
Huston	July 31	None
South Platte River		
Overland Pond	August 12	None
AquaGolf	August 12	None
Groundwater & Urban Runoff		
Vanderbilt	July 17	None
Lollipop	July 15	None
Urban Runoff		
Barnum	July 15	None
Parkfield	July 31	None
Miscellaneous		
Wolcott Lake	August 14	Upon request from PW[b/] and Denver residents

a/ Denver Department of Parks and Recreation
b/ Denver Public Works Department

Table 3. Analytes routinely assessed during mid-summer monitoring visits.

UUField Analytes[1]	Basic Lab Analytes[2]	Contract Lab Analytes[3]
►pH	►Alkalinity	►Dissolved metals:
►Temperature	►Hardness	-Ag, Al, As, Cd,
►Dissolved Oxygen	►Nutrients	Cu, Cd, Cr, Fe,
►Specific conductivity	-Total ammonia[4]	Mn, Mo, Ni,
►Secchi depth	-Nitrite[4]	Pb, Se, Zn
►Temperature- dissolved oxygen profile	-Nitrate[4]	
	-Total phosphorus[4]	►Total Metals[4]:
	-Ortho-phosphate	-Al, Hg, Mn
	-Total Kjeldahl Nitrogen[4]	
	►Total solids	
	►Total dissolved solids	►Total Recoverable Metals
	►Chloride	-As, Cr, Fe
	►Sulfate	
	►Bacteria -*E. coli*	
	►Chlorophyll-a[5]	

1/ Measured with meters or sample equipment directly from lake
2/ Samples collected and delivered to Denver Public Works' Wastewater Management Divisions Laboratory for analysis
3/ Samples collected and delivered to Evergreen Analytical Laboratory (Wheat Ridge, CO) for analysis
4/ Analytes also assessed in sediments by Evergreen Analytical Laboratory
5/ Processed by DEH personnel and delivered to Denver Water Board Laboratory for analysis

II. FINDINGS

This report will provide a very succinct discussion of the primary issues, findings, and some recommendations in a single table (**Table 4**). Unlike previous reports, there will not be extra detail or discussion other than the basic findings and issues. The purpose of this is to provide all pertinent information to the reader in a single, user friendly format. Additional information can be garnered from tables compiled in the appendix that list results from the 2008 sampling efforts (**Appendix I**). More thorough, specific recommendations will be provided in the 2009 report, which is scheduled for completion May 2010. Recommendations are also provided via plan development processes and as requested.

For information beyond this report, please feel free to contact the EQD via the CCD 3-1-1 phone number (720-913-1311 from outside of Denver) or by email to: alan.polonsky@denvergov.org.

Table 4. Summary of issues, data findings, observations, and some initial recommendations based on the 2008 monitoring effort.

Lake • 2008 Notable Issues	**2008 Sample Event Summary**
ROCKY MOUNTAIN DITCH	
Berkeley Lake • FCA • arsenic • bacteria (*E. coli*)	Sampled 7/22/08: Maintained relatively good water clarity as in past years (*secchi depth* ranged from 4 to 5.5ft). *Dissolved oxygen* (D.O.) continues to be acceptable, but consistently ranges from 5 to 6mg/L-ORR_2 (2005-2008) suggesting it is prone to potential oxygen deficit in fall turnover. Chronic issue with elevated water column and sediment arsenic concentrations. No change in the Hg-based *fish consumption advisory* (FCA) for bass (no new sampling by the state). *Chlorophyll-a* levels suggest relatively low phytoplankton productivity (consistent with marginal D.O. measurements). Elevated bacteria (*E. coli*) in 2008 which was also recorded in 2004 and 2001 (in-between years exhibited minimal to no measureable *E. coli* in the water column). ***More frequent sampling for bacteria should be performed to better characterize E. coli concentrations; aeration would be an effective means to improve on marginal D.O. levels.***
Rocky Mountain Lake • FCA • pH	Sampled 7/22/08: *Submerged vegetation* prevalent along edges and in the shallows but not noted in the moderate depths (>~6ft). Water clarity less than typically seen in previous years (secchi depth of 4ft) but still relatively good when compared to other Denver Lakes. D.O. level was consistent with relatively high phytoplankton activity (based on chlorophyll-a concentrations). The *pH* was high, as is typical in lakes with high *productivity* (plankton and vegetation). The mercury-based FCA is still in place due to no new information on fish tissue mercury concentrations. ***More efficient treatment and control of algae will help maintain pH levels below the water quality benchmark (9.0 standard units).***
Sloans Lake • bacteria generally acceptable • dissolved oxygen • algae • water clarity • iron	Annual summer sample event 7/24/08; weekly bacteria sample events from 5/15/08 through 9/25/08; Monthly sampling for chlorophyll-a and nutrients (May through October). **Annual Summer Findings**: High phytoplankton productivity coupled with high suspended solids (plankton and sediment) resulting in chronically low water clarity (shallow secchi depth reading). The high organic load on the lake bottom likely contributed to marginal D.O. levels. Iron and aluminum were measured at high levels in the water column, as they typically are in Sloans Lake. **Weekly Bacteria**: *E. coli* levels were acceptable by *swim beach criteria* (*E. coli* levels <235 colonies/100ml; CDPHE 1998) on 19 of 20 sample events. The one exceedance of the criteria occurred on 8/7/08, and had been preceeded by light to moderate rain events for four days. Follow-up sampling demonstrated that bacteria counts returned to acceptable levels within a week of the elevated findings. **Monthly Sampling**: Found a strong relationship between *total phosphorus* (TP) and chlorophyll-a (indicator of phytoplankton activity) with a peak in productivity in June coinciding with the lowest water clarity (secchi depth) for the growing season. There was no evident relationship between pH and chlorophyll-a or with TP.

Table 4. Summary of issues, data findings, observations, and some initial recommendations based on the 2008 monitoring effort.

Lake • 2008 Notable Issues	**2008 Sample Event Summary**
CITY DITCH	
Grasmere Lake • nutrients • algae • copper	Summer monitoring event on 8/5/08; follow-up sample event 10/10/08: A significant factor for all the City Ditch Lakes is that the source water is *recycled water*, which is high in *nitrogen*. Because it is the most upstream lake and therefore closest to the source, it was not surprising that Grasmere Lake had the highest *inorganic nitrogen* content in 2008[i]. The excessive amount of nitrogen, while not toxic, can further stimulate algal and vegetative growth. Plentiful filamentous algae and submerged vegetation resulted in low phytoplankton activity (and subsequently low chlorophyll-a measurements) and good water clarity. Effective control of filamentous algae and vegetation following this sample event resulted in an increase in phytoplankton activity (increased chlorophyll-a and decreased water clarity). Chemical treatments to control algae and vegetation resulted in relatively high copper concentrations. ***More timely algae control efforts will result in lower quantities of chemicals needed (and lower water column copper concentrations). Additionally, future pilot tests with bacteria (to compete with algae for nutrients) may decrease the amount of chemicals needed for control of algae.***
Smith Lake • nutrients • phytoplankton/ Chlorophyll-a • pH • ammonia	Sampled 8/5/08: Most notable issue was significant phytoplankton bloom resulting in extremely high chlorophyll-a measurement, high pH, and for Smith Lake, relatively low water clarity. The elevated pH also influences the form of ammonia that is prevalent in the water column. At elevated pH, the un-ionized ammonia form becomes increasingly prevalent. This is significant in that this form is of more concern for toxicity to aquatic life. While there were no notable impacts to aquatic life, un-ionized ammonia concentrations did exceed water quality benchmarks. ***More efficient control of algae and plankton in the future will help address chlorophyll-a, phytoplankton, pH, and un-ionized ammonia levels, and will improve conditions for aquatic life. Additional management alternatives could be considered to ameliorate high nutrient levels (e.g., wetlands).***
Ferril Lake • pH • algae • phytoplankton/ chlorophyll-a • nutrients • copper	Summer monitoring event 8/5/08; Sampled bi-monthly from March through October to assess productivity issues: **Annual Summer Findings**: Major filamentous algae bloom (*Cladophora* spp) in late spring/early summer was the focus of high maintenance issues. When the filamentous algae was eventually brought under control in late July, the phytoplankton immediately proliferated (due to decreased competition for nutrients and light). This resulted in Extremely high chlorophyll-a measurements (highest among Denver Lakes in 2008 and highest for Ferril Lake 2001-2008). As in Grasmere Lake, the intensive algae control measures resulted in relatively high copper concentrations. **Productivity monitoring**: Included 4 additional sample events focusing on nutrients and chlorophyll-a. Chlorophyll-a levels were extremely low combined with high water clarity in the spring coinciding with the filamentous algae bloom;

Table 4. Summary of issues, data findings, observations, and some initial recommendations based on the 2008 monitoring effort.

Lake • 2008 Notable Issues	**2008 Sample Event Summary**
Ferril Lake (continued)	following control of filamentous algae, extreme phytoplankton bloom reversed conditions with the highest chlorophyll-a measurements to date in Ferril Lake combined with poor water clarity. The pH levels exceeded water quality benchmarks and were extremely high in the spring and early summer while filamentous algae blooms proliferated. ***More efficient algae control efforts will decrease water column copper concentrations, lower pH levels, and improve water clarity.***
Duck Lake • ammonia • dissolved oxygen • algae • vegetation • copper	Sampled 8/7/08: High productivity of submergent vegetation and filamentous algae dominated in the spring and early summer. A chemical treatment prior to the annual sample event resulted in near 100% removal of all vegetation and algae; subsequent conditions included: the deepest secchi depth (best water clarity) and lowest chlorophyll-a concentration on record for Duck Lake, an *oxygen deficit* throughout the water column, and copper concentrations above water quality benchmarks. This chemical treatment demonstrated the benefits and drawbacks of near complete removal of vegetation and algae. ***In the future, objectives of algae control efforts should be to establish a healthy, acceptable balance of algae, vegetation, and water clarity which will be supportive of aquatic life and other uses. Additional management activities that will enhance water flow and nutrient mitigation must also be considered a significant priority if and when renovation of the lake becomes reality.***
AGRICULTURAL DITCH	
Harvey Lake • iron • arsenic	Sampled 7/29/08: minimal filamentous algae or submergent vegetation but moderately high phytoplankton growth (shallow secchi depth, average chlorophyll-a by Denver standards). Two dead carp were noted on the sample day. The lake was a foot below bankfull, indicating even worse water exchange than normal (the water path from inflowing water to discharge bypasses most of the lake). The arsenic level was below state water quality benchmarks, but was still relatively high compared to other Denver lakes. The iron level was above state water quality benchmarks, but was a significant improvement from 2007 concentrations. It is not expected that either the arsenic or iron pose an environmental risk. Dissolved oxygen levels were marginal. ***Given the poor water path through the lake, water column mixing or aeration could be an effective approach to improve water quality.***
Garfield Lake • dissolved oxygen • iron	Sampled 7/29/08: There is minimal water flowing to the lake, but still over-bankfull due to a malfunctioning outlet structure (DPR and DPW are working on fixing the structure). Impacts of the poor water exchange are reflected in the marginal dissolved oxygen readings and continued poor water clarity (shallow secchi depth). Although relatively low compared to other Denver lakes, the chlorophyll-a level was the highest recorded in Garfield Lake (2001-2008). ***Primary need for the lake is to fix the outlet structure; secondary considerations: aeration and or water column mixing could make a significant difference in lake condition.***

Table 4. Summary of issues, data findings, observations, and some initial recommendations based on the 2008 monitoring effort.

Lake • 2008 Notable Issues	**2008 Sample Event Summary**
Huston Lake (Wetland) • chlorophyll-a • water clarity	Sampled 7/31/08: Slightly below bankfull with moderate inflow (~50gpm) but no outflow. Relatively high chlorophyll-a for Denver lakes, and highest recorded in Huston Lake (2001-2008) resulted in relatively poor water clarity (shallow secchi depth) compared with previous years. This is likely a result of controlling vegetation that competes with phytoplankton for available nutrients and light penetration. ***A more balanced vegetation/algae control approach would benefit overall wetland quality, and improve water clarity.***
SOUTH PLATTE RIVER	
Overland Pond • pH	Sampled 8/12/08: Pond was slightly below bankfull with an indeterminate amount of outflow (outlet is below water surface). There was minimal filamentous algae and vegetation growth, but considerable amount of phytoplankton. Never the less, the chlorophyll-a was the lowest on record for the pond, but still relatively high among Denver Lakes. The chronically high plankton productivity resulted in elevated pH values. ***Efficient and/or alternative algae control measures could help mediate this problem. Short of a dramatic renovation of the park and pond, logistical issues limit management actions possible in this case. Alternative actions (e.g. floating islands, shoreline wetlands) should be considered.***
AquaGolf Lake (Wetland) • pH • iron	Sampled 8/12/08: This shallow, large wetland was one foot below bankfull on the day of sampling (maximum depth of 4 ft-at the west end; 2.5 feet throughout much of the middle of the wetland). The water column was a cloudy green color with minimal algae and vegetation growth. Recent rains had limited the need for irrigation at the golf course, resulting in longer *water residence time*. The chronically high plankton growth results in high pH levels. The elevated iron could be attributable to chemical interactions at the sediment-water interface. It is not expected that these iron levels are posing an environmental or human health issue given the uses of the wetland and the fact that this is total iron[ii] (versus dissolved). ***Alternative approaches to algae control should be considered to address elevated pH; DEH will analyze for dissolved iron starting in future efforts to better characterize iron concentrations***.
GROUNDWATER	
Barnum • *E. coli* • Dissolved oxygen	Sampled 7/15/08: Barnum Lake was bankfull on the sample day, all mudflats around the islands perimeter were inundated which appeared to influence bird activity. Sandpipers and avocets were not seen, although they had typically been observed on previous annual summer monitoring events. Other bird species were noted (killdeer, snowy egret, red wing black birds). *E. coli* levels (bacteria) were below detection, as they were in 2007. D.O. conditions also continued to suggest better conditions than in previous years. These improvements over the past three years are concurrent with operational adjustments in storm basin management by DPW. ***Some management actions that could address challenges posed by the source water conditions (elevated sediments, nutrients, and bacteria during storm events) include aeration, water column mixing/moving options, in addition to upstream (Weir Gulch) watershed Best Management Practices (e.g., wetlands, riparian buffers)***

Table 4. Summary of issues, data findings, observations, and some initial recommendations based on the 2008 monitoring effort.

Lake • 2008 Notable Issues	**2008 Sample Event Summary**
Vanderbilt Lake • Dissolved oxygen • Sediment contaminants	Sampled 7/16/08: Bankfull at the time of sampling; minimal filamentous algae observed; pondweed noted along lake margins. Water column was a rusty-brown color, suggesting species beyond the typically dominant blue-greens, or green algae phyla seen in other Denver Lakes. This is typical of Vanderbilt from previous summer sample events. The dissolved oxygen profile was also typical of what has been measured in previous years with adequate levels in the upper 3 to 4 feet and near *anoxic* conditions from 5 feet to the bottom (8 or 9 feet). Use of the lake as an industrial pond during the 70's and 80's resulted in a buildup of *organic contaminants* and metals in the sediment. Microbes that breakdown organic contaminants use up available oxygen in the bottom layers of the water column. Mitigation is planned for the lake. Current plans call for active aeration of sediments to expedite decomposition of the organic contaminants. The cleanup has been on hold due to funding issues. ***The planned mitigation should result in improved dissolved oxygen concentrations in the lake.***
URBAN RUNOFF	
Lollipop Lake • Selenium	Sampled 7/15/08: Lake was bankfull and had been chemically treated for algae control within two weeks of sample event. Water was very clear with secchi depths to the bottom (>6.5 feet). Some *benthic algae* evident along the lake margins. The algae treatment eliminated most phytoplankton activity and resulted in an extremely low chlorophyll-a measurement. The selenium concentration was below the state water quality benchmark, but was the highest recorded among Denver lakes. This is due to elevated selenium in the source water (groundwater). It is worth noting that copper concentrations were well below state water quality benchmarks even with recent algae control efforts. ***While Lollipop would benefit from a variety of in-lake management options, it currently meets water quality benchmarks.***
Parkfield Lake (Wetland) • pH	Sampled 7/31/08: Depths throughout the wetland/detention pond were 2.5 to 3 feet and there was rooted-submerged vegetation throughout (*Myriophyllum* spp., *Elodea* spp, *Potamogeton* spp, *Ceratophyllum demersum*, and duckweed-probably *Lemna minor*). Much of the vegetation was covered with *epiphytic algae* (attached to the plants). The wetland had elevated pH in the middle and northeast bay, but relatively neutral pH in the southwest region. Dissolved oxygen levels were considerably better than in 2007 and were at good levels for aquatic life. Tadpole activity was noted throughout the wetland as were a variety of bird species. While the productive vegetation community suggests issues for a lake, for a wetland, this provides ideal conditions for a variety of wildlife. It also provides opportunities for settling of suspended solids and associated contaminants (nutrients, metals) that enter during storm events. ***These can be seen as positive attributes for a water body that was designed for storm water retention.***

[i] instream dynamics within the City Ditch can result in decreasing nitrogen concentrations as the water travels downstream to other lakes.

[ii] Iron in the dissolved state is more bioavailable, and thus, more of a concern considering toxicity to aquatic life (Phippen et al. 2008). DEH sampling analysis did not include dissolved iron in 2007 and 2008 (or 2009), but will include this in future sample efforts to better characterize this issue.

APPENDICES

A. Annual Mid-summer Data

B. Quality Assurance/Quality Control

C. References

D. Glossary

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APPENDIX A

DATA

Annual Mid-summer Sample Results

Table A1. Physicochemical results for Denver Lakes, July/August 2008. Bolded values potentially exceed CDPHE water quality benchmarks.

lake	date	pH (su)	Temp (^{o}C)	D.O.[a/] (mg/L-O_2)	Cond (uS/cm)	Alk (mg/L-$CaCO_3$)	Hard	TDS (mg/L-C)	TSS (mg/L-C)	Cl (mg/L)	SO_4 (mg/L)
Rocky Mountain Ditch											
Berkeley	7/22/08	8.4	25.1	5.3	667	177	130	405	J 4.0	69	50
Rocky Mntn	7/22/08	**9.5**	26.5	8.0	609	160	49	359	5.0	63	50
Sloans	7/24/08	8.5	24.0	**4.9**	482	142	120	387	66.7	72	40
City Ditch											
Grasmere	8/5/08	7.9	24.0	6.6	896	88	180	555	J **4.0**	96	146
Smith	8/5/08	**9.6**	25.5	13.5	848	58	130	473	18.8	100	149
Ferril	8/7/08	**9.5**	24.3	19.2	820	62	120	495	21.2	94	143
Duck	8/7/08	7.6	25.2	**2.0**	887	103	150	530	J **2.5**	98	144
Agricultural Ditch											
Harvey	7/29/08	8.3	24.2	5.6	816	122	130	466	28.8	161	50
Garfield	7/29/08	8.7	24.6	7.0	379	62	80	223	22.0	52	50
Huston	7/31/08	8.2	25.4	7.6	341	89	93	170	11.8	31	50
South Platte River											
Overland	8/12/08	**9.2**	23.8	10.9	474	91	150	273	13.6	35	62
AquaGolf	8/12/08	**9.5**	25.0	12.3	507	106	160	303	70.0	43	61
Groundwater											
Lollipop	7/15/08	7.4	22.6	6.4	1348	193	420	856	J 2.5	155	307
Vanderbilt	7/17/08	8.2	25.6	8.9	1321	215	310	826	16.0	204	176
Urban Runoff											
Barnum	7/15/08	8.1	22.2	9.8	800	186	120	464	30.7	71	106
Parkfield	7/31/08	9.0	23.6	5.0	982	91	120	525	< 5.0	223	50
min:		7.4	22.2	2.0	341	58	49	170	2.5	31	40
max:		9.6	26.5	19.2	1348	215	420	856	70.0	223	307
15th percentile:		8.0	23.7	5.1	476	69	100	281	4.0	45	50
85th percentile:		9.5	25.5	11.9	960	184	175	549	30.2	160	148
median:		8.4	24.5	7.3	808	105	130	465	14.8	83	62

a/ DO=dissolved oxygen; Cond=specific conductivity; Alk=alkalinity; Hard=hardness; TDS=total dissolved solids; TSS=total suspended solids

Table A2. Nutrient, bacteria, and associated parameter results for Denver Lakes, July/August 2008. Bolded values exceed CDPHE water quality benchmarks.

lake	date	NH_4 [b/]	UIA	NO_2	NO_3	TIN	TKN	Org-N	T-P	O-P	DOC	Chlor-a	Secchi Depth	Ecoli	Fecal
		(mg/L-N)							(mg/L-P)		(mg/L)	(ug/L)	(in)	(#col/100ml)	
Rocky Mountain Ditch															
Berkeley	7/22/08	< 0.10	< 0.011	< 0.01	< 0.20	< 0.31	< 1.00	< 0.90	0.18	< 0.11	8.5	13.3	56	**570**	**760**
Rocky Mntn	7/22/08	< 0.10	< 0.061	< 0.01	< 0.20	< 0.31	< 1.00	< 0.90	< 0.08	< 0.10	14.6	52.5	48	< 10	< 10
Sloans	7/24/08	0.34	0.048	< 0.01	< 0.20	< 0.55	1.93	1.59	0.21	0.11	12.1	77.0	9	< 10	< 10
City Ditch															
Grasmere	8/5/08	0.36	0.025	0.23	9.70	10.29	< 1.55	< 1.19	0.12	< 0.10	8.0	2.7	48	100	100
Smith	8/5/08	0.39	**0.291**	0.21	5.06	5.66	2.90	2.51	0.16	< 0.10	7.5	191.5	21	< 10	< 10
Ferril	8/7/08	< 0.10	< 0.065	0.27	6.79	< 7.15	2.59	2.49	0.14	< 0.10	8.4	204.1	21	30	**210**
Duck	8/7/08	0.81	0.018	0.49	3.71	5.01	2.29	1.48	0.43	0.38	8.9	2.2	84	50	70
Agricultural Ditch															
Harvey	7/29/08	< 0.10	< 0.010	< 0.01	< 0.20	< 0.31	1.40	1.30	0.13	< 0.10	13.7	41.4	13	100	**260**
Garfield	7/29/08	< 0.10	< 0.026	< 0.01	< 0.20	< 0.31	< 1.00	< 0.90	0.10	< 0.10	8.2	31.3	15	60	170
Huston	7/31/08	< 0.10	< 0.008	< 0.01	< 0.20	< 0.31	1.12	1.02	0.89	0.66	11.9	56.2	24	**140**	160
South Platte River															
Overland	8/12/08	< 0.10	< 0.045	0.04	0.55	< 0.69	1.50	1.40	0.55	0.41	6.5	53.8	24	< 10	< 10
AquaGolf	8/12/08	< 0.10	< 0.079	< 0.01	< 0.20	< 0.31	2.20	2.10	0.48	0.33	8.6	156.0	10	< 10	< 10
Groundwater															
Lollipop	7/15/08	< 0.10	< 0.001	< 0.01	0.22	< 0.33	< 1.00	< 0.90	< 0.08	< 0.08	4.4	1.3	70	10	140
Vanderbilt	7/17/08	< 0.13	< 0.011	< 0.01	< 0.20	< 0.34	2.13	2.00	0.10	< 0.08	15.2	56.3	23	50	40
Urban Runoff															
Barnum	7/15/08	< 0.12	< 0.007	< 0.01	< 0.31	< 0.44	1.77	1.65	0.21	< 0.08	9.7	48.8	15	< 10	80
Parkfield	7/31/08	< 0.10	< 0.051	< 0.01	< 0.20	< 0.31	1.18	1.08	0.24	0.15	16.9	3.1	34	10	30
min:		< 0.10	0.001	< 0.01	< 0.20	< 0.31	< 1.00	< 0.90	< 0.08	< 0.08	4.4	1.3	9.3	10	10
max:		0.81	0.291	0.49	9.70	10.29	2.90	2.51	0.89	0.66	16.9	204.1	84.0	570	760
15th percentile:		< 0.10	< 0.009	< 0.01	< 0.20	< 0.31	< 1.00	< 0.90	0.10	< 0.08	7.7	2.8	13.7	10	10
85th percentile:		0.35	0.064	0.23	4.72	5.50	2.27	2.08	0.47	0.37	14.3	136.3	54.1	100	200
median:		< 0.10	0.025	0.01	0.20	0.34	1.52	1.35	0.17	0.10	8.8	50.6	23.4	20	75

a/ Values are based on the average of 1-4 sites per lake except for ortho-phosphate (OP), chlorophyll-a, and bacteria which are all measured only at the primary sample location

b/ NH_4=total ammonia; UIA=unionized ammonia; NO_2=nitrite; NO_3=nitrate; TIN=total inorganic nitrogen (sum of ammonia, nitrite, and nitrate); TKN=total kjeldahl nitrogen; Org-N=organic N (TKN minus NH_4); Tot-P= total phosphorus; O-P=ortho-phosphate; DOC=dissolved organic carbon; Chlor-a=chlorophyll-a; Ecoli=Escherecia coli; Fecal=fecal coliform.

Table A3. Summary of Trophic Status Index (TSI) values for Denver Lakes from July/August 2008.

		Category			Numeric value[a]			
lake	date	secchi[b]	TP	chlor-a	secchi	TP	chlor-a	Notes
Rocky Mountain Ditch								
Berkeley	7/22/08	E[c]	H	E	55	79	56	
Rocky Mntn	7/22/08	E	E[d]	E	57	68	69	
Sloans	7/24/08	H	H	H	81	81	73	
City Ditch								
Grasmere	8/5/08	E	H	O	57	73	40	algae control resulted in low chlorophyll-a
Smith	8/5/08	E	H	H	69	77	82	
City Park	8/7/08	E	H	H	69	75	83	
Duck	8/7/08	M	H	O	49	92	38	algae control resulted in low chlorophyll-a
Agricultural Ditch								
Harvey	7/29/08	H	H	E	76	74	67	
Garfield	7/29/08	H	H	E	74	71	64	
Huston	7/31/08	E	H	E	67	102	70	
South Platte River								
Overland	8/12/08	E	H	E	67	95	70	
Aquagolf	8/12/08	H	H	H	79	93	80	
Miscellaneous								
Lollipop	7/15/08	E	E[d]	O	52	67	33	algae control resulted in low chlorophyll-a
Vanderbilt	7/17/08	E	H	E	68	71	70	
Urban Runoff								
Barnum	7/15/08	H	H	E	74	81	69	
Parkfield	7/31/08	E	H	M	62	83	42	thick submergent vegetation

a/ TSI value calculations from Carlson 1977, <40=oligotrophic; 41-50=mesotrophic; 51-70=eutrophic; >71=hypereutrophic

b/ secchi = secchi depth; TP = total phosphorus; chlor-a = chlorophyll-a

c/ O = oligotrophic (dark blue); M = mesotrophic (light blue); E = eutrophic (light green); H = hypereutrophic (bright green)

d/ TP was below detection limits; the true value was equal to or less than this

Table A4. Temperature/dissolved oxygen profiles for Denver Lakes from mid-summer sample events, July-August 2008. Units are ^{o}C and mg/L-O_2 at one foot intervals. Lakes are grouped by primary water subsidy source. See footnote on following page for description of dissolved oxygen water quality bench mark[a/].

Rocky Mountain Ditch

depth (ft)	Berkeley 7/22/08		Rocky Mntn 7/22/08		Sloans[E] 7/24/08	
	DO	T	DO	T	DO	T
1	5.3	25.7	8.0	26.5	6.1	25.1
2	5.3	25.1	8.0	26.5	4.2	23.9
3	5.5	25.0	7.8	25.4	4.2	23.7
4	5.6	24.9	7.4	25.1	4.0	23.6
5	5.3	24.8	6.2	24.8	2.2	23.6
6	5.3	24.8	2.8	24.4	B	
7	4.8	24.7	0.2	22.7		
8	2.1	24.5	0.0	21.6		
9	B		0.0	21.0		
10			0.0	20.0		
11						
12			0.0	19.0		
13			B			

City Ditch

depth (ft)	Grasmere 8/5/08		Smith 8/5/08		Ferril 8/7/08		Duck[E] 8/7/08	
	DO	T	DO	T	DO	T	DO	T
1	6.4	24.4	15.1	25.8	20.0	24.5	2.2	25.5
2	6.5	24.4	14.0	25.6	20.0	24.3	2.1	25.4
3	6.6	24.3	11.7	24.7	18.0	24.1	2.1	25.1
4	6.7	24.3	11.0	24.5	17.8	24.1	2.2	25.0
5	6.8	24.2	10.8	24.4	16.7	24.1	2.8	24.9
6	7.2	24.1	10.6	24.4	16.5	24.0	2.7	24.9
7	7.1	24.0	10.4	24.3	12.0	23.9	2.7	24.9
8	7.3	23.9	10.0	24.3	B		B	
9	B		9.8	24.3				
10			9.2	24.2				
11			B					
12								
13								

Agricultural Ditch (Salisbury)

depth (ft)	Harvey[E] 7/29/08		Garfield 7/29/08		Huston 7/31/08	
	DO	T	DO	T	DO	T
1	6.1	25.1	7.3	27.2	7.7	25.8
2	5.3	24.1	7.3	24.5	7.6	25.4
3	4.3	24.0	7.1	24.4	5.1	24.1
4	3.8	23.8	5.7	24.1	2.3	23.9
5	3.6	23.7	5.4	23.9	B	
6	0.1	23.5	4.6	23.8		
7	B		3.0	23.6		
8			1.3	23.5		
9			0.2	23.2		
10			0.1	22.8		
11			0.1	22.0		
12			0.1	20.0		
13			0.1	19.1		
14			0.1	17.5		
15			0.1	16.3		
16			B			

South Platte River

depth (ft)	Overland Pd 8/12/08		AquaGolf 8/12/08	
	DO	T	DO	T
1	10.5	24.0	16.8	26.5
2	10.9	23.8	9.6	23.6
3	10.1	23.5	B	
4	9.4	23.0		
5	8.9	22.9		
6	7.8	22.8		
7	B			
8				
9				
10				

Groundwater

depth (ft)	Vanderbilt 7/17/08		Lollipop 7/15/08	
	DO	T	DO	T
1	9.7	26.2	6.8	22.6
2	8.1	25.5	7.0	22.6
3	6.6	24.9	7.0	22.4
4	2.7	23.9	7.2	22.3
5	0.4	22.9	7.5	22.1
6	<0.1	21.0	7.6	22.1
7	<0.1	19.6	B	
8	<0.1	17.5		
9	<0.1	16.5		
10	B			

Urban Runoff

depth (ft)	Barnum 7/15/08		Parkfield 7/31/08	
	DO	T	DO	T
1	18.4	24.2	7.1	23.7
2	12.0	22.9	7.3	23.6
3	7.0	22.1	5.9	23.6
4	3.2	22.2	B	
5	0.5	20.8		
6	<0.1	20.4		
7	<0.1	19.7		
8	B			
9				
10				

TABLE LEGEND

- D.O. > 5 mg/L
- 5 ≥ D.O. > 4
- 4 ≥ D.O. > 3
- 3 ≥ D.O. > 2
- 2 ≥ D.O.
- range of data for which criteria apply
- E exceeds D.O. benchmark (5mg/L-O_2) based on applicable stat & data range[a/]

Table A4 Footnote

a/ The CDPHE Water Quality Control Division proposed a new dissolved oxygen assessment approach that would apply to Regulation 31, Footnote 9 (CDPHE 2009). This approach balances biological and chemical factors in lakes and lake communities with the objective of having a more ecologically relevant standard. A summary of the approach, which will be officially proposed in a June 2010 rule making hearing is as follows:

Profile Type	Profile depth	Applicable depths for D.O. assessment	Statistic
deep	<4.5 ft	entire water column	median
shallow	4.5 to 16.5 ft	1.5 ft to 40% profile depth	average
very shallow	>16.5 ft	1.5 to 6.5 ft	average

*Table modified from CDPHE 2009

The dissolved oxygen standard protective of aquatic life in warm water lakes is 5.0mg/L-O_2 (CDPHE 2008a). There is currently no allowable frequency of exceedance (e.g. one exceedance in five years) for dissolved oxygen due to its significance to aquatic life. However, it is possible that on-going discussions through CDPHE work groups will eventually modify the assessment approach and listing methodology which is re-visited approximately every two years. DEH actively participates in this process and will advocate for an approach that encompasses all factors concerning our urban lakes and wetlands.

Table A5. Summary of summer water column dissolved metal concentrations (ug/L) from Denver Lakes in July/August 2008. Bolded values indicate results that exceeded CDPHE benchmarks. The summary statistics (median, 15th and 85th percentiles) considered values below detection to be equal to the detection limit.

				Dissolved Metals (*u* g/L)																					
lake	**site**	**date**	**Hard**[a/]		**Ag**		**Al**		**As**		**Cd**		**Cr**		**Cu**		**Fe**		**Mn**		**Mo**		**Ni**		**Pb**		**Se**		**Zn**
Rocky Mountain Ditch																												
Berkeley	BER-M	7/22/08	130	J[b/]	0.02		25		**19.8**	<	0.1		3.2	J	1.8		185		74.9		7.3	J	1.5		0.52		0.6		1.1
Rocky Mntn	RMT-M	7/22/08	49		0.06		14		2.7	<	0.1		2.5	J	1.7		54		6.9		6.5	J	0.9	J	0.07	<	0.4	<	1.0
Sloan	SLN-4	7/24/08	120	J	0.02		20		6.1	<	0.1		1.2	J	1.9		183		5.3		9.9	J	1.6		0.62		0.9	<	1.0
City Ditch																												
Grasmere	GRS-M	8/5/08	180	<	0.04	B	43		1.1	<	0.1		2.0		**40.1**		357		13.7		11.1		4.3		0.28		1.3		16.1
Smith	SMT-M	8/5/08	130	<	0.04	B	7		2.2	<	0.1	J	0.6		4.6		197		2.2		13.1		3.5		0.53		1.2		10.6
Ferril	CPL-M	8/7/08	120	<	0.04	J	4		1.2	<	0.1		1.5		**15.7**		119		4.1		10.4		3.9	J	0.20		1.2		9.6
Duck	DKL-O	8/7/08	150	<	0.04	B	30		1.5	<	0.1		3.1		**25.6**		284		51.0		10.2		4.8		0.65		1.9	B	12.5
Agricultural Ditch																												
Harvey	HRV-M	7/29/08	80	J	0.02		77		6.9	<	0.1		3.3	J	1.7		183		5.9		5.2		2.1	J	0.06		0.4	<	1.0
Garfield	GAR-M	7/29/08	130	J	0.01		134		2.4	<	0.1		1.3	J	1.1		222		8.0		12.2	J	1.6		0.28	<	0.4	<	1.0
Huston	HST-M	7/31/08	93		0.05		181		5.0	<	0.1		2.4	J	0.7		368		10.9		1.6	J	1.4		0.65	<	0.4		1.2
South Platte River																												
Overland	OVL-M	8/12/08	150	<	0.04	B	5		0.7	<	0.1	J	0.7	J	0.3		338		4.7		15.0		2.3	J	0.05		1.0		2.8
AquaGolf	AQG-M	8/12/08	160	<	0.04	B	8		2.3	<	0.1	J	0.5	<	2.0		342		7.1		48.7		2.7	J	0.19		1.1	J	0.8
Groundwater																												
Lollipop	LOL-M	7/15/08	420	J	0.05	J	1		1.7	<	0.1	J	1.2		3.8		510		170.0		1.3		2.9	<	0.20		4.5	B	3.2
Vanderbilt	VBT-M	7/17/08	310	<	0.20	<	5		0.8	<	0.1		4.6	J	0.5		298	J	3.4		240.0		5.0	<	0.20		1.8	B	1.1
Urban Runoff																												
Barnum	BAR-M	7/15/08	120	J	0.05	J	4		1.8	<	0.1		4.6	J	1.2		174	J	4.6		3.5		2.0		0.25		2.2	B	1.5
Parkfield	PFL-M	7/31/08	120	J	0.04		6		3.4	<	0.1		2.2	J	0.4		482		28.3		2.7	J	1.6		0.20		0.7	<	1.0
		min:			0.01		1		0.7	<	0.1		0.5		0.3		54		2.2		1.3		0.9		0.05	<	0.4		0.8
		max:			0.20		181		19.8	<	0.1		4.6		40.1		510		170.0		240.0		5.0		0.65		4.5		16.1
		15th percentile:			0.02		4		1.1	<	0.1		0.8		0.5		176		4.3		2.9		1.5		0.10		0.4	<	1.0
		85th percentile:			0.05		69		5.8	<	0.1		3.2		12.9		365		45.3		14.5		4.2		0.60		1.9		10.4
		median:		<	0.04		11		2.3	<	0.1		2.1		1.8		253		7.0		10.1		2.2		0.23		1.0		1.2

a/ Hard = hardness (mg/L-$CaCO_3$)

b/ "**<**" = less than the detection limit; "**J**" = the result was below the reportable limit and is considered an estimate; "**B**" = method blank associated with this result contained the analyte at less than 20% of the result; "**R**" = method blank associated with this result contained target analyte at greater than 20% of the result and is considered unreportable by the DEH.

Table A6. Summary of summer water column total metal concentrations (ug/L) from Denver Lakes in July/August 2008. Bolded values indicate results that exceeded CDPHE benchmarks. The summary statistics (median, 15th and 85th percentiles) considered values below detection to be equal to the detection limit.

lake	site	date	time	hard[a/]		Al	As[b/]		Cr	Fe[b/]		Hg	Mn
Rocky Mountain Ditch													
Berkeley	BER-M	7/22/08	1015	130	B[c/]	285	17.6	J	0.69	329	<	0.1	83
Rocky Mntn	RMT-M	7/22/08	1235	49	B	33	2.9	J	0.58	82	<	0.1	12
Sloans	SLN-4	7/24/08	1110	120	B	2590	5.7		2.87	**2170**	<	0.1	101
City Ditch													
Grasmere	GRS-M	8/5/08	1055	180	B	558	1.1	J	1.17	775	<	0.1	21
Smith	SMT-M	8/5/08	1225	130	B	120	2.3	J	1.13	306	<	0.1	16
Ferril	CPL-M	8/7/08	1050	120		83	1.4		1.47	394	<	0.1	26
Duck	DKL-O	8/7/08	1250	150		104	1.2		1.25	527	<	0.1	50
Agricultural Ditch													
Harvey	HRV-M	7/29/08	1030	130	B	1310	8.1		1.38	**1220**	<	0.1	150
Garfield	GAR-M	7/29/08	1245	80	B	2170	2.6		1.54	**1710**	<	0.1	136
Huston	HST-M	7/31/08	1220	93	B	17	4.7	J	1.00	304	<	0.1	329
South Platte River													
Overland	OVL-M	8/12/08	1020	150		244	0.9	J	0.89	486	<	0.1	72
AquaGolf	AQG-M	8/12/08	1245	160		1570	2.4		2.36	**1980**	<	0.1	137
Groundwater													
Lollipop	LOL-M	7/15/08	0930	420		21	1.3	J	0.94	B **1350**	<	0.1	218
Vanderbilt	VBT-M	7/17/08	1110	310		9	0.7	J	1.09	B 674	<	0.1	300
Miscellaneous													
Barnum	BAR-M	7/15/08	1220	120		414	2.1		1.63	B 889	<	0.1	103
Parkfield	PFL-M	7/31/08	1015	120	B	40	3.4	J	1.16	239	<	0.1	109
					min:	9	0.7		0.58	82	<	0.1	12
					max:	2590	17.6		2.87	2170	<	0.1	329
					15th percentile:	24	1.1		0.90	305	<	0.1	22
					85th percentile:	1505	5.4		1.61	1620	<	0.1	201
					median:	182	2.3		1.17	601	<	0.1	102

a/ Arsenic and iron analyzed for total recoverable partition
b/ Hard = hardness (mg/L-CaCO3)
c/ "<"=less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated with this result contained the analyte at less than 20% of the result.

Table A7. Summary of sediment total metal concentrations (ug/g) from Denver Area Lakes in 2008. Bolded values are results that exceeded federal guidance (USEPA 2002).

Lake	Site	Date	Time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Zn
Rocky Mountain Ditch																	
Berkeley	BER-M	7/22/08	1015	2.90	17000	**34.0**	3.9	23.0	**170**	28000	0.46	890	3.9	18	**300**	2.2	**620**
Rocky Mntn	RMT-M	7/22/08	1235	2.50	17000	17.0	4.0	24.0	**180**	27000	0.59	1000	14.0	18	**260** J	1.7	**620**
Sloan	SLN-4	7/24/08	1110	2.20	19000	9.6	2.9	23.0	92	27000	0.35	780	3.9	17	**230**	6.2	410
City Ditch																	
Grasmere	GRS-M	8/5/08	1055 J[a/]	0.08	10000	3.1	0.3	9.6 B	14	17000	< 0.04	200	0.6	9	12 J	0.5	48
Smith	SMT-M	8/5/08	1225	1.00	21000	9.5	2.0	26.0 B	86	28000	0.25	390	6.9	16	**140**	3.8	380
Ferril	CPL-M	8/7/08	1050	0.37	18000	3.9	0.8	20.0 B	44	22000	0.07	330	2.6	17	49 J	0.8	160
Duck	DKL-O	8/7/08	1250	0.66	27000	5.3	1.5	28.0 B	66	31000	0.12	420	13.0	21	110	3.5	330
Agricultural Ditch																	
Harvey	HRV-M	7/29/08	1030	0.57	27000	14.0	1.1	16.0	69	35000	0.07	890	3.6	14	39 J	0.9	140
Garfield	GAR-M	7/29/08	1245	0.92	28000	6.8	1.3	17.0	67	35000	0.14	970	2.5	14	67 J	1.2	220
Huston	HST-M	7/31/08	1220	3.00	27000	22.0	**5.6**	22.0	**220**	37000	0.45	510	11.0	21	**330**	1.5	**750**
South Platte River																	
Overland	OVL-M	8/12/08	1020	1.40	12000	1.9	0.9	18.0 B	53	19000	0.11	680	4.4	11	43	3.1	190
AquaGolf	AQG-M	8/12/08	1245	0.32	12000	1.9	0.8	16.0 B	74	19000	0.08	330	9.9	12	40	3.2	120
Groundwater																	
Lollipop	LOL-M	7/15/08	0930	0.27	4700	2.4	0.4	3.7 B	23	7800	< 0.04	330	1.4	5 B	10	5.3	36
Vanderbilt	VBT-M	7/17/08	1110	1.80	9700	6.9	4.4	30.0 B	110	20000	0.23	**2300**	340.0	19 B	**310**	2.2	**860**
Urban Runoff																	
Barnum	BAR-M	7/15/08	1220	0.89	15000	5.8	1.7	18.0 B	79	22000	0.10	470	3.4	15 B	99	3.1	390
Parkfield	PFL-M	7/31/08	1015	0.52	21000	5.5	0.7	22.0	32	26000	< 0.04	540	4.2	18	23 J	2.2	110
		min:		0.08	4700	1.9	0.3	3.7	< 14	7800	0.04	200	0.6	5	10	0.5	36
		max:		3.00	28000	34.0	5.6	30.0	220	37000	0.59	2300	340.0	21	330	6.2	860
		15th percentile:		0.33	10500	2.6	0.7	16.0	< 35	19000	0.05	330	2.5	11	< 27	1.0	113
		85tn percentile:		2.43	27000	16.3	4.0	25.5	155	34000	0.43	950	12.5	19	290	3.7	620
		median:		0.91	17500	6.3	1.4	21.0	< 72	26500	0.12	525	4.1	17	83	< 2.2	275

a/ "<" = less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated with this result contained the analyte at less than 20% of the result; "R" = method blank associated with this result contained target analyte at greater than 20% of the result and is considered unreportable by the DEH.

Table A8. Physicochemical results for the inflows (a) and hypolimnion (b) in Denver Lakes, July-August 2008.

(a) Inflow

lake	date	site	time	pH (su)	Temp (^oC)	D.O.[a/] ($mg/L\text{-}O_2$)	Cond (uS/cm)	Alk ($mg/L\text{-}CaCO_3$)	Hard ($mg/L\text{-}CaCO_3$)	TDS (mg/L-C)	TSS (mg/L-C)	Cl (mg/L)	SO_4 (mg/L)
Rocky Mountain Ditch													
Berkeley	7/22/08	BER-INF	0850	7.6	19.7	7.0	174	35	48	95	25.0	8	50
Rocky Mntn	7/22/08	RMT-INF	0830	7.7	19.6	7.1	154	30	43	67	10.5	6	50
Sloan	7/24/08	SLN-6	0955	7.5	19.8	7.2	253	53	69	116	23.0	10	50
City Ditch													
Grasmere	8/5/08	GRS-INF	0900	6.9	23.3	5.7	855	77	170	514	<[b/] 5.0	90	125
Smith	8/5/08	SMT-INF	0835	7.1	22.9	5.7	863	80	170	530	J 4.5	92	131
City Park	8/7/08	CPL-INF	0925	7.2	23.0	7.1	845	79	150	524	5.0	89	127
Agricultural Ditch													
Harvey	7/29/08	HRV-INF	0905	8.2	23.9	6.0	370	93	110	212	26.0	27	50
Huston	7/31/08	HST-INF	1255	7.3	22.8	5.0	422	86	94	216	49.3	56	50
South Platte River													
Overland	8/12/08	OVL-INF	0940	7.5	20.0	6.1	459	85	150	260	6.0	34	55
Groundwater													
Lollipop	7/15/08	LOL-INF	0825	6.9	14.4	6.2	1319	220	430	868	< 5.0	140	289
Urban Runoff													
Barnum	7/15/08	BAR-INF	1310	8.1	22.9	7.5	968	252	190	585	14.5	84	130
		median:		7.5	22.8	6.2	459	80	150	260	10.5	56	55

(b) Hypolimnion

lake	date	site	time	pH (su)	Temp (^oC)	D.O.[a/] ($mg/L\text{-}O_2$)	Cond (uS/cm)	Alk ($mg/L\text{-}CaCO_3$)	Hard ($mg/L\text{-}CaCO_3$)	TDS (mg/L-C)	TSS (mg/L-C)	Cl (mg/L)	SO_4 (mg/L)	depth of sample / water column (ft)[c/]
Rocky Mntn	7/22/08	RMT-OB	1315	7.2	19.0	0.10	516	163	77	307	6.7	52	50	12 / 25+
Garfield	7/29/08	GAR-MB	1255	6.8	18.0	0.01	579	149	130	298	31.3	70	50	12 / 15
Vanderbilt	7/17/08	VBT-MB	1120	6.9	19.8	0.10	1296	342	310	812	14.7	201	69	6.5 / 9

a/ DO=dissolved oxygen; Cond=specific conductivity; Alk=alkalinity; Hard=hardness; TDS=total dissolved solids
b/ "<"=less than; "J"=below reporting limit
c/ depth of sample is where sample was collected; water column is the depth of sample location from top of water surface to sediment surface

Table A9. Results for nutrients and associated parameters in the inflows (a) and hypolimnion (b) in Denver Lakes, July-August 2008.

(a) Inflow

lake	date	site	time	NH_4[b/]	UIA	NO_2	NO_3	TIN	TKN	Org-N	T-P	O-P	DOC	Ecoli	Fecal
				(mg/L-N)							(mg/L-P)		(mg/L)	(#col/100ml)	
Rocky Mountain Ditch															
Berkeley	7/22/08	BER-INF	0850	< 0.10	< 0.00	< 0.01	< 0.20	< 0.31	< 1.00	< 1.00	< 0.08	< 0.10	2.39	< 10	< 10
Rocky Mntn	7/22/08	RMT-INF	0830	< 0.10	< 0.00	< 0.01	< 0.20	< 0.31	< 1.00	< 1.00	< 0.08	< 0.10	3.78	280	900
Sloans	7/24/08	SLN-6	0955	< 0.10	< 0.00	< 0.01	< 0.20	< 0.31	< 1.00	< 1.00	0.10	0.10	2.78	470	790
City Ditch															
Grasmere	8/5/08	GRS-INF	0900	0.34	0.00	0.02	12.33	12.69	1.70	1.36	0.27	0.25	8.31	30	60
Smith	8/5/08	SMT-INF	0835	0.31	0.00	0.09	11.61	12.01	2.00	1.69	0.23	0.20	7.99	50	110
City Park	8/7/08	CPL-INF	0925	0.12	0.00	0.09	12.22	12.43	1.45	1.33	0.23	0.19	7.35	240	1830
Agricultural Ditch															
Harvey	7/29/08	HRV-INF	0905	< 0.10	< 0.01	< 0.01	< 0.20	< 0.31	< 1.00	< 1.00	< 0.10	< 0.10	7.42	820	2600
Huston	7/31/08	HST-INF	1255	1.08	0.01	0.38	0.80	2.26	1.98	0.90	0.29	< 0.10	7.69	20	30
South Platte River															
Overland	8/12/08	OVL-INF	0940	< 0.10	< 0.00	0.03	1.02	< 1.15	< 1.00	< 1.00	0.29	0.25	4.74	250	260
Groundwater															
Lollipop	7/15/08	LOL-INF	0825	< 0.10	< 0.00	< 0.01	0.97	< 1.08	< 1.00	< 1.00	0.16	0.15	2.58	nm	nm
Urban Runoff															
Barnum	7/15/08	BAR-INF	1310	< 0.10	< 0.01	0.02	0.84	< 0.96	< 1.00	< 1.00	0.12	< 0.08	4.83	340	1250
		median:		< 0.10	0.00	0.02	0.84	1.08	1.00	< 1.00	0.16	0.10	4.83	245	525

(b) Hypolimnion

lake	date	site	time	NH_4[b/]	UIA	NO_2	NO_3	TIN	TKN	Org-N	T-P	O-P	DOC	depth of sample / water column (ft)[d/]
				(mg/L-N)							(mg/L-P)		(mg/L)	
Rocky Mntn	7/22/08	RMT-OB	1315	1.70	0.01	0.01	< 0.20	1.91	1.98	0.28	0.42	0.29	10.8	12 / 25+
Garfield	7/29/08	GAR-MB	1255	5.03	0.01	< 0.01	< 0.20	5.24	5.41	0.38	0.65	0.44	18.2	12 / 15
Vanderbilt	7/17/08	VBT-MB	1120	6.19	0.02	< 0.01	< 0.20	6.40	9.40	3.21	0.34	0.26	16.9	6.5 / 9

a/ NH4=total ammonia; UIA=unionized ammonia; NO2=nitrite; NO3=nitrate; TKN=total kjeldahl nitrogen; Org-N=organic nitrogen (TKN-ammonia); Tot-P=total phosphorus; O-P=ortho-phosphate; Ecoli=Escherecia coli; Fecal=fecal coliform

b/ "<" indicates the analyte was less below analytical detection capabilities

c/ "nm" indicates analyte not measured

d/ depth of sample is where sample was collected; water column is the depth of sample location from top of water surface to sediment surface

Table A10. Summary of water column dissolved metal concentrations (ug/L) from inflows (a) and the hypolimnion (b) in Denver Lakes, July-August 2008. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2008.

INFLOW

lake	site	date	pH	Ag	Al	As	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Rocky Mountain Ditch																
Berkeley	BER-INF	7/22/08	7.6	J[a/] 0.03	12	0.8	< 0.1	J 0.9	2.4	93	7	3.0	J 0.8	0.27	< 0.4	14.4
Rocky Mntn	RMT-INF	7/22/08	7.7	J 0.03	11	0.6	< 0.1	J 0.8	2.6	93	5	3.1	J 0.8	0.35	< 0.4	10.6
Sloans	SLN-6	7/24/08	7.5	J 0.03	34	0.6	< 0.1	1.5	2.5	171	27	3.6	J 0.9	0.43	0.5	12.9
City Ditch																
Grasmere	GRS-INF	8/5/08	6.9	J 0.02	B 123	< 0.5	< 0.1	J 0.8	5.0	371	19	10.4	3.9	0.27	1.6	28.8
Smith	SMT-INF	8/5/08	7.1	< 0.04	B 22	J 0.4	< 0.1	J 0.7	14.1	349	20	10.1	4.1	0.28	1.0	25.0
Ferril	CPL-INF	8/7/08	7.2	J 0.01	B 30	0.9	< 0.1	2.3	13.9	217	7	10.1	3.3	0.32	1.4	24.5
Agricultural Ditch																
Harvey	HRV-INF	7/29/08	8.2	0.08	J 4	14.8	< 0.1	J 1.0	11.8	172	4	8.8	J 1.2	J 0.08	J 0.3	< 1.0
Huston	HST-INF	7/31/08	7.3	0.07	35	3.0	< 0.1	2.4	< 2.0	190	1190	3.8	J 1.8	J 0.17	< 0.4	3.4
South Platte River																
Overland	OVL-INF	8/12/08	7.5	< 0.04	J 3	0.6	< 0.1	J 0.6	J 0.3	328	35	14.3	2.3	J 0.07	0.7	4.6
Groundwater																
Lollipop	LOL-INF	7/15/08	6.9	J 0.03	< 5	1.8	< 0.1	5.2	6.4	583	322	1.1	3.2	0.42	6.5	B 8.6
Urban Runoff																
Barnum	BAR-INF	7/15/08	8.1	< 0.20	J 4	1.3	< 0.1	1.4	J 1.5	284	30	3.4	2.0	J 0.11	3.3	B 2.6
		median:		J 0.03	12	0.8	< 0.1	1.0	2.6	217	20	3.8	2.0	0.27	0.7	10.6

BOTTOM

lake	site	date	pH	Ag	Al	As	Cd	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Se	Zn
Rocky Mntn	RMT-OB	7/22/08	7.2	< 0.04	J 3	1.3	< 0.1	4.4	J 0.5	158	413	1.9	J 1.1	J 0.08	4.0	1.3
Garfield	GAR-MB	7/29/08	6.8	< 0.04	10	4.7	< 0.1	4.8	< 2.0	1300	3130	J 1.0	J 1.5	J 0.14	1.6	< 1.0
Vanderbilt	VBT-MB	7/17/08	6.9	< 0.20	J 2	0.7	< 0.1	8.3	J 0.6	349	3020	55.8	5.0	< 0.20	4.7	B 1.5

a/ "<" = less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated with this result contained the target analyte at less than 20% of the result; "R" = method blank associated with this result contained the target analyte at greater than 20% of the result and is considered unreportable by the DEH.

Table A11. Summary of water column total metal concentrations (ug/L) from inflows (a) and the hypolimnion (b) in Denver Lakes, July-August 2008. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2008.

INFLOW

lake	site	date	time	pH	Al	As	Cr	Fe	Hg	Mn
Rocky Mountain Ditch										
Berkeley	BER-INF	7/22/08	0850	7.6	B 795	1.2	J 1.12	1140	< 0.1	120
Rocky Mntn	RMT-INF	7/22/08	0830	7.7	B 295	1.1	J 0.778	432	< 0.1	23
Sloans	SLN-6	7/24/08	0955	7.5	B 981	1.1	1.49	1500	1.4	154
City Ditch										
Grasmere	GRS-INF	8/5/08	0900	6.9	B 81	< 0.4	J 0.96	405	< 0.1	20
Smith	SMT-INF	8/5/08	0835	7.1	B 397	0.4	1.28	671	< 0.1	23
Ferril	CPL-INF	8/7/08	0925	7.2	275	1.0	1.41	786	< 0.1	16
Agricultural Ditch										
Harvey	HRV-INF	7/29/08	0905	8.2	B 221	17.0	J 1.06	498	< 0.1	125
Huston	HST-INF	7/31/08	1255	7.3	B 3530	3.9	1.83	3090	< 0.1	1140
South Platte River										
Overland	OVL-INF	8/12/08	0940	7.5	180	0.7	J 0.553	452	< 0.1	115
Groundwater										
Lollipop	LOL-INF	7/15/08	0825	6.9	6	1.4	J 0.78	B 1300	< 0.1	357
Miscellaneous										
Barnum	BAR-INF	7/15/08	1310	8.1	538	1.4	1.21	B 1110	< 0.1	42
				median:	B 295	1.1	1.12	< 786	0.1	115

BOTTOM

lake	site	date	time	pH	Al	As	Cr	Fe	Hg	Mn
Garfield	GAR-MB	7/29/08	1255	6.8	B 1290	5.1	1.27	2660	< 0.1	2960
Vanderbilt	VBT-MB	7/17/08	1120	6.9	10	0.5	J 1.15	B 1050	< 0.1	3430

a/ "<" = less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated with this result contained the target analyte at less than 20% of the result; "R" = method blank associated with this result contained the target analyte at greater than 20% of the result and is considered unreportable by the DEH.

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APPENDIX B

QUALITY ASSURANCE / QUALITY CONTROL

The DEH Quality Assurance/Quality Control (QA/QC) procedures were formally documented in 2006 with completion of the DEH's Quality Assurance Project Plan/Sampling and Analyses Plan (QAPP/SAP; 2006). The QA/QC includes both replicate samples and sample blanks to assure data quality.

Replicates

Replicates are field samples collected in one bottle and split into two sets of bottles labeled as different sites. Replicates are performed to determine the precision of laboratory analysis. The 2008 Lakes QA/QC included two sets of replicates collected for parameters analyzed at the CCOD's Wastewater Management Division Laboratory (WMD) and one for aqueous and sediment metal parameters analyzed at Evergreen Analytical Laboratory (EAL[1]).

Replicates were assessed using Relative Percent Difference (RPD; USEPA 2004). The RPD calculation is:

$$RPD = [(mv - rv) / ((mv + rv) / 2)] \times 100$$

Where:

'**mv'** is the measured value
'**rv'** is the replicate value

Based on this approach, inorganic parameters with a RPD less than ±20% are deemed acceptable, while more inherently variable parameters such as bacteria and chlorophyll-a are acceptable up to 35%. The RPD is technically only applicable to parameters that exceed 5X the analyte practical quantitation limit (PQL[2]).

All measured parameters from both the DWW and EAL laboratories were within the 20% RPD limits (**Tables B1a** and **B2a**).

Field and Post-Decontamination Blanks

Equipment blanks are (1) de-ionized water samples poured from the beta bottle (water sample collection apparatus) into a sample container and (2) EPA certified sterile sand samples collected from the eckman dredge and transferred to a sample container (within an acid cleaned bucket saturated with de-ionized water). Equipment blanks assess whether the protocol and/or EAL analyses appeared to be free of contamination.

[1] Evergreen Analytical Laboratories became a branch laboratory of Accutest, Inc. in spring of 2009.
[2] The Practical Quantitation Limit (PQL) is an estimate of the minimal concentration at which a laboratory can accurately measure an analyte. The PQL is a function of the method detection limit (MDL) and is typically 5 to 10X the MDL.

Post-field decontamination blanks are also collected to determine the effectiveness of field protocol. It is expected that results from equipment blanks will be below or near detection limits.

One set of equipment blanks was collected for aqueous metals and one post-decontamination sample was collected. Results for both labs (DWW and EAL) came back below detection or at negligible levels (**Tables B1b** and **B2b**).

Table B1. Quality assurance (a) replicates and (b) de-ionized blanks for physicochemical parameters in Denver Lakes, July/August 2008. These analyses were performed by the City and County of Denver's Wastewater Management Division Laboratory. Relative percent difference (RPD) was calculated for replicate samples; all replicate values were within acceptable limits (±20% for inorganics; ±35% for bacteria and chlorophyll-a).

a) Replicates[a]

	Date	Alk[b]	Hard	TDS	TSS	Cl	SO_4	NH_4	NO_2	NO_3	TKN	tot-P	O-P	DOC	Ecoli	fecal
sample	7/24/08	142	120	387	66.7	72	40	0.33	<[c] 0.01	< 0.20	1.73	0.21	0.11	12.5	< 10	< 10
replicate	7/24/08	140	120	382	70.7	72	70	0.32	< 0.01	< 0.20	1.91	0.20	< 0.08	11.6	< 10	< 10
	RPD[d]:	0.4	0.0	0.3	-1.5	0.0	-13.6	0.8	0.0	0.0	-2.5	1.2	7.9	1.9	0.0	0.0
sample	8/5/08	80	170	530	J 4.5	92	131	0.31	0.09	11.61	2.00	0.23	0.20	8.0	50	110
replicate	8/5/08	nm	nm	501	nm	91	129	0.32	0.09	11.63	1.70	0.23	0.20	7.9	70	110
	RPD:	nm	nm	1.4	nm	0.3	0.4	-0.8	0.0	0.0	4.1	0.0	0.0	0.3	-8.3	0.0

b) De-ionized Blanks[e]

	Date	Alk	Hard	TDS	TSS	Cl	SO_4	NH_4	NO_2	NO_3	TKN	tot-P	O-P	DOC	Ecoli	fecal
field blank	7/31/08	<[c] 5	< 5	10	< 5.0	6	50	< 0.10	< 0.01	< 0.20	< 1.00	< 0.10	< 0.10	2.0	< 10	< 10
post-decon	8/7/08	< 5	< 5	10	< 5.0	6	50	< 0.10	< 0.01	< 0.20	< 1.00	< 0.10	< 0.10	2.0	nm	nm

a/ samples collected in the field in a common container and poured to separate containers; exception for E. coli which is collected side by side

b/ Alk=alkalinity (mg/L-CaCO3); Hard=hardness (mg/L-CaCO3); TDS=total dissolved solids (mg/L); Cl=chloride (mg/L); SO4=sulfate (mg/L); NH4=total ammonia(mg/L-N); NO2=nitrite (mg/L-N); NO3=nitrate (mg/L-N); TKN=total kjeldahl nitrogen (mg/L-N); Tot-P=total phosphate (mg/L-P); O-P=ortho-phosphate (mg/L-P); DOC=dissolved organic carbon (mg/L); Ecoli=Escherecia coli (cfu/100ml); Fecal=fecal coliform (cfu/100ml)

c/ "<" = less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated; "nm" = not measured

d/ Relative percent difference is a measure of similarity between replicate samples, see text for details

e/ De-ionized blanks were de-ionized water poured into a sample container in the field; post-decon is a test of equipment decon in the field

Table B2. Quality assurance (a) replicates and (b) de-ionized blanks for metal parameters in Denver Lakes, July/August 2008. These analyses were performed by the Evergreen Analytical Laboratory (purchased by Accutest, Inc in spring 2009), Wheatridge, Colorado. Relative percent difference (RPD) was calculated for replicate samples; all replicate values were within acceptable limits (±20% for inorganics; ±35% for bacteria and chlorophyll-a).

a) Replicates[a]

	date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Zn	% solids
Water - Dissolved (ug/L)																
sample	7/24/08	J[b] 0.02	19.50	6	< 0.1	1.21	J 1.9	183.0	nm	5.26	9.9	J 1.6	0.6	0.9	< 1.0	*na*
replicate	7/24/08	J 0.02	24.10	6	< 0.1	2.65	J 2.0	199.0	nm	4.57	9.9	J 1.5	0.6	1.0	< 1.0	*na*
	RPD[c]:	4.1	-5.3	-0.2	0.0	-18.7	-1.8	-2.1	nm	3.5	0.1	1.3	-0.7	-2.6	0	*na*
Water - Total/Total Recoverable (ug/L)																
sample	7/24/08	*nm*	B 2590	5.7	*nm*	*2.87*	*nm*	2170	< 0.10	101	*nm*	*nm*	*nm*	*nm*	*nm*	*na*
replicate	7/24/08	*nm*	B 2730	5.7	*nm*	*2.67*	*nm*	2220	< 0.10	100	*nm*	*nm*	*nm*	*nm*	*nm*	*na*
	RPD:	*nm*	-1.3	-0.2	*nm*	*nm*	*nm*	-0.6	0.0	0.3	*nm*	*nm*	*nm*	*nm*	*nm*	*na*
Sediment - Total (mg/Kg)																
sample	7/24/08	2.2	19000	9.6	2.9	23	92	27000	0.35	780	3.9	17.0	230	6.2	410	18.5
replicate	7/24/08	2.1	19000	9.8	2.9	23	95	27000	0.36	800	8.4	18.0	250	4.5	430	18.6
	RPD:	1.2	0.0	-0.5	0.0	0.0	-0.8	0.0	-0.7	-0.6	-18.3	-1.4	-2.1	7.9	-1	-0.1

b) De-ionized Blanks[d]

site	date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Zn	% solid
Water - Dissolved (ug/L)																
field blank	8/7/08	< 0.04	B 5	< 0.5	< 0.10	J 0.5	J 0.4	< 40	*nm*	< 1.0	< 1.0	J 0.1	< 0.2	< 0.4	< 1.0	*na*
post-decon	7/31/08	J 0.04	J 2	< 0.5	< 0.10	J 0.3	< 2.0	< 40	*nm*	< 1.0	< 1.0	< 2.0	< 0.2	< 0.4	< 1.0	*na*
Water - Total/Total Recoverable (ug/L)																
field blank	8/7/08	*nm*	< 5	0.5	*nm*	J 1.09	*nm*	< 40	< 0.10	J 0	*nm*	*nm*	*nm*	*nm*	*nm*	*na*

a/ samples collected in the field in a common container and poured to separate containers
b/ "<" = less than the detection limit; "J" = the result was below the reportable limit and is considered an estimate; "B" = method blank associated; "nm" = not measured; "na"=not applicable
c/ RPD = Relative Percent Difference, see text for details
d/ De-ionized blanks were de-ionized water poured into a sample container in the field; post-decon is a test of equipment decon in the field

APPENDIX C

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APPENDIX D

GLOSSARY

Alkalinity: A measure of the ability of water to buffer changes in pH caused by the addition of acids or bases; in natural waters it is due primarily to the presence of bicarbonates, hydroxides, carbonates and to a much lesser extent occasionally borates, silicates and phosphates. It is typically expressed in units of milligrams per liter (mg/l) of calcium carbonate ($CaCO_3$)

Ammonia (NH_4^+): A biologically available form of nitrogen formed naturally by the breakdown of materials containing organic nitrogen. Anthropomorphic sources of ammonia come from improper waste treatment and illicit sewage connections and fertilizers. Additional sources include heavy use of water bodies by waterfowl and other aquatic life.

Benthic algae: Algae growing on a lake or stream bottom

Beta Bottle: A tube used to collect water from targeted depths; beta-bottles are positioned horizontally and are preferred for accuracy of collection over the vertical sampling bottles (alpha-bottle) when working with shallow lakes and ponds.

Best Management Practices (BMPs): Management approaches that for any given situation minimize water quality impacts as a result of stormwater management. Examples span a variety of options including natural (e.g. wetlands), structural (e.g. detention pond), and house-keeping approaches (e.g. street sweeping).

Bioaccumulate: accumulation of a constituent in organisms in fairly direct proportions to the habitat and food concentrations in which the organism lives and feeds, respectively (i.e., fish in a pond will have similar concentrations of copper as do the insects and phytoplankton on which they feed).

Biomagnification: circumstances in which the concentration of a contaminant increases, or magnifies as it is passed upwards through a food chain; a result of the contaminant being incorporated into the organism's tissues, organs, or bones, rather than passing through the system (i.e., fish in pond will have higher concentrations of mercury than do the insects and phytoplankton on which they feed).

Bioturbidity: surface water turbidity created by the action of organisms (i.e., fish).

Chlorophyll-*a*: Green pigment in plants that transforms light energy into chemical energy during photosynthesis. Measure provides an estimate of planktonic algae activity level in waterbodies.

Conductivity: Measure of water's ability to conduct an electric current or the total ionic concentration of water; conductivity is reported in micro siemens per centimeter (uS/cm) and is directly related to the total dissolved inorganic chemicals in the water.

Detection limit: The minimum concentration of a compound or analyte which can be measured with a specified percentage of confidence, by a specific method or instrument.

Dissolved metals: The concentration of metals determined in a sample after the sample is filtered through a 0.45μm filter and then acidified with nitric acid to a pH<2.

Dissolved Oxygen (DO): Free (not chemically combined) oxygen dissolved in water; usually expressed in milligrams per liter (mg/L), parts per million (ppm), or percent of saturation (%).

Dissolved organic carbon (DOC): A measure of the organic compounds that are dissolved in water.

Eckman Dredge: a stainless steel dredge that can be operated by hand from a small boat used to collect lake or river sediment samples up to 6 inches deep (when using a 6in^3 dredge).

***E. coli* (*Escherechia coliform*) -** one of several types of bacteria that normally inhabit the intestine of humans and animals. Some strains of *E. coli* can cause temporary intestinal problems and/or are capable of causing disease when the immune system is compromised as a result from environmental exposure. Measure of *E. coli* in water bodies serves as a surrogate indicator of a variety of potential anthropogenic sources of contamination.

Epilimnion: The upper layer of a body of water that has been thermally stratified; it extends from the water surface down to the TT*thermocline* (boundary between the warmer epilimnion and the cooler hypolimnion, or lower depths). The epilimnion is less dense than the lower waters and is wind-circulated and essentially well mixed.

Epiphytic algae: Algae growing on plants.

Eutrophic: description of a lake or other body of water characterized by large nutrient concentrations such as nitrogen and phosphorous and resulting in high productivity in the form of algae and vegetation.

Eutrophication: the natural and/or anthropomorphically hastened process of over enrichment of a water body with nutrients resulting in excessive growth of organisms (typically algae and vegetation) and depletion of dissolved oxygen concentration.

Exceedence: A value beyond what is permitted or advised based on regulatory standards or guidance whose purpose is the protection of a specific use of the water and/or habitat.

Fish Consumption Advisory (FCA) – advisory placed on lakes and/or streams by government agencies to caution possible consumers of dangers posed by consumption of aquatic organisms that contain contaminants at levels of concern.

Hardness: A property of water defined by the quantity of multivalent cations (cations with more than one +), primarily calcium and magnesium salts in solution. Amount of hardness relates to the presence of soluble minerals, especially limestone within the watershed.

Hypolimnion: The lowermost, non-circulating layer of cold water in a thermally stratified lake or reservoir that lies below the *thermocline*. This layer is the most dense layer of a *stratified* lake and is usually deficient of oxygen. It is typically the coldest zone in the summer and warmest in the winter.

Inorganic nitrogen: Includes nitrite, nitrate, and ammonia components of the total nitrogen. Under typical surface water conditions, nitrate tends to be the dominant form. Beyond natural sources (e.g. breakdown of organic material, such as leaves), common sources include fertilizer runoff resulting from improper application, treated sewage effluent, human and animal wastes from failing septic systems and livestock confinement areas.

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Lentic: standing surface water such as lakes and wetlands.

Lotic: flowing surface waters such as streams and river.

Metalimnion: The middle layer of a thermally *stratified* lake or reservoir. In this layer there is a rapid decrease in temperature with depth.

Mesotrophic : description of a lake or other body of water characterized by moderate nutrient concentrations (nitrogen and phosphorous) resulting in moderate productivity.

Nitrate (NO_3^-): A prevalent form of inorganic nitrogen which forms primarily through the oxidation of ammonia and nitrite. Treated sewage is a primary source of nitrates in streams, but it can also be added to waters through improper application and/or storage of fertilizers. Natural contributions originate through nitrogen fixation by blue-green algae and the breakdown of organic matter.

Nitrite (NO_2^-): A biologically available form of nitrogen that is typically found in the lowest concentrations among the inorganic forms of nitrogen. Nitrite forms from the oxidation of ammonia and is quickly oxidized to the nitrate form. Common sources of nitrite include treated sewage and animal waste.

Nutrients: Typically refers accumulatively to nitrogen and phosphorus, which are important (essential) contributors to plant and algae growth in surface waters.

Organic load: The contribution of materials to lakes (and streams) that contains carbon in a variety of forms (e.g, petroleum based contaminants, animal waste products). Decomposition of the buildup of these carbon based materials on lake bottoms can result in often greatly decreased oxygen levels in the lower depths of lakes.

Organic nitrogen : Nitrogen that is bound to carbon-containing compounds. This form of nitrogen must be subjected to mineralization or decomposition before it can be used by the plant communities in aquatic and terrestrial environments; the organic nitrogen content consists of *total kjeldahl nitrogen* (TKN) minus *total ammonia*.

Ortho-phosphate (OP): The portion of total phosphorus that is available for uptake by algae and aquatic vegetation; it is produced by natural processes and is also found in sewage effluent.

Oxidation: This describes the reaction when a chemical gives up an electron. This is often associated with the uptake of oxygen, but can occur in other reactions as well:
$H_2S \rightarrow S^{-2} + 2H^+$ or $Fe^{++} \rightarrow Fe^{+++} + e^-$

Oxygen deficit: describes conditions where dissolved oxygen levels are below a particular benchmark, such as levels that will support aquatic life activities, or water quality standards.

pH: the negative logarithm of the hydrogen ion (H+) concentration, giving a measure of acidity on a scale from 0 (acid) through 7 (neutral) to 14 (alkaline); pH = -log10 $[H^+]$, where $[H^+]$ is the concentration of H^+ ions in moles per liter. Natural waters usually have a pH between 6.5 and 8.5*su* (standard units).

Photic zone: The upper water layer down to the depth of effective light penetration where photosynthesis balances respiration; this level (the "compensation level") usually occurs at the depth of one percent light penetration (i.e., one percent of surface light intensity).

Photosynthesis: The process in green plants and certain other organisms by which carbohydrates are synthesized from carbon dioxide and water using light as an energy source.

Plankton: microscopic (not visible to the naked eye) and macroscopic (small but visible to the naked eye) animals (zooplankton) and algae (phytoplankton) inhabiting the water column of lakes and streams.
Potentially dissolved metals: The concentration of metals determined in a sample acidified (nitric to pH<2) upon collection and then filtered 8-96 hrs later with a 0.45μm membrane glass fiber filter.

Productivity: Collective term to encompass growth of algae and vegetation in lakes and streams.

Reduction: A reaction in which a chemical gains electrons, commonly associated with a gain of hydrogen atoms; associated with low oxygenated situations: $S^{-2} + 2H^+ \rightarrow H_2S$

Reporting limit: The lowest level that can be reliably measured by analytical equipment within specified limits of precision and accuracy during routine laboratory operating conditions.

Recycled water: Wastewater treated to a standard that is suitable for irrigation and some commercial and industrial uses. Recycled water is used to irrigate many City and County of Denver parks, subsidize supplies to City lakes, among many other metro area uses.

Secchi depth: A relatively crude measurement of the water clarity and/or turbidity (cloudiness) of surface water using a secchi disk.

Secchi disk: A 10-12 inche diameter disc that is divided into 4 equal quadrates of alternating black and white colors.

Stratification (of the water column)**:** the vertical separation of the water column based primarily on temperature; the warmer upper layer is referred to as the *epilimnion*, while the cooler bottom layer is the *hypolimnion*. The layers are separated by the *thermocline*, the zone of most rapid temperature change.

Submergent vegetation – vegetation rooted on a lake or wetland bottom, growing in the water column, often to the water surface.

Suspended Solids: Includes all particles in water that will not pass through a filter having openings of 0.45 microns in diameter. Typically, suspended solids include items such as soil, algal cells, and plant particles.

Thermocline: The horizontal zone within the water column with the most rapid rate of temperature change; this is situated within the *metalimnion* between the *epilimnion* and the *hypolimnion.*

Total inorganic nitrogen (TIN): A sum of the total ammonia, nitrite, and nitrate concentrations; typically measured in milligrams per liter (mg/l).

Total Kjeldahl Nitrogen (TKN): A biologically unavailable form of nitrogen, typically tied up in organic compounds plus ammonia, which is biologically available. Sources of TKN in surface waters include leaves and other woody/leafy material from outside of the stream, as well as decaying aquatic vegetation and algae.

Total metals: The concentration of metals determined in a sample acidified upon collection and not filtered.

Total phosphorous (Total-P): The sum of organic and inorganic forms of phosphorus and a key component driving eutrophication in surface waters. Phosphorus is a naturally occurring element but is more commonly known as an anthropomorphically supplied contaminant in surface waters. Common sources include sewage treatment effluent, animal waste, and fertilizer runoff.

Total recoverable metals: The concentration of metals in an unfiltered sample following treatment with hot dilute mineral acid.

Trophic status index (TSI): A measure of *eutrophication* of a body of water using a combination of measures of water transparency (*Secchi* depth recordings), *chlorophyll-a* concentrations, and total phosphorus levels; credited to Carlson (1987).

Un-ionized ammonia (UIA, NH_3): A form of nitrogen found in organic materials, sewage, and many fertilizers which has no charge (NH_3); calculated from measured total ammonia, pH, and water temperature. UIA is the primary form of ammonia that is toxic to aquatic life.

Water residence time: The length of time water remains within a lake before continuing around the hydrological cycle (discharge from the lake, recharge groundwater, or evaporate). The time involved may vary from days to months in Denver's lakes.