2005 Lakes Report

City & County of Denver

Department of Environmental Health
Division of Environmental Quality

November 2006

Executive Summary

The Denver Department of Environmental Health's (DEH) Division of Environmental Quality (DEQ) completed its tenth year of annual summer monitoring of the City and County of Denver's lakes in 2005. As with previous efforts, the findings from the year's sample events were used to assess the lake's status regarding public and environmental health.

Guidelines for this assessment are the Colorado Department of Public Health and Environment's (CDPHE) Regulations 31 (CDPHE 2005a) and 38 (CDPHE 2005b). These Regulations include specific standards established for designated uses that were developed to protect humans for several uses (i.e., recreation) and to protect aquatic life. The CDPHE standards were developed as directed by Section 25-8-102(2) of the Water Quality Control Act and are consistent with the Federal Clean Water Act.

If water quality standards are met, conditions in the lakes are assumed to be protective for these uses. If standards are not met, the DEQ will take action with the appropriate agencies to help determine the contributing sources for the exceedance, and as much as possible, a remedy for the situation.

Unlike previous lake reports, this effort focuses on the issues and devotes limited discussion on general lake condition. Please refer to previous reports for the latter (CCOD 2005 and 2006). This report does:

- provide a succinct summary of the 2005 monitoring results for 16 Denver lakes;
- addresses water quality standard and sediment quality guidance exceedances; and
- re-iterates the primary issues within the City's Lake System.

The 2005 findings are provided in a color coded table intended to serve as a one page summary for all the Denver Lakes (**Table 3-1**). Quantitative findings are also provided for those who would like more detailed information. Long term data will eventually be available at the DEH water quality website (~February 2007), and is also available upon request.

A summary of water quality standard and sediment guidance exceedances are provided within the report (**Table A11**). Noteworthy findings and recommendations based on the 2005 sampling efforts are summarized in **Table E-1**.

Comments regarding this report and how the DEQ can better meet your needs regarding lake monitoring can be made by contacting the Department of Environmental Health's DEQ at 720-865-5480.

Table E-1. Summary of noteworthy 2005 findings and recommendations.

Findings	Comments	Recommendations
Seven of the sixteen sampled lakes had pH levels in exceedance of water quality standards.	Elevated pH is common in lakes and can be expected to exceed this standard during the growing season when photosynthesis is occurring at a higher rate.	Methods to mitigate elevated pH would address excessive lake productivity; this could include incorporating BMPs that minimize nutrient loading, increasing water depth (renovations), and use of chemicals to control growth.
Exceedance of the arsenic fish ingestion water quality standard in Berkeley Lake.	Tissue-arsenic concentrations were measured at acceptable concentrations for ingestion (CDPHE sampling in 2004).	The arsenic-fish tissue concentration will be assessed approximately every five years.
Large mouth bass mercury tissue concentrations exceeded acceptable consumption guidelines in Berkeley & Rocky Mountain Lakes.	A fish consumption advisory was established for Berkeley and Rocky Mountain Lakes, March 2006 (CDPHE sampling performed in 2004).	Fish will be re-sampled in the near future to determine the fish consumption advisory status.
Bacteria levels in Sloans Lake were acceptable for recreational purposes on 17 of 19 sample events spanning May 24 through September 20, 2005.	Levels measured on follow-up sampling on the days of exceedance were at acceptable levels.	Sloans Lake will continue to be sampled weekly during the recreational season; follow-up samples will be collected when exceedance occur; DEH will use the CDPHE Natural Swim Beach Regulations as guidance concerning follow-up sampling and posting as needed.
Nitrate levels were relatively high in three of the four City Ditch Lakes (Grasmere, Smith, and Ferril).	Nitrate levels have been elevated in the City Ditch Lakes since 2004 when recycled water became the source water for the ditch. Recycled water contains high nitrate concentrations (10-15mg/L-NO_3 as N).	Management possibilities include incorporating wetlands to mitigate the high nitrogen levels, use of water column mixing options (SolarBees-installed June 2005) and increased aeration, limited use of chemicals to mitigate growth.
Ammonia concentrations in Duck Lake exceeded water quality standards.	Dense population of cormorants, waterfowl, and other birds contribute to nutrient loading.	Mitigation would include decreasing bird activity at the lake, water column mixing and aeration, and limited use of chemicals to decrease algal productivity.
Huston and Parkfield conditions representative of wetlands.	Shallow water depth and healthy submerged vegetation throughout their water bodies not necessarily a negative issue; can be considered an asset if expected conditions for these lakes are that they provide wetland functions.	Either adjust expectations to those appropriate for wetlands or dredge the lakes and alter the hydrological and physical characteristics.
Chlorophyll-a concentrations in South Platte Lakes relatively high.	AquaGolf Lake concentration was the highest yet documented in the Denver Lakes; shallow depths and high-phosphorus loading contribute to the problem.	Determine how the Public Works Florida Lateral project impacts future water quality and quantity (2006-07).
Barnum Lake bacteria (*E. coli*) levels exceeding water quality standards.	High bacteria loading from Weir Gulch; contributes to low dissolved oxygen within the lake.	DEH will increase monitoring of Weir Gulch to determine whether there are illicit connections or other sources contributing to excessive bacteria in the lake (May 2006).
Selenium levels in Lollipop Lake exceeded water quality standards.	Concentrations not at levels that pose a risk to humans.	Will list Lollipop Lake as a candidate for fish tissue analyses to assess consumption issues.
Organic contaminants in Vanderbilt Lake at potentially harmful concentrations.	Based on sampling performed by Brown and Caldwell in 2004/05.	On-going negotiations to determine recommended cleanup procedures.

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List of Acronyms & Abbreviations

AD – Agricultural Ditch
BMP – best management practice
CCOD – 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

I. Introduction

The Denver Department of Environmental Health's (DEH) Division of Environmental Quality (DEQ) completed its tenth year of annual summer monitoring of the City and County of Denver's lakes in 2005. As with previous efforts, the findings from the year's sample events will be used to assess the status of the lakes regarding both public and environmental health.

Guidelines for this assessment are the Colorado Department of Public Health and Environment's (CDPHE) Regulations 31 (CDPHE 2005a) and 38 (CDPHE 2005b). These Regulations include specific standards established for designated uses that were developed to protect humans for several uses (i.e., recreation) and to protect aquatic life. A summary of these standards is provided in Appendix A. The CDPHE standards were developed as directed by Section 25-8-102(2) of the Water Quality Control Act and are consistent with the Federal Clean Water Act.

Due to its proximity to the release of the 2004 Lakes Report, and expected completion of the 2006 Lakes Report (Spring 2007), this report will be a succinct summary of the 2005 monitoring results. It will present findings, highlight noteworthy results, and re-iterate the primary issues within the City's Lake System.

I.A. How to Use This Report

A list of commonly used acronyms and abbreviations is provided prior to the introduction, while a glossary in the back will assist with definitions of technical terms.

Field and laboratory procedures will not be provided in this report but are available within the 2003 and 2004 Lakes Reports. They are also provided in more detail within the DEH *Quality Assurance Project Plan (QAPP) and Sampling and Analysis Plan* (SAP) (DDEH 2006). Detailed information is also available upon request from the DEQ. Information concerning data management and quality assurance/quality control (QA/QC) is also addressed in the 2003 and 2004 Reports and in more detail in the DEH QAPP-SAP.

Section III presents the 2005 results with a brief discussion of the noteworthy findings and highlights based on the 2005 monitoring. The presentation is organized by lake groups which are based on the primary water source during the summer irrigation season (**Table 1-1**). Section IV presents sampling and laboratory analyses QA/QC results.

Tables that are designated with a single letter (i.e., Table A3) and Plates are situated after Section IV. Figures and tables designated by a section followed by a number (i.e., Table 3-1) are embedded within the immediate text to which they apply.

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

Subsidy Source / Lake	Surface Acres[1]	Perimeter (ft)	Primary Water Source Origin
Rocky Mountain Ditch			Clear Creek in Golden
Berkeley	36	4,810	
Rocky Mountain	24	4,870	
Sloans	176	14,780	
City Ditch[3/]			Recycled (re-use) water from Denver Water
Grasmere	16	4,350	
Smith	18	3,230	
Ferril	24	4,590	
Duck Pond	5	1,935	
Agricultural Ditch			Clear Creek in Golden
Harvey	5	2,030	
Garfield	5	2,820	
Huston	14	3,190	
South Platte River			South Platte River @ Florida Ave., Denver
Overland Pond	2	1,060	
AquaGolf	11	2,740	
Groundwater			
Vanderbilt	4	1,710	Possibly groundwater
Lollipop	4	2,210	Groundwater from north side of Garland Park
Miscellaneous			
Barnum	4	2,320	Weir Gulch – urban runoff
Parkfield	10	4,860	Storm runoff

1 Both acreage and perimeter only include surface water acreage, does not include islands

II. Sample Approach

Sixteen lakes were sampled at least once in 2005 to assess mid-summer conditions (**Table 2-1**). Because of its relatively high recreational use, Sloans Lake bacteria concentrations were sampled at weekly intervals from May 24th through September 20th. Analytes collected during routine mid-summer sampling events are summarized in **Table 2-2**.

For details on sample methodology, please refer to the 2004 Lake Report (DEH 2006, Section II), the DEH QAPP-SAP (DEH 2006), or contact the DEH's Division of Environmental Quality.

Table 2-1. Denver Lakes mid-summer sampling dates in 2005.

Subsidy Source / Lake	Mid-summer Sample Date	Miscellaneous sample notes for 2005
Rocky Mountain Ditch		
Berkeley	June 30	Chlorophyll-a on July 21
Rocky Mountain	June 28	None
Sloans	June 29	Weekly bacteria sampling
City Ditch[3/]		
Grasmere	July 14	None
Smith	July 14	None
Ferril	July 12	None
Duck Pond	July 12	TDP[1/] 8/24/05 to assess SolarBees[2/]
Agricultural Ditch		
Harvey	July 5	None
Garfield	July 5	None
Huston	June 28	None
South Platte River		
Overland Pond	July 19	None
AquaGolf	July 19	None
Groundwater & Miscellaneous		
Vanderbilt	July 7	Basic assessment and organics on 2/3/05[3/]
Lollipop	June 22	None
Miscellaneous		
Barnum	June 22	None
Parkfield	June 23	None

1/ "TDP" is temperature-dissolved oxygen profile (see glossary)
2/ SolarBees are solar powered water column mixing apparatus installed in June 2005
3/ Associated with Phase II Environmental Assessment by Brown and Caldwell (2005)

Table 2-2. Analytes routinely assessed during mid-summer monitoring visits

Field 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]	Hg, Mn, Mo, Ni,
>Secchi depth	-Nitrite[4]	Pb, Se, Zn
>Temperature- dissolved	-Nitrate[4]	
oxygen profile	-Total phosphorus[4]	>Total Metals[4]:
	-Ortho-phosphate	-Ag, Al, As, Cd,
	-Total Kjeldahl Nitrogen[4]	Cu, Cd, Cr, Fe,
	>Total solids	Hg, Mn, Mo, Ni,
	>Total dissolved solids	Pb, Se, Zn
	>Chloride	
	>Sulfate	>Total Recoverable Metals
	>*E. coli*	-Fe
	>Fecal coliform	
	>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 Severn Trent Laboratory (Arvada, CO) for analysis
4/ Analytes also assessed in sediments by Severn Trent Laboratory
5/ Processed by DEH personnel and delivered to Denver Water Board Laboratory for analysis

III. Findings - 2005

This year's report will provide a succinct presentation of the 2005 results. More extensive discussions of long term results, issues, and recommendations are available in both the 2003 and 2004 DEH Lake Reports.

The 2005 data is summarized in two formats. **Table 3-1** provides a qualitative summary of all parameters assessed in all lakes within one table. **Tables A1** through **A10** provide a quantitative summary of the 2005 sampling results and are located at the end of Section IV.

Results in Table 3-1 are not presented quantitatively, but are intended to provide the reader with one reference with which to characterize the Denver Lakes relative to water quality standards/guidance and to each other. For comparisons with all sampled lakes within the CCOD, the 85th percentile values (15th percentile for dissolved oxygen and secchi depth) based on 2005 sampling results were used to identify unique characteristics. These values were considered to be beyond what was typically measured in the urban lakes in 2005. This cutoff was selected merely as a measuring stick to highlight distinguishing characteristics among the lakes, and does not necessarily have significance regarding water and sediment quality standards, guidance, or human health.

Table 3-1 also highlights anlaytes that were measured at levels that exceeded or potentially exceeded CDPHE water quality standards and USEPA sediment guidance. Exceedance of the water quality standards and guidance does not necessarily translate to an immediate threat to human or environmental health, but highlights conditions that may warrant further attention from DEH and/or the CDPHE. USEPA sediment guidelines are based on sediment metal concentrations that are potentially harmful to aquatic life which does not necessarily infer risk to human health. Highlights from Table 3-1 will be discussed by each Water Source Group (**Table 1-1**). CDPHE water quality standards and USEPA sediment guidance exceedances for all lakes are also summarized in **Table A11**.

3.A. Rocky Mountain Ditch

3.A.1. Water Quality

The Rocky Mountain Ditch fed lakes include Berkeley, Rocky Mountain, and Sloans Lakes (**Plate A**). Water quality standard exceedances for these lakes in 2005 included:

- pH in Rocky Mountain Lake;
- arsenic in Berkeley Lake (fish ingestion-based standard); and
- dissolved oxygen in Sloans Lake (**Table 3-1**).

The **pH** and **dissolved oxygen** levels in lakes are naturally variable resulting in occasional exceedances of these values in several Denver Lakes over the past ten years. These parameters are both greatly influenced by *photosynthesis* and *decomposition*. Photosynthesis is the process by which plants and algae convert sun energy to growth. The pH values will rise as algae and submerged vegetation photosynthesize during the day. This often results in pH values greater than the CDPHE standard (pH of 9.0su; Regulation 31; CDPHE 2005a). The 2005 pH levels in

Table 3-1. Summary of results for the Denver Lakes in June/July 2005.

Ditch Source / Lake	pH[a/]	Temperature	DO	Conductivity	Alkalinity	Hardness	Ammonia (Nutrients)	UIA[b/] (Nutrients)	Nitrite (Nutrients)	Nitrate (Nutrients)	TIN[c/] (Nutrients)	TKN (Nutrients)	Total-P (Nutrients)	Ortho-P (Nutrients)	Chlorophyll-a	Secchi depth	DOC[d/]	TDS	TSS	*E. coli*	Fecal coliform	Metals – Aqueous – Dissolved[e/, f/]	Metals – Aqueous – Total[g/]	Metals – Sediment – Total
Rocky Mountain Ditch																								
Berkeley				Y	Y						G			Y	G	G	Y	Y	G			**As**[h/]; Mn	As, Mn	**As, Cu, Pb, Zn**; Cd, Cr, Hg
Rocky Mountain	R				Y	G					G		G			G	Y							**Cu, Pb, Zn**; Ag, Cd, Cr, Hg, Mo, Se, Tl
Sloans			Y				Y					Y				Y			Y			Al, As, Zn	**Fe**; Al, Cd, Cr, Pb, Zn	**Pb**
City Ditch																								
Grasmere									Y	Y	Y		G									**Cu**; Ag, Cd	Cu	
Smith	R				G					Y	Y		G									Ag, Cu, Mo, Zn	Mo	**Pb**, Se, Tl
Ferril	R		G							Y	Y		G						G			Pb		**Pb**; Cr
Duck	R		G				R	R	Y			Y	Y	Y	Y							Ni		Mo, Ni, Tl
Agricultural Ditch																								
Harvey	G			G				G			G						G	G					Fe	**Cu**; Al, Fe
Garfield				G							G	G					G			Y	Y	Al	Al	**Mn**; Al, Fe,
Huston	R			G	G	G					G	G			G	G		G	G			As, Mn, Pb		**Cu, Pb, Zn**; Al, As, Cd, Fe, Hg
South Platte																								
Overland						Y			Y				Y	Y	Y							Se, Zn	Cr	
AquaGolf	R											Y	Y		Y	Y			Y			Mo	Cr, Cu, Mo	
Miscellaneous																								
Barnum			R (hatched)				Y	G								Y			Y	R	R	Fe, Se	**Fe**; Al, Zn	
Vanderbilt				Y		Y											Y	Y				Cd, Mn, Mo, Ni	Mn, Mo, Ni	**Mn**; Pb, Mo
Lollipop	G		Y	Y	Y	Y						G					G	Y		Y	Y	**Se**; Mn	Mn	Se
Parkfield	R				G	G					G		G		G			G	G					

a/ [Green] <15th percentile (>85th percentile for DO and Secchi); [Yellow] >85th percentile (<15th percentile for DO and Secchi); [Red] exceeds standard; [Hatched red] exceeds criteria, inadequate sample to determine status regarding standards; [White] within the 15th to 85th percentile range of all Denver Lakes in 2004 and does not exceed the standard.

b/ UIA is Un-ionized ammonia; the ammonia standard is now based on total ammonia

c/ TIN is Total Inorganic Nitrogen which is the sum of ammonia, nitrite, and nitrate

d/ DOC is dissolved organic carbon

e/ listed = >85th percentile among Denver Lakes in 2004; **bold** = exceeds standard

f/ see Appx B for list of elements by symbol

g/ Iron (Fe) is based on total recoverable analyses

h/ based on Fish Consumption Standard

Rocky Mountain Lake were not immediately toxic to aquatic life or humans, but they were indicative of a lake system with productive growth of vegetation and/or algae. Mitigation of elevated pH levels can include implementation of practices that inhibit this productivity including:

- efficient and sparing use of herbicides/algaecides;
- water column mixing and aeration to inhibit nutrient availability;
- continued implementation of water quality management options that decrease nutrient loading in the lakes; and
- use of buffer zones/natural areas that decrease the potential for park maintenance activities to contribute nutrients and organic matter to the lake water column.

The decreased dissolved oxygen concentrations in lakes can also be influenced by the sunlight-dependent process of photosynthesis, the amount of productivity in the lake, and the amount of organic matter loading. The loading component results in decreasing dissolved oxygen as bacteria utilize it for fuel while decomposing organic matter. Low dissolved oxygen during the summer is often a result of high organic buildup combined with cloudy days. The Sloans Lake dissolved oxygen concentrations were below CDPHE water quality standards in 2005 (5mg/L-O_2) and also four of the past eight years during the mid-summer sample events (**Fig 3-1**). While this is a potential threat to fish, there have not been any reported widespread fish die-offs at Sloans Lake since annual sampling commenced in 1996.

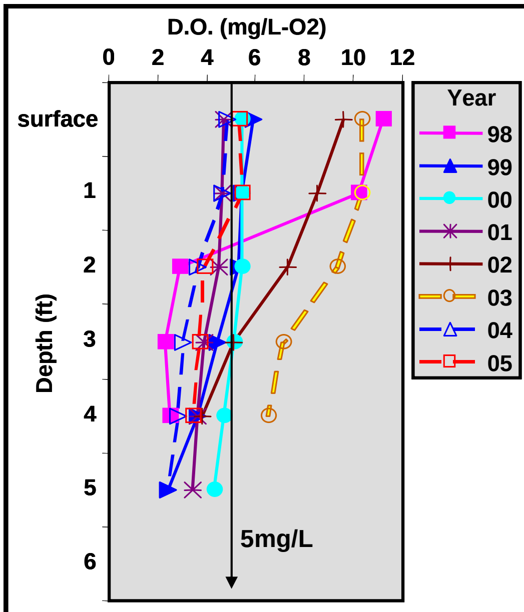

Fig 3-1. Dissolved oxygen profile for Sloans Lake from 1998-2005 (June/July). The arrow indicates 5mg/L-O_2.

Mitigation of the low dissolved oxygen in Sloans Lake could include several options ranging from aeration in several locations of the lake to dredging of the organic material from the lake bottom. Implementation of additional water quality initiatives such as the swale on the south side of the lake (near Xavier Street) will help minimize loading of organic material over time. Use of swales such as this provides an opportunity for the settling of solids and the uptake of nutrients by natural processes rather than depositing all of this into the lake.

The elevated **arsenic** levels in Berkeley Lake have been documented since DEH's annual lake sampling commenced in 1996. Analyses of fish-tissue from Berkeley Lake by the CDPHE have found that arsenic concentrations were acceptable for human consumption. However, mercury levels were found to be elevated and resulted in a CDPHE implemented fish consumption advisory for both Berkeley and Rocky Mountain Lakes. The fish consumption advisory was implemented March 2006 and applies to consumption of large mouth bass. This will be discussed more thoroughly in the 2006 Lakes Report.

Weekly sampling of bacteria in Sloans Lake included nineteen sample events of four sample locations on each event. Exceedance of the State's natural swim beach advisory level for bacteria (254 cfu/100ml; Colorado State Board of Health 1997) occurred on two of the nineteen sample days but resulted in a geometric mean well below the standard (**Fig 3-2**). The days when exceedances occurred followed heavy recreation activity (Dragonboat Festival-early August) and a moderate rain event (early September). The water quality was acceptable for recreation on seventeen of nineteen days sampled in 2005.

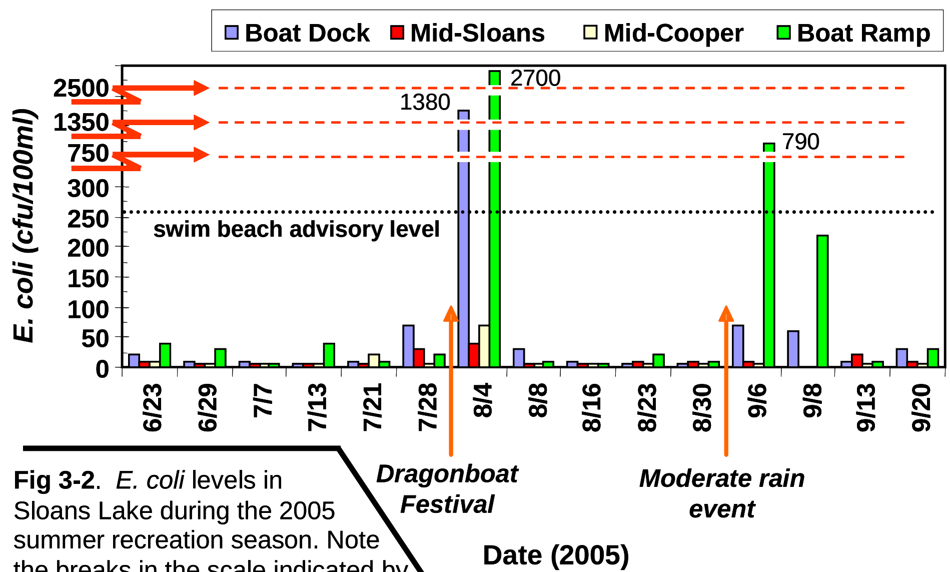

Fig 3-2. *E. coli* levels in Sloans Lake during the 2005 summer recreation season. Note the breaks in the scale indicated by the red arrows and dashed lines.

3.A.2. Sediment Quality

There were several sediment metal analytes in exceedance of USEPA guidance for impacts to aquatic life in the Rocky Mountain Ditch Lakes, including:

- arsenic, copper, lead, and zinc in Berkeley Lake;
- copper, lead, and zinc in Rocky Mountain Lake; and
- lead in Sloans Lake.

The elevated metal concentrations in Berkeley and Rocky Mountain Lakes were attributable, in part, to vehicle emissions from the interstate that borders the north side of the lakes. Elevated lead in several of the Denver Lake sediments (**Table A6**) is likely influenced by historic vehicle emissions. Most metals are also commonly discharged to lakes and streams via urban runoff. Sources of these metals are diverse, including runoff from roof tiles, lawn maintenance materials, and vehicle exhaust and components (i.e., brake pads) to name a few.

A continued emphasis on implementation of water quality management practices that mediate contaminant loading in urban runoff is one approach towards remediating this issue. This could include a combination of a variety of practices including but not limited to use of wetlands, swales, and online filtration approaches.

For a more quantitative summary of the 2005 findings, refer to Tables A1 through A10 located at the end of Section IV. These Tables provide a numeric summary of the 2005 sampling results including analytes from within the lakes (Table A1-A6), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A7-A10). Long term data is available on the DEH Division of Environmental Quality's website at: **http://www.denvergov.org/eac/template116895.asp**.

3.B. City Ditch Lakes

3.B.1. Water Quality

The City Ditch is maintained with recycled water from the Denver Water Board's treatment plant located in Commerce City. The City Ditch subsidizes lakes in Washington Park (Grasmere and Smith) and City Park (Ferril and Duck; Plate A). A summary of water quality standard exceedances indicated in Table 3-1 for these lakes include:

- pH for Smith, Ferril, and Duck Lakes;
- total ammonia and unionized ammonia in Duck Lake; and
- copper in Grasmere Lake.

The **pH** levels in lakes is naturally variable resulting in occasional exceedances in several Denver Lakes over the past ten years. Lake pH is greatly influenced by *photosynthesis*, the process by which plants and algae convert sun energy to growth. The pH values will rise as algae and submerged vegetation photosynthesize during the day. This often results in pH values greater than the CDPHE standard (pH of 9.0su; Regulation 31; CDPHE 2005a). The 2005 pH levels in Smith, Ferril, and Duck Lakes were not immediately toxic to aquatic life or humans, but they were indicative of lake systems with productive growth of vegetation and/or algae. Mitigation of elevated pH levels can include implementation of practices that inhibit this productivity including:

- efficient and sparing use of herbicides/algaecides;
- water column mixing and aeration to inhibit nutrient availability;
- continued implementation of water quality management options that decrease nutrient loading in the lakes; and
- use of buffer zones/natural areas that decrease the potential for park maintenance activities to contribute nutrients and organic matter to the lake water column.

Long term data indicates consistently high although variable **ammonia** concentrations in Duck Lake (**Fig 3-3**), even prior to conversion to recycled water (spring 2004). Since 1997, mid-summer ammonia concentrations in Duck Lake were measured at levels exceeding state water quality standards in 1998, 2000, and from 2003-2005[1]. Ammonia is an inorganic form of nitrogen that is toxic primarily to fish. The primary source of nitrogen to Duck Lake is waste from the intense bird use. Cormorants nest in the trees on the islands from March into September and there are many avian species (including the cormorants) that make use of the lake for feeding and other purposes through much of the year. It is possible that the elevated

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[1] Based on the USEPA 1999 ammonia update which calculates the standard based on pH, temperature, and total ammonia (USEPA 1999).

nitrates entering Duck Lake from Ferril Lake (via the City Ditch) are also impacting ammonia levels. However, the long term data suggest this is secondary to the bird-waste source.

Management actions that may help decrease ammonia concentrations include methods that decrease the source, and also approaches that alter the chemistry within the lake. To decrease the source, which is primarily the nesting cormorants and waterfowl feeding and loafing in the lake, is counter to the valuable wildlife viewing opportunity provided to park visitors. However, a more active outreach effort to keep visitors from feeding ducks and geese at the lake may provide some relief from this waste load.

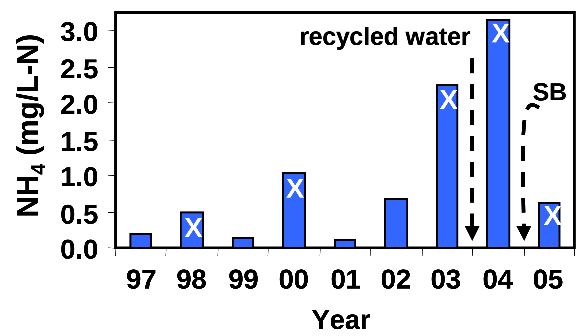


Fig 3-3. Total ammonia in Duck Lake from mid-summer sample events (June/July). 'X' denotes exceedance of the CDPHE standard (based on a calculation involving pH and temperature); the arrows denote the switch to recycled water and installation of SolarBee units (SB).

Approaches that alter lake water column chemistry would likely be more successful at decreasing ammonia levels. This can take the form of aeration and water column mixing. Aeration of portions of the lake was implemented in the 1990's and had continued until 2005 when two SolarBee units were installed in the lake. The ammonia levels exceeded water quality standards three of seven years while aeration was the primary mechanical management action (**Fig 3-3**). The SolarBees were installed approximately one year after City Ditch converted to use of recycled water. Ammonia concentrations were considerably lower in 2005 but still exceeded standards in both 2004 and 2005.

DEH would recommend the continued use of both aeration and the SolarBees to assess how effective they may be in ameliorating the chronically elevated ammonia levels in Duck Lake. The intensive bird activity may also necessitate careful use of algaecides to minimize the organic and nutrient load contributed by algal growth.

Nitrate levels in the Grasmere, Smith, and Ferril Lakes were all relatively high compared with the other Denver Lakes (**Table 3-1** and **Table A2**). This is a result of the elevated nitrate levels in the recycled water which is the source that now supplies City Ditch. This is of interest because of the role nitrate plays in lake productivity. Efforts to mitigate these impacts include the use of SolarBee water column mixing units in Ferril Lake[2]. An alternative approach could include routing the City Ditch water through surface or sub-surface wetlands to help decrease the nitrate loading in the City Ditch reliant lakes.

Elevated **copper** levels in Grasmere Lake had no long term basis and did not appear to be associated with any algae treatment. The filamentous algae was extremely thick in portions of the lake with no signs suggesting there had been a recent chemical application. All appropriate

[2] Originally installed in Grasmere Lake, moved due to planned renovations in 2006/07.

lab and field protocols were followed for collection of this sample; there are no results from previous years sampling efforts with elevated copper levels in Grasmere Lake. The 2006 sample results will help determine whether these results were an anomaly or were truly representative of current conditions.

3.B.2. Sediment Quality

The sediment quality for the City Ditch Lakes was relatively good with zero to three analytes exceeding the 85th percentile among all lakes (**Table 3-1** and **Table A6**). The only analyte measured in exceedance of the USEPA guidelines (2001 and 2002) in the City Ditch Lake sediments was lead in Smith and Ferril Lakes. While these values were in exceedance of the guideline, they were below the 85th percentile among all Denver Lakes.

Lead concentrations exceeded the USEPA guidelines for potential impacts to aquatic life in 6 of the 16 lakes sampled in 2005. Some likely sources of lead in these lake sediments are urban runoff and historical air deposition from vehicles.

While the lead is slightly elevated, there were no immediate concerns based on the 2005 sediment sampling results within the City Ditch Lakes.

For a more quantitative summary of the 2005 findings, refer to Tables A1 through A10 located at the end of Section IV. These Tables provide a numeric summary of the 2005 sampling results including analytes from within the lakes (Table A1-A6), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A7-A10). Long term data is available on the DEH Division of Environmental Quality's website at: **http://www.denvergov.org/eac/template116895.asp**.

3.C. Agricultural Ditch Lakes

3.C.1. Water Quality

The Agricultural Ditch is the source water for Harvey, Garfield, and Huston Lakes in southwest Denver (**Plate A**). A diversion on Clear Creek in Golden provides the base flow for Agricultural Ditch.

Elevated pH in Huston Lake was the single water quality standard exceedance among the Agricultural Ditch Lakes in 2005 (**Table 3-1**). This is not surprising in that Huston Lake was blanketed with submergent vegetation, primarily coontail (*Ceratophylum demersum*) and pond weed (*Potamogeton* spp.). Photosynthesis from the dense growth was likely the primary factor driving the elevated pH conditions.

Because sunlight reaches the bottom of most of the "lake", it promotes growth of submerged vegetation. It is in this manner that the "lake" actually functions more as a wetland. As a wetland, Huston "Lake" provides valuable habitat for waterfowl and other aquatic life that thrives under these conditions. Because wetlands acreage is rare in the Denver Metro area, the DEH recommends this be considered an asset and not a problem. The elevated pH poses no immediate threat to human health or aquatic life, the latter of which will be adapted to these conditions.

While bacteria levels were relatively high in Garfield Lake compared with other Denver Lakes (**Table A2**), this was based solely on a slightly elevated fecal coliform measurement that was well within acceptable limits regarding human health concerns.

There were only a handful of water column metal analytes that were measured in the 85th percentile among the Denver Lakes in 2005 (Table 3-1). None of these were at levels of concern.

3.C.2. Sediment Quality

Sediment quality of the Agricultural Ditch Lakes was comparable to other Denver Lakes in Harvey and Garfield, but was relatively poor in Huston Lake (**Table 3-1**). Analytes measured at values exceeding USEPA guidelines for probable effects to aquatic life included:

- copper in Harvey Lake;
- manganese in Garfield Lake; and
- lead, copper, and zinc in Huston Lake.

Also of note were the handful of metal analytes in the Huston Lake sediment that exceeded the 85th percentile among all Denver Lake sediments in 2005 (Table 3-1 and Table A6). While none of the latter metals exceeded guidelines (there are no established guidelines for some of these; **Table A11**), the relatively high concentration of metals in the Huston Lake sediment suggests unique conditions in this lake from the other metro area lakes. Two possible scenarios that could create this condition include historical practices in the area and/or relatively high amounts of urban runoff per acre of lake.

Because the water column metal concentrations within Huston Lake are generally acceptable, and vegetative growth appears to be uninhibited, the elevated sediment metal levels do not appear to be having a dramatic impact on ecological conditions in the lake. Metals tend to bind to the organic matter in the sediment and do not pose a risk to human health or the lake ecology under normal circumstances.

The elevated levels of **copper** in Harvey Lake sediment are likely a result of herbicide/ algaecide treatments within Harvey and Ward Reservoir #5. Because the outlet from Ward Reservoir #5 drains to Harvey Lake, management actions in that waterbody can influence conditions in the receiving lake. The copper concentrations in Harvey Lake do not pose a threat to human health.

Manganese concentrations in Garfield Lake sediment have been relatively high among the Denver Lakes over the past three years. It also seems to be a trend among the Denver Lakes with a deeper water column and/or a substantial *anaerobic* (low oxygen) layer overlying the sediment. Elevated manganese concentrations were also measured in Rocky Mountain, Berkeley, and Vanderbilt Lakes, all of which are greater than eight feet deep and often have greater than 2-3 feet of anaerobic water.

For a more quantitative summary of the 2005 findings, refer to Tables A1 through A10 located at the end of Section IV. These Tables provide a numeric summary of the 2005 sampling results including analytes from within the lakes (Table A1-A6), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A7-A10). Long term data is available on the DEH Division of Environmental Quality's website at: **http://www.denvergov.org/eac/template116895.asp**.

3.D. South Platte River Lakes

The South Platte River Lakes include Overland Pond and AquaGolf Lake in southwest Denver (**Plate A**). The water path for the lakes starts with a diversion from the South Platte River at Florida Street, flows into Overland Pond, and from Overland Pond into AquaGolf on the west side of the lake. AquaGolf serves as an irrigation source for the Overland Golf Course. Water is pumped from AquaGolf's south shore on the west end of the lake for this purpose.

3.D.1. Water Quality

Water quality in these two lakes is defined by conditions in the South Platte River which is significantly influenced by discharge from the Littleton/Englewood Wastewater Treatment Plant discharge approximately one mile upstream of the diversion to Overland Pond. Overland Pond and AquaGolf Lake tend to have relatively high total phosphorus concentrations and are very productive based on chlorophyll-a measurements (**Table 3-1**, **Tables A2** and **A3)**. Chlorophyll-a concentrations serve as a measure of algae productivity.

Elevated pH in AquaGolf was the only water quality standard exceedance measured in the two lakes in 2005. This was to be expected given the stagnant and productive conditions in AquaGolf. Water flow from Overland Pond had been compromised by blockage in the outlet pipe resulting in even less water exchange in AquaGolf. This resulted in the highest chlorophyll-a measurement from the Denver Lakes to date and would also contribute to subsequently elevated pH levels.

The elevated pH is one symptom of many that create marginal conditions for aquatic life in AquaGolf Lake. The minimal depth, elevated temperatures, poor water exchange, in addition to elevated phosphorus loading from the South Platte River combine to create excellent conditions for algae productivity. A capital project undertaken by the CCOD's Public Works Department in the fall of 2006 will divert additional storm runoff to the lake to accommodate storm events. This will potentially improve water exchange issues in the lake but with the tradeoff of potentially poor quality of incoming water. Future sampling will determine how this project will impact the lake water quality.

There were a few water column metal parameters in Overland Pond and AquaGolf Lake that exceeded the 85^{th} percentile among the Denver Lakes in 2005. None of these exceeded standards or were at levels of concern (**Table 3-1**).

3.D.2. Sediment Quality

Sediment quality of the South Platte River Lakes was surprisingly un-noteworthy relative to the other Denver Lakes in 2005. There were no metal analytes at levels of concern or that were greater than the 85^{th} percentile among all the Denver Lakes.

For a more quantitative summary of the 2005 findings, refer to Tables A1 through A10 located at the end of Section IV. These Tables provide a numeric summary of the 2005 sampling results including analytes from within the lakes (Table A1-A6), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A7-A10). Long term data is available on the DEH Division of Environmental Quality's website at: **http://www.denvergov.org/eac/template116895.asp**.

3.E. Miscellaneous Lakes

The miscellaneous sourced lakes can be broken into sub-groups of groundwater and urban runoff sustained lakes. Lollipop and Vanderbilt Lakes are both sustained primarily by interactions with groundwater. Lollipop Lake receives groundwater pumped from the north side of Garland Park while Vanderbilt lies within the groundwater table that is likely influenced by the South Platte River to the south and hydrogeologic interactions to the west. Vanderbilt Lake also receives urban runoff from the immediate surrounding area.

Barnum and Parkfield Lakes are both maintained primarily by urban runoff, but both interact with groundwater as well. Barnum Lake could be defined as an on-line reservoir on Weir Gulch, which is the primary source of water. Because it is situated at the base of a large hill that makes up much of Barnum Park, the lake is likely also influenced by seasonal groundwater discharges.

Parkfield Lake in northeast Denver was designed as a stormwater detention pond meant to serve a large basin. The base water level of three to four feet throughout the lake suggests this is the level of interaction with groundwater. Large storm events result in significant runoff to Parkfield Lake.

3.E.1. Water Quality

Exceedances of CDPHE water quality standards among the miscellaneous group of lakes in 2005 included:

- bacteria in Barnum Lake;
- pH in Parkfield Lake; and
- selenium in Lollipop Lake.

The **bacteria** levels measured in Barnum Lake in 2005 not only exceeded state water quality standards, but were the highest concentrations documented in the CCOD Lakes since the DEH Lake Sampling Program initiated annual monitoring in 1996. Data from 2003-2005 indicate a significant increase in bacteria concentrations and suggest a source other than routine urban runoff is contributing to the lake (**Fig 3-4**). Possible sources include illicit discharge[3] from sanitary to storm system and Weir Gulch; wildlife, primarily geese but also waterfowl use of the park and lake; or other unaccounted for practices within the drainage basin.

The elevated bacteria levels likely contributed to depressed dissolved oxygen conditions measured in the lake in 2005. The 2005 dissolved oxygen levels in Barnum Lake were anaerobic throughout much of the water column in the mid-portion of the lake. An exceedance of the dissolved oxygen standard requires a representative number of samples to make a determination. Based on long term data, the Barnum Lake water column is not exceeding this standard. However, the increasing bacteria levels have likely reached a point that will result in long term dissolved oxygen problems that will be an exceedance of the water quality standard.

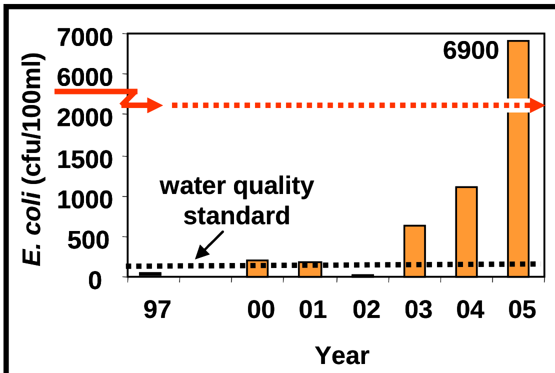


Fig 3-4. E. coli in Barnum Lake from mid-summer sample events (June/July). Note the break in the Y-axis and the CDPHE water quality standard. There was no monitoring in 1998-99 due to renovations.

To help determine excessive bacterial contributions to Barnum Lake, DEH sampled from various locations in Weir Gulch between the lake and Sheridan Boulevard beginning in the spring of 2006. This sampling is performed approximately bi-monthly and will be continued up to a year to determine if there may be illicit connections within the storm drainage system.

Additional developments that helped discern bacterial impacts to Barnum Lake include a routine response by DEH employees to a residential complaint that identified a CCOD management activity that had been contributing to the bacteria loading of the lake. This practice has now been stopped.

It has been recommended that the Department of Parks and Recreation consider purchasing a water column mixing agent or install a more elaborate aeration system to help improve dissolved oxygen conditions in the lake. This could help decrease stagnant conditions and help maintain oxygen levels at the water-sediment interface that will speed decomposition of organic matter that contributes to odor complaints from nearby residents.

The elevated **pH** in Parkfield Lake is routine for habitats such as that provided by this lake. Because sunlight reaches the bottom of most of the "lake", it promotes growth of submerged vegetation. It is in this manner that the "lake" actually functions more as a wetland. As a wetland, Parkfield "Lake" provides valuable habitat for waterfowl and other aquatic life that thrives under these conditions. Because wetlands acreage is rare in the Denver Metro area, the DEH recommends this be considered an asset and not a problem. The elevated pH poses no

[3] A non-permitted connection from a sanitary sewer to the storm sewer; could also be a leak in the sanitary system that has infiltrated the storm sewer system.

immediate threat to human health or aquatic life, the latter of which will be adapted to these conditions.

The exceedance of the **selenium** water quality standard in 2005 was the first documented exceedance for this analyte in Lollipop Lake since analysis of dissolved metals commenced in 2002. This level of selenium poses no risk to human health; the exceedance is based on an aquatic life standard. Newly proposed selenium water quality standards would be based on fish tissue analyses (USEPA 2006). It is unlikely that levels recorded in Lollipop Lake will result in an exceedance of the recently proposed standard.

The source of selenium is likely naturally occurring in the surrounding soils and sediment and may also be influenced by the actively pumped groundwater to the lake (see 3.E.2. below). The 2005 selenium levels would warrant putting Lollipop Lake on the list of potential sites for future fish tissue analyses.

3.E.2. Sediment Quality

Noteworthy sediment quality findings within the four miscellaneous grouped lakes were limited to an exceedance of the USEPA manganese guidelines and relatively elevated lead and molybdenum in Vanderbilt Lake. In general, the 2005 sediment metal concentrations in Vanderbilt Lake were lower than concentrations recorded in 2004 (CCOD 2006).

A Phase II Environmental Site Assessment and Characterization report was produced by Brown and Caldwell for CCOD on Vanderbilt Park and Lake in April 2005 (Brown and Caldwell 2005). Sampling was conducted in December 2004 and February 2005. Some of their findings regarding the lake sediments included:

- sediment lead concentrations exceeded CDPHE *Soil Residential/unrestricted Use Direct Exposure Standards* (CDPHE 2003) in four of nine samples;
- several organic constituents (i.e., polycyclic aromatic hydrocarbons) were detected in the sediment; and
- *TEPH*[4] concentrations were detected at high concentrations in five of nine sediment samples.

One purpose for the Brown and Caldwell investigation was to help determine cleanup needs within the lake. Planned cleanup of Vanderbilt Lake will include some remediation of the sediment based on findings from the Brown and Caldwell work (2005) and previous investigations by DEH (CCOD 2005, 2006). Cleanup negotiations will determine future actions on the Vanderbilt Lake sediments.

For a more quantitative summary of the 2005 findings, refer to Tables A1 through A10 located at the end of Section IV. These Tables provide a numeric summary of the 2005 sampling results including analytes from within the lakes (Table A1-A6), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A7-A10). Long term data is available on the DEH Division of Environmental Quality's website at: **http://www.denvergov.org/eac/template116895.asp**.

[4] Total Extractable Petroleum Hydrocarbons

IV. 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 2005 QA/QC included three sets of replicates collected for parameters analyzed at the CCOD's Wastewater Management (DWMD) Laboratory (**Table A12**) and one replicate for metals parameters (**Table A13-c**) at Severn Trent Laboratory (STL).

Results within 85% of the replicates were considered to have achieved objectives for data quality. The three DWMD replicates were generally favorable with some analytes reported at below the 85 percent criteria on the 7/19/05 samples (**Table A12**). The variability of bacteria requires less stringent criteria. Bacteria replicates within 50% similarity are considered acceptable.

Replicates for metals analyses included both the dissolved and total partitions. The dissolved metal analytes that were below 85 percent included iron and zinc (**Table A13-c**); the latter may have been partially attributable to low concentrations. The total aluminum, chromium, and iron were all less than 85 percent similar to the replicates. The aluminum value was the most notable with only 36% similarity between the two samples.

Field and Laboratory Equipment Blanks

In addition to a replicate sample for metals, one set of field blanks for water metals (**Table A13-a**) and one set of laboratory blanks (**Table A13-b**) were collected for water and sediment metals. Laboratory blanks are deionized water samples poured from the beta bottle (water sample collection apparatus) into a sample container and sterile sand samples collected from the eckman dredge and transferred to a sample container. Field blanks are similar to laboratory blanks but are collected in the field after the equipment has been decontaminated. The field and lab-equipment blanks are performed to assess potential for contamination within the sampling equipment (assess equipment decon) and/or the laboratory processing. Criteria for acceptable QA for field blanks was:

- results were below detection; or
- less than 10% of the 15th percentile among all Denver Lakes in 2005.

Results from the field-equipment blanks came back favorably with all analytes for both dissolved and total constituents meeting the criteria (**Table A13-a**).

Two analytes, dissolved copper and total iron were reported at levels that did not meet the criteria for the laboratory blanks (**Table A13-b**). All sediment laboratory blanks were reported at acceptable levels.

V. Summary

A summary of findings based on the 2005 monitoring effort include:

- Seven of the sixteen sampled lakes had pH levels in exceedance of water quality standards;
- Exceedance of the arsenic fish ingestion water quality standard in Berkeley Lake;
- Large mouth bass mercury tissue concentrations exceeded acceptable consumption guidelines;
- Bacteria levels in Sloans Lake were acceptable for recreational purposes on 17 of 19 sample events spanning May 24 through September 20, 2006;
- Nitrate levels were relatively high in three of the four City Ditch Lakes (Grasmere, Smith, and Ferril);
- Ammonia concentrations in Duck Lake exceeded water quality standards;
- Huston and Parkfield conditions representative of wetlands rather than lakes[5];
- Chlorophyll-a concentrations in South Platte Lakes relatively high;
- Barnum Lake bacteria (*E. coli*) levels exceeding water quality standards;
- Selenium levels in Lollipop Lake exceeded water quality standards; and
- Organic contaminants in Vanderbilt Lake at potentially harmful concentrations.

These findings are also presented in Table E-1 (within the executive summary, page ii) with further comments, recommendations, and a summary of DEH actions to help remedy the issues.

Future reports will use this abbreviated format but will include a detailed analysis of results from two to four lakes per year. This approach will allow for a five year cycle by which to address each lake on a long term basis.

The DEH would like to hear your comments on our Lakes Monitoring Program. Some suggested topics for response include:

- Sample approach;
- Reporting; and
- How our program could better serve your needs.

Please feel free to give the DEH Division of Environmental Quality your comments/questions on these topics or others at 720-865-5452 or via email (alan.polonsky@ci.denver.co.us).

[5] These waterbodies are dominated by shallow depths with light penetrating to the bottom sediments and have limited water exchange. These conditions are conducive to establishment of submerged and emergent vegetation which creates excellent habitat for a variety of wildlife. The paucity of wetland habitat in the Denver metro area makes these habitats increasingly valuable for wildlife and associated recreation uses.

Tables

2005 Data (Tables A1 through A13)

Table A1. Physicochemical results for Denver Lakes, June/July 2005. Bolded values potentially exceed CDPHE water quality standards.

Lake	Date	# Sites[a/]	pH (su)	Temp (°C)	D.O.[b/] (mg/L-O_2)	Cond (uS/cm)	Alk (mg/L-$CaCO_3$)	Hard (mg/L-$CaCO_3$)	DOC (mg/L-C)	TDS (mg/L)	TSS (mg/L)
Rocky Mountain Ditch											
Berkeley	6/30/05	3	8.1	23.1	7.1	1167	277	140	14.0	676	4
Rocky Mntn	6/28/05	3	**9.3**	24.3	19.6	708	200	63	14.5	440	26
Sloans	6/29/05	6	7.9	22.4	**4.0**	759	166	143	10.2	459	59
City Ditch											
Grasmere	7/14/05	3	8.6	25.4	10.8	941	82	135	8.7	640	17
Smith	7/14/05	3	**9.6**	27.8	18.8	896	65	105	10.2	552	12
City Park	7/12/05	3	**9.6**	25.5	19.3	879	66	106	10.9	541	4
Duck	7/12/05	2	**9.7**	26.7	25.9	948	122	148	9.9	554	7
Agricultural Ditch											
Harvey	7/5/05	3	7.7	22.0	6.6	380	105	118	6.4	202	18
Garfield	7/5/05	3	8.3	22.6	6.8	390	83	105	7.5	242	16
Huston	6/28/05	2	**10.0**	23.3	8.4	261	65	74	11.1	194	15
South Platte River											
Overland	7/19/05	2	8.9	23.5	14.7	666	115	187	8.8	511	31
Aquagolf	7/19/05	3	**10.0**	25.3	16.9	531	80	127	12.2	341	52
Miscellaneous											
Barnum	6/22/05	4	7.8	20.9	**0.6**	546	153	115	13.4	319	35
Vanderbilt	7/7/05	4	8.1	23.2	11.1	1098	196	283	15.9	680	23
Lollipop	6/22/05	2	7.4	21.7	5.6	1353	200	426	6.4	859	8
Parkfield	6/23/05	3	**9.8**	22.7	8.3	496	61	74	9.7	193	1
		min:	7.4	20.9	0.6	261	61	63	6.4	193	1
		max:	10.0	27.8	25.9	1353	277	426	15.9	859	59
		15th percentile:	7.8	22.1	5.8	417	65	81	7.8	212	5
		85th percentile:	9.8	25.5	19.2	1060	199	177	13.8	667	34
		median:	8.8	23.3	9.6	733	110	123	10.2	485	17

a/ Values are based on the average of 2-5 sites per lake

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

Table 2A. Nutrient,bacteria, and associated parameter results for Denver Lakes, June/July 2005. Bolded values exceed CDPHE water quality standards.

Lake	Date	# Sites[a/]	pH[b/] (su)	NH_4	UIA	NO_2	NO_3	TIN	TKN	T-P	O-P	Chlor-a (ug/L)	Secchi Depth (in)	Ecoli	Fecal
				- - - - - - - - - - -	- (mg/L-N)	- - - - - - - - - - -				- (mg/L-P) -				(#col/100ml)	
Rocky Mountain Ditch															
Berkeley	6/30/05	3	8.1	<0.10	<0.009	<0.01	<0.20	<0.31	1.17	0.30	0.23	7.6	58.7	<10	<10
Rocky Mntn	6/28/05	3	**9.3**	<0.10	<0.052	<0.01	<0.20	<0.31	1.93	0.08	0.08	56.8	46.0	<10	<10
Sloans	6/29/05	6	7.9	0.84	0.025	0.04	<0.20	<1.08	2.56	0.25	0.15	20.1	9.3	<15	<15
City Ditch															
Grasmere	7/14/05	3	8.6	<0.10	<0.025	0.25	8.88	<9.23	1.43	<0.08	<0.08	13.2	35.3	<10	10
Smith	7/14/05	3	**9.6**	<0.10	<0.071	0.13	5.02	<5.25	2.03	<0.08	<0.08	52.7	23.5	<10	<10
City Park	7/12/05	3	**9.6**	<0.10	<0.070	0.14	4.94	<5.18	1.93	<0.08	nm[c/]	66.2	21.0	<10	<10
Duck	7/12/05	2	**9.7**	**0.63**	**0.456**	0.31	1.25	2.19	4.00	0.69	0.40	135.3	18.5	<10	<10
Agricultural Ditch															
Harvey	7/5/05	3	7.7	<0.10	<0.002	<0.01	<0.20	<0.31	1.01	0.11	<0.08	44.8	21.3	20	20
Garfield	7/5/05	3	8.3	<0.10	<0.009	<0.01	<0.20	<0.31	1.00	<0.13	<0.08	22.5	23.7	20	60
Huston	6/28/05	2	**10.0**	<0.10	<0.081	<0.01	<0.20	<0.31	1.00	<0.10	<0.08	6.0	45.0	<10	<10
South Platte River															
Overland	7/19/05	2	8.9	<0.10	<0.029	0.23	4.44	<4.77	2.10	0.79	0.56	153.6	20.0	10	40
Aquagolf	7/19/05	3	**10.0**	<0.10	<0.085	0.03	<0.31	<0.44	3.15	0.45	<0.08	337.8	9.7	<10	<10
Miscellaneous															
Barnum	6/22/05	4	7.8	0.18	0.004	0.13	1.01	1.32	1.36	0.19	0.12	9.9	12.8	**6,900**	**24,400**
Vanderbilt	7/7/05	4	8.1	<0.10	<0.005	0.02	<0.20	<0.32	1.50	0.09	0.08	40.8	23.5	<10	10
Lollipop	6/22/05	2	7.4	0.12	0.001	<0.01	<0.20	<0.33	<1.00	0.10	<0.08	18.2	29.0	70	150
Parkfield	6/23/05	3	**9.8**	<0.10	<0.073	<0.01	<0.20	<0.31	<1.00	<0.08	<0.08	1.3	37.3	<10	<10
		min:	7.7	<0.10	<0.001	0.01	0.20	0.31	1.00	0.08	0.08	1.3	9.3	10	10
		max:	10.0	0.84	0.456	0.31	8.88	9.23	4.00	0.79	0.56	337.8	58.7	6900	24400
		15th percentile:	7.8	<0.10	0.004	0.01	0.20	0.31	1.00	0.08	0.08	8.2	14.2	10	10
		85th percentile:	9.7	0.16	0.079	0.21	4.82	5.08	2.44	0.41	0.22	118.0	43.1	20	55
		median:	8.8	0.10	0.027	0.03	0.20	0.38	1.47	0.11	0.08	31.6	23.5	10	10

a/ Values are based on the average of 2-5 sites per lake

b/ NH4=total ammonia; UIA=unionized ammonia; NO2=nitrite; NO3=nitrate; TKN=total kjeldahl nitrogen; Tot-P=total phosphorus; O-P=ortho-phosphate; Chlor-a=chlorophyll-a; Ecoli= Escherecia coli; Fecal=fecal coliform

c/ not measured

Table A3. Summary of Trophic Status Index (TSI) values for Denver Lakes from June/July 2005.

		Category			Numeric value[a]		
lake	date	secchi[b]	TP	chlor-a	secchi	TP	chlor-a
Rocky Mountain Ditch							
Berkeley	6/30/05	E[c]	H	M	54	86	50
Rocky Mntn	6/28/05	E	E	E	58	67	70
Sloans	6/29/05	H	H	E	81	84	60
City Ditch							
Grasmere	7/14/05	E	E	E	62	67	56
Smith	7/14/05	E	E	E	67	68	69
City Park	7/12/05	E	H	H	69	71	72
Duck	7/12/05	H	H	H	71	89	79
Agricultural Ditch							
Harvey	7/5/05	E	H	E	69	72	68
Garfield	7/5/05	E	H	E	67	75	61
Huston	6/28/05	E	H	M	58	71	48
South Platte River							
Overland	7/19/05	E	H	H	70	100	80
Aquagolf	7/19/05	H	H	H	80	92	88
Miscellaneous							
Barnum	6/22/05	H	H	E	76	80	53
Vanderbilt	7/7/05	E	E	E	67	68	67
Lollipop	6/22/05	E	E	E	64	70	59
Parkfield	6/23/05	E	E	O	61	68	33

a/ TSI value calculations from Carlson 1977
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)

Table A4. Summary of mid-summer water column dissolved metal concentrations (ug/L) from Denver Lakes in June/July 2005. Bolded values indicate results that exceeded CDPHE standards. The summary statistics (median, 15[th] and 85[th] percentiles) considered values below detection to be equal to the detection limit.

lake	date	site	time	hard[a/]	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																			
Berkeley	6/30/05	BER-M	0940	140	< 0.01	B 28	**22.0**	< 0.04	< 0.82	2.2	21	< 0.04	140	B 8.4	< 1.2	B 0.44	B 0.8	< 0.02	< 4.4
Rocky Mntn	6/28/05	RMT-M	1155	66	< 0.01	< 17	B 2.7	< 0.04	< 0.82	B 1.8	B 26	< 0.04	B 5	< 5.3	JB R	B 0.09	0.3	< 0.02	< 4.4
Sloan	6/29/05	SLN-4	0950	142	< 0.01	B 40	5.5	< 0.04	< 0.82	B 1.7	21	< 0.04	B 1	B 10.0	< 1.2	B 0.70	B 0.9	< 0.02	B 14.0
City Ditch																			
Grasmere	7/14/05	GRS-M	0940	121	B 0.31	< 17	B 2.5	B 0.07	< 0.82	**63.0**	B 24	< 0.04	< 1	B 11.0	B 3.4	B 0.14	B 2.0	< 0.02	B 6.7
Smith	7/14/05	SMT-M	1240	103	B 0.07	B 18	B 3.2	B 0.05	< 0.82	3.0	B 21	< 0.04	< 1	B 16.0	B 2.9	B 0.27	B 1.5	< 0.02	B 14.0
Ferril	7/12/05	CPL-M	1100	105	< 0.01	B 20	B 2.8	B 0.06	< 0.82	2.5	JB R	< 0.04	< 1	B 11.0	B 3.5	1.00	B 2.2	< 0.02	B 9.5
Duck	7/12/05	DKL-O	1250	150	< 0.01	B 21	B 3.3	< 0.04	< 0.82	B 1.7	JB R	< 0.04	B 1	B 13.0	B 4.0	B 0.27	B 2.0	< 0.02	B 5.8
Agricultural Ditch																			
Harvey	7/5/05	HRV-M	1000	119	< 0.01	B 23	B 4.9	< 0.04	< 0.82	B 0.8	B 28	< 0.04	< 1	B 7.0	< 1.2	0.09	B 0.4	B 0.04	< 4.4
Garfield	7/5/05	GAR-M1	1245	104	< 0.01	B 31	B 2.5	< 0.04	< 0.82	B 1.1	B 31	< 0.04	< 1	B 5.3	< 1.2	0.09	0.3	< 0.02	< 4.4
Huston	6/28/05	HST-M	0925	75	< 0.01	< 17	6.5	< 0.04	< 0.82	B 1.8	120	< 0.04	23	< 5.3	JB R	B 0.96	0.3	< 0.02	< 4.4
South Platte River																			
Overland	7/19/05	OVL-M	0945	187	< 0.02	< 17	B 1.3	< 0.04	< 0.82	2.6	B 25	< 0.04	B 3	B 15.0	< 1.2	B 0.13	B 2.5	JB R	B 12.0
AquaGolf	7/19/05	AQG-M	1130	125	< 0.02	< 17	B 1.7	< 0.04	< 0.82	2.8	B 21	< 0.04	B 2	B 16.0	< 1.2	B 0.23	B 1.7	< 0.01	< 4.4
Miscellaneous																			
Barnum	6/22/05	BAR-M	1235	114	< 0.01	B 29	B 2.3	< 0.04	< 0.82	2.7	B 51	< 0.04	20	< 5.3	B 1.6	B 0.13	B 2.6	< 0.02	B 9.1
Vanderbilt	7/7/05	VBT-M	1010	283	< 0.01	< 17	B 1.4	B 0.17	< 0.82	B 0.8	B 26	< 0.04	72	180.0	B 4.1	B 0.13	B 1.4	< 0.02	< 4.4
Lollipop	6/22/05	LOL-M	1000	426	< 0.01	< 17	B 3.0	< 0.04	< 0.82	B 1.0	B 50	< 0.04	230	< 5.3	< 1.2	0.09	**5.0**	< 0.02	< 4.4
Parkfield	6/23/05	PFL-M	1000	70	< 0.01	B 21	B 2.2	< 0.04	< 0.82	B 0.8	B 30	< 0.04	B 10	< 5.3	B 1.2	0.09	0.3	< 0.02	< 4.4
				median:	< 0.01	19	2.8	< 0.04	< 0.82	1.8	26	< 0.04	2	9.2	< 1.2	0.14	1.5	< 0.02	< 4.4
				15[th] percentile:	< 0.01	< 17	1.8	< 0.04	< 0.82	0.9	21	< 0.04	< 1	< 5.3	< 1.2	0.09	0.3	< 0.02	< 4.4
				85[th] percentile:	< 0.02	29	5.4	0.06	< 0.82	2.8	50	< 0.04	60	15.8	3.5	0.64	2.4	< 0.02	11.4

a/ hard = water hardness in mg/L-$CaCO_3$

b/ "**<**" = less than the detection limit; "B" = the result was below the reportable limit and is considered an estimate; "**J**" = method blank associated with this result contained the analyte at less than 20% of the result; "B" = the result was below the reportable limit and is considered an estimate; "**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 A5. Summary of mid-summer water column dissolved metal concentrations (ug/L) from Denver Lakes in June/July 2005. Bolded values indicate results that exceeded CDPHE standards. The summary statistics (median, 15th and 85th percentiles) considered values below detection to be equal to the detection limit.

Lake	Site	Date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																	
Berkeley	BER-M	6/30/05	JB R	240	17.0	< 0.45	< 0.82	< 4.5	150	< 0.04	180	B 6.1	< 1.2	< 2.2	< 4.4	< 4.9	B 4.4
Rocky Mntn	RMT-M	6/28/05	< 0.7	B 28	< 4.4	< 0.45	< 0.82	< 4.5	B 47	< 0.04	10	B 5.7	< 1.2	< 2.2	< 4.4	< 4.9	B 14.0
Sloan	SLN-4	6/29/05	< 0.7	3900	B 5.7	B 0.59	B 3.30	10.0	**2200**	< 0.04	J 100	B 6.7	B 3.4	16.0	< 4.4	< 4.9	J 33.0
City Ditch																	
Grasmere	GRS-M	7/14/05	< 0.7	B 60	< 4.4	< 0.45	< 0.82	78.0	130	< 0.04	B 9.9	B 9.6	B 3.0	< 2.2	< 4.4	< 4.9	JB R
Smith	SMT-M	7/14/05	< 0.7	B 93	< 4.4	< 0.45	< 0.82	< 4.5	110	< 0.04	B 8	B 15.0	B 3.9	< 2.2	< 4.4	< 4.9	JB R
Ferril	CPL-M	7/12/05	< 0.7	140	< 4.4	< 0.45	< 0.82	< 4.5	210	< 0.04	B 7.2	B 12.0	B 3.8	< 2.2	< 4.4	< 4.9	JB R
Duck	DKL-O	7/12/05	< 0.7	400	< 4.4	< 0.45	< 0.82	< 4.5	240	< 0.04	43	B 12.0	B 4.1	3.4	< 4.4	< 4.9	B 17.0
Agricultural Ditch																	
Harvey	HRV-M	7/5/05	J R	J 770	B 5.8	< 0.45	< 0.82	4.5	910	< 0.04	150	B 5.3	B 1.6	< 2.2	< 4.4	< 4.9	JB R
Garfield	GAR-M1	7/5/05	JB R	J 890	B 4.6	< 0.45	< 0.82	4.5	810	< 0.04	120	< 5.3	B 1.9	< 2.2	< 4.4	< 4.9	JB R
Huston	HST-M	6/28/05	< 0.7	B 22	B 6.4	< 0.45	< 0.82	4.5	210	< 0.04	46	< 5.3	< 1.2	< 2.2	< 4.4	< 4.9	B 4.7
South Platte River																	
Overland	OVL-M	7/19/05	< 0.7	J 490	< 4.4	< 0.45	B 0.98	< 4.5	480	< 0.04	110	B 14.0	B 2.5	< 2.2	< 4.4	JB R	B 12.0
AquaGolf	AQG-M	7/19/05	< 0.7	J 770	< 4.4	< 0.45	B 0.94	B 6.3	610	< 0.04	46	B 15.0	B 1.7	3.6	< 4.4	< 4.9	B 13.0
Miscellaneous																	
Barnum	BAR-M	6/22/05	< 0.7	1900	< 4.4	< 0.45	< 0.82	B 4.9	**2700**	B R	110	< 5.3	B 2.0	3.6	< 4.4	< 4.9	24.0
Vanderbilt	VBT-M	7/7/05	< 0.7	B 43	< 4.4	< 0.45	B 0.84	< 4.5	130	nm	460	180.0	B 4.3	< 2.2	< 4.4	< 4.9	B 4.7
Lollipop	LOL-M	6/22/05	< 0.7	200	< 4.4	< 0.45	< 0.82	< 4.5	240	B R	370	< 5.3	B 1.4	< 2.2	< 4.4	< 4.9	< 4.4
Parkfield	PFL-M	6/23/05	< 0.7	B 34	< 4.4	< 0.45	< 0.82	4.5	B 60	< 0.04	22	< 5.3	< 1.2	< 2.2	< 4.4	< 4.9	B 7.1
		median:	< 0.7	220	< 4.4	< 0.45	< 0.82	< 4.5	225	< 0.04	73	6.4	2.0	< 2.2	< 4.4	< 4.9	12.0
		15%:	< 0.7	36	< 4.4	< 0.45	< 0.82	< 4.5	115	< 0.04	10	< 5.3	< 1.2	< 2.2	< 4.4	< 4.9	4.6
		85%:	< 0.7	860	5.8	< 0.45	0.92	6.0	885	< 0.04	173	14.8	3.9	3.6	< 4.4	< 4.9	20.5

a/ hard = water hardness in mg/L-$CaCO_3$

b/ "**<**" = less than the detection limit; "B" = the result was below the reportable limit and is considered an estimate; "**J**" = method blank associated with this result contained the target analyte at less than 20% of the result; "B" = the result was below the reportable limit and is considered an estimate; "**R**" = measured value considered unreportable by DEH because the method blank associated with this result contained the target analyteat greater than 20% of the result and/or measured value is less than 50% of the method reporting limit.

c/ All iron values are total recoverable with the exception of Harvey and Garfield Lakes, which are total.

d/ "*nm*" indicates the analyte was not measured

Table A6. Summary of sediment total metal concentrations (ug/g) from Denver Area Lakes in 2005. Bolded values are indicative of results that exceeded federal guidance.

Lake	Site	Date	Time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																		
Berkeley	BER-M	6/30/05	0940	B **3.5**	34000	**44**	3.5	36	**220**	J 36000	0.48	1100	B 4.7	22	**330**	4.5	3.4	**680**
Rocky Mntn	RMT-M	6/28/05	1155	**3.5**	36000	19	4.3	38	**190**	J 36000	0.40	J 1200	B 13.0	B 26	**320**	6.2	4.7	J **700**
Sloans	SLN-4	6/29/05	0950	2.5	27000	8	B 1.4	27	86	J 29000	0.27	770	B 1.6	B 17	**210**	4.5	3.4	350
City Ditch																		
Grasmere	GRS-M	7/14/05	0940	0.7	J 8500	2	0.0	10	10	J 11000	B 0.01	J 110	B 0.6	B 5.1	11	1.2	0.9	J 41
Smith	SMT-M	7/14/05	1240	3.1	J 26000	14	0.2	32	87	J 31000	0.25	J 420	B 9.9	B 18	**150**	B 6.0	4.2	J 380
Ferril	CPL-M	7/12/05	1100	1.5	33000	8	B 0.8	37	69	J 35000	0.26	260	B 6.0	20	**200**	2.7	2.0	J 350
Duck	DKL-O	7/12/05	1250	2.9	34000	8	B 0.4	33	74	J 34000	B 0.08	400	16.0	B 23	100	5.3	4.0	J 310
Agricultural Ditch																		
Harvey	HRV-M	7/5/05	1000	2.0	43000	18	B 0.5	23	**160**	J 44000	B 0.04	1200	B 3.5	17	40	3.6	2.7	150
Garfield	GAR-M1	7/5/05	1245	2.4	52000	9	B 1.1	24	97	J 49000	B 0.12	**1400**	B 2.2	B 17	83	4.3	3.2	280
Huston	HST-M	6/28/05	0925	B 2.8	42000	23	4.0	27	**200**	J 45000	0.44	J 510	7.4	20	**320**	2.6	2.0	J **610**
South Platte River																		
Overland	OVL-M	7/19/05	0945	1.9	J 23000	4	B 0.6	30	83	J 27000	0.14	J 890	B 5.6	B 15	57	B 3.6	2.5	240
AquaGolf	AQG-M	7/19/05	1130	1.3	J 16000	4	B 0.4	18	89	J 20000	B 0.06	J 280	5.9	11	37	B 3.4	1.8	110
Miscellaneous																		
Barnum	BAR-M	6/22/05	1235	1.6	J 30000	8	B 1.4	27	83	J 31000	B 0.10	540	B 2.3	18	J 110	B 3.4	2.2	410
Vanderbilt	VBT-M	7/7/05	1010	2.0	7500	6	B 1.6	17	45	J 13000	0.34	J **2800**	460.0	B 12	**130**	3.7	2.8	410
Lollipop	LOL-M	6/22/05	1000	1.5	J 13000	4	B 0.3	9	24	J 16000	B 0.03	510	B 1.3	B 7	J 20	6.4	2.0	71
Parkfield	PFL-M	6/23/05	1000	2.6	J 35000	7	B 0.3	31	31	J 33000	B 0.03	560	B 3.5	21	J 24	4.6	3.5	120
			median:	< 2.2	31500	8	0.7	27	85	32000	0.13	550	5.2	18	105	4.0	2.8	330
			15%:	< 1.5	13750	4	0.3	17	35	17000	0.03	310	1.8	11	27	2.9	2.0	113
			85%:	3.1	40500	19	3.0	35	183	42000	0.39	1200	12.2	22	293	5.8	3.9	560

a/ "**<**" = less than the detection limit; "B" = the result was below the reportable limit and is considered an estimate; "**J**" = method blank associated with this result contained the target analyte at less than 20% of the result; "B" = the result was below the reportable limit and is considered an estimate; "**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 A7. Physicochemical results for the inflows **(a)** and hypolimnion **(b)** in Denver Lakes, June/July 2005.

(a) Inflow

Lake	Site	Date	pH[a/] (su)	Temp (°C)	DO ($mg/L-O_2$)	Cond (uS/cm)	Alk ($mg/L-CaCO_3$)	Hard ($mg/L-CaCO_3$)	DOC (mg/L-C)	TDS (mg/L)	TSS (mg/L)
Rocky Mountain Ditch											
Berkeley	BER-INF	6/30/05	7.5	15.0	8.6	133	35	40	2.67	95	6
Sloan	SLN-6	6/29/05	7.8	15.0	8.3	203	47	56	7.04	138	18
City Ditch											
Grasmere	GRS-INF	7/14/05	7.0	22.5	6.8	946	86	164	7.98	625	4
Smith	SMT-INF	7/14/05	7.1	22.6	6.7	942	86	156	7.97	nm[b/]	nm
City Park	CPL-INF	7/12/05	7.5	23.3	8.7	920	90	155	7.71	596	4
Agricultural Ditch											
Harvey	HRV-INF	7/5/05	7.6	22.0	6.7	311	82	97	6.11	262	10
Huston	HST-INF	6/28/05	8.8	20.6	7.2	282	75	85	6.13	nm	nm
South Platte River											
Overland	OVL-INF	7/19/05	7.6	21.4	7.0	534	103	157	6.38	354	9
Miscellaneous											
Barnum	BAR-INF	6/22/05	8.4	23.5	8.4	646	188	144	10.9	nm	nm
		median:	7.6	22.0	7.2	534	86	144	7.0	308	8

(b) Hypolimnion

Lake	Site	Date	pH[a/] (su)	Temp (°C)	DO ($mg/L-O_2$)	Cond (uS/cm)	Alk ($mg/L-CaCO_3$)	Hard ($mg/L-CaCO_3$)	DOC (mg/L-C)	TDS (mg/L)	TSS (mg/L)
Rocky Mntn	RMT-OB	6/28/05	8.1	16.6	<0.1	745	230	85	13.6	nm	nm
Duck	DKL-OB	7/12/05	8.9	25.0	12.9	958	130	153	9.08	nm	nm
Garfield	GAR-M1B	7/5/05	7.1	20.7	0.1	409	106	110	7.4	nm	nm
Vanderbilt	VBT-MB	7/7/05	6.7	17.0	<0.1	1140	333	305	16.2	678	56

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

b/ "nm" indicates analyte not measured

Table A8. Nutrient and associated parameter results for the inflows **(a)** and hypolimnion **(b)** in Denver Lakes, June/July 2005.

(a) Inflow

Lake	Site	Date	pH	NH_4[a/]	UIA	NO_2	NO_3	TIN	TKN	T-P	O-P	Ecoli	Fecal
			(su)	- - - - - - - - - - -	(mg/L-N)	- - - - - - - - - - -		- (mg/L-P) -		(#col/100ml)	
Rocky Mountain Ditch													
Berkeley	BER-INF	6/30/05	7.5	<[b] 0.10	< 0.001	< 0.01	0.26	< 0.37	< 1.00	< 0.08	< 0.08	760	980
Sloan	SLN-6	6/29/05	7.8	< 0.10	< 0.002	< 0.01	0.21	< 0.32	< 1.00	< 0.08	< 0.08	200	460
City Ditch													
Grasmere	GRS-INF	7/14/05	7.0	< 0.10	< 0.000	< 0.01	16.90	< 17.01	< 1.00	0.13	0.1	10	< 10
Smith	SMT-INF	7/14/05	7.1	< 0.10	< 0.001	0.06	15.28	< 15.44	1.20	0.10	< 0.08	nm[c]	nm
Ferril	CPL-INF	7/12/05	7.5	< 0.10	< 0.002	0.07	12.99	< 13.16	1.50	0.11	< 0.08	200	650
Agricultural Ditch													
Harvey	HRV-INF	7/5/05	7.6	< 0.10	< 0.002	< 0.01	< 0.20	< 0.31	< 1.00	< 0.08	< 0.08	10	< 10
Huston	HST-INF	6/28/05	8.8	< 0.10	< 0.019	0.10	0.93	< 1.13	< 1.00	0.12	nm	30	30
South Platte River													
Overland	OVL-INF	7/19/05	7.6	0.19	0.003	0.14	2.72	3.05	1.22	0.52	0.47	280	410
Miscellaneous													
Barnum	BAR-INF	6/22/05	8.4	< 0.10	< 0.012	0.03	1.18	< 1.31	< 1.00	0.11	nm	1600	6000
		median:	7.6	0.10	0.002	0.03	1.18	< 1.31	1.00	0.11	0.08	200	435

(b) Hypolimnion

Lake	Site	Date	pH	NH_4[a/]	UIA	NO_2	NO_3	TIN	TKN	T-P	O-P
			(su)	- - - - - - - - - - -	(mg/L-N)	- - - - - - - - - - -		- (mg/L-P) -	
Rocky Mntn	RMT-OB	6/28/05	8.1	< 0.10	< 0.004	< 0.01	< 0.20	0.31	1.21	0.26	nm
Duck	DKL-OB	7/12/05	8.9	1.77	0.546	0.29	0.79	2.85	4.50	0.83	0.63
Garfield	GAR-M1B	7/5/05	7.1	0.79	0.004	< 0.01	< 0.20	1.00	< 1.00	< 0.08	< 0.08
Vanderbilt	VBT-MB	7/7/05	6.7	7.92	0.012	< 0.01	< 0.20	8.13	8.20	1.10	0.87

a/ NH4=total ammonia; UIA=unionized ammonia; NO2=nitrite; NO3=nitrate; TKN=total kjeldahl nitrogen; 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

Table A9. Summary of mid-summer water column dissolved metal concentrations (ug/L) from inflows **(a)** and the hypolimnion **(b)** in Denver Lakes, June-July 2005. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2005.

(a) Inflow

lake	date	site	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																		
Berkeley	6/30/05	BER-INF	0840	B[a] 0.05	B 28	B 0.6	B 0.05	< 0.82	3.4	B 60	< 0.04	B 3	< 5.3	< 1.2	B 0.61	< 0.3	< 0.02	24.0
Sloan	6/29/05	SLN-6	0835	< 0.01	< 17	B 0.6	< 0.04	< 0.82	2.8	B 34	< 0.04	B 1	< 5.3	< 1.2	B 0.29	B 0.7	< 0.02	B 19.0
City Ditch																		
Grasmere	7/14/05	GRS-INF	0835	B 0.01	B 17	B 1.5	B 0.04	B 0.99	3.3	100	< 0.04	27	B 17.0	B 3.9	B 0.15	B 2.0	JB R	24.0
Ferril	7/12/05	CPL-INF	0940	< 0.01	< 17	B 1.6	B 0.06	B 2.50	5.9	JB R	< 0.04	< 1	B 8.8	B 3.8	B 0.27	B 2.7	< 0.02	B 16.0
Agricultural Ditch																		
Harvey	7/5/05	HRV-INF	0900	< 0.01	< 17	8.2	< 0.04	< 0.82	B 1.5	21	< 0.04	< 1	B 6.1	< 1.2	0.09	< 0.3	< 0.02	< 4.4
Huston	6/28/05	HST-INF	1015	< 0.01	< 17	B 2.4	< 0.04	< 0.82	2.0	B 47	< 0.04	21	< 5.3	< 1.2	B 0.49	< 0.3	< 0.02	B 11.0
South Platte River																		
Overland	7/19/05	OVL-INF	0845	< 0.02	< 17	B 1.1	B 0.04	< 0.82	2.5	B 31	< 0.04	48	B 9.5	B 1.2	< 0.10	B 1.5	JB R	B 8.2
Miscellaneous																		
Barnum	6/22/05	BAR-INF	1330	< 0.01	B 34	B 2.3	< 0.04	< 0.82	2.5	B 51	< 0.04	19	< 5.3	< 1.2	B 0.27	B 3.8	0.02	B 9.6
			median:	< 0.01	17	1.6	< 0.04	< 0.82	2.7	47	< 0.04	11	5.7	< 1.2	0.27	1.1	< 0.02	< 13.5

(b) Hypolimnion

lake	date	site	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Garfield	7/5/05	GAR-M1B	1300	< 0.01	B 32	B 4.2	< 0.04	< 0.82	0.6	B 96	< 0.04	1600	< 5.3	< 1.2	B 0.3	< 0.3	< 0.02	< 4.4
Vanderbilt	7/7/05	VBT-MB	1015	< 0.01	17	B 1.6	B 0.04	B 1.40	B 1.3	B 99	< 0.04	4000	63.0	B 3.0	B 0.2	12.0	< 0.02	< 4.4

a/ "**<**" = less than the detection limit; "B" = the result was below the reportable limit and is considered an estimate; "**J**" = 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 A10. Summary of mid-summer water column total metal concentrations (ug/L) from inflows **(a)** and the hypolimnion **(b)** in Denver Lakes in June-July 2005. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2005.

(a) Inflows

lake	site	date	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																		
Berkeley	BER-INF	6/30/05	0840	JB R	360	< 4.4	< 0.45	< 0.82	< 4.5	400	< 0.04	31	< 5.3	< 1.2	4.6	< 4.4	< 4.9	45.0
Sloans	SLN-6	6/29/05	0835	< 0.7	540	< 4.4	< 0.45	< 0.82	B 9.3	580	< 0.04	J 64	< 5.3	B 1.9	6.7	< 4.4	< 4.9	J 55.0
City Ditch																		
Grasmere	GRS-INF	7/14/05	0835	< 0.7	B 38	< 4.4	< 0.45	< 0.82	< 4.5	330	< 0.04	34	B 13.0	B 2.4	< 2.2	< 4.4	< 4.9	J R
Smith	SMT-M	7/14/05	1240	< 0.7	B 93	< 4.4	< 0.45	< 0.82	< 4.5	110	< 0.04	B 8	B **15.0**	B 3.9	< 2.2	< 4.4	< 4.9	JB R
Ferril	CPL-INF	7/12/05	0940	< 0.7	580	< 4.4	< 0.45	B 1.20	B 7.9	640	< 0.04	29	B 11.0	B 3.3	< 2.2	< 4.4	< 4.9	J R
Agricultural Ditch																		
Harvey	HRV-INF	7/5/05	0900	JB R	J 430	B 11.0	< 0.45	< 0.82	< 4.5	410	< 0.04	66	B 6.8	< 1.2	B 2.4	< 4.4	< 4.9	JB R
Huston	HST-INF	6/28/05	1015	< 0.7	430	< 4.4	< 0.45	< 0.82	B 5.4	510	< 0.04	140	< 5.3	B 1.5	3.0	< 4.4	< 4.9	32.0
South Platte River																		
Overland	OVL-INF	7/19/05	0845	< 0.7	J 170	< 4.4	< 0.45	< 0.82	< 4.5	560	< 0.04	170	B 9.4	B 1.7	< 2.2	< 4.4	J R	B 11.0
			median:	< 0.7	395	< 4.4	< 0.45	< 0.82	< 4.5	460	< 0.04	49	8.1	1.8	< 2.3	< 4.4	< 4.9	38.5

(b) Hypolimnion

lake	site	date	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Garfield	GAR-M1B	7/5/05	1300	JB R	J 2500	B 4.6	< 0.45	B 1.70	< 4.5	2100	< 0.04	1500	< 5.3	B 2.9	4.4	< 4.4	< 4.9	J R
Vanderbilt	VBT-MB	7/7/05	1015	< 0.7	B 22	< 4.4	< 0.45	B 1.20	< 4.5	380	na	4200	110.0	B 3.2	< 2.2	< 4.4	< 4.9	B 7.2

a/ hard = water hardness in mg/L-$CaCO_3$

b/ "**<**" = less than the detection limit; "B" = the result was below the reportable limit and is considered an estimate; "**J**" = method blank associated with this result contained the target analyte at less than 20% of the result; "B" = the result was below the reportable limit and is considered an estimate; "**R**" = measured value considered unreportable by DEH because the method blank associated with this result contained the target analyteat greater than 20% of the result and/or measured value is less than 50% of the method reporting limit.

c/ All iron values are total recoverable with the exception of Harvey and Garfield Lakes, which are total.

d/ "*na*" indicates the analyte was not assessed

Table A11. A summary of exceedances of State water quality standards and Federal sediment guidance for metals in the Denver Lakes, June/July 2005. The water quality standards are based on CDPHE Regulations 31 and 38 (CDPHE 2005a and 2005b) and are dissolved portions unless otherwise noted, while the federal sediment guidance values values are probable effect concentrations (PEC's) established by the USEPA (USEPA 2002). The "W"and "S" are indicative of water and sediment quality exceedances, respectively.

Lake	Ag	Al	As	Cd	Cu	Fe	Hg	Mn	Mo[c/]	Ni	Pb	Se	Zn	Other
Water Standard (ug/L)[a/]:	TVS[d/]	na	7.6[e/]	TVS	TVS	f/	0.01	TVS	na	a/	TVS	4.6	TVS	see Appx **
Sediment Guidance (mg/kg)[b/]:	na	58,000	33	5	149	250,000	1.1	1,200	na	49	128	na	459	na
Rocky Mountain Ditch														
Berkeley			W/S		S						S		S	
Rocky Mntn					S						S		S	pH
Sloans						W					S			
City Ditch														
Grasmere					W									
Smith											S			pH
Ferril											S			pH
Duck														pH, ammonia
Agricultural Ditch														
Harvey					S									
Garfield								S						
Huston					S						S		S	pH
South Platte														
Overland														
AquaGolf														pH
Miscellaneous														
Barnum						W								bacteria[h/]
Vanderbilt								S	W[g/]					
Lollipop												W		
Parkfield														pH

a/ Based on CDPHE Regulations Numbers 31 and 38 (2001 and 2002, respectively). Please refer to Appendix A for details.
b/ Based on USEPA guidance provided by MacDonald and Ingersoll (2002); "na" indicates there was no guidance available
c/ there were no established water or sediment guidance values provided for molybdenum, and no sediment guidance for selenium.
d/ TVS = table value standard, see Appendix G for details.
e/ exceedances based on fish ingestion standard, see Appendix A for further details
f/ based on total recoverable concentration
g/ While there was no molybdenum standard, it is worth noting the relatively high concentrations in Vanderbilt Lake relative to the other Denver Lakes.
h/ bacteria includes *E. coli* and fecal coliform

Table A12. Quality assurance replicates for physicochemical parameters in Denver Lakes, June/July 2005. Replicates are samples collected in the same bottle and split into two sets of samples for analyses. Samples are delivered to the analytical laboratory as if they were two different sites. Values less than 85% similarity are bolded (50% for E. coli and Fecal coliform).

Lake	Site	Date	Alk[a]	Hard	DOC	NH4	UIA	NO2	NO3	TIN	TKN	tot-P	O-P	TDS	TSS	Ecoli	fecal
Berkeley	BER-INF	6/30/05	35	40	2.67	<[b] 0.10	0.00	< 0.01	0.26	< 0.37	< 1.00	< 0.08	< 0.08	95	6	760	980
Berkeley	BER-INF(R)	6/30/05	35	40	2.89	< 0.10	0.00	< 0.01	0.27	< 0.38	< 1.00	< 0.08	nm	nm	nm	730	880
Overland	OVL-INF	7/19/05	103	157	6.38	0.19	0.00	0.14	2.72	3.05	1.22	0.52	0.47	354	9	280	410
Overland	OVL-INF(R)	7/19/05	104	156	6.36	0.16	0.00	0.14	2.73	3.03	1.00	0.52	nm	365	11	200	320
Rocky Mntn	RMT-OB	6/28/05	230	85	13.6	< 0.10	0.00	< 0.01	< 0.20	< 0.31	1.21	0.26	nm	nm	nm	nm[c]	nm
Rocky Mntn	RMT-OB(R)	6/28/05	231	86	13.8	< 0.10	0.00	< 0.01	< 0.20	< 0.31	1.30	0.26	nm	nm	nm	nm	nm

Percent of Replicate

Lake	Site	Date	Alk	Hard	DOC	NH4	UIA	NO2	NO3	TIN	TKN	tot-P	O-P	TDS	TSS	Ecoli	fecal
Berkeley	BER-INF(R)	6/30/05	100	100	92	100	100	100	96	97	100	100	nm	nm	nm	96	90
Overland	OVL-INF(R)	7/19/05	99	99	100	**84**	**84**	100	100	99	**82**	100	nm	97	**82**	71	78
Rocky Mntn	RMT-OB(R)	6/28/05	100	99	99	100	100	100	100	100	93	100	nm	nm	nm	nm	nm

a/ Alk=alkalinity (mg/L-$CaCO_3$); Hard=hardness (mg/L-$CaCO_3$); NH4=total ammonia (mg/L-N); UIA=unionized 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); TDS=total dissolved solids (mg/L); TSS=total suspended solids (mg/L)

b/ "<" indicates the analyte was below detection

c/ "nm" indicates the analyte was not measured

Table A13. Quality assurance replicates for metals parameters in Denver Lakes, June/July 2005. All analyses was performed at Severn Trent Laboratory, Arvada, Colorado. Bolded equipment blank values are greater than 20% of the reporting limit; bolded replicate values are less than 85% of their respective replicate.

a) Field-Equipment Blanks[a]

site	date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Water																
Dissolved	7/19/05	< 0.0	< 17	< 0.5	< 0.04	< 0.82	B 0.7	< 21	< 0.04	< 0.9	< 5.3	< 1.2	< 0.1	< 0.5	< 0.0	< 4.4
Total	7/19/05	< 0.7	JB R	< 4.4	< 0.45	< 0.82	< 4.5	< 21	< 0.04	< 0.9	< 5.3	< 1.2	< 2.2	< 4.4	< 4.9	< 4.4

b) Laboratory-Equipment Blanks[b]

	date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Water																
Dissolved	7/21/05	< 0.02	< 17	< 0.5	< 0.04	< 0.82	B **0.18**	< 21	< 0.044	< 0.88	< 5.3	< 1.2	< 0.1	< 0.48	< 0.0	< 4.4
Total	7/21/05	< 0.72	< 100	< 4.4	< 0.45	< 0.82	< 4.5	**21**	< 0.044	< 0.88	< 5.3	< 1.2	< 2.2	< 4.4	< 4.9	< 4.4
Sediment																
Total	7/21/05	< 0.6	J 43	< 0.8	< 0.03	< 0.32	< 0.7	J 210	< 0.01	J 3.2	< 0.31	B 0.31	< 0.32	< 1.0	< 0.8	B 0.56

c) Replicates[c]

Water	date	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Dissolved																
OVL-INF	7/19/05	< 0.02	< 17	B 1.1	B 0.04	< 0.82	2.5	B **31**	< 0.04	48	B 9.5	B 1.2	< 0.1	B 1.5	JB R	B **8.2**
OVL-INF(R)	7/19/05	< 0.02	< 17	B 1.1	< 0.04	< 0.82	2.2	B **39**	< 0.04	45	B 10.0	< 1.2	< 0.1	B 1.5	< 0.0	B **6.7**
Total																
OVL-INF	7/19/05	< 0.7	J **170**	< 4.4	< 0.45	< **0.82**	< 4.5	**560**	< 0.04	170	B 9.4	B 1.7	< 2.2	< 4.4	J R	B 11.0
OVL-INF(R)	7/19/05	< 0.7	J **470**	< 4.4	< 0.45	B **1.40**	< 4.5	**420**	< 0.04	190	B 9.7	B 2.0	< 2.2	< 4.4	J R	B 12.0

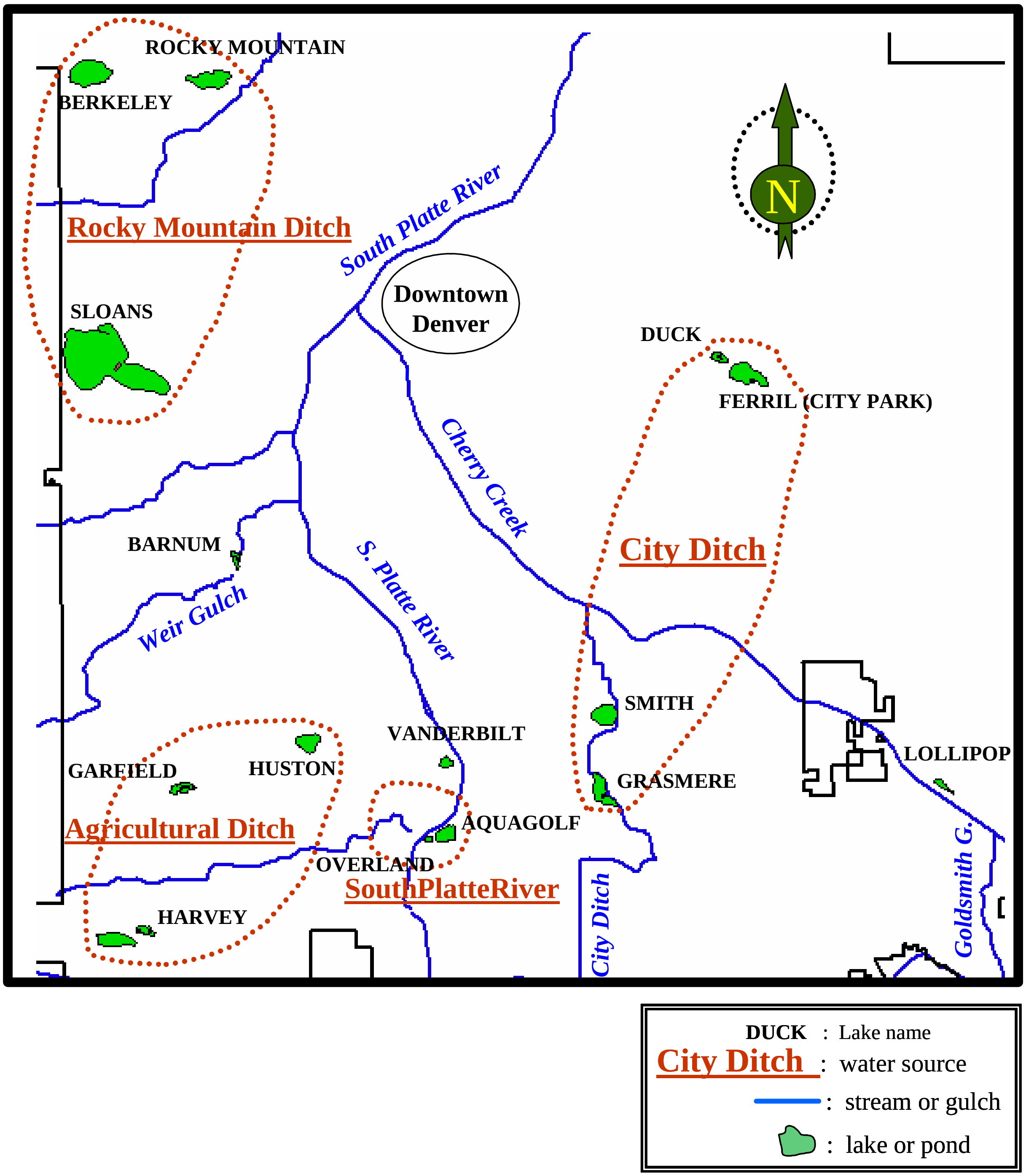
a/ Field-Equipment blanks are deionized water poured from beta bottle (water) in field after after decon

b/ Laboratory-bottle blanks are deionized water poured from beta-sample apparatus into sample container and sand collected from sterile container with eckman dredge (sediment) and stored on ice for delivery to laboratory with other samples

c/ Replicates are the same sample collected in one bottle and poured into two separate bottles, labeled as two different sites

Plate

Plate A. Regularly sampled Denver Lakes grouped into water sources. The Lakes in the miscellaneous group (Barnum, Vanderbilt, Lollipop, and Parkfield) have no indicated water source. SPR is the South Platte River. Parkfield Lake is not displayed but is located northeast of the selected area.



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APPENDICES

Appendix A. CDPHE Water Quality Standards

This is a summary of the Colorado Department of Public Health and Environment's (CDPHE) water quality standards for segments in the South Platte and Cherry Creek Basins within the City & County of Denver. They are presented in CDPHE's Regulations 31 (CDPHE 2005a) and 38 (CDPHE 2005b).

Stream Segment Designation

segment	*description*	*Use protected*	*Aquatic Life*	*Rec*	*Ag*	*Water Supply*	*Temp Modifications & Qualifiers*
SP - 16c	all tribs to SP, including lakes and CC	yes	Warm 2	1a	yes	no	Fish ingestion, organics
SP - 17a	City Park, Wash Park, Rocky Mountain, & Berkeley Lakes	yes	Warm 1	1a	yes	no	none
SP - 17b	Sloans Lake	no	Warm 1	1a	yes	no	none
CC - 4	tribs to CC (Lollipop Lake)	yes	Warm 2	1a	yes	no	none

Physical & Biological

D.O.	*pH*	*Fecal*	*Ecoli*
5.0	6.5-9.0	200/100ml	126/100ml

Inorganic (mg/L)

	NH_4	Cl_2	*CN*	*S*	*B*	NO_2
acute	TVS[a/]	0.019	0.005	0.002	0.75	0.5
chronic	TVS	0.011				

Metals (ug/L)[b/]

	Ag	*As*	*Cd*	*Cr*	*Cu*	*Fe*	*Hg*	*Ni*	*Mn*	*Pb*	*Se*	*Zn*
acute	TVS	--	TVS	TVS	TVS	--	--	TVS	TVS	TVS	18.4	TVS
chronic	TVS	100(TR)[c/]	TVS	TVS	TVS	1000(TR)	0.01(T)	TVS	TVS	TVS	4.6	TVS

Fish Ingestion

As	*Ni*	*Sb*	*Tl*
7.6[d/]	4600	4300	6.3

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a/ calculation based on USEPA ammonia update (USEPA 1999)
b/ all metals are dissolved unless otherwise noted; TR = total recoverable, T = total metals
c/ see fish ingestion
d/ updated in CDPHE standards in 2005 (CDPHE 2005a)

Appendix A. (continued)

Table value standards (TVS) from CDPHE's Regulation #31 (2005a). Typical water hardness in Denver Lakes ranges from 100-200$mg/L\text{-}CaCO_3$, with three lakes at 50-100 (Garfield, Huston, and Rocky Mountain), and one lake often above 400 (Lollipop). For purposes of calculating TVSs, 400$mg/L\text{-}CaCO_3$ is the maximum water hardness used.

Acute Values

Hardness	Ag	Cd	Cr (III)	Cu	Mn	Ni	Pb	U	Zn
50	0.62	2.0	323	7.0	2370	260	30.1	1119	65
100	2.03	4.3	570	13.4	2986	468	64.6	2402	117
150	4.08	6.6	794	19.7	3417	660	100.1	3756	165
200	6.69	9.0	1005	25.8	3761	842	136.1	5157	211
250	9.81	11.5	1207	31.9	4051	1017	172.3	6595	255
300	13.43	14.0	1401	37.8	4305	1186	208.6	8062	297
400	22.02	19.1	1773	49.6	4738	1513	280.8	11070	379

Chronic Values

Hardness	Ag	Cd	Cr (III)	Cu	Mn	Ni	Pb	U	Zn
50	0.10	1.34	42	5.0	1309	29	1.17	699	66
100	0.32	2.24	74	9.0	1650	52	2.52	1501	118
150	0.64	3.02	103	12.7	1888	73	3.90	2346	167
200	1.05	3.73	131	16.2	2078	93	5.31	3221	213
250	1.55	4.40	157	19.6	2238	113	6.72	4119	257
300	2.12	5.03	182	22.9	2379	132	8.13	5036	300
400	3.47	6.22	231	29.3	2618	168	10.94	6915	382

Appendix B. Sediment Guidance Values

B.1. *Sediment Guidance – Metals*

Table B-1. USEPA sediment metal guidance values. The PEC was the primary value referred to in the report. If this was not available, other values were used as a reference.

	USEPA [1/]		USEPA [2/]	
	PEC[3/]	TEC[4/]	ERM[5/]	PEL[6/]
(Ag) silver	nv[7/]	nv	58,000	nv
(Al) aluminum	nv	nv	nv	nv
(As) arsenic	**33**	9.8	50	48
(Cd) cadmium	**5.0**	1.0	3.9	3.2
(Cr) chromium	**111**	43	270	120
(Cu) copper	**149**	32	190	100
(Fe) iron	nv	nv	280,000	250,000
(Hg) mercury	**1.1**	0.2	nv	nv
(Mn) manganese	nv	nv	1,700	1,200
(Mo) molybdenum	nv	nv	nv	nv
(Ni) nickel	**49**	23	45	33
(Pb) lead	**128**	36	99	82
(Se) selenium	nv	nv	nv	nv
(Tl) thallium	nv	nv	nv	nv
(Zn) zinc	**459**	121	550	540

1/ USEPA 2002
2/ USEPA 2001
3/ probable effect concentration: concentration above which a toxicological effect is expected
4/ threshold effect concentration: concentration below which no toxicological effect is expected
5/ effects range-median
6/ probable effect level: concentration below which no toxicological effect is expected
7/ no value was available

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.

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.

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.

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).

Epilimnion: The upper layer of a body of water that has been thermally stratified; it extends down from the surface to the *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 homothermous.

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 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.

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.

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. 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.

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 majority of the organic content consists of *total kjeldahl nitrogen* (TKN).

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 $Fe^{++} \rightarrow Fe^{+++} + e^-$

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.

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.

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.

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

Secchi disk: A disk that is 10-12 inches in diameter and 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.

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. 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.