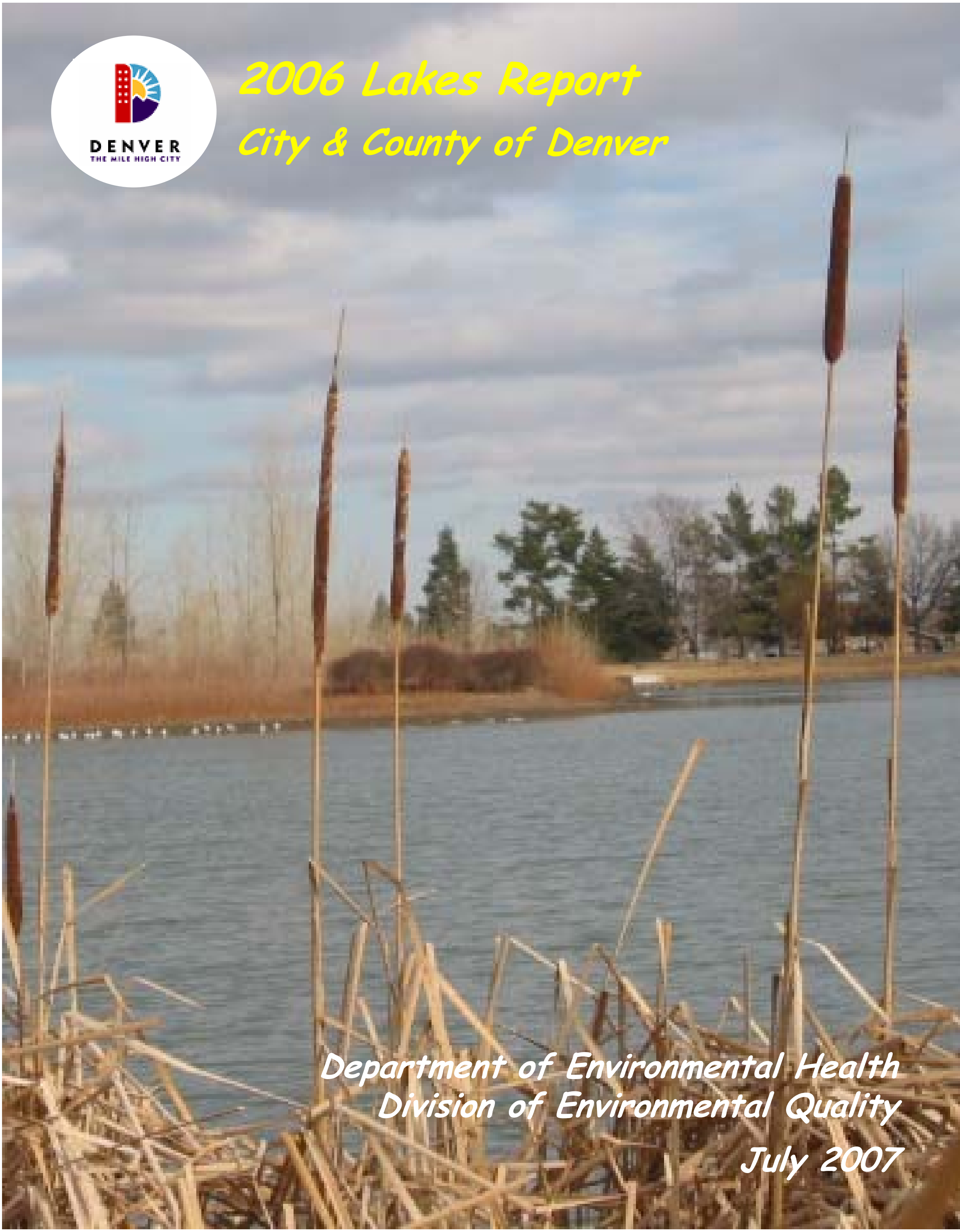
2006 Lakes Report

City & County of Denver



Department of Environmental Health
Division of Environmental Quality

July 2007

Executive Summary

This report summarizes findings and recommendations based on the Denver Department of Environmental Health's (DEH) Division of Environmental Quality (DEQ) annual summer lake sampling effort. Annual sampling commenced in 1996 and has continued through 2006. As with previous efforts, the findings from the 2006 sample events were used to assess the lake's status in terms of public and environmental health.

Guidelines for this assessment are the Colorado Department of Public Health and Environment's (CDPHE) Regulations 31 (CDPHE 2005) and 38 (CDPHE 2006). 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 determine the contributing sources for the exceedance, and as much as possible, develop a remedy for the situation.

This report 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:

- provides a succinct summary of the 2006 monitoring results for 15 Denver lakes;
- addresses water quality standard and sediment quality guidance exceedances; and
- re-iterates the primary issues within the City's lake system.

The 2006 findings are provided in a color coded table intended to serve as a one page summary for all the Denver lakes (**Table A1**). Quantitative findings are also provided for those who prefer more detailed information. Long term data will eventually be available on the DEH water quality website (~August 2007), but is also available upon request.

A summary of water quality standard and sediment guidance exceedances are provided within the report (**Table A13**). Noteworthy findings and recommendations based on the 2006 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 2006 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), incorporation and expansion of natural areas, 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).	DEH will recommend that CDPHE investigate fish tissue from other CCoD lakes as well as re-sample Berkeley and Rocky Mountain fish in the near future to determine the advisory status.
Bacteria levels in Sloans Lake were acceptable for recreational purposes on 17 of 18 sample events spanning May 23 through September 12, 2006.	Bacteria levels were near or below the detection limit throughout most of the year with one exceedance following a moderate rainfall event. An informational sign was posted at the boat ramp and it contains advisory information concerning water quality and recreation.	Sloans Lake will continue to be sampled weekly during the recreational season; DEH will use the CDPHE Natural Swim Beach Regulations as guidance concerning altering the advisory sign from a yellow caution message to a red warning message.
Rocky Mountain Lake copper concentration exceeded state water quality standards.	The sample event closely followed a copper-containing herbicide application in the lake. Highlights the need to use application rates as prescribed by the manufacturer.	DPR management must be certain that contractors are using the appropriate amount of chemicals with treatments. DEH recommends that DPR's various districts work with one certified contractor (or certified employee) that the city can be confident is using appropriate measures.
Conversion to re-use water as City Ditch source water in 2004 has altered water quality of the City and Washington Park Lakes. This includes elevated nitrate levels and salt concentrations as indicated by conductivity, TDS, and cation measurements.	Recycled water contains high nitrate (10-15mg/L-NO_3 as N) and salt concentrations. Primary concerns include increased productivity due to increased nitrate loading resulting in problems with algae for aesthetic and odor problems as well as increased oxygen demand and potential blue-green algae toxicity to fish and wildlife.	Continue to assess effectiveness of SolarBee mixing units in Duck Lake (installed June 2005). If still connected, utilize aeration system in Duck Lake. Use all water quality BMPs possible (i.e., natural area establishment, wetlands, barley straw) to decrease negative impacts.
Ammonia concentrations in Duck Lake exceeded water quality standards.	Dense population of cormorants, waterfowl, and other birds contribute to nutrient loading. Fish die-offs in spring of 2005 and 2006.	Mitigation would include decreasing bird activity at the lake and incorporation of water quality BMPs as listed above.

Table E-1 (continued). Summary of noteworthy 2006 findings and recommendations.

Findings	Comments	Recommendations
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.
South Platte Lakes hyper-eutrophic for all three Carlson TSI parameters (chlorophyll-a, secchi depth, total phosphorus) with continued highest total phosphorus, chlorophyll-a levels among all Denver lakes.	AquaGolf Lake concentration is perennially the highest among the Denver lakes with Overland typically the second highest. High-phosphorus loading and shallow depths are ideal for algal productivity, particularly in 2006 with AquaGolf at low depths for renovation. If depths have been further decreased by the renovation, it is likely the algal productivity will persist and may be more severe.	Monitor impacts of the Florida Lateral project on water quality and quantity. The lake may need more intensive management to protect irrigation use, balanced by realization that the lake will discharge to the South Platte (waters of the State).
Barnum Lake bacteria (*E. coli*) levels exceeding water quality standards.	The elevated bacteria, or associated contaminants may be contributing to the low dissolved oxygen problem within the lake. Sampling of Weir Gulch did not detect illicit discharges to date, but has isolated a tributary of interest concerning bacteria.	DEH has continued focused bi-monthly sampling on Weir Gulch to determine whether there are illicit connections or other sources contributing to excessive bacteria in the lake.
Iron water column exceedances in three lakes: Garfield, Barnum, and AquaGolf	The Barnum Lake iron concentrations have exceeded the standard on occasion throughout the past ten years while Garfield and AquaGolf concentrations have typically not. The shallow AquaGolf depths likely contributed to the problem in 2006 and will not be repeated on hydrologically “normal” years. Incoming waters and geochemical interacations are likely contributors.	The concentrations in Barnum and Garfield Lakes are variable and pose no human health threat and little if any environmental threat. The elevated AquaGolf concentrations are likely an artifact of drawdown for renovation and will likely not repeat in following years. Given the above, there are no recommendations to address iron at this time.
Continued investigations on Vanderbilt Lake add information towards renovation planning.	DEH contracted with HWS to perform additional sediment characterization and aquatic community assessment (May 2007) towards a feasibility study concerning management recommendations. The current objective is to establish a functional, sustainable aquatic community with a native fishery. This will require remediation of elevated organic contaminants in the sediment which will increase oxygen concentrations throughout the water column.	On-going discussions with potential contractors to develop a preferred alternative towards sediment remediation. DEH is working with DPR in developing a long term plan.

Table of Contents

List of Tables

List of Figures

List of Plates

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

This report summarizes findings and recommendations based on the Denver Department of Environmental Health's (DEH) Division of Environmental Quality (DEQ) annual summer lake sampling effort. Annual sampling commenced in 1996 and has continued through 2006. As with previous efforts, the findings from the 2006 sample events will be used to assess the status of the lakes in terms of public and environmental health.

Guidelines for this assessment are the Colorado Department of Public Health and Environment's (CDPHE) Regulations 31 (CDPHE 2005) and 38 (CDPHE 2005). 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.

This report will provide a succinct summary of the 2006 monitoring results with discussion of findings and highlights of noteworthy results, updates on primary issues within the City's lake system, and management recommendations concerning primary issues.

I.A. How to Use This Report

A list of commonly used acronyms and abbreviations is provided prior to the introduction, while a glossary 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 (DDEH 2005 and 2006, respectively). 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 provided in more detail in the DEH QAPP-SAP.

Section III presents the 2006 results with a brief discussion of the noteworthy findings and highlights based on the 2006 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.

A summary of key findings, lake issue updates, and some recommendations are provided in Section V. The issues and recommendations are summarized more thoroughly within the Executive Summary (Table E-1).

Tables that are designated with a single letter (i.e., Table A3) and Plates are located at the end of Section V. 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

Eighteen "lakes" were sampled at least once in 2006 to assess mid-summer conditions (Table 2-1). Because of its relatively high recreational use, Sloans Lake bacteria concentrations were sampled weekly from May 23rd through September 12th. Analytes collected during routine mid-summer sampling events are summarized in Table 2-2. Three of the sample events (Heron Pond, Harvard Gulch Golf Course-Pond, and Wolcott Lake) were special events and will only be repeated as requested or deemed necessary. Sampling from these three water bodies is not included in this report although the information is available upon request.

Table 2-1. Denver lakes sampling dates in 2006.

Subsidy Source / Lake	Sample Date	Miscellaneous for 2006
Rocky Mountain Ditch		
Berkeley	June 27	Chlorophyll-a on 7/3/06
Rocky Mountain	June 26	Chlorophyll-a on 7/3/06
Sloans	June 27	Chlorophyll-a on 7/3/06; bac-t weekly 5/23/06 – 9/12/06
City Ditch		
Grasmere	not sampled	Drawdown for renovation
Smith	July 20	Inflow also on 5/16/06
Ferril	July 25	None
Duck Pond	July 25	3/2/06 and 4/19/06 – fish die off follow-up
Agricultural Ditch		
Harvey	July 13	None
Garfield	July 18	None
Huston	July 18	None
South Platte River		
Overland Pond	June 29	None
AquaGolf	June 29	None
Groundwater & Urban Runoff		
Vanderbilt	July 11	None
Lollipop	July 6	None
Urban Runoff		
Barnum	July 11	None
Parkfield	July 6	None
Miscellaneous		
Heron Pond	April 18	Fish die-off follow-up
Harvard Gulch P	July 20	Upon request from DPR[a/]
Wolcott Lake	July 13	Upon request from PW[b/] and Denver residents

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

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 DEQ.

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, Hg,
	►Total solids	Mn, Mo, Ni, Pb,
	►Total dissolved solids	Se, Zn
	►Chloride	
	►Sulfate	►Total Recoverable Metals
	►Bacteria	-As, Fe
	-*E. coli*	
	-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 Evergreen Analytical Laboratory (Wheat Ridge, CO) for analysis
4/ Analytes also assessed in sediments by Evergreen Analytical Laboratory
5/ Processed by DEH personnel and delivered to Denver Water Board Laboratory for analysis

III. Findings - 2006

This report provides a succinct summary of the 2006 results. More extensive discussions of long term results, issues, and recommendations for all lakes are available in both the 2003 and 2004 DEH Lake Reports. The 2006 data is summarized in two formats. Table A1 provides a qualitative summary of all parameters assessed in all lakes within one table. Tables A2 through A12 provide a quantitative summary of the 2006 sampling results and are located at the end of Section V. Long term data (1996-2006) and aerial photographs with lake sample locations will be available for most parameters at the DEH website by November 2007 (CCD 2007).

Results in Table A1 are not presented quantitatively, but are intended to provide the reader with one reference with which to characterize the Denver lakes relative to state water quality standards (CDPHE 2005, 2006), federal sediment guidance (USEPA 2002), 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 2006 sampling results were used to identify unique characteristics. These values were considered to be beyond what was typically measured in the urban lakes in 2006. 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 A1 also highlights anlaytes that were measured at levels that exceeded or potentially exceeded CDPHE (2005, 2006) water quality standards and USEPA (2002) sediment guidance. Exceedance of the water quality standards and guidance highlights conditions that may warrant further attention from DEH and/or the CDPHE. These exceedances do not necessarily translate to an immediate threat to human or environmental health. USEPA sediment guidelines are based on sediment metal concentrations that are potentially harmful to aquatic life. This does not typically infer risk to human health but highlights a potential environmental issue.

Highlights from Table A1 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 A13.

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 2006 included:

- pH and copper in Rocky Mountain Lake;
- fish ingestion-based arsenic in Berkeley Lake; and
- low dissolved oxygen in Berkeley Lake (Table A1 and A13).

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 of 9.0*su* (CDPHE 2005). The 2006 pH levels in Rocky Mountain Lake (lake average of 9.1*su*) 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:

- water column mixing and aeration to inhibit nutrient availability;
- continued implementation of water quality management options that decrease nutrient loading in the lakes;
- 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; and
- efficient and sparing use of herbicides/algaecides.

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 organic loading component contributes to lower dissolved oxygen by increasing the bacterial food source which subsequently increases decomposition, a process that relies on the available oxygen at the lake bottom. In addition to this, extended periods of cloud cover could potentially decrease photosynthesis rates and subsequent dissolved oxygen levels.

The low dissolved oxygen concentrations in Berkeley Lake in 2006 were not typical of any previous measurement in the lake (1997-2005) and therefore do not entail a sufficient amount of data to declare an exceedance of the CDPHE standard ($5 mg/L\text{-}O_2$). Regardless, the Berkeley Lake oxygen conditions should be more carefully scrutinized in the future, particularly in light of the September 2004 fish die off. This die-off was credited to a turnover (high winds mixed the *anaerobic* layer with the rest of the lake resulting in extremely low oxygen conditions) that was toxic to trout which are one of the more, if not the most sensitive species to low oxygen concentrations in the Denver lakes.

Mitigation of the low dissolved oxygen in Berkeley Lake could be considered for future actions, but at this time, should be considered a lesser priority than other City-wide lake issues. If lake oxygen mitigation was to be implemented, it could include many 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 water quality ponds, wetlands, or forebay could help minimize loading of organic material over time.

The elevated copper level in Rocky Mountian Lake was likely the result of sampling immediately after a copper containing algaecide had been applied. This would help explain the extremely deep secchi depth reading as well. The long term data indicates one additional potential exceedance of the copper standard in 1997. All measurements from 1998 through 2005 were below the water quality standard.

Elevated Arsenic in Berkeley Lake

In addition to routine summer sampling performed by DEH, Brown and Caldwell was contracted to perform a phase II Environmental Site assessment to attempt to discern a source driving the chronically elevated arsenic levels in Berkeley Lake (Brown and Caldwell 2006). The assessment included soil and groundwater sampling within Berkeley Park and the south side of the Willis Case Golf Course. Sampling was conducted from May 10-15, 2006.

While the Brown and Caldwell phase II assessment did find arsenic and mercury in the soil samples, measured concentrations were typical of Denver metro area background levels. Arsenic was not detected in the groundwater monitoring above the method detection limit (4.4*ug/L*). Conclusions derived from the study did not discern an arsenic source unique to Berkeley Lake within the soils or groundwater. The most likely scenario at this time is that historical activities contributed to the elevated arsenic levels in the lake. Current arsenic levels are likely impacted by geochemical interactions at the water sediment interface that result in minor variations over time.

Fish Consumption

The CDPHE water quality standards are implemented to protect a variety of uses in the states' surface waters. One of these uses includes fish ingestion, a use intended to protect humans from being overly exposed to contamination as a result of fish consumption. Berkeley Lake arsenic concentrations were found to be consistently in exceedance of the fish ingestion standard from the time routine summer sampling commenced in 1997.

In light of the elevated Berkeley Lake arsenic concentrations, fish tissue from the lake was sampled in 2002 to assess potential human health issues. This sample effort found fish tissue-arsenic concentrations near the EPA screening level indicating that further analysis was warranted. As a result, a more intensive fish tissue assessment was performed by CDPHE in Berkeley, Rocky Mountain, and Sloans Lakes in 2004.

In addition to analysis for fish tissue arsenic concentrations, selenium and mercury were also assessed. Fish tissue-arsenic and selenium concentrations were measured at acceptable levels in all three lakes. Fish tissue-mercury levels from both Berkeley and Rocky Mountain Lakes were found in exceedance of EPA guidance (CDPHE 2006) and resulted in CDPHE implemented fish consumption advisories for both lakes. The advisories were implemented March 2006 and apply to consumption of large mouth bass (Appendix C).

Mercury advisories have become increasingly common throughout the US with at least 43 states having freshwater advisories for specific water bodies (USEPA 2005). The primary source of mercury has been found to be coal-fired power plant air emissions making it a difficult challenge for surface water managers to address.

The DEH will continue to work with the CDPHE and CDOW in assessing the fish tissue from other Denver lakes. The current fish advisories will remain in place until future sampling efforts indicate fish tissue metal concentrations warrant their removal. Please visit the DEH website for more detailed information on mercury and fish consumption advisories.

Sloans Lake Bacteria

Weekly sampling of bacteria in Sloans Lake in 2006 included eighteen weekly sample events from four sample locations spanning May 23rd through September 12th. Exceedance of the State's natural swim beach advisory level for bacteria (235 cfu/100ml; Colorado State Board of Health 1997) occurred on one occasion and from only one site (boat dock; Fig 3-1). This one exceedance occurred within 24 hours of a moderate summer rain event (sampled July 6th). The water quality was predominantly near or below the detection level of 10*cfu/100ml* in 2006.

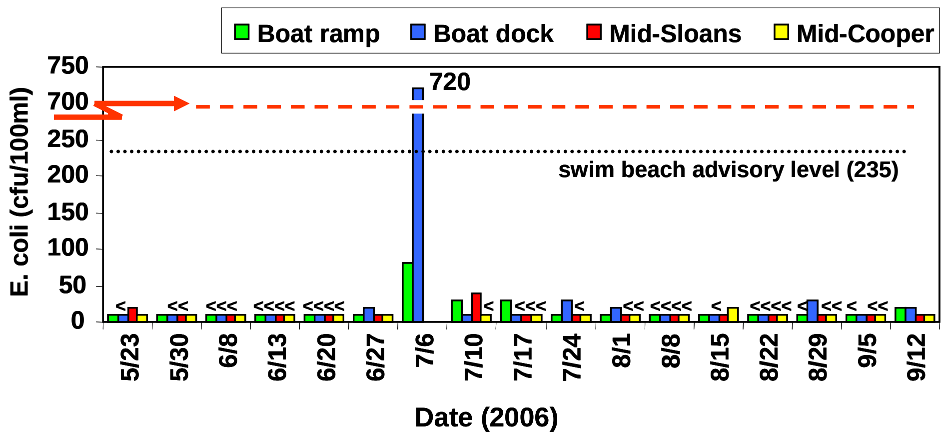


Fig 3-1. 2006 *E. coli* levels in Sloans Lake. Note the break in the scale indicated by the red arrow and red dashed line. The "<" indicates that the result was below detection (10*cfu/100ml*).

An informational sign addressing the history and water quality issues associated with Sloans Lake was installed at the Sloans Lake boat ramp in the fall of 2006. The sign includes an advisory concerning risks associated with recreation in surface waters. When bacteria sample results indicate levels in exceedance of the state advisory level (235*cfu/100ml*), the yellow advisory portion of the sign will be replaced with a red warning sign reflecting this information. The warning sign will remain in place until sample results indicate bacteria concentrations below the state advisory level. Regularly updated bacteria sample results will be available on the DEH website (www.denvergov.org/BacTrac) for the 2007 summer recreation season.

3.A.2. Sediment Quality

Sediment-Metals

There were several sediment metal analytes in exceedance of USEPA (2002) guidance for impacts to aquatic life in the Rocky Mountain Ditch Lakes, including:

- arsenic, copper, lead, and zinc in Berkeley Lake;
- lead and zinc in Rocky Mountain Lake; and
- lead in Sloans Lake (Tables A1, A3).

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 A7) 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 minimize 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, inline filtration approaches, and increased street sweeping within the lake watersheds.

Sediment-Nutrients

Sediment nutrient concentrations within the three Rocky Mountain Ditch Lakes were near or below median values measured in all Denver lakes in 2006 (Table A8). One exception to this was the Rocky Mountain Lake organic nitrogen (TKN) concentration which was relatively high among the Denver lakes (above the 85th percentile). This is likely attributable to the high loading that occurs with the annual die off of the dense submerged vegetation.

For a more quantitative summary of the 2006 findings, refer to Tables A2 through A12 located at the end of Section V. These tables provide a numeric summary of the 2006 sampling results including analytes from within the lakes (Table A2-A8), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A9-A12). Long term data is available on the DEH Division of Environmental Quality's website in the Lake Reports section (CCD 2007).

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 Grasmere and Smith Lakes in Washington Park and Ferril and Duck Lakes in City Park (Plate A). Grasmere Lake had been drained for upcoming renovations and was not sampled in 2006. A summary of water quality standard exceedances indicated in Table A1 for these lakes include:

- pH in Smith, Ferril, and Duck Lakes; and
- acute and chronic ammonia concentration in Duck Lake.

pH in City Ditch Lakes

The pH in Denver's shallow urban lakes is variable and has exceeded the state water quality standard in several water bodies 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. The amount of photosynthesis increases as lakes become more productive. The extent of this productivity is influenced by nutrient (nitrogen and phosphorus) loading and other factors. This often results in pH values greater than the CDPHE standard of 9.0*su* (CDPHE 2005).

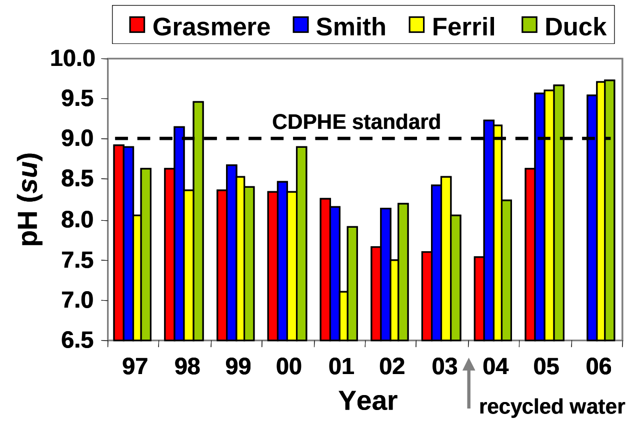


Fig 3-2. City Ditch Lakes pH values from mid-summer sample events (June/July). The arrow denotes the switch to recycled water as the primary water source for City Ditch. Grasmere Lake was not sampled in 2006.

The pH levels in all the City Ditch Lakes rose dramatically since the transition to recycled water in 2004 (Fig 3-2). Prior to 2004, there were only two documented instances among the four lakes where the water quality standard was exceeded. Smith and Ferril Lakes exceeded the standard from 2004-06 while Duck Lake exceeded the standard in 2005-06. While pH of Grasmere Lake was also relatively elevated in 2004, draining of the lake in 2003 and 2006 make long term assessments difficult over this time period.

Mitigation of elevated pH levels can include implementation of practices that inhibit lake productivity including:

- water column mixing and aeration to inhibit nutrient availability;
- continued implementation of water quality management options that decrease nutrient loading in the lakes;
- 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; and
- efficient and sparing use of herbicides/algaecides.

Nitrogen in City Ditch Lakes

Long term data indicates variable but generally high **ammonia** concentrations in Duck Lake even prior to conversion to recycled water in the spring of 2004. Summer ammonia concentrations in Duck Lake were measured at levels exceeding state water quality standards in 1998, 2000, and from 2003-2006[1] (Fig 3-3). Ammonia is an inorganic form of nitrogen that is toxic to fish and other aquatic life at elevated concentrations. A March 2006 fish die-off in Duck Lake was likely partially attributable to elevated ammonia levels (9.2*mg/L as N*).

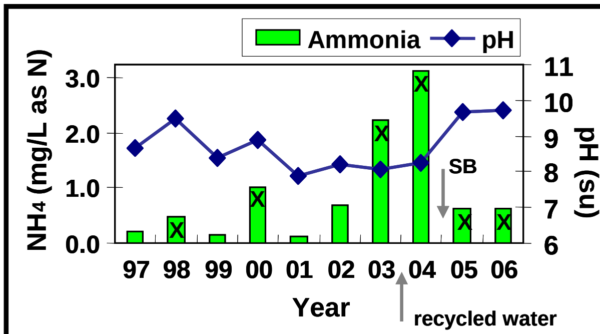


Fig 3-3. Total ammonia and pH in Duck Lake from mid-summer sample events (June/July). 'X' denotes exceedance of the CDPHE standard (based on a calculation involving pH and temperature); the arrows denote the switch to recycled water and installation of SolarBee units (SB).

The primary source of ammonia to Duck Lake is waste from the intense bird use. Cormorants nest in the trees on the islands

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

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

In addition to elevated ammonia in Duck Lake, nitrogen levels were high in all the City Ditch Lakes in 2006. Ferril Lake inorganic nitrogen and Duck Lake nitrite and organic nitrogen (TKN) concentrations exceeded the 85th percentile among all Denver lakes (Tables A1 and A3). The primary source of nitrates (the predominate form of inorganic nitrogen in surface waters) for the City Ditch Lakes is the recycled water used to subsidize the Washington and City Park Lakes. This is of interest because of the role nitrate plays in lake productivity and subsequent impacts on pH (see discussion above on pH).

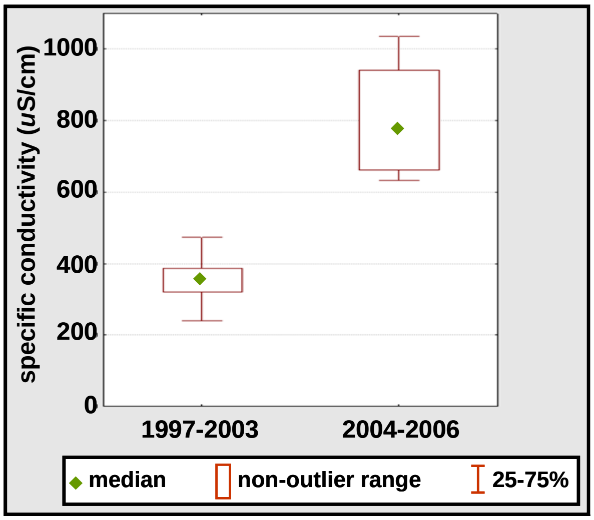


Fig 3-4. Specific conductivity from all sites sampled during the annual summer (June/July) sample events in the City Ditch Lakes. The primary water source for the lakes was switched to recycled water in the spring of 2004 (number of samples is 71 and 39 for pre- and post-recycled water, respectively).

Additional Trends

In addition to elevated pH and nitrogen in the City Ditch Lakes following transition to recycled water, there was also a dramatic increase in specific conductivity (Fig 3-4) and total dissolved solids with a decrease in alkalinity. The increased conductivity is attributable primarily to the elevated salts in the recycled water. Even with these changes, the conductivity and TDS levels are still within the range measured in other Denver lakes. While these changes could alter the aquatic community through its influence on the lower end of the food chain, primarily the plankton species, it is unclear how warmwater fish will be impacted over the long term.

Management Efforts & Recommendations

Management efforts to counter the elevated pH and productivity issues can focus on addressing either the source (nutrient loading) and/or the symptoms (elevated pH). Efforts to mitigate elevated nutrient loading can focus on decreasing the concentration of nitrogen and phosphorus reaching the lakes and/or the availability of these nutrients to contribute to algal productivity.

To decrease the primary source of ammonia in Duck Lake would entail control of nesting cormorants and waterfowl feeding and loafing in the lake. An overtly aggressive approach to this is counter to the valuable wildlife viewing and educational use provided to park visitors. A more active outreach effort to keep visitors from feeding ducks and geese at the lake may provide some relief from this waste load.

Past management has included the use of limited aeration in the City Ditch Lakes and installation of SolarBee water column mixing units in Duck and Grasmere Lakes[2] in 2005. While the SolarBee units were effective at de-stratifying the water column of Duck Lake, it is too early to assess how effective they will be at diminishing productivity and subsequently at decreasing pH values.

Water column mixing with the SolarBees may have diminished ammonia availability in the water column, but they have not effectively decreased concentrations to within the water quality standards. The ammonia levels exceeded water quality standards four of eight years while aeration was the primary mechanical management action (Fig 3-3). The SolarBees were installed approximately one year after City Ditch was converted to use of recycled water. Ammonia concentrations were considerably lower in 2005 and 2006 but still exceeded standards in both post-water column mixing years (due primarily to elevated pH).

An additional test of the effectiveness of the SolarBee units is their apparent impact on productivity levels. Chlorophyll-a concentrations serve as an indicator of phytoplankton productivity. Chlorophyll-a concentrations within Duck Lake were still slightly higher in 2006 than they were prior to installation of the SolarBee units, but they were significantly lower than 2005 concentrations (Fig 3-5). More time (up to two years) and additional data will help determine apparent effectiveness of the SolarBee units and their impact on Duck Lake productivity.

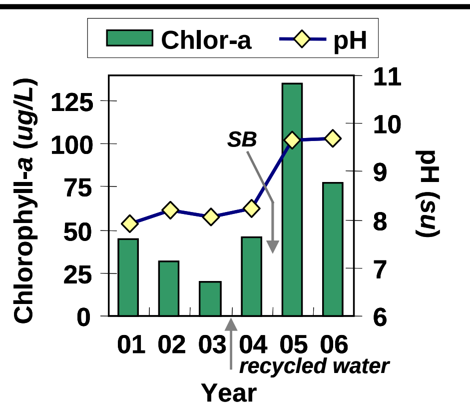


Fig 3-5. Chlorophyll-*a* and pH in Duck Lake from summer sample events (June/July). The arrows denote the switch to recycled water and installation of SolarBee units (SB).

A preferred management approach would address the nutrient source and availability; the use of wetlands is one such alternative. Routing City Ditch water through surface or sub-surface wetlands prior to discharge to City Park and Washington Park lakes could help minimize nutrient loads credible to the high-nitrate containing recycled water. This option could be pursued after a determination is made on the effectiveness of the SolarBee units and/or as opportunities arise with renovations in City Park and Washington Park.

DEH recommends the continued use of both aeration and the SolarBees to assess how effective they are 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.

3.B.2. Sediment Quality

Sediment-Metals

[2] Originally installed in Grasmere in 2005 but moved to Ferril due to planned renovations in Grasmere (2006/07).

The sediment metal concentrations within the City Ditch Lakes were typical of, or below values measured in the other Denver lakes in 2006 (Tables A1 and A7). 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 lead concentrations were among the seven Denver lakes with sediment lead levels in exceedance of the guideline in 2006 (Table A13), they were well below the 85^{th} percentile among all lakes (Denver lakes-2006).

Sediment-Nutrients

Sediment nutrient concentrations within the City Ditch Lakes were within the 2006 range (15^{th}-85^{th} percentile) of all Denver lakes with the exception of ammonia in Duck Lake (Table A8). This is likely attributable to the chronically high amount of bird excrement loading in the lake.

For a more quantitative summary of the 2006 findings, refer to Tables A2 through A12 located at the end of Section V. These Tables provide a numeric summary of the 2006 sampling results including analytes from within the lakes (Table A2-A8), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A9-A12). Long term data is available on the DEH Division of Environmental Quality's website in the Lake Reports section (CCD 2007).

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. A summary of potential water quality standard exceedances indicated in Table A1 for these lakes include:

- dissolved oxygen in Huston Lake; and
- iron in Garfield Lake.

Although Huston Lake had depressed dissolved oxygen in 2006, the long term data (1996-2007) do not support an exceedance of the water quality standard based on a representative number of samples. The depressed dissolved oxygen was likely a result of a recent treatment that killed most of the submergent vegetation and algae. The relatively low pH and moderate chlorophyll-a levels (Table A3) are further indicators of low productivity.

The iron concentrations in Garfield Lake exceed the current water quality standard for aquatic life but pose no health threats to humans. Previous iron analyses were performed on the total component, the 2006 analyses was the first year to look at the total recoverable component on which the iron standard is based. Regardless, long term data (CCD 2007) suggests this elevated iron level is above what is typically measured in Garfield Lake.

The literature is varied but suggests there may or may not be indirect impacts (i.e., development, productivity) on some aquatic life at these iron concentrations. It is possible that recent measured values may have indirect impacts on aquatic life (i.e., productivity) but are likely not acutely toxic (van Anholt *et al.* 2002, Iowa DNR 2005, Linton *et al.* 2006).

The agricultural Lakes all had relatively low total dissolved solids compared with other lakes in 2006 (Table A2). Garfield and Huston Lakes had relatively low total inorganic nitrogen and organic nitrogen (TKN).

While bacteria levels were relatively high in Garfield Lake compared with other Denver lakes (Table A3), 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 within the Agricultural Ditch Lakes that were measured in the 85th percentile among the Denver lakes in 2006 (Table A1). None of these were at levels of concern.

3.C.2. Sediment Quality

Sediment-Metals

Sediment quality of Harvey and Garfield Lakes was comparable to other Denver lakes, while Huston Lake sediment quality was relatively poor (Table A1). Analytes measured at values exceeding USEPA guidelines for probable effects to aquatic life included copper, lead, 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 2006 (Table A1 and Table A7). Possible sources that contribute to elevated sediment-metals in the Huston Lake sediment include historical practices in the area and/or relatively high amounts of unmitigated urban runoff per acre.

While sediment-metal concentrations were still relatively high, they were generally lower than what had been measured in the lake in previous years. Based on water column measurements and the tendency for metals to bind to the organic matter in the sediment, these elevated sediment metal concentrations do not pose a risk to human health or the lake ecology under normal circumstances.

Sediment-Nutrients

Harvey and Huston nutrient sediment concentrations were generally within the range measured in other Denver lakes (Table A8). The ammonia and total phosphorus concentrations were relatively high in Garfield Lake. The Garfield Lake sediment-ammonia concentration was the highest among the Denver lakes and is likely attributable to a well established anoxic zone in the mid-section of the lake coupled with a considerable amount of waterfowl activity. It is also possible that park maintenance, more specifically fertilizer applications are having an impact in the lake sediments.

Huston sediment-ammonia concentrations were actually below the normal range measured in other lakes (Table A8). This is possibly a result of the shallow water and limited anoxic zone that minimizes ammonia retention within the sediments. It may also be an artifact of the recent renovation in the lake (2002-03).

For a more quantitative summary of the 2006 findings, refer to Tables A2 through A12 located at the end of Section V. These Tables provide a numeric summary of the 2006 sampling results including analytes from within the lakes (Table A2-A8), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A9-A12). Long term data is available on the DEH Division of Environmental Quality's website in the Lake Reports section (CCD 2007).

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.

AquaGolf is currently under-going a major renovation which commenced in the fall of 2006. Consequently, the AquaGolf water level was at approximately 50% of bank full during the 2006 summer sample event. The primary objective of the renovation is to utilize AquaGolf as a five year retention pond for the nearby storm basin. Physical "improvements" include a new outlet on the south-central shore that discharges into a forebay. The forebay is designed to accommodate regular maintenance (sediment removal). Additional changes include a new outfall on the 'north' bank that discharges directly to the South Platte River. The typical lake depth does not appear to have been increased by these renovations and may have been kept constant or decreased.

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 (Tables A1, A2, and A3). Conditions in AquaGolf were further influenced by lower water volumes due to impending renovations. A summary of water quality standard exceedances indicated in Table A1 for these lakes include:

- pH in Overland and AquaGolf;
- un-ionized ammonia in AquaGolf ; and
- total recoverable iron in AquaGolf.

Additional highlights in the two lakes included relatively high phosphorus, chlorophyll-a, and dissolved oxygen. These factors are related in that excessive amounts of phosphorus promote algal growth which results in more photosynthesis and subsequently high dissolved oxygen (and pH) levels. Overland Pond, AquaGolf, and Sloans Lake are the only three among the fifteen sampled lakes that rated hypereutrophic on all three Carlson trophic status indicators (TSI)[3] in 2006 (Table A4).

Factors unique to AquaGolf included the un-ionized ammonia exceedance and relatively high total metals concentrations. Both of these factors are not typical of past conditions (CCD 2007) and are likely a result of the limited separation between the anaerobic sediment layer and the entire water column (1- 2.5 foot depth throughout). Overland and AquaGolf have experienced elevated pH levels on many occasions over the past ten years of sampling (Fig 3-6). A blocked inlet from Overland Pond in 2005 and the intentionally lowered water levels in 2006 further enhanced productivity and contributed to subsequently higher pH values. The elevated pH levels in Overland Pond are likely most influenced by high nutrient loading from the South Platte River and subsequent algal productivity.

Completion of the Public Works capital improvement project in 2006/07 will divert additional storm runoff to AquaGolf to accommodate storm events. While this will potentially improve water exchange issues in the lake, poor quality of incoming water could add to already marginal conditions. Future sampling will help determine to what degree this project impacts existing water quality issues in the lake and assist with recommendations for future renovations on the City and County of Denver's Lakes.

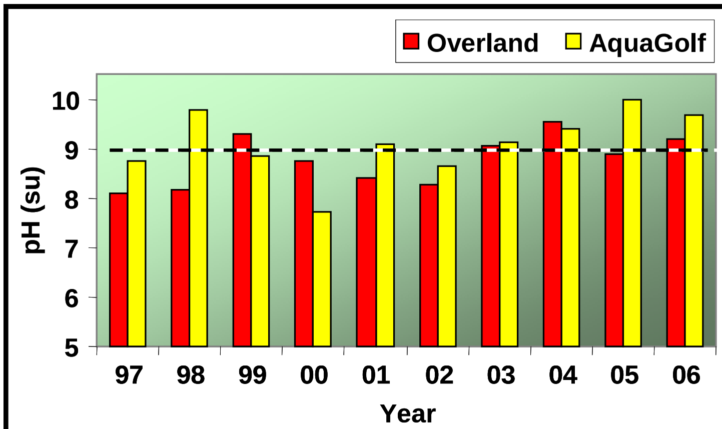


Fig 3-6. Mid-summer (June/July) pH in Overland Pond and AquaGolf Lake from 1997-2006. The dashed line indicates the state water quality standard of 9.0su.

3.D.2. Sediment Quality

Sediment-Metals

As in 2005, sediment metal concentrations of the South Platte River Lakes were surprisingly un-noteworthy relative to the other Denver lakes in 2006. There were no metal analytes at levels of concern or that were greater than the 85th percentile among all the Denver lakes.

Sediment-Nutrients

Noteworthy sediment nutrient information from 2006 includes:

- relatively low ammonia and phosphorus in AquaGolf; and
- the highest phosphorus concentrations among all lakes in Overland.

[3] The trophic status index (Carlson 1979) is a calculation of the eutrophic condition of a lake based on selected parameters including algal productivity (chlorophyll-a), water clarity (secchi depth), and total phosphorus concentrations. Ratings range from oligotrophic to hypereutrophic (low productivity to very high productivity). It is common for urban lakes to score as hypereutrophic.

The low AquaGolf sediment nutrient values are coupled with the relatively high aqueous ammonia and phosphorus. This likely reflects water-sediment interactions (possibly anaerobic night time conditions) that resulted in a release of sediment bound phosphorus, phosphorus bound up in the phytoplankton, or other factors. Overland Lake had elevated phosphorus levels in both the water column and the sediments. A likely difference between the two water bodies is the ample water exchange in Overland Pond (allowing for conditions that maintain sediment bound phosphorus) opposed to extremely poor water exchange in AquaGolf Lake.

For a more quantitative summary of the 2006 findings, refer to Tables A2 through A12 located at the end of Section V. These Tables provide a numeric summary of the 2006 sampling results including analytes from within the lakes (Table A2-A8), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A9-A12). Long term data is available on the DEH Division of Environmental Quality's website in the Lake Reports section (CCD 2007).

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 but limited retention due to the outlet elevation.

3.E.1. Water Quality

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

- bacteria, dissolved oxygen, and iron in Barnum Lake; and
- pH in Parkfield Lake (Tables A1 and A13).

Barnum Lake

While the 2006 July bacteria levels (*E. coli* and fecal coliform) were considerably lower than the previous three years, they still exceeded state water quality standards, and were the highest concentrations among the CCOD Lakes. Long term data indicate a significant increase in *E. coli* concentrations in 2003 and suggest a source other than routine urban runoff is contributing to the lake (Fig 3-7). Possible sources include illicit discharge[4] from the 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.

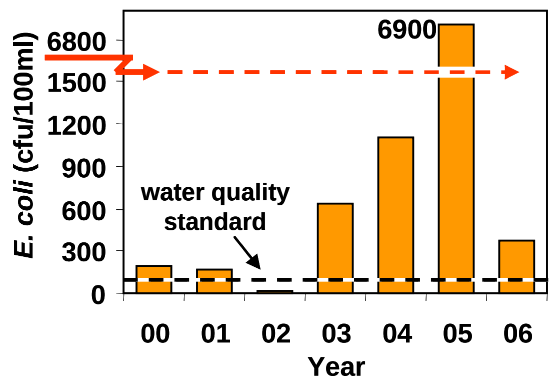


Fig 3-7. *E. coli* in Barnum Lake from mid-summer sample events (June/July). Note the break in the Y-axis and the CDPHE water quality standard (black dash line).

The elevated bacteria levels likely contribute to depressed dissolved oxygen conditions measured in the lake in 2005 and 2006. The 2006 dissolved oxygen levels in Barnum Lake were not anaerobic throughout the entire water column but were below the state water quality standard of 5*mg/L*-O_2. This was an improvement compared with 2005 conditions. If the bacteria levels continue to decrease, it is anticipated that dissolved oxygen levels will increase over time.

Total and total recoverable iron concentrations have ranged widely in Barnum Lake during sampling from 2000-2006 (360-2700*ug/L*). The 2006 value of 1200*ug/L* was considerably lower than the 2005 value but is still in exceedance of the CDPHE water quality standard (1000*ug/L*) for aquatic life. While this poses no threat to human health literature indicates potential toxicity to aquatic life posed by iron is very complex and dependent on many other chemical factors (i.e., pH). It is possible that recent measured values may have indirect impacts on aquatic life (i.e., productivity) but are likely not acutely toxic (van Anholt *et al.* 2002, Linton *et al.* 2006). It is anticipated that general improvements to the lake (such as water column mixing or aeration) may help maintain lower water column iron concentrations.

Weir Gulch

To gain a more thorough understanding of bacterial contributions to Barnum Lake, DEH sampled from various locations in Weir Gulch between the lake and Sheridan Blvd beginning in the spring of 2006. This sampling was performed approximately bi-monthly to assess whether there was an illicit connection or other traceable bacteria sources within the storm drainage system.

Results from this sampling suggest an increase in bacterial contributions between Wolff Street at Center Ave and 1rst Avenue (Fig 3-8). This is likely a result of several urban runoff

[4] 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.

contributions between these two sampling sites including Alameda Ave, significant amounts of residential runoff, and an un-named gulch originating west of Sheridan Blvd. More focused sampling over the next year will help further define contributions from this watershed.

The primary issues in Barnum Lake: elevated bacteria, low dissolved oxygen, and odor complaints) are likely all connected. It is recommended that a water column mixing agent or aeration system be considered for mitigation of these issues. The Department of Environmental Health is available to help with some recommended options.

Parkfield Lake - pH

The pH in Parkfield Lake was higher than previously measured values in the lake and was the highest among the Denver lakes in 2006. This is not unexpected due to the high productivity of Parkfield Lake. The shallow and clear conditions typical of the lake promote a dense growth of submerged vegetation resulting in a high photosynthetic rate. The process of photosynthesis raises the pH which is not necessarily an environmental risk in itself and does not pose a public health issue.

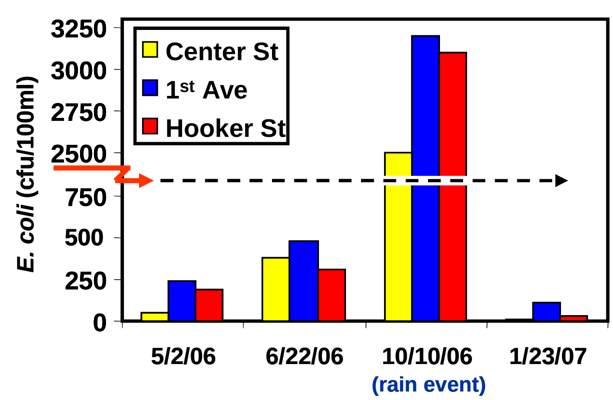


Fig 3-8. *E. coli* in Weir Gulch between Sheridan Blvd and Barnum Lake. Designated sites from upstream to downstream included (upstream of) Center Ave, (upstream of) 1rst Ave, and (downstream of) Hooker St.

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

Vanderbilt Lake – Update

Based on findings from annual DEH (2005, 2006) summer sampling and the Brown and Caldwell Phase II Site Assessment (2005), discussions are on-going to guide lake quality improvements. Additional investigations were also conducted to further characterize the sediment and to also qualitatively assess the *littoral zone* macroinvertebrate community. Results of the investigation will help with development of recommended management options to (1) address the sediment organic contaminants and (2) to establish a functional aquatic community.

Current objectives for the Vanderbilt Lake renovation include the establishment of a functional native fishery. This would require mitigation of the chronically low summer dissolved oxygen. Likely forms of mitigation could include moderately aggressive aeration, some benefits of which include:

- addition of oxygen into the bottom half of the water column;

- expedite degradation of organic sediment contaminants; and
- decrease in availability of nutrients and some metals within the water column.

3.E.2. Sediment Quality

Sediment-Metals

Sediment metal concentrations for three of the four miscellaneous-sourced lakes were generally within or below values typical of all Denver lakes in 2006. The exception was limited to exceedances of the USEPA guidelines (2002) for manganese, lead, and zinc in Vanderbilt Lake. While these sediment metal concentrations did exceed the federal guidance levels, they were generally within the range of previous findings (CCD 2007) in Vanderbilt Lake.

A Phase II Environmental Site Assessment and Characterization of Vanderbilt Lake in December 2004/February 2005 also documented the elevated lead concentrations in addition to organic constituents (Brown and Caldwell 2005). Additional sampling and discussions in 2007 will help guide planned renovations for the lake.

Sediment-Nutrients

Noteworthy sediment-nutrient findings in the miscellaneous group of lakes included relatively high (among Denver lake sediments) ammonia (inorganic nitrogen), TKN (organic nitrogen), and phosphorus in Vanderbilt; and TKN in Parkfield Lake.

Elevated sediment-nutrient concentrations in Vanderbilt Lake are likely attributable to a variety of factors that are ultimately a result of chronic substantial summer-time anoxic zone in the bottom half of the lake. Other factors include the historical use of the lake (industrial holding pond) and the limited water exchange. Both aggressive aeration or water column mixing could help mitigate these sediment-nutrient concentrations over time.

A build up of organic nitrogen in Parkfield Lake is possibly attributable to the dense vegetative growth throughout the lake. In that this lake is actually more of a wetland, this should not be considered an issue to be mitigated.

For a more quantitative summary of the 2006 findings, refer to Tables A2 through A12 located at the end of Section V. These Tables provide a numeric summary of the 2006 sampling results including analytes from within the lakes (Table A2-A8), and for sampling of the inflows and the *hypolimnion* (see glossary) (Tables A9-A12). Long term data is available on the DEH Division of Environmental Quality's website in the Lake Reports section (CCD 2007).

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 2006 QA/QC included two sets of replicates collected for parameters analyzed at the CCOD's Wastewater Management Division Laboratory (WMD) and for metals parameters at Evergreen Analytical Laboratory (EAL).

Results within 85% of the replicates were considered to have achieved objectives for data quality. Due to the inherent variability of bacteria presence and measurement, the *E. coli* and fecal coliform criteria is less stringent with a 50% similarity considered acceptable.

Replicate Results

The two WMD Laboratory replicates met the 85% similarity criteria for all measured parameters (Table A14b).

Replicates for metals analyses included both the dissolved and total partitions. The dissolved metal analytes that were below 85 percent included chromium, manganese, and selenium (Table A15b). These results are not surprising given the low concentrations measured for these parameters. The total selenium and zinc replicates were less than 85 percent similarity for one of the replicates. The zinc measurement was the most noteable with only a 38% similarity.

The sediment replicates included five parameters from one of the two comparisons that were not within the 85% similarity criteria (Table 15b). While none of the differences were egregious (lowest similarity was 75%) it was interesting that all analytes met the 85% similarity in the second replicate pair.

Field and Equipment Blanks

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

One field blank was collected to assess analyses of nutrients and basic chemistry performed at the WMD Laboratory. Field blanks consist of de-ionized water poured into a sample container in the field. The field blanks are performed to assess potential contamination within the field and laboratory processing.

Criteria for acceptable QA for field and equipment blanks are:

- results are below detection; or
- results are less than 25% of the 15th percentile among all Denver lakes in 2006.

Equipment blanks for samples delivered to EAL were also flagged if results were within 20% of the reporting limit (Table 15a).

Field-Equipment Blank Results

The WMD Laboratory field blank came back favorably for all analytes except nitrate and total suspended solids (TSS)(Table A14a). The WMD Laboratory had expressed concern for the accuracy of their analyses of low level TSS, so this was to be expected. The elevated nitrate value was of considerable concern. There was no discernable explanation for this finding. Documented equipment calibration and (field and laboratory) protocol did not reveal any complications that would have contributed to the elevated reading. Analyses over the sample period by the DEQ did not reveal any results that suggested nitrate contamination credible to either sample protocol or laboratory practices.

While there were a few analytes detected in EAL equipment blanks for metals (dissolved chromium, manganese, and selenium; total chromium), none of these exceeded 25% of the 15th percentile among the Denver Lake in 2006 (Table A15a). Several sediment analytes were also detected, but the reported concentrations were typically fractions of reported values from genuine field samples.

V. Summary & Recommendations

A summary of findings based on the 2006 monitoring effort and other activities include:

- Seven of the sixteen sampled lakes had pH levels in exceedance of water quality standards. Parkfield Lake (which is one of the seven) is actually more typical of a wetland[5] than a lake.
- Nitrate was again measured at relatively high concentrations in the Smith and Ferril Lakes, attributable to the quality of the re-use water.
- Ammonia concentrations in Duck Lake exceeded water quality standards for the fourth consecutive year.
- Chlorophyll-a concentrations in Overland Pond and AquaGolf Lake (South Platte Lakes) were extremely high relative to the other Denver lakes. These lakes were two of three that had hypereutrophic ratings for all three measured parameters (chlorophyll-a, secchi depth, and total phosphorus).
- Bacteria levels in Sloans Lake were acceptable for recreational purposes on 17 of 18 sample events spanning May 23rd through September 12th, 2006.
- Although *E. coli* levels were considerably lower in Barnum Lake, they exceeded water quality standards for the fourth consecutive year and sixth of the past seven years.
- Continued exceedance of the arsenic fish ingestion water quality standard in Berkeley Lake. A phase II survey performed by Brown and Caldwell did not discern arsenic or mercury sources in the ground water or soils surrounding the lake.
- Fish consumption advisories were posted for Berkeley and Rocky Mountain Lakes based on the 2004 CDPHE fish tissue assessment. The advisory applies to consumption of one species, large mouth bass.
- Elevated copper concentrations in Rocky Mountain Lake were likely attributable to recent algaecide/herbicide applications and were not typical of previous years results.
- Aqueous iron water quality standards were exceeded in three lakes: Garfield, Barnum, and AquaGolf. Results from Garfield and AquaGolf were atypical of previous years' measurements while Barnum Lake has had a wide range of results over the past several years. The iron concentrations do not pose a risk to human health.
- Further investigations (sediment depth characterization, macroinvertebrate sampling) were performed on Vanderbilt Lake to help with recommendations on renovation and rehabilitation of the lake in order to establish a functional aquatic community.

These findings are also presented in Table 5-1 with further comments, recommendations, and a summary of DEH actions to help remedy the issues.

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[5] It is dominated by shallow depths with light penetrating to the bottom sediments and has 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.

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@denvergov.org).

Table 5-1. Summary of noteworthy 2006 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), incorporation and expansion of natural areas, 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).	DEH will recommend that CDPHE investigate fish tissue from other CCoD lakes as well as re-sample Berkeley and Rocky Mountain fish in the near future to determine the advisory status.
Bacteria levels in Sloans Lake were acceptable for recreational purposes on 17 of 18 sample events spanning May 23 through September 12, 2006.	Bacteria levels were near or below the detection limit throughout most of the year with one exceedance following a moderate rainfall event. An informational sign was posted at the boat ramp and it contains advisory information concerning water quality and recreation.	Sloans Lake will continue to be sampled weekly during the recreational season; DEH will use the CDPHE Natural Swim Beach Regulations as guidance concerning altering the advisory sign from a yellow caution message to a red warning message.
Rocky Mountain Lake copper concentration exceeded state water quality standards.	The sample event closely followed a copper-containing herbicide application in the lake. Highlights the need to use application rates as prescribed by the manufacturer.	DPR management must be certain that contractors are using the appropriate amount of chemicals with treatments. DEH recommends that DPR's various districts work with one certified contractor (or certified employee) that the city can be confident is using appropriate measures.
Conversion to re-use water as City Ditch source water in 2004 has altered water quality of the City and Washington Park Lakes. This includes elevated nitrate levels and salt concentrations as indicated by conductivity, TDS, and cation measurements.	Recycled water contains high nitrate (10-15mg/L-NO_3 as N) and salt concentrations. Primary concerns include increased productivity due to increased nitrate loading resulting in problems with algae for aesthetic and odor problems as well as increased oxygen demand and potential blue-green algae toxicity to fish and wildlife.	Continue to assess effectiveness of SolarBee mixing units in Duck Lake (installed June 2005). If still connected, utilize aeration system in Duck Lake. Use all water quality BMPs possible (i.e., natural area establishment, wetlands, barley straw) to decrease negative impacts.
Ammonia concentrations in Duck Lake exceeded water quality standards.	Dense population of cormorants, waterfowl, and other birds contribute to nutrient loading. Fish die-offs in spring of 2005 and 2006.	Mitigation would include decreasing bird activity at the lake and incorporation of water quality BMPs as listed above.

Table 5-1 (continued). Summary of noteworthy 2006 findings and recommendations.

Findings	Comments	Recommendations
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.
South Platte Lakes hyper-eutrophic for all three Carlson TSI parameters (chlorophyll-a, secchi depth, total phosphorus) with continued highest total phosphorus, chlorophyll-a levels among all Denver lakes.	AquaGolf Lake concentration is perennially the highest among the Denver lakes with Overland typically the second highest. High-phosphorus loading and shallow depths are ideal for algal productivity, particularly in 2006 with AquaGolf at low depths for renovation. If depths have been further decreased by the renovation, it is likely the algal productivity will persist and may be more severe.	Monitor impacts of the Florida Lateral project on water quality and quantity. The lake may need more intensive management to protect irrigation use, balanced by realization that the lake will discharge to the South Platte (waters of the State).
Barnum Lake bacteria (*E. coli*) levels exceeding water quality standards.	The elevated bacteria, or associated contaminants may be contributing to the low dissolved oxygen problem within the lake. Sampling of Weir Gulch did not detect illicit discharges to date, but has isolated a tributary of interest concerning bacteria.	DEH has continued focused bi-monthly sampling on Weir Gulch to determine whether there are illicit connections or other sources contributing to excessive bacteria in the lake.
Iron water column exceedances in three lakes: Garfield, Barnum, and AquaGolf	The Barnum Lake iron concentrations have exceeded the standard on occasion throughout the past ten years while Garfield and AquaGolf concentrations have typically not. The shallow AquaGolf depths likely contributed to the problem in 2006 and will not be repeated on hydrologically "normal" years. Incoming waters and geochemical interacations are likely contributors.	The concentrations in Barnum and Garfield Lakes are variable and pose no human health threat and little if any environmental threat. The elevated AquaGolf concentrations are likely an artifact of drawdown for renovation and will likely not repeat in following years. Given the above, there are no recommendations to address iron at this time.
Continued investigations on Vanderbilt Lake add information towards renovation planning.	DEH contracted with HWS to perform additional sediment characterization and aquatic community assessment (May 2007) towards a feasibility study concerning management recommendations. The current objective is to establish a functional, sustainable aquatic community with a native fishery. This will require remediation of elevated organic contaminants in the sediment which will increase oxygen concentrations throughout the water column.	On-going discussions with potential contractors to develop a preferred alternative towards sediment remediation. DEH is working with DPR in developing a long term plan.

Tables

2006 Data (Tables A1 through A15)

Table A1. Summary of findings for all Denver Lakes sampled in June/July 2006.

							- - - Nutrients - - -															- - - Metals - - -		
																						Aqueous		Sediment
Ditch Source / Lake	pH[a/]	Temperature	DO	Conductivity	Alkalinity	Hardness	Ammonia	UIA[b/]	Nitrite	Nitrate	TIN[c/]	TKN	Total-P	Ortho-P	Chlorophyll-a	Secchi depth	DOC[d/]	TDS	TSS	*E. coli*	Fecal coliform	Dissolved[e/, f/, g/]	Total[h/]	Total
Rocky Mountain Ditch																								
Berkeley			hatched	yellow	yellow										green	green		yellow				**As**; Cr, Cu, Mn	As	**As, Cu, Pb, Zn**; Ag, Hg, Mn
Rocky Mountain	red				yellow	green							green		green	green			green			**Cu**; Cr	Cu	**Pb, Zn**; Ag, Cd, Cu, Hg, Mo
Sloans				green			yellow									yellow			yellow		yellow	Cr	Cr, Pb, Zn	**Pb**
City Ditch																								
Grasmere		- - - - - - - - - - *not sampled* - - - - - - - - - -																						
Smith	red				green								green									Zn		**Pb**; Cr, Fe
Ferril	red		green		green					yellow	yellow											Ni, Pb, Zn	Pb	**Pb**
Duck	red						red	red	yellow			yellow			green							Ni		
Agricultural Ditch																								
Harvey																		green				Al	As	
Garfield				green		green					green	green						green		yellow		Al, Fe, Pb	**Fe**; Al	Al, Fe, Mn
Huston	green		hatched	green							green	green					nm	green	green			Mn	As, Mn	**Cu, Pb, Zn**; Ag, Al, Cd, Fe, Hg, Tl
South Platte																								
Overland	red		green						yellow	yellow	yellow		yellow	yellow	yellow					yellow	yellow	Mo, Se	Mo	
AquaGolf	red		green			yellow		red				yellow	yellow	yellow	yellow	yellow			yellow			Mo, Zn	**Fe**; Al, Cd, Cr, Cu, Mo, Ni, Pb, Se, Zn	
Miscellaneous																								
Barnum			hatched									green			green		green		yellow	red	yellow		**Fe**; Cr, Zn	
Vanderbilt				yellow		yellow											yellow	yellow				Mn, Mo	Mn, Mo, Ni	**Mn, Pb, Zn**; Cr, Mo
Lollipop	green			yellow	yellow	yellow											green	yellow		yellow	yellow	Se	Mn, Se	Se
Parkfield	red														green	green	yellow		green					Al

a/ green: <15th percentile (>85th percentile for DO and Secchi); yellow: >85th percentile (<15th percentile for DO and Secchi);
red: exceeds standard; hatched: exceeds criteria, inadequate sample to determine status regarding standards; blank: within the 15th to 85th percentile range of all Denver Lakes in 2006 and does not exceed the standard.

b/ listed = >85th percentile among Denver Lakes in 2004; blue bold = exceeds standard/criteria based on estimate below laboratory reporting limit; bold = exceeds standard;

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 2006; **bold** = exceeds standard

f/ see Appx D for list of elements by symbol

g/ based on Fish Consumption Standard

h/ Iron (Fe) exceedances are based on total recoverable analyses

Table A2. Physicochemical results for Denver Lakes, June/July 2006. 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	DOC (mg/L-C)	TDS (mg/L)	TSS (mg/L)
Rocky Mountain Ditch											
Berkeley	6/26/06	3	8.3	23.6	**4.6**	1102	293	162	10.4	618	6
Rocky Mntn	6/26/06	3	**9.1**	22.7	**4.9**	659	194	70	10.2	377	5
Sloans	6/27/06	5	8.8	24.4	8.3	547	163	163	10.9	474	27
City Ditch											
Grasmere			- - - - - - - - - -		***not sampled***	- - - - - - - - - -					
Smith	7/20/06	3	**9.6**	25.4	12.5	646	60	108	6.6	449	11
Ferril	7/25/06	3	**9.7**	25.6	15.1	667	56	121	8.9	504	34
Duck	7/25/06	2	**9.7**	26.0	12.1	662	91	137	9.3	505	14
Agricultural Ditch											
Harvey	7/13/06	3	9.0	22.9	12.1	562	131	128	9.6	276	25
Garfield	7/18/06	3	8.0	24.6	5.8	283	73	93	5.5	214	22
Huston	7/18/06	1	7.6	25.1	**3.6**	271	83	97	nm[c]	209	6
South Platte River											
Overland	6/29/06	1	**9.2**	20.9	15.5	718	111	207	5.9	449	29
Aquagolf	6/29/06	3	**9.7**	22.6	15.5	782	75	244	9.3	499	256
Miscellaneous											
Barnum	7/11/06	3	7.9	19.1	**4.0**	641	178	154	5.1	361	25
Vanderbilt	7/11/06	4	8.4	22.8	10.1	1150	185	262	12.6	662	11
Lollipop	7/6/06	2	7.9	22.2	7.9	1292	214	414	3.8	830	27
Parkfield	7/6/06	3	**10.1**	22.2	8.8	1014	95	101	14.8	606	3
		min:	7.6	19.1	3.6	271	56	70	3.8	209	3
		max:	10.1	26.0	15.5	1292	293	414	14.8	830	256
		15th percentile:	7.9	22.2	4.6	549	73	97	5.5	285	6
		85th percentile:	9.7	25.4	14.8	1093	193	240	11.0	617	29
		median:	9.0	22.9	8.8	662	111	137	9.3	474	22

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

c/ not measured

Table A3. Nutrient, bacteria, and associated parameter results for Denver Lakes, June/July 2006. Bolded values exceed CDPHE water quality standards.

Lake	# Sites[a/]	Date	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	3	6/26/06	8.3	0.24	0.022	< 0.01	< 0.20	0.47	1.20	0.34	0.27	15.0	53	< 10	20
Rocky Mntn	3	6/26/06	**9.1**	< 0.10	< 0.036	< 0.01	< 0.20	< 0.35	1.23	< 0.08	< 0.08	2.6	136	< 10	< 10
Sloans	5	6/27/06	8.8	< 0.10	< 0.025	< 0.01	< 0.20	< 0.34	1.64	0.16	< 0.08	67.6	12	13	175
City Ditch															
Grasmere						- - - - - - - - *not sampled* - - - - - - - - -									
Smith	3	7/20/06	**9.6**	< 0.10	< 0.068	0.14	4.28	4.59	1.44	< 0.08	< 0.08	51.9	32	na	na
Ferril	3	7/25/06	**9.7**	< 0.10	< 0.077	0.15	7.40	7.73	2.47	0.10	< 0.08	88.3	17	10	30
Duck	2	7/25/06	**9.7**	**0.63**	**0.473**	0.25	2.56	3.91	3.15	0.51	0.35	77.7	26	20	40
Agricultural Ditch															
Harvey	3	7/13/06	9.0	< 0.10	< 0.033	< 0.01	< 0.20	< 0.35	1.36	0.12	< 0.08	75.4	21	30	40
Garfield	3	7/18/06	8.0	< 0.10	< 0.006	< 0.01	< 0.20	< 0.32	< 1.02	0.10	< 0.08	24.6	20	40	70
Huston	1	7/18/06	7.6	< 0.10	< 0.002	< 0.01	< 0.20	< 0.31	< 1.00	0.19	0.11	15.1	42	< 10	< 10
South Platte River															
Overland	1	6/29/06	**9.2**	< 0.10	< 0.040	0.21	5.62	< 5.97	2.40	0.99	0.80	196.4	13	60	140
Aquagolf	3	6/29/06	**9.7**	0.22	**0.153**	0.16	1.52	2.06	7.67	1.00	0.58	265.4	6	< 10	< 10
Miscellaneous															
Barnum	3	7/11/06	7.9	0.20	0.005	0.03	0.93	1.17	< 1.05	0.19	0.16	7.6	14	**370**	1280
Vanderbilt	4	7/11/06	8.4	< 0.13	< 0.014	< 0.01	< 0.20	< 0.35	2.36	0.15	< 0.08	75.1	26	< 10	10
Lollipop	2	7/6/06	7.9	< 0.11	< 0.004	< 0.01	< 0.20	< 0.33	1.40	0.12	< 0.08	66.1	23	60	180
Parkfield	3	7/6/06	**10.1**	< 0.10	< 0.085	< 0.01	< 0.20	< 0.40	1.80	0.34	0.21	10.4	41	< 10	< 10
		min:	7.6	< 0.10	< 0.002	< 0.01	< 0.20	< 0.31	< 1.00	< 0.08	< 0.08	2.6	6	< 10	< 10
		max:	9.7	0.63	0.473	0.25	7.40	7.73	7.67	1.00	0.80	265.4	136	60	175
		15[th] percentile:	8.2	< 0.10	0.014	< 0.01	< 0.20	< 0.33	1.11	0.09	< 0.08	15.1	13	< 10	< 10
		85[th] percentile:	9.7	0.23	0.115	0.18	4.95	5.28	2.81	0.75	0.46	142.4	48	37	116
		median:	9.1	0.10	0.036	0.01	0.20	0.47	1.44	0.16	0.08	67.6	21	11	35

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 A4. Summary of Trophic Status Index (TSI) values for Denver Lakes from June/July 2006.

lake	date	Category			Numeric value[a]		
		secchi[b]	TP	chlor-a	secchi	TP	chlor-a
Rocky Mountain Ditch							
Berkeley	6/26/06	E[c]	H	E	56	88	57
Rocky Mntn	6/26/06	M	E	O	42	68	40
Sloans	6/27/06	H	H	H	77	77	72
City Ditch							
Grasmere		- - - - - *not sampled* - - - - -					
Smith	7/20/06	E	E	E	63	67	69
Ferril	7/25/06	H	E	H	72	70	75
Duck	7/25/06	E	H	H	66	94	73
Agricultural Ditch							
Harvey	7/13/06	E	H	H	69	73	73
Garfield	7/18/06	E	H	E	70	71	62
Huston	7/18/06	E	H	E	59	80	57
South Platte River							
Overland	6/29/06	H	H	H	76	104	82
Aquagolf	6/29/06	H	H	H	87	104	85
Miscellaneous							
Barnum	7/11/06	H	H	M	75	80	50
Vanderbilt	7/11/06	E	E	H	66	76	73
Lollipop	7/6/06	E	E	H	68	74	72
Parkfield	7/6/06	E	H	E	60	88	54

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 A5. Summary of summer water column dissolved metal concentrations (ug/L) from Denver Lakes in June/July 2006. Bolded values indicate results that exceeded CDPHE standards (2006). The summary statistics (median, 15th and 85th percentiles) considered values below detection to be equal to the detection limit.

lake	site	date	time	hard[a/]	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																			
Berkeley	BER-M	6/26/06	1240	164	J[b/] 0.03	11	**25.0**	< 0.10	7.70	2.5	200	< 0.10	200	9.3	J 1.6	0.54	1.0	< 0.2	2.3
Rocky Mntn	RMT-M	6/26/06	1120	69	J 0.03	16	2.8	< 0.10	6.10	**20.0**	120	< 0.10	27	5.2	J 0.9	J 0.19	0.7	< 0.2	1.5
Sloan	SLN-4	6/27/06	1040	157	J 0.03	29	4.9	J 0.06	5.40	2.4	240	< 0.10	4	12.0	J 1.8	0.64	1.7	< 0.2	1.4
City Ditch																			
Grasmere	- - - - - - - - - - not sampled - - - - - - - - - - - - - - - - - -																		
Smith	SMT-M	7/20/06	0940	109	< 0.04	11	1.6	< 0.10	1.70	< 2.0	180	< 0.10	4	21.0	3.8	J 0.25	1.4	< 0.2	7.2
City Park	CPL-M	7/25/06	1010	121	< 0.04	7	1.2	< 0.10	1.40	< 2.0	190	< 0.10	2	22.0	4.3	1.80	2.1	< 0.2	7.4
Duck	DKL-O	7/25/06	1240	136	< 0.04	12	1.7	< 0.10	1.50	< 2.0	250	< 0.10	10	22.0	4.4	0.63	1.4	< 0.2	4.5
Agricultural Ditch																			
Harvey	HRV-M	7/13/06	0940	131	< 0.04	130	7.0	J 0.08	2.00	< 2.0	330	< 0.10	23	10.0	J 1.6	J 0.32	0.7	< 0.2	J 0.8
Garfield	GAR-M	7/18/06	1015	92	< 0.04	190	1.8	< 0.10	1.60	< 2.0	420	< 0.10	24	6.2	J 1.8	1.00	0.6	< 0.2	2.7
Huston	HST-M	7/18/06	1245	97	< 0.04	J 4	5.8	< 0.10	1.60	< 2.0	270	< 0.10	330	5.8	J 1.8	J 0.22	0.5	< 0.2	1.1
South Platte River																			
AquaGolf	AQG-M	6/29/06	1145	277	J 0.02	9	2.5	< 0.10	2.80	2.3	320	< 0.10	3	36.0	3.4	0.43	2.8	< 0.2	1.3
Overland	OVL-M	6/29/06	0940	207	J 0.03	J 4	1.2	< 0.10	3.70	2.1	330	< 0.10	20	29.0	2.7	J 0.14	2.3	< 0.2	7.6
Miscellaneous																			
Barnum	BAR-M	7/11/06	0950	144	< 0.04	13	1.2	< 0.10	2.00	< 2.0	250	< 0.10	81	3.8	J 1.5	J 0.13	1.6	< 0.2	2.4
Vanderbilt	VBT-M	7/11/06	1205	260	< 0.04	< 5	J 0.4	< 0.10	2.00	< 2.0	310	< 0.10	240	150.0	3.7	< 0.40	1.4	< 0.2	2.7
Lollipop	LOL-M	7/6/06	0930	413	< 0.04	< 5	1.3	J 0.08	1.50	< 2.0	nm[c/]	< 0.10	16	J 0.9	2.2	< 0.40	4.1	< 0.2	J 0.4
Parkfield	PFL-M	7/6/06	1240	111	< 0.04	6	3.8	< 0.10	J 0.87	< 2.0	nm	< 0.10	59	3.4	J 1.1	< 0.40	0.7	< 0.2	< 1.0
				median:	< 0.04	11	1.8	< 0.10	< 2.00	2.0	250	< 0.10	23	10.0	< 1.8	0.40	1.4	< 0.20	< 2.3
				15th percentile:	< 0.03	< 5	1.2	< 0.08	< 1.50	2.0	188	< 0.10	< 4	< 3.9	< 1.5	0.19	0.7	< 0.20	< 1.0
				85th percentile:	< 0.04	28	5.7	0.10	< 5.23	2.4	330	< 0.10	188	28.3	3.8	0.64	2.3	< 0.20	6.9

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

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

Table A6. Summary of summer water column total metal concentrations (ug/L) from Denver Lakes in June/July 2006. Bolded values indicate results that exceeded CDPHE standards (2006). The summary statistics (median, 15[th] and 85[th] percentiles) considered values below detection to be equal to the detection limit.

Lake	Site	Date	Ag	Al	As[c/]	Cd	Cr	Cu	Fe[c/]	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																	
Berkeley	BER-M	6/26/06	<[b/] 0.3	290	24.0	< 0.40	2.30	J 3.0	180	< 0.10	260	11.0	J 2.2	J 1.8	J 0.7	< 0.50	J 3.5
Rocky Mntn	RMT-M	6/26/06	< 0.3	44	2.9	< 0.40	J 2.00	21.0	J 52	< 0.10	J 48	5.6	J 1.2	< 2.0	< 1.0	< 0.50	J 1.3
Sloan	SLN-4	6/27/06	< 0.3	1400	5.3	< 0.40	3.10	5.0	830	< 0.10	68	13.0	J 2.8	6.3	1.4	< 0.50	45.0
City Ditch																	
Grasmere	- - - - - - - - - - - - - not sampled -																
Smith	SMT-M	7/20/06	< 0.3	110	1.9	< 0.40	J 1.70	< 4.0	120	< 0.10	J 17	22.0	J 3.4	J 1.0	J 0.8	< 0.50	21.0
Ferril	CPL-M	7/25/06	< 0.3	510	1.5	< 0.40	J 1.80	< 4.0	460	< 0.10	J 14	23.0	J 4.1	5.1	1.2	< 0.50	11.0
Duck	DKL-O	7/25/06	< 0.3	320	1.8	< 0.40	J 1.60	< 4.0	280	< 0.10	J 36	22.0	J 4.1	J 1.7	1.1	< 0.50	5.8
Agricultural Ditch																	
Harvey	HRV-M	7/13/06	< 0.3	1100	7.4	< 0.40	2.20	J 3.0	930	< 0.10	74	12.0	J 2.7	J 0.9	J 0.8	< 0.50	10.0
Garfield	GAR-M	7/18/06	< 0.3	2200	1.6	< 0.40	J 1.80	J 3.4	**1700**	< 0.10	99	5.6	J 1.8	3.0	< 1.0	< 0.50	23.0
Huston	HST-M	7/18/06	< 0.3	92	6.2	< 0.40	J 1.10	< 4.0	550	< 0.10	390	6.1	J 1.6	J 1.2	< 1.0	< 0.50	22.0
South Platte River																	
Overland	OVL-M	6/29/06	J 0.1	630	1.7	< 0.40	2.40	J 3.7	650	< 0.10	120	32.0	J 3.4	J 1.3	2.3	< 0.50	13.0
AquaGolf	AQG-M	6/29/06	< 0.3	3500	2.8	1.30	4.80	14.0	**2700**	< 0.10	120	40.0	J 5.8	4.8	3.5	J 0.03	33.0
Miscellanous																	
Barnum	BAR-M	7/11/06	< 0.3	1400	1.5	< 0.40	2.60	4.9	**1200**	< 0.10	190	6.0	J 2.9	3.4	2.0	< 0.50	28.0
Vanderbilt	VBT-M	7/11/06	< 0.3	< 25	0.9	< 0.40	J 2.00	< 4.0	J 54	< 0.10	720	170.0	J 5.0	< 2.0	1.3	< 0.50	5.4
Lollipop	LOL-M	7/6/06	< 0.3	92	1.8	< 0.40	J 1.70	< 4.0	110	< 0.10	290	J 1.2	J 3.9	< 2.0	4.0	< 0.50	J 2.0
Parkfield	PFL-M	7/6/06	< 0.3	64	4.0	< 0.40	J 1.90	< 4.0	J 67	< 0.10	120	J 3.9	J 1.7	< 2.0	J 0.9	< 0.50	< 5.0
		median:	< 0.3	320	< 1.9	< 0.40	< 2.00	< 4.0	460	< 0.10	120	12.0	2.9	< 2.0	< 1.1	< 0.5	11.0
		15%:	< 0.3	67	< 1.5	< 0.40	< 1.70	< 3.4	71	< 0.10	37	< 5.6	< 1.7	< 1.2	< 0.8	< 0.5	3.7
		85%:	< 0.3	1400	6.1	< 0.40	2.58	5.0	1173	< 0.10	287	31.1	4.1	4.7	< 2.3	< 0.5	27.5

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

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

c/ All iron and arsenic values are total recoverable.

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

Table A7. Summary of sediment total metal concentrations (ug/g) from Denver Area Lakes in 2006. Bolded values are results that exceeded federal guidance (USEPA 2002).

Lake	Site	Date	Time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn	total solids (%)
Rocky Mountain Ditch																			
Berkeley	BER-M	6/26/06	1240	2.3	B 12000	**36**	3.5	19	B **150**	23000	0.52	810	3.7	15	**290**	2.3	0.5	**460**	20.4
Rocky Mntn	RMT-M	6/26/06	1120	1.9	B 11000	15	3.9	18	B 130	20000	0.47	740	14.0	15	**270**	1.7	0.5	**520**	15.9
Sloan	SLN-4	6/27/06	1040	1.0	B 12000	7	2.2	17	B 72	20000	0.32	680	1.7	13	**220**	3.2	0.5	290	18.0
City Ditch																			
Grasmere	- - - - - - - not sampled -																		
Smith	SMT-M	7/20/06	0940	1.1	17000	17	2.0	27	100	27000	0.31	360	9.9	16	**170**	< 4.3	< 1.1	340	16.9
Ferril	CPL-M	7/25/06	1010	1.1	11000	5	1.7	18	49	18000	0.19	170	4.2	12	**170**	1.9	0.3	290	29.4
Duck	DKL-O	7/25/06	1240	0.6	13000	4	1.2	18	49	21000	0.15	260	10.0	15	91	2.1	0.4	260	20.0
Agricultural Ditch																			
Harvey	HRV-M	7/13/06	0940	0.3	16000	12	0.7	9	57	19000	0.08	560	2.8	9	33	1.0	0.4	82	26.3
Garfield	GAR-M	7/18/06	1015	0.8	30000	6	1.3	16	65	34000	0.15	950	2.3	13	66	< 4.3	< 1.1	200	19.4
Huston	HST-M	7/18/06	1245	2.4	21000	17	4.6	17	**160**	26000	0.41	320	7.7	14	**280**	< 1.7	0.6	**520**	38.1
South Platte River																			
Overland	OVL-M	6/29/06	0940	1.5	7100	2	0.6	14	B 46	12000	0.13	590	B 3.2	8	35	2.5	0.3	140	28.6
AquaGolf	AQG-M	6/29/06	1145	0.2	5500	2	0.4	10	B 62	10000	0.07	180	B 5.5	7	28	2.7	0.3	67	37.3
Miscellaneous																			
Barnum	BAR-M	7/11/06	0950	0.4	13000	4	1.5	14	52	20000	0.11	380	3.1	10	87	3.5	0.4	290	23.2
Vanderbilt	VBT-M	7/11/06	1205	0.9	6500	5	3.0	20	59	20000	0.17	**2300**	360.0	13	**190**	2.2	0.4	**570**	19.0
Lollipop	LOL-M	7/6/06	0930	0.1	5700	2	0.4	4	B 15	8900	0.04	340	0.6	5	12	5.2	0.2	43	38.7
Parkfield	PFL-M	7/6/06	1240	<[a/] 0.1	18000	4	0.5	17	B 24	21000	0.05	400	2.5	15	19	2.0	0.5	76	19.5
			median:	< 0.9	12000	5	1.5	17	59	20000	0.15	400	3.7	13	91	2.3	0.4	290	20.4
			15%:	< 0.2	6560	2	0.5	10	46	12600	0.07	266	2.3	8	29	1.7	0.3	77	18.1
			85%:	1.9	17900	17	3.5	19	127	25700	0.40	803	10.0	15	265	4.2	0.5	514	36.5

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 A8. Summary of sediment nutrient concentrations (ug/g) from Denver Area Lakes in June/July 2006.
bolded values are indicative of results that exceeded the 85th percentile among all lakes.

Lake	Site	Date	Time	total ammonia (mg/L as N)	nitrite + nitrate (mg/L as N)	organic nitrogen (TKN) (mg/L as N)	total phosphorus (mg/L as P)	total solids (%)
Rocky Mountain Ditch								
Berkeley	BER-M	6/26/06	1240	<[a] 10	3.7	3780	650	20.4
Rocky Mntn	RMT-M	6/26/06	1120	64	4.8	**7260**	760	15.9
Sloan	SLN-4	6/27/06	1040	120	4.2	3140	820	18.0
City Ditch								
Grasmere	- - - - -	- - - - -	- - -	- - - - -	not sampled	- - - - -	- - - - -	
Smith	SMT-M	7/20/06	0940	62	< 4.5	6020	1000	16.9
Ferril	CPL-M	7/25/06	1010	56	< 2.6	3590	530	29.4
Duck	DKL-O	7/25/06	1240	**370**	< 3.8	2330	870	20.0
Agricultural Ditch								
Harvey	HRV-M	7/13/06	0940	230	< 2.9	3100	1000	26.3
Garfield	GAR-M	7/18/06	1015	**440**	< 3.9	2640	**1200**	19.4
Huston	HST-M	7/18/06	1245	28	< 2.0	4190	930	38.1
South Platte River								
Overland	OVL-M	6/29/06	0940	120	2.7	6290	**2000**	28.6
AquaGolf	AQG-M	6/29/06	1145	51	2.0	2380	590	37.3
Miscellaneous								
Barnum	BAR-M	7/11/06	0950	150	1.6	4090	1000	23.2
Vanderbilt	VBT-M	7/11/06	1205	**300**	< 4.0	**6400**	1000	19.0
Lollipop	LOL-M	7/6/06	0930	190	< 2.0	3360	510	38.7
Parkfield	PFL-M	7/6/06	1240	140	< 3.9	**9120**	620	19.5
			median:	120	3.7	3780	870	20.4
			15%:	52	2.0	2686	593	18.1
			85%:	293	4.2	6389	1000	36.5

a/ "**<**" = less than the detection limit

Table A9. Physicochemical results for the inflows **(a)** and hypolimnion **(b)** in Denver Lakes, May-July 2006.

(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											
Rocky Mntn	RMT-INF	6/26/06	7.8	18.0	8.0	116	28	41	1.9	71	42
Sloan	SLN-6	6/27/06	8.0	16.4	8.0	824	185	225	4.4	512	16
City Ditch											
Smith	SMT-INF	7/20/06	7.2	22.8	6.6	759	85	168	6.8	565	9
Agricultural Ditch											
Harvey	HRV-INF	7/13/06	8.4	22.3	6.6	380	106	122	5.1	198	8
Huston	HST-INF	7/18/06	7.5	20.5	6.8	170	44	62	2.6	129	26
South Platte River											
Overland	OVL-INF	6/29/06	7.8	18.8	6.9	551	103	174	3.4	328	12
Miscellaneous											
Barnum	BAR-INF	7/11/06	8.3	17.9	7.5	872	244	228	4.1	538	25
		median:	7.8	18.8	6.9	551	103	168	4.1	328	16

(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-IB	6/26/06		17.7	0.1	*nm*	247	99	11.1	455	11
Garfield	GAR-MB	7/18/06		21.3	0.1	*nm*	79	94	5.3	195	32

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 A10. Nutrient and associated parameter results for the inflows **(a)** and hypolimnion **(b)** in Denver Lakes, June-July 2006.

(a) Inflow

Lake	Site	Date	pH (su)	NH_4[a/]	UIA	NO_2	NO_3	TIN	TKN	T-P	O-P	Ecoli	Fecal
				- - - - - - - - - - -		(mg/L-N)	- - - - - - - - - - - -			- (mg/L-P) -		(#col/100ml)	
Rocky Mountain Ditch													
Rocky Mntn	RMT-INF	6/26/06	7.8	< 0.10	< 0.002	< 0.01	< 0.20	< 0.31	< 1.00	0.09	< 0.08	560	4700
Sloan	SLN-6	6/27/06	8.0	< 0.10	<	< 0.01	0.34	< 0.45	< 1.00	< 0.08	< 0.08	550	930
City Ditch													
Smith	SMT-INF	7/20/06	7.2	0.37	0.003	0.08	15.39	15.84	1.49	0.13	0.09	nm[c]	nm
Agricultural Ditch													
Harvey	HRV-INF	7/13/06	8.4	< 0.10	< 0.010	< 0.01	< 0.20	< 0.31	< 1.00	< 0.08	< 0.08	70	260
Huston	HST-INF	7/18/06	7.5	0.18	0.002	0.02	< 0.20	< 0.40	< 1.00	0.14	0.08	550	750
South Platte River													
Overland	OVL-INF	6/29/06	7.8	< 0.10	< 0.002	0.06	2.34	< 2.50	1.80	0.53	0.49	210	510
Miscellaneous													
Barnum	BAR-INF	7/11/06	8.3	< 0.10	< 0.006	0.17	1.39	< 1.66	< 1.00	0.15	0.12	220	2100
		median:	7.8	0.10	0.003	0.02	0.34	< 0.45	1.00	0.13	0.08	385	840

(b) Hypolimnion

Lake	Site	Date	pH (su)	NH_4[a/]	NO_2	NO_3	TIN	TKN	T-P	O-P
				- - - - - - - - - -	(mg/L-N)	- - - - - - - - -			- (mg/L-P) -	
Rocky Mntn	RMT-IB	6/26/06	nm	0.45	< 0.01	< 0.20	< 0.66	2.10	0.51	0.39
Garfield	GAR-M1B	7/18/06	nm	0.62	< 0.01	< 0.20	< 0.83	1.47	0.21	0.18

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 A11. Summary of water column dissolved metal concentrations (ug/L) from inflows **(a)** and the hypolimnion **(b)** in Denver Lakes, May-July 2006. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2006.

(a) Inflow

lake	site	date	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																		
Rocky Mntn	RMT-INF	6/26/06	1320	J[a/] 0.04	21	1.1	J 0.09	1.40	**2.6**	92	< 0.10	11	3.6	J 0.8	0.40	< 0.4	J 0.01	**14.0**
Sloan	SLN-6	6/27/06	0820	J 0.03	6	0.9	< 0.10	**5.30**	2.0	**350**	< 0.10	52	8.6	J 1.8	J 0.12	**3.7**	J 0.01	**12.0**
City Ditch																		
Smith	SMT-INF	5/16/06	0935	0.02	JB **58**	B 1.2	B 0.04	2.60	**4.7**	B 42	**0.03**	24	**29.0**	B **4.5**	B 0.17	B 1.6	0.01	**29.0**
Smith	SMT-INF	7/20/06	0910	< 0.04	5	J 0.3	< 0.10	1.90	**2.5**	**380**	< 0.10	34	15.0	3.6	J 0.25	2.2	< 0.20	**21.0**
Agricultural Ditch																		
Harvey	HRV-INF	7/13/06	0845	< 0.04	11	**12.0**	< 0.10	1.30	< 2.0	210	< 0.10	7	9.5	J 1.9	J 0.14	J 0.4	< 0.20	J 1.0
Huston	HST-INF	7/18/06	0815	< 0.04	16	1.4	< 0.10	J 1.10	< 2.0	180	< 0.10	**220**	4.2	J 1.3	**0.76**	J 0.4	< 0.20	**12.0**
South Platte River																		
Overland	OVL-INF	6/29/06	0910	J 0.03	J 5	0.9	< 0.10	4.60	< 2.0	310	< 0.10	65	**29.0**	J 2.0	J 0.12	1.6	J 0.00	6.2
Miscellaneous																		
Barnum	BAR-INF	7/11/06	0815	< 0.04	J 4	1.3	< 0.10	3.10	< 2.0	**360**	< 0.10	19	4.2	J 1.6	J 0.13	**3.0**	< 0.20	2.0
			median:	< 0.04	9	1.2	< 0.10	< 2.25	2.0	260	< 0.10	29	9.1	< 1.9	0.16	1.6	< 0.11	< 12.0

(b) Hypolimnion

lake	site	date	time	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mntn	RMT-IB	6/26/06	1245	J 0.03	J 4	2.8	< 0.10	6.80	< 2.0	140	< 0.10	1100	4.1	J 1.4	J 0.18	J 0.4	< 0.20	2.5
Garfield	GAR-MB	7/18/06	1035	< 0.04	7	2.6	< 0.10	3.10	< 2.0	320	< 0.10	890	5.1	J 1.5	J 0.13	J 0.4	< 0.20	< 1.0

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

Table A12. Summary of water column total metal concentrations from inflows in Denver Lakes in May-July 2006. Bolded results highlight values that exceed the 85th percentile for inlake sites in 2006.

lake	site	date	time	Ag	Al	As[b/]	Cd	Cr	Cu	Fe[b/]	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Rocky Mountain Ditch																		
Rocky Mntn	RMT-INF	6/26/06	1320	J[a/] 0.2	**1700**	1.8	**0.43**	**3.20**	**11.0**	**1600**	< 0.10	100	4.2	J 2.0	**15.0**	< 1.0	J 0.0	**64.0**
Sloan	SLN-6	6/27/06	0820	< 0.3	480	1.1	< 0.40	2.30	J 3.5	500	< 0.10	97	9.5	J 2.9	2.1	**3.5**	< 0.5	24.0
City Ditch																		
Smith	SMT-INF	5/16/06	0935	**2.8**	J 310	4.4	**0.45**	B **3.60**	B **7.1**	500	B **0.04**	41	20.0	B 7.7	2.6	**4.6**	**4.9**	**33.0**
Smith	SMT-INF	7/20/06	0910	< 0.3	300	0.5	< 0.40	J 1.80	J 3.3	580	< 0.10	J 48	15.0	J 3.6	J 1.1	1.6	< 0.5	**38.0**
Agricultural Ditch																		
Harvey	HRV-INF	7/13/06	0845	< 0.3	330	**14.0**	< 0.40	J 1.80	J 3.2	330	< 0.10	78	8.6	J 1.6	J 1.6	< 1.0	< 0.5	J 3.1
Huston	HST-INF	7/18/06	0815	J 0.1	**1500**	1.6	J 0.21	J 1.90	**8.4**	**1500**	< 0.10	**350**	4.3	J 1.6	**9.2**	< 1.0	< 0.5	**63.0**
South Platte River																		
Overland	OVL-INF	6/29/06	0910	< 0.3	200	1.0	< 0.40	2.00	< 4.0	200	< 0.10	110	31.0	J 2.6	< 2.0	1.4	< 0.5	8.9
Barnum	BAR-INF	7/11/06	0815	< 0.3	1300	1.7	< 0.40	2.50	J 3.2	1100	< 0.10	69	4.8	J 3.2	3.0	**2.7**	< 0.5	14.0
			median:	< 0.3	330	< 1.6	< 0.40	< 2.00	< 4.0	500	< 0.10	97	9.5	2.6	< 2.1	< 1.4	< 0.5	33.0

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

b/ All arsenic and iron values are total recoverable.

Table A13. A summary of exceedances of State water quality standards and Federal sediment guidance for metals in the Denver Lakes, June/July 2006. The water quality standards are based on CDPHE Regulations 31 and 38 (CDPHE 2005 and 2006) and are dissolved portions unless otherwise noted, while the federal sediment guidance values are probable effect concentrations (PEC's) established by the USEPA (2002). The "W"and "S" are indicative of water quality standard and sediment guidance exceedances, respectively.

Lake	Ag	Al	As	Cd	Cu	Fe	Hg	Mn	Mo[f/]	Ni	Pb	Se	Zn	Other
Water Standard (ug/L)[a/]:	TVS[c/]	na	7.6[d/]	TVS	TVS	e/	0.01	TVS	na	a/	TVS	4.6	TVS	see Appx A
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	DO[h/]
Rocky Mntn					W/S						S		S	pH
Sloans											S			
City Ditch														
Grasmere	- - - - - - - - -				*not sampled*	- - - - - - - - - - - - -								
Smith											S			pH
Ferril											S			pH
Duck														pH, ammonia
Agricultural Ditch														
Harvey														
Garfield						W								
Huston					S						S		S	DO[h/]
South Platte														
Overland														pH
AquaGolf						W								pH, UIA
Miscellaneous														
Barnum						W								DO[h/],bacteria[i/]
Vanderbilt								S	W[g/]		S		S	
Lollipop														
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/ TVS = table value standard, see Appendix G for details.
d/ exceedances based on fish ingestion standard, see Appendix A for further details
e/ based on total recoverable concentration
f/ there were no established water or sediment guidance values provided for molybdenum, and no sediment guidance for selenium.
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/ exceeded dissolved oxygen standard on one time measurement, however, not adequate number of samples to establish long term exceedance.
i/ bacteria includes *E. coli* and fecal coliform

Table A14. Quality assurance (a) field blank and (b) replicates for physicochemical parameters in Denver Lakes, May and July 2006. analyses performed by the City and County of Denver's Wastewater Management Division Laboratory. Bolded "Field blank" results indicate values that were greater than 25% of the 15th percentile among all Denver Lakes in 2006. All replicate values were within acceptable limits (85% similarity and 50% for E. coli and fecal coliform).

a) Field Blank[a]

Lake	Site	Date	Alk[b]	Hard	DOC	NH4	NO2	NO3	TKN	tot-P	O-P	TDS	TSS	Ecoli	fecal
QA Lake	na	5/16/06	2	0	0.2	<[c] 0.10	< 0.01	**6.74**	< 1.00	< 0.08	< 0.08	13	**4**	< 10	< 10

b) Replicates[d]

Lake	Site	Date	Alk[b]	Hard	DOC	NH4	NO2	NO3	TKN	tot-P	O-P	TDS	TSS	Ecoli	fecal
Smith	SMT-M	7/20/06	60	109	6.61	< 0.10	0.14	4.65	1.51	< 0.08	< 0.08	449	11	nm	nm
Smith	SMT-M(R)	7/20/06	61	110	6.58	< 0.10	0.14	4.56	1.64	< 0.08	< 0.08	440	10	nm	nm
Duck	DKL-O	7/25/06	90	136	9.34	0.63	0.25	2.65	2.90	0.47	0.35	505	14	20	40
Duck	DKL-O(R)	7/25/06	89	137	9.00	0.63	0.26	2.72	2.60	0.48	0.34	497	16	10	20

Percent of Replicate[d]

Lake	Site	Date	Alk[b]	Hard	DOC	NH4	NO2	NO3	TKN	tot-P	O-P	TDS	TSS	Ecoli	fecal
Smith	SMT-M(R)	7/20/06	98	99	100	100	100	98	92	100	100	98	91	nm	nm
Duck	DKL-O(R)	7/25/06	99	99	96	100	96	97	90	98	97	98	88	50	50

a/ Field blank was deionized water poured into a sample container in the field.

b/ 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)

c/ "<" indicates the analyte was below detection; "nm" = not measured

d/ the lowest value between the replicate results divided by the highest value and multiplied by 100

Table A15. Quality assurance (a) field-equipment blanks and (b) replicates for metals parameters in Denver Lakes, July 2006. All analyses were performed at Evergreen Analytical Laboratory, Wheatridge, Colorado. Bolded "field-equipment blank" values are greater than 20% of the reporting limit[a]. Bolded "replicate" values are less than 85% of their respective replicate.

a) Field-Equipment Blanks[b]

site	date	Ag	Al	As[c]	Cd	Cr	Cu	Fe[c]	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Water (ug/L)																
Dissolved	7/18/06	<[d] 0.04	< 5	< 0.5	< 0.10	J **0.4**	< 2.0	< 40	< 0.10	J **0.7**	J 0.2	< 2.0	< 0.40	J **0.3**	< 0.2	J 0.2
Total	7/18/06	< 0.30	< 25	< 0.4	< 0.40	J **1.0**	< 4.0	< 70	< 0.10	< 50.0	< 4.0	< 10.0	< 2.00	< 1.0	< 0.5	< 5.0
Sediment (mg/Kg)																
Total	7/18/06	< 0.03	**29**	< 0.1	< 0.01	**0.2**	**0.2**	**100**	< 0.00	**1.5**	**0.1**	**0.2**	**0.13**	< 0.2	< 0.1	< 2

a/ All of the detections that were greater than 20% of the reporting limit were less than 25% of the 15th percentile among all Denver Lakes in 2006.

b) Replicates[e]

Water (ug/L)	date	Ag	Al	As[b]	Cd	Cr	Cu	Fe[b]	Hg	Mn	Mo	Ni	Pb	Se	Tl	Zn
Dissolved																
SMT-M	7/20/06	< 0.04	11	1.6	< 0.1	1.7	< 2.0	180	< 0.10	**4.3**	21.0	3.8	J 0.25	1.4	< 0.2	7.2
SMT-M(R)	7/20/06	< 0.04	11	1.4	< 0.1	**1.2**	< 2.0	190	< 0.10	5.6	21.0	4.0	J 0.28	1.2	< 0.2	7.4
DKL-O	7/25/06	< 0.04	12	1.7	< 0.1	1.5	< 2.0	250	< 0.10	9.8	22.0	4.4	0.63	**1.4**	< 0.2	4.5
DKL-O(R)	7/25/06	< 0.04	11	1.7	< 0.1	J **1.1**	< 2.0	240	< 0.10	9.2	22.0	4.3	0.63	1.7	< 0.2	4.5
Total																
SMT-M	7/20/06	< 0.3	110	1.9	< 0.4	J 1.7	< 4.0	120	< 0.10	J 17	22.0	J 3.4	J 0.96	J **0.8**	< 0.5	21.0
SMT-M(R)	7/20/06	< 0.3	100	1.7	< 0.4	J 1.7	< 4.0	120	< 0.10	J 16	22.0	J 3.5	J 0.97	1.0	< 0.5	**7.9**
DKL-O	7/25/06	< 0.3	320	1.8	< 0.4	J 1.6	< 4.0	280	< 0.10	J 36	22.0	J 4.1	J 1.70	1.1	< 0.5	5.8
DKL-O(R)	7/25/06	< 0.3	360	1.9	< 0.4	J 1.6	< 4.0	290	< 0.10	J 40	23.0	J 4.2	J 1.80	1.2	< 0.5	6.3
Sediment (mg/Kg)																
HVG-M	7/20/06	< **0.3**	12000	**12.0**	2.3	19	35	16000	0.16	170	7.5	12	370	2.5	< 0.6	290
HVG-M(R)	7/20/06	0.4	14000	15.0	2.8	22	40	19000	0.12	190	10.0	13	470	2.8	< 0.7	340
DKL-O	7/25/06	0.6	13000	4.2	1.2	18	49	21000	0.15	260	10.0	15	91	2.1	0.4	260
DKL-O(R)	7/25/06	0.6	12000	4.5	1.2	17	50	19000	0.15	250	11.0	15	90	1.9	0.4	250

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

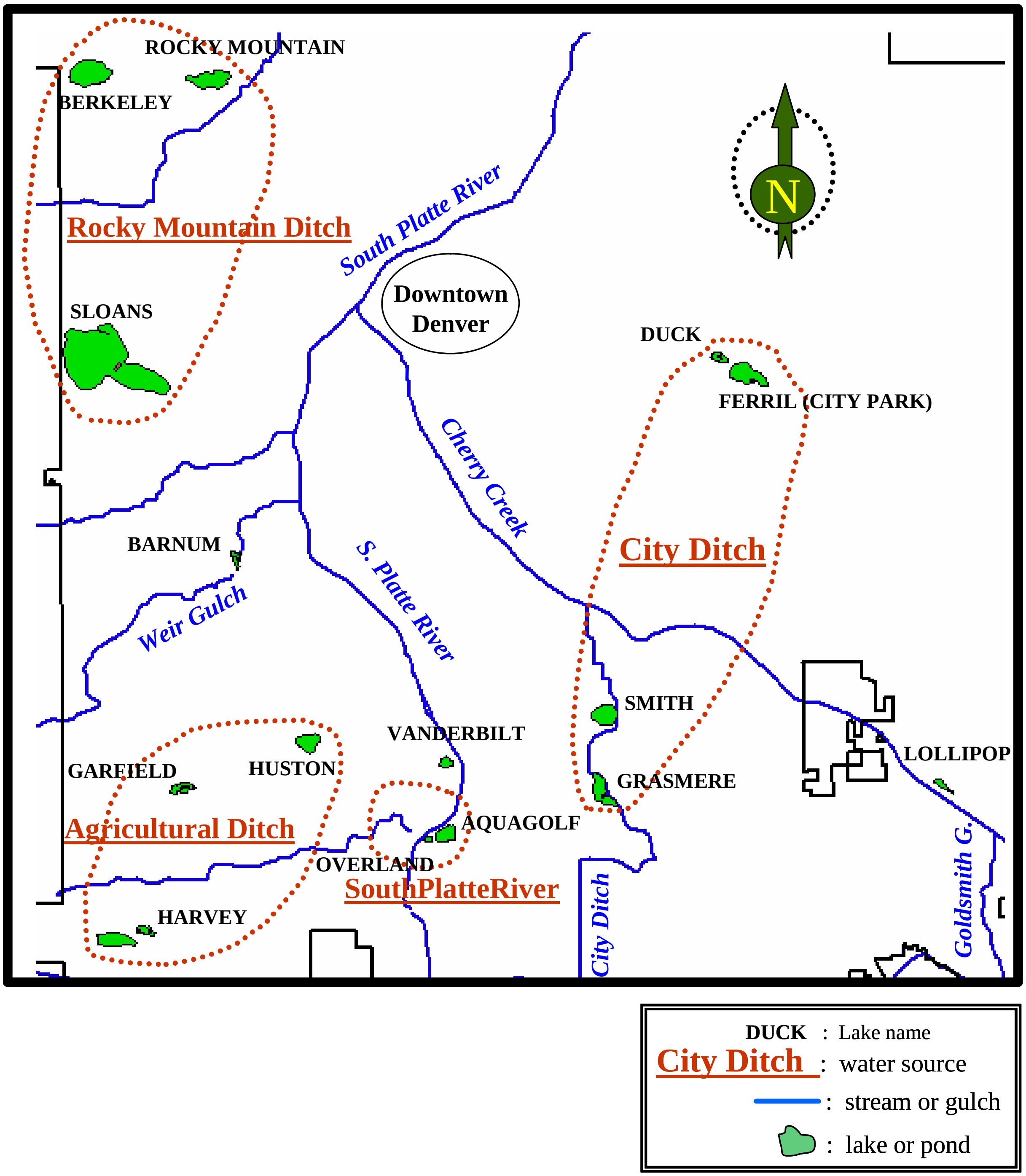
c/ Total arsenic and iron were analyzed as total recoverable

d/ '<' = less than; 'J' = analyte was detected below the reporting limit

e/ 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

---

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-*$CaCO_3$, 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-*$CaCO_3$ 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

Appendix C

Fish Consumption Advisories within the City & County of Denver

Colorado Department of Public Health and Environment

BERKELEY LAKE

2006

ATTENTION ANGLERS

Routine sampling has shown that some fish from this water exceed the mercury action level of 0.5 parts per million set by the Colorado Department of Public Health and Environment. Eating fish that exceed this level may cause health problems, especially for the unborn fetus and small children.

The Colorado Department of Public Health and Environment has categorized the fish according to mercury levels. To determine recommended amounts of fish that may be consumed, find the fish and size you caught and follow the recommendations described below, in terms of the number of meals per month for each group of people.

FISH	SIZE	PREGNANT WOMEN, NURSING WOMEN AND WOMEN WHO PLAN ON BEING PREGNANT	CHILDREN 6 YEARS OR YOUNGER	GENERAL POPULATION
Largemouth Bass	Larger than 14 inches	1 Meal per Month	Do Not Consume	1 Meal per Month
Largemouth Bass	Smaller than 14 inches	2 Meals per Month	1 Meal per Month	3 Meals per Month

Meal size for adults weighing 150 pounds = 8 ounces
Meal size for children = 4 ounces.

If the fish and size you caught are not listed above, either the Department hasn't tested them or they were found to be safe to eat. The report "Mercury Concentrations in Fish from Berkeley Lake" can be found at http://www.cdphe.state.co.us/wq/monitoring/monitoring.html. For questions regarding mercury in fish call the Water Quality Control Division (303 692-3500). For general information about fish and nutrition, consult: http://www.epa.gov/waterscience/fish/. For questions about human health and mercury call the Disease Control And Environmental Epidemiology Division (303 692-2700). For general information about Berkeley Lake, contact Denver Department of Environmental Health at 720 865-5452.

Colorado Department of Public Health and Environment

ROCKY MOUNTAIN LAKE

2006

ATTENTION ANGLERS

Routine sampling has shown that some fish from this water exceed the mercury action level of 0.5 parts per million set by the Colorado Department of Public Health and Environment. Eating fish that exceed this level may cause health problems, especially for the unborn fetus and small children.

The Colorado Department of Public Health and Environment has categorized the fish according to mercury levels. To determine recommended amounts of fish that may be consumed, find the fish and size you caught and follow the recommendations described below, in terms of the number of meals per month for each group of people.

FISH	SIZE	PREGNANT WOMEN, NURSING WOMEN AND WOMEN WHO PLAN ON BEING PREGNANT	CHILDREN 6 YEARS OR YOUNGER	GENERAL POPULATION
Largemouth Bass	Larger than 10 inches	1 Meal per Month	Do Not Consume	1 Meal per Month
Largemouth Bass	Smaller than 10 inches	2 Meals per Month	1 Meal per Month	3 Meals per Month

Meal size for adults weighing 150 pounds = 8 ounces
Meal size for children = 4 ounces.

If the fish and size you caught are not listed above, either the Department hasn't tested them or they were found to be safe to eat. The report "Mercury Concentrations in Fish from Rocky Mountain Lake" can be found at http://www.cdphe.state.co.us/wq/monitoring/monitoring.html. For questions regarding mercury in fish call the Water Quality Control Division (303 692-3500). For general information about fish and nutrition, consult: http://www.epa.gov/waterscience/fish/. For questions about human health and mercury call the Disease Control and Environmental Epidemiology Division (303 692-2700). For general information about Rocky Mountain Lake, contact Denver Department of Environmental Health at 720 865-5452.

Appendix D

Chemical Element Abbreviations

Ag – silver
As – arsenic
Al – aluminum
Cd – cadmium
Cr – chromium
Cu – copper
Fe – iron
Hg – mercury
Mn – manganese
Mo – molybdenum
Ni – nickel
Pb – lead
Se – selenium
Tl – thallium
Zn – zinc

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 $0.45 \mu m$ 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.