Water Quality and Quantity in the McBaine Bottoms

submitted to
City of Columbia



Executive Summary

A review of available reports and data regarding water quality and quantity in the McBaine bottoms was conducted, with emphasis on USGS reports.

Groundwater Flow

Historical observations (1968 and 1978) described groundwater flow through the McBaine bottoms as parallel to the flow of the Missouri River. Recent USGS reports indicate that this flow has been altered due to: 1) the mound of groundwater beneath the Eagle Bluffs Conservation Wetlands, and 2) the cone of depression associated with the city's wellfield. The Eagle Bluffs wetlands receive an average of 30 million gallons of water per day from the city's treatment wetlands, precipitation, and water pumped from the Missouri River. In the unlined wetlands, much of this water would be expected to migrate into the ground.

From USGS (Smith, 2003): "Flow toward the well field was from the south in the vicinity of the Eagle Bluffs Conservation Area, from the west from the Missouri River, flow from the north downgradient through the alluvial aquifer, from the northeast beneath treatment wetland unit 1, and from the east through the alluvial aquifer in the vicinity of Perche Creek."

Groundwater Quality

While many measurements of many parameters have been taken in an effort to observe potential changes in aquifer water quality, probably the most meaningful is chloride. This is because chloride is persistent and is consistently around 20 mg/l in the Missouri River and 200 mg/l in typical wastewater. Therefore, a chloride level significantly greater than 20 mg/l would indicate the influence of wastewater.

Highly elevated chloride levels in monitoring wells adjacent to treatment wetlands unit #1 suggest significant leakage from that unit. Leakage is also indicated by a groundwater mound beneath this unit. The City is in the process of making repairs to unit #1.

Elevated chloride levels have also been observed in water supply wells #5 and #6, which are the closest to the Eagle Bluffs Conservation Area. This suggests that water from the wetlands has percolated into the groundwater and reached the water supply wells. However, this does not suggest that the safety of the water supply has been compromised, as travel times may be quite long and there has been no sign of fecal indicator bacteria in the supply wells.

It is recommended that, at a minimum, the City continues to sample all water supply wells for chloride and total coliform on a monthly basis. Additional sampling is also recommended in the report.

Purpose

Numerous studies have been conducted since the wetlands were constructed in and adjacent to the McBaine Bottoms alluvial aquifer to determine the impact of these constructed facilities on Columbia's drinking water supply (see References). To provide guidance for future initiatives with respect to protection of the drinking water supply, the City of Columbia retained H₂O'C Engineering to:

- review the relevant hydrologic and water quality data from the previous reports,
- summarize the accumulated information with respect to observed impacts on groundwater flow and water quality,
- formulate an appropriate and efficient monitoring protocol to assess changes in drinking water quality in the future.



Columbia's Constructed Wastewater Treatment Wetlands and a Water Supply Well

History of Columbia's Water Supply

Initially, Columbia's community water supply was derived from a small surface reservoir on a dammed section of the Hinkson Creek. In 1903, Columbia voters, motivated by public health concerns, voted by a margin of 2 to 1, in favor of an alternate deep well water supply. Following voter approval of the purchase of the Columbia Water and Light Plant in 1904, a series of 1,200 feet deep wells yielding water of exceptionally high quality were constructed. By 1947, a 1 million gallon water tower was put into service. In 1960, Guyton and Associates projected that continued withdrawals up to 8 mgd from the deep wells would lower water levels to the top of the Roubidoux formation (700 ft. below ground surface).

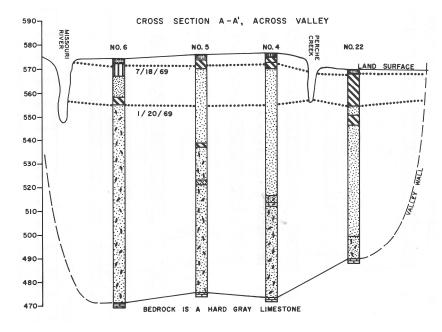
Development of the City of Columbia's Alluvial Well Field

In the summer of 1968, Layne-Western Company, Inc. of Kansas City, Missouri undertook a study (Nuzman, 1969) to assess the potential of the "McBaine Bottoms", a 14 square mile alluvial flood plain adjacent to the Missouri River, extending from Huntsdale to Easley, as an alternate water source for the City of Columbia. The locations of *nineteen test holes* bored to bedrock to observe static water levels and geological profiles in the alluvium plus *two test wells* to determine water yields and the effects of pumping on water levels are shown on Figure 1, below.

The alluvial fill of the Missouri River limestone erosional channel was found to be 100 feet deep to the limestone bedrock formation. Since the fill consisted of porous materials, such as silts, sands and gravel, "excellent communication" existed between the Missouri River and the aquifer in this area. Overall, the aquifer was expected to yield several times more than the 24 mgd (year 2000) projected future water use. As a result, the original planning for the well field called for 12 wells with a capacity of 2.5 mgd each for a total yield of 30 mgd.

Excess recharge from the alluvial aquifer was drained by the Missouri River and Perche Creek, the principal tributary creek in the McBaine Bottoms. The ground water temperature was found to be a near-constant 14.4 °C. (58 °F.).

Characteristics of McBaine Bottoms Aquifer



Alluvium Profile and Depth to Ground Water

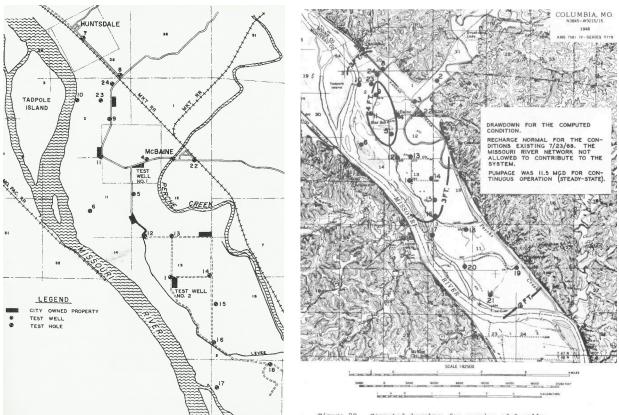


Figure 1. Sampling Bore & Test Well Locations

Figure 20. Computed drawdown for pumping of 6 wells

Figure 2. Water Surface Drawdown

Modeling of Aquifer Yield and Drawdown

Figure 2 shows the results of electric analog modeling (1969) to determine the drawdown of the water table and yield of the aquifer under various conditions of water withdrawal by pumping plus recharge from the Missouri River and upland infiltration. The results of this testing and modeling indicated that the 14 square mile alluvial flood plain area from Huntsdale to Easley, consisting largely of sand and gravel deposited in an eroded limestone channel, would provide a suitable aquifer that would meet Columbia's water needs for decades to come. Pumping of the test wells in the aquifer provided abundant high quality water and created a modest hydraulic gradient leading toward the water supply wells.



Missouri River Alluvial Flood Plain - "McBaine Bottoms"

Minimal household water use was found within the alluvial flood plain. Where such use occurred, there were complaints related to iron, including discoloration and taste. However, an alternate public water supply district source was available for domestic use. At the time of the investigation, there were no irrigation wells. Based on their findings, the Layne-Western Company offered the following observations, estimates and recommendations:

Layne-Western Observations, Estimates and Recommendations (Nuzman, 1969)

Normal static water level: 19 ft below land surface Lowest: 20 ft Highest: 5 ft (flood) Average depth of saturated material (sand and gravel): 76 ft

Test well #1 (42 inch diameter) pumped at 3,500 gpm for 10,000 consecutive minutes (7 days). Pumping resulted in drawdown of 1.8 feet at a distance of 1,000 feet.

Field coefficient of transmissivity:	440,000 gpd/ft of width of aquifer material
Thickness of aquifer at test site:	44 ft
Field coefficient of permeability	10,000 gpd/ft ² for the most permeable zones
Velocity of ground water movement:	0.5 ft/day (average) 2.0 ft/day (maximum)
Velocity 1,000 ft. from test well:	10 ft/day (average)
Total inflow into groundwater:	12.1 mgd (8.3 from upstream, 3.3 from Perche Creek);
(with no pumpage in aquifer)	0.5 mgd direct infiltration through soil below root zone
Total estimated aquifer storage:	44 billion gallons

Layne-Western Well Design and Location Recommendations (Nuzman, 1969):

2 mgd (1,400 gpm) yield rate per well 54 inch diameter hole to approximately 100 feet depth (gray limestone) At bottom of hole, 35 feet of 26 inch SS shutter screen 80 feet of silica gravel pack beneath 20 feet of casing and grout seal Screen entrance velocity: limited to 4.7 feet per minute

Radius of influence between wells:2,600 feetOptimal spacing between wells:1,300 feetSpacing plan: tracts of land 200' x 600' for each pair of wells spaced 500' apartTracts spaced 2,600 feet apart

	Well / Year	Flow, mgd	Drawdown, feet
	1 / 1972	1534	8.7
	2 / 1972	1479	10.4
	3 / 1972	1750	12.0
	4 / 1972	1714	8.4
	5 / 1972	1507	29.4
No. of the second s	6 / 1972	1500	6.0
	7 / 1978	1500	8.4
	8 / 1984	1500	13.9
	9 / 1990	2007	8.7
	10 / 1990	1556	12.1
and the second s	11 / 1998	1667	5.2
and the second sec	12 / 1998	1514	7.2

Rectangular tracts, 200' x 600', each with two wells Well Construction Data (Col. Water Dept., 1999)

Growth in Columbia's Water Supply Requirements and Well Field Withdrawals

Following the development of seven water supply wells over the period, 1972-1978, Foreman and Sharp (1981) determined that ground-water levels were primarily controlled by Missouri River stage as well as by pumping from wells. Less influential factors included recharge from precipitation and bedrock aquifers as well as interchange with Perche Creek.

By 1983 (Black and Veatch), Columbia was supplied by seven wells, [#1(1 mgd); #2-#7 (2.5 mgd)] in the alluvial plain with 13.5 mgd in firm pumping capacity (with one 2.5 mgd well out of service). The iron removal and lime-softening plant at McBaine, completed in 1972, had a rated capacity of 16 mgd.

Stanley Consultants (1989) called for construction of Wells #9 and #10 as well as a south pumping station and reservoir to accommodate growth in that region of the City. Wellfield development continued as Columbia's water supply needs increased. By 2004, 14 alluvial wells had been developed and plant capacity had been increased to 24 mgd. An estimated 85,000 Columbians consumed a daily average of 14 mgd. For a 2 mgd emergency (peaking) supply, one of Columbia's deep wells had been reconditioned.

Construction of Wetlands

City of Columbia Constructed Wastewater Treatment Wetlands

Columbia's wastewater treatment wetlands Unit #1 was put in operation in 1994. By 2004, four wetland treatment units with one-foot clay liners had been placed in operation covering 130 acres (0.2 square miles). These four units were designed to treat an average of 20.6 mgd of combined primary (settled) and secondary (activated sludge) Columbia wastewater treatment plant effluent and handle peak flows of up to 60 mgd. After sequential treatment through all four units, the wetlands effluent is pumped to the MDC wetlands from adjacent Unit #3.

Missouri Department of Conservation Eagle Bluffs Wildlife Area Wetlands

To create a wildlife area covering approximately the southern one-half of McBaine Bottoms alluvial aquifer, the Missouri Department of Conservation (MDC) acquired a 4,269 acre (6.7 square mile) site and constructed 1,300 acres (2 square miles) of unlined wetlands. After several years of delay due to Missouri River flooding and washouts, the MDC wetlands were put in operation in 1996, receiving treated effluent from the City of Columbia wetlands.



Overland Flows

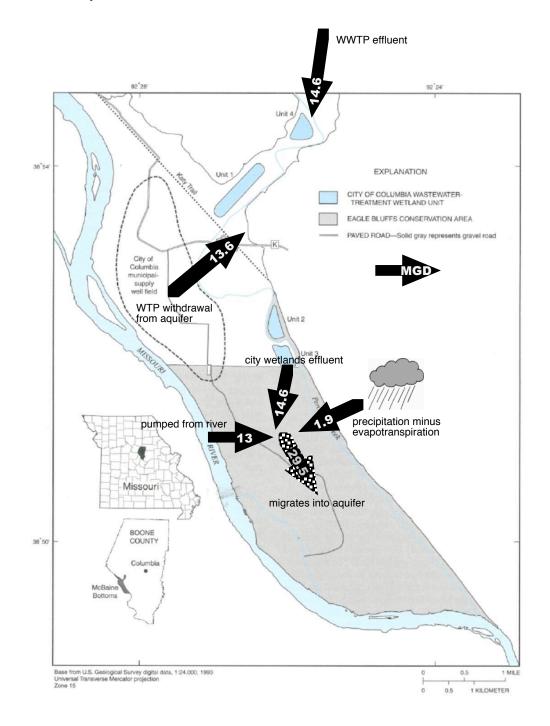
According to WWTP flow measurement records from January 2000 - June 2004, WWTP effluent averaged 13.7 MGD, and the flow from the final city treatment wetlands cell (Unit #3) to the Eagle Bluffs wetlands averaged 15.4 MGD. This is counterintuitive, as it would be expected that water lost due to leakage and evapotranspiration would more than offset water gained through precipitation. Despite quarterly calibrations on the flowmeters, they are not the most precise devices by nature, and WWTP personnel estimate the actual flow at both points to be between these two numbers. For purposes of this discussion, we will average the two and use a figure of 14.6 MGD.

The Eagle Bluffs Conservation Area has the option to apply the city's effluent to the wetlands or discharge it to the Missouri River. According to the MDC, the Eagle Bluffs wetlands can use all the water it can get, and river discharge rarely happens. Instead, the city's effluent is supplemented with Missouri River water, primarily in the fall and spring. The flow of water pumped from the river to Eagle Bluffs is not measured, but rough estimates of 30 MGD in the fall and 10 MGD in the spring result in an average throughout the year of 13 MGD.

USGS estimates Missouri's evapotranspiration rate to be 30-35 in/yr, and NRCS reports precipitation of 38-40 in/yr. Assuming a net gain of 6 in/yr (precipitation minus evapotranspiration), the contribution to the Eagle Bluffs area (4,269 acres) would average 1.9 MGD.

Summing the flow estimates of the contribution of the city's wetlands, pumpage from the river, and precipitation minus evapotranspiration, the total influent to Eagle Bluffs averages 29.5 MGD. Much of this water would be expected to migrate into the ground, causing the groundwater mound beneath the wetlands and changing the dynamics of groundwater flow.

Overland Flows Map



Historical Groundwater Flows

Studies in 1968 and 1978 described groundwater flow through the McBaine bottoms as parallel to the flow of the Missouri River.

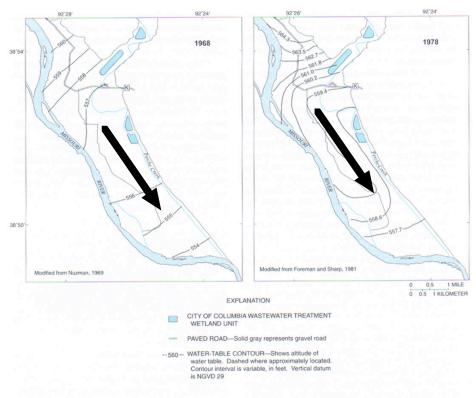


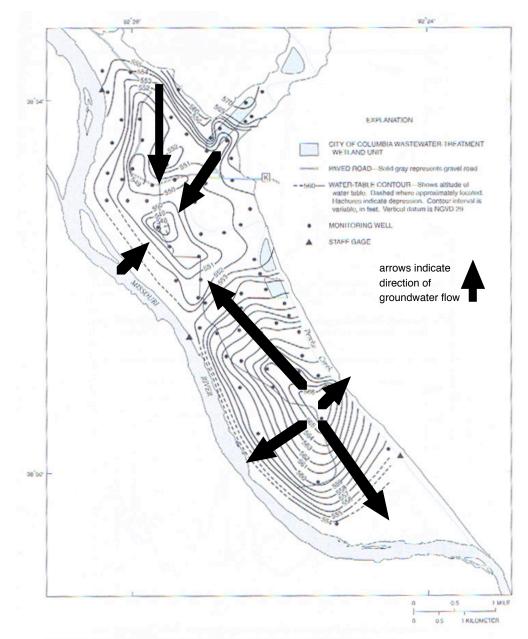
Figure 33. Pre-development altitude of the water table, July 1968 and August 1978.

Present Groundwater Flows

USGS studies from 2003 indicate that the pattern of groundwater flow has changed due to a cone of depression around the city wellfield and recently-developed groundwater mounds beneath treatment and MDC wetlands.

According to Columbia Water Treatment Plant records for 2003, an average of 13.6 MGD is pumped out of the aquifer from the water supply wells. This creates a cone of depression in the wellfield and causes groundwater to flow towards the wells from all directions.

From USGS (Smith, 2003): "Flow toward the well field was from the south in the vicinity of the Eagle Bluffs Conservation Area, from the west from the Missouri River, flow from the north downgradient through the alluvial aquifer, from the northeast beneath treatment wetland unit 1, and from the east through the alluvial aquifer in the vicinity of Perche Creek." "The presence of a sustained ground-water high underlying the Eagle Bluffs Conservation Area indicates potential for ground-water flow toward the City of Columbia well field. Elevated concentrations of several constituents from monitoring wells... indicated flow of water from the Eagle Bluffs Conservation Area toward the well field."



Present Groundwater Flows Map



USGS Groundwater Quality Monitoring Program

Between August 1992 and March 1999, USGS analyzed quarterly samples from 19 city-installed monitoring wells, 14 USGS-installed monitoring wells, and four surface water sites. While a large number of parameters were measured, perhaps most significant of the analyses conducted are those for chloride ion, a conservative constituent that is elevated in wastewater.

The amount of chloride in the Missouri River and the McBaine Bottoms has historically been relatively constant and around 20 mg/l. In the McBaine Bottoms, any values significantly higher than 20 mg/l would indicate the influence of wastewater.

water	average chloride, mg/l
Treatment Wetlands Effluent ¹	181
Eagle Bluffs Effluent ¹	151
Missouri River ²	20
City of Columbia Water Supply Wells ³	21
USGS/Columbia Monitoring Wells⁴	
pre-wetlands	7
post-wetlands	26

¹USGS data, 1996-98 ²Columbia WWTP data, 1994-2002 ³Columbia WTP data, 1998-2004 ⁴USGS data, 1992-99

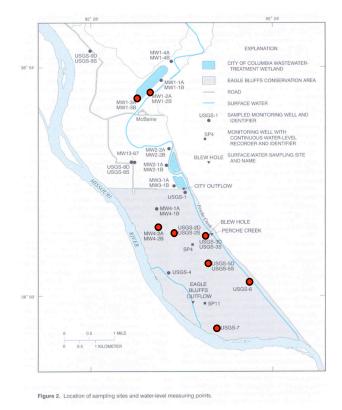
The following graph and map depict the results of the USGS's chloride measurements from 1992-'99.

As would be expected, elevated levels of chloride have been found in most of the monitoring wells in the Eagle Bluffs Conservation Area.

Peaks in chloride levels as high as 220 mg/l from monitoring well MW1-2A suggest that the liner of city treatment wetlands unit #1 has been compromised.

The City is in the process of making repairs to unit #1. Saturation-related sloughing on the levee is being repaired with geotextile and landscape fabric, and holes from previous bridge construction are being plugged.

USGS also sampled monitoring wells for fecal indicator bacteria (coliform and streptococci) and found very few positive samples. The few samples that did test positive were mostly streptococci from monitoring wells adjacent to wetland treatment units during one sampling event: August, 1998.

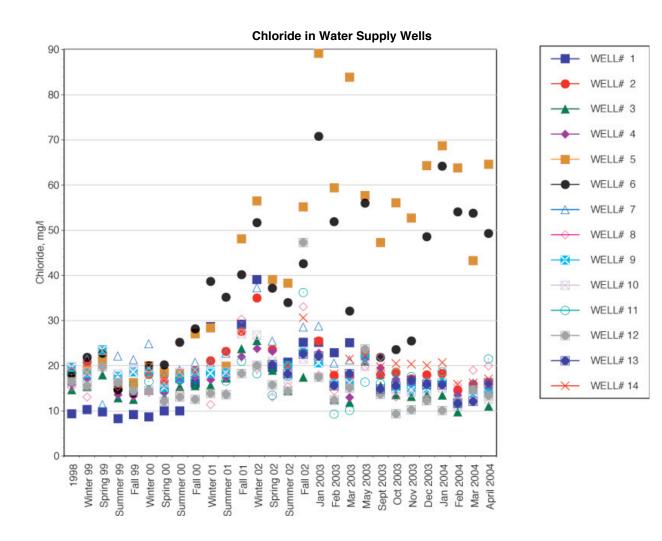


USGS Sampling Sites with Elevated Chloride Levels

Water Quality Monitoring Programs: Columbia's Water Supply Wells

As part of a long-term monitoring program, Columbia WTP personnel have been monitoring the city's water supply wells for chloride and total coliform bacteria for several years. Two of the wells (#5 and #6) have shown significant increases in chloride. These two supply wells are the closest to the Eagle Bluffs Wetlands. It is likely that, in the absence of a liner, water flows into the ground underneath Eagle Bluffs and is subsequently drawn towards the wellfield.

While elevated levels of chloride show a linkage between wastewater and water supply wells, they do not suggest that the safety of the water supply has been compromised. From a health and safety standpoint, we are mostly concerned with the pathogens (disease-causing organisms) in wastewater. Pathogens will not survive very long or travel very far in the ground, and travel times from the surface to a water supply well intake may be quite long. To date, there has been no sign of fecal indicator bacteria in the supply wells.



Recommended Monitoring Protocols

Wastewater, even after primary, secondary and tertiary treatment, contains elevated concentrations of conservative (non-degradable) minerals (e.g., chloride, sodium, sulfate, fluoride ions). As a result, these individual ions as well as total dissolved solids (TDS) can provide an indication of the degree to which more highly mineralized wastewater effluent may be blending with well water sources.

Many components of municipal wastewater (e.g., solids, organic matter) are removed or markedly diminished by treatment. However, some of these dissolved organic compounds are also refractory (persistent), in this case, not readily biodegraded. One sensitive measure of this residual organic fraction is total organic carbon (TOC).

Chloride is easy to measure and a good indicator of well water contamination from wetlands. Continued monthly analysis for chloride should be run on samples from all water supply wells and the Missouri River. Total coliform should also be run monthly on samples from all water supply wells. TOC, TDS, sodium, sulfate, and fluoride should be run semiannually on samples from all water supply wells.

Additionally, the City should consider monitoring for chloride at some of the monitoring wells used in the USGS studies. Monitoring wells USGS-8D and USGS-8S are between City supply wells #5 and #6 and the rest of the City's wellfield. Chloride levels at these monitoring wells would help give an indication as to whether the current situation represents a new equilibrium or the influence of the wetlands is increasing over time. To date, these monitoring wells have not shown elevated levels of chloride.

Monitoring wells near each wetland treatment unit should also be sampled periodically for chloride to confirm the integrity of the clay liners.

Appendices

USGS Aquifer Monitoring Program: Bore Holes and Wetlands Water Quality in Perche Creek Data Related to Columbia's Water Supply References

USGS Aquifer Monitoring Program: Bore Holes and Wetlands

McBaine Bottoms Alluvial Aquifer Sampling:

Water

Pre-effluent (background) conditions: Aug. 1992 to Aug. 1994 Post-effluent (wetlands) conditions: Dec. 1994 to Mar. 1999						
Potentiometric (water level) surface, quarterly monitoring						
Monitoring Bores (33): MW1-1a,b; 2a,b; 3a,b;4a,b MW2-1a,b; 2a,b Columbia Wetland's Unit #1 Columbia Wetland's Unit #2 MW3-1a,b Columbia Wetland's Unit #3 MW4-1a,b; 2a,b Columbia Wetland's Unit #3 MW4-1a,b; 2a,b Columbia Wetland's Unit #4 MW13-67 USGS-1,2d,2s,3d,3s,4,5d,5s,6,7,8d,8s,9d,9s						
Surface Samples (4):	e Samples (4): Perche Creek Columbia Wetland's Effluent Conservation Wetland's Effluent Blew Hole (12' deep scour depression formed by levee failure)					
Quality Parameters (all samples)						

Specific ConductanceSurrogate for measurement of total dissolved solids
Ground-water, pre-effluent mean:
839 μ S/cmpH (related to pCO2)Ground-water mean: 7.0
Ground-water mean: 7.0pH (related to pCO2)Ground-water mean: 7.0
Columbia wetland effluent median: 7.4 (heterotrophic respiration)
Conservation wetlands effl. median: 8.4 (autotrophic activity)AlkalinityAcid neutralizing capacity depleted by production of carbon dioxide and

organic acids

Major inorganic constituents (Balanced electroneutrality condition)Cations:Calcium, magnesium, sodium, potassium, ammonium, iron, manganeseAnions:Bicarbonate, sulfate, chloride, nitrate, fluoride

Trace inorganic constituents (dissolved)

Aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, vanadium, zinc.

- Nutrients Organic nitrogen; ammonium, nitrite, and nitrate ions; phosphorus (total)
- Temperature Ground-water mean: 14.4 °C. (buffered by materials in aquifer)
- Dissolved oxygen Columbia wetlands effluent median DO: 4.8 mg O/l (undersaturated) Conservation wetlands effl. median DO: 12.0 mg O/l (supersaturated) Absent in ground-waters (0.0 mg O/l) when iron, sulfides are present.

Fecal coliform Fecal streptococci

Dissolved Organic Carbon (DOC)

Columbia wetlands effluent median DOC: 7.0 mg C/l Conservation wetlands effl. median DOC: 6.8 mg C/l

Detailed Organic Analysis (8 of 33 monitoring wells and 4 surface-water sites)

Base/neutral/acid semi-volatile organic compounds

Selected pesticides and metabolites (detected):

Alachlor, carbaryl, metolachlor, propachlor, lindane (total and dissolved), p,p'-DDE, pendimethalin, trifluralin, chlorpyrifos, diazinon, linuron, tebuthiuron, propargite, DCPA, atrazine, cyanazine, diethylatrazine, prometron, simazine, metribuzin, chlordane, perthane.

Selected organochlorine compounds

Compounds Detected in Monitoring Well and Surface Water Samples (USGS, 2002)

Selected pesticides and metabolites (detected):

Alachlor, carbaryl, metolachlor, propachlor, lindane (total and dissolved), p,p'-DDE, pendimethalin, trifluralin, chlorpyrifos, diazinon, linuron, tebuthiuron, propargite, DCPA, atrazine, cyanazine, diethylatrazine, prometron, simazine, metribuzin, chlordane, perthane.

Compounds Detected in Columbia and Conservation Wetlands Samples (USGS, 2000)

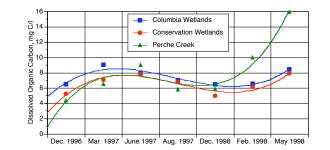
Source	Analyte
Pain reliever:	ibuprofen
Urine (coffee, tea, caffeinated beverages):	caffeine
Herbicides (corn production) :	atrazine and its metabolites; hydroxyatrazine, desethylatrazine, deisopropylatrazine
Surfactant degradation products:	nonyl phenol
Vitamin:	nicotinic acid
Treatment for viral, intestinal disorders:	oxindole
Synthetic hormone:	17a-ethynylestradiol
Antibiotics:	Sulfamerazine, sulfadiazine

Water Quality in Perche Creek

Dissolved Organic Carbon

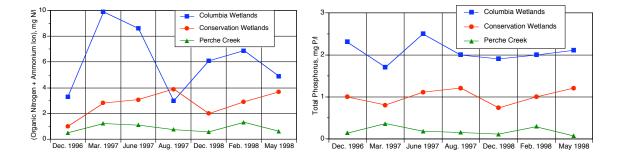
Treated Effluent from Columbia's Constructed Wetlands	6.5 - 9.0 mg C/I
Overflow from MDC Wetlands	5.0 - 7.9 mg C/l
Perche Creek	4.4 -16.0 mg C/l

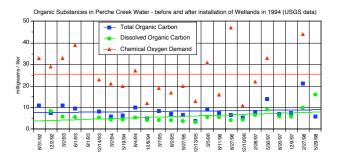
The DOC concentration ranges observed are comparable in all three surface waters.





Algal growth, cloudiness, surface accumulations and presence of rough fish indicate eutrophic conditions in Perche Creek. However, monitoring for nutrients (Organic N, NH_4^+ , NO_2^- , NO_3^- , total P) indicates that Perche Creek contains considerably less nutrient than the discharges from the wetlands.

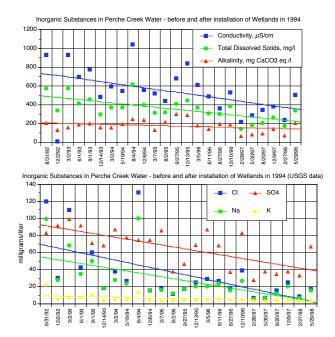


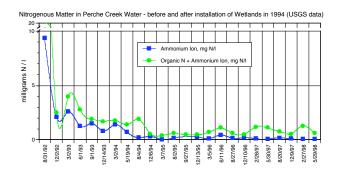


Longer-term USGS monitoring data (1992-1998) indicates that the diversion of the Columbia wastewater treatment plant effluent from Perche Creek into the constructed wetlands has had little effect on the concentrations of total and dissolved organic carbon found in the Creek water. Chemical oxygen demand measurements also indicate that the Perche Creek water has not changed significantly.

Alternately, the routing of the wastewater plant effluent through the wetlands has had a marked effect on the mineral content of the Perche Creek water. Both specific conductivity and total dissolved solids measurements indicate the mineral content of the Creek has decreased by half. Alkalinity indicates a lesser decrease.

Specific inorganic constituents also reflect the marked decline in mineral content. Of special interest is the marked decrease in chloride and sodium ions which appear to be the most sensitive reflection of the reduced wastewater discharge. Alternately, these ions also serve as conservative tracers of groundwater contamination.





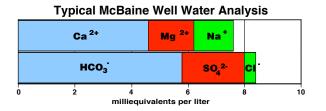
From periodic peaks during 1992, nitrogenous matter also shows a progressive reduction in Perche Creek water after 1994.

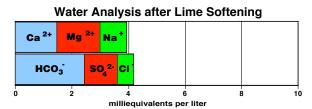


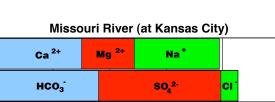
Data Related to Columbia's Water Supply

Columbia (1931-1968)	Average Tem Average Rain	rage Temperature: 54.9 °F July: rage Rainfall: 37.8 in. Min.:									January: 30.1°F Max. 47.7 in.		
	-			Mon	thly Ave	rage Ra	infall, C	olumbia	MO				
	5-												
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	0-	Jan	Feb Ma	r Apr	May	Jun	Jul	Aug	Sept.	Oct	Nov.	Dec.	
Year 1965	Population	Сс	olumbi	a's V	/atei	r Use	e, m	gd					% Unaccounted
1969	42,000 55,000	5.7	7 (avo	. dav) 8	(tota	al fro	om d	leep	wel	ls)		18
1980	62,000	5.7 (avg. day) 8 (total from deep wells) 18											
1983	63,000		1 (avg										19
2000	76,400	12	? (avg	. day) 1	8.0	(max	x. da	iy)				
Per Capita Water Use, gpcd:Residential: 50Indust., Commerc., Instit.: 120Avg. Daily Water Use, mgdResidential: 2.76 (1983)Indust., Commerc., Instit.: 3			-										
University Wat	er Use, mgd	2.4	4 (avg	. day) 3	.6 (n	nax.	day) In	dep	ende	ent S	Supply (seasonal)

Effect of Softening on Inorganic Composition of Columbia Water (Electroneutrality Conditions)





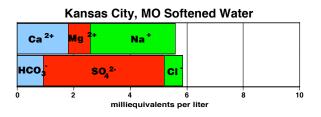


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2 4 6 milliequivalents per liter

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Flood Control and Security Measures at Columbia's Water Treatment Plant

Columbia's Deep Wells and Water Storage Facilities

Columbia's six deep wells, although idle, are still in operating condition. Wells #1, 4 & 5 are located at the Power Plant and discharge to the power plant reservoirs.

Wells #7, 8 & 9 would pump to the West Ash reservoir in case of emergency need. A total of 4 mgd might be available from these three wells.

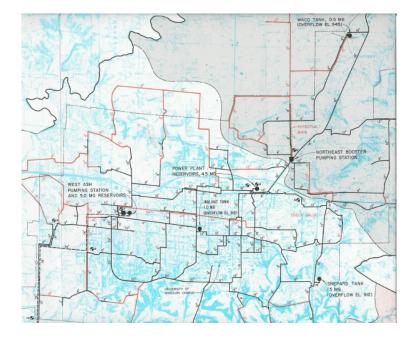
Columbia's deep well water quality is similar to that of the University's deep wells. While moderately hard, these well water are of exceptional quality with respect to low organic content. For example, deep well #10 exhibits a dissolved organic carbon content of 0.4 mg C/l, putting it in a class with premium bottled waters.

The injection of treated water from McBaine into the deep well aquifer, as part of a program of aquifer storage and recovery (ASR), will subsequently increase dissolved organic carbon levels in water withdrawn from the deep wells to about 2.5 mg C/l.

Dissolved Organic Carbon

Columbia's and UMC Deep Wells	< 0.4 mg C/l
Softened Water from McBaine WTP	2.5 mg C/l
Softened Missouri River Water, KC, MO	2.5 mg C/l

Storage, mg: Ground: 5 (West Ash); 4.5 (Power Plant); Elevated: 1.5 (Shepard); 1 (Walnut); 0.5 (Waco)



References (in Chronological Order)

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Treated wastewater effluent from Columbia's constructed Wetlands Unit #1



Emergent Vegetation and Muskrat in Wetlands Unit #1