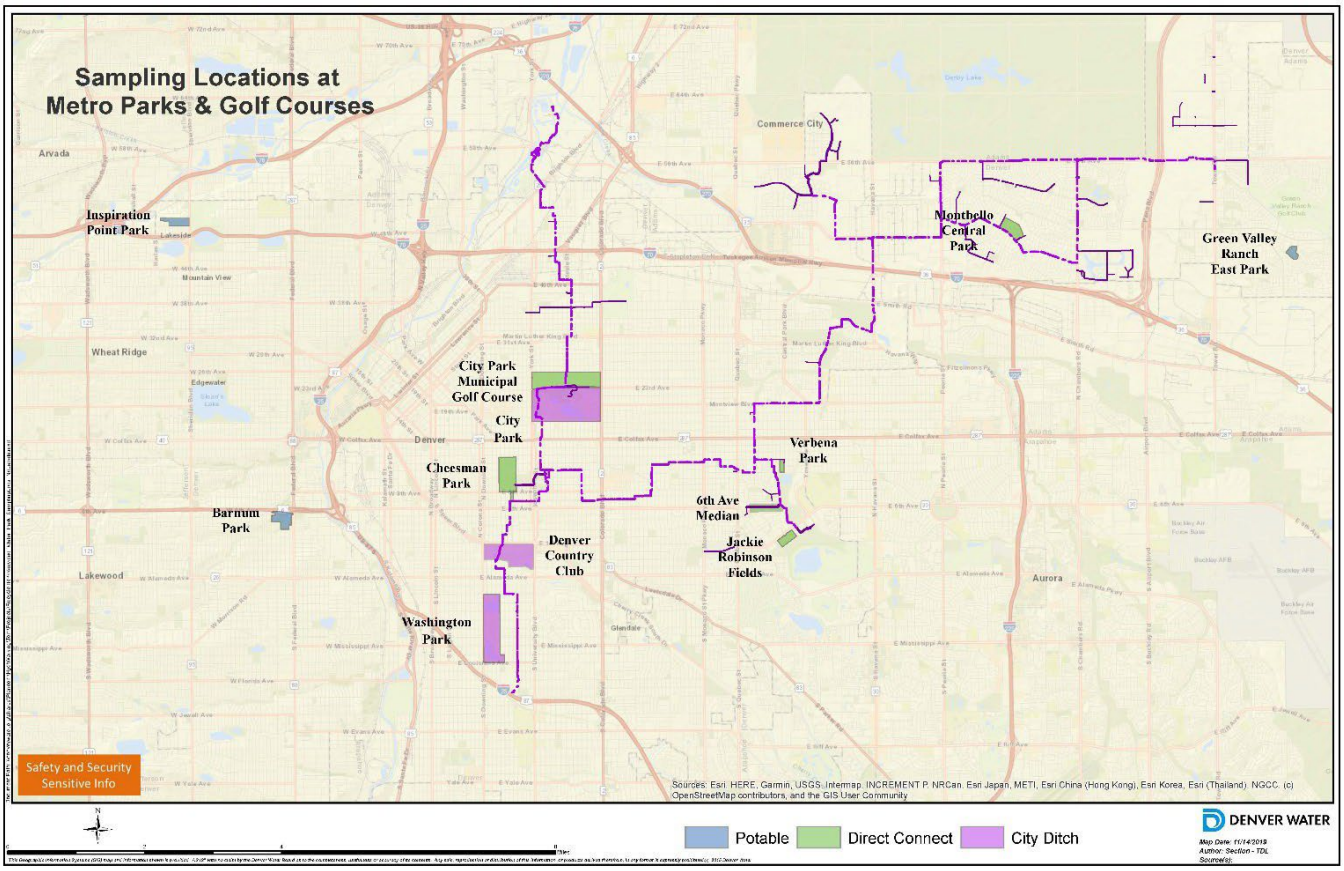
Denver Parks & Recreation – Recycled Water Management Advisory Committee Report

Table of Contents

1.0 Background

- Denver Water and Denver Parks and Recreation (DPR) entered into an Intergovernmental Agreement (IGA) regarding Reuse Water in 2016. One objective of the IGA designated a study to evaluate the effects of reuse water on trees in the parks and determine possible mitigation strategies that may be incorporated into park maintenance practices. The IGA designated DPR, Denver Water, community members and technical experts to participate in committee to determine how recycled water is currently used in the parks, tree/plant and soil health indicators, monitoring and testing sites, and mitigation options. Of greatest concern is salinity and chloride build up in the soil and plant tissue, and how to protect tree health moving forward. See 2016-2019 reports for annual updates.
- Most plants will typically suffer injury if sodium exceeds 70 milligrams per liter in water, or 0.5 percent (5000 ppm) in plant tissue, or 230 milligrams per liter in soil (in the extract from a saturated soil paste). Plants will usually be injured by chloride if it exceeds 350 milligrams per liter in water, or 1 percent in plant tissue, or 250 milligrams per liter in soil (in an extract). Plants typically will be injured by boron if it exceeds 1 milligram per liter in water, or 200 parts per million in plant tissue, or 5 milligrams per liter in soil (in extract). **Salinity Management Guide: https://watereuse.org/salinity-management/index.html**
- Baseline data was collected in 2016 for soil, plant tissue and irrigation water at specific reuse direct connect sites, City Ditch sites and potable sites. Parameters tested allow a greater understanding of the character and effects of seasonal changes and weather events on reuse and ditch water compared to potable water, and changes in tree tissues irrigated by reuse, City Ditch and potable water.
- Follow-up on testing and data collection occurred annually 2017-2020 to provide a total of five years of test data. Annual reports were compiled to update 2016 baseline data, mitigation strategies, ongoing maintenance practices, and recommendations moving forward. Refer to the original 2016 baseline report, and the subsequent 2017-2019 annual reports for additional information. This report is the final update and committee recommendations.

DPR and Denver Water continued sampling and testing at the following locations during 2020:



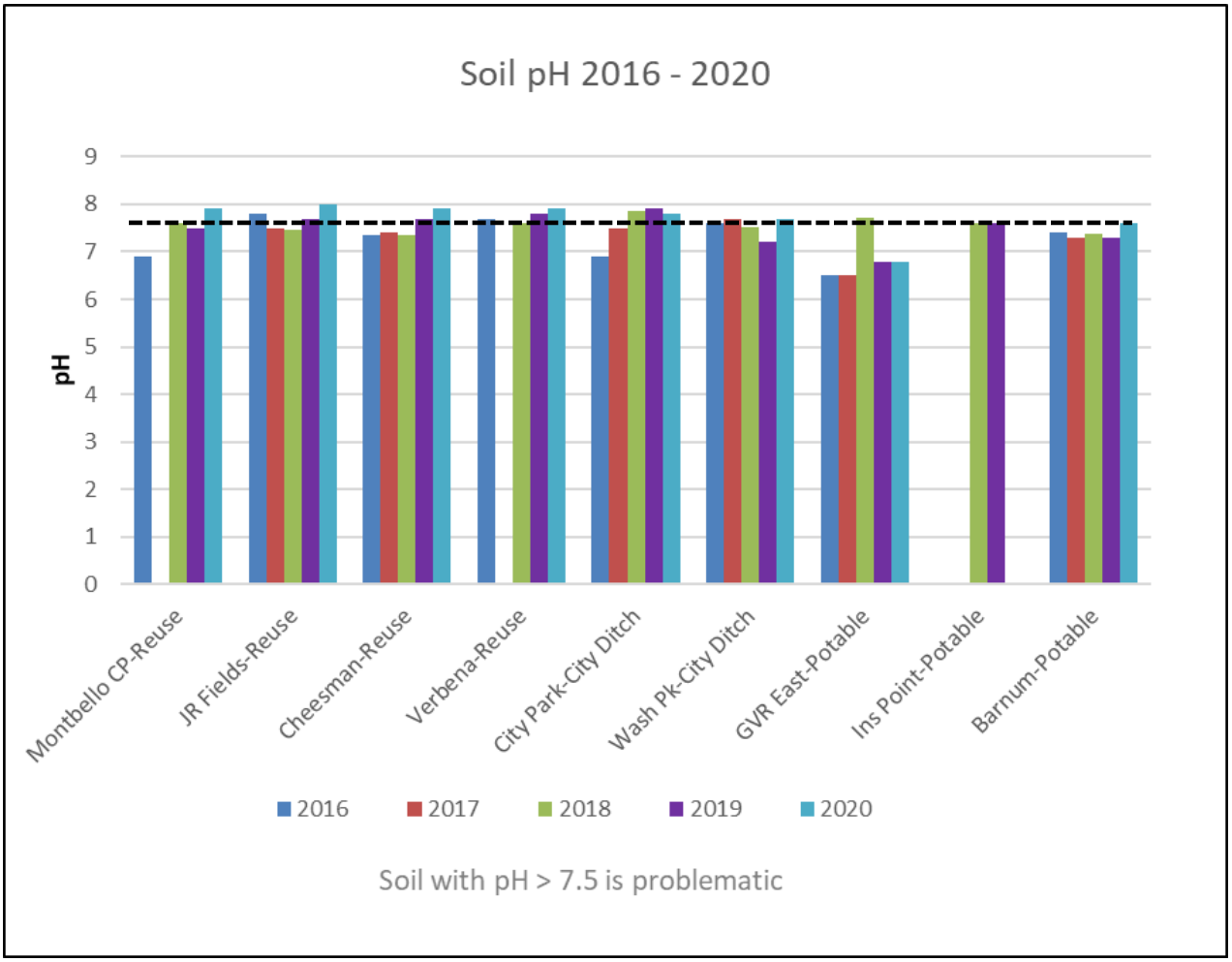
2.0 Soil Sampling

Denver Water and Denver Parks completed soil testing for all locations per the original 2016 locations, and an added potable water location beginning 2018. (See Appendix A)

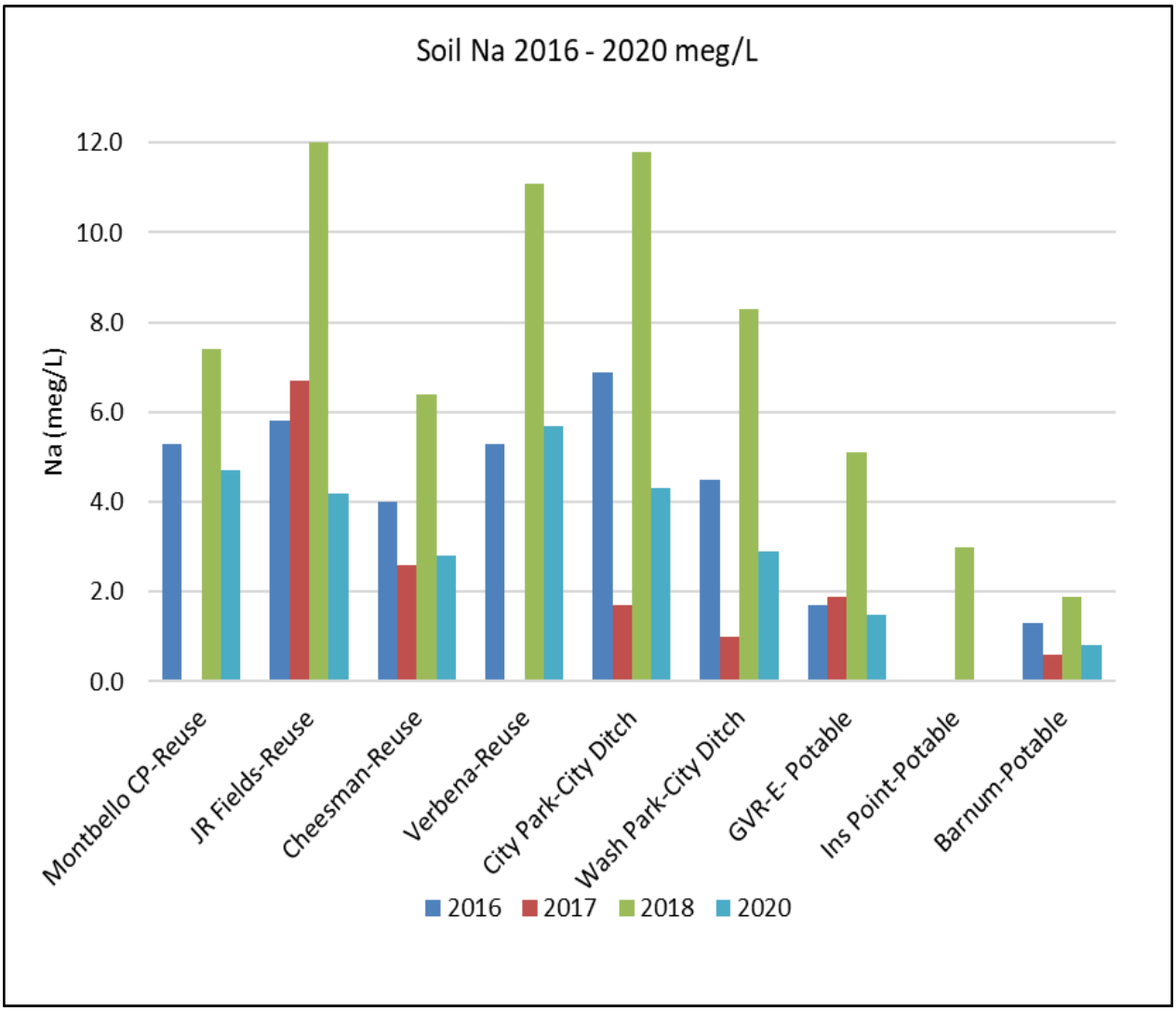
- Soil was assessed for soil makeup, nutrients, metals, pH, salinity, sodium and chloride concentrations.
- The graphs below show changes for significant parameters between 2016 baseline data and through 2020 testing results.
- Soil testing for all years was completed by the Colorado State University Soil, Water and Plant Testing Laboratory.

- Inspiration Point was added as a potable test location in 2017 to provide a wider sample of potable soil testing. Soil testing was not made for Montbello Central Park and Verbena Park in 2017.
- Although soil testing continued with the E 6th Avenue location, results have been excluded below because sampling depth is inconsistent due to buried trash.

Soil Sample Test Results:

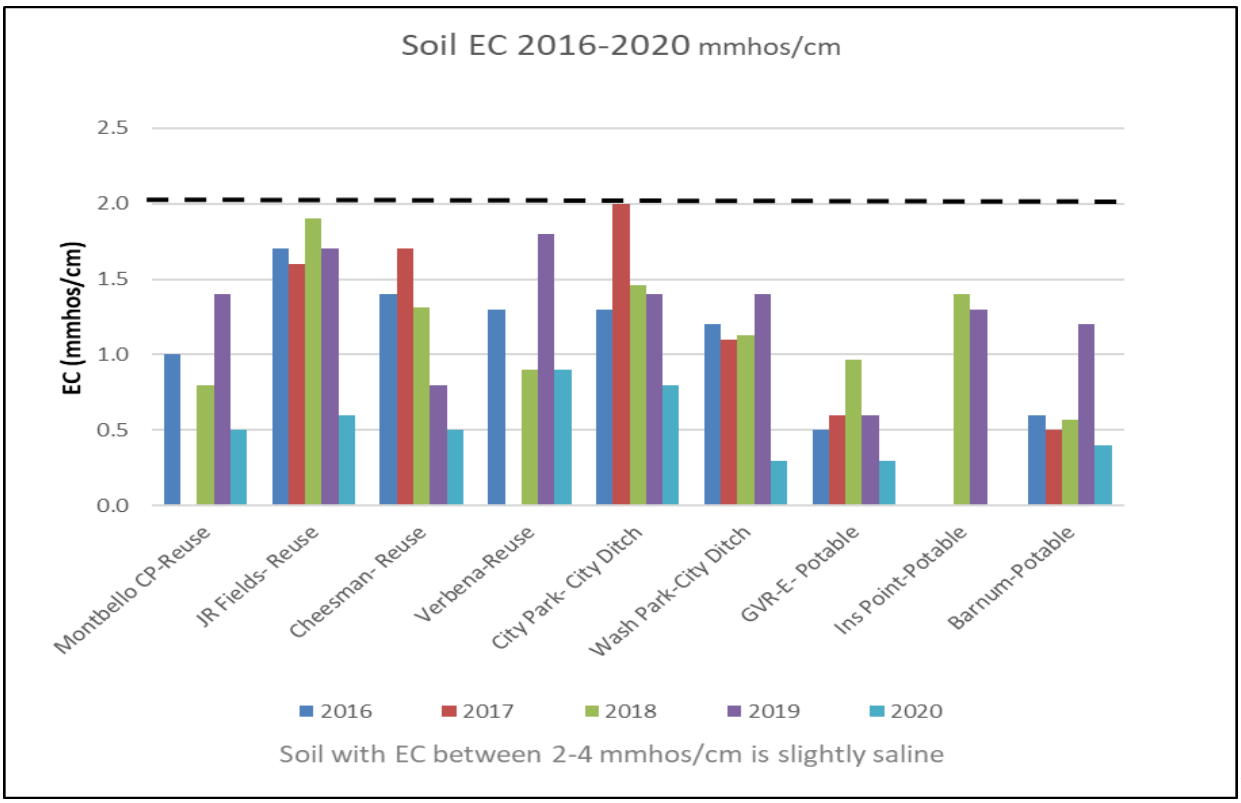


Per CSU Extension Fact Sheet 0.502 Soil Test Explanation: 7.0 is neutral pH. Most Colorado soils are alkaline, having a pH between 7.2 and 8.3.

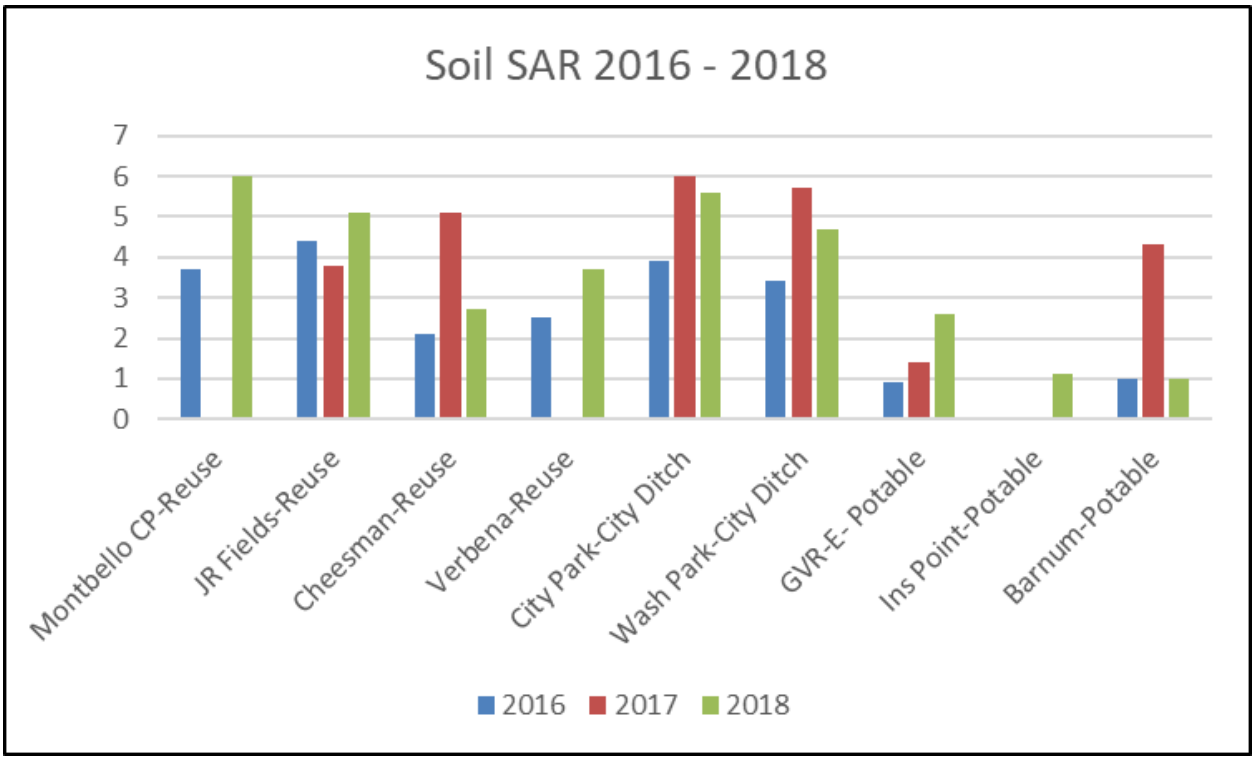


Notes:

- Data for 2019 Na eliminated due to apparent testing/lab errors.
- Saline/sodic soil is more accurate indicated by EC, and SAR (see charts on next page).

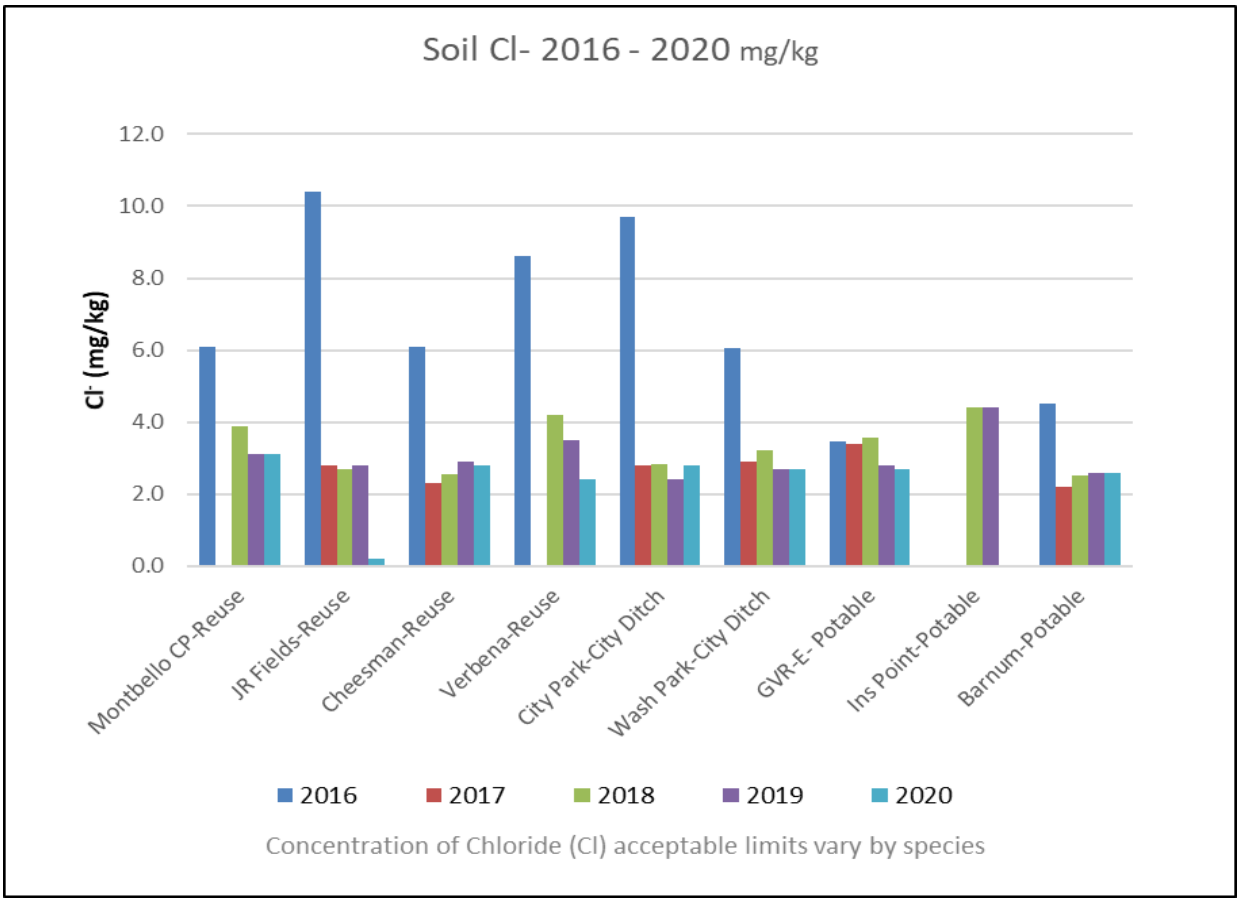


Per CSU Extension Fact Sheet 0.502 Soil Test Explanation: 0-2 EC is satisfactory.



Soil is considered sodic if SAR> 13, and pH is greater than 8.5 (CSU Fact Sheet 0.521)

SAR was not tested in 2019. 2020 results were eliminated due to apparent lab errors.



Chloride Levels above 8.00 mg/kg cause impaired root growth and become toxic at 13.00mg/kg

2016 testing results appear to be inaccurate.

3.0 Irrigation Water Testing

2020 water testing was conducted three times during the irrigation season (See Appendix B).

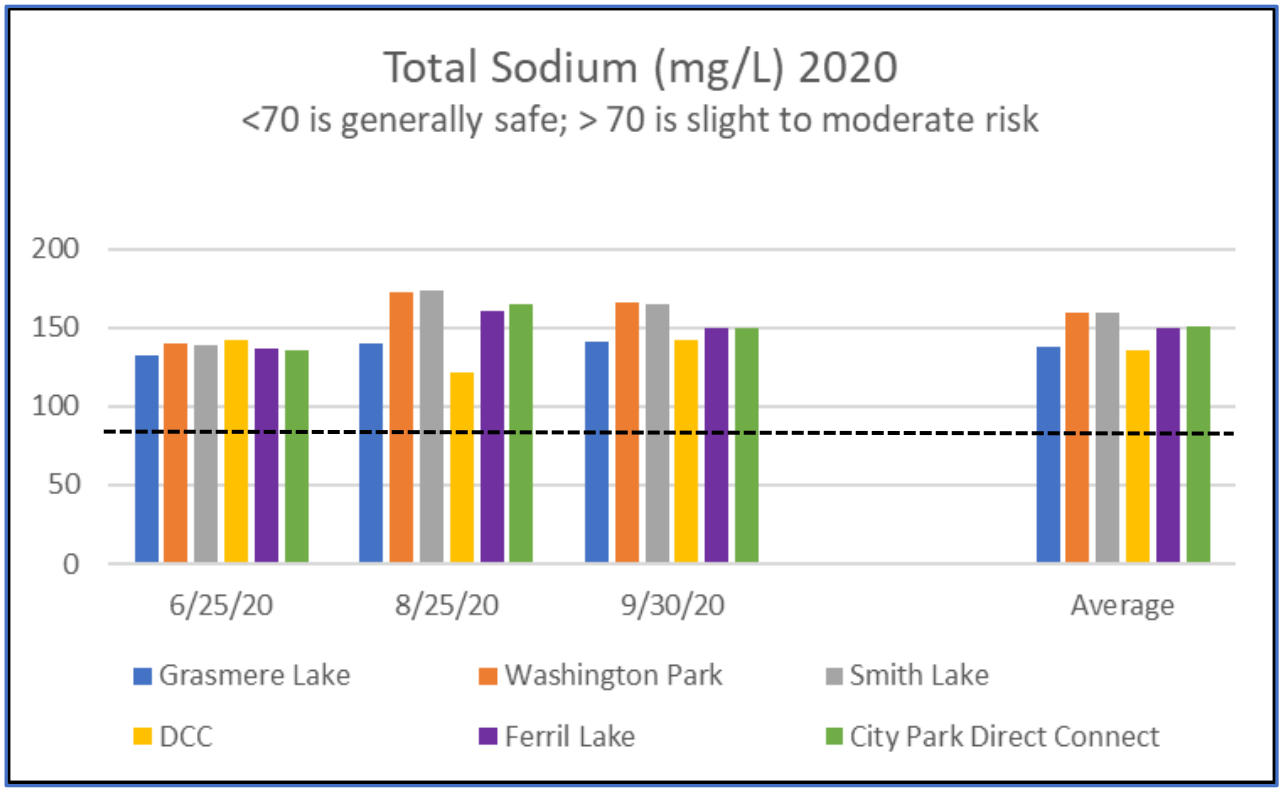
- Test dates were June 25th, August 25th, and September 30th. No instances were after a precipitation event.
- Locations at Washington Park (Grasmere Lake and irrigation water), City Park, Denver Country Club, Ferril Lake (City Ditch locations) and City Park (direct connect to reuse) were tested for Alkalinity, pH, Total Sodium, Chloride, Total Dissolved Solids (TDS), Specific Conductivity (SC), and Sodium Adsorption Ratio (SAR).
- Water testing and analysis for 2016 - 2017 was completed by Denver Water; 2018 - 2020 sampling was collected by Al Polonsky, Environmental Analyst / Denver Dept of Public Health & Environment. Sample analysis was provided by Denver Public Works Waste Water Lab and Test America.
- Denver Water did not provide potable water to flush through the reuse lines and City Ditch in 2020.
- Note City Park Golf was under construction and inaccessible 2018-2019, and not included in testing after.

Irrigation Water Quality Criteria, per Colorado State University Extension, Fact Sheet No 0.506, lists the following parameters affecting plants:

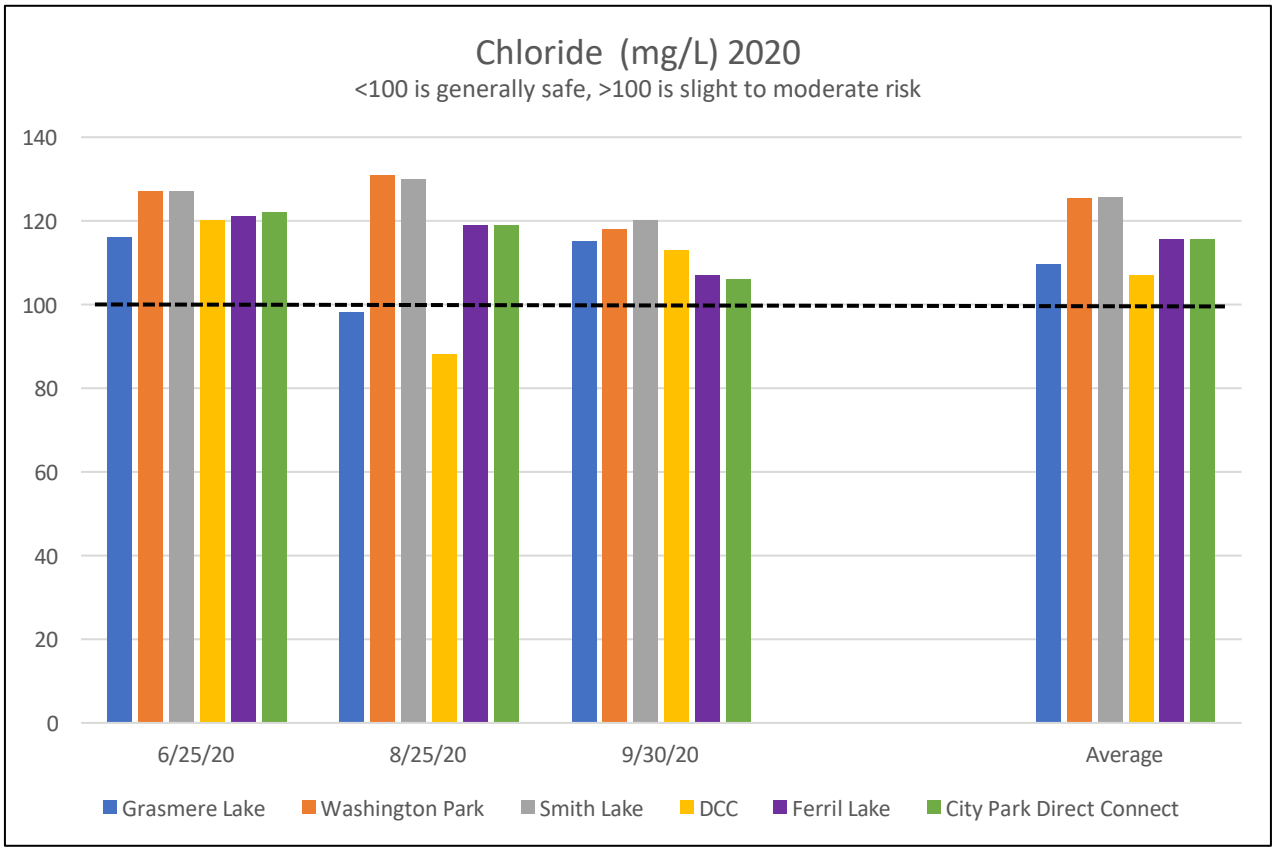
- Total Sodium (threshold varies between species)
- pH at 7.5 begins to affect plant health
- Alkalinity
- Chloride
- TDS (total dissolved solids) are inorganic compounds that are found in water such as salts, heavy metals and some traces of organic compounds that are dissolved in water. TDS is affected by run-off and storm drain activity.
- Specific Conductivity, the most influential guideline for salinity hazard
- SAR – Sodium Absorption Ratio (assesses sodicity in water and soil)

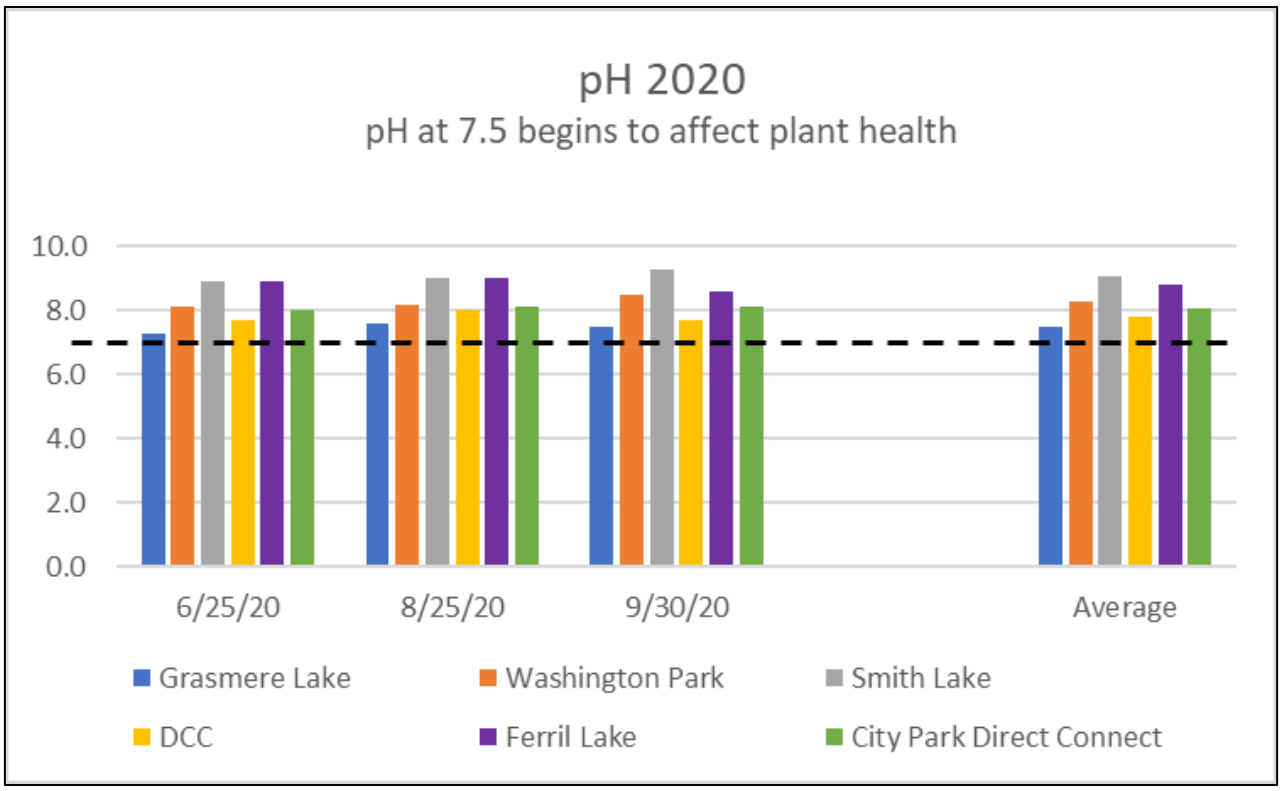
Guidelines for risk are per the Salinity Management Guide: https://watereuse.org/salinity-management/index.html

Charts on the following pages show changes in these parameters over the irrigation season of 2020.

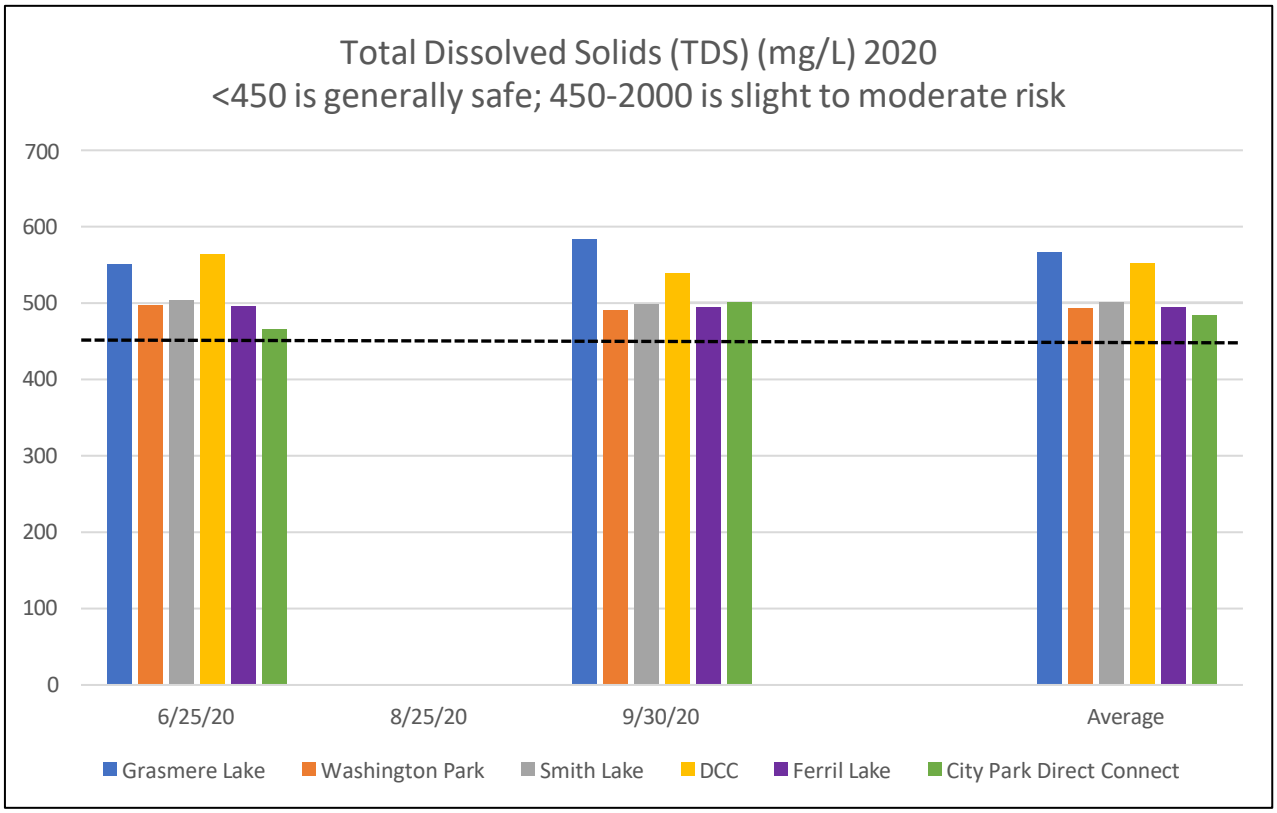


Note: Threshold of tolerance for Sodium and Chloride varies by species.

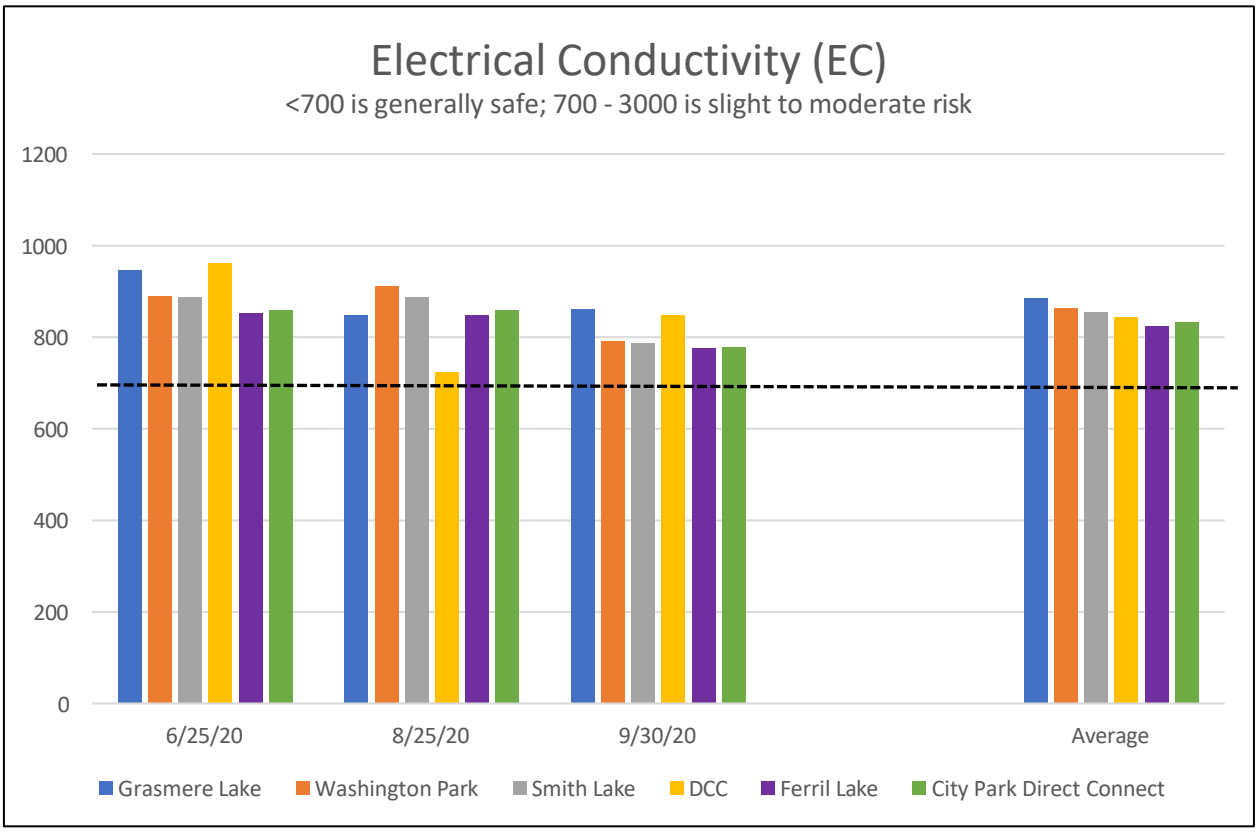


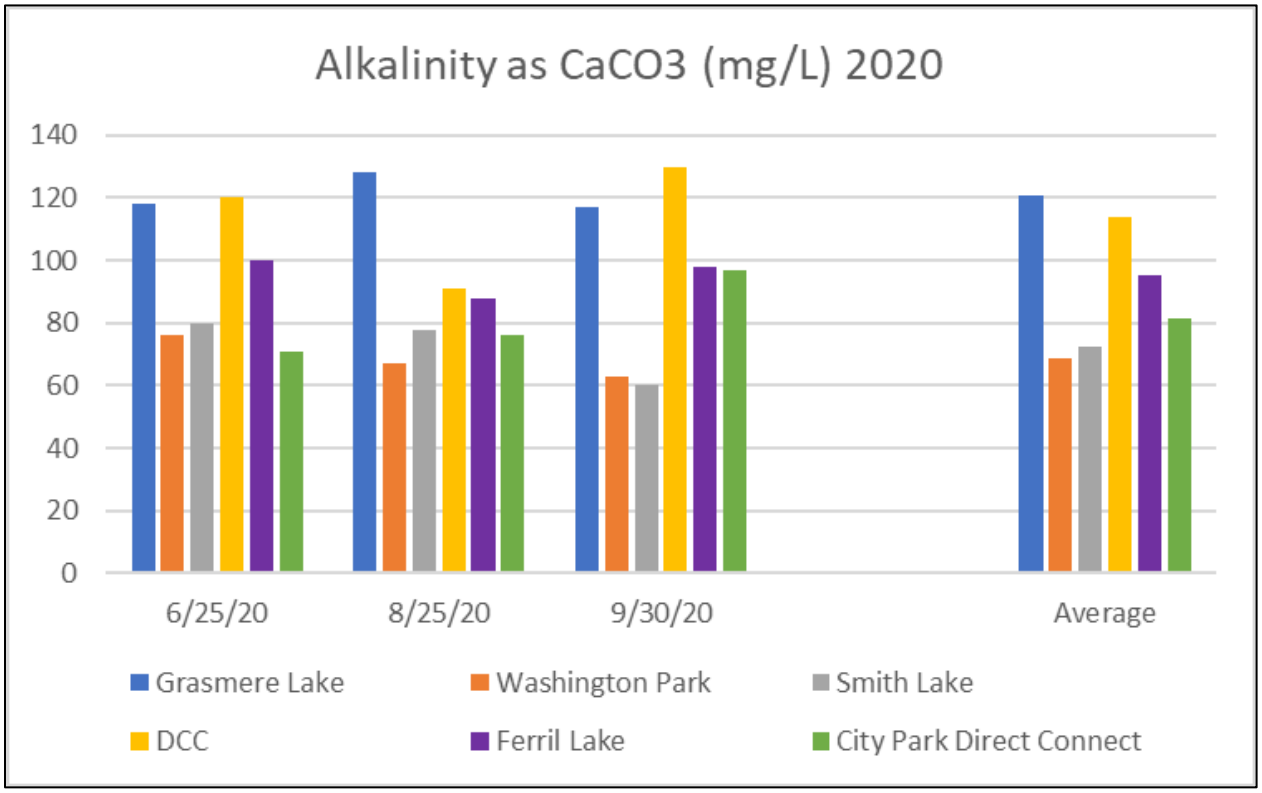


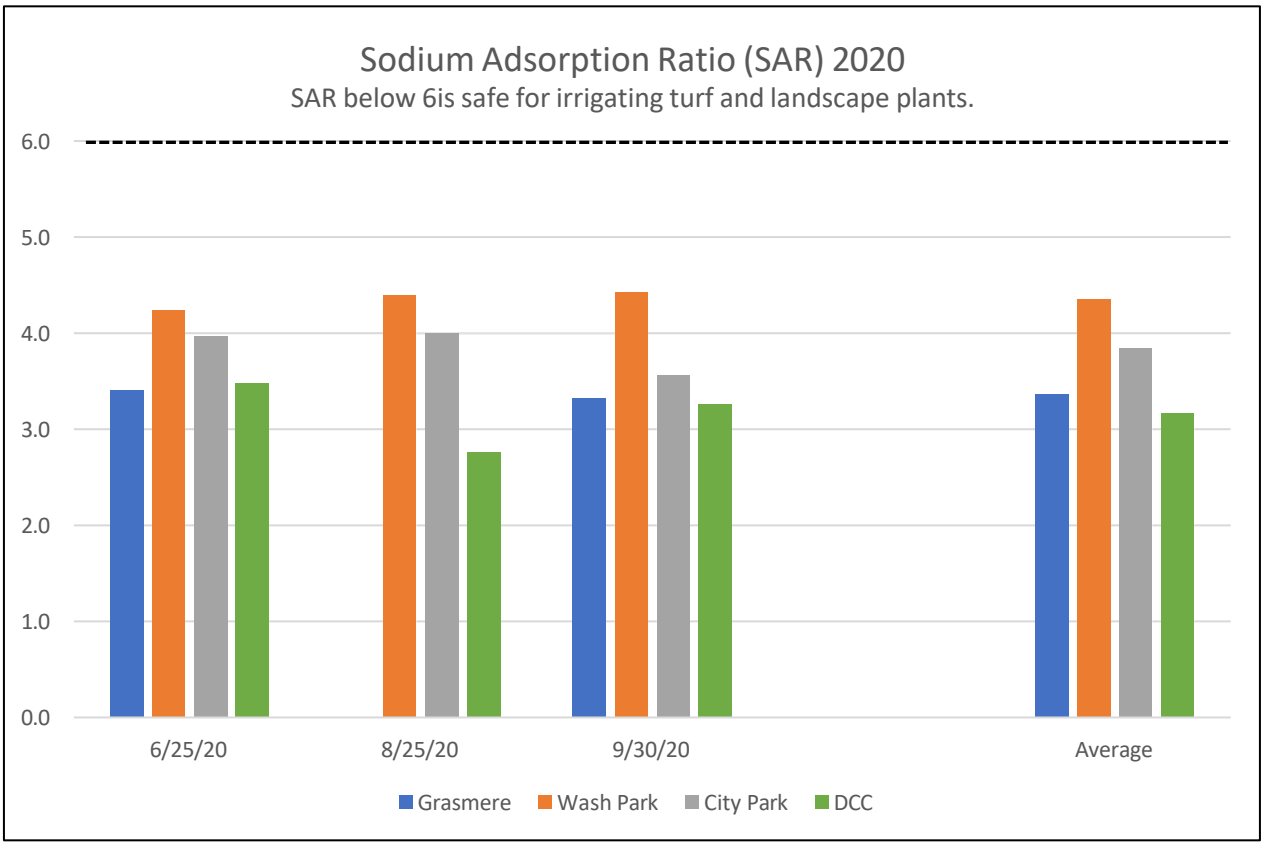
Irrigation water with pH range of 6.5-7 is ideal.



Note: TDS was not tested on 8/25/20.

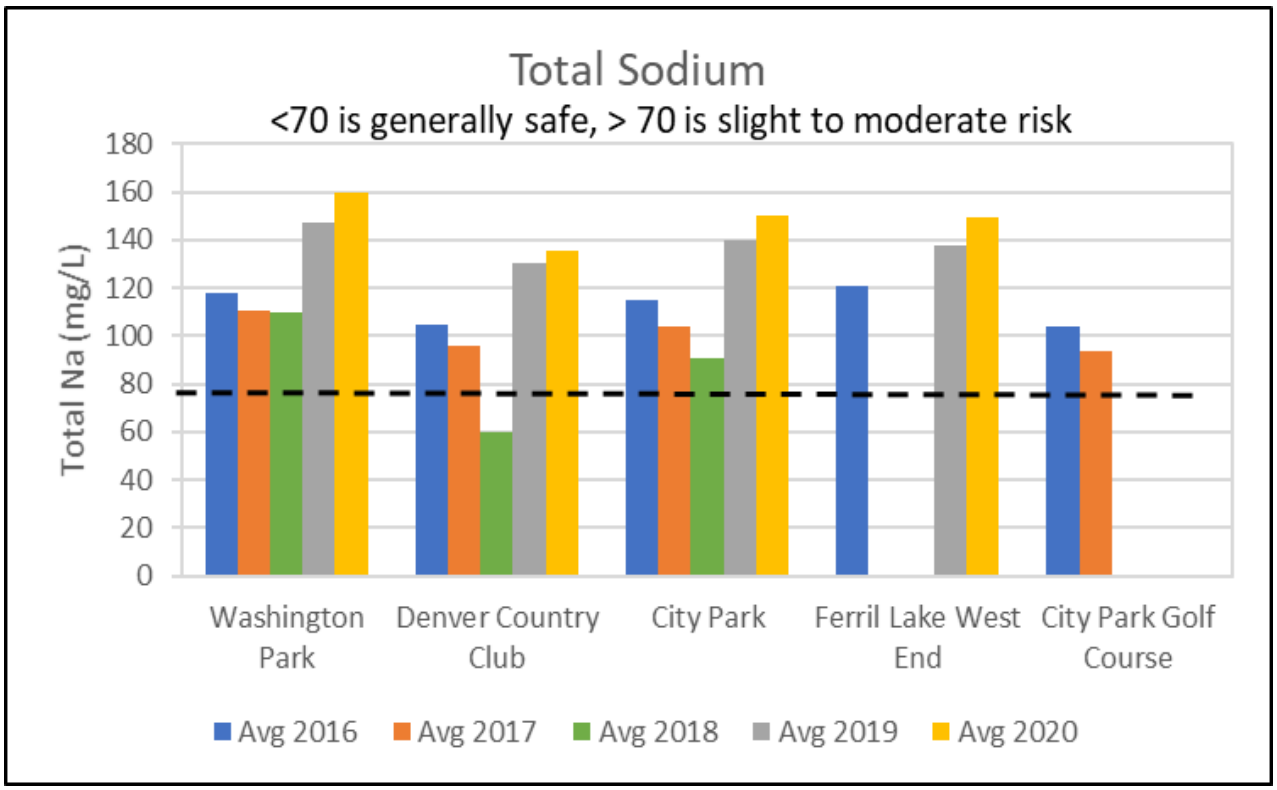

Electrical Conductivity (EC)
<700 is generally safe; 700 - 3000 is slight to moderate risk
1200
1000
800
600
400
200
0
6/25/20
8/25/20
9/30/20
Average
Grasmere Lake
Washington Park
Smith Lake
DCC
Ferril Lake
City Park Direct Connect

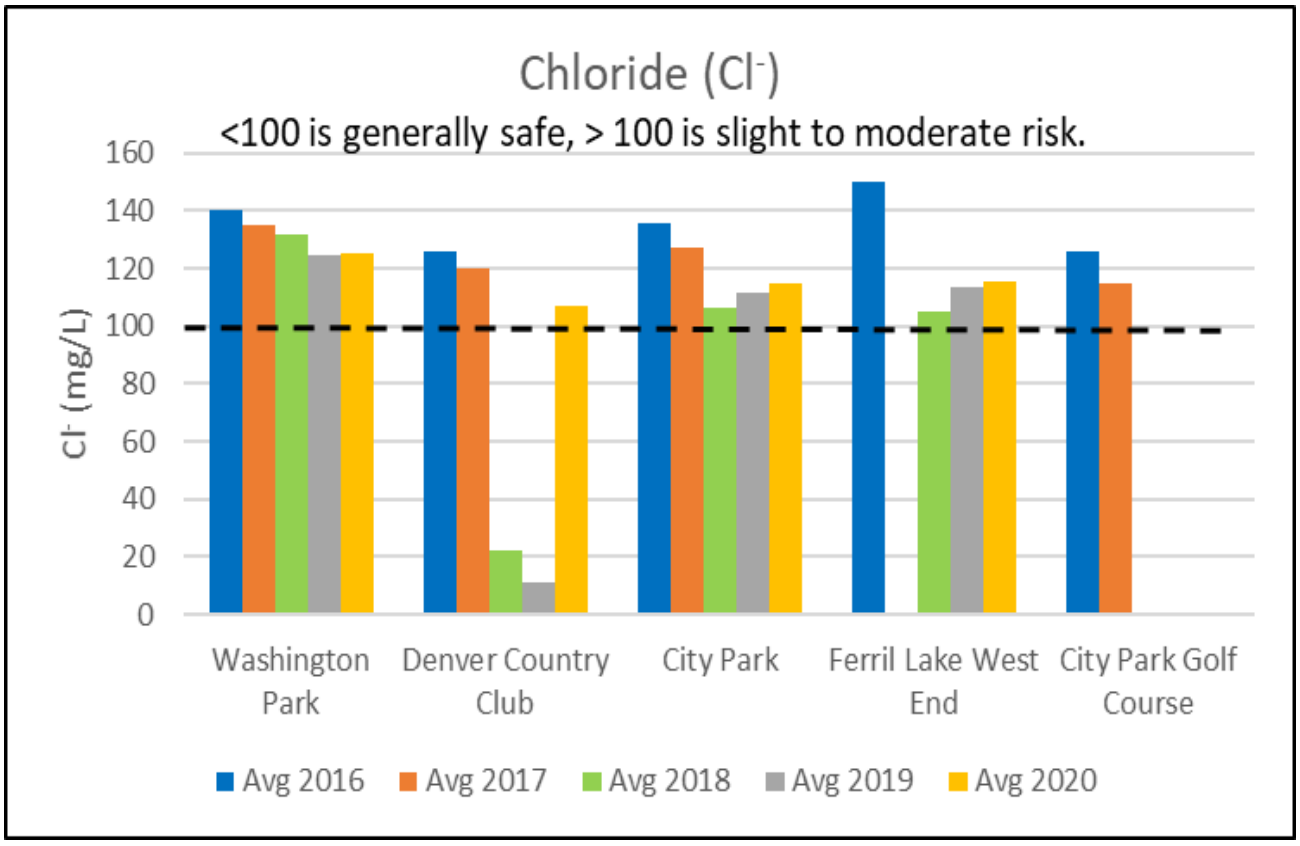

Alkalinity as CaCO3 (mg/L) 2020
140
120
100
80
60
40
20
0
6/25/20
8/25/20
9/30/20
Average
Grasmere Lake
Washington Park
Smith Lake
DCC
Ferril Lake
City Park Direct Connect

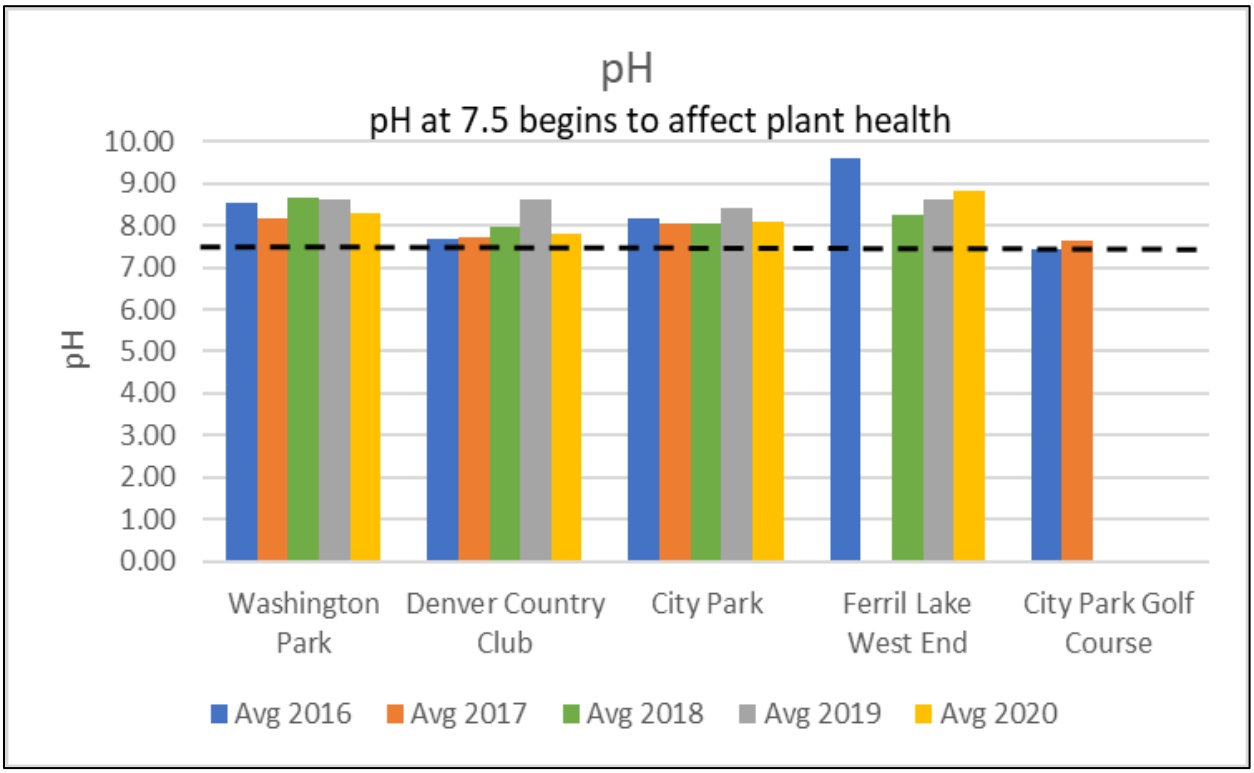


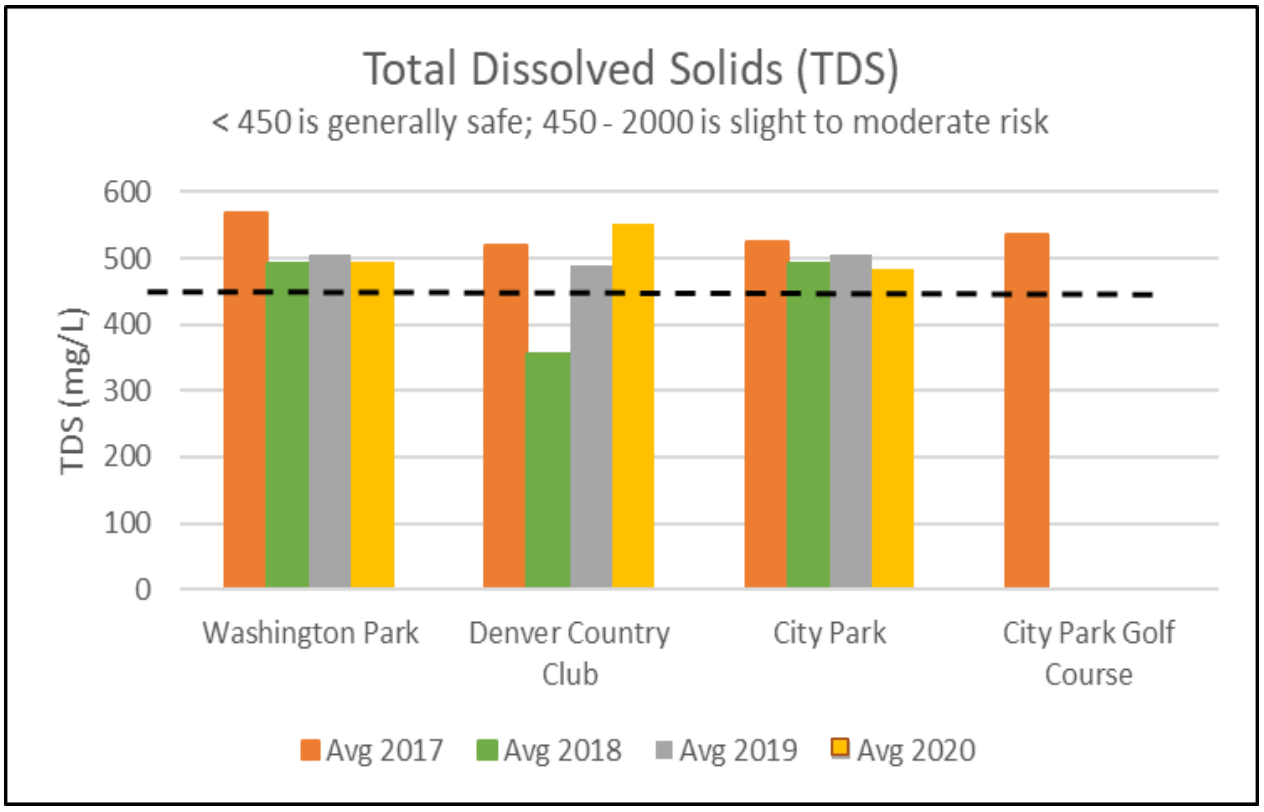
The likelihood that sodium present in irrigation water will cause permeability problems can be evaluated by computing a parameter known as the sodium adsorption ratio, or SAR. Generally, water that has an SAR below 6 is safe for irrigating turf and other ornamental landscape plants. Water that has an SAR greater than 9, on the other hand, can cause severe permeability problems when applied to fine-textured soils (for example, a silty clay loam) and should be avoided. Coarse-textured (sandy) soils typically are less susceptible to permeability problems. For those types of soils, the irrigation water's SAR can be a bit higher than for fine-textured soils.

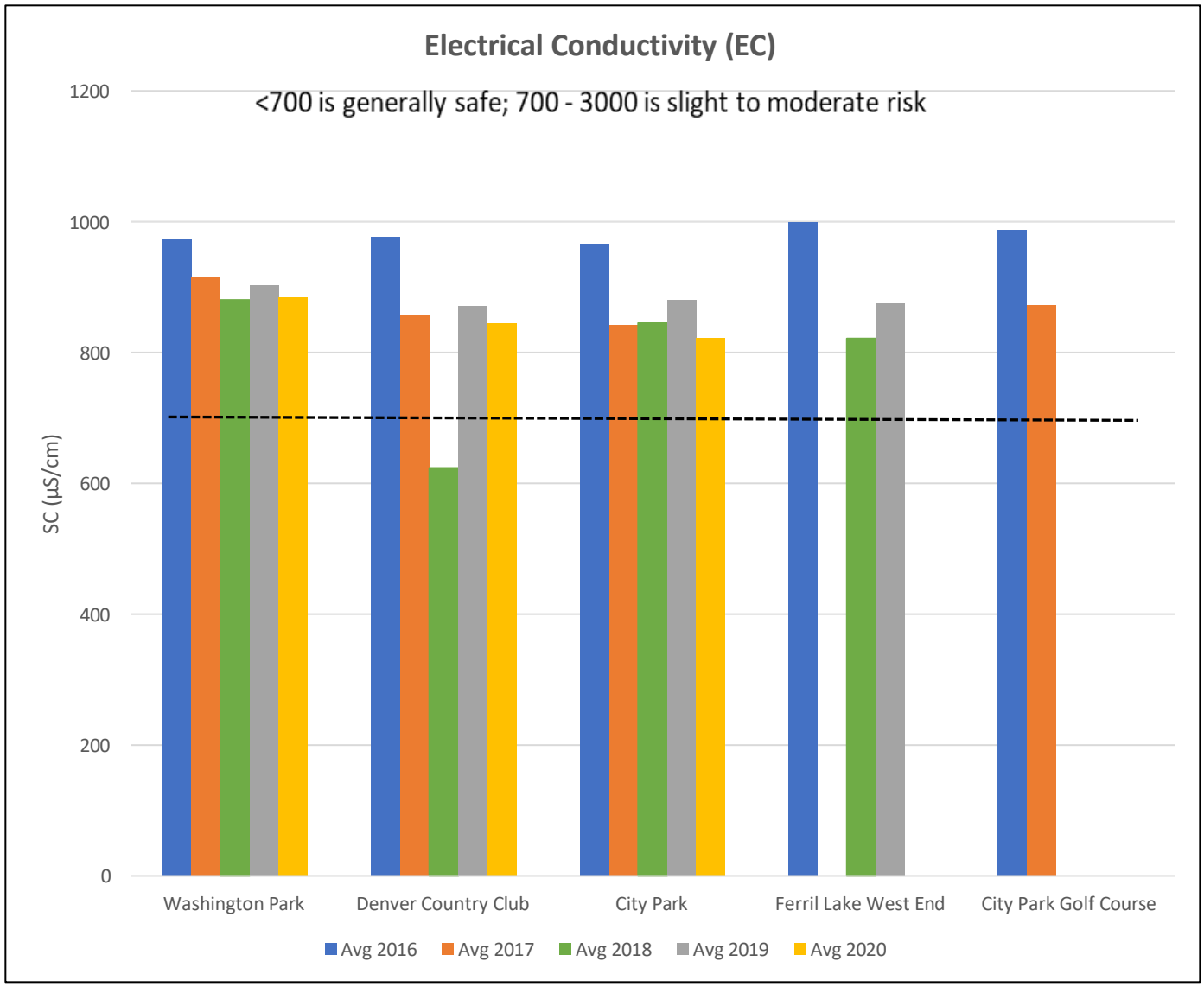
The following charts show water test results for the five years of the study:

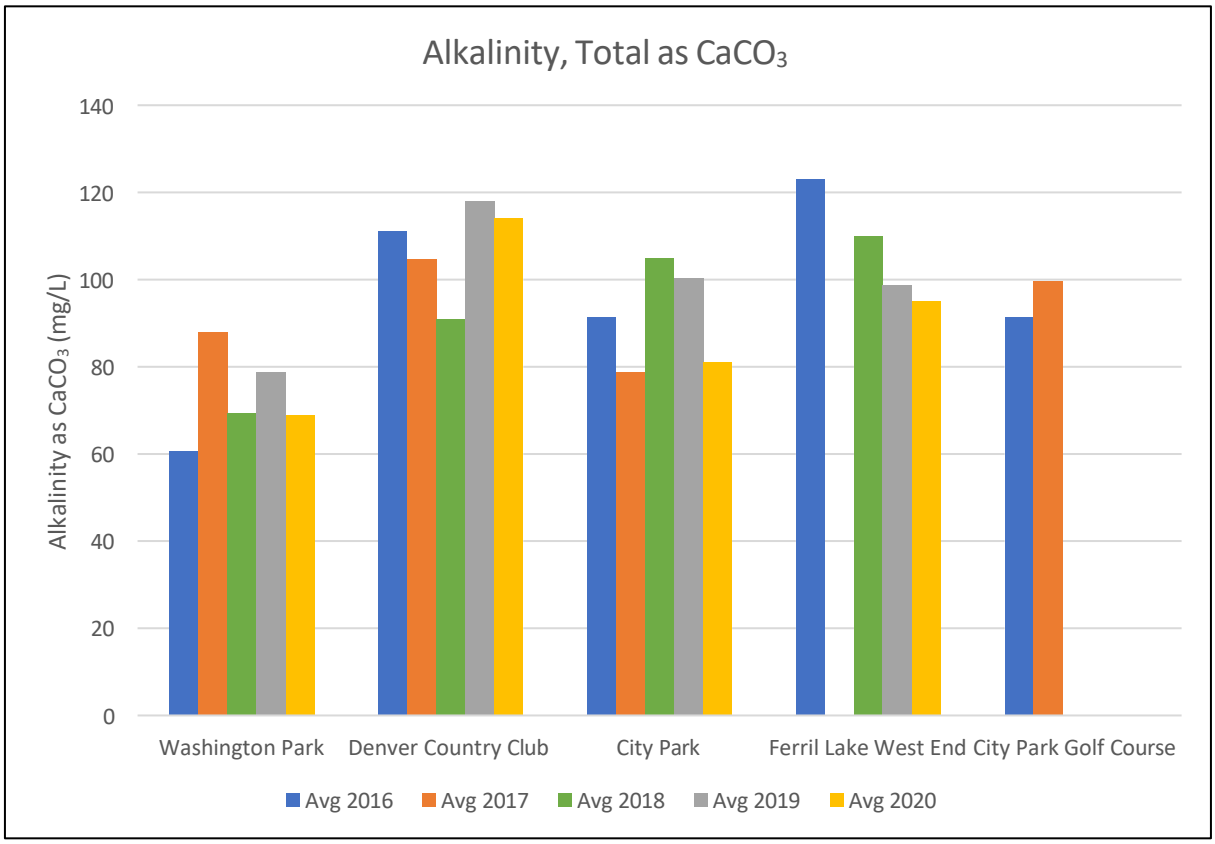


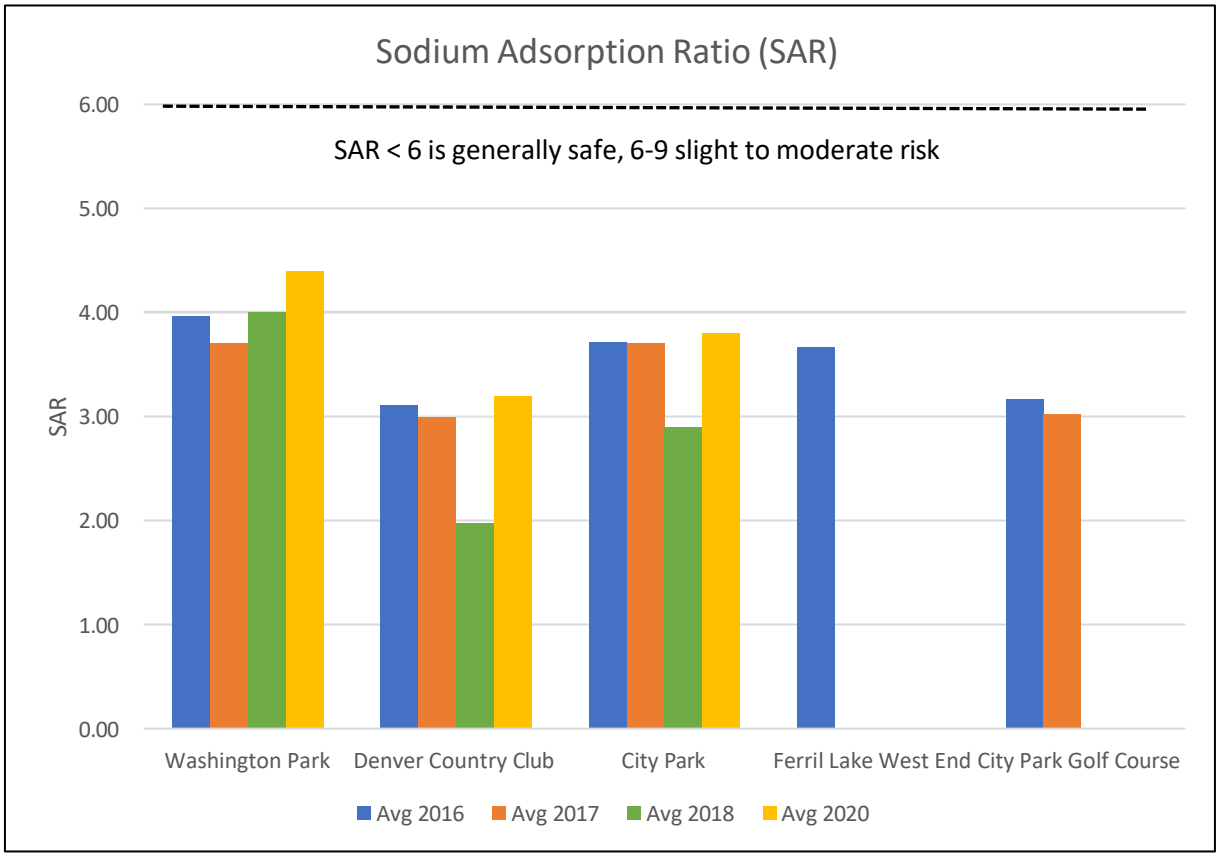

Chloride (Cl-)
<100 is generally safe, > 100 is slight to moderate risk.
Cl- (mg/L)
160
140
120
100
80
60
40
20
0
Washington Park
Denver Country Club
City Park
Ferril Lake West End
City Park Golf Course
Avg 2016
Avg 2017
Avg 2018
Avg 2019
Avg 2020


pH
pH at 7.5 begins to affect plant health
pH
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Washington Park
Denver Country Club
City Park
Ferril Lake West End
City Park Golf Course
Avg 2016
Avg 2017
Avg 2018
Avg 2019
Avg 2020


Total Dissolved Solids (TDS)
< 450 is generally safe; 450 - 2000 is slight to moderate risk
TDS (mg/L)
600
500
400
300
200
100
0
Washington Park
Denver Country Club
City Park
City Park Golf Course
Avg 2017
Avg 2018
Avg 2019
Avg 2020


Electrical Conductivity (EC)
<700 is generally safe; 700 - 3000 is slight to moderate risk
SC (µS/cm)
1200
1000
800
600
400
200
0
Washington Park
Denver Country Club
City Park
Ferril Lake West End
City Park Golf Course
Avg 2016
Avg 2017
Avg 2018
Avg 2019
Avg 2020


Alkalinity, Total as CaCO3
Alkalinity as CaCO3 (mg/L)
140
120
100
80
60
40
20
0
Washington Park
Denver Country Club
City Park
Ferril Lake
West End City Park Golf Course
Avg 2016
Avg 2017
Avg 2018
Avg 2019
Avg 2020


Sodium Adsorption Ratio (SAR)
SAR < 6 is generally safe, 6-9 slight to moderate risk
SAR
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Washington Park
Denver Country Club
City Park
Ferril Lake
West End City Park Golf Course
Avg 2016
Avg 2017
Avg 2018
Avg 2020

4.0 Plant Tissue Testing

The primary parameters, Chloride and Sodium, are the benchmarks of a tree's health when irrigated by reuse water. Betty Goodrich and William Jacobi reported "In other previous field studies of NaCl, leaf injury generally occurred when foliar chloride reached 10,000 -ppm in deciduous tree species and 5,000-ppm in conifer species. Approximately 13,000-16,000 ppm chloride was associated with a FDI (foliar damage indicator) of 80 for all conifers, a threshold of severe damage where trees will probably not recover." (Foliar Damage, Ion Content, and Mortality Rate of Five Common Roadside Tree Species Treated with Soil Applications of Magnesium Chloride, p860).

Chloride concentrations in leaves, rather than the soil, are a better indicator of potential damage. Species will vary in susceptibility to damage, but conifer species are the most severely affected at lower levels than deciduous species. The following chart, which shows this variability, is an excerpt from CSU Fact Sheet No. 7.425, Magnesium Chloride Toxicity in Trees:

Roadside Field Trees:	
Species	Severe Foliar Damage (ppm)*
Lodgepole pine	4000
Aspen	20000
Engelmann spruce	6500
Subalpine fir	5000
Ponderosa pine	7500

* Concentrations necessary to cause ~ 50% crown damage

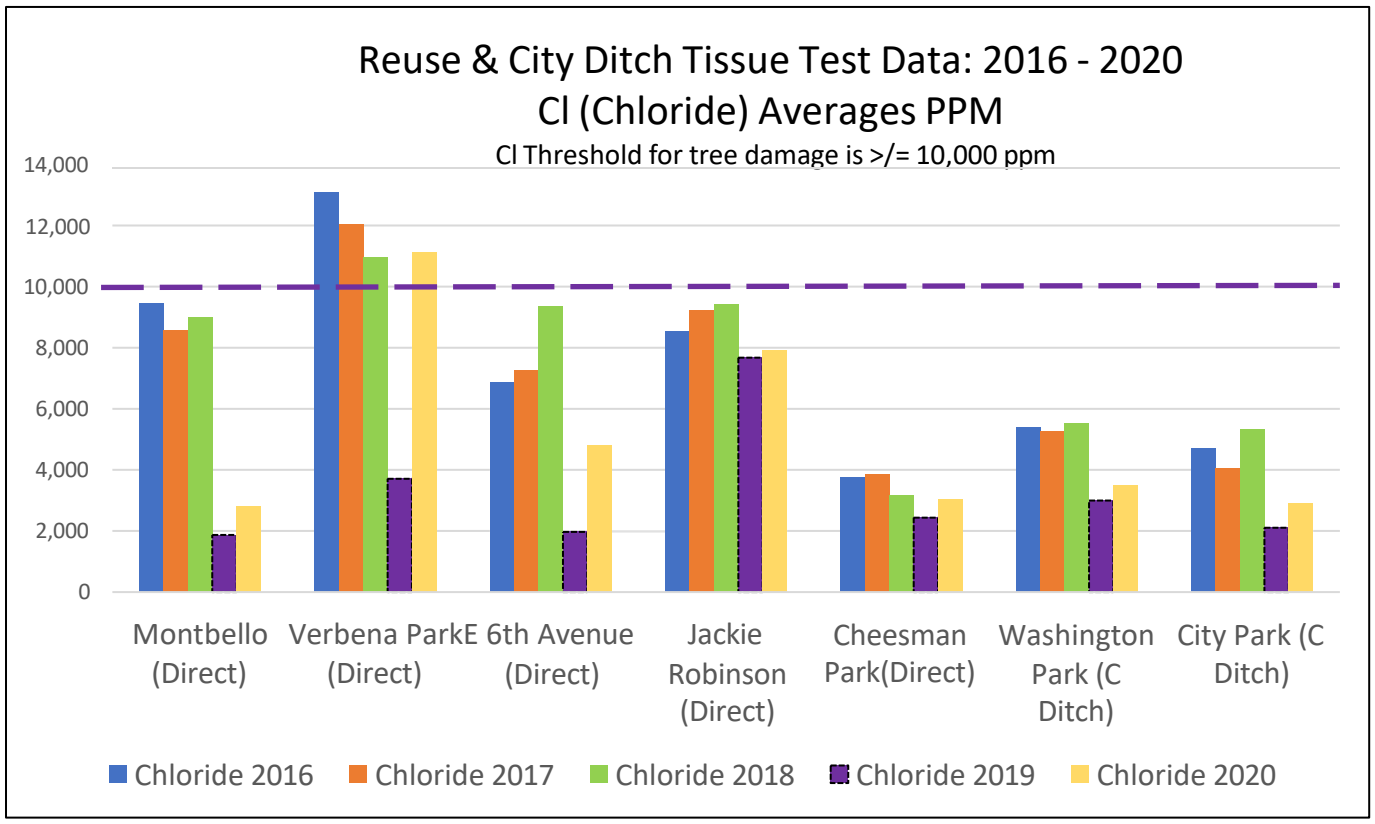
Plant tissue testing of 91 trees were completed in 2020 (See Appendix C)

Denver City Forestry tissue-sampled 105 conifer trees at the start of the study in 2016. By 2020, 26 trees had died or been removed due to death or condition. Additional trees were added to the study to compensate for these trees. Collection of tissue samples were performed in late summer/early fall.

Note that 2016 tissue samples were evaluated by Colorado Analytical Laboratories, Inc, but 2017-2020 tissue samples were analyzed by the Colorado State University Soil, Water and Plant Testing Laboratory. An anomaly (shift) in Chloride test results occurred in results for four years, but the tests were reevaluated and revised per data in this report.

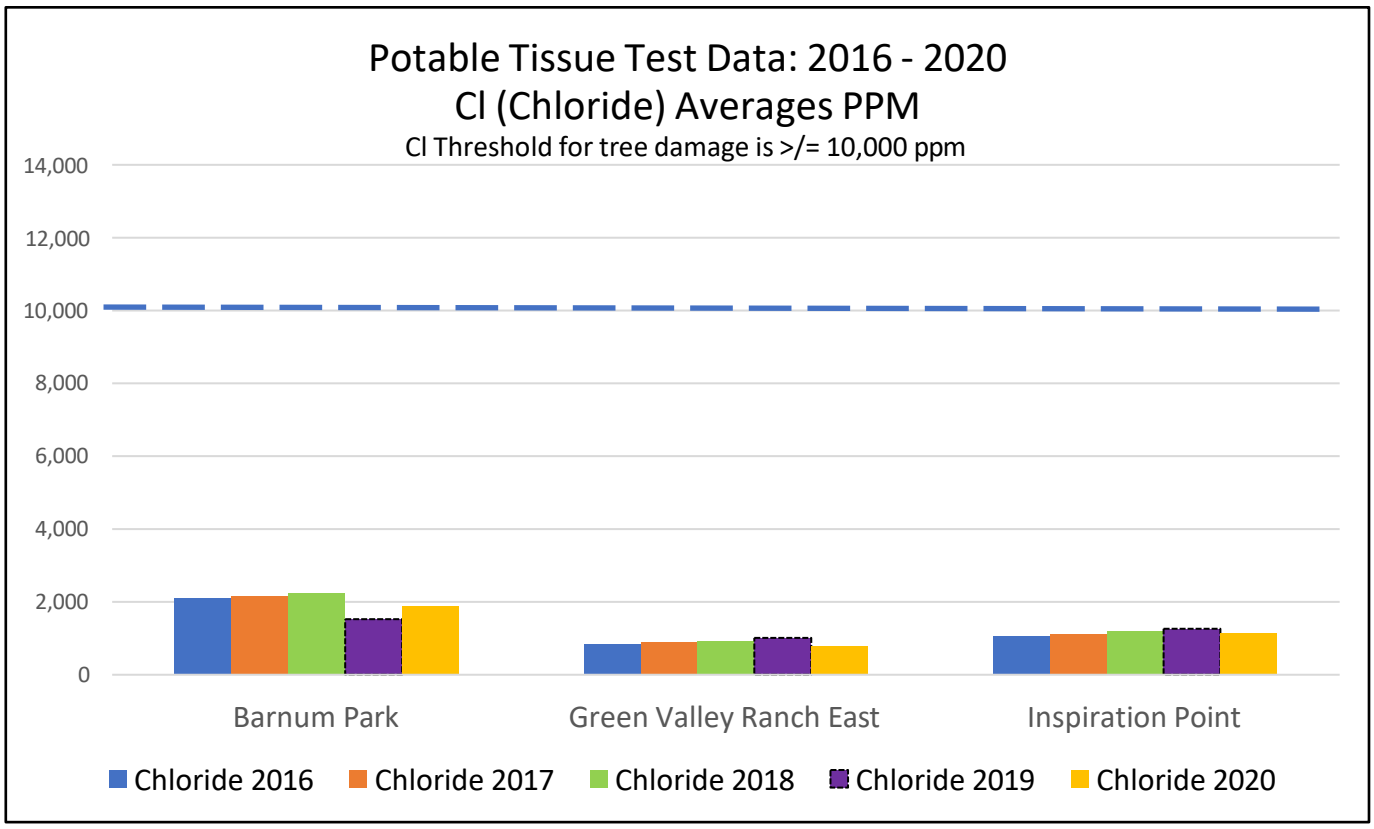
Tip burn on conifer foliage. Low severity of tip burn (left), High severity of tip burn (right).

Note that as trees most severely affected by high salt levels decline, die and are removed, there is a decline in the average Na and Cl values for the relatively less affected trees in the study that remain alive. This gives the erroneous impression that the Na and Cl levels in tree foliage are gradually improving. Additionally, it should be noted that as trees die, they are often replaced by younger trees and sometimes different species.



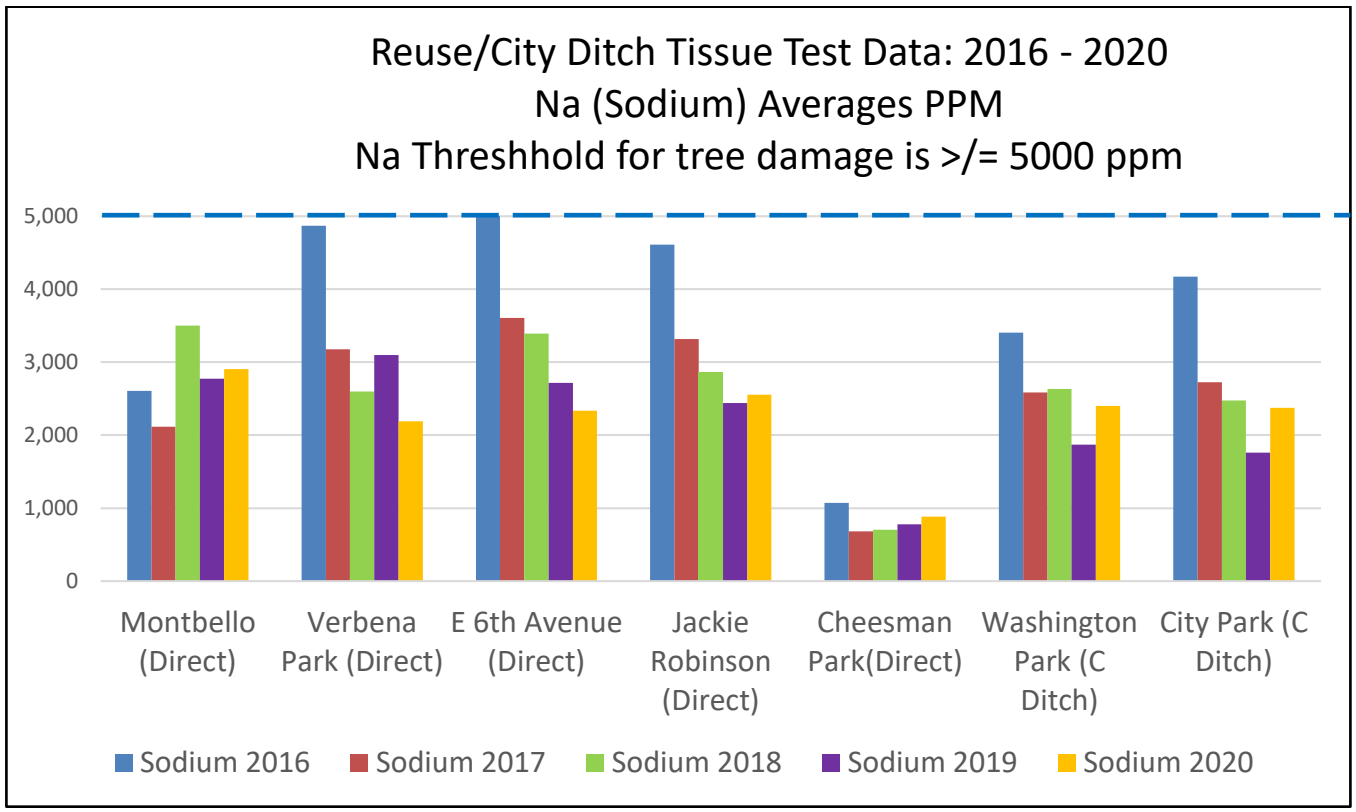
WateReuse Foundation's website states chloride levels in plant tissues are damaging If they exceed 1% or 10,000 ppm

Recycled Water Sites	Chloride 2016	Chloride 2017	Chloride 2018	Chloride 2019	Chloride 2020
Montbello (Direct)	9,433	8,577	8,998	1,869	2,791
Verbena Park (Direct)	13,075	12,048	10,949	3,710	11,110
E 6th Avenue (Direct)	6,854	7,268	9,343	1,970	4,816
Jackie Robinson (Direct)	8,550	9,230	9,407	7,672	7,920
Cheesman Park(Direct)	3,757	3,838	3,159	2,437	3,019
Washington Park (C Ditch)	5,380	5,260	5,538	2,996	3,492
City Park (C Ditch)	4,710	4,037	5,328	2,106	2,888

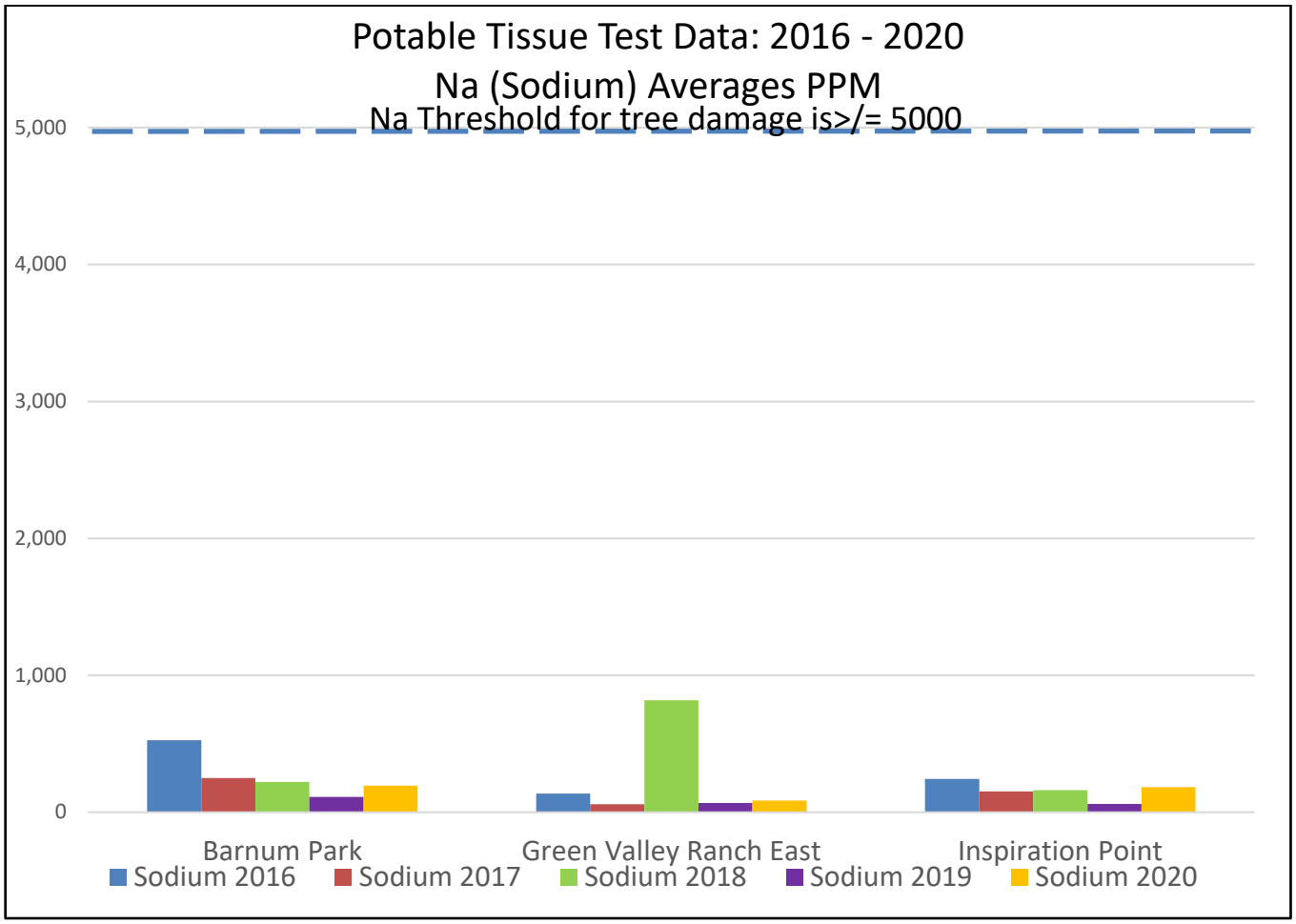


WateReuse Foundation's website states chloride levels in plant tissues are damaging If they exceed 1% or 10,000 ppm

Potable Water Sites	Chloride 2016	Chloride 2017	Chloride 2018	Chloride 2019	Chloride 2020
Barnum Park	2,100	2,168	2,230	1,527	1,885
Green Valley Ranch East	833	885	922	1,010	780
Inspiration Point	1,060	1,120	1,182	1,261	1,152



Recycled Water Sites	Sodium 2016	Sodium 2017	Sodium 2018	Sodium 2019	Sodium 2020
Montbello (Direct)	2,605	2,117	3,500	2,775	2,905
Verbena Park (Direct)	4,869	3,175	2,600	3,100	2,189
E 6th Avenue (Direct)	4,999	3,608	3,391	2,718	2,336
Jackie Robinson (Direct)	4,612	3,317	2,867	2,440	2,554
Cheesman Park(Direct)	1,071	681	705	779	883
Washington Park (C Ditch)	3,403	2,586	2,633	1,870	2,402
City Park (C Ditch)	4,710	4,037	5,328	2,106	2,888



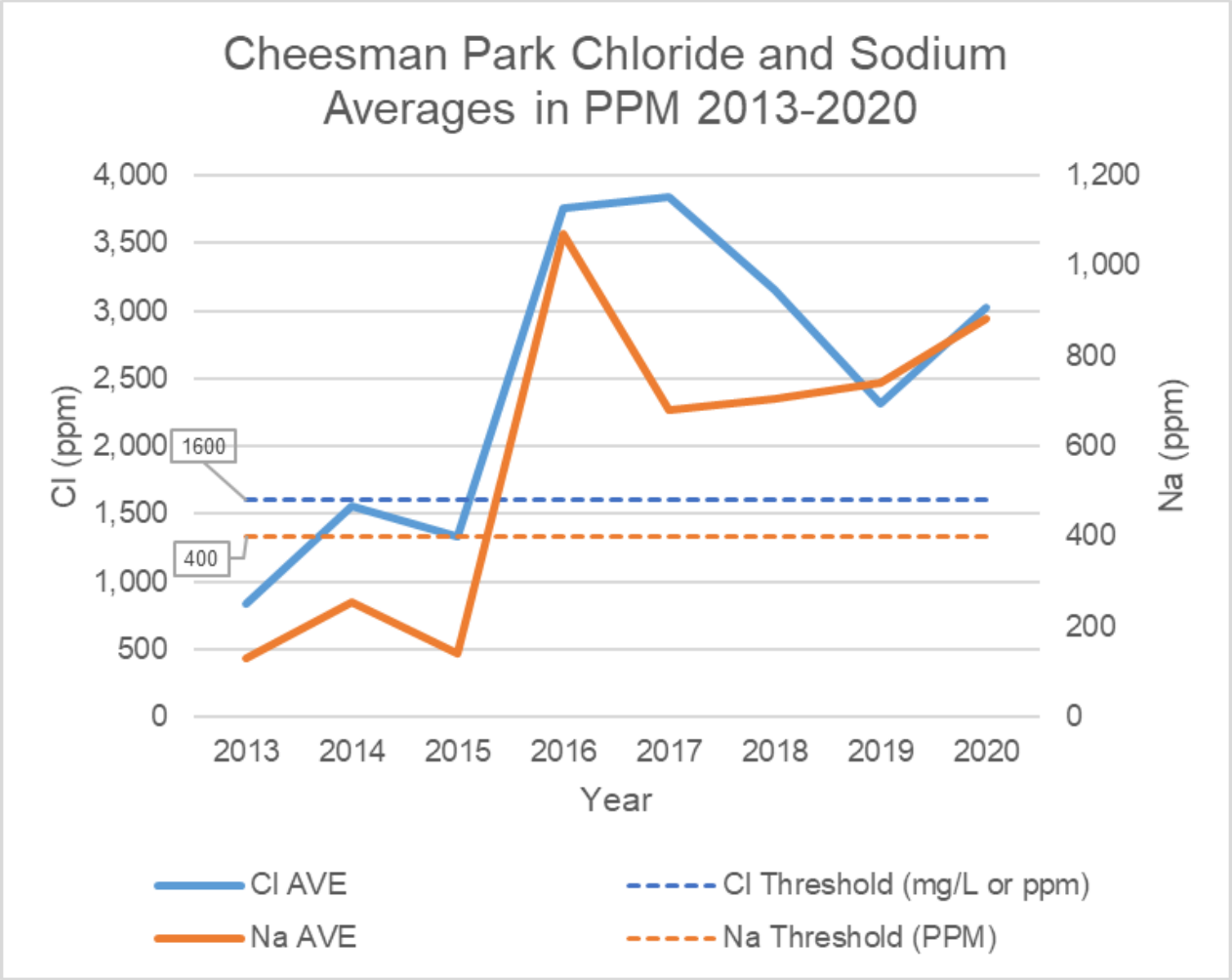
Potable Water Sites	Sodium 2016	Sodium 2017	Sodium 2018	Sodium 2019	Sodium 2020
Barnum Park*	526	249	222	111	194
Green Valley Ranch East	136	58	817	67	85
Inspiration Point	244	153	160	60	184

* One tree in Barnum Park located near a drain discharge showed a very high Na in 2016, and died. The data for this tree significantly changed the Na average at Barnum Park after 2016 due to the small number of trees sampled.

DPR has the most data for Cheesman Park. Tissue test results are available for 21 trees for years 2013 – 2020.

- Five trees were added to the sampling in 2016 (indicated by blue highlight)
- No trees were lost in the study during 2013 – 2017; one tree was lost in 2018; one tree was lost in 2019, and one tree was lost in 2020.
- A variety of coniferous species were tested.

The chart below indicates the changes in Chloride (Cl) and Sodium (Na) between 2013 (Reuse conversion date) and 2020:



Na is high if >/= to 400 PPM Cl is high if >/= to 1600 PPM

Visual assessment of condition for each tree has been made annually along with tissue testing.

Average condition at the start of testing in 2013 and at testing in 2016 are shown below:

Cheesman Park Tree Tissue Testing Results:

		2013 Tissue Test Results			2014 Tissue Test Results		2015 Tissue Test Results		2016 Tissue Test Results	
Site ID	Species	Chloride: CL PPM	Sodium: NA PPM	Initial Condition	Chloride: CL PPM	Sodium: NA PPM	Chloride: CL PPM	Sodium: NA PPM	Chloride: CL PPM	Sodium: NA PPM
25724	Limber Pine(vanderwolf)	300	96	excellent	600	118	800	65	2,000	64
25728	White fir	600	57	good	1,200	65	1,600	38	3,500	66
26191	Blue Spruce	800	70	good	1,800	139	2,000	46	5,700	252
26190	Blue Spruce								7,500	8,337
26195	Blue Spruce	1,300	154	good	8,200	412	2,600	251	1,900	204
25746	Red Pine	1,000	225	excellent	800	486	600	68	1,000	87
25787	Ponderosa Pine	500	224	excellent	400	597	200	245	500	848
26251	Blue Spruce	1,100	83	good	2,400	223	2,500	242	5,000	959
26243	Ponderosa Pine	500	98	excellent	700	500	400	140	500	318
26244	Blue Spruce	800	93	excellent	1,100	186	1,300	278	800	230
26676	White fir	1,600	112	excellent	1,900	289	1,800	92	5,100	420
26757	Blue Spruce								12,300	354
26786	White Pine	500	92	excellent	200	104	300	102	500	219
26788	Bristlecone Pine	400	116	excellent	300	224	200	176	300	220
26827	Blue Spruce	1,600	60	excellent	3,300	202	4,700	57	5,700	232
26367	White fir	1,500	263	excellent	1,300	149	1,600	206	2,800	703
26366	White fir								5,400	3,284
26893	Ponderosa Pine	300	208	good	200	206	300	202	400	1,035
26898	White fir								15,500	4,410
26899	White fir								2,200	176
26901	Mugo Pine	500	108	good	600	190	500	43	300	68
Living Tree	Averages:	831	129	excellent/ good	1,563	256	1,338	141	3,757	1,071

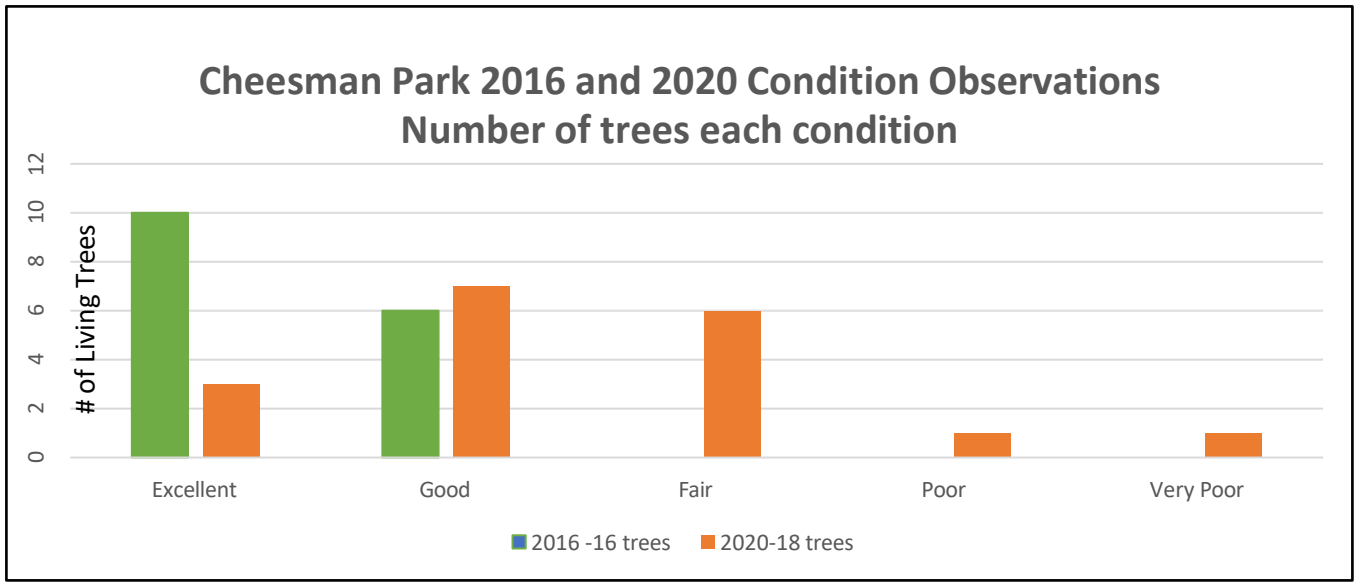
Denotes added tree

Continued on Page 22

Cheesman Park Tissue Testing Results (Cont.):

Site ID	Species	2017 Tissue Test Results		2018 Tissue Test Results		2019 Tissue Test Results		2020 Tissue Test Results		
		Chloride: CL PPM	Sodium: NA PPM	Chloride: CL PPM	Sodium: NA PPM	Chloride: CL PPM	Sodium: NA PPM	Chloride: CL PPM	Sodium: NA PPM	2020 Condition
25724	Limber Pine(vanderwolf)	2,250	100	2,395	500	1782	100	2142	304.7	excellent
25728	White fir	3,460	100	3,569	100	3152	200	3222	347	fair
26191	Blue Spruce	5,480	100	5,510	100	5063	900	4883	871	fair
26190	Blue Spruce	7,800	4,400	7,953	200	6107	3900	7421	3388	very poor
26195	Blue Spruce	1,850	500	1,945	100	1899	1100	1789	935	good
25746	Red Pine	1,110	100	1,252	200	952	100	11442	65	good
25787	Ponderosa Pine	520	300	631	700	524	600	502	561	good
26251	Blue Spruce	5,120	1,000	5,210	5,400	4913	2600	4982	1599	good
26243	Ponderosa Pine	610	200	705	600	642	100	641	281	fair
26244	Blue Spruce	870	200	956	200	795	300	836	236	fair
26676	White fir	5,240	200	5,362	700	4225	300	4895	593	excellent
26757	Blue Spruce	12,270	500	12,975	400		removed			removed
26786	White Pine	560	100	661	1,400	520	200	525	126	good
26788	Bristlecone Pine	340	200	389	1,200	351	400	325	443	excellent
26827	Blue Spruce	5,370	200	5,241	400	4982	400	5011	318	fair
26367	White fir	2,840	100	2,753	300	2533	1200	2641	2715	poor
26366	White fir	5,490	1,600	5,533	200	4899	1200			removed
26893	Ponderosa Pine	410	400	596	1,300	447	300	512	347	good
26898	White fir	16,470	3,600		removed		removed			removed
26899	White fir	2,160	300	2,246	400	2073	500	2195	1880	good
26901	Mugo Pine	380	100	399	400	443	400	375	879	fair
Living Tree	Averages:	3,838	681	3,156	705	2,437	779	3,019	883	good/fair

Denotes added tree



Note: Five trees were added and three of those died; (one is now in very poor condition and the other good)

Year	Excellent	Good	Fair	Poor	Very Poor
2016 -16 trees	10	6	0	0	0
2020-18 trees	3	7	6	1	1

Parks Forestry Tree Testing Totals, removals/Additions 2016-2020:

Location	# tested 2016	26 removed since 2016 (25 reuse sites; 1 potable site)	15 trees added since 2016
Montbello Central Park	6	1 Colorado Spruce (2017) 2 Colorado Spruce (2019)	Colorado Spruce (2017)
Verbena Park	4	Colorado Spruce (2018) Colorado Spruce (2019) Colorado Spruce (2020)	
E 6th Ave Pkwy	13	2 Colorado Spruce (2018)	
Jackie Robinson Fields	6	Ponderosa Pine (2018) White Fir (2020)	
Washington Park	15	Colorado Spruce (2017) 2 Colorado Spruce (2018) Colorado Spruce (2019) Ponderosa Pine (2019)	
City Park	19	Ponderosa Pine (2017) Austrian Pine (2017) Colorado Spruce (2018) Austrian Pine (2018) Scotch Pine (2018) Colorado Spruce (2019)	Austrian Pine (2018) Colorado Spruce (2018)
City Park Golf Course*	2	Ponderosa Pine (2018)	Colorado Spruce (2018) Austrian Pine (2018)
Cheesman Park	21	White Fir (2018) Colorado Spruce (2019) White Fir (2020)	
Barnum South Park	10	Ponderosa Pine (2017)	
Green Valley Ranch East	6		
Inspiration Park	0		5 Colorado Spruce (2017) 5 Ponderosa Pine (2017)

***City Park Golf underwent a multi-year renovation beginning 2018, and testing was not completed due to limited access.**

Notes:

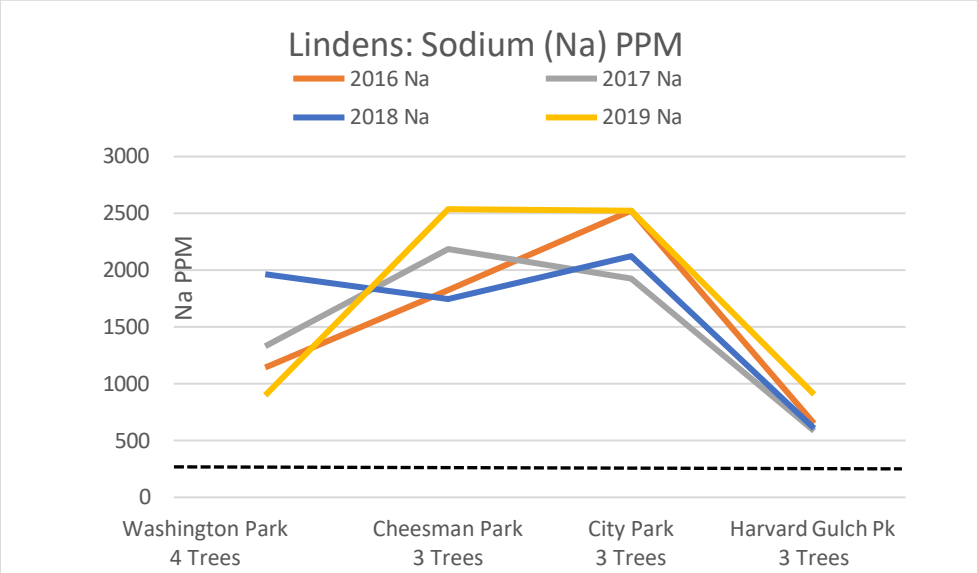
Of 117 trees (counting added trees), in 2020 there are 91 living trees.

Of 91 trees on reuse/City ditch sites, 25 have been removed (27.5% loss rate)

Of 26 trees in locations irrigated with potable water, one was removed (4% loss rate)

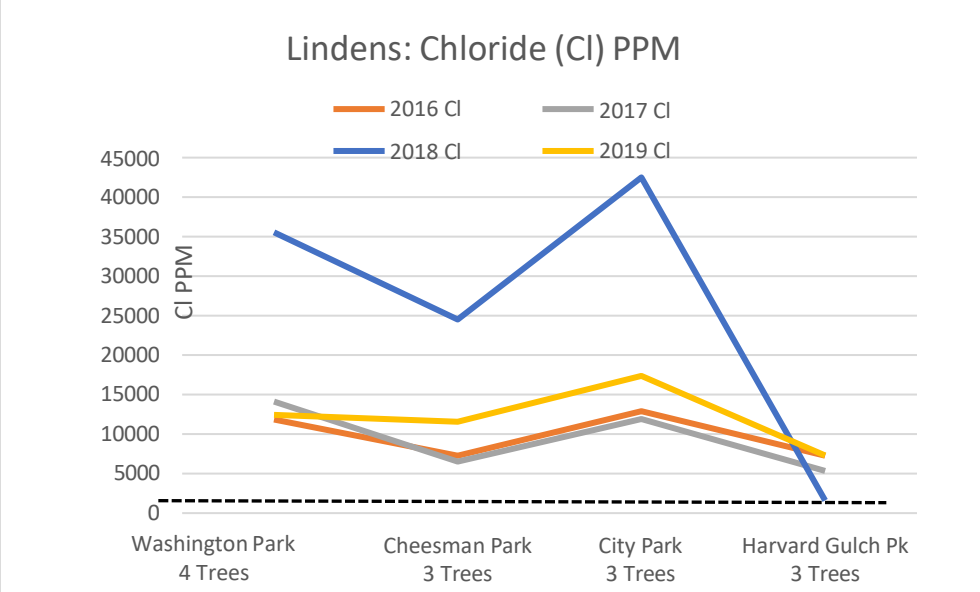
Linden and Novel Conifer Tissue Testing

Advisory Committee member Sonia John provided additional tissue testing in 2016 - 2019 for trees in Washington Park, City Park (City Ditch), Cheesman Park (direct-connect reuse), and Harvard Gulch Park (potable water but converted to a raw water source in 2020). She also provided testing of novel conifers 2017 – 2019 and additional conifers in 2020. Although not part of the original study, the testing is consistent with the goals of the study, and the results are as follows. See Appendix C for test results and comments regarding test data.



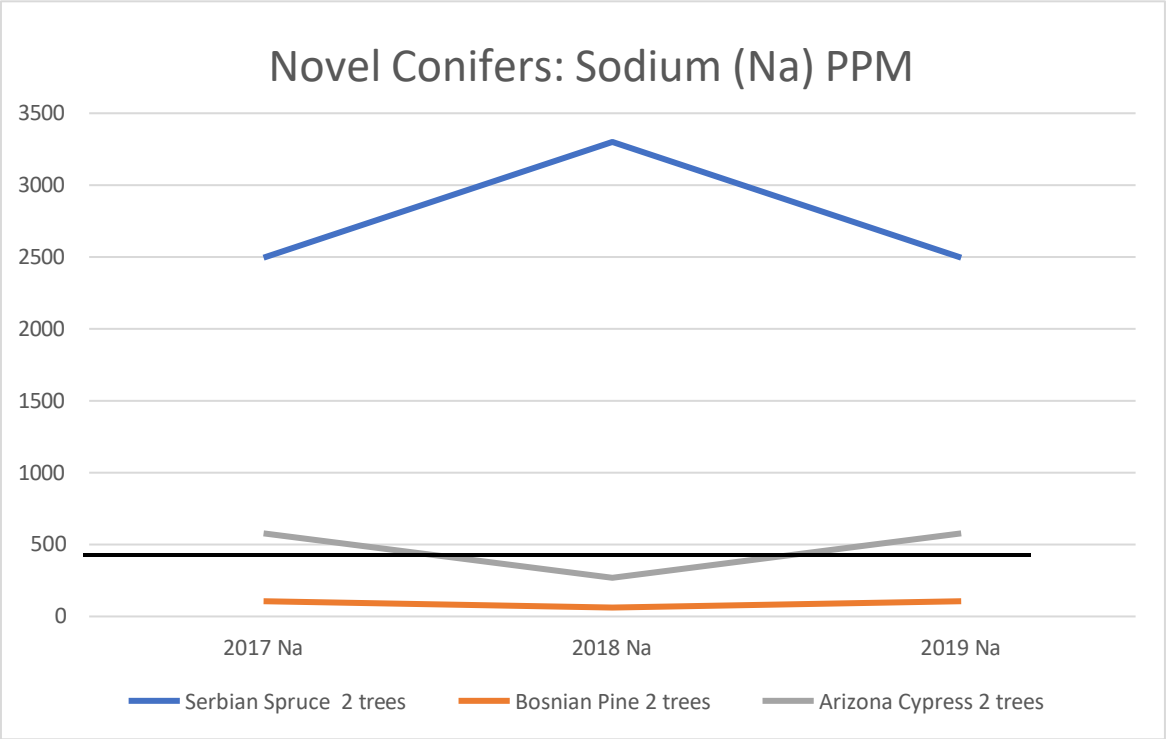
1 Tree at Wash Park was removed in 2019.

Sodium (Na) is high if >/= 400 PPM

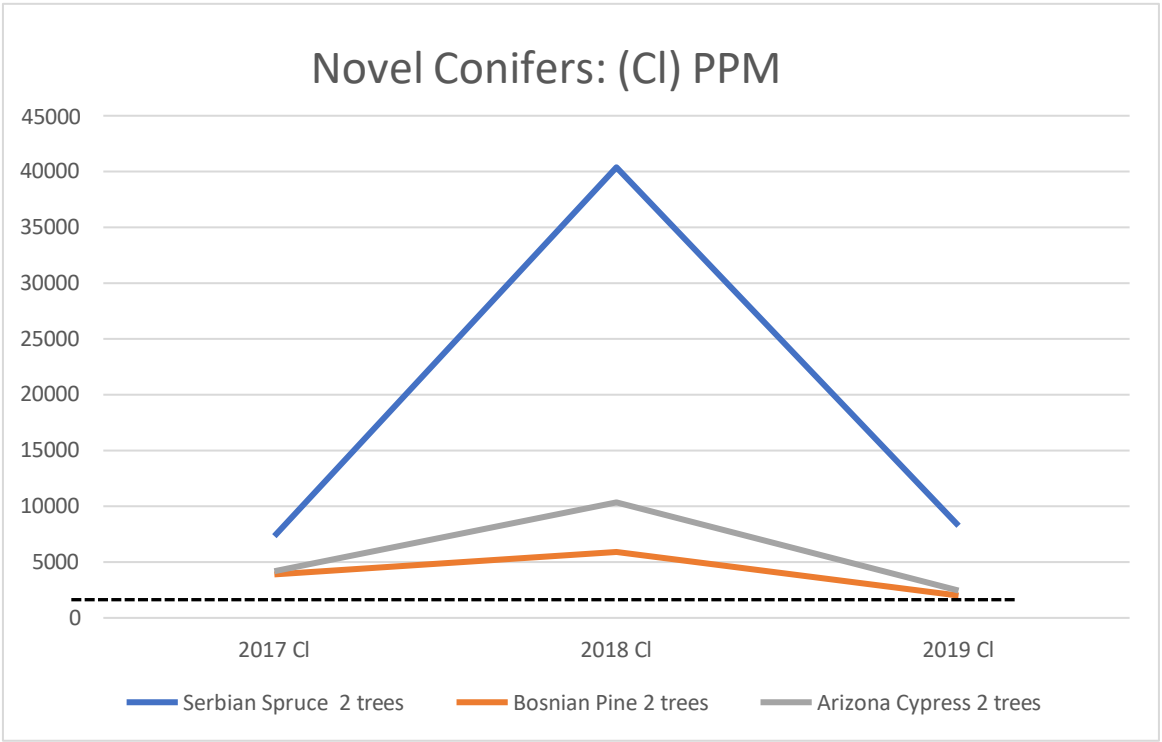


1 Tree at Wash Park was removed in 2019.

Chloride (Cl) is high if >/=1600 PPM



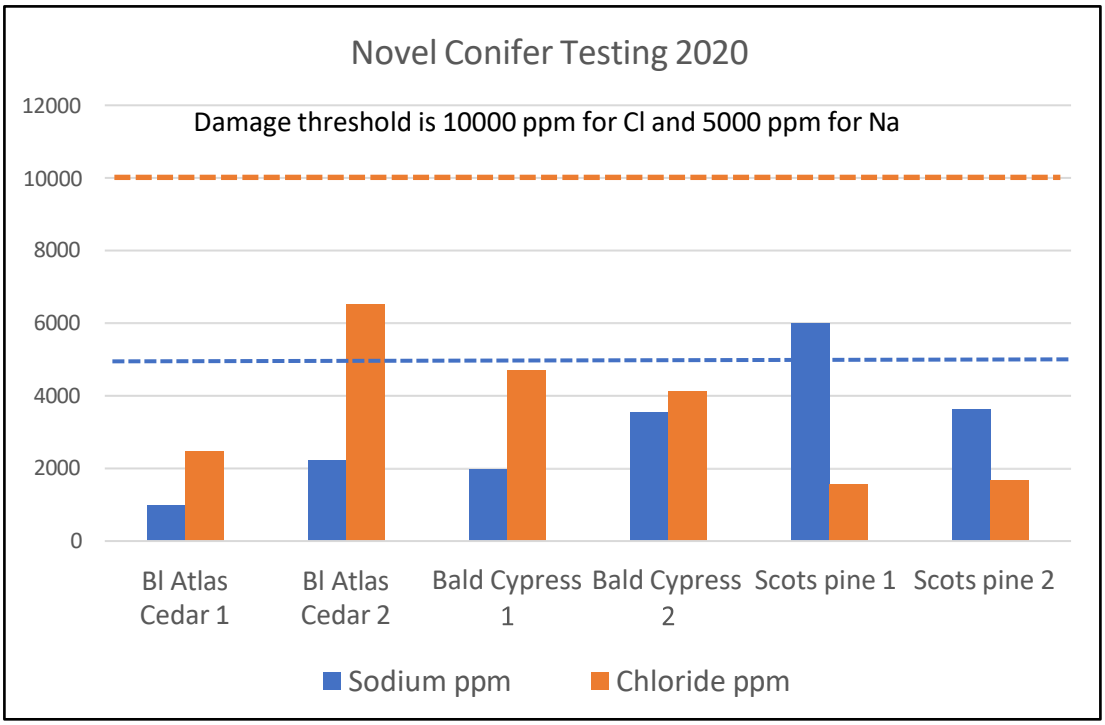
Sodium (Na) is high if >/= 400 PPM



Chloride (Cl) is high if >/=1600 PPM

2020 Washington Park Novel Conifer Foliage Testing

Sonia John provided tissue testing for additional novel conifers in 2020. The goal is to provide data for reuse effects on less commonly used conifers:



Tree	Sodium ppm	Chloride ppm
Blue Atlas Cedar 1	980	2460
Blue Atlas Cedar 2	2230	6510
Bald Cypress 1	1980	4700
Bald Cypress 2	3550	4130
Scots pine 1	6000	1570
Scots pine 2	3620	1660

Note:

Typical damage thresholds in foliage are 5000 ppm for sodium (Na); and 5,000 ppm in conifers and 10,000 ppm deciduous species for chloride (Cl)

5.0 2020 DPR Maintenance, Management and Mitigation Practices for Reuse Sites

The following list recaps the maintenance practices in place during 2020 for DPR Parks on reuse water.

Washington Park:

- 18-0-6 Fertilizer & Sodium Knockout (fertigation)
- Core and slice aeration 1-2 times per season with added focus on conifer trees
- Lake management: 1 Solar Bee in Grasmere and Smith, and a grid bee in Grasmere. Grasmere Lake treated with 180 pounds of Cutrine Plus Granular product and 310 gallons of Cutrine Plus Liquid, all copper-based products to control filamentous algae.

Cheesman Park:

- Fertilization remained twice a year (1# Nitrogen/1,000 sq. ft.) except for central meadows which was fertilized only once (1# Nitrogen/1,000 sq. ft.)
- Core and slice aeration 1-2 times per season with added focus on conifer trees

City Park:

- Fertigation system, 27-0-0 formula
- Core aeration 1-2 times per season with added focus on conifer trees

Lake management:

- 8 diffuser Otterbine aerators in both Ferril Lake and Duck Lake installed. Grasmere Filamentous algae treated with 180 lbs. Cutrine Plus granular, and 300 gallons of Cutrine Plus liquid. Smith Lake blue-green algae treated with 16 gallons Cutrine Plus liquid. City Park Sediment Pond filamentous algae was treated with 2 gallons Cutrine Plus liquid. Ferril Lake blue-green algae treated with 8 gallons Cutrine Plus liquid. Duck Lake filamentous algae treated with 40 gallons Cutrine Plus.

Mowing, aeration, irrigation, fertilization remain the same as the previous year for all other sites.

Ongoing Maintenance Strategies:

Cheesman Park

- Parks/Forestry reviewing location and products to trial such as granular gypsum
- Create large mulched areas around groupings of conifers, and redirect irrigation.
- Continue potable flood irrigation of mulched areas.

Washington Park

- Create large mulched areas around groupings of conifers, and redirect irrigation.
- Continue potable flood irrigation of mulched areas with emphasis on Evergreen Hill.

City Park

- Create large mulched areas around groupings of conifers, and redirect irrigation.
- Continue potable flood irrigation of mulched areas with emphasis on conifers.

All locations: Continue Zone checks to reduce spray into conifers

2020 IRRIGATION:

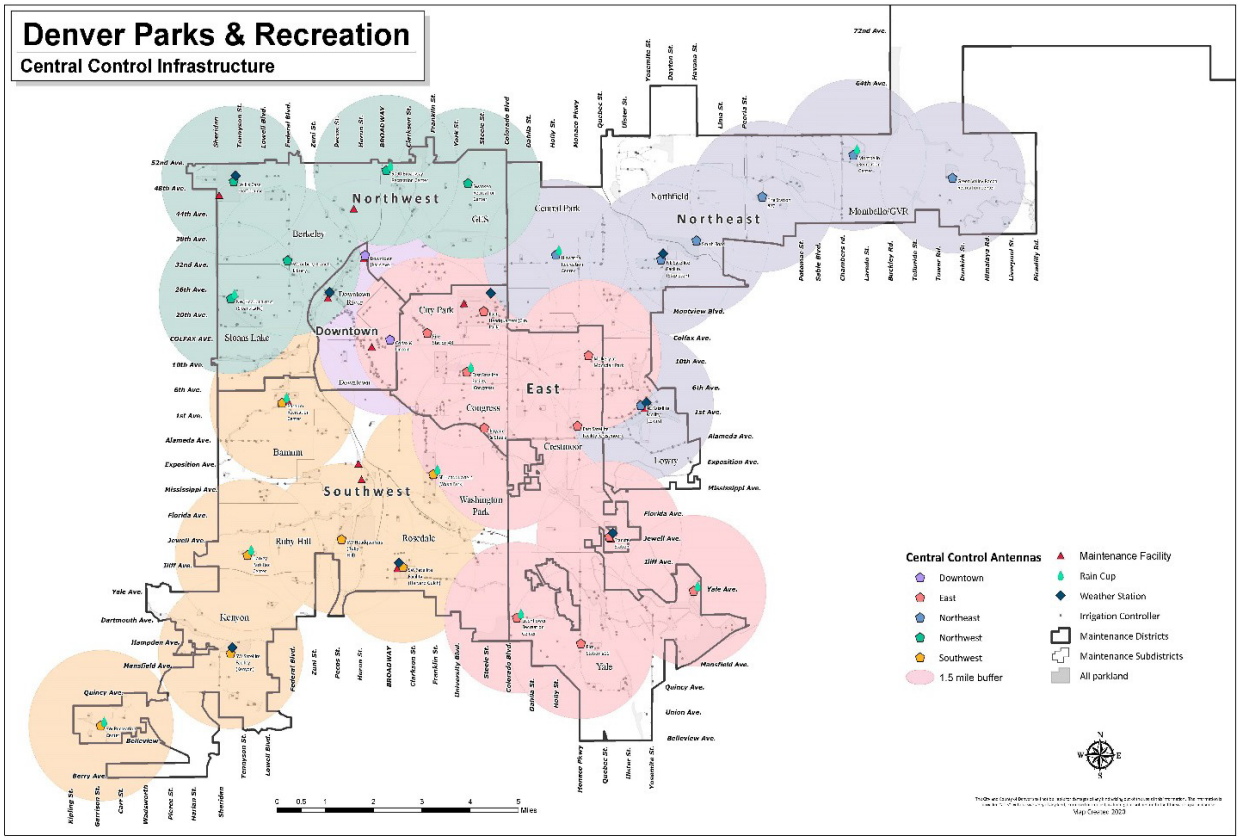
Park/Location	Type Water	Irrigated Acres	K-Gallons Use	Gals/SF Use
Montbello Central	Direct Reuse	33.8	30730	30.5
Verbena	Direct Reuse	7.2	4196	21.3
E 6th Ave Syracuse-Trenton	Direct Reuse	2.68	2212	30.4
Jackie Robinson	Direct Reuse	17.1	12066	25.9
Washington Park[1]	City Ditch	105.4	58636.8	20.5
City Park[2]	City Ditch	181.7	117224	23.8
Cheesman Park[3]	Direct Reuse	77.5	49368	23.5
Barnum	Potable	27.8	13113	17.4
Green Valley Ranch East	Potable	9	4570	24.9
Inspiration Point	Potable	12.7	9087	13.3
1. Received additional potable irrigation: 56,345 gallons - 746 conifers watered -selected evergreens throughout park but primarily evergreen hill; each tree watered approximately 3x's (M Swanson)				
2. City Park did not receive potable contract watering in 2020. There is a contract in place to augment irrigation with potable water for 2021.				
3. Received additional potable irrigation: 75,090 gallons - 720 conifers watered, evergreens on east side of park; each tree water approximately 3x's (M Swanson)				

2020 IRRIGATION WATER REQUIREMENT (IWR)

DPR is now using five weather stations to monitor weather data across the City. Weather station data is used to determine the Irrigation Water Requirement (IRW). This information is provided on a monthly basis as a guideline for maintenance staff to irrigate to plant health needs.

IWR through Apr 15-Oct 15, 2020 in inches:					
Location:	Rosedale/Kenyon	Transfer Station	Centennial Garden	Stapleton	DW Hist YTD
ET	35.0355	38.33	42.903	43.075	34.19
ET Water Req (Kc 0.88)	30.83	33.73	37.75	37.91	30.09
Precipitation	4.45	4.21	5.52	5.09	10.91
Effective Rain (76%)	3.38	3.20	4.20	3.87	8.29
Adjusted ET Req	27.45	30.53	33.56	34.04	21.80
System Efficiency Adj	70%	70%	70%	70%	70%
Adjusted Irr Req	**39.22**	**43.62**	**47.94**	**48.63**	**31.14**
GPSF	24.45	27.19	29.89	30.32	19.41

DPR Weather Stations and Central Control Antenna Systems helps to dial in plant water needs:



DPR is conducting trials of new products which may be useful in management of reuse sites.

- Parks is evaluating magnetic water treatment (Maximum H2O) that is purported to help with water quality on reuse sites. Magnetic hydraulic water treatment is chemical free and has apparently helped farmers increase production.
- Location of magnet water treatment installations:
  - Veterans: installed June 2019
  - Wash Park: Installed July 2019
  - Denison: Installed July 2019
  - Greenhouse: Installed January 2020
  - Lowry Soccer: Installed June 2020
  - Greenway/Fred Thomas: Installed April 2021
  - Dunham: Installed June 2021

DPR is also evaluating the use of a drone and software to evaluate plant health of Park's irrigated areas. This information is also helpful to evaluate reuse areas compared to potable sites, and can help identify changes in plant health over time. The two images below are a field health report for Veterans Park, which was recently converted to reuse. Various software is currently being evaluated; the image below is one.

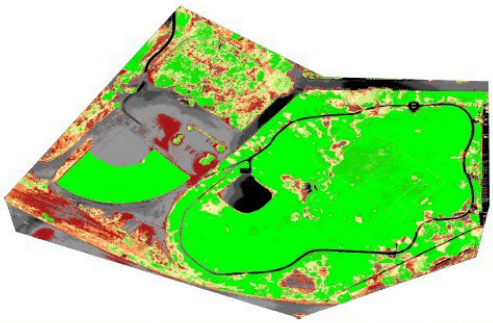
Agribotix

Contact us:
3309 Airport Rd. | Boulder, CO 80301
(720) 295 3625 | @Agribotix

Field Health Report - Statistics

This report, produced by ParkView, measures the results on a Relative NDVI (rNDVI) scale. This means that the color coding, and measurement, is relative to the field itself. The areas in this field that are most reflective in the NIR are highest and the areas that are least reflective in the NIR score lowest. Caution should be exercised when comparing results between locations and across time periods. For more details on this index please see agribotix.com/rndvi.

Percent	Color	rNDVI (min)	rNDVI (max)	Area (ac.)
4%		-0.235	-0.177	0.89
3%		-0.173	-0.114	0.56
6%		-0.111	-0.052	1.29
9%		-0.048	0.010	2.07
4%		0.014	0.072	0.96
3%		0.076	0.134	0.74
4%		0.138	0.197	0.80
4%		0.201	0.259	0.80
4%		0.263	0.321	0.78
3%		0.325	0.383	0.76
4%		0.387	0.446	0.81
4%		0.449	0.508	0.92
5%		0.512	0.570	1.18
8%		0.574	0.632	1.71
17%		0.636	0.694	3.77
18%		0.698	0.757	3.96



6.0 Reuse Study Evaluation and Committee Recommendation for Reuse Sites

The following recommendations for mitigation and remediation of reuse sites are guidelines for new parks, as well as existing parks that are converted to reuse. Some of these methods are ongoing. Implementation of these strategies are limited by the City of Denver's budgetary realities.

1. The right plant in the right location is a determinant of plant survival. Forestry should continue to compile and annually update a tree-list of species that are more adaptable to salts and less sensitive to chloride.[1] Forestry should be active in decisions regarding continued replacement of existing trees as they fail in reuse locations. Parks Planning should continue to use these species in planning parks that are likely to receive reuse irrigation. Salt-tolerant conifer species that have already been widely used in Denver parks, such as pinyon pine and juniper species, should continue to be used, and new planting of blue spruce, white fir, white pine, Douglas-fir, or Scots pine should be avoided (these species appear to suffer the most from reuse irrigation). Continue to monitor health of Austrian pine trees in recycled water parks and if stable, consider adding this species to the conifer planting list for recycled water parks. Continue to investigate potential new conifer species by making and monitoring limited plantings in recycled water parks of the following: cedar species, Norway spruce, white spruce, Caucasian fir, and a variety of pines not previously often used in the Denver area. Consideration should be given to continued planting and study of novel conifer species[2] that appear tolerant of high salt loads in irrigation water and foliage, such as in areas where remediation measures are impractical or to diversify the species inventory in areas that are planned for remediation. Continue to monitor these plantings, at least visually and log observations.
2. Proactively underplant new appropriate salt-resistant species underneath declining conifers rather than waiting for their demise/removal.
3. Apply supplemental potable water irrigation of conifers via potable flush through irrigation systems, or water truck applied by flood irrigation to tree rooting areas including at least 50% beyond the drip line. Supplemental potable water irrigation may alternatively be supplied to concentrated groves of conifers by means of mobile wide-area agricultural-quality sprinklers. Soil needle application is not desired because it does not affect a sufficient portion of the rooting areas. The amount of potable water to be applied must be enough, when combined with the amount of recycled water being furnished by a park's normal irrigation system, to effectively dilute overall sodium and chloride loads as much as possible. [3] Develop standards for potable water remediation quantities for various size and classes of conifers. Include these standards in agreements with outside contractors charged with potable water remediation and develop oversight mechanisms for verifying compliance.
4. During the planning process of park conversion to reuse, or planning new reuse parks, separate conifer groves into zones irrigated with potable water, as possible per CDPHE Regulation 84 requirements. Taps, underground delivery, and water application must be separated by 10 ft per Regulation 84. Since this requires separate taps and isolated systems, this is not economically feasible for widespread application.
5. Continue to monitor sodium and chloride in the foliage of selected conifers in areas to be given short-term remediation so the efficacy of remediation measures can be determined.
6. Continue to monitor health of lindens in recycled water parks to detect signs of premature decline from salts exposure as opposed to typical abiotic end-of-season leaf scorch; remain alert for similar signs of premature mortality of other deciduous tree species. Continue tissue testing of select Linden trees in reuse areas. With three years of linden foliage tests now in hand, there is preliminary indication that while lindens irrigated with recycled water do show significantly elevated levels of sodium and chloride in their foliage compared to "control" trees in potable irrigation areas, these levels may be tolerable over the long term if they stabilize and if the trees continue to appear healthy.

7. Continue a limited soil testing program in recycle and potable locations, on a reduced schedule (every three to five years). The indications from 2016 – 2020 testing show that the soil testing does not always coincide with tree health. All locations to be converted or planned with reuse water should be soil-tested to obtain a baseline.
8. Continue a limited tree tissue-testing program of trees followed during the reuse study. Testing tissue provides the opportunity to follow effects of individual species and ages of trees. The tree locations should be those with the greatest amount of existing data and number of trees. Both direct connect reuse, potable and City Ditch locations should be included.
9. Avoid conversion of historic parkways to recycled water irrigation unless it's feasible to do so only for such portions of them without healthy "legacy" conifers. This would apply to Monaco, 17th Avenue, 6th Avenue and Marion St. Parkways.
10. Continue to adjust sprinkler systems in recycled water parks to avoid as far as possible spraying reuse water on conifer foliage. Continue to apply mulch to conifer stands in these areas. Continue to study the efficacy of this method of remediation.
11. Continue to study the remediation efficacy of application of sodium blockers, granular gypsum and magnetic hydraulic water treatment at the tap. These methods appear to provide some relief for turf but the efficacy of remediation for the effects of reuse on sensitive tree species remain unknown.
12. Continue cost-effective methods of observing and monitoring changes in trees such as drone observation, comparison pictures of trees over time with existing data, and observational studies of trees by size and age versus species. Continue record-keeping of tree removal due to decline and death.

Notes:

1. Salt-sensitive conifer species include Scots pine (*Pinus sylvestris*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), eastern white pine (*Pinus strobus*), Colorado blue spruce (*Picea pungens*) and ponderosa pine (*Pinus ponderosa*). There was earlier some thought that Austrian pine (*Pinus nigra*) was intermediate in terms of salt-sensitivity, but recent results from City Park indicate it is better included in the sensitive category.

2. Bosnian pine (*Pinus heldreichii*), Arizona cypress (*Cupressus arizonica*) and Serbian spruce (*Picea omorika*); there may be other conifer species worth testing for salt tolerance, such as bald cypress (*Taxodium distichum*), Sequoia (*Sequoiadendron giganteum*), etc.

3. According to the Salinity Management Guide of the National Water Reuse Foundation (70 ppm), Arborist Steve Day's report for Denver Water (75 ppm) and other researchers, 70ppm is the level of sodium in irrigation water that most conifers can withstand before suffering damage. Comparable data for chloride is less available but this ion will automatically be reduced to not far above the 75 ppm level by the dilution required to address the sodium problem.

7.0 Continued Studies of Reuse Water Effects on Conifer Trees and Soils

Denver Parks and Recreation and Denver Water will conduct ongoing monitoring of trees and soil at potable and reuse sites selected from the original study, starting 2022. The study will continue as DPR funding is available, and for the duration of Denver Water's Lead Reduction Program.

Scope:

Twenty-five (25) trees will have tissue samples taken from potable sites, and thirty-two (32) trees will have tissue samples taken from reuse sites. Lab analysis will be made to determine chloride and sodium. Results will be compared to the results of the *Recycled Water Management Advisory Committee Report* for the purpose of monitoring ongoing effects of reuse water on conifers and soils. Note that the number of trees will depend on the survival of the specific trees chosen for the study.

Schedule:

Potable control sites: Every other year, starting Fall 2023

- Barnum: 9 trees
- Green Valley Ranch East: 6 trees
- Inspiration Point: 10 trees

Reuse and City Ditch sites: Every other year, starting Fall 2024

- Cheesman: 19 trees (direct connect site selected due to the large amount of data collected on this Park)
- City Park: 13 trees (City Ditch site selected due to large number of trees and end location of City Ditch)

Soil testing will be conducted at three-to-five-year intervals to determine pH, chloride and sodium.

Water testing of potable and reuse water will be conducted by Denver Water every two years, as per the potable tree-testing schedule. The City Ditch water will be sampled every two years, as per the schedule of reuse tree tissue sampling.

Denver Parks acknowledges and greatly appreciates collaboration with the Advisory Committee, the Community, and Denver Water as we study the effects of reuse water in the Park System and explore methods for mitigation and maintenance.