Occurrence of *Cryptosporidium, Giardia*, and Metals in Florida Stormwater Ponds and Assessment as Alternative Water Supplies for Irrigation.

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Abstract

Reclaimed water treated to achieve public access irrigation water quality is currently used and regulated as a water resource management technique to supplement potable water. It is believed that stormwater from detention ponds can also be used for irrigation at public access areas such as golf courses, parks, schools, and residences in the State of Florida. To date little work has been done to quantify the presence of protozoan pathogens, metals, indicator organisms, nutrients, and physicochemical water quality parameters in stormwater ponds used for irrigation in Florida. We evaluated 22 stormwater ponds throughout Florida with different attendant land uses. Three of these ponds were used for irrigation. The others were candidates for irrigation. Results were compared to existing data from currently operating reclamation facilities in Florida. Total suspended solids and turbidity levels, which are regulated for irrigation quality water and implicated in harboring *Cryptosporidium* and *Giardia* (oo) /cysts, are also presented. The averages for both of these parameters exceed regulatory standards for irrigation quality water. The results of this study show that the presence of *Cryptosporidium* in stormwater ponds in Florida exceeds average guidelines as suggested by York et al. in one of twenty-nine samples (3.45%). Levels of *Giardia* exceed the average and maximum guidelines in 3 out of 28 samples (10.7% of samples). Other comparisons show that Florida stormwater pond water compared favorably to reclaimed water currently being used for irrigation where there is public access. Certain metals are also examined and compared to EPA drinking water standards. For each primary and secondary regulated metal, the averages found in Florida stormwater ponds does not exceed drinking water standards, therefore, the presence of metals is not problematic in Florida stormwater ponds. This investigation is a preliminary measure towards understanding biofiltration of these parameters if deemed necessary to meet current public access irrigation water quality standards, thereby accomplishing, public health protection, pollutant load mitigation, and potable water conservation goals.

Introduction

Stormwater is an obvious choice for augmenting other water sources for landscape and turf irrigation as a stormwater management technique in land development, and a solution to increasing water demands. In 1995, the USGS reported 281 MGD of freshwater used for recreation, of this, 187 MGD was used for golf course irrigation, an additional 110 MGD of reclaimed water was also used for golf course irrigation of the existing 419 golf courses at that time in the State of Florida (FDEP). These numbers have grown substantially while potable water supplies are reaching the maximum safe yield in some areas of Florida. Stormwater is being considered as an alternative source of irrigation water, thus reducing the demand on existing potable water supplies that are commonly used for irrigation. The supply of stormwater runoff is extensive in Florida, and the reuse of stormwater can closely replicate the hydrologic cycle that is often disrupted through land development. However, as with reclaimed wastewater, there are public health issues regarding the presence of waterborne pathogens and chemicals of concern in runoff (Toze, 2006). Within this work are outlined the data gathered on the protozoan pathogens *Cryptosporidium parvum* and *Giardia lamblia*. Laboratory analysis was conducted on 29 samples with duplicates from 22 ponds across the State, including samples from three ponds currently used for irrigation. A brief background is given regarding the microbial pathogens of concern, previous studies conducted on their presence, and associated risk assessment, and state guidelines for their tolerable occurrence in reclaimed water used for irrigation. The results of this study are presented and also compared to Florida's guidelines for pathogen levels in reclaimed water used for irrigation. The ponds in this study were selected for their potential as landscape and turf irrigation sources and distinguished by their adjacent land use. Land use may be considered a criterion for risk of human exposure evaluation as well as an indication of potential pollutants, though this is not examined here in detail. See Table 1 for the waters analyzed and their attendant land use.

Table 1: Pond Name and Land Use (At least one sample at each location)

Pond Name/ID	**Land Use**
Lake Condel	**Residential**
Terrier Pond	**Residential**
Lake Patrik	**Industrial**
417-1 Greeneway	**Major expressway**
417-2 Greeneway	**Major expressway**
417-3 Greeneway	**Major expressway**
417-4 Greeneway	**Major expressway**
417-5 Greeneway	**Major expressway**
University Blvd. and Hall Rd.	**Heavily traveled urban roadway**
Horatio 1	**Heavily traveled urban roadway**
Horatio 2	**Heavily traveled urban roadway**
South Irrigation	**University of Central Florida Campus**
Pegasus Pond	**University of Central Florida Campus**
Channel A	**Mixed Residential and Rural**
Celery Fields	**Mixed Residential and Rural**
French Town Pond	**Mixed Commercial and Light Industrial**
Regional SW Facility	**Mixed Urban and FSU Campus**
Copper Leaf	**Residential**
Bent Pine GC	**Golf Course**
Stadium Pond UCF	**University of Central Florida Campus**
Miramar	**Commercial**

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Background

Cryptosporidium parvum and *Giardia* lamblia are waterborne protozoan pathogens. Both are ubiquitous in the environment, and are transmitted by the fecal-oral route. Forty mammals including humans are host to these pathogens that can cross species barriers (Finch 2001, York et al, 1999). Protozoa, in general may survive 15 days to one month in soil, 2-10 days in vegetation and 15 days to greater than 2 months in water (Crook, 2001) They are chlorine resistant but may be removed by filtration due to their size (Jamieson et al, 2002). Both Crypto and *Giardia* have been implicated in several waterborne disease outbreaks associated with drinking and recreational water in Florida, nationwide and globally. Irrigation has not directly been implicated in outbreaks caused by these or other pathogens. However, according to the Center for Disease Control, three outbreaks were associated with direct consumption of water from irrigation systems, between 1999 and 2000. Irrigation systems were implicated as contaminating factors in three other irrigation-related outbreaks.

Cryptosporidium Parvum

Cryptosporidium causes the disease cryptosporidiosis, the telltale symptoms of which are severe diarrhea, abdominal pain, nausea, anorexia, dehydration, and weight loss. The disease can be fatal for immuno-compromised individuals. The median infectious dose (ID50) identified in a 1995 study for humans is 132 (viable) oocysts (York et al, 2003) Though a more conservative infectious dose is 1-10 viable cysts (Crook, 2001)

Giardia lamblia

Giardia causes mild to severe diarrhea, nausea, vomiting, fatigue, and cramps. Symptoms may be manifest for a period of days to months (AWWA, 5th ed. and Mackenzie et al, 1994. Based on human feeding studies, performed by Rendtorff (1979) the infectious dose is 10 cysts or fewer. The environmentally resistant and infectious form of this pathogen is the cyst. It is noted that *Giardia* can be inactivated by chlorine and UV.

Cryptosporidium and *Giardia Measurements*

EPA method 1623, a standardized immunofluorescence assay was used for the detection of *Cryptosporidium* and *Giardia*. This is currently the most accurate EPA accepted method for simultaneous detection of *Cryptosporidium* oocysts and *Giardia* cysts. The method was developed through exhaustive research for detection of *Cryptosporidium* and *Giardia* in raw surface waters used as drinking water sources. It is important to note that method 1623 serves only as a method of identifying and enumerating "potentially" viable (oo) cysts. The method has a minimum detection limit of 10 (oo) cysts/100L and greater, this is higher than the EPA's regulated limit of 1 (oo) cyst/100L, however for non-potable consumption this MDL is suitable. The analyses were conducted by Orange County Utilities Central Laboratory.

Presence Does Not Guarantee Viability

It is important to note that the occurrence of the infectious forms of *Cryptosporidium* and *Giardia* does to guarantee their viability. In order for viability to be determined, certain animal infectivity or tissue culture studies must be conducted. These tests are not required by Florida regulation and were not conducted as part of this study.

Past work Performed in Florida

Both of these pathogens have proven resistant to disinfection. Two Florida studies document that reclaimed water treated to meet public access irrigation standards, with low TSS and turbidity and operating in compliance with regard to these parameters have failed to eliminate these pathogens to levels beneath the suggested state guidelines for irrigation water quality (Slifko 2007 and York, D.W. et al 1999). These studies and others indicate that to better understand the occurrence and risk of infection of the pathogens in public access irrigation water, further monitoring is warranted.

Occurrence of *Cryptosporidium* and *Giardia* in Florida's Stormwater Ponds

The method of detection has some limitations. When using lake waters, the filters may clog easily but care was exercised to get a representative sample volume. It is noted however, that most samples did not represent the minimum reporting limit required for reporting pathogen levels to the FDEP.

Cryptosporidium

One measurement of *Cryptosporidium* (3.5%) or 1 of 29 samples exceeded minimum detection limits. This measurement was 12.9 oocysts/100 L

Giardia

There were 3 measurements of 28 samples tested for *Giardia* above the detection limit, or (10.7%) of all samples. The measurements were 70, 80 and 76.9 cysts/100 L respectively.

Comparison between Cryptosporidium and Giardia, TSS, Turbidity and Nutrients?

In at least one previous study a strong correlation was observed between the detection of *Cryptosporidium* and *Giardia* and higher than average levels of turbidity and total suspended solids. In Florida the regulatory standard for TSS is 5 mg/l per single sample, and in lieu of TSS data, the standard for turbidity is 2 NTU. The total nitrogen standard for injecting reclaimed water for groundwater recharge and indirect potable use is < 10mg/L. In this study, an observation of higher than average levels of turbidity, total suspended solids, nitrite, and orthophosphates were observed in a sample manifesting measured levels of *Cryptosporidium*. Table 2 below shows the parameters measured in that sample as compared to average levels. Any apparent correlation warrants further investigation. The one measured value of *Cryptosporidium* occurred at the Highway 417-4 pond. Pond 417-4 is adjacent to a heavily traveled urban highway in Central Florida.

Table 2- Comparison between levels of *Cryptosporidium* and other physicochemical parameters measured.

Date	Crypto Oocysts/100L	TSS mg/L	Turbidity NTU	NO3/NO2 mg/L as N	NO2 mg/L as N	NH_3 mg/L as N	PO_4-P mg/L
6/20/2006	12.9	23	34	0.022	0.022	0.02	0.102
Average	**7.78**	**13.46**	**10.55**	**0.06**	**0.007**	**0.06**	**0.038**

In the case of *Giardia*, the measurement values were higher than those of *Cryptosporidium*, as was the exceedence of minimum detection limits (MDLs), the measurements were observed in 10.7% of samples as opposed to 3.45% of samples for *Cryptosporidium*. While higher than average values of turbidity were found in all three exceedence cases, higher than average levels of TSS were observed in two of the three cases. In two of the three exceedence measurements for *Giardia*, phosphate levels were elevated above average (Table 3). The measurements of *Giardia* exceeding MDL were found at 417-2, RSF- Tallahassee, both of which are urban roadway ponds and Lake Condel, a residential lake in an older Florida community where septic systems are common, Two of the three exceedence measurements were found in the warmer summer months in Central Florida and the third in December 2006 Tallahassee , Fl., so while temperature might play a role in pathogen proliferation further investigation is warranted to determine the correlation, if any, between location of a stormwater pond, season, or land use, and the elevated risk of protozoan pathogen presence.

Table 3- Comparison between levels of *Giardia* and other physicochemical properties

Date	***Giardia***	**TSS**	**Turbidity**	**NO_3**	**NO_3/ NO_2**	**NO_2**	**NH_3**	**PO_4**
	cysts/ 100L	**mg/L**	**NTU**	**mg/L as N**	**mg/L as N**	**mg/L as N**	**mg/L**	**mg/L as P**
07/11/06	80	13	23	<0.004	NM[a]	0.019	<0.02	0.106
07/20/06	70	31	29	<0.004	NM[a]	0.017	<0.02	0.056
12/12/06	76.9	20	29	0.02	0.02	0.002	<0.02	0.025
Average	13.5	13.5	10.6	0.03	0.06	0.007	0.06	0.038

Florida's Standards, Guidelines, and Norms- how the data from this study compare to Florida Requirements.

Public health standards for irrigation using alternative reclaimed water supplies were investigated to compare with water from stormwater ponds in Florida. Although, Florida does not have numeric pathogen standards (York et al, 2003), the following Table 4 presents guidelines based on risk assessment for infectivity conducted by York and Walker-Coleman. This assessment was based on the assumption that (oo)cysts were viable. Also, it is noted that these 2003 reported data were measured using methods that produced higher minimum detection limits.

Cryptosporidium parvum

Of the twenty-nine samples investigated for the occurrence of *Cryptosporidium*, there was only one measure (3.45% of all samples) above the MDL. This measure was 12.9 oocysts/100L that exceeds the average Florida State guideline for a single sample, but is below the state maximum guideline of 22 viable cysts/100L (Table 4). The averages shown in Table 4 were calculated based on ½ of the MDL when the sample values were less than the MDL. The maximum measure is a threshold, the exceedence of which is

[a] NM- not measured

cause for remediation at reclamation facilities. The guidelines for infectivity, however, are based upon "viable" cysts. In the case of the "average" value, this represents a risk of infectivity of 10^{-4} should 1 mL of reclaimed irrigation water be consumed on each day of one year. The maximum guideline represents a worst-case scenario in which 100 mL of reclaimed irrigation water be ingested, again with a risk of infection of 10^{-4}.

Table 4- Suggested State of Florida guidelines for pathogen monitoring in irrigation waters compared to stormwater ponds throughout Florida.

Organism	Units	Suggested Guidelines		Storm water ponds	
		Average	Maximum	Average	Maximum
Giardia	Viable cysts/100L	1.4	5	13.5	80
Cryptosporidium	Viable oocysts/100L	5.8	22	6.75	12.9

Note: viability was presumptive and not assessed.

Giardia lamblia

Three of the twenty-eight samples (10.7%) manifested *Giardia* at levels that surpass the Florida state guideline for maximum levels of *Giardia* (Table 4). The average occurrence of *Giardia* also exceeds the Florida state guideline. However, in Table 5 when compared with results from a 1992 study in St. Petersburg Florida of reclaimed water, and to the overall results of investigation of reclamation facilities by Walker-Coleman, the percentage of stormwater pathogen detections in Florida ponds are similar.

Table 5- Percent detection comparison of *Cryptosporidium* and *Giardia* in Reclamation Facilities in Florida, and Florida Stormwater Ponds

	Reclaimed Wastewater		Stormwater Ponds	
Statistic	*Giardia*	*Crypto*	*Giardia*	*Crypto*
Number of observations	69	68	28	29
% having detectable concentrations	58%	22%	10.7%	3.45%
Maximum (#/100 L)	3,096	282	80	12.9

Table 6 presents a comparison of average and maximum measures in the St. Petersburg study, as compared to the Florida stormwater ponds.

Table 6- Quantitative comparison of St. Petersburg's reclaimed water with Florida stormwater ponds

Organism	St. Petersburg's Reclaimed Water		Florida Stormwater Ponds	
	Average (oo)cysts/100L	Maximum (oo)cysts/100L	Average (oo)cysts/100L	Maximum (oo)cysts/100L
Giardia [a]	0.49	3.3	13.8	80
Cryptosporidium[b]	0.75	5.35	7.8	12.9

(a) viability of cysts was presumptive and not assessed
(b) viability of oocysts was presumptive and not assessed

Fecal Coliforms

Fecal Coliforms are specific to warm-blooded animal waste; they are not all pathogenic but act as indicator organisms for fecal contamination. This study and others deem fecal coliforms found in surface waters unsatisfactory indicators of protozoan pathogen presence. This might be a result of fecal coliforms in stormwater arising from various sources including wildlife, sewage and soil, while in WWTPs the source of fecal coliforms is substantially human, leading to a higher probability of viable pathogens. The use of the state regulation for irrigation quality water is therefore more suitable for reclaimed water when the source of the indicator is considered (Crook, 2001). The fecal coliform regulation for reclaimed water in Florida is 25/100ml (single sample) or 75% of daily samples below MDL (30-day period). This regulation is somewhat subjective and varies state to state (Crook, 2001). The average found for fecal coliform in this study is 548 CFU/100mL (+/- 873 95% CI), the range was 11,999 CFU/100 mL. The geometric mean was found to be 40 CFU/100mL. Twelve of 28 samples or 43% of samples met or exceeded the 25 CFU/100mL standard. No correlation was observed between higher than average FC levels and any other microbiologicals and/or physicochemical parameters measured simultaneously.

TSS and Turbidity

High levels of suspended solids are undesirable because they may harbor microorganisms, heavy metals and organic contaminants. Excessive solids may also cause plugging of irrigation equipment (USEPA, 2004) Average levels of TSS and turbidity can be seen in Table 2. The regulatory irrigation water quality standard for TSS is 5 mg/L and turbidity in lieu of TSS data is 2 NTU. Stormwater ponds in Florida, on average, do not meet the state regulation with regard to TSS and turbidity. However 32% of ponds had TSS levels beneath 5 mg/L and 6 of 28 samples or 21% of stormwater ponds met Florida's turbidity regulation.

BOD

The list of naturally occurring and anthropogenic organic contaminants in surface waters include but are not limited to: humic substances, fecal matter, liquid detergents, oils, grease, solvents, pesticides, and polynuclear aromatic hydrocarbons (PAHs) (Kolpin et al 2002). BOD is the measure of organics present in a water that act as substrate for microorganisms that break down the BOD and utilize dissolved oxygen in the process. The following is a non-exhaustive list of contra-indications caused by the presence of excessive organic content in waters: Excessive BOD in surface water severely depletes dissolved oxygen causing fish kills and an overall deterioration in the aquatic ecosystem. Organics in water may also cause acute or chronic disease when ingested, and BOD may also cause clogging of irrigation systems. The US EPA recommends BOD less than 10 mg/l for agricultural irrigation (York et al) and 20 mg/l unrestricted urban use. In this study the BOD arithmetic mean was 3.6 mg/L.

Metals

The following metal levels were investigated in this study: Copper, Lead, Zinc, Chromium, Cadmium, Sodium, Magnesium, Mercury, Selenium, and Arsenic. Of concern in agricultural irrigation are accumulated residues on crops that are not processed, potential bioavailability to plants, root uptake of metals, and foliar uptake in broad leaf plants such as spinach and lettuce (Toze, 2006). A five-year study conducted in Monterey County, California concluded that heavy metals present in reclaimed wastewater did not significantly accumulate in crops or soils. A three-year study conducted in Melbourne, Australia investigating the use of reclaimed water for crop irrigation concluded similarly that there was no health risk associated with heavy metal accumulation from irrigation waters containing normal levels of metals (York et al 2003). The metals measured in stormwater ponds in Florida were compared to USEPA drinking water standards and results presented in Table 8.

Table 8- Results and Comparisons to USEPA Drinking Water Standards

Metal	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	Cr (µg/L)	Cd (µg/L)	Na (mg/L)	Mg (µg/L)	Hg (µg/L)	Se (µg/L)	As (µg/L)
Mean	5.1	2.1	37.9	6.2	1.1	15.5	5.5	0.1	1.7	2.2
Standard Deviation	1.8	1.8	32.3	3.1	0.4	20.1	9.0	0.1	1.2	1.2
Maximum	8.0	7.0	113.0	15.0	3.0	82.4	36.9	0.4	8.0	63.9
Count	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Confidence Level (95%)	0.7	0.7	12.3	1.2	0.1	7.6	3.4	0.0	0.5	0.5
USEPA Primary Drinking Water Standard	1300.0	15.0	N/A	100.0	5.0	N/A	N/A	2.0	50.0	10.0
USEPA Secondary Drinking Water Standard	N/A	N/A	5000	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Sodium and Magnesium

Excessive salinity due to the presence of positively charged ions may damage crops through reduction in pore space caused by attraction of negatively charged clay particles resulting in swelling dispersion, reduced drainage, and increased water retention at the surface creating a drought situation for crops. The extent of this effect is dependent upon the soil composition. In less clayey soils, hydraulic conductivity is increased, as is the potential for sodium transport to unconfined aquifers (Toze, 2006). The sodium absorption ratio (SAR) is a measure of the proportion of sodium to magnesium and calcium in irrigation waters. If the proper amounts of calcium and magnesium are present, the soil will be granular in texture, easily worked, and well drained (James M. Montgomery Consulting Engineers Inc., 1985). Irrigation water quality standards suggest an acceptable range for SAR of 6-9, with a normal standard of 6. Water conductivity is another measure of the ionic concentration and hence the suitability of source water for irrigation. Typical irrigation quality water should exhibit a range of 500-2000 μS/cm with an average of 1000 μS/cm.

Summary and Conclusions

Cryptosporidium was detected in 3.45% of 29 samples, or one measurement above MDL. *Giardia* was detected in 3 of 28 samples or 10.7% of samples in this study contained *Giardia* above MDL. The one measurement of *Cryptosporidium* above the minimum detection limit (MDL) was 12.9 oocysts and the *Giardia* measurements above detection limits were 70, 80 and 76.9 cysts/ 100L. Higher than average TSS and turbidity levels were observed with the presence of *Cryptosporidium* and *Giardia* above MDL. The average for TSS was 13.46 mg/L and the average for turbidity was 10.55 NTU. The sample that contained 12.9 oocysts also contained 23 mg/L TSS and 34 NTU. In the case of the three *Giardia* detections TSS was 31, 13 and 20 mg/L respectively and turbidity, 23, 29 and 29 NTU.

Compared with St. Petersburg's reclaimed water used for irrigation, the percentage of measures above the minimum detection level for Florida stormwater ponds compares favorably. In the case of *Cryptosporidium*, there were 3.45% measurements as compared to the St. Petersburg study that found 17% positive detections and in the case of *Giardia* there were only 10.7% positive detections in Florida stormwater as compared to 25% in St. Petersburg reclaimed waters. Data compiled by Walker-Coleman (2002) on operational reclamation facilities indicated that *Giardia* cysts and *Cryptosporidium* oocysts were detected in 58%, and in 22% respectively of sixty-nine and sixty eight observations. The maximum measurements observed in the Florida reclamation facility study for both *Cryptosporidium* and *Giardia* also exceed Florida stormwater pond levels. This comparison at the reclamation facility is based on a 2003 methods of measurement. Thus the updated measurement methods for reclamation water should be used to gain a more accurate comparison to the results of this study.

Florida's stormwater compared favorably to results from a study of St. Petersburg's reclaimed water already being used for irrigation, and other reclamation facilities throughout Florida. Quantitative measures were higher than St. Petersburg's results for both pathogens but when compared to maximum measurements at reclamation facilities throughout the State, stormwater ponds manifests lower maximum levels of pathogens. These results, while positive in terms of water quality from reclaimed sources used currently warrant the investigation of biofiltration for the removal of *Cryptosporidium. parvum* and *Giardia lamblia* from stormwater ponds to achieve suggested guidelines.

Metal levels were low in this study. Each average measurement shown in Table 7 is orders of magnitude below primary or secondary drinking water standards where applicable. There are no water quality concentration standards set for sodium and magnesium, therefore further analysis may be warranted for electroconductivity or the sodium absorption ratio.

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