CHAPTER 6: EVALUATION OF HARMFUL ALGAL BLOOM DATA IN FARMINGTON BAY, GREAT SALT LAKE

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

2016 Final Integrated Report

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CONTENTS

ABBREVIATIONS

<	less than
>	greater then
cell(s)/mL	cell(s) per mililiter
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
HAB(s)	harmful algal bloom(s)
IR	Integrated report
mL	milliliter
UAC	Utah Administrative Code
UDWQ	Utah Division of Water Quality
WHO	World Health Organization
µg/l	microgram per liter

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INTRODUCTION

The Utah Division of Water Quality (UDWQ) performed an evaluation of data related to harmful algal blooms that could pose a health risk to recreational users in Farmington Bay. Extensive datasets were submitted to UDWQ by two stakeholders, the Central Davis Sewer District and Utah State University, and were aggregated for the purpose of this evaluation. The data were compared to indicators of human health risks for harmful algal blooms (HABs) to provide context to the public about potential risks associated with recreating in Farmington Bay. HABs can adversely affect human health during recreational activities in and on the water. UDWQ is obligated to analyze these data and report findings to the public. In this chapter, UDWQ discusses the recreational uses of Farmington Bay, HAB indicators, and the results of the data evaluation.

When developing the 2016 IR assessment methods, UDWQ did not anticipate having new data that could be used to perform a beneficial use assessment in Farmington Bay or Great Salt Lake and therefore deferred any 303(d) listing decisions until further methods were developed and data collected. The HAB assessment methods adopted in 2015, and applied to freshwater lakes in the 2016 Integrated Report, combined with the recently available data for HABs in Farmington Bay represents a significant step forward in UDWQ's ability to assess recreational uses in Farmington Bay. UDWQ intends to assess recreational use support in Farmington Bay using Utah's Narrative Standard in the 2018 Integrated Report. For the 2016 IR, Farmington Bay remains in Category 3C - assessment methods in development. This chapter constitutes a status update on the monitoring, management, and progress UDWQ has made towards developing an assessment methods for Great Salt Lake.

Recreational Uses in Farmington Bay

Like other portions of Great Salt Lake, Farmington Bay has a single beneficial use classification that includes protections for both recreational and aquatic wildlife beneficial uses. These uses are, "Infrequent primary and secondary contact recreation, waterfowl, shore birds and other water-oriented wildlife including their necessary food chain," (UAC R317-2-6).

Recreational uses in Farmington Bay are known to include activities such as air boating, kayaking, canoeing, hunting, and bird watching. Air boating is a popular recreational use of Farmington Bay. R. Jefre Hicks, secretary and treasurer of the Utah Airboat Association, estimates that as many as 50 air boat trips occur per weekend from mid-September through December and 30 airboat trips per weekend in January and February (personal communication between Jodi Gardberg and R. Jefre Hicks, March 31, 2016). During the weekdays, there are usually 3 to 8 airboats per day on Farmington Bay. Some users estimate that they air boat on Farmington Bay as much as 20-50 times annually (2016 IR comment letter E). While air boating, recreationists are exposed through dermal contact with the waterbody and potential inhalation from water spray. Much of the western shoreline of Farmington Bay is formed by Antelope Island State Park, one of the most popular Great Salt Lake tourism and recreation destinations. The Antelope Island Causeway that runs along the north end of Farmington Bay, serves as the first introduction many tourists have to Great Salt Lake. One of the primary access points to the waters of Great Salt Lake, Antelope Island Marina, is located on Gilbert Bay right outside the outlet from Farmington Bay and when water levels of Great Salt Lake are higher, the marina is accessible to boaters for airboating, kayaking, paddle boarding, and canoeing.

Available data

Two external groups submitted extensive datasets and summary reports of data collected along transects of Farmington Bay spanning the summer seasons of 2012 – 2014 (Marden et al. 2015, McCulley et al. 2015, Marden et al. unpublished data). In all, these data include 31 transects distributed across the summer months with samples collected at up to nine sites per transect. For additional details on sampling location and timing, see the cited reports. Data from both groups passed the credible data check process outlined in the IR assessment methods (Chapter 2), and were aggregated into a single dataset for analyses.

Harmful Algal Bloom Indicators

UDWQ compared data to indicators of human health risks for HABs to provide context to the public about potential risks associated with recreating in Farmington Bay. The indicators used are the same as those used for the formal harmful algal bloom assessment of Utah Lake (see Chapter 5). The applicability of these indicators for Farmington Bay will be further evaluated in *Utah's Assessment Methods for the 2018 Integrated Report*.

The World Health Organization (WHO) has established three types of human health based indicators for HABs: cyanobacteria cell counts, cyanotoxin concentrations, and algae growth measured as chlorophyll *a* concentrations (WHO 2003; Table 1). Exposure routes that may result in adverse human health effects from HABs and cyanotoxins can occur through dermal contact, inhalation, or ingestion of cyanobacteria or associated cyanotoxins. Utah protects Farmington Bay for infrequent primary contact recreational beneficial uses (UAC 317-2.6) that includes activities such as wading or boating where occasional dermal contact and inhalation are the most likely exposure routes.

UDWQ evaluated the Farmington Bay datasets using three indicators: 1) number of cyanobacteria cells per milliliter (cells/mL), an indicator of a health risk from HABS; 2) cyanotoxin concentrations; and 3) algal concentrations measured as chlorophyll *a*. Additional literature supporting these thresholds as well as references of thresholds used in other states are provided in the sections that follow and in Chapter 5.

Table 1. WHO recommended thresholds of human health risk for cyanobacteria, microcystin-LR, and chlorophyll *a*.

Health Effects Threshold	Cyanobacteria (cells/mL)	Microcystin-LR (µg/L)	Chlorophyll-a (µg/L)
Low	< 20,000	<10	<10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	> 10,000,000	>2,000	>5,000

Cyanobacteria Cell Counts

The 100,000 cell/mL cyanobacteria indicator is a well-supported indicator of human health risk and adverse impacts on recreational uses in a waterbody. WHO first identified 100,000 cells/mL as a threshold representing high human health risk in 1999. WHO identifies health risks including acute poisoning, long-term illness, skin irritation, and gastrointestinal illness associated with exposure to cyanobacteria at these levels. The cell count threshold is not taxon-specific, but rather represents an expected risk of HAB exposure based on overall cyanobacteria occurrence. Review of the studies underlying the WHO recommendations as well as other research literature strengthens the association between cyanobacteria and human health issues. Prominent studies on the human health effects of recreational exposure to cyanobacteria consistently report human health issues such as gastrointestinal distress, headaches and earaches, skin or eye irritation, and temporary respiratory illness occurring at cyanobacteria cell counts at or below 100,000 cells/mL (Pilotto et al. 1997, Stewart et al. 2006, Levesque et al. 2014, Lin et al. 2016). For example, Pilotto et al. 1997 identify a significantly higher occurrence of these types of symptoms at a threshold of only 5,000 cells/mL. Levesque et al. 2014 identified increased gastrointestinal illness associated with limited contact activities such as fishing and boating at cyanobacteria cell counts exceeding 20,000 cells/mL, demonstrating that even limited contact with water containing greater than 100,000 cells/mL of cyanobacteria could result in adverse health effects for recreational users. Stewart et al. 2006 and Lin et al. 2016 also both identify similar adverse human health effects associated with recreational contact to cyanobacteria cell counts at or below 100,000 cells/mL. Importantly, the adverse health effects observed in several of these studies (Pilotto et al. 1997, Stewart et al. 2006, Lin et al. 2015) were not necessarily associated with cyanotoxin concentrations, suggesting cyanotoxin concentrations alone are not sufficient for determining health risk associated with HABs.

Cyanotoxin Concentration Indicators

For recreational waters, WHO identifies microcystin-LR concentrations greater than 20 µg/L as a human health risk. The WHO guideline for microcystin in recreational waters is based on a tolerable daily intake calculated from a microcystin exposure study (Fawell et al. 1994) and the expected incidental consumption of water of a 60 kilogram adult. However, several states and countries have set lower thresholds for human health advisories based on studies that have identified lower values for microcystin toxicity or based on expected recreational exposures for small children.

Data and reports for Farmington Bay identify extensive occurrence of HABs which are often dominated by the toxin producing cyanobacteria, *Nodularia* (Marden et al. 2015, McCulley et al. 2015), an algal species common to brackish waters such as Farmington Bay. Nodularia can produce the cyanotoxin nodularin. Although nodularin-specific benchmarks are not yet available, nodularin is similar to microcystin-LR with respect to chemical structures, modes of toxicity, experimental lethal dose values, and potential for bioaccumulation of both toxins (Karjalainen et al. 2008, Pearson et al. 2010, Rinehart et al. 1988, Sipia et al. 2006, USEPA 2015, Yoshizawa et al. 1990, Chen et al. 2013). The WHO Guidelines for Safe Recreational Water Environments place the lethal dose of 50% for mice for microcystin-LR at 60 µg/kg and for nodularin at 30-50 µg/kg (WHO 2003, Table 8.1). Both toxins have similar modes of action and can result in liver hemorrhaging, tissue damage, and liver failure (Pearson et al. 2010). Although nodularin mortality in humans is rare or undocumented, it has been documented in dogs (e.g. Edler et al. 1985, Harding et al. 1995, Nehring and Stefan 1993). Another potentially harmful cyanobacteria, *Pseudanabaena*, occurs in Farmington Bay in very high numbers (>12 million cells/mL). *Pseudanabaena* is relatively understudied, but toxin production has been identified within the genus (Oudra et al. 2002, Teneva et al. 2009), and the genus has been associated with adverse biological effects in bioassays on mice (Oudra et al. 2002, Rangel et al. 2014) and cladocerans (Olvera-

Ramirez et al. 2010). One study that included the species of *Pseudanabaena* known to occur in Farmington Bay, *P. catenata*, identified adverse health effects of the cyanobacteria on *Artemia* that were not associated with known cyanotoxins (Mohamed and Al-Shehri 2015), suggesting this species may produce other potentially harmful substances that have not yet been fully described in the scientific literature.

Chlorophyll *a* Concentration Indicators

As with the cyanotoxin concentration indicators, WHO has established recommended thresholds for chlorophyll *a* concentrations that are associated with adverse human health effects. WHO identifies chlorophyll *a* concentrations greater than 50 µg/L as a potential human health risk. The chlorophyll *a* indicator is only used as a supporting indicator in the IR, and assessment decisions have not been based solely on the chlorophyll *a* threshold. The chlorophyll *a* indicator as used in the IR is not intended to assess whether individual HAB events have occurred in a waterbody. Instead, this indicator is intended to provide supporting information regarding the overall productivity of a waterbody and its underlying potential for HABs. Although high chlorophyll *a* levels do not necessarily indicate an immediate human health risk, they may be indicative of the potential for frequent and intense HAB events and associated health impacts from recreational contact. For example, several scientific studies identify a pattern of increasing cyanobacterial dominance (as either density or biovolume) with increasing chlorophyll *a* concentrations in lakes and reservoirs (e.g. Downing et al. 2001, Rogalus and Watzin 2007). Similarly, the likelihood of occurrence of cyanotoxins has also been shown to increase with elevated chlorophyll *a* concentrations (WHO 2003, Rogalus and Watzin 2007, Lindon and Heiskary 2009, Yuan et al. 2014). This pattern of a positive relationship between cyanotoxins and chlorophyll *a* concentrations has been identified both within a single lake as demonstrated by Rogalus and Watzin (2007) in Lake Champlain and across lakes at a national scale as demonstrated by Yuan et al. 2014 using the EPA’s National Lakes Assessment dataset.

RESULTS AND DISCUSSION

Cyanobacteria Cell Counts

Concentrations of cyanobacteria over 100,000 cells/mL occurred frequently in Farmington Bay in 2013 and 2014 (Figure 1). Of 68 available phytoplankton samples, 53% exceeded the 100,000 cell/mL HAB benchmark, and 15% exceeded 1,000,000 cyanaboacteria cells/mL. Cell counts of Nodularia alone exceeded 100,000 cells/mL in 35% of samples. Exceedances of the 100,000 cell/mL cyanobacteria cell count occur frequently from April through September. A single exceedance was observed during October.

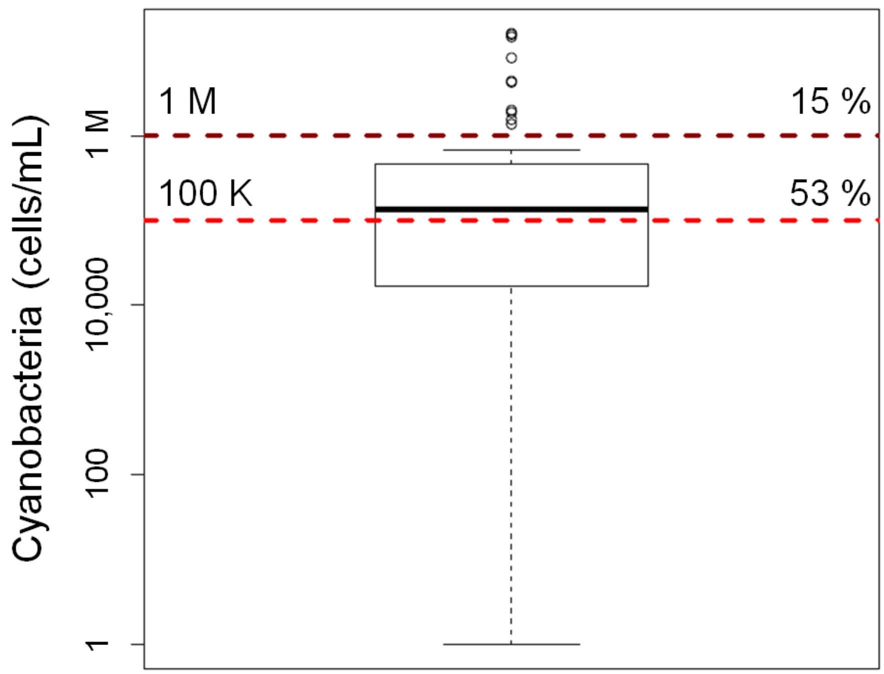

Figure 1. Cyanobacteria concentrations for all samples from the aggregated stakeholder datasets (n=68). The 100,000 cell/mL recreational use HAB indicator is identified by the dashed red line. 1 million cells/mL is shown as a dark red dashed line.

Cyanotoxin Concentrations

Nodularia blooms in Farmington Bay have been associated with significant concentrations of the cyanotoxin, nodularin. Nodularin concentrations were positively related to Nodularia cell counts with a significant increase in toxin concentrations occurring at the HAB indicator of 100,000 cells/mL (Marden et al. 2015, Figure 2). Nodularin concentrations averaged 15 µg/L and exceeded 20 µg/L in 25% of samples. Spatially, nodularin concentrations peaked in the mid-portion of the bay then dissipated towards the outlet culvert to Gilbert Bay (Figure 3). Detectable concentrations of Nodularin were exported from Farmington Bay to Gilbert Bay where the higher salinity usually prevents Nodularia growth.

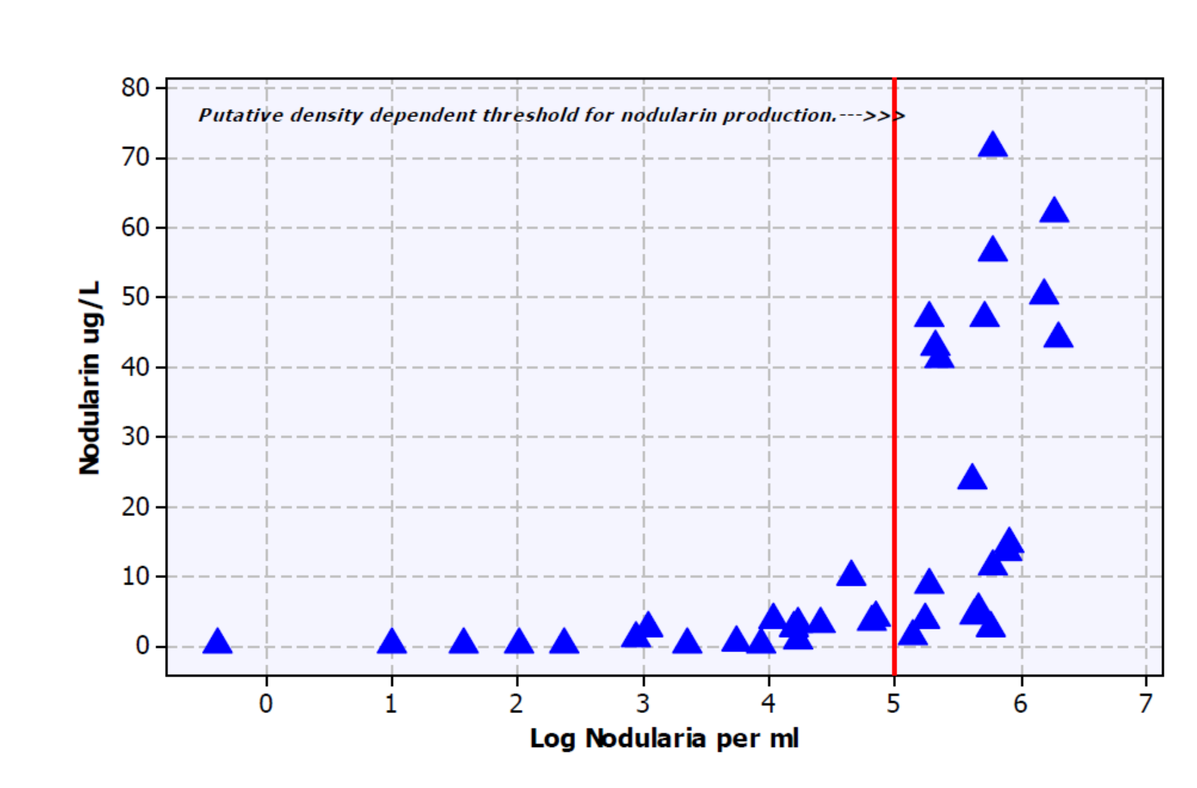

Figure 2. The relationship between Nodularia cell concentrations (x-axis) and concentrations of the cyanotoxin Nodularin (y-axis) in Farmington Bay showing a significant increase in Nodularin concentrations at 100,000 cells/mL of Nodularia. Figure from Marden et al. 2015.

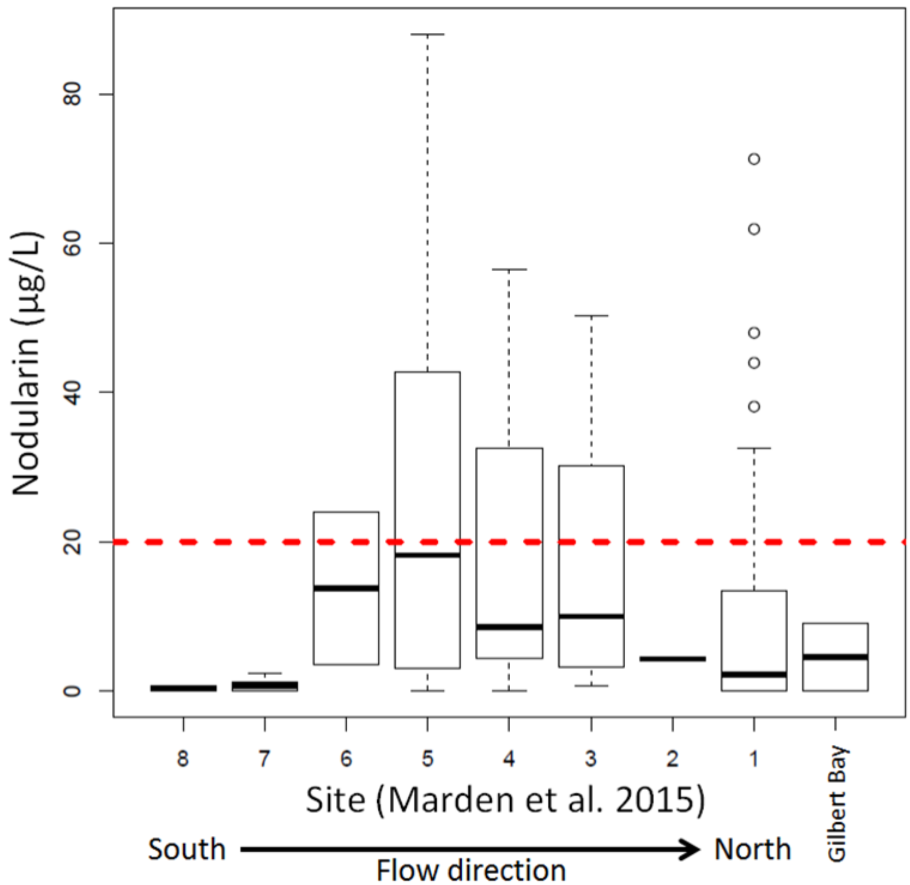

Figure 3. Nodularin concentrations in Farmington Bay by location replotted from Marden et al. 2015. The human health risk level for microcystin-LR (20 µg/L) is plotted as a dashed red line.

Chlorophyll *a* Concentrations

Chlorophyll *a* concentrations consistently exceeded the human health risk indicator of 50 µg/L. Chlorophyll *a* concentrations in Farmington Bay averaged nearly 100 µg/L (Figure 4), and exceeded the human health risk indicator of 50 µg/L in 59% of samples. This is indicative of extremely high algal growth in the water column, and a consistent potential for HAB occurrence.

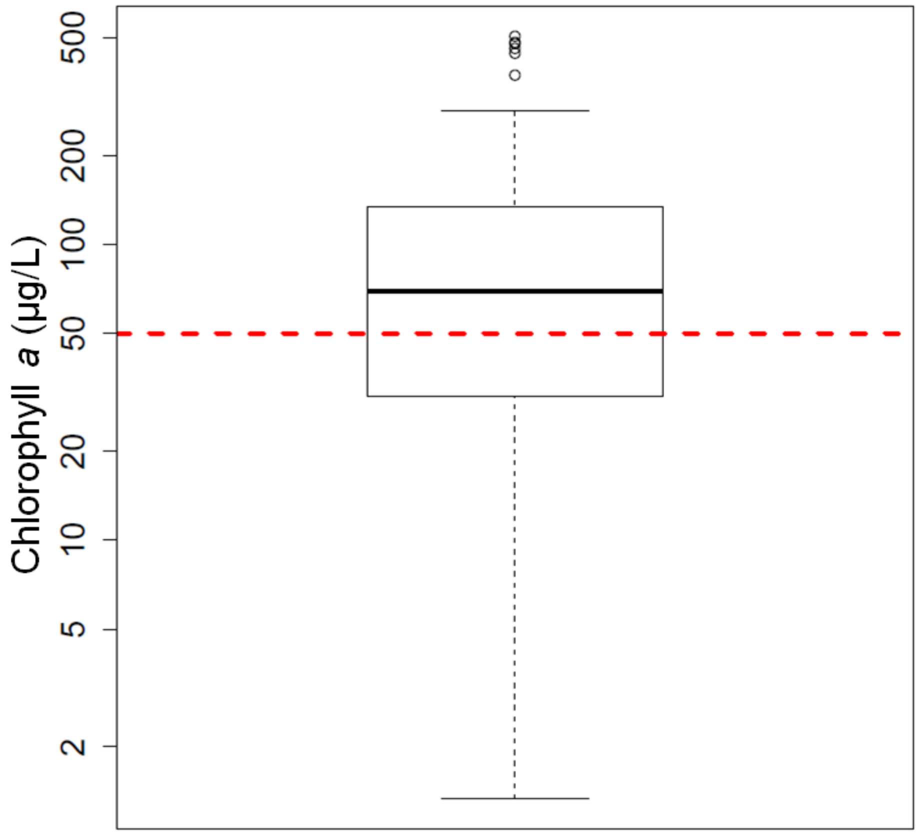

Figure 4. Chlorophyll *a* concentrations in Farmington Bay. The WHO indicator for human health risk (50 µg/L) is identified by the dashed red line.

SUMMARY

Data from Farmington Bay show frequent and extensive HABs (Table 2). Phytoplankton samples in Farmington Bay exceeded 100,000 cyanobacteria cells/mL in over 50% of samples. In addition, the cyanotoxin and chlorophyll *a* indicators also frequently exceeded thresholds for human health risk. Farmington Bay will remain in category 3C - assessment methods in development for the 2016 IR. UDWQ intends to assess recreational uses for Farmington Bay in the 2018 Integrated Report. Frequent exceedances of the indicators do identify a potential human health risk for recreational users of Farmington Bay. UDWQ is committed to human health protection and maintaining safe and enjoyable recreational experiences on Utah's waters. UDWQ will work with the Davis County Health Department to manage the public health risks posed by HABs in Farmington Bay while continuing to collect additional data and develop appropriate assessment methodologies.

Table 2. Number and percent of exceedances in Farmington Bay for all three indicators at human health risk thresholds as defined by WHO. Thresholds for microcystin-LR are used for Nodularin benchmarks.

Parameter	Cyanobacteria	Nodularin	Chlorophyll *a*
Threshold	100,000 cells/mL	20 µg/L	50 µg/L
Number of samples	68	105	159
Exceedances	36	27	94
Percent exceedance	53	26	59

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