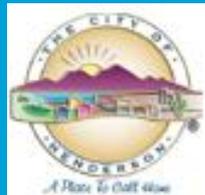
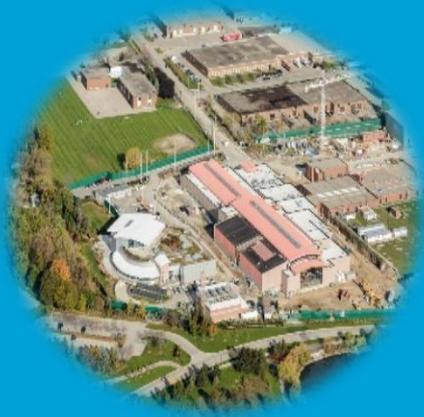
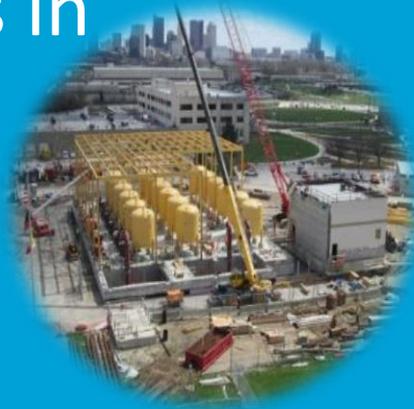


# Idaho Water Reuse Conference 2017

## Evaluation of Virus Removal Capabilities of Membrane Bioreactor (MBR) Systems in Full-Scale Water Reuse Facilities in Nevada

May 18, 2017



ch2m.<sup>SM</sup>

# Acknowledgments

- We thank the following co-authors for their valuable contributions to the study:
  - Adrian Edwards, Howard Analla, Priscilla Howell - City of Henderson
  - Julian Hoyle and Larry Schimmoller – CH2M
  - Randy DeVaul and Frazier Speaks, City of North Las Vegas
  - Ufuk Erdal – formerly of CH2M
- We also thank COH, CNLV, and SNWA laboratory staff for their meticulous efforts on microbial analyses

# Presentation Outline

- COH Objectives and Background
- COH SWRF Facility
- COH Study Approach and Phases
- COH Results
- COH Path Forward
- CNLV Case Study
- Questions and Comments



# Discussion

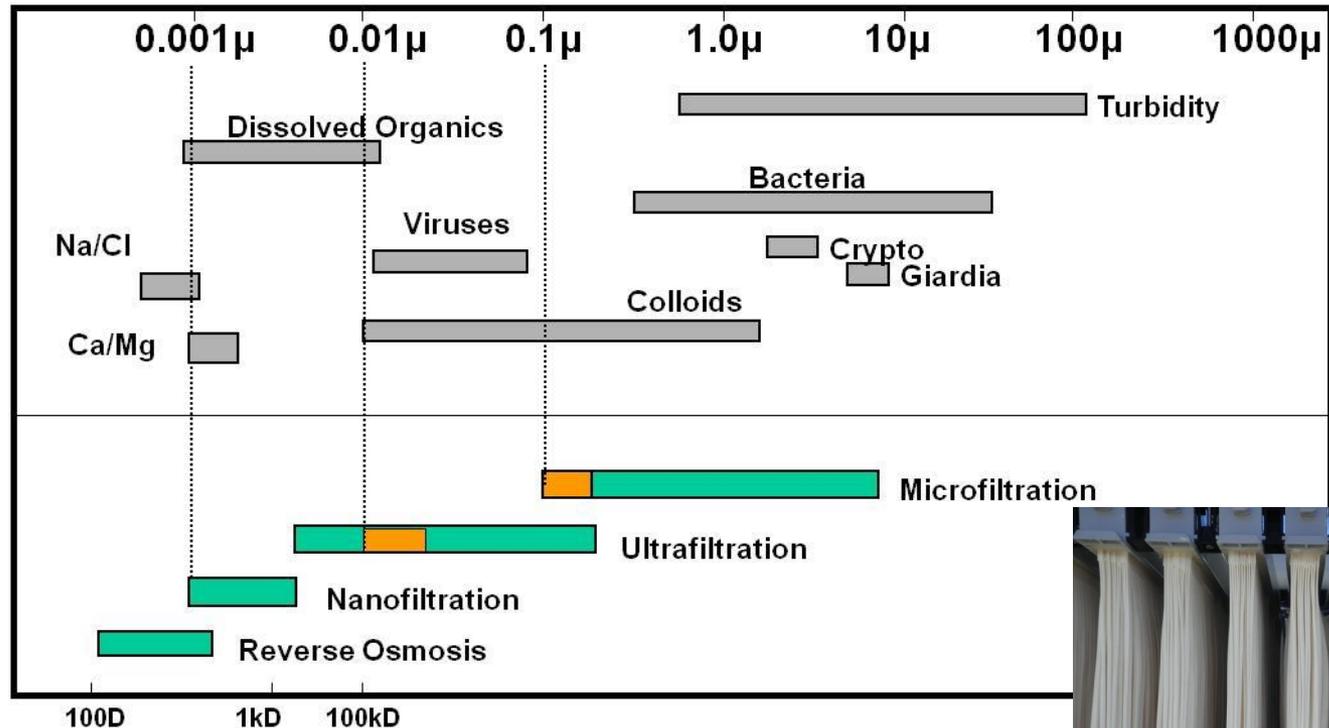
- The basis for WWTP permits is coliform or E. coli bacteria
- Giardia, Cryptosporidium, and viruses are not typically addressed
- Upstream processes (nitrification, membranes) have a significant impact on overall disinfection performance
- What is the intent of bacterial discharge limits?
  - COH and CNLV MBR processes meet discharge limits for disinfection
  - COH and CNLV went a step further and investigated performance versus the intent of discharge limits, even though virus reduction is not specifically required
  - Both utilities maintain multi-barrier approaches and go above and beyond regulatory requirements

# Objectives and Background



# Objectives of the Study

- *To Evaluate the Removal of Pathogens in a Full-Scale MBR-UV Facility*



# Objectives of the Study

- Expected results
  - Understand the synergy of MBR and UV disinfection/chlorination for pathogen reduction
  - Develop operational treatment goals that protect public health and optimize energy and chemical use
  - Reduce operational costs of SWRF facilities

# Background

- Increasing numbers of non-potable reuse facilities using MBR followed by UV or other disinfection
  - This combination provides two effective barriers for pathogen reduction
  - Discharge limits for disinfection are based on bacterial levels
  - “Implicit” standards for disinfection are often assumed, such as virus removal/inactivation
- What is happening now?
  - Sampling of membrane permeate has demonstrated that no coliform bacteria are present
  - Reuse plant operators are asking why a separate disinfection process is needed
  - Energy use and cost of UV equipment, as well as chemical use, is being driven higher than needed for public health

# Background

- A “disconnect” now exists between:
  - Bacterial discharge limits that address disinfection
  - Implicit regulatory goals for disinfection
- This study addressed this “disconnect” by:
  - Developing operating recommendations
  - Lowering energy and chemical costs for operating facilities
  - Reducing construction costs for future facilities



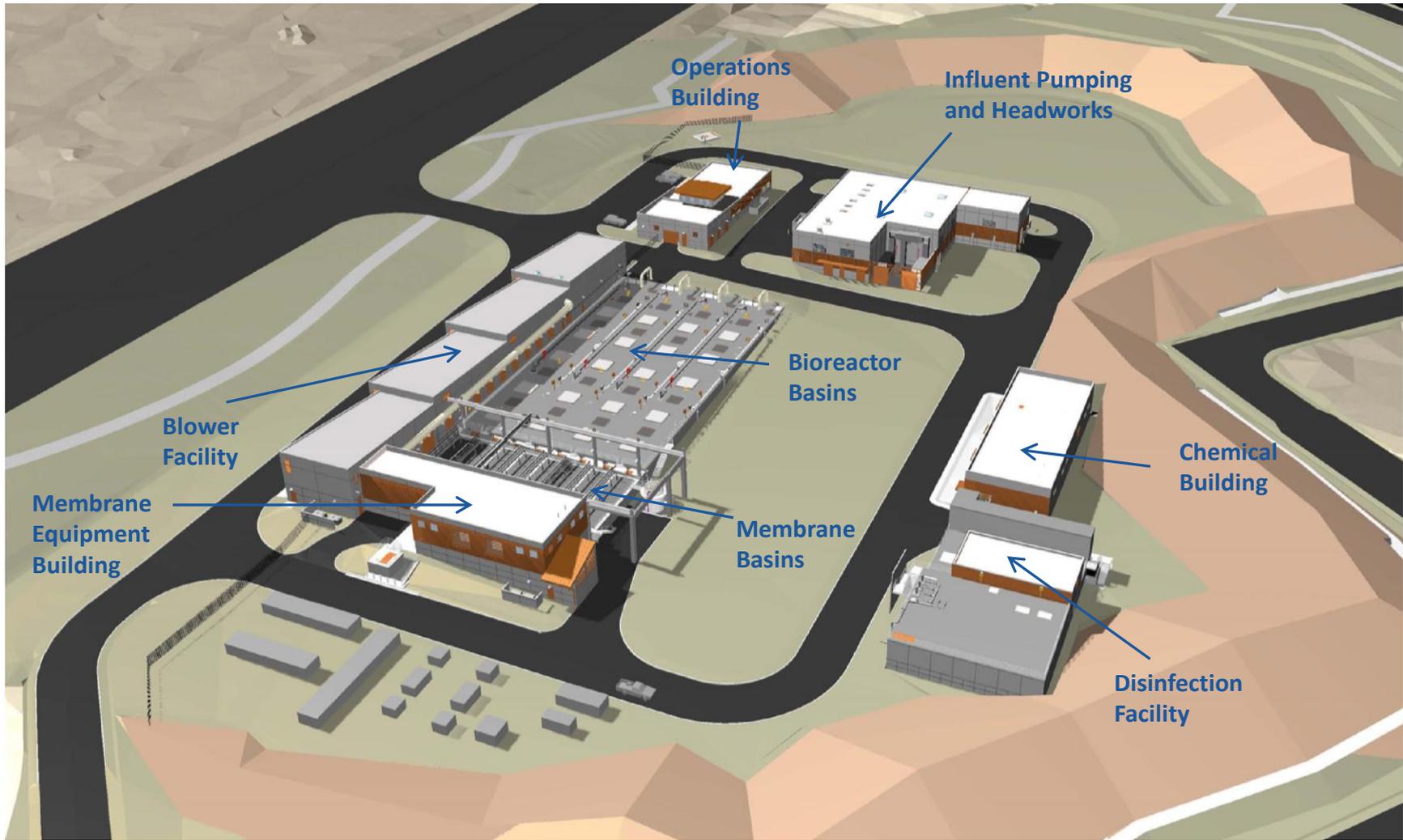
# Background

- California Department of Public Health Guidelines
  - When using membrane filtration, the impact of particles is eliminated and viruses represent the pathogen of concern
- Title 22 defines “disinfected tertiary recycled water” as:
  - A disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 99.999% of MS2, or poliovirus, in the wastewater
- Title 22 focuses on 5-log poliovirus reduction through filtration and disinfection rather than disinfection alone
- No credit for virus removal through filtration is mentioned in the National Water Research Institute (NWRI) guidelines, which set UV dose requirements for reuse applications

# SWRF Facility



# City of Henderson SWRF

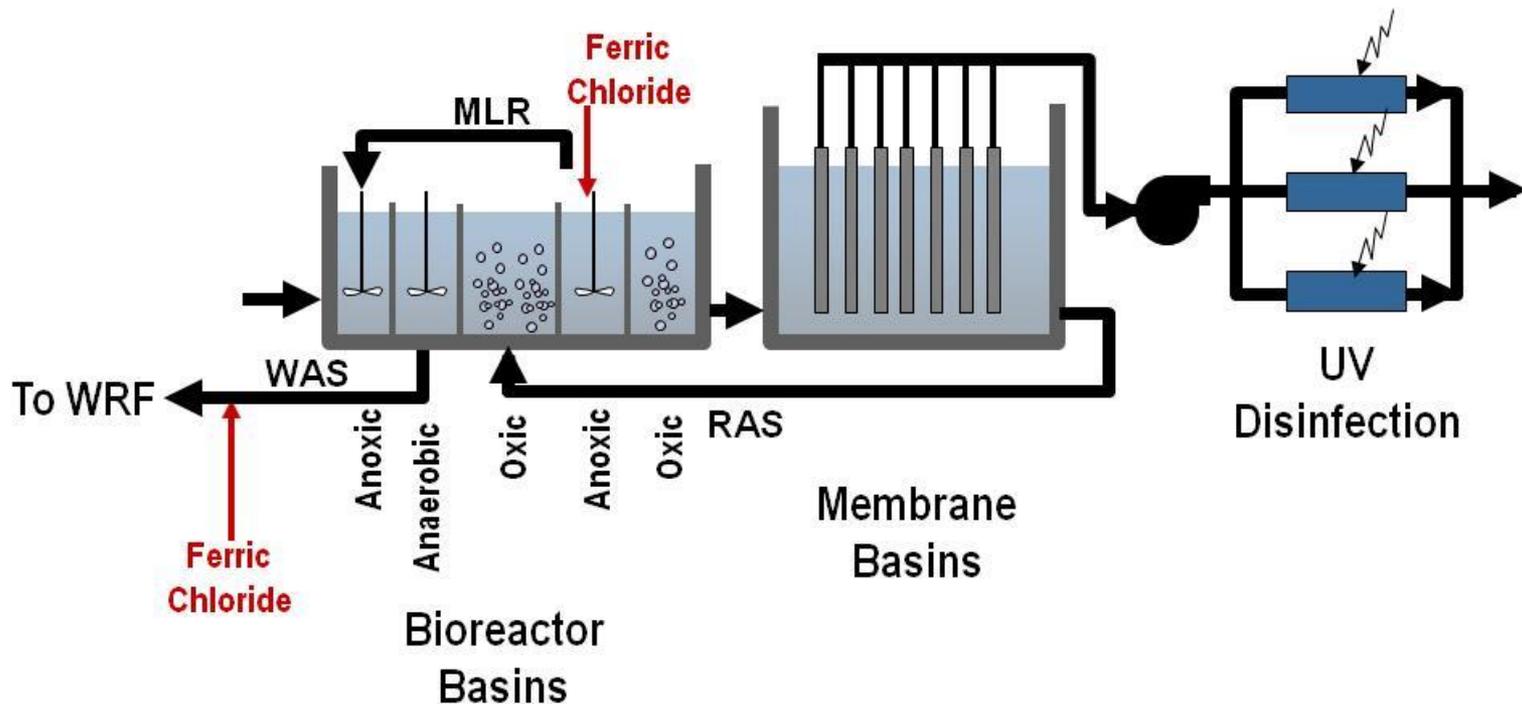


# Treatment Capacity

- Phase I capacity:
  - 8.0 mgd at annual average daily flow rate (AADF)
  - 13.6 mgd at peak hourly flow rate (PHF)
- Phase 2 capacity:
  - 16.0 mgd at annual average daily flow rate (AADF)
  - 27.2 mgd at peak hourly flow rate (PHF)



# SWRF couples biological nutrient removal and MBR technology...



# SWRF Design Criteria

- UV disinfection system was designed according to National Water Research Institute Guidelines (NWRI, 2012):
  - To meet 5-log inactivation of poliovirus
  - Design UV Dose: 80 mJ/cm<sup>2</sup> (design UV Transmittance of 65%)
  - Effluent fecal coliform requirements:
    - 2.2 MPN/100 mL (30-day geometric mean)
    - 23 MPN/100 mL (Daily maximum)

# Study Phases and Approach



# Study Phases

## Phase I - Initial Screening

**Objective: Identify and select virus species for the study**

## Phase II – Testing

**Objective: Determine MBR virus removal capabilities under different operating conditions**

# Phase I – Initial Screening

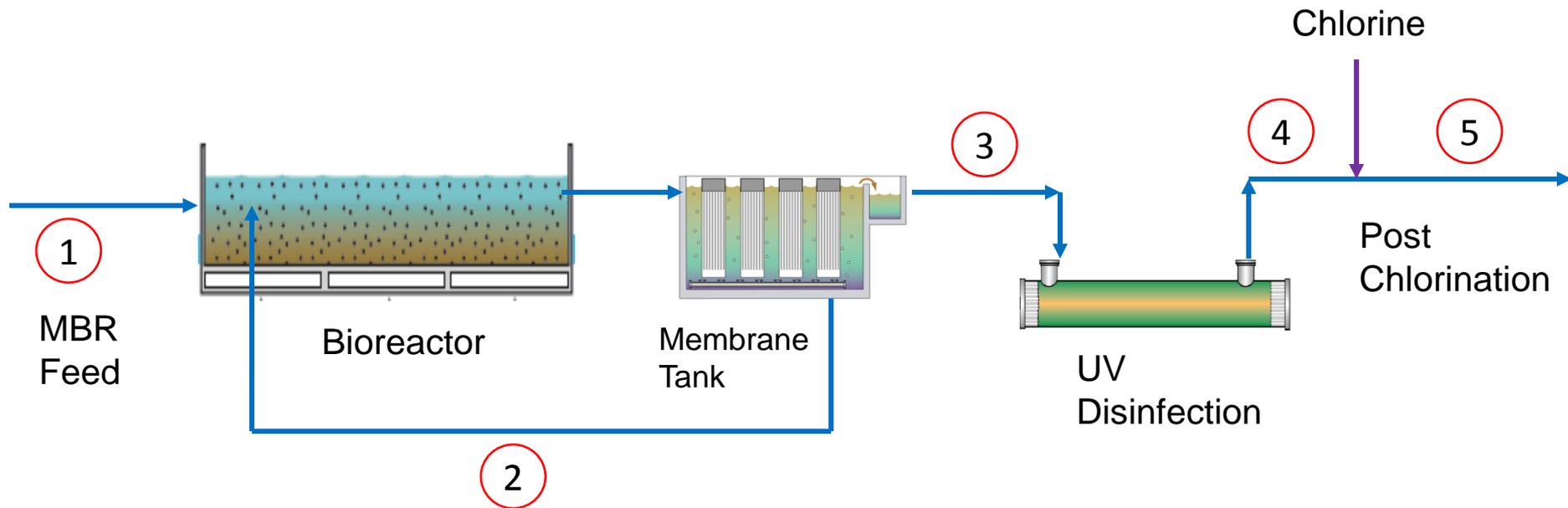
- Samples were collected under normal operating conditions (i.e., flux, SRT, RAS rates, etc.) and for the following virus analyses:
  - Human Adenovirus (HAdV)
  - Norovirus G1 and G2
  - F specific (MS-2) and Somatic Coliphage
  - Enterovirus
  - Hepatitis A
  - Rotovirus

# Phase II – Virus Removal/Rejection of the System

Sampling was performed under the four following operating conditions:

1. **Clean Membranes** (immediately after sodium hypochlorite maintenance clean)
2. **Clean Membranes** (immediately after citric acid maintenance clean)
3. Operating at **Increased Flux**
4. Normal Operating Conditions with **Reduced UV Dose** (40 mJ/cm<sup>2</sup>)

# Sampling Locations



# Microbiological Analyses

- Sample collection was performed by COH staff.
- With the exception of MS-2 and Somatic Coliphage, all virus analyses were performed by Southern Nevada Water Authority
- Coliphage analysis was performed at Biovir Laboratories
- Coliform testing was performed by the COH's certified lab
- Low solids containing virus analysis (i.e., MBR permeate, UV disinfection) were performed per EPA Method 1602 whereas high solids containing samples (i.e., bioreactor influent, RAS) were performed per Adams Method

# Monitoring Parameters

- BOD (Bioreactor feed, MBR Effluent)
- MLSS (RAS Line or MBR tank)
- Turbidity (MBR effluent)
- TMP (MBR system)
- SRT (MBR system)
- MLSS and RAS recycle rates (MBR systems)
- Water Temperature (any reported point)
- UV Dose (UV system)

# Study Results



# Study Results

## Phase I - Initial Screening

- Enterovirus
  - Hepatitis A, 24-30 nm
  - Rotovirus, 60-80 nm
- Not detected in the influent and at any of the sampled locations

- Human Adenovirus (HAdV), 80-100 nm
  - Norovirus G1 and G2, 35-40 nm
  - F specific (MS-2), 24-28 nm
  - Somatic Coliphage, 65-100 nm
- Were abundant in the influent. Therefore, they were identified as the indicator organisms

Nominal Pore size of Membrane: 40 nm (0.04  $\mu\text{m}$ )

# Phase I Initial Screening (Normal Operating Cond.)

	Influent	Bioreactor Tank	MBR Permeate	Concentration Limit in Recycled Water	Additional Log Removal Requirement for Disinfection System
HAdV, Copies/1 L	665,377	292,385	ND (<5)	NSL <sup>1</sup>	0
Norovirus G1, Copies/1 L	8,049	1,729	ND (<5)	NSL <sup>1</sup>	0
Norovirus G2, Copies/1 L	25,845	ND (<5)	ND (<5)	NSL <sup>1</sup>	0
MS2 Coliphage, pfu/100 mL	1,900	11	ND (<1)	NSL <sup>1</sup>	0
Somatic Coliphage, pfu/100 mL	1,600	12	ND (<1)	NSL <sup>1</sup>	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to reported detection limit

# Phase II – Test 1 (Clean Membranes with Hypo)

	Influent	Bioreactor Tank	MBR Permeate	Concentration Limit in Recycled Water	Additional Log Removal Requirement for Disinfection System
HAdV, Copies/1 L	37,572,276	332,247	1	NSL <sup>1</sup>	0
Norovirus G1, Copies/1 L	1,038,037	80,608	ND (<1)	NSL <sup>1</sup>	0
Norovirus G2, Copies/1 L	197,974	3,886	ND (<1)	NSL <sup>1</sup>	0
MS2 Coliphage, pfu/100 mL	2,400	22	5	NSL <sup>1</sup>	0.70
Somatic Coliphage, pfu/100 mL	1,900	16	3	NSL <sup>1</sup>	0.48
Total Coliform, cfu/100 mL	13,000,000	1,700,000	<b>30?</b>	NSL <sup>1</sup>	<b>1.13</b>
Fecal Coliform, cfu/100 mL	5,000,000	400,000	ND (<2)	2.2	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to its reported detection limit

# Phase II – Test 2 (Clean Membranes with Citric Acid)

	Influent	Bioreactor Tank	MBR Permeate	Concentration Limit in Recycled Water	Additional Log Removal Requirement for Disinfection System
HAdV, Copies/1 L	2,016	5,823	ND (<1)	NSL <sup>1</sup>	0
Norovirus G1, Copies/1 L	ND (<1)	ND (<1)	ND (<1)	NSL <sup>1</sup>	0
Norovirus G2, Copies/1 L	ND (<1)	ND (<1)	ND (<1)	NSL <sup>1</sup>	0
MS2 Coliphage, pfu/100 mL	1,800	12	21	NSL <sup>1</sup>	1.32
Somatic Coliphage, pfu/100 mL	1,500	17	7	NSL <sup>1</sup>	0.85
Total Coliform, cfu/100 mL	11,000,000	1,100,000	ND (<2)	NSL <sup>1</sup>	0
Fecal Coliform, cfu/100 mL	11,000,000	800,000	ND (<2)	2.2	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to its reported detection limit

# Phase II – Test 3 (Operating at Increased Flux)

	Influent	Bioreactor Tank	MBR Permeate	Concentration Limit in Recycled Water	Additional Log Removal Requirement for Disinfection System
HAdV, Copies/1 L	338,555	66,095	ND (<1)	NSL <sup>1</sup>	0
Norovirus G1, Copies/1 L	13,063,946	927,348	ND (<1)	NSL <sup>1</sup>	0
Norovirus G2, Copies/1 L	13,133	ND (<1)	ND (<1)	NSL <sup>1</sup>	0
MS2 Coliphage, pfu/100 mL	2,100	16	4	NSL <sup>1</sup>	0.60
Somatic Coliphage, pfu/100 mL	2,300	13	ND (<1)	NSL <sup>1</sup>	0
Total Coliform, cfu/100 mL	30,000,000	5,000,000	ND (<2)	NSL <sup>1</sup>	0
Fecal Coliform, cfu/100 mL	11,000,000	1,700,000	ND (<2)	2.2	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to its reported detection limit

# Phase II – Test 4 (Normal Operating with Reduced UV Dose)

	Influent	Bioreactor Tank	MBR Permeate	Concentration Limit in Recycled Water	Additional Log Removal Requirement for Disinfection System
HAdV, Copies/1 L	588	23,490	ND (<1)	NSL <sup>1</sup>	0
Norovirus G1, Copies/1 L	ND (<1)	ND (<1)	ND (<1)	NSL <sup>1</sup>	0
Norovirus G2, Copies/1 L	ND (<1)	ND (<1)	ND (<1)	NSL <sup>1</sup>	0
MS2 Coliphage, pfu/100 mL	4,400	45	ND (<1)	NSL <sup>1</sup>	0
Somatic Coliphage, pfu/100 mL	6,200	53	ND (<1)	NSL <sup>1</sup>	0
Total Coliform, cfu/100 mL	17,000,000	8,000,000	ND (<2)	2.2	0
Fecal Coliform, cfu/100 mL	3,000,000	700,000	ND (<2)	NSL <sup>1</sup>	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to its reported detection limit

# Conclusions and Path Forward



# Conclusions and Path Forward

- Influent virus concentrations showed great fluctuations (i.e., Norovirus G1 (<1 to 13,063,946 copies/L))
- Without disinfection, the MBR was very effective for reducing virus and bacteria concentrations to very low levels (in most cases to ND levels)
- The lowest virus rejection by the MBR was observed for MS-2 Coliphage and under clean membrane conditions

# Conclusions and Path Forward

- Under these conditions, the MBR permeate contained viruses and additional removal was required by the disinfection system (either UV disinfection or chlorine disinfection)
- NWRI and Title 22 recycled water regulations do not set numeric concentration limits for viruses in recycled water
- Conservatively assuming that recycled water should contain non-detectable virus levels, the additional virus reduction required by disinfection was 1.32 log reduction
  - COH assumed 2-log reduction is required by disinfection

# Conclusions and Path Forward

- 2-log additional virus inactivation can be satisfied with UV disinfection
- 2-log additional virus removal can also be satisfied with free chlorine CT of 3 mg/L\*min
  - At residual chlorine concentration of 0.3 mg/L, it requires a contact time of 10 minutes (at 10°C, pH 6-9 per EPA SWTR GM)
  - Contact time can be satisfied using the 2 mile pipeline that conveys recycled water to the reservoir (>15 minutes, at 10 ft/s maximum water velocity in pipe and T10/TDT or Baffling Factor of 0.9)



# Conclusion and Path Forward

- The virus study results supported the conclusion that the MBR alone provides a level of disinfection consistent with permit compliance
- The City of Henderson has been sampling for fecal coliform in the MBR permeate for several years and has never had a level outside of their permit compliance values
- The State of Nevada weighed the outcome of the findings in this study and all related facts prior to concluding that UV disinfection following membrane treatment was not necessary to meet the plant effluent standards.
- The UV system will be used as a backup system, kept in an operations-ready condition, with the membranes and residual chlorine providing primary disinfection.

# Conclusion and Path Forward

- The State determination allowed for the City of Henderson to achieve significant savings in power, equipment replacement costs, and operator time.
- An annual savings of over 1.2 million kWh represents a great savings in greenhouse gas emissions
- This type of regulatory process will allow MBR systems to become more cost-competitive compared to other treatment alternatives by providing alternative approaches to disinfection
- This approach has also been accepted by Iowa (City of North Liberty) and Minnesota (City of Hutchinson) and may be looked at by other States going forward

# Evaluation of Virus Removal Capabilities of the Membrane Bioreactor (MBR) System at the City of North Las Vegas Water Reclamation Facility



# City of North Las Vegas WRF (50 mgd)



# CNLV WRF Permit

Effluent Discharge and Groundwater Discharge from the WRF are regulated by NV0023647 and NS2016501 (Appendix A & B)

Appropriate disinfection is measured by fecal coliform, in MPN/ 100 mL

WRF is limited to 2.2 MPN/100 mL as a geometric mean of all samples in the month, and 23 MPN/100 mL as a Daily Maximum to reclaimed system (Groundwater Discharge Permit)

WRF is limited to 200 MPN/100 mL as a geometric mean of all samples in the month, and no more than 10% of the samples can exceed 400 MPN/100 mL to the Las Vegas Wash (NPDES Permit)

# Sampling Data

Fecal Coliform testing done daily at the membrane effluent since start-up of plant on June 9, 2011.

- Of all 1,825 samples, none were over the permitted range of 23 MPN/100mL daily maximum, nor would the 2.2 MPN/100mL Geometric Mean have been exceeded for any calendar month for reclaimed water.
- Of all 1,825 samples, none were over the permitted range of 200 MPN/100mL daily maximum, nor would the 400 MPN/100mL have been exceeded for 10% of the samples.
- There was 1 instance of detectable fecal coliform
- Highest fecal coliform was 2.0 MPN/100mL

## Virus Study

The City of North Las Vegas and CH2M recognized that the WRF permeate was meeting permitted fecal coliform levels. Knowing that virus removal is anticipated if fecal coliform levels are low, we decided to perform a targeted study to determine if virus removal was in fact being attained.

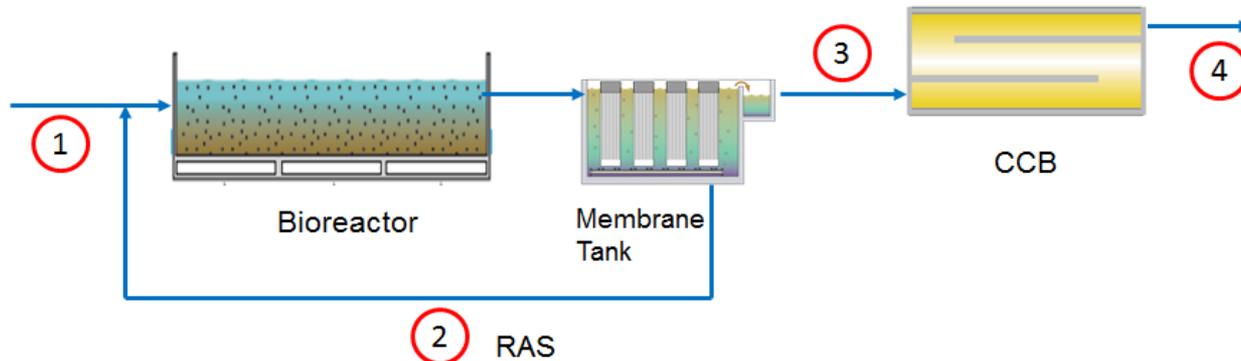
# Phase I Initial Screening (Normal Operating Conditions)

	Bioreactor Influent	MBR Permeate	Concentration Limit in NEVADA	Log Removal Achieved Thru MBR	Additional Log Removal for Complete Disinfection, if Required
HAdV, Copies/1 L	57,650,405	40	NSL <sup>1</sup>	6.16	1.60
Norovirus G1, Copies/1 L	74,548	ND (<1)	NSL <sup>1</sup>	>4.87	0
Norovirus G2, Copies/1 L	40,914,388	ND (<1)	NSL <sup>1</sup>	>7.61	0
MS2 Coliphage, pfu/100 mL	1,000	ND (<1)	NSL <sup>1</sup>	>3	0
Somatic Coliphage, pfu/100 mL	1,800	ERROR	NSL <sup>1</sup>		
Total Coliform, cfu/100 mL	>1,000,000	ND (<1)	NSL <sup>1</sup>	>6	0
Fecal Coliform, cfu/100 mL	>1,000,000	ND (<1)	<2	>6	0

<sup>1</sup>No Set Limit; conservatively assumed that it is equal to reported detection limit

# Virus Study - Conclusion

While a very small number of viruses were present in the membrane permeate under worst-case conditions, the quality of the WRF effluent will still meet permit requirements, as shown by the weekly fecal coliform tests.



- ① MBR Feed
- ② RAS; MBR tank content
- ③ MBR Permeate; CCB Feed
- ④ CCB Effluent

# Safety Factors

The results of the virus study were very conservative, considering the following:

- Samples of membrane permeate after cleaning were taken from one train. Twelve trains are normally in service, providing greater capture of viruses and coliform.
- 2-log additional reduction recommended for viruses, but not necessary to meet permitted fecal coliform limits.

# Plant Safety Factors

- Automation of plant will shut down membranes if problems are detected.
- Higher dosing of hypochlorite is available if needed.
- Sodium hypochlorite will also be added for algae control in reclaimed system. That addition will continue and will provide additional disinfection for removal of both coliform and viruses.

# Conclusions

- The virus study results support the conclusion that the MBR alone provides a level of disinfection consistent with permit compliance
- Could reduce chemical costs (chlorination and dechlorination) in the CCB, instead operating to have 0.1 mg/L chlorine residual concentration at outfall (for discharged flow)

# Operation and Maintenance Modification

**The City of North Las Vegas (CNLV) requested to be allowed to modify the operation of the CNLV Water Reclamation Facility.**

The approved Operation and Maintenance Manual of the WRF outlines that chlorine (sodium hypochlorite) is the primary source of disinfection for the effluent of the plant.

Data from plant operation collected for five years, and a targeted study on virus removal, indicated that the required disinfection is achieved after membrane filtration.

# Discussion

- The basis for WWTP permits is coliform or E. coli bacteria
- Giardia, Cryptosporidium, and viruses are not typically addressed
- Upstream processes (nitrification, membranes) have a significant impact on overall disinfection performance
- What is the intent of bacterial discharge limits?
  - COH and CNLV MBR processes meet discharge limits for disinfection
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  - Both utilities maintain multi-barrier approaches and go above and beyond regulatory requirements

# Questions and Comments

Thanks for your attention!

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