ENVIRON

July 31, 2013

Michael Anderson, P.E.
Nevada State Engineer
Nevada Division of Water Resources
901 South Stewart Street, Suite 2002
Carson City, Nevada 89701-5249

Re: Request for Temporary Exceedance of Permit Requirement
Nevada Environmental Response Trust Site; Henderson, NV
Dam Permit #J-665

Dear Mr. Anderson,

The Nevada Environmental Response Trust (NERT or the Trust) maintains Permit #J-665, which covers the earthen embankment associated with the 11-acre synthetically double-lined aquifer retention basin (GW-11 or the GW-11 pond). ENVIRON International Corporation (ENVIRON), on behalf of the Trust, has performed an analysis of the wave runup that could occur in GW-11 based on conservative assumptions. With this letter, ENVIRON is requesting a temporary exceedance of the permit requirement to maintain three feet of freeboard in the GW-11 pond [Attachment A, Item 6].

Recently, certain components of the Groundwater Extraction and Treatment System (GWETS) have experienced operational problems which have resulted in diversions of treated effluent and untreated influent to GW-11 in order to maintain compliance with the NPDES permit effluent limitations. Furthermore, Envirogen Technologies, Inc. (Envirogen), the treatment plant operator as of July 24, 2013, has proposed emergency refurbishment of the GWETS that may require additional diversions to GW-11. The attachment to this letter presents wave runup calculations that support temporarily reducing the minimum freeboard allowance at the GW-11 pond from three feet to two feet, corresponding to an allowable water level elevation of 1748 feet.

Please also note that ENVIRON is currently reviewing the volume calculations for GW-11 to verify its capacity and anticipate that we will provide results of this analysis in a separate deliverable. The wave runup calculations are unaffected by the volume of the pond.

Should you have any questions concerning this correspondence, please contact Allan DeLorme at (510) 420-2565 or adelorme@environcorp.com or Kimberly Kuwabara at (510) 420-2525 or kkuwabara@environcorp.com. Thank you.

Sincerely,

Allan J. DeLorme, PE
Principal

Kimberly Kuwabara, MS
Senior Manager
Nevada CEM 2353, exp. 3/20/2015

cc. Greg Lovato, Bureau of Corrective Actions, NDEP
James Dotchin, Bureau of Corrective Actions, NDEP
Weiquan Dong, Bureau of Corrective Actions, NDEP
Nevada Environmental Response Trust
Tanya O'Neill, Foley and Lardner LLP
Todd Webster, Envirogen Technologies
Bill Schwartz, Envirogen Technologies
John Pekala, ENVIRON International Corporation
Chris Ritchie, ENVIRON International Corporation

Attachment: *GW-11 Pond Wave Runup Calculations*

1 Introduction

Recently, certain components of the Groundwater Extraction and Treatment System (GWETS) have experienced operational problems which have resulted in diversions of treated effluent and untreated influent to GW-11 in order to maintain compliance with the NPDES permit effluent limitations. Furthermore, Envirogen Technologies, Inc. (Envirogen), the treatment plant operator as of July 24, 2013, has proposed emergency refurbishment of the GWETS that may require additional diversions to GW-11.

GW-11 currently has approximately five feet of available freeboard below the top of the pond liner at 1750 feet above mean sea level (amsl). As such, only limited capacity (approximately six days at maximum extraction rates) is available in the pond to receive diverted influent and effluent should the GWETS continue to experience operational issues. Once capacity of GW-11 is reached, the only option for dealing with additional plant operational issues would be to shut down extraction wells, which would allow uncontrolled migration of contaminated groundwater.

The purpose of this attachment is to present the basis for temporarily reducing the minimum freeboard allowance at the GW-11 pond from three feet to two feet, corresponding to an allowable water level elevation of 1748 feet amsl compared to the current maximum allowable water elevation of 1747 feet amsl. This will act as a contingency measure to mitigate the effects of further treatment plant disruptions.

At the request of Mike Anderson of the Nevada Department of Conservation and Natural Resources Division of Water Resources, wave runup calculations have been performed to assess the potential effect of temporarily decreasing the freeboard allowance to two feet. Section 2 presents an overview of the general approach and four different methodologies that were evaluated. Section 3 provides a discussion of model parameter selection. A discussion of the results follows in Section 4. References are provided in Section 5.

2 Methods

Wave runup calculations were performed to estimate the potential vertical water rise in the GW-11 pond due to wind-generated waves. “Total runup” is the sum of the following two components:

(1) “Wind setup” refers to the “tilting” of the water surface due to wind stress. The downwind side of the pond is expected to have a higher water level elevation and the upwind side of the pond a lower water level elevation.

(2) “Wave runup” refers to the increase in water level due to breaking waves dissipating on the embankment. Wave runup is expected to be higher for impermeable, smooth embankments and lower for permeable embankments with rough slopes. Wave runup is presented in terms of what percentage of incident waves will exceed the calculated runup height.

Since there is no one preferred approach to calculate total runup, the following four different methodologies were evaluated to obtain a range of reasonable total runup estimates:

- *USACE (2002, Last revised 2011) Coastal Engineering Manual* – USACE guidance focuses on the coastal environment, but is commonly applied at inland water bodies like the GW-11 pond.
- *Linsley et al. (1992) Water-Resources and Environmental Engineering* – This book presents an approach to determine total runup in large water storage reservoirs.
- *USBR (1992) Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams* – U.S. Bureau of Reclamation policy describes how to calculate freeboard allowances for storage dams.
- *USEPA (1988) Freeboard Determination and Management in Hazardous Waste Surface Impoundments* – USEPA guidance was developed for hazardous waste impoundments with short fetches, and shallow liquid depths. Fluid property adjustments allow for consideration of fluids other than water.

A summary of wave runup calculation assumptions and results for each methodology are included in Table 1.

3 Model Parameters

Wave runup is a function of wind speed, fetch, pond depth, and the roughness and slope of the embankment. The embankment is known to have a 3:1 slope and is conservatively assumed to have an impermeable smooth surface. The determination of a design wind speed for each methodology and fetch are described in more detail below.

Design Wind Speed

Various wind speed data sources were reviewed for this analysis and are summarized in Table 2. According to Las Vegas Residential and Building Codes, the 50-year mean recurrence three-second gust speed at 33 feet (10 meters) above ground in open country is 90 mph (equivalent to 76 mph fastest-mile speed) (City of Las Vegas 2007). Local building code previously required a 50-year recurrence speed of 70 mph (fastest-mile at 10 m in open country) (Boggs 2005). However, these values are derived from figures that group the entire inland of the United States into the same category from Nevada to Maine.

Site-specific data was obtained from the nearest weather station at the Las Vegas airport (WBAN Station No. 23169: 36° 4'48.00"N, 115°10'12.00"W) through the U.S. Department of Agriculture web site (USDOA 2013a, 2013b). The maximum wind gust speed measured during 1948-2000 was 62.82 mph at 6.1 meters above ground in 1984 at 310 degrees (blowing from the NW to the SE). Average wind speed over the same time period was 10.26 mph.

The maximum 3-second wind gust speed recorded at the Las Vegas airport of 62.82 mph is transformed into a design wind speed in accordance with each methodology's specifications as follows:

(1) Wind speed is adjusted from 6.1 meters to either 7.6 or 10 meters above ground. USEPA guidance does not specify required anemometer height, so the standard of 10 meters is used.

(2) 3-second wind gust speed is converted to an averaging time more appropriate for wave prediction based on the amount of time required for waves to fully develop over the modeled fetch. USACE, USBR, and USEPA guidance recommend using the maximum sustained wind speed. USACE methodology indicates a 9-minute average is appropriate and USBR methodology indicates a 7-minute average is appropriate. USEPA does not provide further guidance on what sustained wind speed is appropriate, so a 9-minute average is used because this is the most conservative time duration from the other two estimates.

(3) Wind speed is adjusted to account for the difference between measured overland speeds and actual overwater wind speeds. The overwater to overland wind speed ratios used range from 1.08 to 1.2 for short fetch distances in accordance with each methodology's specifications.

See Tables 3 through 6 for a summary of how design wind speeds were calculated for each methodology. The model parameters for each method are summarized in Tables 7-10.

Fetch

The fetch is estimated to be the longest distance in the direction of the maximum wind gust observed in 1984 (blowing from the NW to the SE). This distance was determined from Google Earth to be 980 feet from a point on the west side of the pond to the southeast corner of the pond.

4 Discussion

As discussed in Section 1, the purpose of this analysis is to present the basis for a temporary reduction in the minimum freeboard allowance. Freeboard allowance calculations associated with permanent designs should consider extreme wave runup and setup coincidental with rare waves (i.e. waves exceeded only 2 percent of the time), probable maximum precipitation typical of the area, and additional safety factors that account for a full design life and an entire spectrum of operational and climactic scenarios that are not appropriate for temporary measures.

For the purposes of this analysis, four different methodologies were evaluated based on conservative assumptions for model parameters. USACE (2002), USBR (1992), USEPA (1988), and Linsley et al. (1992) produce similar estimates of total runup in the pond associated with generation and breakup of a significant wave (wave height only exceeded by 13 percent of waves). These estimates range from 1.1 to 1.6 feet above an assumed maximum water level elevation of 1748 feet amsl. Based on this analysis, a 1.1-1.6 feet range should be sufficient for a temporary freeboard allowance and a reduction in minimum freeboard from three feet to two feet is reasonable and appropriate as a temporary contingency measure.

5 References

Boggs, D., Wright, B., Denoon, R. (2005) Wind Engineering for the Las Vegas Stratosphere Tower. The Sixth Asia-Pacific Conference on Wind Engineering (APCWE-VI). Seoul, Korea. September 12-14.

City of Las Vegas (2007) Bill No. 2006-77, Ordinance No. 5883, First Amendment, Ordinance to Adopt as the City's Building Code the 2006 Editions of the International Building Code and International Residential Code, Together with Amendments Thereto, and to Provide for Other Related Matters. January 17. Last Accessed 7/22/2013: http://archive.org/search.php?query=creator%3A%22City+of+Las+Vegas%22

Linsley, R., Franzini, J., Freyberg, D., Tchobanoglous, G. (1992) Water-Resources and Environmental Engineering. Fourth Edition. Irwin/McGraw-Hill

National Oceanic and Atmospheric Administration (2013) 2012 Annual Climatological Report for Las Vegas, NV. National Weather Service. January 3. Last Accessed 7/23/2013: http://www.srh.noaa.gov/productview.php?pil=CLALAS&max=61

United States Army Corps of Engineers (2002) Engineering and Design Coastal Engineering Manual (CEM). Manual No. 1110-2-1100. Washington, DC. Published April 30. Last Revision September 28, 2011 (Change 3).

United States Department of Agriculture (2013a) U.S. Stations Wind Summary. Natural Resource Conservation Service, National Water and Climate Center FTP Site. Last Accessed 7/22/2013: http://www.wcc.nrcs.usda.gov/ftpref/downloads/climate/

United States Department of Agriculture (2013b) Anenometer Height Info. Natural Resource Conservation Service, National Water and Climate Center FTP Site. Last Accessed 7/22/2013: http://www.wcc.nrcs.usda.gov/ftpref/downloads/climate/windrose/

United States Environmental Protection Agency (1988) Freeboard Determination and Management in Hazardous Waste Surface Impoundments. EPA/600/2-88/015. Office of Research and Development, Cincinnati, Ohio. August.

United States Department of the Interior (1992) Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams. Bureau of Reclamation, Denver, Colorado.

Table 1: Summary of Wave Run-up Model Calculations

Methodology [1]	Application	Slope Type [2]	Probability of Exceedance [3]	Wind Setup	Runup	Total Vertical Rise	Design Wind Speed [4]	Wind Speed Adjustments
				feet	feet	feet	mph	
USACE (2002)	Coastal Structures	smooth slopes	2%	0.02	1.3	1.3	56.6 (9-minute)	Adjusted for anenometer height (10 meters), duration, and land-to-water (1.2 ratio) differences. Duration set to 9 minutes because that is the time required for waves to fully develop.
			13%		1.1	1.1		
Linsley et al. (1992)	Reservoirs	smooth slopes	2%	0.04	2.7	2.8	70.0 (3-second)	Adjusted for anenometer height (to 7.6 meters) and land-to-water (1.08 ratio) differences.
			13%		1.5	1.6		
USBR (1992)	Storage Dams	smooth slopes	0.4%	0.03	1.7	1.7	57.3 (7-minute)	Adjusted for anenometer height (to 10 meters) and land-to-water (1.2 ratio) differences. There is a method to further reduce design wind speed, but for such a small fetch the effect is negligible. Duration set to 7 minutes because that is the time required for waves to fully develop.
			4%		1.4	1.4		
			13%		1.2	1.2		
EPA (1988) [5]	Hazardous Waste Impoundments	smooth synthetic liners	0.4%	0.49	1.3	1.8	47.1 (9-minute)	Use local historical data for maximum sustained winds. Adjusted to 10 meters although not stated what height to use. Duration set to 9 minutes because that is the time required for waves to fully develop. There is no indication that the wind speed should be adjusted for overland to overwater differences.
			2%		1.1	1.6		
			13%		0.8	1.3		

Notes:

[1] Values calculated for a water level elevation of 1748 feet in the pond.

[2] Runup was calculated for smooth and rough slopes, but only the most conservative results are shown here.

[3] Significant wave height is defined as the average height of the highest one-third of the waves of a given group or spectrum, which corresponds to a probability of exceedance of 13%. "Wave height" is the vertical distance between a wave crest and the preceding trough (ft). See Table 3 of USBR (1992) guidance for the best summary of this relationship. A probability of exceedance of 0.4% is based on the average wave height of the highest 1% of waves; a probability of exceedance of 2% is based on the average wave height of the highest 5% of waves; and a probability of exceedance of 4% is based on the average wave height of the highest 10% of waves.

[4] The maximum 3-second gust wind speed (1948-2000) was adjusted in accordance with each methodology's specifications.

[5] EPA (1988) states that roughness coefficients for synthetic membranes were not available and runup may be different than calculated.

Table 2: Wind Speed Data

USDOA FTP Web Site [1]		
Average wind speed (1984-2000)	10.26	mph
Maximum wind gust speed (1984)	62.82	mph
Las Vegas Residential and Building Codes		
three-second gust speed (50-year recurrence)	90	mph
fastest-mile speed	76	mph

Notes:

[1] Anenometer height at time of maximum wind, 6.10 m

USDOA = United States Department of Agriculture

Table 3: Design Wind Speed Calculations (USACE 2002)

Part I: Identify Site-Specific Meteorological Data		
Overland maximum wind gust speed (@ 6.1 m)	62.82	mph
Part II: Adjust to 10 meters above ground		
U/U_{10}	0.93	--
Overland maximum wind gust speed (@ 10 m)	67.42	mph
Part III: Adjust for Wind Duration (3-second wind gust to 9-min average)		
Measured maximum wind gust speed duration, 3-s	3	s
Desired maximum wind speed duration, 9-min	540	s
U_{540}/U_{3600}	1.06	--
U_3/U_{3600}	1.51	--
U_{540}/U_3	0.70	--
Overland maximum 9-minute wind speed (@ 10 m)	47.13	mph
Part IV: Adjust Overland Wind Speed to Overwater		
U_w/U_L	1.2	--
Overwater maximum 9-minute wind speed (@ 10 m)	56.6	mph

Notes:

Assumed anenometer height is 10 meters.

A 9-minute averaging period is chosen because this is the time required for wave generation to become fetch-limited according to Equation II-2-35.

Table 4: Design Wind Speed Calculations (Linsley 1992)

Part I: Identify Site-Specific Meteorological Data		
Overland Maximum wind gust speed (@ 6.1 m)	62.82	mph
Part II: Adjust to 7.6 meters above ground		
U/U_{10}	0.97	--
Overland Maximum wind gust speed (@ 7.6 meters)	64.82	mph
Part III: Adjust Overland Wind Speed to Overwater		
U_w/U_L	1.08	--
Overwater Maximum wind gust speed (@ 7.6 meters)	70.0	mph

Notes:

Assumed anenometer height is 7.6 meters (25 feet).

Equation to adjust wind speed to 10 meters above ground is taken from USACE guidance (USACE last revised 2011).

Table 5: Design Wind Speed Calculations (USBR 1992)

Part I: Identify Site-Specific Meteorological Data		
Overland maximum wind gust speed (@ 6.1 m)	62.82	mph
Part II: Adjust to 10 meters above ground		
U/U_{10}	0.93	--
Overland maximum wind gust speed (@ 10 m)	67.42	mph
Part III: Adjust for Wind Duration (3-second wind gust to 7-min average)		
Measured maximum wind gust speed duration, 3-s	3	s
Desired maximum wind speed duration, 7-min	420	s
U_{420}/U_{3600}	1.07	--
U_3/U_{3600}	1.51	--
U_{420}/U_3	0.71	--
Overland maximum 5-minute wind speed (@ 10 m)	47.7	mph
Part IV: Adjust Overland Wind Speed to Overwater		
U_w/U_L	1.2	--
Overwater maximum 5-minute wind speed (@ 10 m)	57.3	mph

Notes:

Assumed anenometer height is not specified so the standard of 10 meters is used.

USBR guidance recommends using the maximum sustained wind speed. A 5-minute averaging period is chosen because this is the time required for wave generation to become fetch-limited according to Equation 1.

Equations to adjust wind speed to 10 meters above ground and to a 5-minute averaging period are taken from USACE guidance (USACE last revised 2011).

Table 6: Design Wind Speed Calculations (USEPA 1988)

Part I: Identify Site-Specific Meteorological Data		
Overland maximum wind gust speed (@ 6.1 m)	62.82	mph
Part II: Adjust to 10 meters above ground		
U/U_{10}	0.93	--
Overland maximum wind gust speed (@ 10 m)	67.42	mph
Part III: Adjust for Wind Duration (3-second wind gust to 9-min average)		
Measured maximum wind gust speed duration, 3-s	3	s
Desired maximum wind speed duration, 9-min	540	s
U_{540}/U_{3600}	1.06	--
U_{3}/U_{3600}	1.51	--
U_{540}/U_{3}	0.70	--
Overland maximum 9-minute wind speed (@ 10 m)	47.13	mph

Notes:

Assumed anenometer height is not specified so the standard of 10 meters is used.

USEPA guidance recommends using the maximum sustained wind speed, but no specific method is suggested. A 9-minute averaging period is chosen because this is the maximum time required for wave generation to become fetch-limited USBR (1992) and USACE (Last revised 2011) methods.

Equations to adjust wind speed to 10 meters above ground and to a 9-minute averaging period are taken from USACE guidance (USACE last revised 2011).

Table 7: Wave Run-up Model Parameters (USACE 2002, Last revised 2011)

Parameter Description	Symbol	Value	Units	Source
Runup level exceeded by 2 percent of the incident waves	$R_{2\%}$	1.26	feet	Equation VI-5-3 (Coefficients A and C from Table VI-5-2)
Runup level exceeded by 13 percent of the incident waves	R_s	1.07	feet	Equation VI-5-3 (Coefficients A and C from Table VI-5-2)
Runup level exceeded by 2 percent of the incident waves	$R_{2\%}$	0.39	m	Equation VI-5-3 (Coefficients A and C from Table VI-5-2)
Runup level exceeded by 13 percent of the incident waves	R_s	0.32	m	Equation VI-5-3 (Coefficients A and C from Table VI-5-2)
Influence factor for influence of a berm	γ_b	1.0	--	For non-bermed profiles = 1.0
Reduction factor for surface roughness	γ_r	1.0	--	For smooth slopes = 1.0
Reduction factor for shallow-water conditions where the wave height distribution deviates from the Rayleigh distribution	γ_h	1.0	--	For Rayleigh distributed waves = 1.0
Reduction factor for angle of incidence of the waves	γ_β	1.0	--	For head-on long-crested waves = 1.0
Surf similarity parameter (Iribarren number)	E_{op}	0.94	--	Equation VI-5-2
Wave steepness	s_{op}	0.13	--	Equation VI-5-2 (Assumes H_{mo} is equivalent to H_s)
Limiting wave period	$T_{p\ (to\ not\ exceed)}$	6.79	s	Equation II-2-39
Peak wave period	T_p	1.14	s	Equation II-2-36
Limiting wave height	H_∞	17.61	m	Equation II-2-30
Energy-based significant wave height	H_{mo}	0.26	m	Equation II-2-36
		0.84	feet	
Friction velocity	u*	1.13	m/s	Equation II-2-36
Drag coefficient	C_D	2.0E-03	--	Equation II-2-36

Table 7: Wave Run-up Model Parameters (USACE 2002, Last revised 2011)

Parameter Description	Symbol	Value	Units	Source
time required for waves to become fetch-limited	$t_{x,u}$	552.24	s	Equation II-2-35
		9.20	min	
Angle of slope	alpha	18.43	degrees	1:3 slope embankment
Average depth of pond	d	15.5	feet	Average depth of pond is calculated as water level elevation - 1732.5 feet to obtain most conservative wind setup value.
		5	m	
Water level elevation of pond	SWL	1748	feet	
Design wind speed, Las Vegas, NV	V_w	83.0	ft/s	
		25	m/s	
		56.6	mph	
Fetch	F	980	feet	Measured in Google Earth as longest diagonal distance of the as-built pond dimensions in the direction of maximum wind gust speed observed in 1984.
		299	m	
		0.19	miles	
gravity	g	9.80	m/s^2	
Maximum setup	n_{max}	0.01	m	Equation II-4-25
		0.02	f	
Delta x	dx	0.02	m	Equation II-4-25
Gradient	dn/dx	0.02	--	
Setdown at the breaker point	n_b	0.00	m	
Setup at the still-water shoreline	n_s	0.01	m	Equation II-4-24
Breaker depth	d_b	0.49	m	
Breaker depth index	$gamma_b$	0.40	--	
a	--	43.72	--	
b	--	1.56	--	
Breaker height	H_b	0.19	m	
Breaker height index	$omega_b$	0.76	--	Assume H_{mo} is equivalent to H_o
Deepwater wavelength	L_o	1.17	m	
Mean wave period	T_m	0.87	s	
Mean to peak wave period ratio	T_m/T_p	0.76	--	Example Problem VI-7-1

Table 8: Wave Run-up Model Parameters (Linsley et al. 1992)

Parameter		Value	Units	Source
Maximum vertical rise of pond (2%)	$R + Z_s$	2.75	feet	
Maximum vertical rise of pond (13%)	$R + Z_s$	1.57	feet	
2% wave runup height	R = (R/H)*H	2.71	feet	
13% wave runup height	R = (R/H)*H	1.53	feet	
Ratio of runup to the 2% wave height	R/H	1.39	--	Determined from Figure 7.16 based on slope of embankment and value of $z_{2\%}/\lambda$
Ratio of runup to the 13% wave height	R/H	1.10	--	Extrapolated from Figure 7.16 based on slope of embankment and value of $z_{13\%}/\lambda$
2% wave height / wavelength	$z_{2\%} / \lambda$	0.11	--	
13% wave height / wavelength	$z_{13\%} / \lambda$	0.08	--	
Wave period	T	1.86	s	
Wavelength	λ	17.74	feet	
Wave height that will be exceeded in height by only 2% of the waves	$z_{2\%}$	1.95	feet	
Significant wave height (average height of highest one-third of waves)	$z_{13\%}$	1.39	feet	Height of this wave exceeded 13% of the time.
Wind setup	Z_s	0.04	feet	
Average depth of pond	d	15.5	feet	Average depth of pond is calculated as water level elevation - 1732.5 feet to obtain most conservative wind setup value. The final result is not sensitive to this parameter.
Static water level elevation of pond	SWL	1748	feet	
Design top wind speed, Las Vegas, NV	V_w	102.7	ft/s	
		70.0	mph	
Maximum fetch	F_{max}	980	feet	Maximum fetch measured in Google Earth as longest diagonal distance of the as-built pond dimensions.
		0.19	miles	

Notes:

Results are for a smooth slope embankment.

Table 9: Wave Run-up Model Parameters (USBR 1992)

Parameter	Symbol	Value	Units	Source
Wave runup height (riprap)	$R_{4\%}$	0.93	feet	
Wave runup height (smooth)	$R_{4\%}$	1.40	feet	1.5 is the maximum roughness coefficient used to be conservative
Wave runup height (riprap)	$R_{0.4\%}$	1.11	feet	
Wave runup height (smooth)	$R_{0.4\%}$	1.66	feet	1.5 is the maximum roughness coefficient used to be conservative
Wave runup height (riprap)	$R_{1/3}$	0.80	feet	
Wave runup height (smooth)	$R_{1/3}$	1.20	feet	1.5 is the maximum roughness coefficient used to be conservative
Wave period	T	1.40	s	Equation 6
Wavelength	λ	10.08	feet	Equation 5
Wave height that will be exceeded in height by only 2% of the waves	$z_{0.4\%}$	1.87	feet	USBR recommended if overtopping by only an infrequent wave is permissible
Wave height that will be exceeded in height by only 4% of the waves	$z_{4\%}$	1.42	feet	USBR recommended if erosion is not an issue and public traffic will not be interrupted
Significant wave height (average height of highest one-third of waves)	z_w or $H_{1/3}$	1.12	feet	Equation 4; height of this wave exceeded 13% of the time.
Minimum duration required to build up the maximum waves	t_{min}	7.3	min	Equation 1 (converted from hours to minutes)
Wind setup	Z_s	0.03	feet	Equation 8
Average depth of pond	d	15.5	feet	Average depth of pond is calculated as water level elevation - 1732.5 feet to obtain most conservative wind setup value. The final result is not sensitive to this parameter.
Static water level elevation of pond	SWL	1748	feet	
Design top wind speed, Las Vegas, NV	V_w	84.0	ft/s	
		57.3	mph	
Fetch	F	980	feet	Measured in Google Earth as longest diagonal distance of the as-built pond dimensions in the direction of maximum wind gust speed observed in 1984.
		0.19	miles	

Table 10: Wave Run-up Model Parameters (USEPA 1988)

Parameter	Symbol	Value	Units	Source
Freeboard allowance	F_A	2.24	feet	25% Safety Factor
Maximum vertical rise of pond	Rc + S	1.79	feet	
Corrected runup height	Rc	1.31	feet	0.4% runup
2% runup height	$R_{2\%}$	1.10	feet	2% runup
Wave runup height	R	0.78	feet	33% runup
Ratio of runup to the wave height (for smooth surface)	R/H'_o	0.83	--	Obtained from Figure 3-5 using H'_o/gT^2 for a 1:3 slope. Equal to 0.83 for d_m values 15.3 feet and greater.
--	H'_o/L_o	0.11	--	
--	H'_o/gT^2	0.017	--	
Deep water wave height	H'_o	0.94	feet	
--	H/H'_o	1.00	--	If dm/Lo >1.0 then this is equal to 1, otherwise obtain from Table 4-1.
--	d_m/L_o	2.03	--	
Deep water wave length	L_o	8.88	feet	Typo in document. (g)/2 should be g/2pi, which is 5.12
Wind setup	S	0.49	feet	
Wind speed; Formula Characteristic Velocity	U_o	13.82	ft/s	
--	A	3.3E-06		
--	B	2.1E-04		
Wave Period	T	1.32	s	
Wave Height	H	0.94	feet	
Maximum depth of pond	d_m	18.0	feet	
Static water level elevation of pond	SWL	1748	feet	
Wind stress factor	U_a	108	ft/s	
		74	mph	
Design top wind speed, Las Vegas, NV	V_w	69.1	ft/s	
		47.1	mph	
Maximum fetch	F_{max}	980	feet	Measured in Google Earth as longest diagonal distance of the as-built pond dimensions in the direction of maximum wind gust speed observed in 1984.
		0.19	miles	
gravity	g	32.2	ft/s^2	
Density of water	ρ_L	62.3	lbs/ft^3	@ 70 degrees Farenheit
Density of air	ρ_a	0.075	lbs/ft^3	@ 20 degrees Celcius and 760 mm Hg
Kinematic viscosity of water	v_L	1.1E-05	ft^2/s	@ 70 degrees Farenheit