Clive Facility Total Ditch Flow Calculations

The following calculations are completed to determine the adequacy of the Clive facility ditch systems to contain runoff associated with both normal and abnormal precipitation events that could occur during operations. This assessment was performed specifically for the introduction of the Class A West (CAW) embankment. After operations cease, Energy*Solutions* will take no credit for the remaining ditch systems.

As currently planned, drainage from completed portions of all covers will be directed throughout the ditch systems to an outlet in the southwestern corner of the site. At this point, the water is dispersed into the desert south of the facility. A simple depiction of the drainage plan is provided in Figure 1.

Figure 1. Simple schematic of the site with general drainage flows (not to scale)

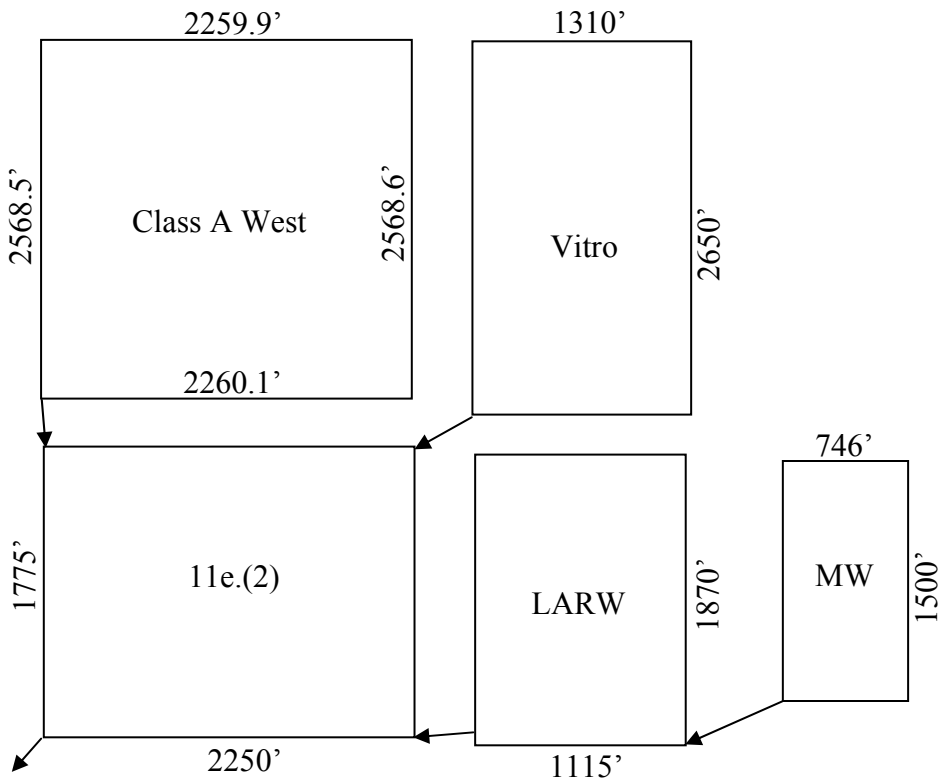


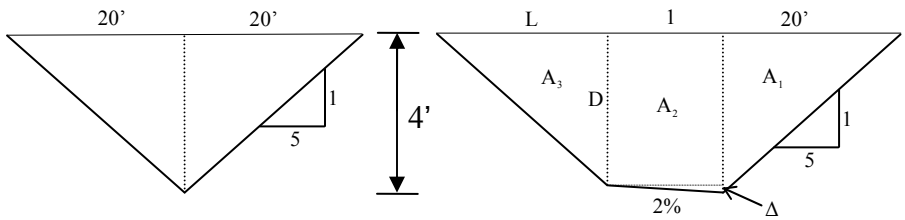
Figure 1 also provides details on the length/width geometry of each of the embankments that are part of this drainage system. With the exception of the Vitro embankment, the dimensions presented in Figure 1 are the waste limit dimensions for each embankment. The stated dimensions of the Vitro Embankment are for the entire run-off area. Four separate dimensions have been given for the Class A West embankment as it's design dimensions are slightly different for each side.

Water from all embankments will flow through the 11e.(2) drainage ditches before reaching the drainage system outlet. The outlet channel is much larger than the ditches

feeding it; therefore, the performance requirement of the entire system will depend on the performance characteristics of the 11e.(2) drainage ditches.

1. Flow Velocities for the Class A West and 11e.(2) Drainage Ditches

To begin the performance assessment of the CAW and 11e.(2) drainage ditches, the peak flow velocities for the ditches must be calculated. These flow velocities are based upon the flow area and slope of the ditches. A conservative assumption has been made that all ditches throughout the site have triangular geometry 4 feet deep by 40 feet wide (5H:1V side slopes). This geometry is the minimum requirement for the ditches and thereby provides the minimum cross-sectional flow area within the ditches. To achieve the desired slopes, as described in the design drawings, the actual ditches will have sections (on the waste side) that will have only 2% slopes within the ditch. The not-to-scale drawing below shows the two ditch designs side-by-side; the calculations that follow demonstrate that the "V" ditch geometry is the most conservative.



The cross-sectional area of the "V" ditch design on the left is the simply one-half the surface (40 feet) times the depth (4 feet), or 80 ft^2. The cross-sectional area of the design with a 2% slope section is more difficult. As an example, we will use a 2% slope area of only 1 foot as shown in the drawing. In order to find the surface area of this cross-section, it is necessary to add up the cross-sectional area of the three sections (A_1, A_2, and A_3). A_1 is simply one-half the surface (20 feet) times the depth 4 feet), or 40 ft^2. Delta (Δ) is the depth associated with the 2% slope section of the ditch. At 1 foot of length and a 2% slope, the value of Δ is 0.02 feet. The depth of water in the other triangular area (A_3) is the original depth of the ditch (4 feet) minus Δ, or 3.98 feet. Since the side slope of the embankment is 5:1, the length of the other triangular area, L = 3.98 x 5 = 19.9 feet. Therefore, the area of the second triangular area, A_3, is ½(19.9)(3.98) = 39.6 ft^2. The area of the middle section, A_2, is the sum of the areas of the rectangle and the small triangle over the 2% slope section of the ditch. The rectangle area is 3.98 x 1 = 3.98 ft^2 and the small triangle area is ½(1)(0.02) = 0.01 ft^2. Therefore, the area of the middle section, A_2 = 3.99 ft^2 and the entire cross-sectional area of the ditch is 40+39.6+3.99 = 83.6 ft^2, which is larger than the cross-sectional area of the "V" ditch (80 ft^2). As the length of the 2% slope section increases, this area discrepancy becomes greater. This analysis shows that assuming all ditches are the "V" ditch design is a conservative approach.

Drawing 10014-C01 shows design dimensions for the CAW ditches. Drawing 10014-C03 shows the distance between the toe of waste and the centerline of the ditch is 15.3 feet. In conjunction, these drawings depict a 1.6 foot drop in elevation

within the northern ditch over a length of 2290.5 feet; a 2.9 foot drop in elevation within the eastern ditch over a length of 2599.2 feet; a 1.6 foot drop in elevation within the southern ditch over a length of 2290.7 feet; and a 2.9 foot drop in elevation within the western ditch over a length of 2599.1 feet. Based on these dimensions, the calculated slopes are:

North: 1.6 feet / 2290.5 feet = 6.99×10^{-4} foot/foot
East: 2.9 feet / 2599.2 feet = 1.12×10^{-3} foot/foot
South: 1.6 feet / 2290.7 feet = 6.98×10^{-4} foot/foot
West: 2.9 feet / 2599.1 feet = 1.12×10^{-3} foot/foot

Slopes for the 11e.(2) ditch system may be discerned from the ditch centerline elevations provided in Drawing 9420-4. For the 11e.(2) ditch system, the following slopes are calculated based on ditch centerline drop in elevation across the ditch centerline length (note that the dimensions of the ditch centerline are the edge of waste dimensions provided in Figure 1 plus 42.5 feet in all directions):

North/South Lengths: 1.1 feet / 2335 feet = 4.71×10^{-4} foot/foot
East/West Lengths: 0.9 feet / 1860 feet = 4.84×10^{-4} foot/foot

Based on these slopes, and using Manning's Formula, the maximum flow rate for each side of the embankment may be calculated using the V-shaped ditch that is 40 feet wide by 4 feet deep with a 5:1 (H:V) side slope. Manning's Formula is:

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

where,

Q = flow in cubic feet per second
n = Manning's Coefficient of Roughness (= 0.035 for ditches with earth, stone, and weeds)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius; area of flow divided by wetted perimeter (WP) (ft)
S = slope (ft/ft)

Since the side slopes are 5:1, the water in the ditch, at the surface, will extend five times the depth (d) in each direction. Therefore, the cross-section will be a triangle with a base of 2(5d) and a height of d. Therefore, the cross-sectional area will be ½ x $2(5d)d = 5d^2$. Furthermore, a single side of the wetted perimeter is the hypotenuse of the right triangle created by the depth, d, and the surface, 5d. Therefore, the wetted perimeter is $2 \times (d^2 + 25d^2)^{½}$.

The literature value for the Manning's Coefficient of Roughness for ditches with earth, stone, and weeds (0.035) may be found in several references; the particular reference used for this analysis was "Environmental Engineering Reference Manual for the PE Exam", by Michael R. Lindeburg, PE, 2001, Professional Publications, Inc. This value may alternatively be calculated based on the diameter of rocks in the

ditch. An equation has been derived by Abt, et. al. in 1988 ("Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II," NUREG/CR-4651). This equation only constitutes effects to Manning's Coefficient of Roughness due to the size of the rock within the ditch. The formula is as follows:

$$n = 0.0456 * (D_{50}*S)^{0.159}$$

The design of the ditch consists of a six inch thick Type A filter layer placed on the ground surface within the ditch and one foot of Type A RipRap overlying this filter layer. Utilizing the Abt equation above, and noting that the D_{50} of the Type A Filter Rock within the drainage ditches is 40 mm (1.57 inches), the Coefficient of Roughness based on the filter rock is calculated as:

n = 0.0186 for the north and south ditches and
n = 0.0168 for the east and west ditches.

Comparatively, the D_{50} of the Type A RipRap is 4.5 inches. Therefore, the Coefficient of Roughness based on the RipRap rock may be calculated as:

n = 0.0220 for the north and south ditches and
n = 0.0200 for the east and west ditches.

Therefore, the literature value for the Manning's Coefficient of Roughness provides a conservative estimate of the flow of water in the ditches.

Tables 1 and 2, on the next page, display the calculated flow rates of the CAW and 11e.(2) ditch systems using Manning's formula. The tables also depict the peak flows that each of the ditch systems is able to manage.

Table 1. Ditch Flow Rates for the CAW Drainage Ditches

Height of water in Ditch (ft)	Flow area in Ditch A (ft^2)	Wetted Perimeter WP (ft)	Hydraulic Radius R=A/WP	North (S = 0.07%)		East (S = 0.11%)		South (S = 0.07%)		West (S = 0.11%)	
				Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)	Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)	Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)	Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)
0.5	1.25	5.10	0.25	0.55	32.97	0.69	41.66	0.69	41.66	0.55	32.96
1.0	5.00	10.20	0.49	3.49	209.32	4.41	264.54	4.41	264.54	3.49	209.31
1.5	11.25	15.30	0.74	10.29	617.13	13.00	779.94	13.00	779.94	10.29	617.11
2.0	20.00	20.40	0.98	22.15	1329.07	28.00	1679.71	28.00	1679.71	22.15	1329.02
2.5	31.25	25.50	1.23	40.16	2409.77	50.76	3045.51	50.76	3045.51	40.16	2409.67
3.0	45.00	30.59	1.47	65.31	3918.55	82.54	4952.34	82.54	4952.34	65.31	3918.38
3.5	61.25	35.69	1.72	98.51	5910.86	124.50	7470.24	124.50	7470.24	98.51	5910.60
4.0	80.00	40.79	1.96	140.65	**8439.09**	177.76	**10665.47**	177.76	**10665.47**	140.65	**8438.72**

Table 2. Ditch Flow Rates for the 11e.(2) Drainage Ditches

Height of water in Ditch (ft)	Flow area in Ditch A (ft^2)	Wetted Perimeter WP (ft)	Hydraulic Radius R=A/WP	North/South (S = 0.05%)		East/West (S = 0.05%)	
				Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)	Flow Rate Q (ft^3/sec)	Flow Rate Q (ft^3/min)
0.5	1.25	5.10	0.25	0.45	27.07	0.46	27.44
1.0	5.00	10.20	0.49	2.86	171.89	2.90	174.21
1.5	11.25	15.30	0.74	8.45	506.80	8.56	513.63
2.0	20.00	20.40	0.98	18.19	1,091.46	18.44	1,106.16
2.5	31.25	25.50	1.23	32.98	1,978.95	33.43	2,005.61
3.0	45.00	30.59	1.47	53.63	3,217.98	54.36	3,261.34
3.5	61.25	35.69	1.72	80.90	4,854.10	81.99	4,919.49
4.0	80.00	40.79	1.96	115.51	**6,930.33**	117.06	**7,023.70**

2. **Storm Events**

The performance of the drainage ditches to contain runoff is only important during the active life of the facility (approximately 25 years). Upon closure, the drainage ditches will either be removed or become silted in to allow sheet flow across the site over the natural grade of the area. Therefore, a reasonable maximum normal storm event over the active life of the ditches is the 25 year, 24 hour storm event (1.9 inches). A reasonable abnormal event during the active life of the ditches is the 100 year, 24 hour storm event (2.4 inches). Both of these storm events are depicted in the isopluvial maps of NOAA Atlas 2, Volume VI (1973; see web sight www.wrcc.dri.edu/pcpnfreq.html). These maps contain 6 and 24 hour events with return frequencies of 100 and 25 years. Region specific equations to calculate storm distributions are also provided in the text accompanying these maps. This text portion is attached to this document.

The rainfall amount at one hour during the 100- and 25-year events may be calculated using the equations provided in the text of NOAA Atlas 2. For the region of Utah that Clive is located in (region 2; see figure 18 of the attached NOAA text), the equation is:

$$1\text{-hr} = 0.322 + 0.789\left[(6\text{-hr})\left(\frac{6\text{-hr}}{24\text{-hr}}\right)\right]$$

The variables (6-hr) and (24-hr) are the precipitation amounts read from the isopluvial maps.

Empirical equations have been developed for the 15-min, 30-min, 2-hour, and 3-hour events. These equations are based upon the previously derived 1-hour and 6-hour events:

$$\text{15-min} = 0.57 \text{ x } (\text{1-hr})$$

$$\text{30-min} = 0.79 \text{ x } (\text{1-hr})$$

$$\text{2-hr} = 0.299 \text{ x } (\text{6-hr}) + 0.701 \text{ x } (\text{1-hr})$$

$$\text{3-hr} = 0.526 \text{ x } (\text{6-hr}) + 0.474 \text{ x } (\text{1-hr})$$

The 12-hour distribution may be easily found using graphical methods, based upon the 6-hr and 24-hr events, described in the NOAA text.

Using the equations and methods described above, the following storm distributions may be obtained:

Time (minutes)	Normal Event (25 Year Storm) (inches)	Abnormal Event (100 Year Storm) (inches)
15	0.65	0.73
30	0.90	1.00
60	1.14	1.27
120	1.21	1.40
180	1.27	1.50
360	1.40	1.70
720	1.65	2.05
1440	1.90	2.40

Over the short active life span of the drainage ditches, it would not be reasonable to assume larger storm events such as the Probable Maximum Precipitation (PMP). These larger storm events are more appropriately utilized in the longer life elements of the embankment design such as the rock cover over the embankment.

3. **Drainage Area**

With the exception of the Vitro embankment, the dimensions presented in Figure 1 are the waste limit dimensions for each embankment. The stated dimensions for the Vitro embankment are for the entire run-off area. For the 11e.(2) embankment, the distance between the waste limits and the centerline of the ditch is 42.5 feet (8.5 feet of cover times 5 for a 5:1 side slope). For the Mixed Waste Landfill, the distance between the waste limits and the centerline of the ditch is 65 feet. For the LARW embankment, the distance between the waste limits and the centerline of the ditch varies between 15 and 35 feet, but a more conservative 35 feet is used in the area calculation. For the Class A West embankment, the distance between the waste limits and the centerline of the ditch is a 15.3 feet (see Drawing 10014-C03). Further, for all embankments except Vitro, the drainage area conservatively extends another 45.6 feet beyond the centerline of the ditch to the outer edge of the inspection road (see drawing 10014-C03). Using the information described above, the actual drainage dimensions and areas for each embankment are:

Embankment	Length (E-W) (ft)	Width (N-S) (ft)	Drainage Area (ft^2)
Class A West	2,381.8*	2,690.35*	6,407,875.63
Vitro	1,310	2,650	3,471,500.00
LARW	1,276.2	2,031.2	2,592,217.44
11e.(2)	2,426.2	1,951.2	4,734,001.44
MW	967.2	1,721.2	1,664,744.64

* In order to obtain an accurate drainage area, the length and width dimensions for the Class A West embankment are an average of each of the different length/width dimensions as shown in Figure 1.

Summing these drainage areas, the total drainage area is 18,870,339.15 square feet.

Run-off Coefficient, C = 0.5 (for earth with stone surface).

Thus, the Site Weighted Total Drainage Area = (18,870,339.15)(0.5)
= **9,435,169.58 ft^2**

The run-off coefficient has been estimated based upon a worst-case review of literature values for similar surfaces (see "Environmental Engineering Reference Manual for the PE Exam", by Michael R. Lindeburg, PE, 2001, Professional Publications, Inc. The value of 0.5 provides a conservative estimation for drainage from the embankments at the Clive facility. The Cover Test Cell (CTC) is a simulation of the designed embankment cover. The CTC has been providing run-off data for nine years. Calculated run-off data from the CTC combined with precipitation data from the site weather station provides an observed run-off coefficient for the embankment cover design. The data for the nine years of operation are as follows:

Year:	2002	2003	2004	2005	2006	2007	2008	2009	2010
Run-off (in/yr):	0.112	0.000	0.727	1.341	0.838	0.335	0.000	0.112	0.009
Precip (in/yr):	5.75	7.46	9.06	10.16	7.39	8.29	3.20	8.12	9.00
Run-off Coefficient:	**0.019**	**0.000**	**0.080**	**0.132**	**0.113**	**0.040**	**0.000**	**0.014**	**0.001**

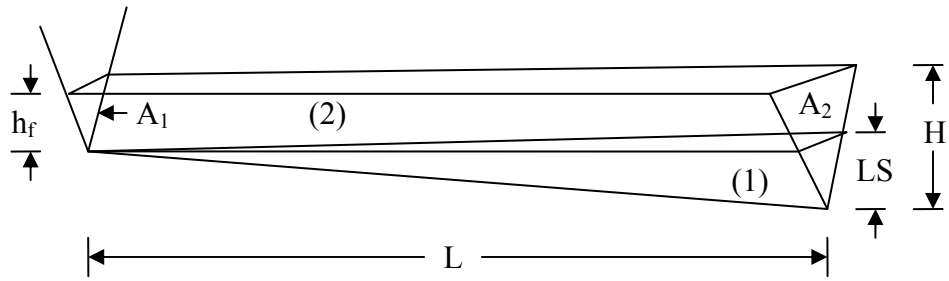
Disregarding the two years that no run-off was observed (2003 and 2008), the average annual run-off coefficient is calculated at 0.057. Therefore, the literature value run-off coefficient of 0.5 used in these calculations provides conservative drainage results.

4. Ditch Volume Equations

To obtain a realistic volume, the geometry and slope of the ditches must be reviewed together. This is necessary because the ditches are sloped so that the height of water in each ditch will increase as you progress down slope within the ditch. The calculations of ditch volume require an understanding of the geometry within each ditch.

To illustrate the geometry, Figure 2 provides a cross-section view of a ditch with the geometric features described below highlighted.

Figure 2. Ditch Cross-Section



The following parameters are depicted in Figure 2 and explained further below:

H	=	height of water in the ditch at the lowest point of the ditch
L	=	length of the ditch
LS	=	length of ditch times slope of ditch
	=	height of water in the pyramid section of the ditch (see below)
h_f	=	height of water in the frustum section of the ditch (see below)
A_1	=	triangular plane of the frustum section of the ditch (see below)
A_2	=	trapezoidal plane of the frustum section of the ditch (see below)

To calculate the volume of each ditch section, the ditch must be separated into two solid geometric figures, as depicted in Figure 2.

(1) A three-sided pyramid created by visualizing a zero-slope plane that bisects the ditch such that the plane rests upon the ditch centerline at the upper end of the slope. This, when extended across the length of the ditch, creates a pyramid below the plane that has a triangular base on the down slope side of the ditch with a water height equal to the length of the ditch multiplied by the slope.

(2) The volume above this plane is a frustum of a second pyramid with the upper end of the slope consisting of a triangular area and the lower end of the slope a trapezoid formed from the visualized plane mentioned above up to the height of the ditch.

The volume of each section of the ditch may be calculated by first calculating these two separate volumes and adding them together. Using geometry and algebra, the volume within any ditch may be calculated from three factors: the length of the ditch (L), the height of water in the ditch at the low point of the ditch (H), and the slope of the ditch (S). The derivations of the required formula's follow:

(1) <u>Pyramid Section</u>

Volume of pyramid, $V_{pyramid}$ = 1/3 (base area) (length)

The height of water at the base of the pyramid (lowest point of the ditch) is:

$$h = LS$$

The base area, A_{base} = ½ (width) h

Since all of the ditches have 5:1 slopes on both sides, the width of water within the ditch is simply 2 x 5 x h = 10h = 10LS.

Therefore, $A_{base} = ½ (10LS) LS = 5(LS)^2$;

and $\mathbf{V_{pyramid} = 1/3\ (5(LS)^2)\ L = 5/3(L^3S^2)}$.

Note in the case that the ditch height, H, is lower than the triangle height, h, then length of water up the ditch, L may be represented as L = H/S, and

$$V_{pyramid} = 5/3(H/S)^3S^2 = 5/3(H^3/S)$$

(2) Frustum Section

Volume of frustum, $V_{frustum} = 1/3\left(A_1 + A_2 + \sqrt{A_1A_2}\right)L$

where A_1 and A_2 are the areas of the two planes at the top and bottom of the frustum as depicted in Figure 2 (A_1 is the area of the triangle on the upslope end of the ditch and A_2 is the area of the trapezoid on the downslope end of the ditch).

Since the base height of water in the frustum at the downslope end is LS (the height of water in the pyramid section), the height of water in the frustum, h_f, may be correlated to the height of water in the ditch at the downstream end, H, using the following equation:

$$h_f = H - LS$$

A_1 = triangle = ½ (width)h_f = ½ ($10h_f$)h_f = $5(H - LS)^2$.

A_2 = trapezoid = ½ ($W_{bottom} + W_{top}$)h_f

W_{bottom} and W_{top} are the widths of the triangular ditch at the bottom and top of the trapezoid. From the geometry of the ditch:

W_{bottom} = width of pyramid section = 10LS

and

$W_{top} = 10H$

Therefore, $A_2 = ½ (10LS + 10H)(H – LS) = 5(H + LS)(H – LS)$; and

$$\mathbf{V_{frustum} = 1/3\ L\ \{5(H - LS)^2 + 5(H + LS)(H - LS) + [5(H - LS)^2(5(H + LS)(H - LS))]^{½}\}.}$$

Upstream Storage

Some account must be made for water that backflows up into upslope ditch sections. In general, this backflow will not exceed the pyramid section of the upslope ditch. Furthermore, the upslope ditch will have a different slope from the down slope ditch; this slope will be designated S_2. The pyramid volume for the upslope ditch section uses the same formula derived for the down slope section; however, the length that liquid travels up the ditch into this upslope area (L_2) is slightly different:

$$L_2 = \frac{H - LS}{S_2}$$

Further, A_{base} for this ditch section is equivalent to A_1 from the trapezoid section of the down slope ditch. Therefore,

$$\mathbf{V_{pyramid,up} = 1/3\left(5(H - LS)^2\right)\left(\frac{H - LS}{S_2}\right) = 5/3\left(\frac{(H - LS)^3}{S_2}\right)}$$

In the event that the height of water in the upslope ditch exceeds the height of the pyramid section, L_2 will equal the design length of the upslope ditch and the upslope ditch pyramid section will be completely full:

$$V_{pyramid,up} = 5/3(L_2^3 S_2^2).$$

Furthermore, an additional volume within the upslope ditch frustum section should also be accounted for. The height of water in the upslope frustum section, h_f, is calculated as follows:

$$h_f = H – LS – L_2S_2$$

and the other calculations are the same as above to give:

$$A_{1,up} = 5(H – LS – L_2S_2)^2$$

$$W_{bottom,up} = 10L_2S_2$$

$$W_{top,up} = 10(H – LS)$$

$$A_{2,up} = 5(H - LS + L_2S_2)(H - LS - L_2S_2)$$

$V_{frustum,up}$ may then be calculated using these areas and the frustum volume equation provided previously.

Total Storage

The total storage volume is the sum of all the appropriate individual ditch volumes:

$$\mathbf{V_{total} = V_{pyramid} + V_{frustum} + V_{pyramid,up} + V_{frustum,up}}$$

These equations have been used to define ditch storage volume in the calculations that follow.

5. Drainage Calculations – CAW Ditches

From design drawing 10014-C01, the ditches around the CAW embankment are highest at the northeast corner and flow south-west or west-south to the discharge point in the southwest corner. Half of the flow from the embankment will be directed through the northern and western drainage ditches; the other half will be directed through the eastern and southern drainage ditches. Individual ditches will have different drainage areas associated with them. From design drawing 10014-C01, the northern ditch has approximately 22% of the entire drainage area. Likewise, the eastern ditch has approximately 28% of the entire drainage area. Both the western and the southern ditches receive water from upstream as well as off the embankment above; both with approximately 50% of the drainage area. The overall drainage area of the CAW embankment, as well as the slopes and lengths of ditches were provided previously in this report.

The calculations that follow perform a simple mass balance over each ditch:

Flow into the ditch – Flow out of the ditch = Accumulated Storage

The accumulated flow into the ditch is calculated by multiplying the accumulated rainfall by the drainage area associated with that particular ditch. The flow out of the ditch (volume of water discharged) is calculated by multiplying the flow rate at a specific depth (as calculated in Section 1 above) by the elapsed time of rainfall.

The volume of each ditch at a specified depth (H) is calculated using the equations derived in Section 4 of this report. The volume associated with this depth may be compared to the required storage volume calculated by subtracting the available discharge from the accumulated flow into the ditch. Iterations based on the depth of water in the ditch may be made to equate these two volumes, providing a maximum depth of flow within the ditch for a particular storm event.

Northern CAW Ditch

NORMAL STORM EVENT

The drainage area for the northern CAW ditch is 22% of the total drainage area for the CAW embankment, or 6,407,875.63 × 0.5 × 0.22 = 704,866 ft^2. This is the beginning of drainage and therefore there is no upstream storage available. For the worst-case normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the northern CAW ditch. This depth was found to be 2.01 feet at the lowest portion of the ditch (NW corner). Using this depth and the slope of the CAW embankment northern ditch (6.99×10^{-4}), the discharge flow rate was found to be approximately 1,347 ft^3/min. The storage volume at this height is approximately 17,969 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
CAW Northern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.01 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.65	38,032	20,203	**17,829**
30	0.90	52,711	40,406	12,305
60	1.14	66,722	80,812	*
120	1.21	71,360	161,624	*
180	1.27	74,882	242,436	*
360	1.40	82,234	484,873	*
720	1.65	96,919	2,821,358	*
1440	1.90	111,604	5,642,717	*

* no storage will be necessary

CONCLUSION:

During the worst-case normal condition 25 year, 24 hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the CAW embankment northern ditch is approximately 17,829 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water at the deepest portion of the ditch (NW Corner) of approximately 2.01 feet, leaving approximately 1.99 feet of freeboard. Therefore, the four foot-deep ditch in the northern section of the CAW embankment is adequately designed to contain the normal precipitation event, allowing at least one-foot of freeboard.

Northern CAW Ditch

ABNORMAL STORM EVENT

For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the northern CAW ditch. This depth was found to be 2.10 feet. Using this depth and the slope of the CAW embankment northern ditch (6.99×10^{-4}), the discharge flow rate was found to be approximately 1,514 ft^3/min. The volume of the ditch at this height is approximately 20,386 ft^3.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
CAW Northern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.10 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	42,591	22,706	**19,885**
30	1.00	59,030	45,412	13,617
60	1.27	74,721	90,825	*
120	1.40	82,236	181,650	*
180	1.50	87,942	272,475	*
360	1.70	99,856	544,950	*
720	2.05	120,415	2,821,358	*
1440	2.40	140,973	5,642,717	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100 year, 24 hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the CAW embankment northern ditch is approximately 19,885 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water within the ditch of approximately 2.10 feet, leaving approximately 1.90 feet of freeboard. Therefore, the four-foot deep ditch in the northern section of the CAW embankment is adequately designed to contain the abnormal precipitation event, allowing more than one-foot of freeboard.

Eastern CAW Ditch

NORMAL STORM EVENT

The drainage area for the eastern CAW ditch is 28% of the total drainage area for the CAW embankment, or 6,407,875.63 × 0.5 × 0.28 = 897,103 ft^2. Similar to the northern ditch, this is the beginning of drainage and therefore there is no upstream storage available. For the worst-case normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the eastern CAW ditch. This depth was found to be 2.21 feet at the lowest portion of the ditch (SE corner). Using this depth and the slope of the CAW embankment northern ditch (1.12×10^{-3}), the discharge flow rate was found to be approximately 2,192 ft^3/min. The storage volume at this height is approximately 16,124 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
CAW Eastern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.21 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.65	48,404	32,882	**15,522**
30	0.90	67,086	65,764	1,322
60	1.14	84,919	131,528	*
120	1.21	90,822	263,055	*
180	1.27	95,304	394,583	*
360	1.40	104,662	789,166	*
720	1.65	123,352	3,565,682	*
1440	1.90	142,041	7,131,363	*

* no storage will be necessary

CONCLUSION:

During the worst-case normal condition 25 year, 24 hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the CAW embankment eastern ditch is approximately 15,522 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water at the deepest portion of the ditch (SE Corner) of approximately 2.21 feet, leaving approximately 1.79 feet of freeboard. Therefore, the four foot-deep ditch in the eastern section of the CAW embankment is adequately designed to contain the normal precipitation event, allowing at least one-foot of freeboard.

Eastern CAW Ditch

ABNORMAL STORM EVENT

For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the eastern CAW ditch. This depth was found to be 2.30 feet. Using this depth and the slope of the CAW embankment northern ditch (1.12×10^{-3}), the discharge flow rate was found to be approximately 2,438 ft^3/min. The volume of the ditch at this height is approximately 18,175 ft^3.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
CAW Eastern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.30 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	54,207	36,575	**17,632**
30	1.00	75,129	73,150	1,978
60	1.27	95,099	146,300	*
120	1.40	104,664	292,601	*
180	1.50	111,926	438,901	*
360	1.70	127,090	877,802	*
720	2.05	153,255	3,565,682	*
1440	2.40	179,421	7,131,363	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100 year, 24 hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the CAW embankment eastern ditch is approximately 17,632 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water within the ditch of approximately 2.30 feet, leaving approximately 1.70 feet of freeboard. Therefore, the four-foot deep ditch in the eastern section of the CAW embankment is adequately designed to contain the abnormal precipitation event, allowing more than one-foot of freeboard.

Western CAW Ditch

NORMAL STORM EVENT

The drainage area for the western CAW ditch includes all of the drainage from the northern CAW ditch and is 50% of the total drainage area for the CAW embankment, or 6,407,875.63 × 0.5 × 0.5 = 1,601,969 ft^2. Upstream storage is available within the northern CAW ditch; however, none was needed during this storm event. For the worst-case normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the western CAW ditch. This depth was found to be 2.72 feet at the lowest portion of the ditch (SW corner). Using this depth and the slope of the CAW embankment western ditch (1.12×10^{-3}), the discharge flow rate was found to be approximately 3,814 ft^3/min. The storage volume at this height is approximately 30,059 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
CAW Western Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.72 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.65	86,436	57,205	**29,230**
30	0.90	119,797	114,411	5,386
60	1.14	151,642	228,821	*
120	1.21	162,183	457,643	*
180	1.27	170,186	686,464	*
360	1.40	186,896	1,372,929	*
720	1.65	220,271	3,565,750	*
1440	1.90	253,645	7,131,501	*

* no storage will be necessary

CONCLUSION:

During the worst-case normal condition 25 year, 24 hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the CAW embankment western ditch is approximately 29,230 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water at the deepest portion of the ditch (SW Corner) of approximately 2.72 feet, leaving approximately 1.28 feet of freeboard. Therefore, the four foot-deep ditch in the western section of the CAW embankment is adequately designed to contain the normal precipitation event, allowing at least one-foot of freeboard.

Western CAW Ditch

ABNORMAL STORM EVENT

For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the western CAW ditch. This depth was found to be 2.83 feet. Using this depth and the slope of the CAW embankment western ditch (1.12×10^{-3}), the discharge flow rate was found to be approximately 4,239 ft^3/min. The volume of the ditch at this height is approximately 33,856 ft^3. Upstream storage is available within the northern CAW ditch; however, none was needed during this storm event.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
CAW Western Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.83 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	96,798	63,584	**33,213**
30	1.00	134,158	127,169	6,989
60	1.27	169,820	254,337	*
120	1.40	186,901	508,675	*
180	1.50	199,868	763,012	*
360	1.70	226,946	1,526,024	*
720	2.05	273,670	3,565,750	*
1440	2.40	320,394	7,131,501	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100 year, 24 hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the CAW embankment western ditch is approximately 33,213 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water within the ditch of approximately 2.83 feet, leaving approximately 1.17 feet of freeboard. Therefore, the four-foot deep ditch in the western section of the CAW embankment is adequately designed to contain the abnormal precipitation event, allowing more than one-foot of freeboard.

Southern CAW Ditch

NORMAL STORM EVENT

The drainage area for the southern CAW ditch includes all of the drainage from the eastern CAW ditch and is 50% of the total drainage area for the CAW embankment, or 6,407,875.63 × 0.5 × 0.5 = 1,601,969 ft^2. Upstream storage is available within the eastern CAW ditch and was utilized during this storm event. For the worst-case normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the southern CAW ditch. This depth was found to be 2.69 feet at the lowest portion of the ditch (SE corner). Using this depth and the slope of the CAW embankment southern ditch (6.98×10^{-4}), the discharge flow rate was found to be approximately 2,929 ft^3/min. The storage volume at this height is approximately 43,096 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
CAW Southern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.69 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.65	86,436	43,942	**42,494**
30	0.90	119,797	87,884	31,913
60	1.14	151,642	175,768	*
120	1.21	162,183	351,537	*
180	1.27	170,186	527,305	*
360	1.40	186,896	1,054,610	*
720	1.65	220,271	2,821,235	*
1440	1.90	253,645	5,642,471	*

* no storage will be necessary

CONCLUSION:

During the worst-case normal condition 25 year, 24 hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the CAW embankment southern ditch is approximately 42,494 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water at the deepest portion of the ditch (SW Corner) of approximately 2.69 feet, leaving approximately 1.31 feet of freeboard. Therefore, the four foot-deep ditch in the southern section of the CAW embankment is adequately designed to contain the normal precipitation event, allowing at least one-foot of freeboard.

Southern CAW Ditch

ABNORMAL STORM EVENT

For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth within the southern CAW ditch. This depth was found to be 2.80 feet. Using this depth and the slope of the CAW embankment southern ditch (6.98×10^{-4}), the discharge flow rate was found to be approximately 3,260 ft^3/min. The volume of the ditch at this height is approximately 48,538 ft^3. Upstream storage is available within the eastern CAW ditch and was utilized in these calculations.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
CAW Southern Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.80 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	96,798	48,899	**47,899**
30	1.00	134,158	97,797	36,361
60	1.27	169,820	195,594	*
120	1.40	186,901	391,189	*
180	1.50	199,868	586,783	*
360	1.70	226,946	1,173,566	*
720	2.05	273,670	2,821,235	*
1440	2.40	320,394	5,642,471	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100 year, 24 hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the CAW embankment southern ditch is approximately 47,899 ft^3. This maximum volume occurs approximately 15-minutes into the storm event and decreases rapidly. This volume equates to a depth of water within the ditch of approximately 2.80 feet, leaving approximately 1.20 feet of freeboard. Therefore, the four-foot deep ditch in the southern section of the CAW embankment is adequately designed to contain the abnormal precipitation event, allowing more than one-foot of freeboard.

Therefore, the CAW embankment ditches are adequately designed to contain runoff from the embankment.

6. Drainage Calculations – 11e.(2) Ditches

Similar calculations were performed for the 11e.(2) ditches to ascertain if they could maintain the flow from the entire site during the normal and abnormal storm events. Initially, the worst-case scenario included all water from the site drainage area filling the 11e.(2) drainage ditches and being bound by the lowest slope ditch (north/south lengths, 4.71×10^{-4}). After this was examined, a more realistic approach to the calculations was made where the 11e.(2) west side ditch retained water from the CAW drainage area as well as half of the 11e.(2) drainage area and the 11e.(2) south side ditch managed water from VITRO, LARW, MW, and the other half of the 11e.(2) drainage areas. Both of these scenarios are detailed below.

For both scenarios, the length of the ditch system, at the centerline, around the 11e.(2) embankment is 8,390 feet, 2335 feet for both the northern and southern ditches and 1,860 for the eastern and western ditches.

During the design storm events water will backflow into the "feeder" ditches from the other embankments around the site. The capacity of each of the ditches is dependent on the geometry of the ditch as described in Section 4 of this report. Utilizing these equations, the capacity of the 11e.(2) ditch system alone is approximately 386,331 ft^3 when the low end (southwest corner) is at a four-foot depth. Backflow into the CAW ditch system adds another 108,297 ft^3 to the capacity; backflow into the LARW embankment adds an additional 102,435 ft^3 of capacity; and backflow into the VITRO ditch system was estimated, assuming slopes within the VITRO ditches, as an additional 20,067 ft^3 of capacity. Since the design of the Mixed Waste ditches has not been finalized, their capacity was conservatively left out of this assessment. Therefore, considering all potential backflow scenarios (excepting the Mixed Waste ditches), the total storage capacity within the ditch system at the site is approximately 625,656 ft^3.

The backflow volume calculations provided in this section were performed using the pyramid and frustum equations described in Section 4 along with the following additional information:

LARW North/South Side Ditch Lengths = 1185 feet
LARW East/West Side Ditch Lengths = 1740 feet
LARW West Side Drop in Slope = 1.1 feet
LARW South Side Drop in Slope = 1.0 feet
LARW East Side Drop in Slope = 2.1 feet
LARW North Side Drop in Slope = 2.0 feet

VITRO South Side Ditch Length = 1270 feet
VITRO West Side Ditch Length = 2610 feet
VITRO South Side Drop in Slope = 2.0 feet

VITRO West Side Drop in Slope = 3.0 feet

The LARW information was obtained from the design drawings for the LARW embankment. The VITRO information was conservatively estimated based upon known drainage area lengths and the approximate drop in slope for known embankments running parallel with the respective ditches.

The overall storage is conservative because it assumes all embankments are completed to design capacity, including the 11e.(2) and Mixed Waste embankments, and does not consider the additional storage that could be attained from the completed Mixed Waste embankment.

Calculations pertaining to the storm events for the worst-case scenario of all water inundating the 11e.(2) lowest slope (south side) ditch are as follows.

NORMAL STORM EVENT – Worst-Case Scenario

For the normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.81 feet (< 4 feet). Using this depth and the smallest slope (4.71×10^{-4}), the discharge flow rate was found to be approximately 6,087 ft^3/min. The volume of the ditch systems at this height is approximately 535,956 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
11e.(2) Drainage Ditches

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 3.81 foot depth	
			Volume of Water Discharged (ft^3)	Required Storage (ft^3)
15	0.65	509,084	91,303	417,781
30	0.90	705,573	182,606	522,967
60	1.14	893,130	365,212	**527,918**
120	1.21	955,214	730,424	224,790
180	1.27	1,002,348	1,095,636	*
360	1.40	1,100,770	2,191,272	*
720	1.65	1,297,336	2,316,948	*
1440	1.90	1,493,902	4,633,896	*

* no storage will be necessary

CONCLUSION:

During the normal condition 25-year, 24-hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the 11e.(2) ditch system with runoff from all embankments is approximately 527,918 ft^3. This occurs approximately one hour into the storm event and decreases rapidly over the

next few hours. This volume equates to a depth of water within the ditch of approximately 3.81 feet, leaving approximately 0.19 feet of freeboard. Therefore, the design of the ditch system throughout the site and around the 11e.(2) embankment is adequately designed to contain the normal precipitation event.

ABNORMAL STORM EVENT – Worst-Case Scenario

For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.96 feet (< 4 feet). Using this depth and the smallest slope (4.71×10^{-4}), the discharge flow rate was found to be approximately 6,747 ft^3/min. The volume of the ditch at this height is approximately 599,372 ft^3.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
11e.(2) Drainage Ditches

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.96 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	570,112	101,206	468,906
30	1.00	790,155	202,412	587,744
60	1.27	1,000,197	404,823	**595,373**
120	1.40	1,100,796	809,647	291,149
180	1.50	1,177,171	1,214,470	*
360	1.70	1,336,649	2,428,940	*
720	2.05	1,611,841	2,316,948	*
1440	2.40	1,887,034	4,633,896	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100-year, 24-hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the 11e.(2) ditch system with runoff from all embankments is approximately 595,373 ft^3. This occurs approximately one hour into the storm event and decreases rapidly over the next few hours. This volume equates to a depth of water within the ditch of approximately 3.96 feet, leaving approximately 0.04 feet of freeboard. Therefore, the design of the ditch system throughout the site and around the 11e.(2) embankment is adequately designed to contain the abnormal precipitation event.

These calculations demonstrate that the site ditch system is adequately designed to contain runoff from the total embankment drainage areas under both the normal and abnormal rainfall events during the worst-case scenario that all water will inundate the 11e.(2) smallest slope (south side) ditch.

Calculations for the more likely scenario of split water flows throughout the 11e.(2) ditch system follow. These calculations are split into both the west side ditch and the south side ditch, individually.

NORMAL STORM EVENT – Split Water Scenario

Western 11e.(2) Ditch:

The drainage area associated with the western 11e.(2) drainage ditch under this scenario is all of the CAW drainage area and half of the 11e.(2) drainage area, weighted with the runoff coefficient of 0.5 (0.5 x (6,407,875.63 + (0.5)(4,734,001.44)) = **4,387,438.18 ft^2**). For this analysis, backflow is only considered into the 11e.(2) northern ditch and the CAW ditch system. For the normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.44 feet. Using this depth and the slope of the western ditch (4.84 x 10^{-4}), the discharge flow rate was found to be approximately 4,698 ft^3/min. The volume of the western 11e.(2) ditch system (with backflow portions) at this height is approximately 189,637 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
Western 11e.(2) Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 3.44 foot depth	
			Volume of Water Discharged (ft^3)	Required Storage (ft^3)
15	0.65	236,729	70,467	166,262
30	0.90	328,098	140,934	**187,163**
60	1.14	415,313	281,868	133,445
120	1.21	444,183	563,736	*
180	1.27	466,101	845,605	*
360	1.40	511,868	1,691,209	*
720	1.65	603,273	2,348,163	*
1440	1.90	694,678	4,696,326	*

* no storage will be necessary

CONCLUSION:

During the normal condition 25-year, 24-hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the western 11e.(2) ditch system with runoff from the CAW and half of 11e.(2) is approximately 187,163 ft^3. This occurs approximately 30 minutes into the storm event and decreases rapidly over the next few hours. This volume equates to a maximum depth of water within the ditch of approximately 3.44 feet, leaving approximately 0.56 feet of freeboard.

Southern 11e.(2) Ditch:

The drainage area associated with the southern 11e.(2) drainage ditch under this scenario is all of the VITRO, LARW, and MW drainage areas and half of the 11e.(2) drainage area, weighted with the runoff coefficient of 0.5 (0.5 x (3,471,500 + 2,592,217.44 + 1,664,744.64 + (0.5)(4,734,001.44)) = **5,047,731.40 ft^2**). For this analysis, backflow is only considered into the 11e.(2) eastern ditch as well as the LARW and VITRO ditch systems. For the normal storm event, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.63 feet. Using this depth and the slope of the southern ditch (4.71 x 10^{-4}), the discharge flow rate was found to be approximately 5,350 ft^3/min. The volume of the southern 11e.(2) ditch system (with backflow portions) at this height is approximately 219,369 ft^3.

Drainage Flows and Storage for the Normal (1.9") Storm Event
Southern 11e.(2) Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 3.63 foot depth	
			Volume of Water Discharged (ft^3)	Required Storage (ft^3)
15	0.65	272,355	80,248	192,107
30	0.90	377,475	160,497	**216,978**
60	1.14	477,816	320,993	156,823
120	1.21	511,031	641,987	*
180	1.27	536,247	962,980	*
360	1.40	588,902	1,925,960	*
720	1.65	694,063	2,316,948	*
1440	1.90	799,224	4,633,896	*

* no storage will be necessary

CONCLUSION:

During the normal condition 25-year, 24-hour storm event (1.9 inches of precipitation), the maximum volume retained in storage within the southern 11e.(2) ditch system with runoff from VITRO, LARW, MW, and half of 11e.(2) is approximately 216,978 ft^3. This occurs approximately 30 minutes into the storm event and decreases rapidly over the next few hours. This volume equates to a depth of water within the ditch of approximately 3.63 feet, leaving approximately 0.37 feet of freeboard.

ABNORMAL STORM EVENT – Split Water Scenario

Western 11e.(2) Ditch:

As described above for the normal scenario, the drainage area for the western 11e.(2) ditch is 4,387,438.18 ft^2. For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.57 feet. Using this depth and the slope of the western ditch (4.84×10^{-4}), the discharge flow rate was found to be approximately 5,186 ft^3/min. The volume of the western 11e.(2) ditch system (with backflow portions) at this height is approximately 212,986 ft^3.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
Western 11e.(2) Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 3.57 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	265,107	77,794	187,313
30	1.00	367,429	155,588	**211,842**
60	1.27	465,100	311,176	153,925
120	1.40	511,880	622,351	*
180	1.50	547,395	933,527	*
360	1.70	621,554	1,867,054	*
720	2.05	749,521	2,348,163	*
1440	2.40	877,488	4,696,326	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100-year, 24-hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the western 11e.(2) ditch system with runoff from the CAW and half of 11e.(2) is approximately 211,842 ft^3. This occurs approximately 30 minutes into the storm event and decreases rapidly over the next few hours. This volume equates to a depth of water within the ditch of approximately 3.57 feet, leaving approximately 0.43 feet of freeboard.

Southern 11e.(2) Ditch:

As described above for the normal scenario, the drainage area for the southern 11e.(2) ditch is 5,047,731.40 ft^2. For the abnormal storm event, as above, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. This depth was found to be 3.73 feet. Using this depth and the slope of the southern ditch (4.71×10^{-4}), the discharge flow rate was found to be

approximately 5,752 ft^3/min. The volume of the ditch at this height is approximately 251,478 ft^3.

Drainage Flows and Storage for the Abnormal (2.4") Storm Event
Southern 11e.(2) Drainage Ditch

Lapsed Time (min)	Accum. Rainfall (in)	Accum. Flow (ft^3)	Ditch flow at 2.73 foot depth	
			Available Discharge (ft^3)	Required Storage (ft^3)
15	0.73	305,005	86,280	218,725
30	1.00	422,726	172,559	**250,167**
60	1.27	535,096	345,119	189,978
120	1.40	588,916	690,238	*
180	1.50	629,776	1,035,356	*
360	1.70	715,095	2,070,713	*
720	2.05	862,321	2,316,948	*
1440	2.40	1,009,546	4,633,896	*

* no storage will be necessary

CONCLUSION:

During the abnormal condition 100-year, 24-hour storm event (2.4 inches of precipitation), the maximum volume retained in storage within the southern 11e.(2) ditch system with runoff from VITRO, LARW, MW, and half of 11e.(2) is approximately 250,167 ft^3. This occurs approximately 30 minutes into the storm event and decreases rapidly over the next few hours. This volume equates to a depth of water within the ditch of approximately 3.73 feet, leaving approximately 0.27 feet of freeboard.

These additional calculations demonstrate that the drainage system over the entire site is designed well enough to capture all of precipitation that may occur at the site and safely drain it off-site, and maintain a small amount of freeboard.

7. **Peak Run-off Rate**

The rational formula can be used to estimate the peak run-off rates from the embankments and determine if the CAW and 11e.(2) ditches are designed sufficiently to contain these rates.

To complete this analysis, it is first necessary to calculate the maximum length for the travel of water to the discharge point and then determine the time required for water to travel this maximum distance and reach the discharge point. This time of concentration is determined from the following formula:

$$T_c = 0.00013\ L^{0.77}\ S^{-0.385}$$

Where L is the length in feet and S is the slope (foot/foot).

CAW Embankment

The maximum distance for water to travel within the CAW embankment ditch system is from the northern crest of the embankment, down the northeast corner slope, through the ditches, to the discharge point in the southwest corner of the embankment ditch. Ditch flow will either go across the northern ditch and then down the western ditch, or down the eastern ditch and then across the southern ditch. Since slopes and lengths are similar in the northern and southern ditches and the eastern and western ditches, both of these flow paths will result in similar calculated travel times. The distance that water must travel can be broken down into four discrete sections:

1. Northern crest to northeast corner shoulder of embankment;
2. Down northeastern shoulder to northeast corner of ditch;
3. Across the northern ditch to the northwest corner; and
4. Down the western ditch to the southwest corner.

The individual T_c's may be calculated and summed to determine a total time of concentration. These calculations are described in the following table:

Travel Time
(CAW Embankment North and West Ditches)

Section	L (ft)	S	T_c (hrs)
1	1329.4	0.04	0.114
2	290.3	0.20	0.019
3 (N)	2381.7	0.000699	0.849
4 (W)	2690.3	0.001116	0.779
		Total T_c =	**1.762**

Therefore, the time it takes for water to travel the farthest distance within the CAW embankment watershed is approximately 1.76 hours (~106 minutes). It is only necessary to estimate the peak runoff flow rates during the abnormal condition, since it is the bounding condition. If the flow rates for the abnormal condition are within tolerance for the ditch system, then the normal condition will also be within tolerance. Extrapolating from the storm intensity data in Section 3 above, the storm intensity at 106 minutes is approximately 1.20 inches of rainfall. This equates to rainfall intensity (i) of 0.0113 inches/min or 9.43×10^{-4} feet/min.

The rational formula, Q = CiA may now be used to calculate the flow rate from the embankment. As the flow is split from the beginning of this assessment (NE corner), only half of the CAW embankment drainage area is utilized in this calculation. The drainage area for half of the CAW embankment is 3,203,938 ft^2. Therefore, flow from the CAW embankment is calculated as:

$Q = (0.5)(9.43 \times 10^{-4})(3{,}203{,}938) =$ **1,510.6 cfm**

From the ditch flow calculations in Section 1 of this report, this is within the flow capacity of both the southern and the western CAW ditches. The calculated flow would yield a runoff depth of approximately 2.1 feet in the southern ditch outlet and approximately 1.93 feet in the western ditch outlet. Therefore, the CAW embankment ditch system is designed sufficiently to contain runoff generated from the embankment drainage area during the abnormal storm event.

11e.(2) Embankment – Total Site Drainage

Disregarding the Vitro embankment, the maximum distance for water to travel through the embankment systems is from the northeast corner of the CAW embankment to the discharge point in the southwest corner of the 11e.(2) embankment ditch. This distance can be broken down into six discrete sections of water flow (the first four being those described for the CAW embankment above):

1. Northern crest to northeast corner shoulder of CAW embankment;
2. Down northeastern shoulder to northeast corner of ditch;
3. Across the northern CAW ditch to the northwest corner;
4. Down the CAW western ditch to the southwest corner;
5. Flow between CAW and 11e.(2) embankments;
6. Down the western 11e.(2) ditch.

The transition area (section 5) may be ignored in the overall T_c calculations as the distance is very short and the slope is rather large; therefore, the time spent in this section will be inconsequential to the overall travel time. The T_c's for the other five sections may be calculated and summed to determine a total time of concentration. The following table lists the calculated lengths and travel times for each water flow section and the total travel time for flow through the embankment systems.

Travel Time
(Clive Embankment System)

Section	L (ft)	S	T_c (hrs)
1	1329.4	0.04	0.114
2	290.3	0.20	0.019
3	2381.7	0.000699	0.849
4	2690.3	0.001116	0.779
6	1860	0.000484	0.809
		Total T_c =	**2.57**

Therefore, the time for water to travel the farthest distance within the Clive embankments watershed is approximately 2.57 hours (~154 minutes). It is only necessary to estimate the peak runoff flow rates during the abnormal condition, since it is the bounding condition. If the flow rates for the abnormal condition are within tolerance for the ditch systems, then the normal condition will also be within tolerance. Extrapolating from the storm intensity data in Section 3 above, the storm intensity at 154 minutes is approximately 1.25 inches of rainfall. This equates to rainfall intensity (i) of 0.0081 inches/min or 6.75×10^{-4} feet/min.

The rational formula, Q = CiA may now be used to calculate the individual flow rates from the Clive embankments watershed. The total drainage area was calculated in Section 3 of this report as 18,870,339.15 ft^2. Therefore, flow from the Clive embankment watershed to the southeast corner of the 11e.(2) ditch system is calculated as:

$$Q = (0.5)(6.75 \times 10^{-4})(18{,}870{,}339.15) = 6{,}367.9 \text{ cfm}$$

As calculated in Section 1, the capacity of the 11e.(2) ditches is at least 6,930 cfm (not including backflow into other ditches). The calculated total flow would yield a runoff depth of approximately 3.88 feet in the southern 11e.(2) ditch outlet and approximately 3.86 feet in the western 11e.(2) ditch outlet. Therefore, the 11e.(2) ditches are designed sufficiently to contain site-wide drainage, during operations, from the abnormal storm event.

Therefore, all ditch systems are satisfactorily designed to handle the flows associated with both the normal and abnormal storm events during operations.

Calculations Performed by:

Timothy L. Orton, P.E. — Date: 4/26/11

Calculations Checked by:

David F. Booth, P.E. — Date: 4/26/11