APPENDIX K

DRAINAGE DITCH CALCULATIONS

PERIMETER DITCH CALCULATIONS FOR THE FEDERAL CELL FACILITY

The following calculations are performed to justify the perimeter ditch design proposed in Engineering Drawings 14004-C01 and 14004-C03.

K.1 Perimeter Ditch Flow Capacity Evaluation

The drainage area contained by the Federal Cell Facility perimeter drainage ditch includes the landfill embankment and the ditch itself surrounding the Federal Cell Facility. Engineering Drawing 14004-C03 provides centerline drainage ditch locations and elevations around the Federal Cell Facility. From Engineering Drawing 14004-C03, the following ditch centerline distances may be estimated:

North Side = 1,226 feet
South Side = 1,226 feet
East Side = 1,919 feet
West Side = 1,919 feet

From these dimensions, an estimate of the total drainage area is calculated:

Drainage Area = (1,226 ft)(1,919 ft) = 2,353,033 ft^2

From the ditch lengths and centerline elevations in Drawing 14004-C03, the following ditch slopes are determined:

North Side = 1,227 feet in length with an elevation change of 0.6 feet; this yields a slope of (0.6 ft / 1,227 ft) = 4.89×10^{-4} ft/ft

South Side = 1,226 feet in length with an elevation change of 0.7 feet; this yields a slope of (0.7 ft / 1,226 ft) = 5.71×10^{-4} ft/ft

East Side = 1,919 feet in length with an elevation change of 0.85 feet; this yields a slope of (0.85 ft / 1,919 ft) = 4.43×10^{-4} ft/ft

West Side = 1,919 feet in length with an elevation change of 0.95 feet; this yields a slope of (0.95 ft / 1,919 ft) = 4.95×10^{-4} ft/ft

As marked, the east side slope present the least amount of slope and are therefore the limiting slopes for the analysis.

Based on the ditch slopes and factoring in a triangular geometry for the ditch shape, Manning's Formula can be used to determine the maximum flow rate for each side of the cell. The ditch depth is 4 feet with a total ditch width of 40 feet, a ditch side-slope ratio of 1V:5H is produced.

Manning's Formula is:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}. \qquad (1)$$

where,

Q = Flow in ft^3/sec;
A = Cross sectional area of flow in ft^2;
R = The hydraulic radius, the area of flow divided by the wetted perimeter, in feet; and,
S = Slope in ft/ft.
n = Manning's coefficient of roughness, calculated as:

$$n = 0.0456 (D_{50} S)^{0.159}. \qquad (2)$$

D_{50} is equal to 4.5 inches for the rock in the ditch.
$n_{(east)}$ = 0.016966;
$n_{(west)}$ = 0.017269;
$n_{(north)}$ = 0.017238;
$n_{(south)}$ = 0.017665;

The cross sectional area of the ditch is determined by multiplying the height of the ditch squared by 5, and the wetted perimeter is determined by multiplying two times the height of the water in the ditch by the square root of one plus five squared; or:

$$\text{WP} = 2h\sqrt{1+5^2}. \qquad (3)$$

The Manning calculations for flow around the embankment perimeter yields the following tables:

Table 1 - East Side Ditch (S = 0.000443 ft/ft)

Height of Water in Ditch (feet)	Flow Cross-Section Area in Ditch (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Flow Rate (ft^3/sec)	Flow Rate (ft^3/min)
0.5	1.25	5.1	0.25	0.90	54.15
1.0	5.00	10.2	0.49	5.73	343.82
1.5	11.25	15.3	0.74	16.90	1,013.70
2.0	20.00	20.4	0.98	36.39	2,183.14
2.5	31.25	25.5	1.23	65.97	3,958.29
3.0	45.00	30.6	1.47	107.28	6,436.61
3.5	61.25	35.7	1.72	161.82	9,709.17
4.0	80.00	40.8	1.96	231.03	13,862.04

Table 2 - West Side Ditch (S = 0.000495 ft/ft)

Height of Water in Ditch (feet)	Flow Cross-Section Area in Ditch (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Flow Rate (ft^3/sec)	Flow Rate (ft^3/min)
0.5	1.25	5.1	0.25	0.94	56.24
1.0	5.00	10.2	0.49	5.95	357.11
1.5	11.25	15.3	0.74	17.55	1,052.89
2.0	20.00	20.4	0.98	37.79	2,267.53
2.5	31.25	25.5	1.23	68.52	4,111.31
3.0	45.00	30.6	1.47	111.42	6,685.44
3.5	61.25	35.7	1.72	168.08	10,084.51
4.0	80.00	40.8	1.96	239.97	14,397.93

Table 3 - North Side Ditch (S = 0.000489 ft/ft)

Height of Water in Ditch (feet)	Flow Cross-Section Area in Ditch (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Flow Rate (ft^3/sec)	Flow Rate (ft^3/min)
0.5	1.25	5.1	0.25	0.93	56.02
1.0	5.00	10.2	0.49	5.93	355.73
1.5	11.25	15.3	0.74	17.48	1,048.81
2.0	20.00	20.4	0.98	37.65	2,258.75
2.5	31.25	25.5	1.23	68.26	4,095.39
3.0	45.00	30.6	1.47	110.99	6,659.56
3.5	61.25	35.7	1.72	167.42	10,045.46
4.0	80.00	40.8	1.96	239.04	14,342.18

Table 4 - South Side Ditch (S = 0.000571 ft/ft)

Height of Water in Ditch (feet)	Flow Cross-Section Area in Ditch (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Flow Rate (ft^3/sec)	Flow Rate (ft^3/min)
0.5	1.25	5.1	0.25	0.98	59.05
1.0	5.00	10.2	0.49	6.25	374.93
1.5	11.25	15.3	0.74	18.42	1,105.42
2.0	20.00	20.4	0.98	39.68	2,380.66
2.5	31.25	25.5	1.23	71.94	4,316.42
3.0	45.00	30.6	1.47	116.98	7,018.98
3.5	61.25	35.7	1.72	176.46	10,587.63
4.0	80.00	40.8	1.96	251.94	15,116.25

The calculations in Tables 1 through 4 show the amount of runoff that can be successfully collected in each section of the Federal Cell Facility perimeter drainage ditch system.

K.2 Erosion Evaluation

The geotechnical literature (NUREG/CR-4620, "Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments") indicates that an acceptable velocity of water traveling over a compacted clay surface without significant erosion is no greater than 3 ft/sec. Water velocity may be calculated using the simple equation:

$$v = \frac{Q}{A}. \qquad (4)$$

In order to calculate the interstitial velocities associated with the ditch flow, the dimensions of the rock inside the ditch is required. Engineering Drawing 14004-C03 notes that the perimeter ditch is lined with Type A rock which has a D_{15} of 2 to 4 inches. A conservative value of 4 inches (yielding the fastest water velocity) is selected for the following equation to calculate the interstitial velocity:

$$v_f = \frac{1.4Ki}{n}. \qquad (5)$$

where,

K is the coefficient of permeability = $0.35(D_{15})^2$ = 5.6 in/sec = 0.467 ft/sec
i is the slope
n is the porosity = 0.33
tortuosity factor = 1.4.

The tortuosity factor describes the extra length that a flow must travel to eventually reach the outflow area. This is calculated as the length of actual flow (L_c) to the total length of the porous media (L). Typical ranges for this factor can be calculated from ranges provided by Bear ("Dynamics of Fluids in Porous Media," Dover Publications, Inc., 1972) for a similar tortuosity factor. The typical range provided by Bear converts to a range of 1.12 – 1.34 for the tortuosity factor used in this equation. Therefore, a tortuosity factor of 1.4 is conservatively selected.

Water velocities and interstitial velocities are calculated for a conservative maximum potential centerline height of 4 feet of water in each drainage ditch. The calculated velocities are presented in Table 5, which demonstrate all interstitial velocities are well below 3 ft/sec.

Table 5 - Water Velocities

Location	Area (ft^2)	Flow Rate (ft^3/sec)	Water Velocity (ft/sec)	Interstitial Velocity (ft/sec)
North	80	239.04	2.99	$9.69x10^{-4}$
South	80	251.94	3.15	$1.13x10^{-3}$
East	80	231.03	2.89	$8.77x10^{-4}$
West	80	239.97	3.00	$9.80x10^{-4}$

K.3 Storm Events

The performance of the drainage ditches to contain runoff is only important for the active life of the facility (estimated as 25 years). Upon closure, the drainage ditches will be removed or eventually become silted in to allow sheet flow across the site over the natural grade of the area. Therefore, a reasonable maximum storm event over the active life of the facility is the 25-year, 24-hour storm event (1.9 inches). A reasonable potential worst-case event during the active life of the facility is the 100-year, 24-hour storm event (2.4 inches). Both of these storm events are depicted in the isopluvial maps of the National Oceanic and Atmospheric Administration (NOAA) Atlas 2, Volume VI (1973).

The rainfall amount at one hour during the 100 and 25-year events is calculated using the equations provided in NOAA, Atlas 2. For the Clive region , the equation is:

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

Where the (6-hr) and (24-hr) are the precipitation amounts displayed on the isopluvial maps.

Empirical equations are developed for the 15-min, 30-min, 2-hour and 3-hour events, based upon the 1-hour and 6-hour events:

15-min = 0.57 x (1-hr). (7)

30-min = 0.79 x (1-hr). (8)

2-hr = 0.299 x (6-hour) + 0.701 x (1-hr). (9)

3-hr = 0.526 x (6-hour) + 0.474 x (1-hr). (10)

As is described in the NOAA text, the 12-hour distribution is estimated using graphical methods, based upon the 6-hour and 24-hour events. Using the equations and methods described above, the following storm distributions is estimated for the design storm events.

Table 6 - Storm Distributions

Time (min)	Maximum Normal Event (inches)	Potential Worst Case Event (inches)
15	0.65	0.73
30	0.9	1.00
60	1.14	1.27
120	1.21	1.40
180	1.27	1.50
360	1.4	1.70
720	1.65	2.05
1,440	1.9	2.40

Over the short active life span of the drainage ditches, it is unreasonable 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.

K.4 Drainage Calculations

Drainage calculations for the Federal Cell Facility ditch system are determined from a mass balance over the system itself, where

(flow in) – (flow out) = Accumulated water (required storage space)

The total accumulated flow into the system is calculated by multiplying the accumulated rainfall by the weighted total drainage area. The calculated drainage area is equal to 2,353,033 ft^2. The run-off coefficient is equal to 0.5 (for earth with stone surface). Therefore, the total weighted drainage area is equal to (2,353,033 ft^2)(0.5) = 1,175,516 ft^2.

Flow out of the system is calculated by multiplying the flow rate at specific depths (as presented in Tables 1 through 4) by the elapsed time of rainfall. The volume of the ditch at a specific depth is calculated by multiplying the cross-sectional flow area in the ditch at a given depth by the length of the ditch. The volume associated with a given depth is compared to the required storage volume calculated by subtracting the available discharge from the accumulated flow into the system. The volume associated with a given depth is equated the required storage volume by iterating over the depth of water in the ditch to estimate a maximum flow within the ditch for a particular storm event.

The total length of the drainage ditch, calculated from the ditch centerline coordinates provided in Engineering Drawing 14004-C03 is approximately 6,291 ft. The cross-sectional flow areas of the ditch varies with depth (as shown in Tables 1 through 4). Conservatively assuming that the discharge rate from the perimeter berm is dependent on the least sloped ditch (east side ditch = 4.43×10^{-4} ft/ft). Using the maximum normal storm event described in Table 6, an iterative method is used to equate the required storage with the available storage volume at a specific water depth. Using the lowest ditch slope (4.43×10^{-4} ft/ft), the discharge flow rate and volume of required ditch storage is calculated.

Table 7 - Drainage Flows and Storage for the Maximum Normal Storm Event

Rainfall Duration (min)	Rainfall Depth (in)	Flow Into Ditch System (ft^3)	Flow Out of Ditch System (ft^3)	Required Storage (ft^3)
15	0.65	63,728	12,879	50,849
30	0.9	88,239	25,758	62,481
60	1.14	111,769	51,515	60,254
120	1.21	118,632	103,031	15,601
180	1.27	124,515	154,546	0
360	1.4	137,260	309,092	0
720	1.65	161,771	618,185	0
1440	1.9	186,282	1,236,370	0

K.5 Conclusions

During the maximum normal precipitation event, the greatest volume retained in storage within the Federal Cell Facility drainage ditch system is approximately 62,481 ft^3. This occurs approximately 30 minutes into the event and decreases over the next couple of hours. This volume equates to a depth of water within the ditch of approximately 1.41 feet, which is well within the four-foot perimeter ditch height specifications. Therefore the Federal Cell Facility ditch design adequately contains the maximum normal precipitation event. Similarly, Table 8 reports the discharge and water perimeter elevations for the worst-case storm event.

Table 8 - Drainage Flows and Storage for the Worst Case Storm Event

Rainfall Duration (min)	Rainfall Depth (in)	Flow Into Ditch System (ft^3)	Flow Out of Ditch System (ft^3)	Required Storage (ft^3)
15	0.73	71,571	14,636	56,935
30	1.0	98,043	29,272	68,771
60	1.27	124,515	58,544	65,971
120	1.4	137,260	117,088	20,172
180	1.5	147,065	175,632	0
360	1.7	166,673	351,265	0
720	2.05	200,988	702,529	0
1440	2.4	235,303	1,405,058	0

During the potential worst-case scenario, the maximum volume retained in storage within the Federal Cell Facility ditch system is approximately 68,771 ft^3, occurring roughly 30 minutes into the event and decreasing over the couple of next hours. This volume equates to a water height within the ditch slightly higher than 1.48 feet (well within the four-foot design height of the ditches). It is therefore concluded that the Federal Cell Facility embankment is capable of adequately containing the worst-case storm precipitation event.

K.6 Peak Run-Off Rate for Small Watersheds

The maximum length for the travel of water to the discharge point is down the sloped corner of the Federal Cell Facility, from the crest to the northeast corner of the drainage ditch, then west down the northern drainage ditch and finally south toward the discharge point in the southwest corner. Engineering Drawing 14004-C03 illustrates this travel distance at approximately distance down the corner slope from the crest to the shoulder at roughly 584 feet with a slope of 8.74 / 584 = 0.015 ft/ft. From that point, the distance down the corner slope from the shoulder to the northeast corner is approximately 247 feet with a slope of 34.7 / 247 = 0.14 ft/ft. Flow across the northern drainage ditch is approximately 1,226 feet with a slope of 0.000489 ft/ft. Flow across the western drainage ditch is approximately 1,919 feet with a slope of 0.000495 ft/ft.

Rainfall intensity (i) is estimated by determining the time of concentration, T_c, or time required for water to travel from the most distant location in the watershed to the watershed discharge point. The formula for determining T_c is:

$$T_c = 0.00013L^{0.77}S^{-0.385} \quad (11)$$

The cumulative T_c over the path length of water travel, yields the following:

Table 9 - Travel Time

Path Length (ft)	Slope (ft/ft)	T_c (hr)
584	0.015	0.088
247	0.14	0.019
1,226	0.000489	0.584
1,919	0.000495	0.821
	Cumulative	**1.513**

Therefore, the total time required for water to travel the farthest distance within the watershed is roughly one hour and thirty-one minutes.

As it is a boundary condition, only the estimate of peak runoff flow rates during the potential worst-case condition is necessary. If the flow rates for the worst-case scenario are within tolerance, then the normal conditions will also be within tolerance. From Table 6, the most applicable storm intensity data for the above abnormal event is 1.27 inches over a one-hour time period. This equates to a rainfall intensity (i) of 1.76×10^{-3} feet/minute. Using this intensity, the drainage area and runoff coefficient values herein described the estimated peak runoff during the abnormal event is:

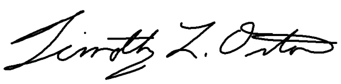
$$Q = CiA = (0.5)(1.76 \times 10^{-3} \text{ ft/min})(2{,}353{,}033 \text{ ft}^2) = 2{,}070.7 \text{ ft}^3\text{/min} \quad (12)$$

This value is less than the lowest design flow rates for the 2.5-foot deep ditch described in Tables 1 through 4 (ranging between 3,958 ft^3/min and 4,316 ft^3/min).

Using the calculations of Tables 1 through 4 as maximum flow, this calculated flow results in depths of approximately 1.76 feet in all of the ditches (all allowing a freeboard of more than 2 feet). Therefore, the Federal Cell Facility ditches are sufficiently designed to contain the peak runoff flow from the potential worst case (and subsequently normal) storm events.

Calculations were performed by Vern C. Rogers and reviewed by Timothy L. Orton, P.E.

Reviewed by:



Tim Orton
Apr 9 2021 11:28 AM
cosign

Timothy L. Orton, P.E.
Environmental Engineer and Manager

References

Bear. J, (1972). Dynamics of Fluids in Porous Media, Dover Publications, Inc., 1972

NOAA, (2012). "NOAA Atlas 2 Precipitation Frequency Estimates in GIS Compatible Formats." Accessed at http://www.nws.noaa.gov/oh/hdsc/noaaatlas2.htm on 20 October 2012.

NRC, (1986). "NUREG/CR-4620: Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments," June 1986.