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An Examination of Drainage Systems Related to Jefferson Lab's End Station Complex

Walt Akers*, Suresh Chandra, Carroll Jones, Tom Renzo and Ed Winslow
Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, VA 23696

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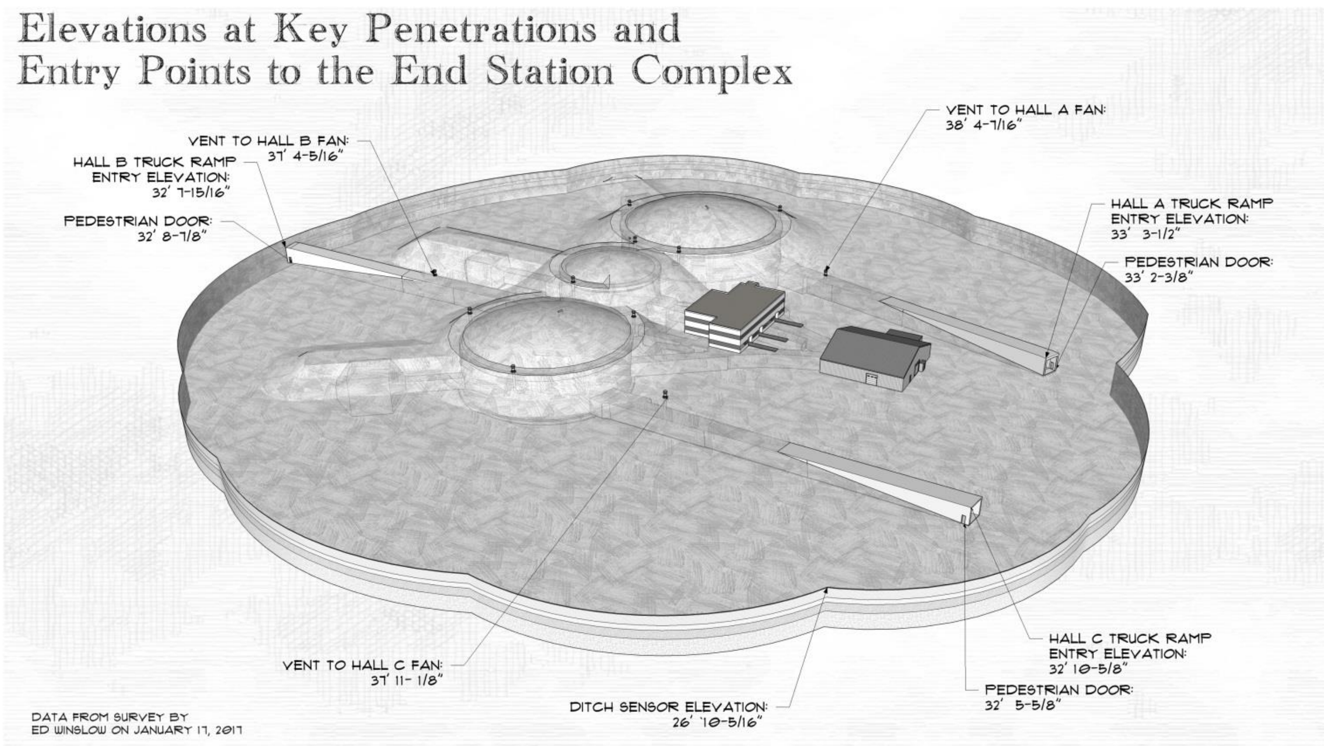


Figure 1. Surface Elevations

I. INTRODUCTION

On August 8, 2012 a sudden storm, combined with poorly maintained off-site drainage systems, resulted in significant flooding in the end station complex[1]. Following the recovery from this event, Jefferson Lab Facilities Management allocated funds to install new, automatic flood gates at the entry of each experimental hall. The installation of these flood gates was completed in late 2016.

Initial testing of the new flood gates demonstrates that they do not provide a completely impenetrable barrier to rising water, and some leakage was detected. The combined leakage from all gates and personnel doors into the three halls was measured to be around 200 gallons per minute. The magnitude of these leaks required an assessment to determine the level of performance necessary to ensure that the experimental halls remain protected in the event of another flood.

In pursuit of that goal, this document will identify the configuration of the end station complex and the location and magnitude of potential sources of water encroachment. Once the hazards are identified, the document will discuss the mitigations that are currently in place and their effect on protecting the halls. This will be followed by a list of potential failure points and additional efforts that can be taken to ensure that the halls are protected. Finally, a performance level for existing and future protective measures will be discussed along with recommended corrective actions.

* Corresponding author

[1] The end station complex includes experimental Halls A, B and C which were part of the original CEBAF installation. Experimental Hall D is geographically separate from the original end stations and will be referred to as the Hall D complex.

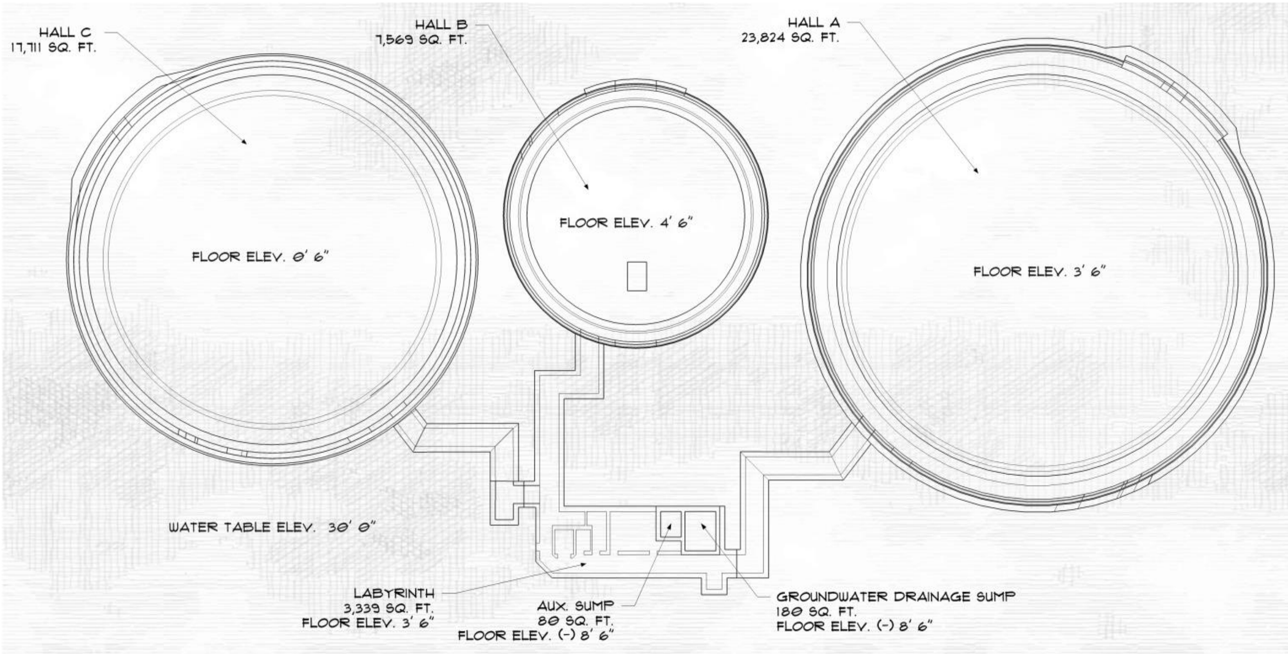


Figure 2. Elevations within the End Station Complex

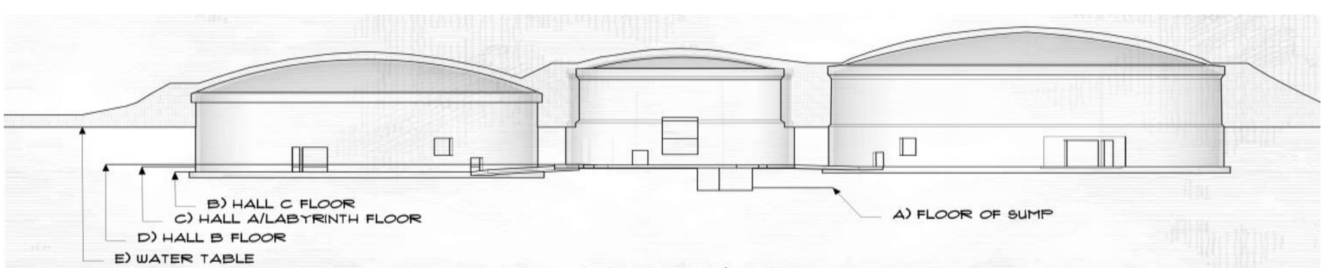
II. SITE CONDITIONS AND CONFIGURATION

1. End Station Complex

The end station complex consists of three underground experimental halls which are joined by an interconnecting labyrinth for pedestrian traffic. Each hall is equipped with a truck ramp, one or more beam dumps and an entry point for beam delivery. The surface elevations of each of the truck ramps and their associated pedestrian doors are shown in figure 1. The elevations of the floors within each of the halls and labyrinth are shown in figure 2. Figure 2 also shows the two sumps used to manage water drainage from the end station; the auxiliary sump, which supports floor drainage, and the groundwater drainage sump, which discharges groundwater.

Because both the halls and the labyrinth are below the water table, the elevation and volume of each of these sumps are critical elements in determining how water will fill the halls in the event of a flood. This is illustrated in the figure below.

As demonstrated in figure 3 and the included table, water fills from the lowest levels in the end station complex (the sump) and then moves upward into the halls. As it encroaches into each new area, the available floor space increases and requires a greater volume of liquid to raise the water level by 1 inch. For example, it only requires 57 gallons to raise the water level by 1 inch in the sump, while nearly 33,000 gallons are required for a 1 inch increase once water has encroached into all three halls.



	START ELEV.	END ELEV.	VOLUME (GALS)	GALS/ INCH	NOTES
A) AUXILIARY SUMP AND DRAINAGE PIPES	(-) 8' 6"	0' 6"	6,102	56.5	INCLUDES SUMP AND DRAINAGE PIPES UP TO HALL C FLOOR
B) HALL C FLOOR TO HALL A FLOOR	0' 6"	3' 6"	399,503	11,097	INCLUDES HALL C FLOOR AND BALANCE OF SUMP/PIPES
C) HALL A FLOOR TO HALL B FLOOR	3' 6"	4' 6"	335,829	27,986	INCLUDES HALL A, HALL C AND LABYRINTH FLOORS
D) HALL B FLOOR TO TOP OF LABYRINTH	4' 6"	11' 6"	2,746,106	32,692	INCLUDES HALLS A, B, C AND LABYRINTH FLOORS

Figure 3. Volumetric Levels in End Station Complex

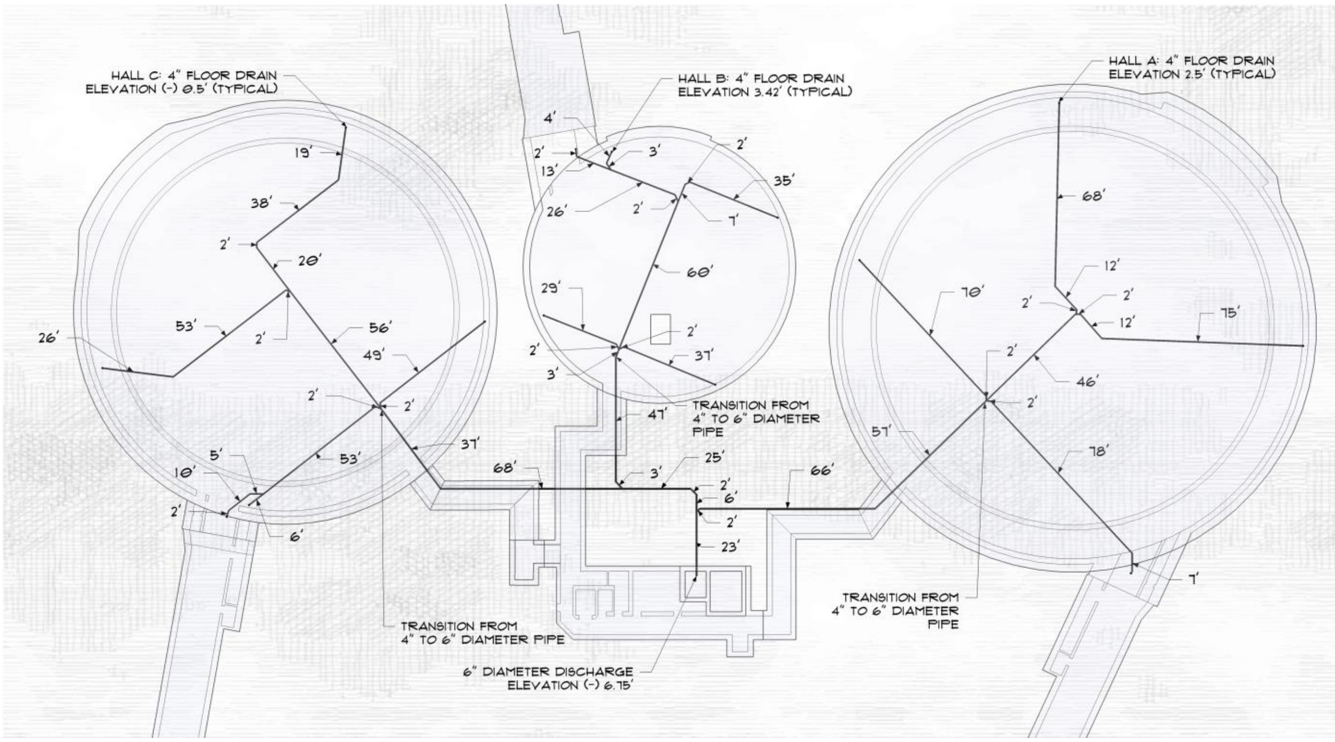


Figure 4. Auxiliary Drainage Pipes in the End Station Complex

2. Surface Water Management

Surface water management is a generic term that represents the disposal system for all water that enters the halls from the surface. This includes storm water that enters through doors, water that comes from leaking penetrations, water from spills or pipe leaks and any other water that is disposed of using the floor drains. This water is removed from the end station complex using a system of pipes, sumps and pumps that are described below.

a. Floor Drainage Systems

The floor drainage system is a collection of interconnected drains installed in the concrete slabs of each of the experimental halls. The entries to these drains are located at floor level in each hall and the drainage pipes provide a direct conduit to the auxiliary sump under the Counting House. The configuration of this piping system is illustrated in figure 4.

Because these pipes are gravity fed, the maximum amount of water that can be carried through the system is limited by the slope and diameter of the individual pipes. Notably, since the 4" drainage pipes in each hall are combined into a single 4" pipe before leaving the hall, the maximum flow from any one hall is limited to the capacity of a single 4" pipe. However, once these pipes leave the hall, they are merged into a 6" pipe which provides sufficient capacity to support two halls with maximum flow. The maximum flow rates listed below have been computed using the Hazen-Williams formula[2].

Water Source	*Capacity*
Hall A Trench Drain	226 GPM
Hall B Trench Drain	251 GPM
Hall C Trench Drain	183 GPM
Maximum Combined Flow	533 GPM

b. Tunnel Drainage Systems

In addition to the experimental halls, the accelerator tunnel also drains into the auxiliary sump at the Counting House. As illustrated in figure 5, there are 9 sump locations in the tunnel complex, each of which is equipped with two 30 GPM pumps. One should note that in the original CEBAF design, water that accumulated in the accelerator tunnel was discharged to the surface. However, following an environmental assessment, it was determined that this water should be discharged into the sanitary sewer system instead. Following this decision, the drainage lines in the accelerator complex were diverted to the auxiliary sump.

[2] While the effect of pipe fittings and junctions were not included in this calculation, they may still cause a minimal decrease in the rate of flow.

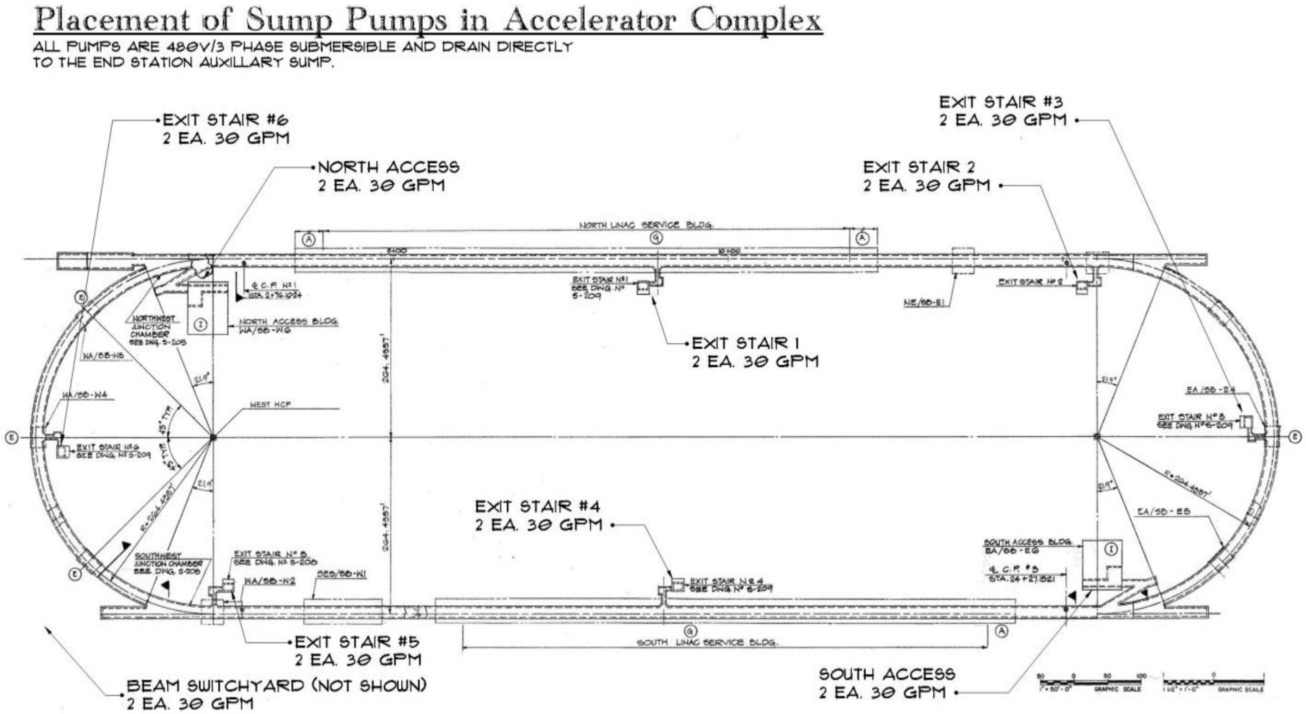


Figure 5. Sump Pumps in the Accelerator Complex

This water, which is largely condensate from mechanical systems combined with some groundwater seepage, is regularly pumped from the accelerator to the sump. The monitoring system installed in the auxiliary sump reports that these pumps are activated at least once weekly to discharge accumulated water. Based on the volume of the sump and the water levels required to trigger the pumps (figure 6), 1,795 gallons of water are being removed during each pumping cycle. This water is a combination of water originating in the halls and in the accelerator tunnels.

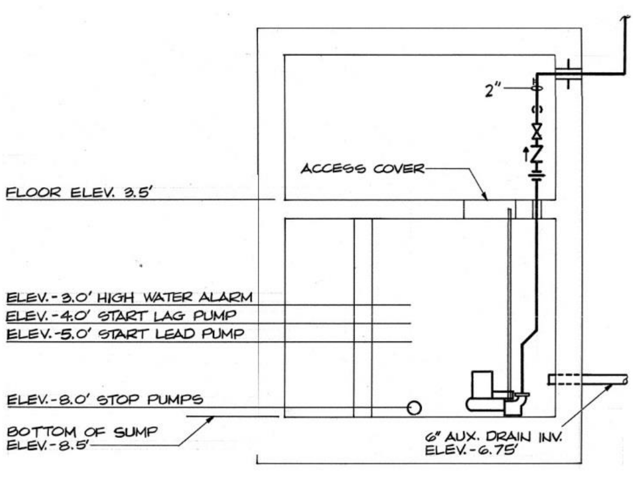


Figure 6. Trigger Levels in the Aux. Sump

c. Auxiliary Sump

The auxiliary sump is in the basement of the Counting House and has a functional capacity of 720 cu. ft. (5,386 gallons). The term '*functional capacity*' is used because once the water depth in the sump exceeds 9 feet, the rising water will begin to fill Hall C through the existing drain pipes. As discussed earlier, the auxiliary sump receives water from the floor drains of the experimental halls, as well as water from the 18 sump pumps in the accelerator complex.

The auxiliary sump is equipped with two 65 GPM pumps which connect to a single 2" discharge pipe. The discharge pipe transfers water from the sump directly to the sanitary sewer system. To ensure reliable operation, these pumps are supported by the Counting House generator.

The auxiliary sump is immediately adjacent to the *drainage sump*, which is used to collect and discharge groundwater. A junction exists between the two sumps which can be opened in an emergency to allow the higher capacity pumps in the drainage sump to handle water from the floor drain system. Note that this junction is normally closed because the drainage sump discharges directly to the surface.

3. Ground Water Management

As illustrated in figure 2, the floor elevation of all three halls is 25 to 30 feet below the water table in the surrounding area. Because of this, the groundwater under the hall provides continuous uplifting pressure that must be alleviated to prevent the halls from *'floating'*. This pressure is relieved by a system of buried pipes that allow the water to flow to a drainage sump where it is discharged to the surface. This drainage system is described below.

a. Underground Piping Systems

The drainage system under the end station complex consists of a series of 6" diameter perforated drainage pipes that allow ground water to flow to the drainage sump. It should be noted that these pipes are entirely gravity fed, and no pumping mechanisms are in place to deliver the water to the sump. *This is a critical distinction, because in the event of a power outage, groundwater will continue to flow to the sump.*

The 6" drainage pipes under each hall combine into an 8" pipe as they enter the area beneath the labyrinth. These three 8" diameter pipes are then combined into a single 10" diameter pipe that empties into the sump.

b. Groundwater Drainage Sump

The groundwater drainage sump is also in the basement of the Counting House and has a capacity of 1,980 cu. ft. (14,811 gals.) As shown in figure 7, the drainage sump is fed by a 10" diameter pipe and is serviced by 3 pumps that deliver the water to the surface. Once pumped to the surface, the water is discharged into the south ditch where it drains off site.

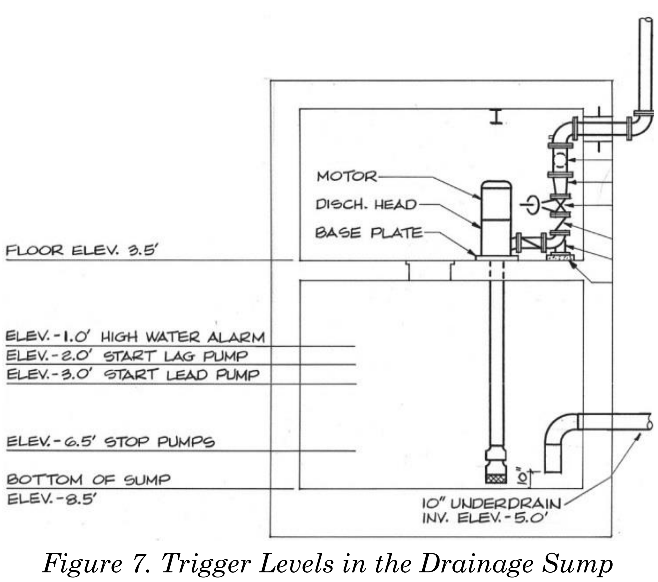


Figure 7. Trigger Levels in the Drainage Sump

The pumping system consists of two large pumps, each of which can remove 625 gallons per minute, and a small submersible pump capable of discharging 53 gallons per minute. All of these pumps are supported by the Counting House generator and can operate in parallel, giving a total discharge capacity of 1,303 gallons per minute.

It should be noted that groundwater is constantly draining into this sump and the pumps are activated 3 or more times each day to discharge the accumulated water. Based on the frequency of operation, the volume of the sump and the water levels required to trigger the pumps, **it is estimated that between 12,000 and 14,000 gallons of groundwater are discharged daily.**

III. ISSUES, IMPACTS AND MITIGATIONS

After examining the design and capacity of the drainage systems, a number of specific risks can be identified. The risks and failure modes discussed here are specific to the end station complex and experimental halls. None the less, there may be additional failure modes that impact other parts of the accelerator complex. Those issues are beyond the scope of this document.

The risks and failure modes for the surface water and groundwater systems will be discussed separately.

1. Storm/Surface Water

a. Improper Drainage Paths

Issue: As has been observed in Experimental Hall B, when water flows down the truck ramp it can flow around the drainage trench and into the hall. This is because the existing drainage trench does not extend completely across the truck ramp and the floor grade does not direct all water into the trench.

Note: The Hall B entry was modified after the original construction to support delivery of larger loads. In the original implementation, the trench was similar to that in Halls A and C and extended fully across the opening.

Impact: In the event of significant flooding, water can flow past the drainage trench and enter the hall, resulting in significant damage to equipment and property at floor level.

Mitigation: A number of possible mitigations have been discussed with Facilities Management. These options include:

i. Extending the drainage trench across the entire width of the truck ramp.
ii. Constructing a 2" to 3" dam on the far side of the trench to slow the flow of water while it fills the drainage trench.
iii. Contouring the truck ramp to direct water flow toward the drainage trench.

These alternatives and others are being evaluated based on time, cost and potential impact to operations.

b. Inadequate Flow Rate in Pipes

Issue: During flood gate testing in late 2016, approximately 50 gallons per minute of water leaked through the Hall B flood gate and into the truck ramp. The water quickly filled and overflowed the drainage trench; after which water began to flow into the experimental hall. Because this trench has a calculated drainage capacity of 251 gallons per minute, it is suspected that a blockage in the pipe may be obstructing water flow.

Impact: In the event of significant flooding or leakage within the hall, water cannot drain at a fast enough rate to prevent damage to equipment and property at floor level.

Mitigation: Facilities Management recommends that the drainage system be tested annually and that steps be taken to ensure an acceptable rate of flow through the pipes. The Facilities Maintenance group has developed an approach for enlarging the drain openings which a) improves water capture, and b) simplifies the process of cleaning accumulated debris from the system.

Note: in all circumstances, the entries and penetrations into the hall must be designed to ensure that water flow does not exceed the rated capacity of the drainage system.

c. Inadequate Pumping Capacity

Issue: The total capacity of the pumps in the auxiliary sump is significantly less than the capacity of the drainage system. These pipes can be easily overwhelmed if there is significant water flow into any of the three halls.

Impact: Once the auxiliary sump is full, water will begin to back-up into the experimental halls through the drainage system. Regardless of the entry point, Hall C *(the lowest hall)* will begin to flood first, followed by Hall A and then Hall B. As noted in figure 3, the volumes of the spaces being filled increase dramatically as each new chamber is entered. This increase in volume will slow the rise of water, but the water level will continue to increase until the rate of flow decreases below the capacity of the pumps.

Mitigations: There are several alternatives that may be employed to reduce this risk.

i. Increase the size of the pumps to support the maximum volume of water that can enter through the *sealed* doors and penetrations.

   Note: The maximum pumping capacity remains limited to the maximum amount of water that can be delivered through the floor drains and pipes.

ii. Reduce leakage from all sources so that water intrusion remains below the pumping capacity.
iii. Install a junction between the auxiliary sump and the ground water sump at an elevation of (-) 1'-0". This will allow water that exceeds the capacity of the auxiliary pumps to immediately flow into the groundwater sump where it can be handled by the larger pumps.

   It should be noted that the slightly irradiated water from the auxiliary sump should only be discharged to the ground in an emergency situation. Based on the information provided in this document, when the water level in the auxiliary sump reaches a depth of 8 feet, it is within 1 foot of beginning to flood Hall C. It is the contention of this document, that this condition constitutes an emergency situation and warrants the discharge of the water to the surface. Still, Jefferson Lab's Radiation Control Group and Environmental Office must assess the impacts of this change to determine if the impacts will be acceptable.

d. Pump/Power Failure

Issue: In the event of a pump or power failure, water will not be discharged from the sump and will begin to accumulate.

Impact: If more than 5,300 gallons of water drains into the auxiliary sump during a power failure, water will begin to back-up into Hall C through the floor drain system, potentially resulting in property damage.

Existing Mitigations:

i. The pumps in the auxiliary sump are connected to the Counting House generator. The generator is maintained and tested to ensure reliable operation.

ii. An existing monitoring system detects and reports the water level in the sump and generates an alarm when it exceeds a safe threshold.

iii. Pumps are tested and maintained at a regular interval by Facilities Management staff.

Potential Mitigations:

i. The acceptable rate of leakage from all sources can be reduced to a level where the sump can hold the accumulated water for an acceptable period of time.

For example: Based on the size of the sump, for this system to tolerate a 4 hour power outage during a flood, the maximum acceptable leakage from all sources must be less than 23 gallons per minute.

Note that the expense of achieving this level of performance may be unwarranted. Further improving the reliability of the power and pump systems may be a more practical investment.

2. Groundwater

a. Inadequate Pumping Capacity

Issue: In the event of a major flooding event, the groundwater discharge pumps can also be used to discharge surface water. If the leaks are sufficiently large, these pumps may also be overwhelmed.

Impact: Extensive flooding of the end station complex.

Mitigation: Unnecessary. The pumping capacity of the groundwater discharge pumps already exceeds the maximum drainage speed of the floor drain. Therefore, if these pumps are operating, they can only be overwhelmed after water has flooded the labyrinth and is draining directly into the sump. If the water has reached that level, then all three halls are already flooded and additional pumping capacity will do little or nothing to improve the situation.

b. Pump/Power Failure

Issue: If there is a power failure to the groundwater discharge pumps, then water draining from the water table will continue to accumulate in the sump and will eventually flood the labyrinth and experimental halls.

To clarify, as discussed earlier, groundwater drains into the drainage sump at a rate of 14,000 gallons each day. The groundwater discharge pumps run several times daily to remove this water. If there is an extended power outage to these pumps, within 1 day the groundwater will fill the sump and begin spilling into the labyrinth and the experimental halls. The water will continue to rise in the halls until it reaches equilibrium with the water table.

Impact: Extensive flooding of the end station complex, as well as the accelerator tunnels and beam dumps.

Mitigation: Awareness is the principal mitigation for this issue. Any time extended work will be performed that will take the generator or power sources to these pumps offline, accommodations must be made to ensure that a) they are back online within 24 hours, or b) alternate pumping systems are put in place.

IV. SUGGESTED STEPS

As suggested by the proceeding list of issues and potential mitigations, the following steps are recommended:

1. Assess Current Leakage Rates

Complete testing on all of the flood doors and pedestrian doors to determine the current rate of leakage. Make feasible corrections to the gates to achieve the best obtainable performance, and fully document the results.

2. Assess Current Drainage Rates

Perform flow rate tests on all hall floor drains to determine if they are performing at an acceptable capacity. Where results warrant, take corrective action to enhance flow to an acceptable level and document performance.

3. Assess and Correct Water Flow Issues

Assure that water entering the hall is directed toward the nearest drain or trench that can accommodate it. Install dams, contours or other impediments to prevent quick bursts of water from flowing over or past the existing drain.

4. Size Pumps to Accommodate Load

Based on the leakage and flow rates identified in assessments steps 1 and 2, increase the size of the pumps in the auxiliary sump to accommodate the expected rate of flow, plus an additional safety margin.

5. Install an Emergency Conduit Between Sumps

As discussed earlier, a conduit for water to flow between the auxiliary sump and the groundwater sump may be installed to handle dangerously high water levels. The addition of larger pumps would decrease the likelihood that this conduit would ever be used; however, it would provide an additional contingency in the event of an extreme leak or a pump failure.

6. Alternatives and Contingency Planning

The automatic flood gates are designed to provide protection year-round for unpredicted weather events. Still, hurricanes and major storms are often identified well in advance of their arrival, allowing time for additional preparations. If provided with adequate instructions, the Hall Coordinators and their staff can take supplemental actions to improve the performance of the doors and gates. These steps, which may involve the use of additional sealants or water barriers, should be identified and documented and the required materials should be procured.

7. Document, Review and Regularly Assess the System

The results of all tests and activities in these steps should be documented and made available for future review. Annual or semi-annual performance tests on the drainage system should also be documented and compared to prior results to detect degradation in system performance.

V. CONCLUSION

This document has identified the current configuration, elevations, capacities and drainage solutions that exist in the end station complex. The distinction between surface water management and groundwater discharge are important ones, as each presents unique problems.

While the areas of concern identified here are largely focused on flooding and storm water, the constant accumulation and disposal of groundwater remains an issue that requires vigilance. The specific issues identified in this document include, a) establishing a tolerance threshold for leaks into the hall, b) managing the flow of water once it has entered the hall, c) ensuring the performance of our existing drainage system can accommodate the expected level of water, d) determining if our pumping capacity is sufficiently large and reliable enough to handle the expected load, and e) assessing the practicality and environmental impacts related to discharging water from the floor drains to the surface.

Efforts to further assess our drainage and flood protection systems should continue until an acceptable baseline has been achieved and documented. Notably, this work should be undertaken with haste in order to have a reliable system in place by the beginning of the 2017 hurricane season.

VI. REFERENCES

1. Daniel, Mann, Johnson & Mendenhall, 1989, End Station – Underground Design Package, Southeastern Universities Research Association.
2. Daniel, Mann, Johnson & Mendenhall, 1990, End Stations – Above Ground Design Package – Volume I, Southeastern Universities Research Association.
3. Daniel, Mann, Johnson & Mendenhall, 1990, End Stations – Above Ground Design Package – Volume II, Southeastern Universities Research Association.