HDR

# Air Flow and Ventilation in Sewers and Tunnels

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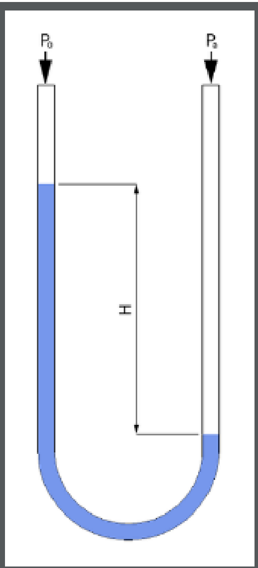
# Why is air flow in sewers & tunnels important?

# 01 Basics of Air-Water Interactions

# Basics of Air-Water Interactions

- Forces at work
  - Friction
  - Pressure-gradient
  - Buoyancy
- Of interest for many types of hydraulic structures
  - Dam spillways and outlet gates
  - Inverted siphons
  - Pipelines
  - Drop shafts
  - **Closed conduits**



# 02 Factors Affecting Air Flow in Sewers and Tunnels

# What Causes Air Flow in Sewers and Tunnels

- Friction drag force
- Displacement air
- Flushing airflow effect
- Buoyancy airflow effect
- Drop structure eduction

# What Causes Air Flow in Sewers and Tunnels

- Friction drag force – any sewer/tunnel with hydraulic flows
- Displacement air – occurs while sewer/tunnel is filling (storm or diurnal)
- Flushing airflow effect – rapid displacement, at the start of storm events
- Buoyancy airflow effect – sewer/tunnel with no dry weather flows, cold-weather climate
- Drop structure eduction – large-diameter tunnels

# What Causes Air Flow in Sewers and Tunnels

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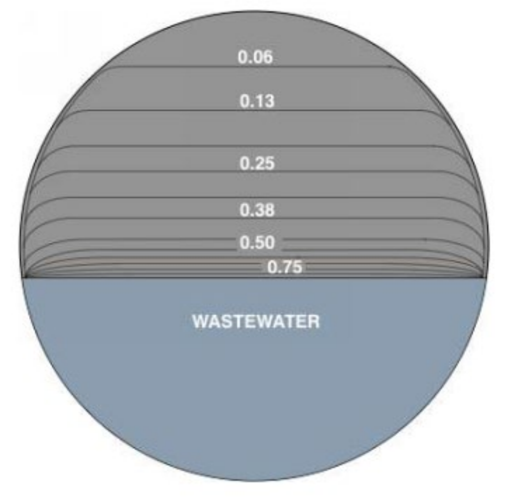
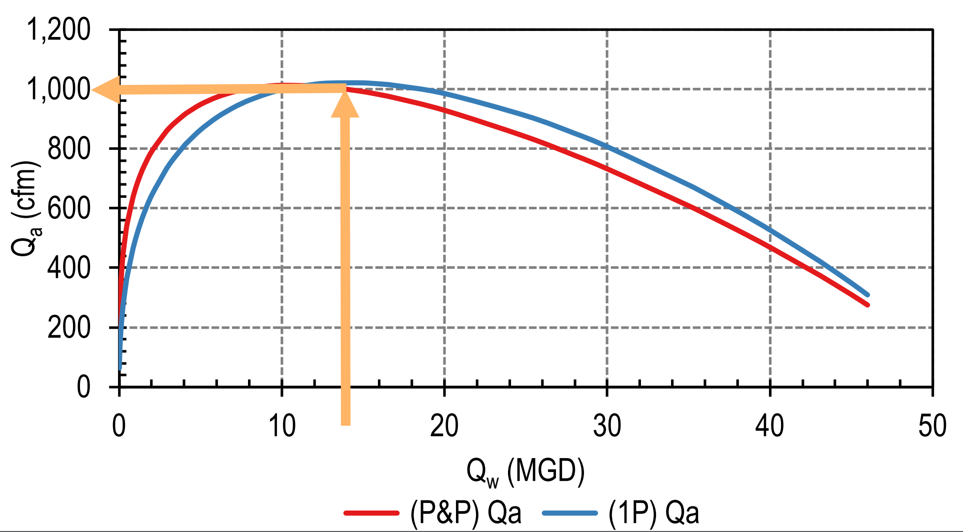
- Drop structure eduction – large-diameter tunnels

# Friction Drag Airflow

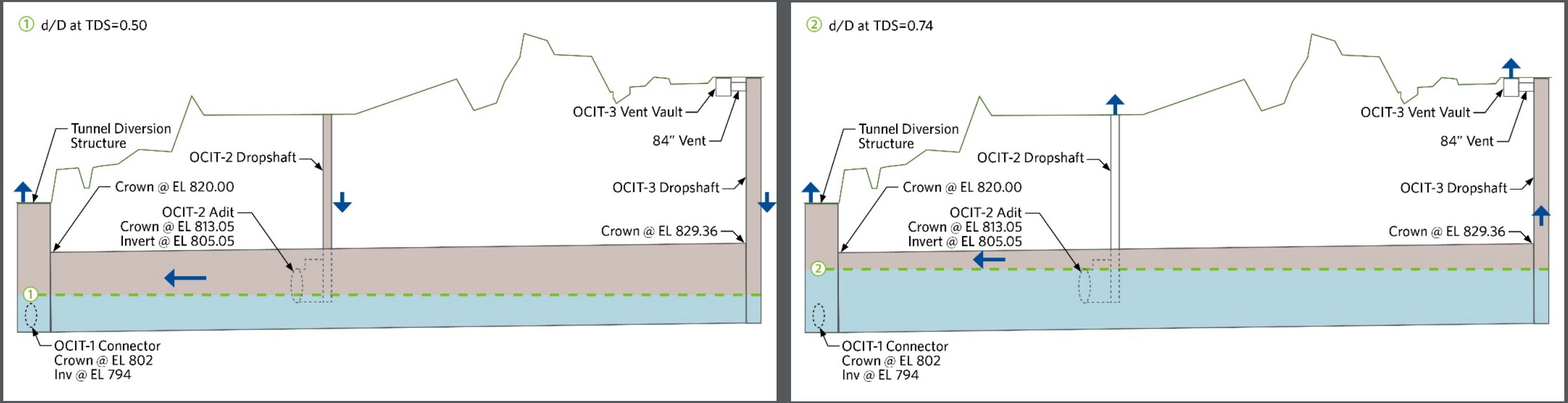
- Flowing wastewater results in friction at air-water interface, which induces flow of air
- Predominant factor influencing ventilation in sewers and tunnels with dry-weather flows
- **Air flows maximized when d/D = 0.5**
- Modeled by Pescod & Price (1982)
- More recent models developed
  - HDR First Principles



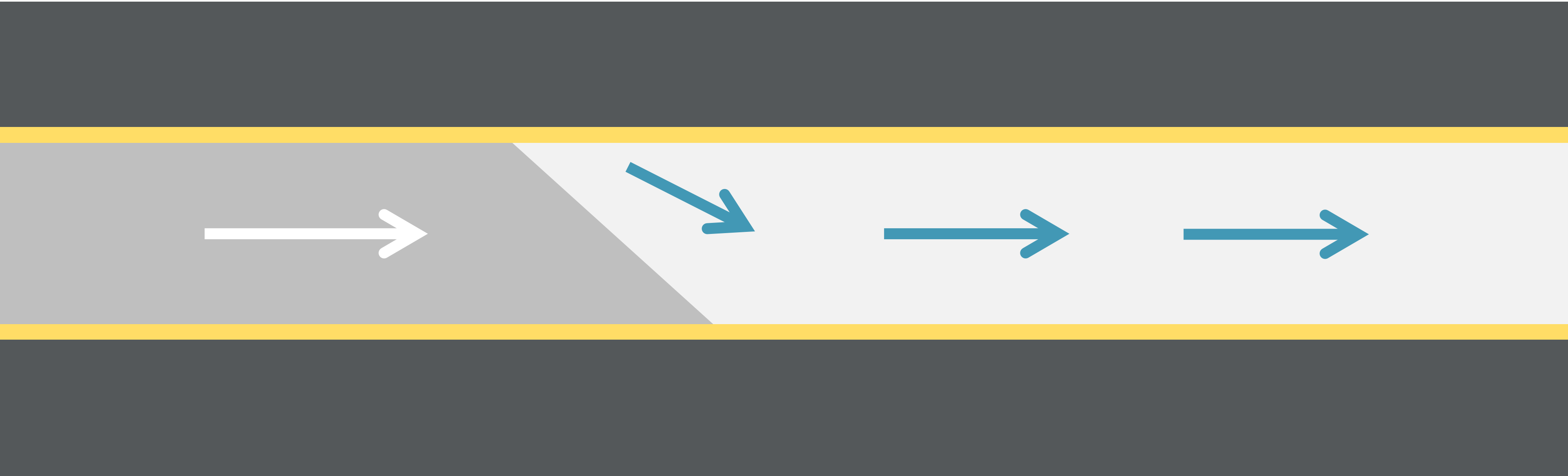
# Displacement Air

- Rising water levels during wet-weather events forces air out of the sewer or tunnel
- Air Emission Time and Flow Rate – inversely proportional
- Tends to exhaust at the farthest downstream outlet that is not occluded (blocked) by water levels



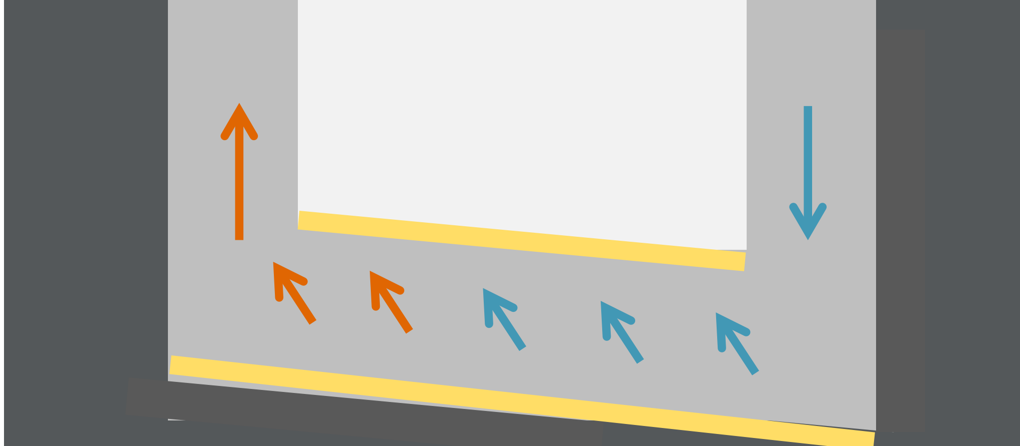
# Flushing Airflow Effect

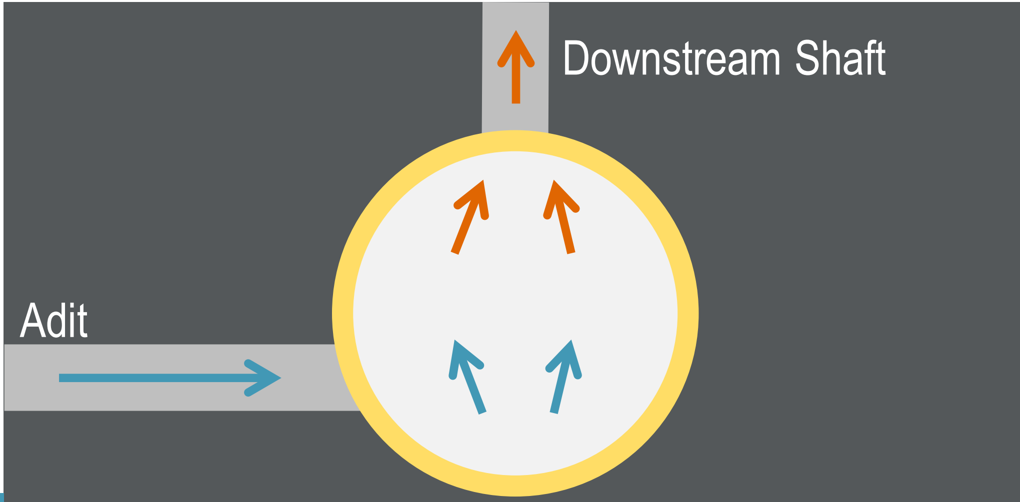
- Short-term displacement event in which a nearly-empty tunnel experiences a rapid inflow of water
- Can create high air pressures, blowing manhole covers or damaging ventilation structures
- Mitigate through design by spreading out hydraulic inlets to tunnel/sewer



# Buoyancy Effect

- Temperature difference between tunnel air and atmospheric air causes pressure gradient
- Most common during cold weather
- Air flow travels upstream
- Has been observed in tunnels with no dry weather flow

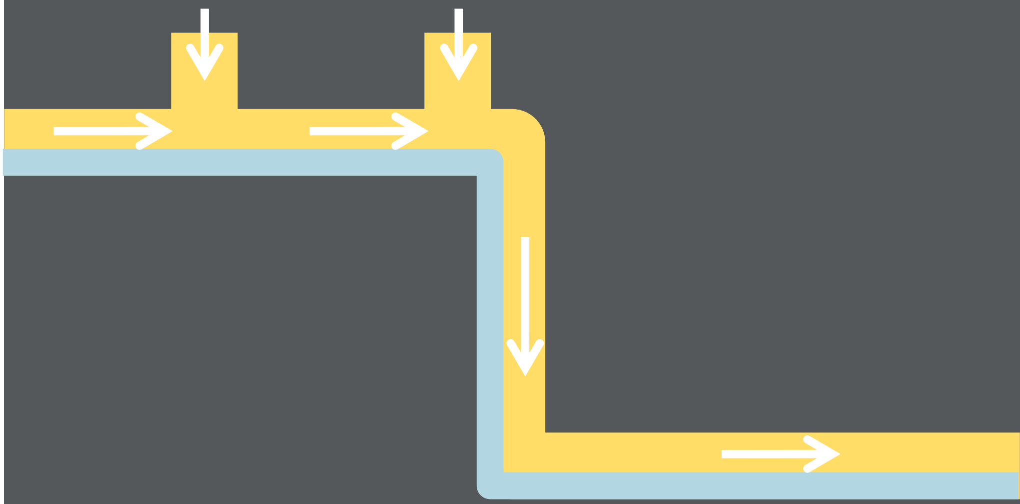

Profile of Tunnel with Upstream and Downstream Shafts



Cross-section of Tunnel

# Drop Structure Eduction

- Acceleration of falling wastewater induces airflow as a result of drag force
- Increased surface area → greater airflow
- Mitigation options:



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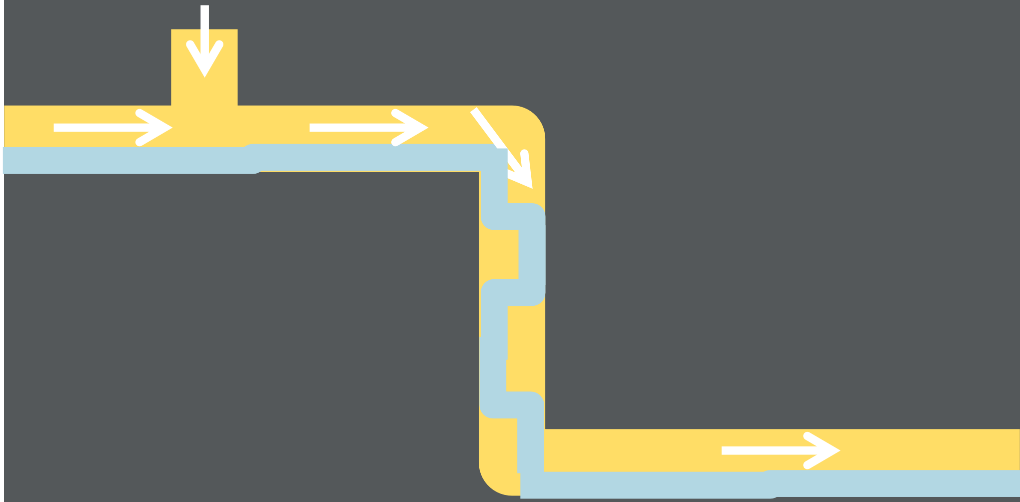
  - Baffle drop structure ⟶ reduce formation of droplets and dissipate energy



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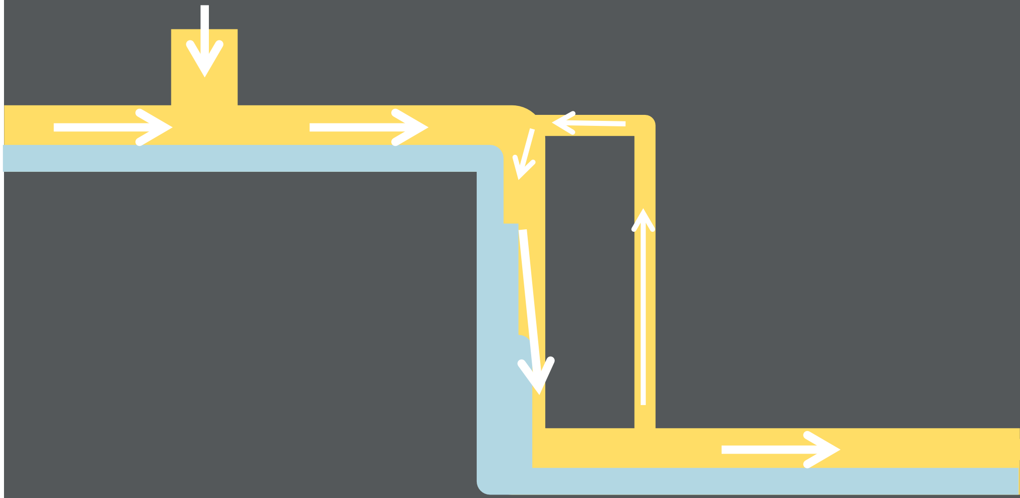
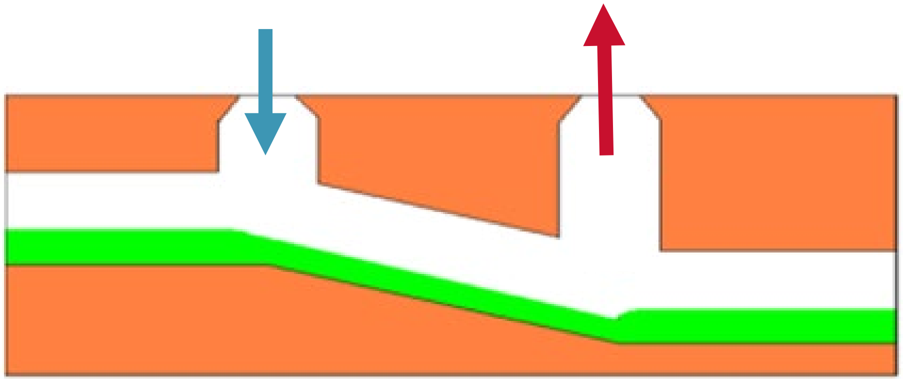
  - Return air duct → reduce net airflow into tunnel



# 03 Airflow & Odor Considerations for Sewer Design

# Considerations for Sewer and Tunnel Ventilation Design

- Friction drag
  - Minimize slope/diameter changes
  - Wind over an open stack/manhole can induce air flow – seal or use dampers.
  - Select pipe diameters considering both wastewater flow rate and air flow at different storm conditions
- Displacement airflows
  - Consider occlusion of the sewer/tunnel during different storm conditions
- Buoyancy airflows
  - Consider siting of tunnel drop shafts
  - Use of dampers to manage airflow



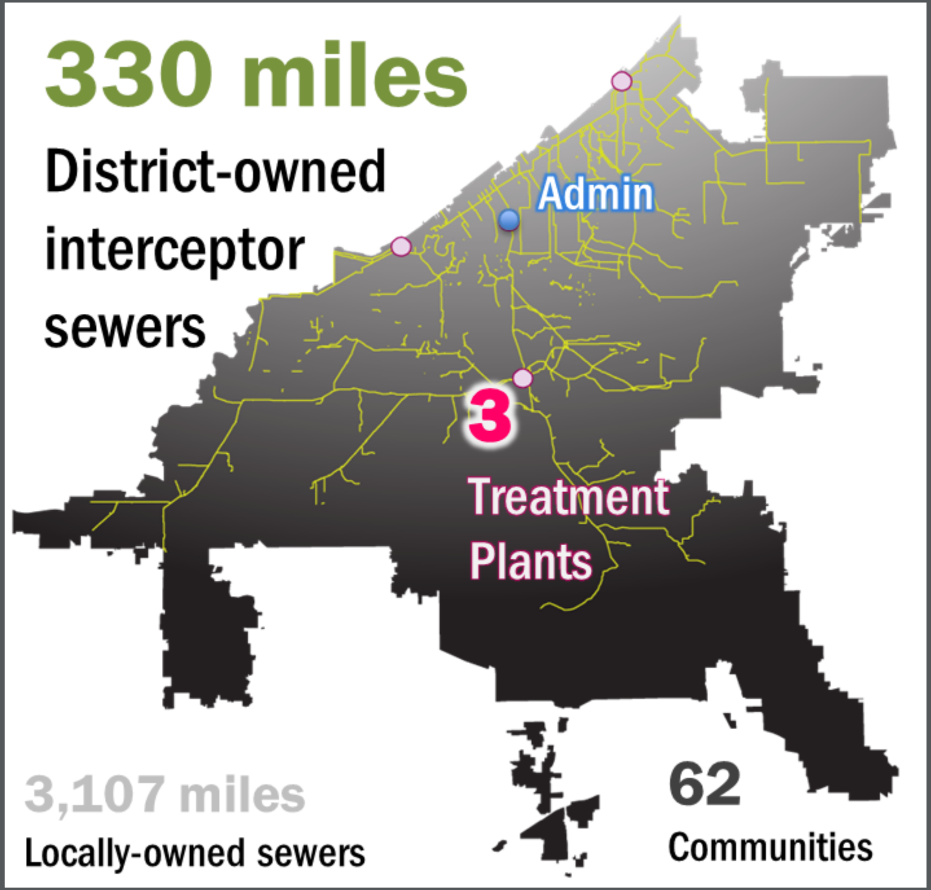
# Considerations for Sewer and Tunnel Ventilation Design

- Drop structure eduction
  - Mitigate through design
- Flushing airflow
  - Allow sewer/tunnel to “breathe”
  - Hydraulic modeling of flow inputs
- Other considerations:
  - Use of a fan to pull air from a sewer or tunnel
  - Selection of Materials: Consider corrosion resistant materials

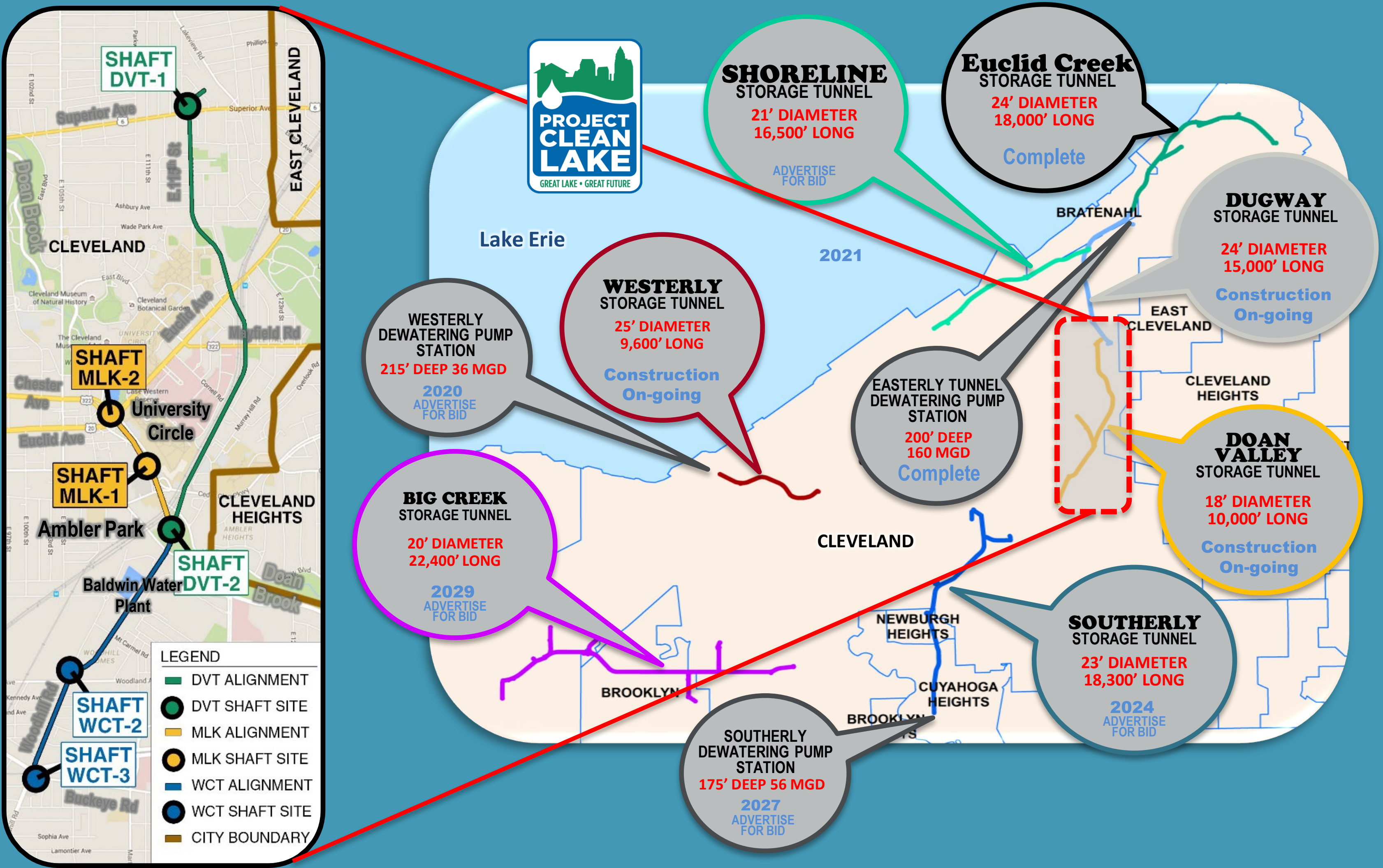
# 04 Case Study: Doan Valley Tunnel (NEORSD)

# Case Study: Doan Valley Tunnel (NEORSD)

- Northeast Ohio Regional Sewer District (NEORSD)
- DVT project team:
  - McMillen Jacobs Associates and Wade Trim Joint Venture
  - HDR subconsultant to Joint Venture
- HDR performed ventilation study
- Ventilation study goals:
  - Provide review of existing odor control (air treatment) technologies and case studies
  - Determine potential locations of odorous air emissions
  - Evaluate potential capital costs and required land areas for odor control facilities

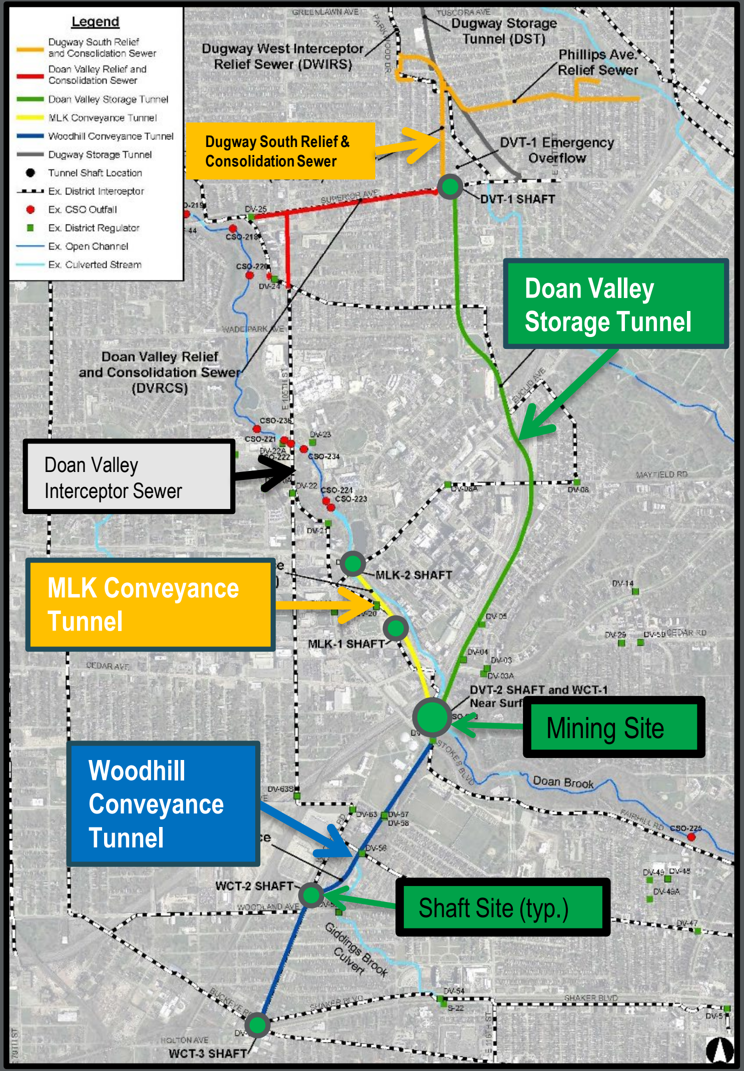


# Project Location



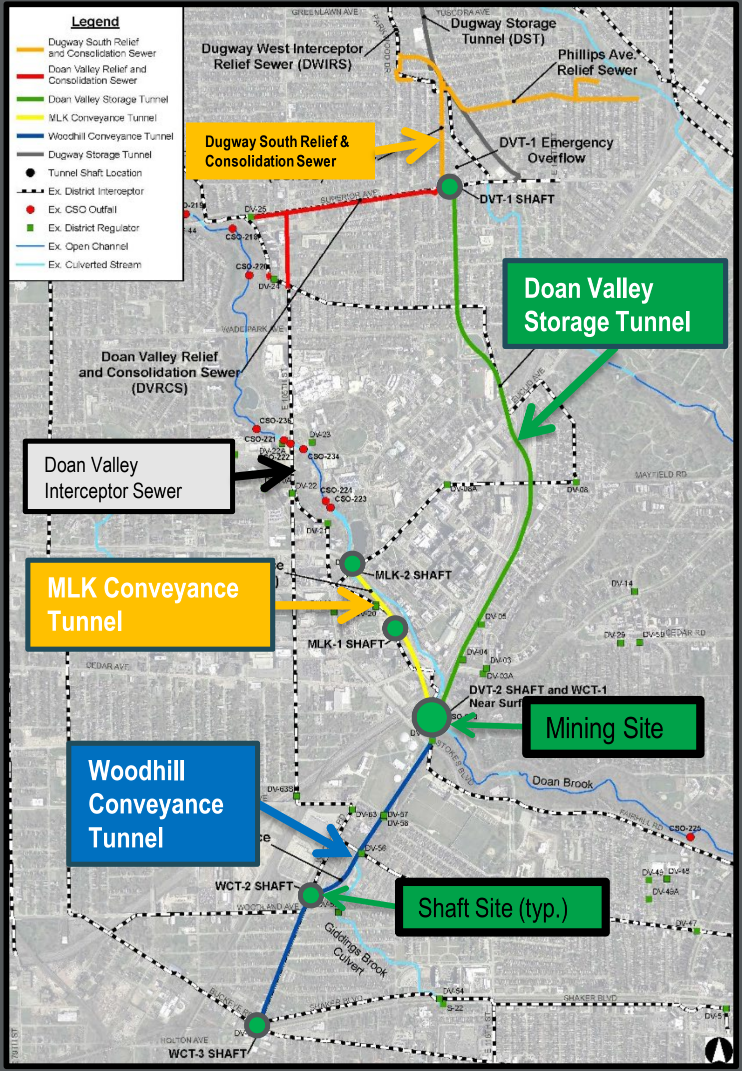
# Doan Valley Tunnel

- Project Overview
  - 3.7 miles total of rock tunnel
  - 18-ft to 8.5-ft diameter
  - (3) Tunnel segments
  - (6) Shaft sites
  - Contractor: McNally/Kiewit JV
  - Scheduled Completion: End of 2021

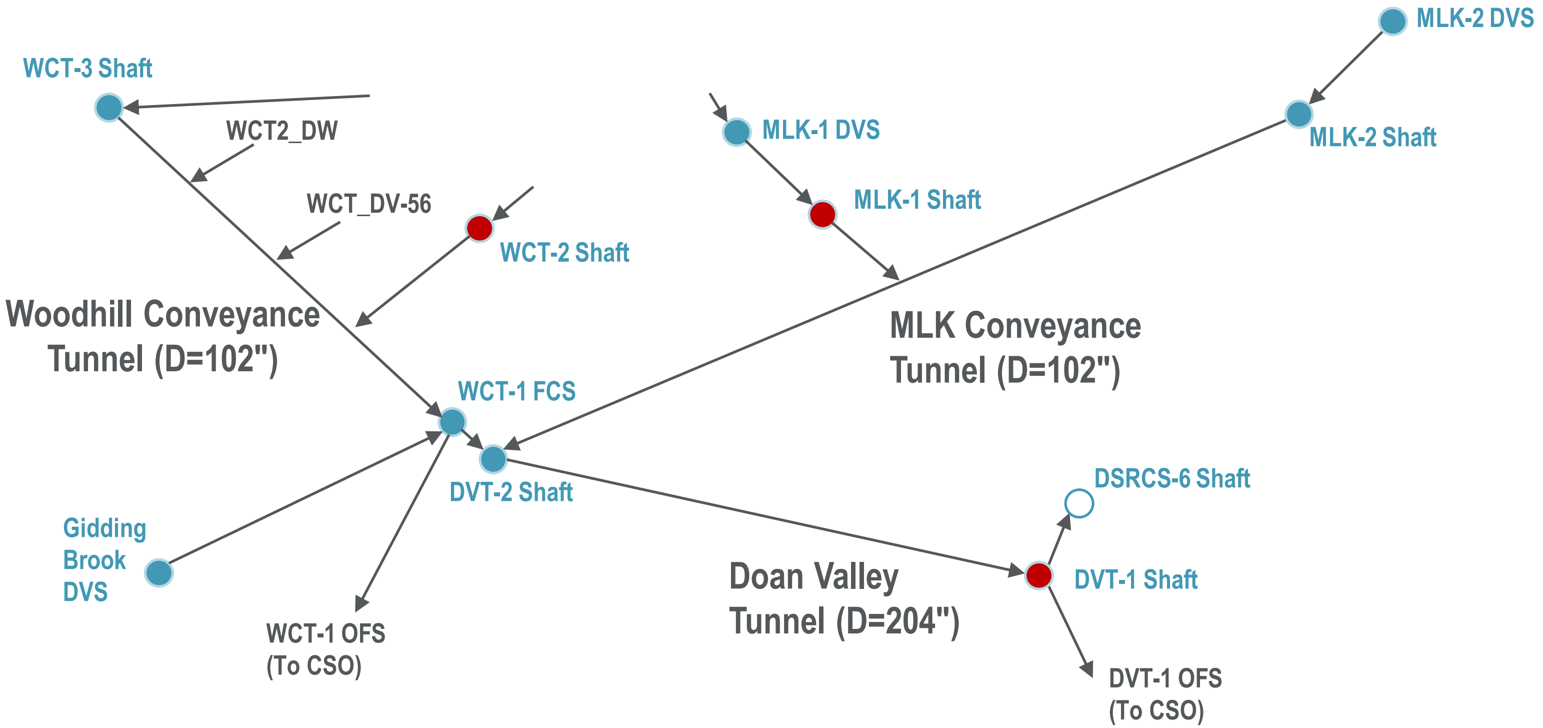


# Doan Valley Tunnel

- Ventilation Evaluation
  - Technology, Industry Reviews
  - Two conditions:
    - Dry weather
    - Wet weather (1-month, 6-hour storm)
- Study Deliverables:
  - Locations of pressurization and approximate air emission flow rates (friction drag)
  - Theoretical buoyancy flow rates at each shaft
  - Odor control facility alternatives
    - Locations, prioritized
    - Cost estimates
    - Required footprint



# DVT System Schematic for Analysis



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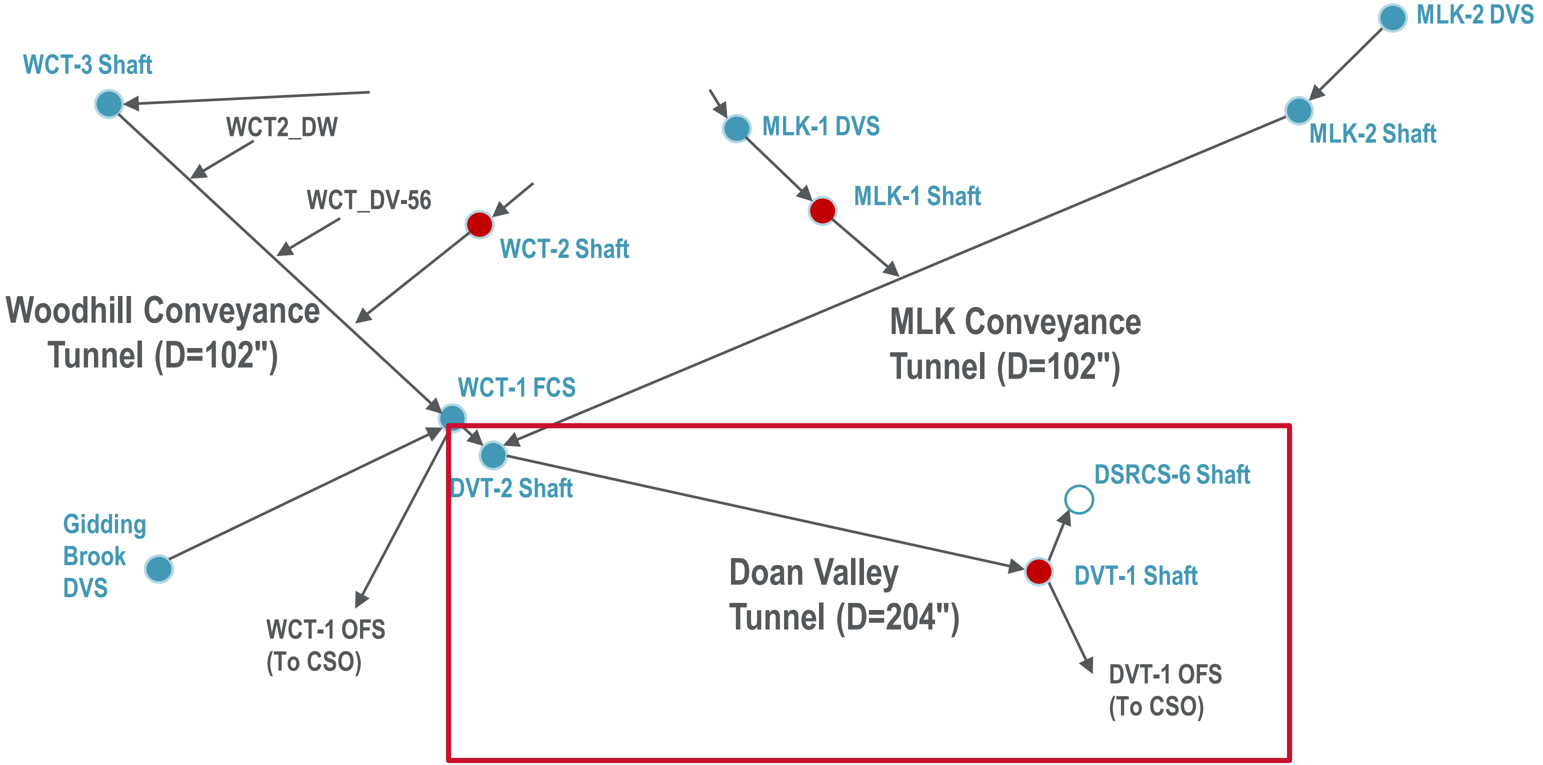

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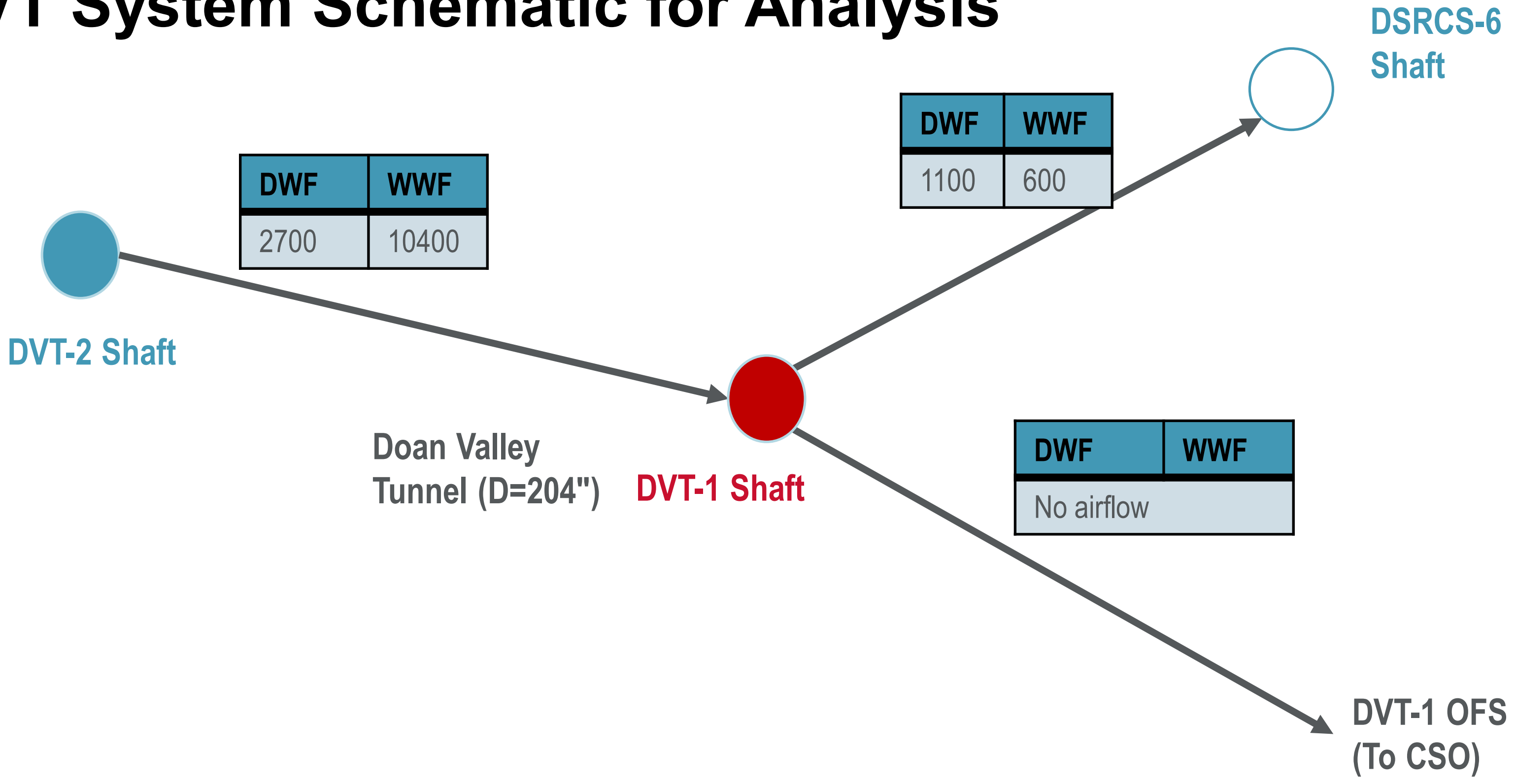


# Doan Valley Tunnel
## Results

- Risk of emissions during dry & wet weather:
  - DVT-1
  - WCT-2
  - DSRCS-6
- Risk of emissions during wet weather:
  - MLK-1
- Low risk of emissions:
  - WCT-3
  - WCT-1 FCS (duct carries airflow to DVT-2)
  - MLK-2

Table 4-8. Potential Airflow Emissions at Shafts due to Friction Drag

| Shaft | Diameter (ft) | Vent Vault Area (ft2) | Friction Drag Airflow | |
|---|---|---|---|---|
| | | | DWF (cfm) | 1-month, 6-hour (cfm) |
| WCT-3 | 34 | 20 | 0 | 0 |
| WCT-2 | 55 | 20 | 650 | 2,150 |
| WCT-1 FCS | 28 X 37 | TBD | 1,100 | 3,200 |
| MLK-2 | 20 | 20 | 0 | 0 |
| MLK-1 | 7 | 20 | 0 | 1,200 |
| DVT-2 | 16 | 49 | 200 | 2,650 |
| DVT-1 | 18 | 70 | 1,600 | 9,800 |

# Doan Valley Tunnel

## Odor Control Alternatives

| No. | Alternative | Cost ($MM) | Footprint (SF) |
|---|---|---|---|
| 1 | No OCFs | $0 | 0 |
| 2a | DVT-1 OCF: 30,000 cfm (AC) | $1.72 | DVT-1: 1,500 |
| 2b | DVT-1 OCF: 30,000 cfm (AC)<br>WCT-2 OCF: 5,000 cfm (AC) | $2.35 | DVT-1: 1,500<br>WCT-2: 250 |
| 3a | DVT-1 OCF: 15,000 cfm (BF)<br>DVT-2 OCF: 15,000 cfm (BF) | $2.43 | DVT-1: 16,500<br>DVT-2: 8,200 |
| 3b | DVT-1 OCF: 15,000 cfm (BF)<br>DVT-2 OCF: 15,000 cfm (BF)<br>WCT-2 OCF: 5,000 cfm (AC) | $3.06 | DVT-1: 16,500<br>DVT-2: 8,200<br>WCT-2: 250 |
| 4 | Option 2a, 2b, 3a, 3b PLUS:<br>MLK-1 OCF: 5,000 cfm (AC, AD) | $2.35-$3.69 | MLK-1: 250 |

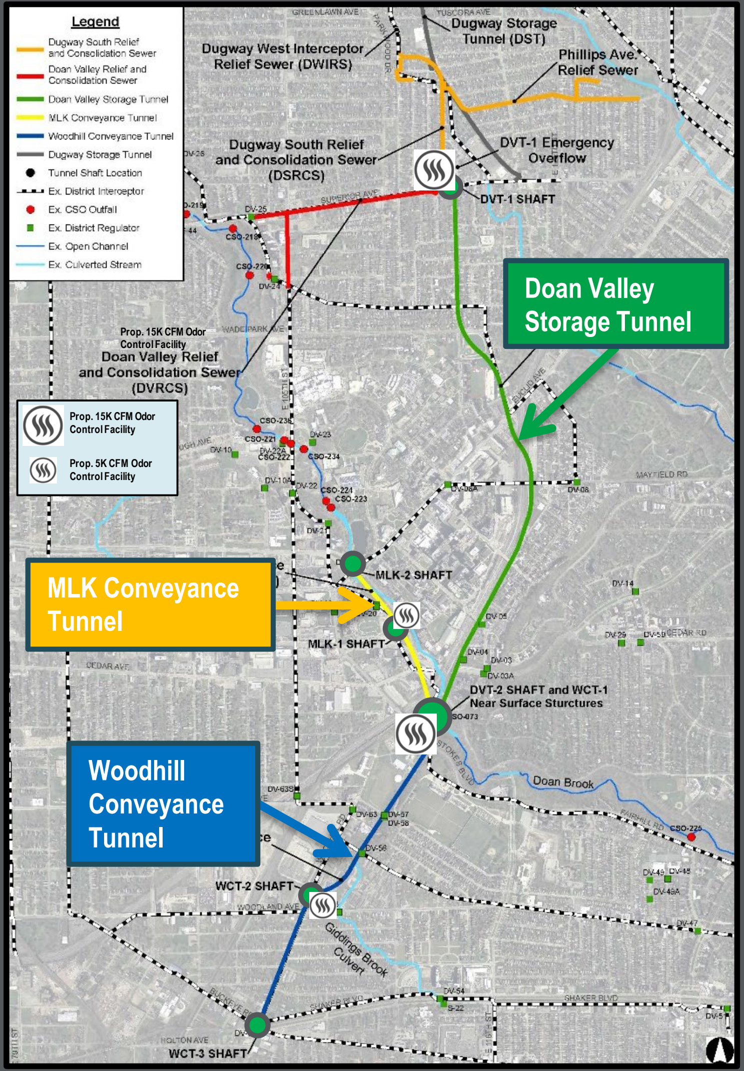
AC: Activated Carbon
BF: Biofilter
AD: Air Dispersion

Note: costs in 2016 dollars.

# Doan Valley Tunnel

## Recommendations

- Planning for space/footprint on site, should potential odor control facilities be needed, at four sites:
  - 30,000 CFM activated carbon at DVT-1 OR 15,000 CFM biofilter at DVT-1 and 15,000 CFM biofilter at DVT-2
  - 5,000 CFM activated carbon at MLK-1
  - 5,000 CFM activated carbon at WCT-2
- Further ventilation evaluation under a greater range of storm conditions



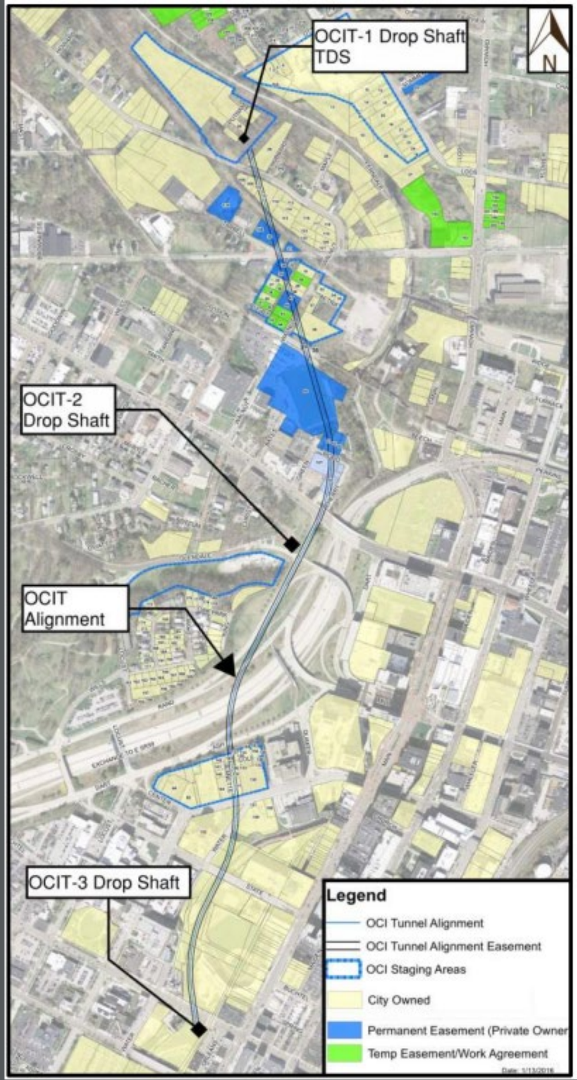
# 05 Case Study: Ohio Canal Interceptor Tunnel (City of Akron)

# Ohio Canal Interceptor Tunnel (OCIT)

- City of Akron Water Reclamation Services
  - Serves City of Akron and neighboring communities
  - 96 square miles, population of 330,000
  - Akron Waterways Renewed!
    - Series of projects to reduce CSOs
    - OCIT:  largest AWR project - $300M
- OCIT Team:
  - DLZ:  Lead Designer
  - McMillan-Jacobs:  Tunnel Designer
  - HDR: Odor Evaluation & Design

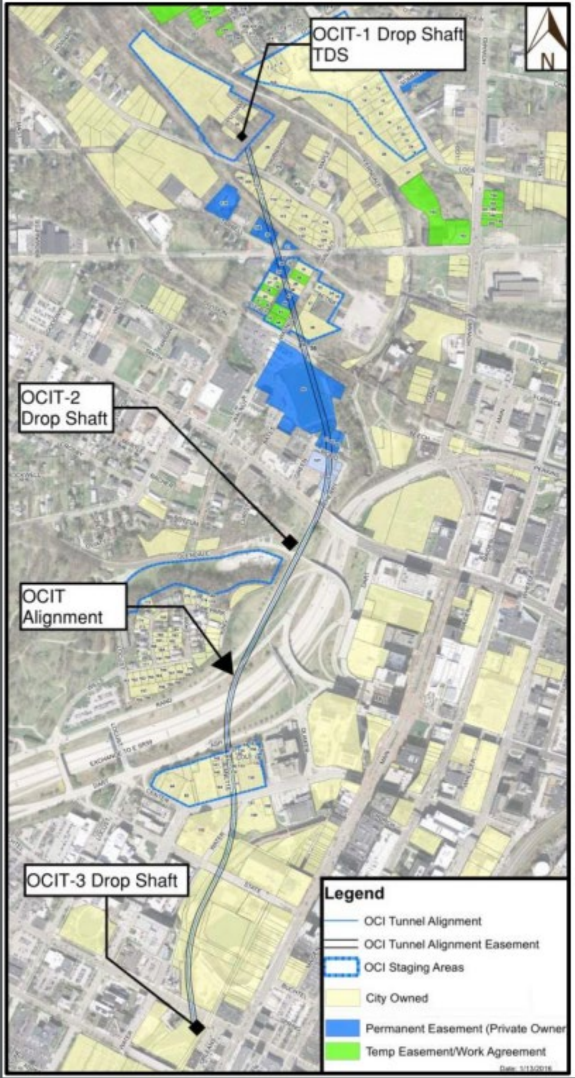
# Ohio Canal Interceptor Tunnel (OCIT)

- 6,200 linear feet, 27-foot diameter
- Contractor: Kenny Obayashi Joint Venture
- Completion 2020
- Three dropshaft sites:
  - OCIT-1/TDS: Downstream, residential
  - OCIT-2: Midpoint, potential future development
  - OCIT-3: Downtown
- HDR has performed the following:
  - Odor evaluation of existing system
  - OCIT ventilation study
  - OCIT odor control facility plan
  - OCIT-1 odor control facility design

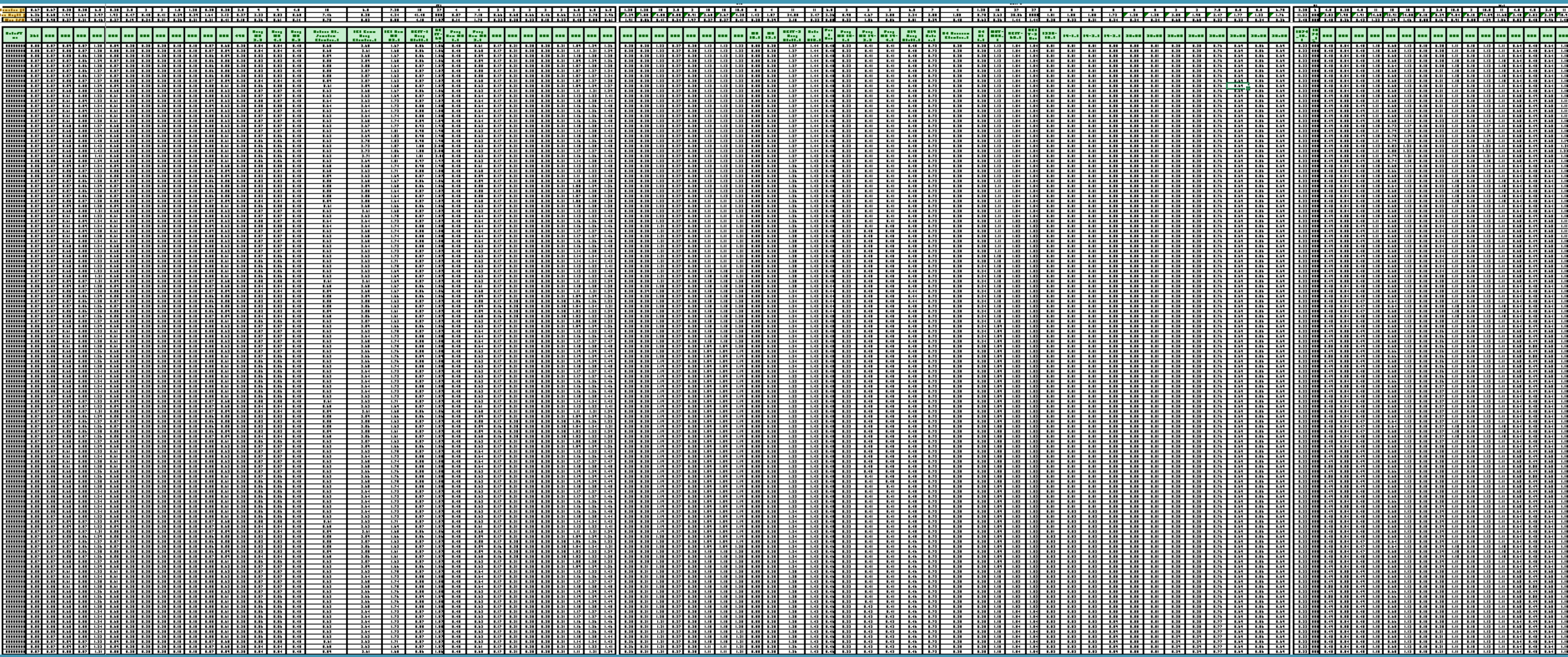


# Ohio Canal Interceptor Tunnel (OCIT)

- Ventilation Evaluation
  - Technology review
  - Typical year storm data
- Facility Plan Deliverables:
  - Frequency/duration/intensity of odorous air emissions – friction drag and displacement
  - Odor control facility alternatives
    - Site layouts
    - Cost estimates
    - Level of service

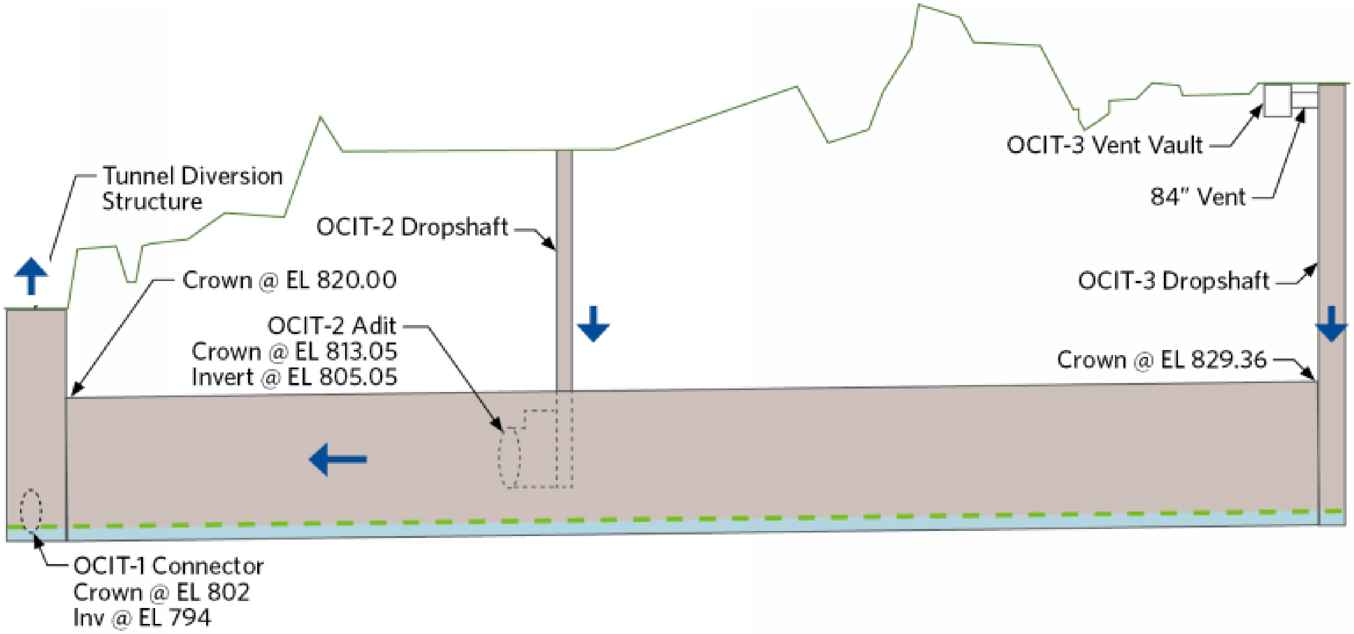


# A picture of 0.1% of the data…



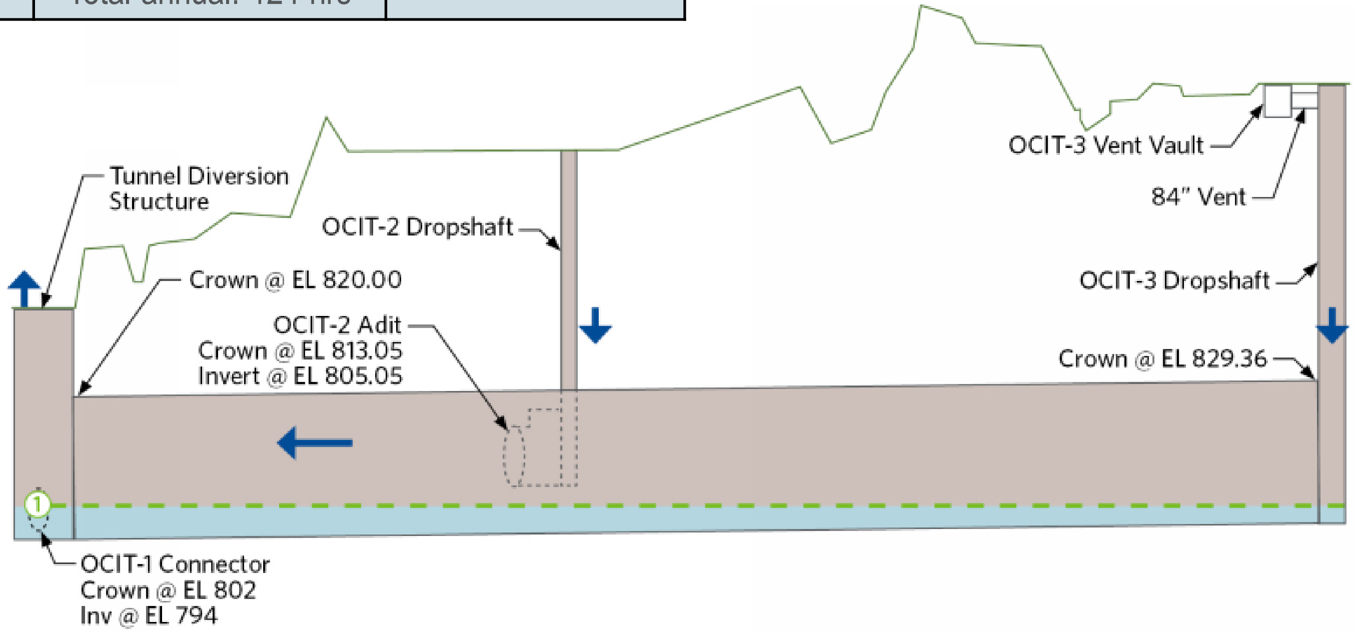
# Dry Weather Flow (d/D ≅ 0.07)

| Frequency | Duration | Return Interval |
|---|---|---|
| N/A | >90% of Year (>328 days/yr) | N/A |



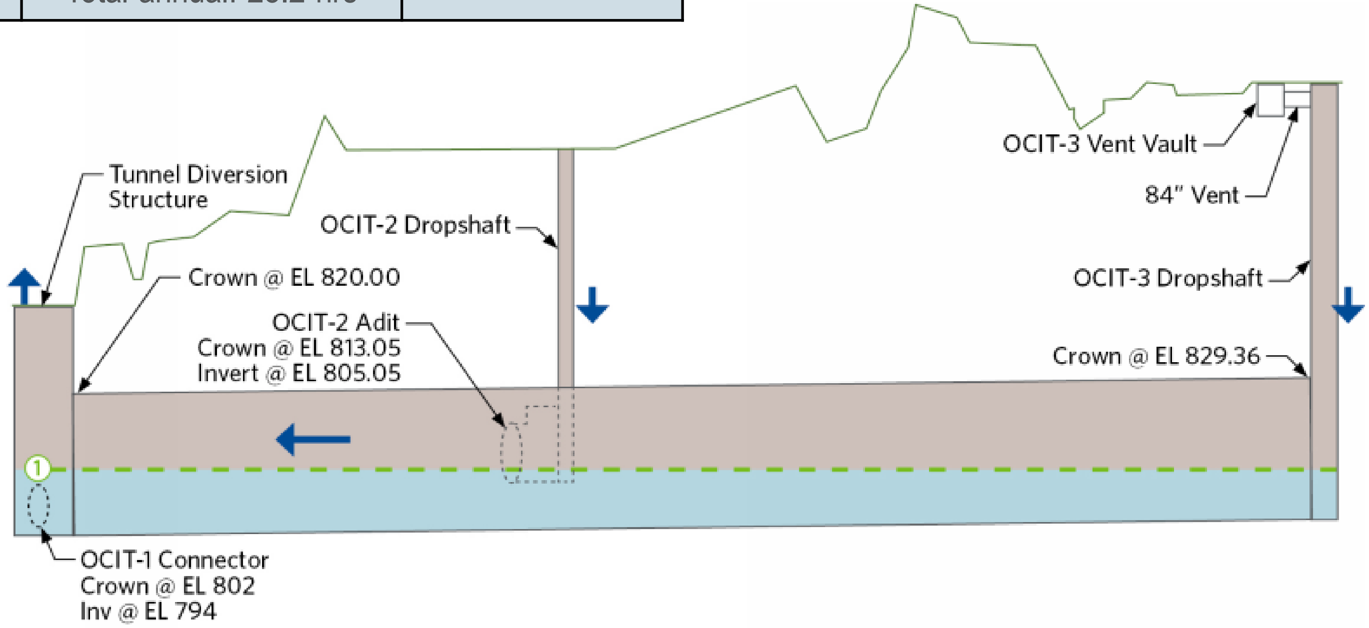
# d/D at TDS ≥ 0.3

| Frequency | Duration | Return Interval |
|---|---|---|
| 22 / yr | Avg event: 5.2 hrs<br>Max event: 20.4 hrs<br>Total annual: 124 hrs | <2 month |



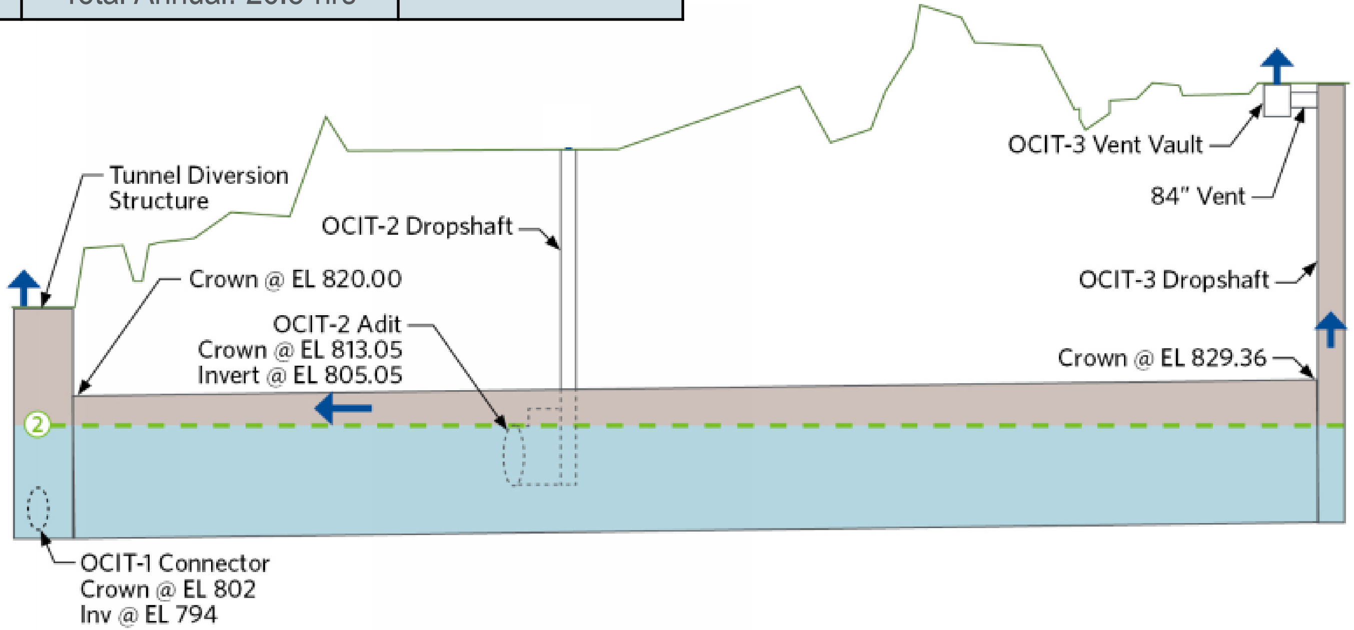
# d/D at TDS = 0.45 to
# d/D at TDS = 0.65

| Frequency | Duration | Return Interval |
| --- | --- | --- |
| 13 / yr | Avg event: 2.2 hrs<br>Max event: 5.1 hrs<br>Total annual: 28.2 hrs | <2 month |



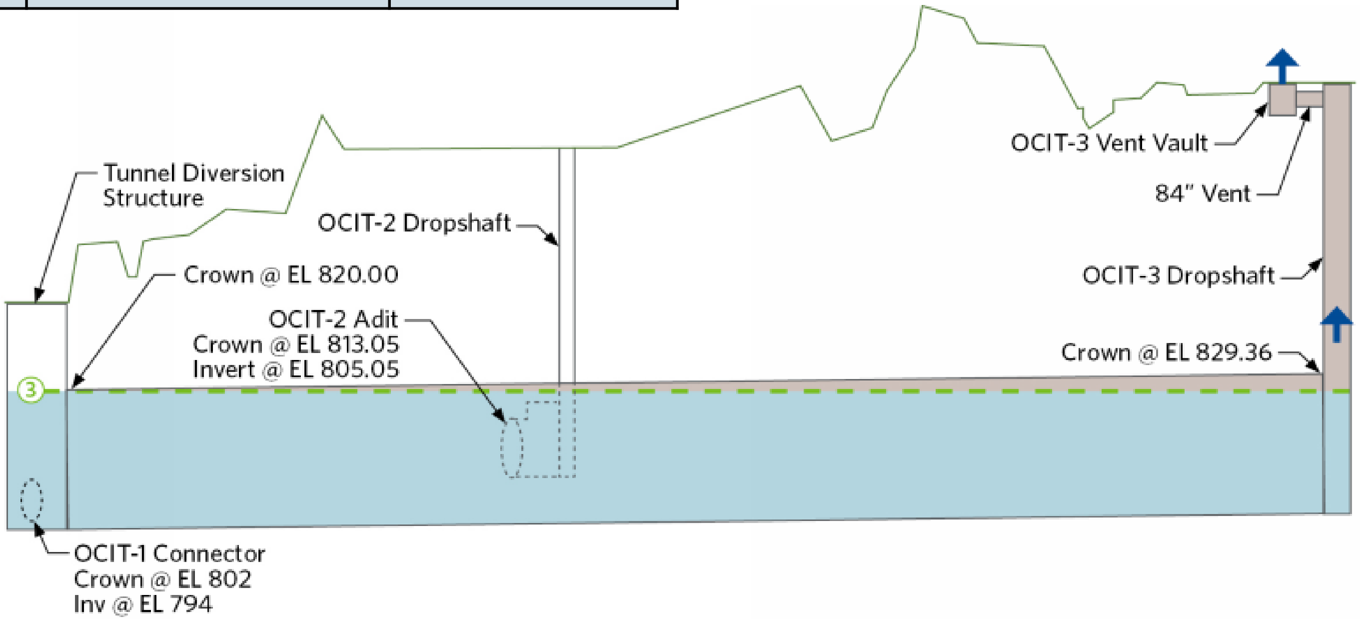
# d/D at TDS = 0.65 to
# d/D at TDS = 1.0

| Frequency | Duration | Return Interval |
|---|---|---|
| 6 / yr | Avg Event: 4.5 hrs<br>Max Event: 7.6 hrs<br>Total Annual: 26.8 hrs | >2 month |



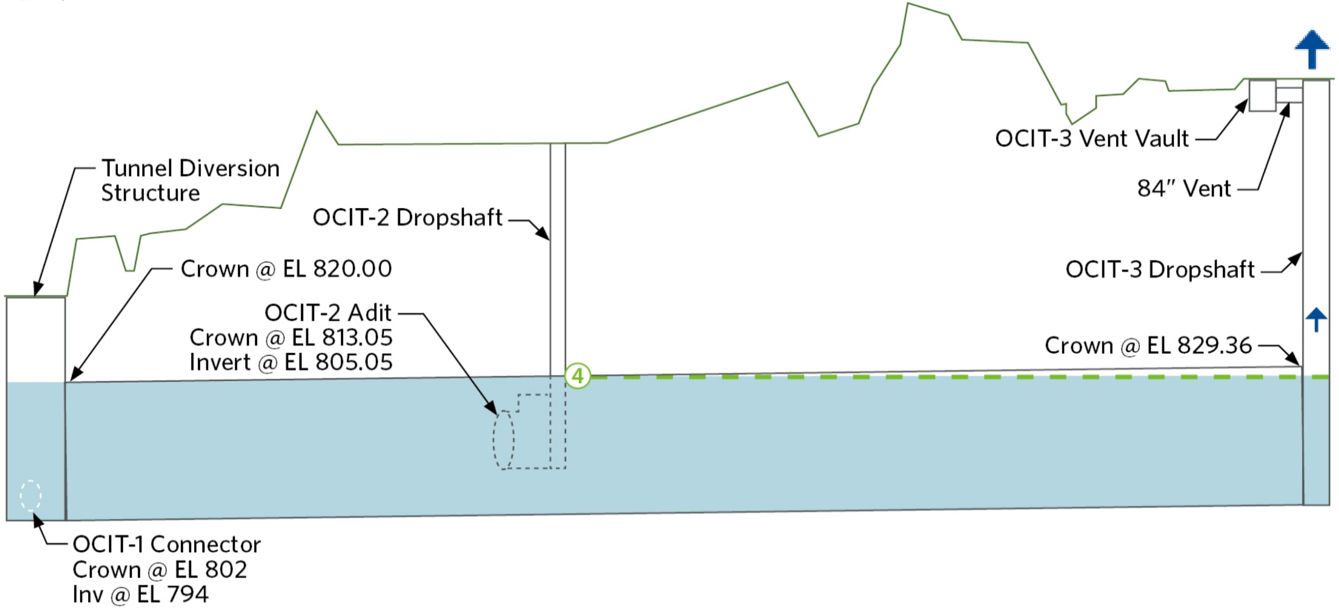
# d/D at TDS = 1.0 to
# d/D at OCIT-2 = 1.0

| Frequency | Duration | Return Interval |
|---|---|---|
| 5 / yr | Avg Event: 1.8 hrs<br>Max Event: 2.5 hrs<br>Total Annual: 8.8 hrs | >3 month |



# d/D at OCIT-2 = 1.0 to d/D at OCIT-3 = 1.0

| Frequency | Duration | Return Interval |
|---|---|---|
| 5 / yr | Avg Event: 1.8 hrs<br>Max Event: 2.5 hrs<br>Total Annual: 8.8 hrs | >3 month |



# d/D at OCIT-3 > 1.0

| Frequency | Duration | Return Interval |
|---|---|---|
| 5 / yr | Avg Event: 1.8 hrs<br>Max Event: 2.5 hrs<br>Total Annual: 8.8 hrs | >3 month |

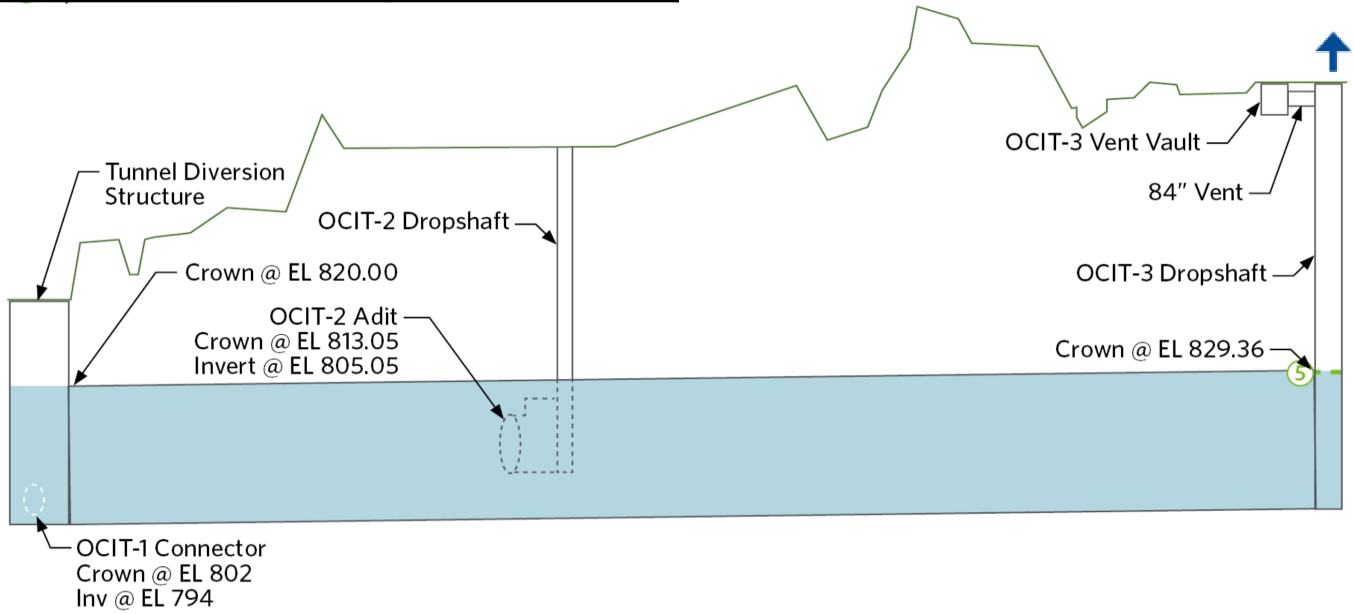


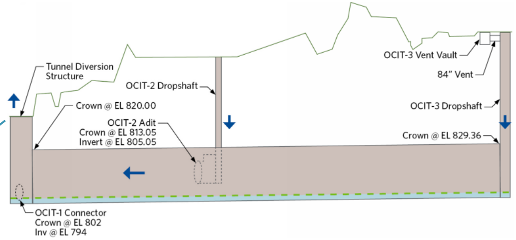
**Table 3-2. Peak d/D and Airflow Scenario Duration for Typical Year Storms**

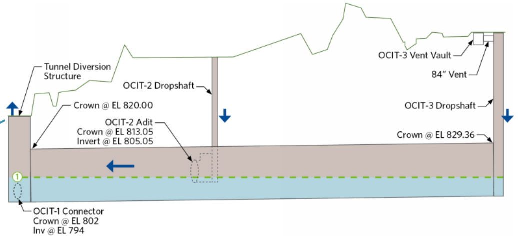
| Storm Start Date | Peak d/D | | | Time Spent In Scenario (hours) | | | | |
|---|---|---|---|---|---|---|---|---|
| | TDS | OCIT-2 | OCIT-3 | 1. Filling Adit | 2. Full at Adit | 3. Full at TDS | 4. Full at OCIT-2 | 5. Full at OCIT-3 |
| 4/12 | 1.57 | 1.44 | 1.24 | 2.1 | 3.4 | 1.2 | 0.9 | 5.4 |
| 8/13 | 1.57 | 1.42 | 1.23 | 1.8 | 7.6 | 2.5 | 1.8 | 5.6 |
| 7/7 | 1.56 | 1.42 | 1.23 | 1.6 | 3.2 | 1.2 | 1.1 | 2.7 |
| 7/2 | 1.11 | 0.95 | 0.76 | 1.6 | 3.9 | 2.2 | - | - |
| 8/20 | 1.02 | 0.87 | 0.68 | 1.7 | 5.2 | 1.6 | - | - |
| 4/13 | 0.85 | 0.70 | 0.51 | 2.4 | 3.4 | - | - | - |
| 7/21 | 0.65 | 0.48 | 0.31 | 3.7 | - | - | - | - |
| 4/9 | 0.64 | 0.48 | 0.30 | 5.1 | - | - | - | - |
| 9/9 | 0.55 | 0.40 | 0.21 | 1.9 | - | - | - | - |
| 7/28 | 0.55 | 0.39 | 0.21 | 2.2 | - | - | - | - |
| 1/27 | 0.49 | 0.34 | 0.16 | 2.9 | - | - | - | - |
| 8/11 | 0.48 | 0.31 | 0.13 | 0.7 | - | - | - | - |
| 6/29 | 0.46 | 0.30 | 0.12 | 0.4 | - | - | - | - |

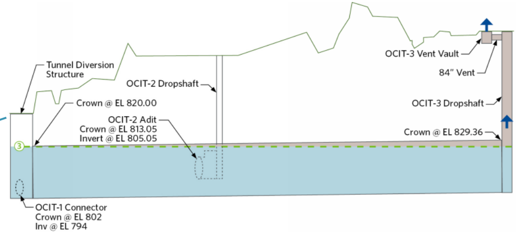
# Ohio Canal Interceptor Tunnel

## Airflow Scenario Frequency and Duration

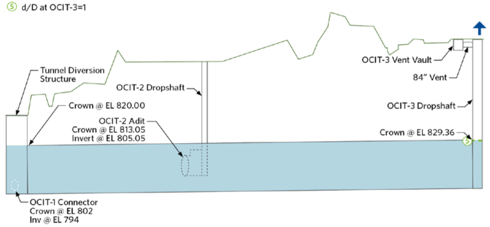
| Airflow Scenario | Typical Year Frequency[5] | Duration (hours) | Return Interval |
|---|---|---|---|
| Dry Weather Flow (d/D at TDS≤0.07) | >90% of year | N/A | N/A |
| Tunnel Full at OCIT-1 Connector (d/D at TDS>0.3) | 22 / yr | Avg: 5.2<br>Max: 20.4<br>Annual: 124.0 | >1 month |
| (1) OCIT-2 Adit Begins to Fill (d/D at TDS>0.45) | 13 / yr | Avg: 6.2<br>Max: 19.3<br>Annual: 81.2 | >1 month |
| (2) Tunnel Full at OCIT-2 Adit (d/D at TDS>0.65) | 6 / yr | Avg: 8.8<br>Max: 17.5<br>Annual: 53.0 | >2 month |
| (3) Tunnel Full at TDS (d/D at TDS>1.0) | 5 / yr | Avg: 5.2<br>Max: 9.9<br>Annual: 26.2 | >3 month |
| (5) Tunnel Full at OCIT-3 (d/D at OCIT-3=1.0) | 3 / yr | Avg: 4.6<br>Max: 5.6<br>Annual: 13.7 | >7 month |




5 d/D at OCIT-3=1



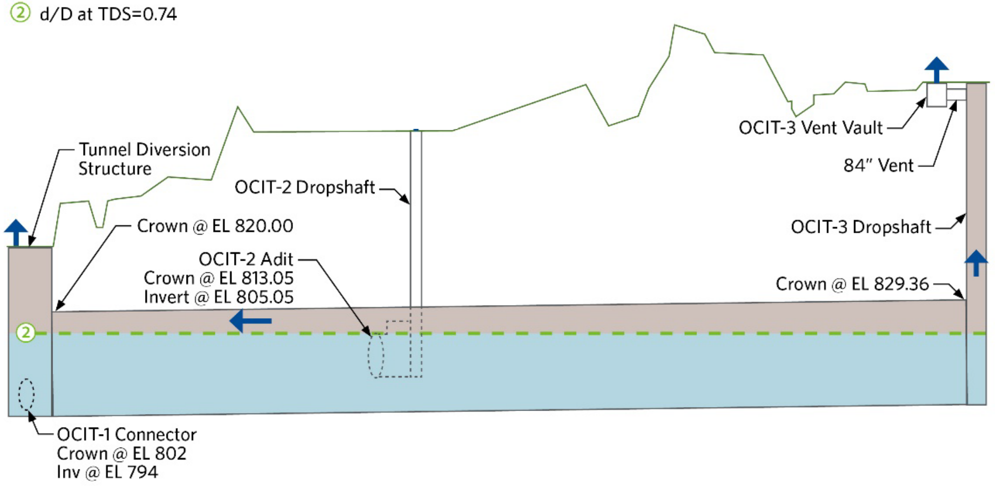
# Ohio Canal Interceptor Tunnel – Level of Service

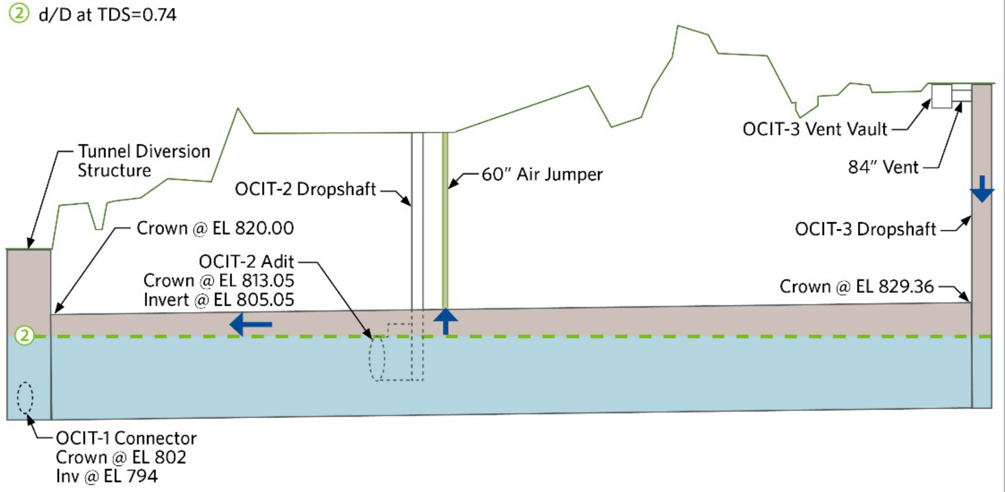
## Untreated Airflow Emissions at TDS at Various OCF Levels of Service

| TDS OCF Capacity (cfm) | Level of Service | Frequency of Untreated Emissions | Duration of Untreated Emissions |
|---|---|---|---|
| 30,000 | DWF Only | 10% of typ year.<br>100+ / yr | Avg: 8 hrs / event<br>Max: 34 hrs / event<br>Annual: 40 days / yr |
| 40,000 | DWF + minor WWF (d/D<0.15) | 40 / yr | Avg: 5 hrs / event<br>Max: 21 hrs / event<br>Annual: 16 days / yr |
| 60,000 | DWF + moderate WWF (d/D<0.35) | 14 / yr | Avg: 5.5 hrs / event<br>Max: 20 hrs / event<br>Annual: 3 days / yr |
| 80,000 | DWF + all WWF | <1 / yr | N/A |

# Ohio Canal Interceptor Tunnel

- Recommendations:
  - Air Flaps/Ducts throughout system (Auxiliary Structures)
  - OCIT-1 Odor Control Facility
  - OCIT-2 Air Jumper
  - OCIT-3 Air Dispersion Stack



# Ohio Canal Interceptor Tunnel

## Odor Control Alternatives

| No. | Alternative | Cost ($MM) |
|---|---|---|
| 1 | -OCIT-1 Odor Control Facility, 30,000 cfm<br>-OCIT-2 Air Jumper<br>-Ventilation “Auxiliary Structures” | $5.06 |
| 2 | Alternative 1 PLUS:<br>-OCIT-2 Odor Control Facility | $6.70 |
| 3 | Alternative 2 PLUS:<br>-OCIT-1 Odor Control Facility, add’l 50,000 cfm<br>-OCIT-3 Odor Control Facility | $9.99 |

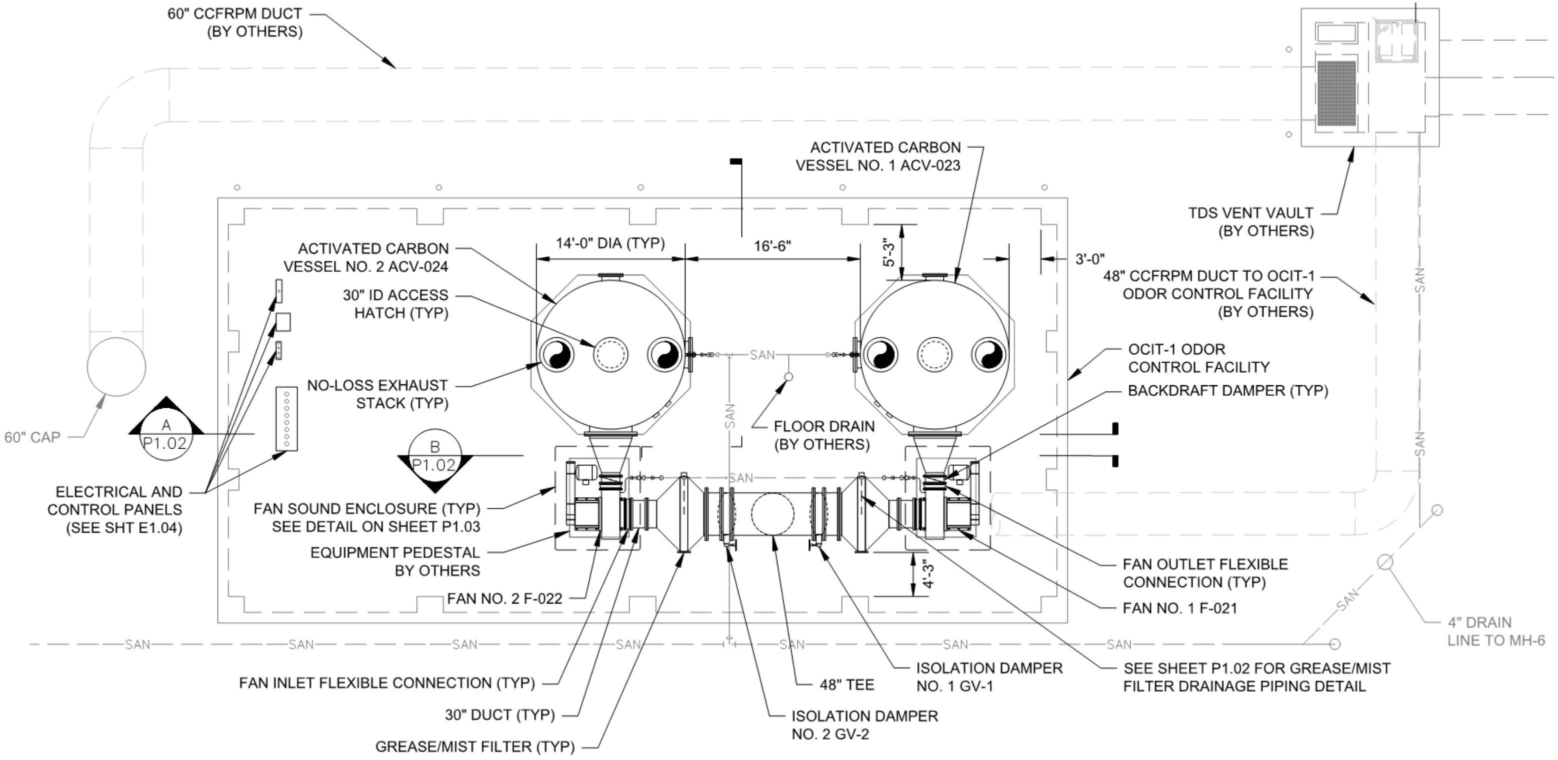
# Ohio Canal Interceptor Tunnel

## OCIT-1 Odor Control Facility

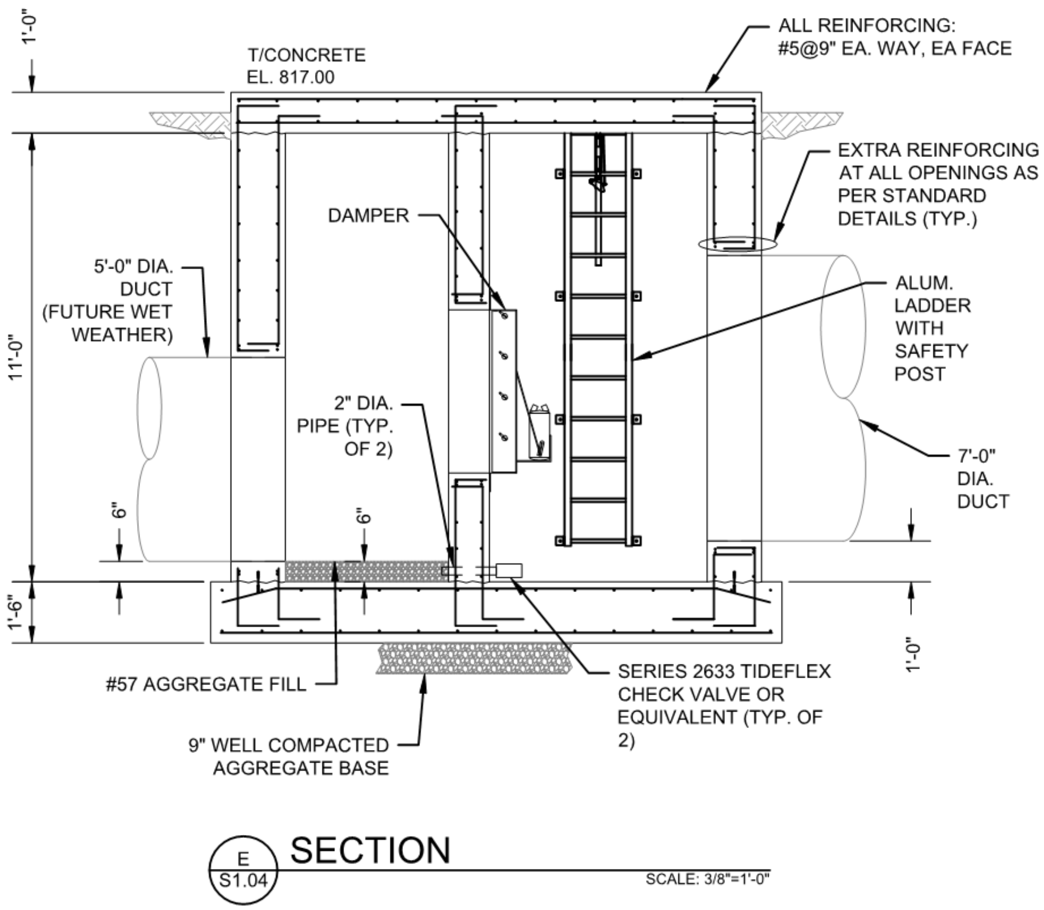
- Technology Selection Workshop
- 30,000 cfm Activated Carbon system
  - Two 15,000 cfm fans
  - Sized to induce negative pressure throughout entire tunnel system
- Vent Vault for control of excess air flows

# OCIT

## OCIT-1 Odor Control Facility Plan View



# OCIT
## Vent Vault Structural Section



# 06 Summary

# Summary

- Air-water interactions are key to many types of structures, including sewers
- Several mechanisms ventilate and move air within sewers and tunnels
- Consider air flow when designing sewers and tunnels.
  - Ventilation considerations may affect sewer diameters and potential air ducts.
- For complex tunnel systems, evaluate the air flow and ventilation strategies of the entire system holistically early in the design
- Two case studies were presented in which tunnels under design were assessed for ventilation and odor control planning
- Proactive air management strategies decrease operations risk upon start-up / commissioning

# 07 Acknowledgements & Questions

# Acknowledgements


- City of Akron
  - DLZ Corporation
  - V&A Consulting Engineers, Inc.
- NEORSD
  - McMillen Jacobs Associates & Wade Trim Joint Venture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# Questions?