Water Quality Monitoring Results at the Markland Hydroelectric Project (FERC No. 2211) 2011 - 2015

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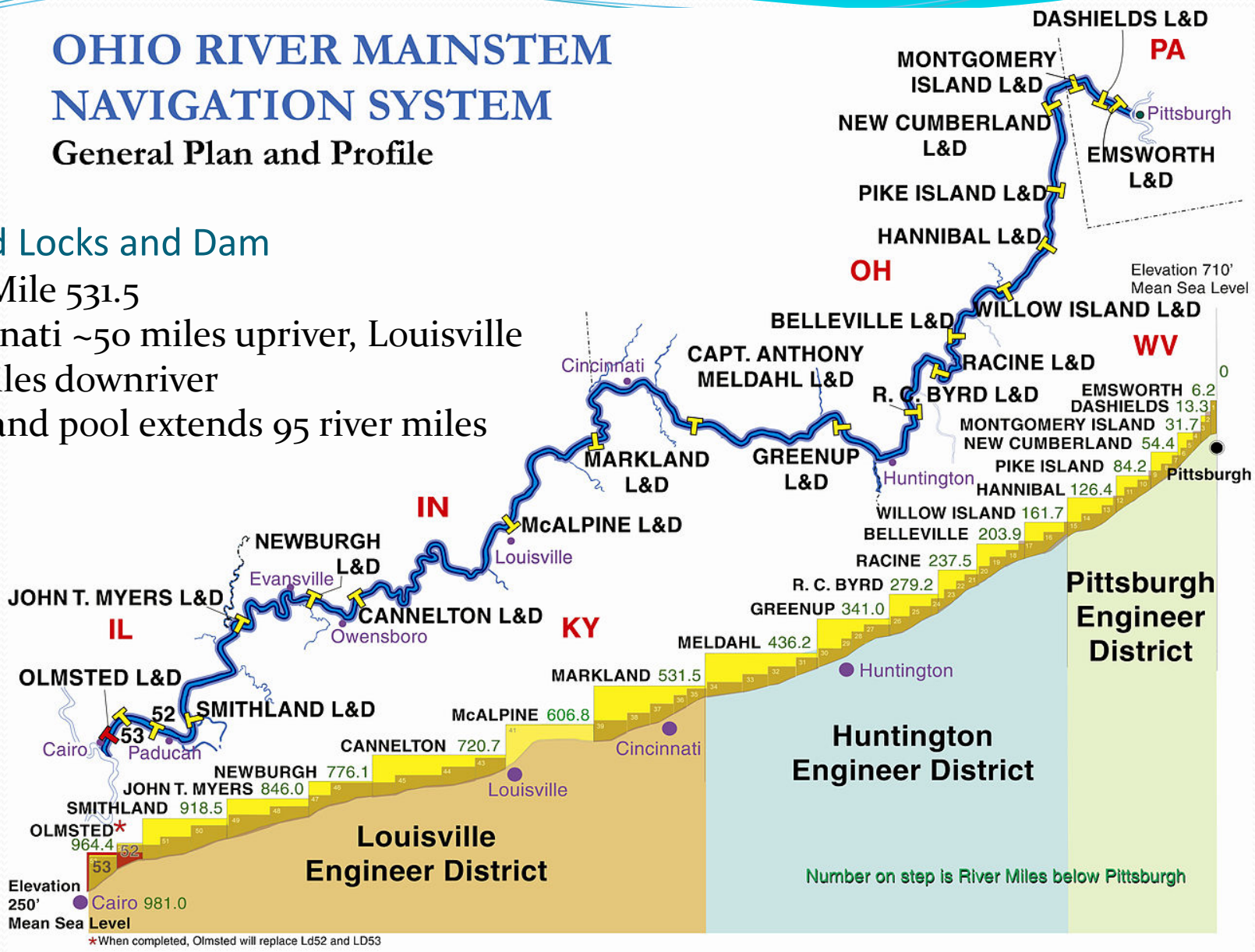
Presentation to Ohio River Valley Water Sanitation Commission Technical Committee,
Pittsburgh, Pennsylvania, June 7, 2016

OHIO RIVER MAINSTEM NAVIGATION SYSTEM

General Plan and Profile

Markland Locks and Dam

- River Mile 531.5
- Cincinnati ~50 miles upriver, Louisville ~50 miles downriver
- Markland pool extends 95 river miles



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Project Operations

- Project originally licensed in 1961, construction of locks & dam completed 1964
- Hydro completed with commercial operation beginning in 1967
- Three 21.6-MW Kaplan turbine/generator units, 64.8-MW licensed capacity
- Hydraulic capacity of 40 kcfs (3 units at 34 ft head)
- Run-of-release operation: Per MOA, USACE stipulates how much water is available after navigation needs and maintenance of the pool elevation are met.

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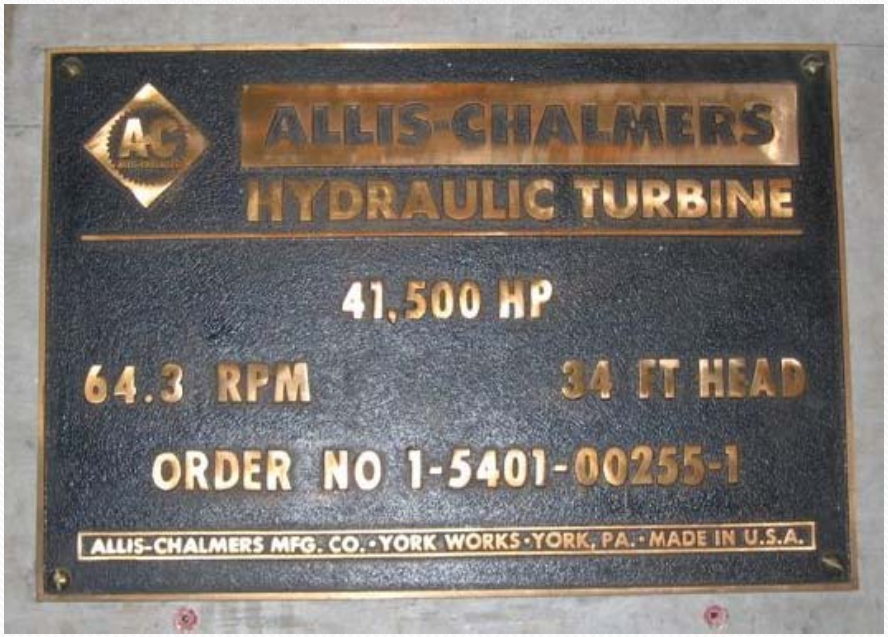
Four-Blade Kaplan runner being installed at Markland

Turbine power rating



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Markland Tainter Gate Spillage – Influence on Water Quality

- The Markland Dam is 1,395 feet long, 42 feet high, and consists of twelve 42-foot high Tainter gates; each 100 feet wide.
- At low flows / low velocities, the sub-surface flow under Tainter gates generates limited turbulence and re-aerates relatively inefficiently

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Markland Project 401 Water Quality Certification

- IDEM Section 401 WQ Certification granted December 8, 2009; re-issued January 22, 2010; June 21, 2012
- FERC Order issuing New License, September 7, 2010; effective May 1, 2011, adopting 401 WQ Certification conditions

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IDEM Policy & Water Quality Standards

- Dissolved oxygen (DO) standards apply to hydroelectric generation releases

- *Concentrations of dissolved oxygen shall:*
  - *(A) average at least five (5.0) milligrams per liter per calendar day; and*
  - *(B) not be less than four (4.0) milligrams per liter at any time.*

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FERC License and 401 Requirements

1. (2010) Install continuous WQ monitors at Project
2. (2011-2015) Conduct 5-years of WQ monitoring to assess compliance with WQS and potential need for aeration. Reporting required for March-October continuous monitoring (monthly, annually) and river profiling (annually)
3. (Feb 2014) Provide summary of initial 3 years of monitoring and outline options to address instances where DO WQS not met
4. (June 28, 2016) Within 120 days after of the 5-year DO Monitoring Plan, submit to IDEM a plan and implementation schedule for compliance with WQS

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FERC License and 401 Requirements

- <u>5-Year Study Initial Question</u>: Are DO levels of water released via the Markland Dam gates "substantially different" than the DO levels of water passed through the project?

- The Markland FERC Project License requires consultation with IDEM, ORSANCO, and USACE Louisville District prior to submitting to IDEM for approval a plan and implementation schedule assuring Project compliance with state water quality standards, if needed.

Five-Year Study Objectives

- Determine extent that Project tailwaters meet WQS

- Compare hydro tailwater DO to spillage DO and assess potential for reaeration when tailwater DO is below the WQS

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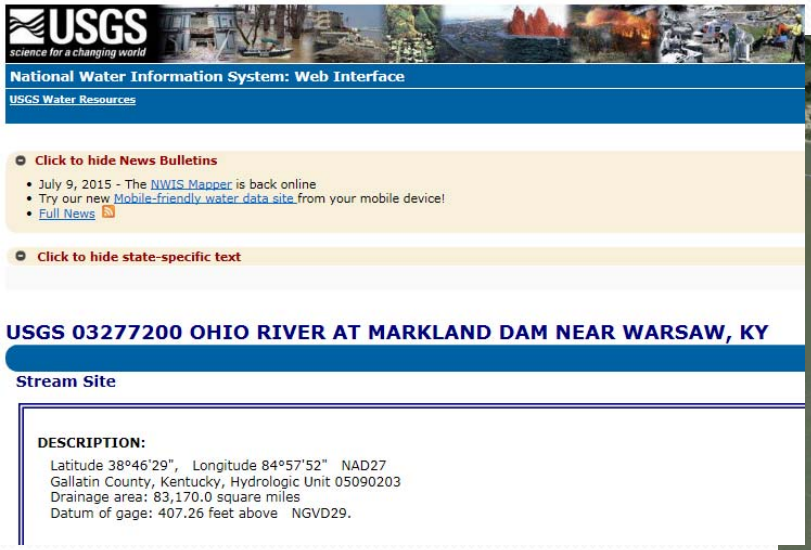
Study Design & Methods

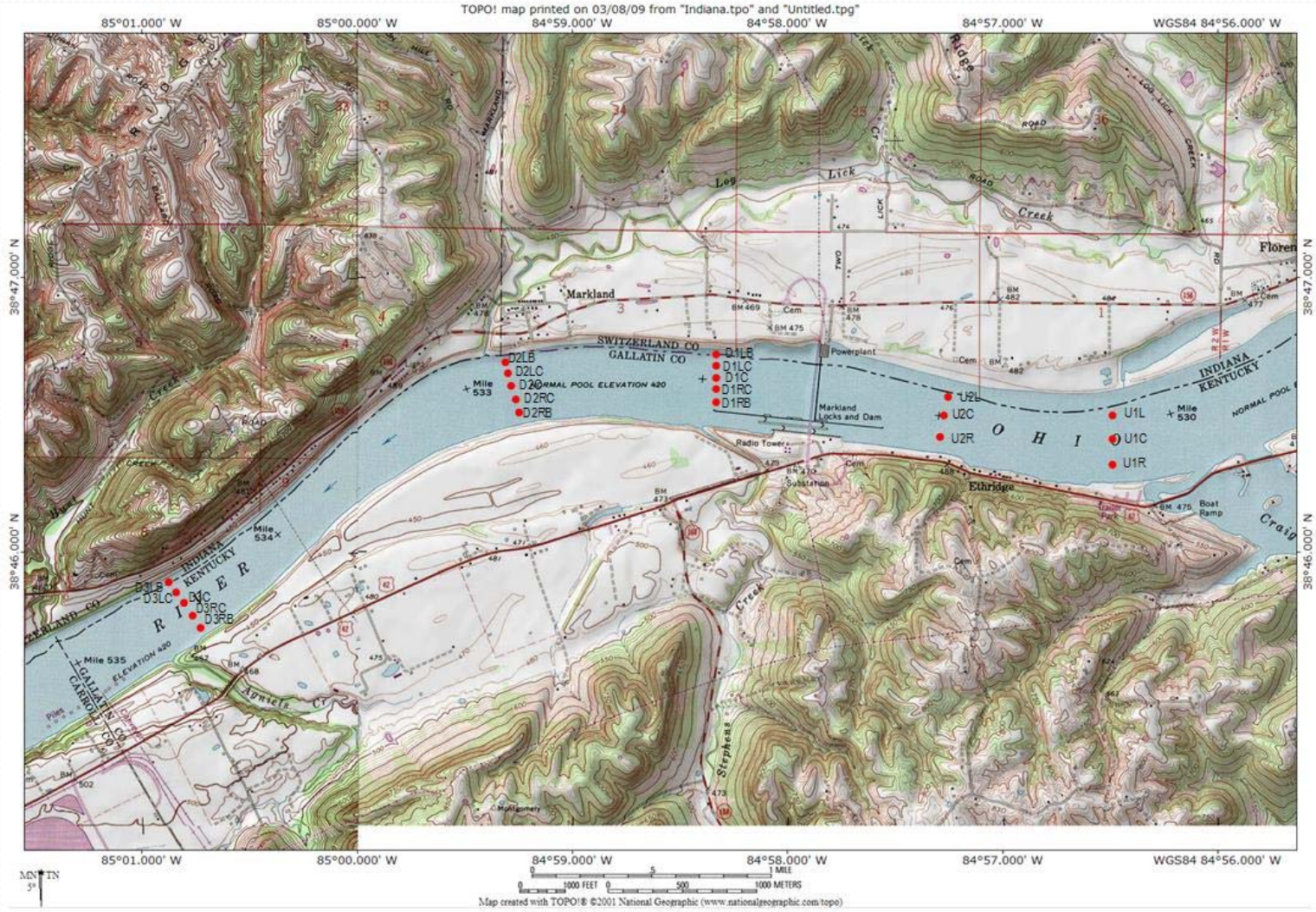
- Seasonal continuous WQ monitoring by USGS Kentucky Water Science Center, Louisville, KY



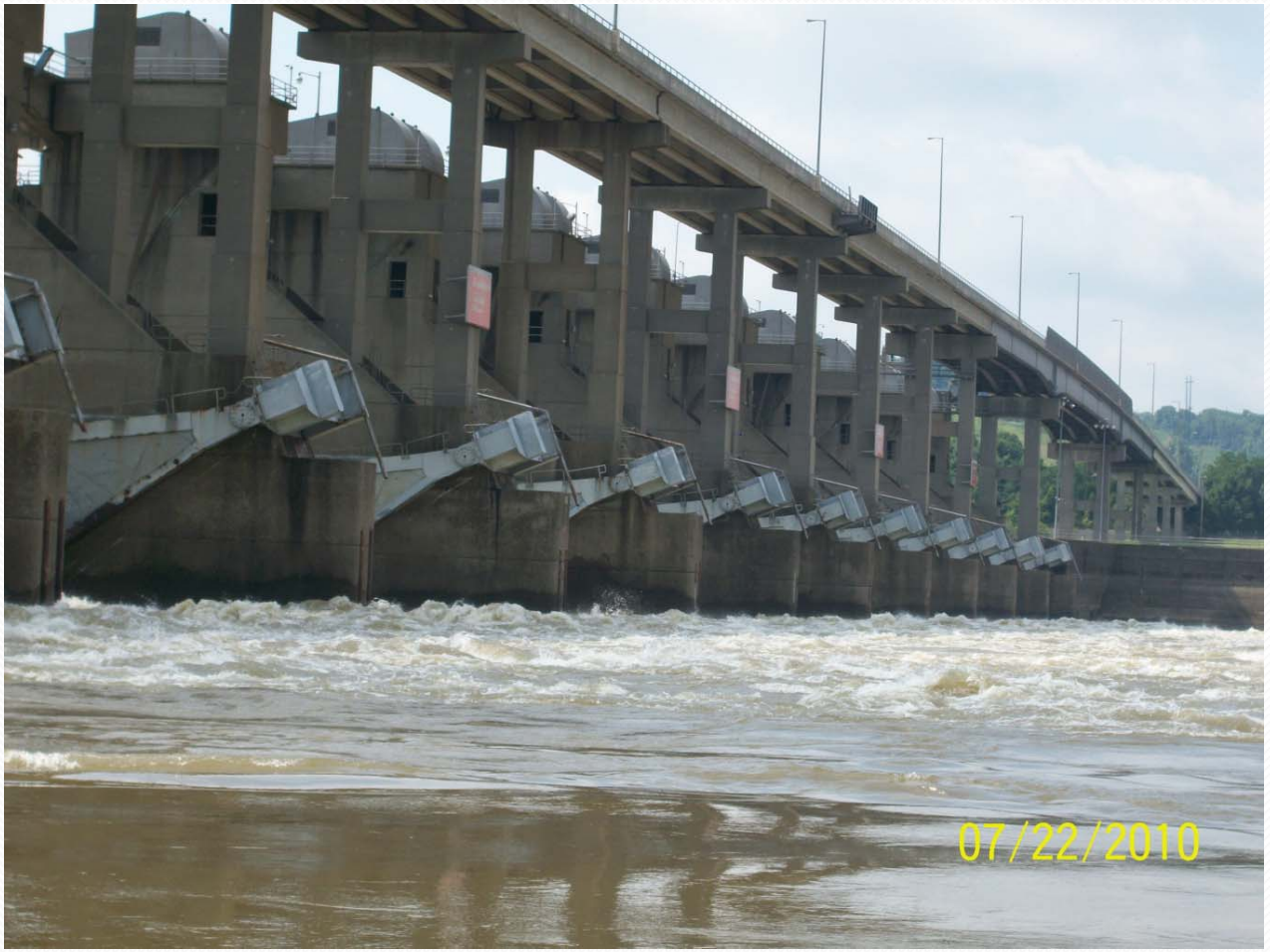
15-minute recording interval, March 1 – October 31

- WQ Monitors

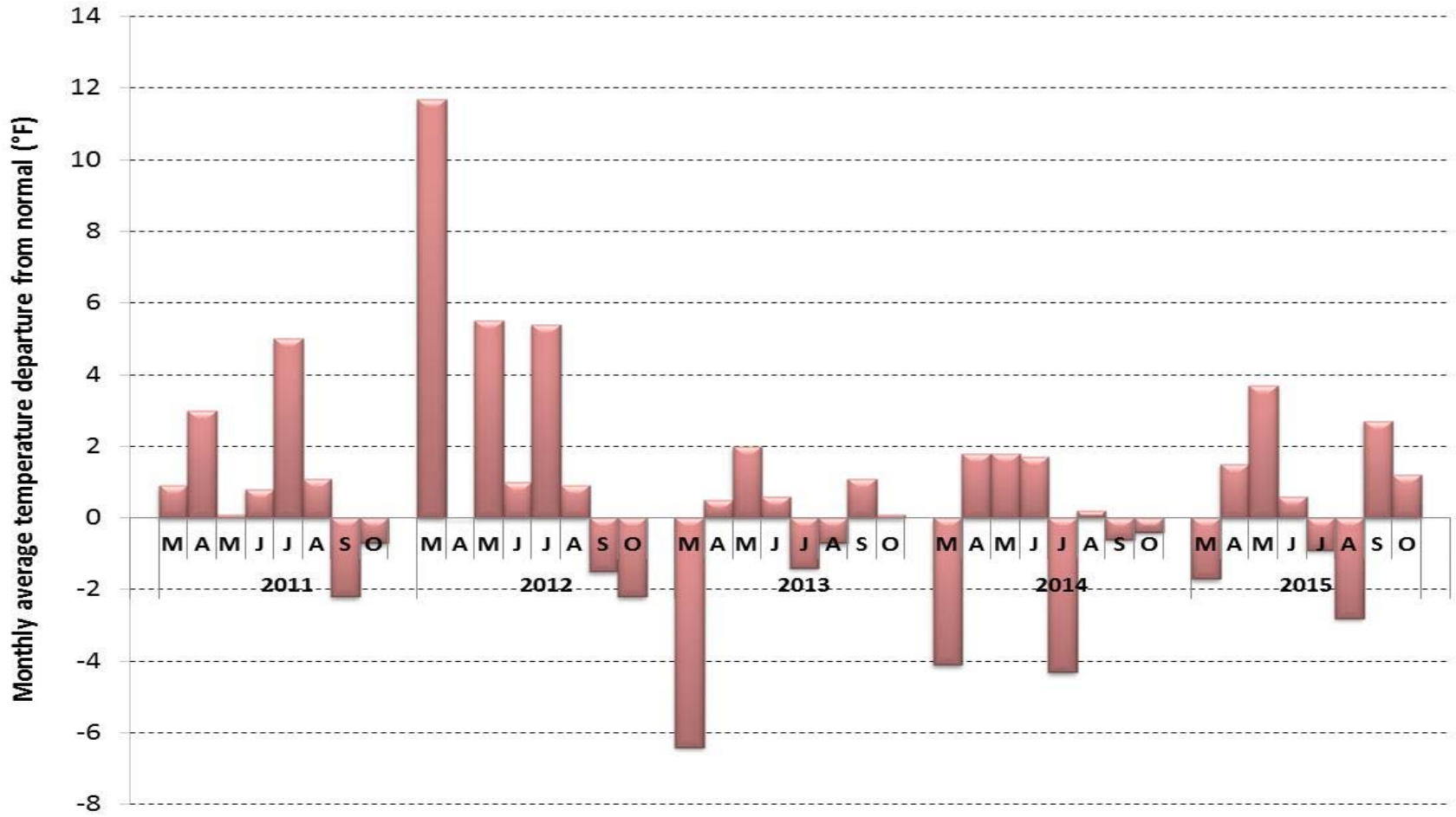
- Low-Flow Ohio River Vertical Profile Sampling (3X Annually)



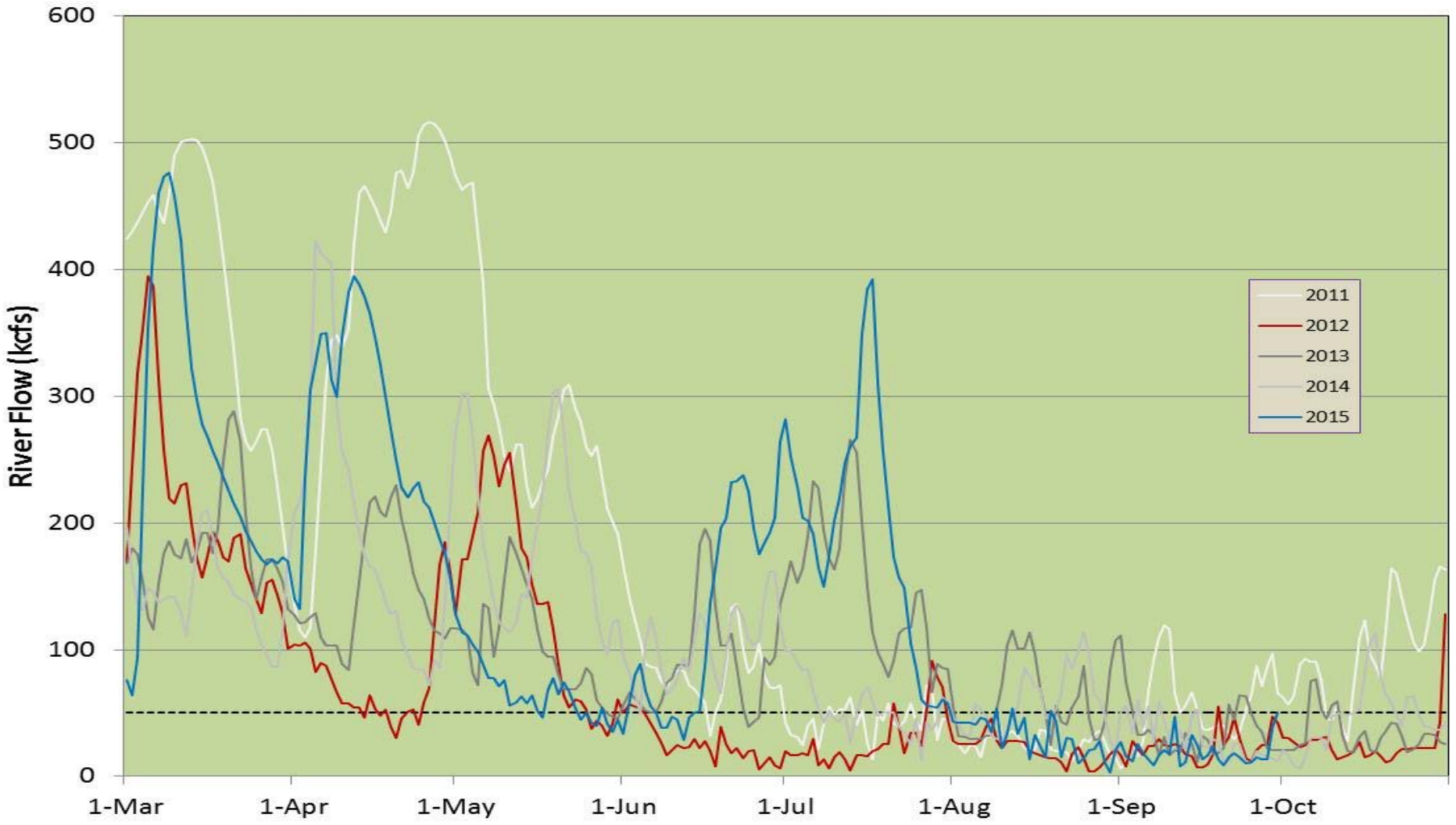
2011 – 2015 Meteorology and River Flows



Air Temperatures (CVG) – Monthly Average Departure from Normal



Ohio River Daily Flows March – October of 2011 – 2015



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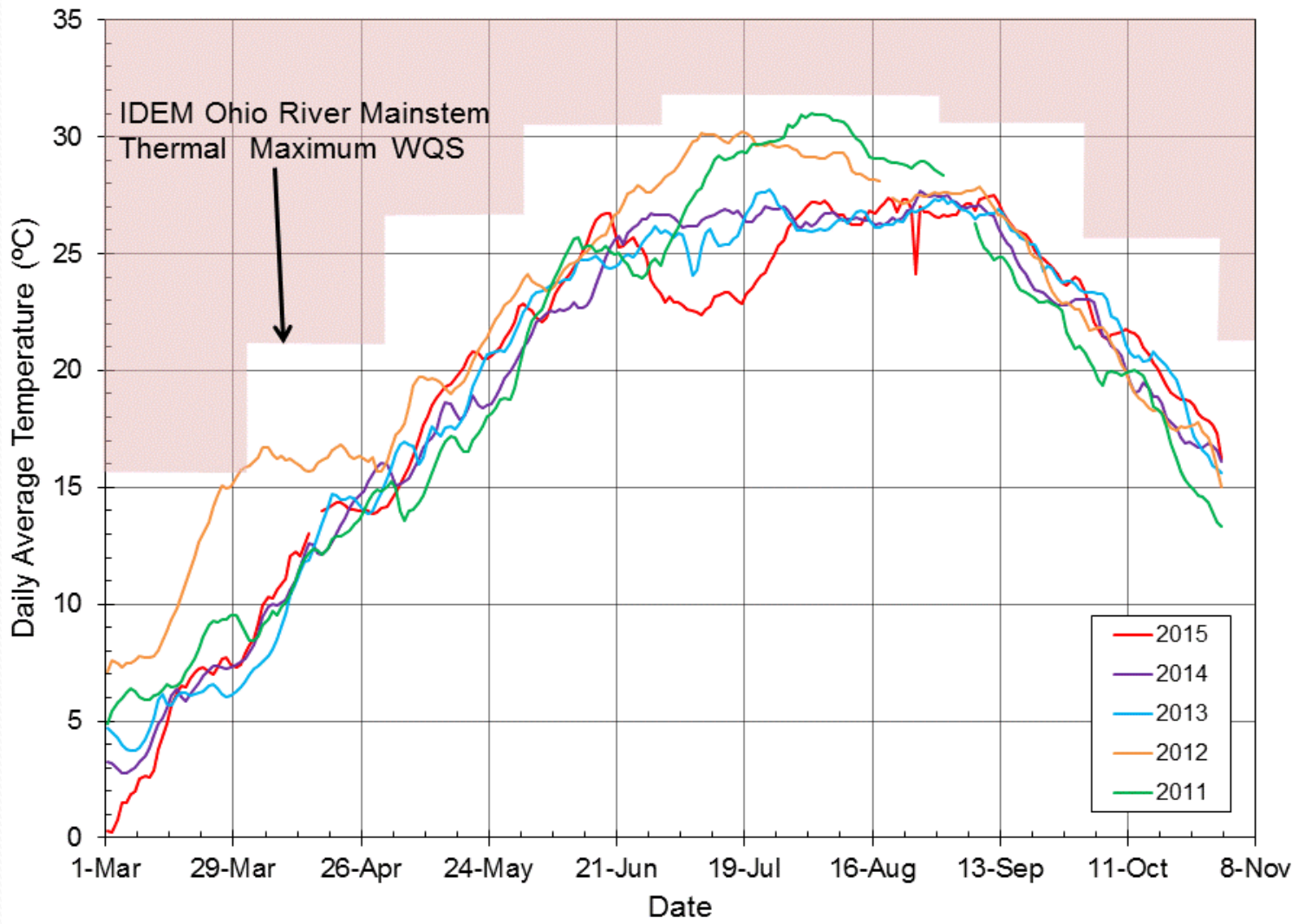
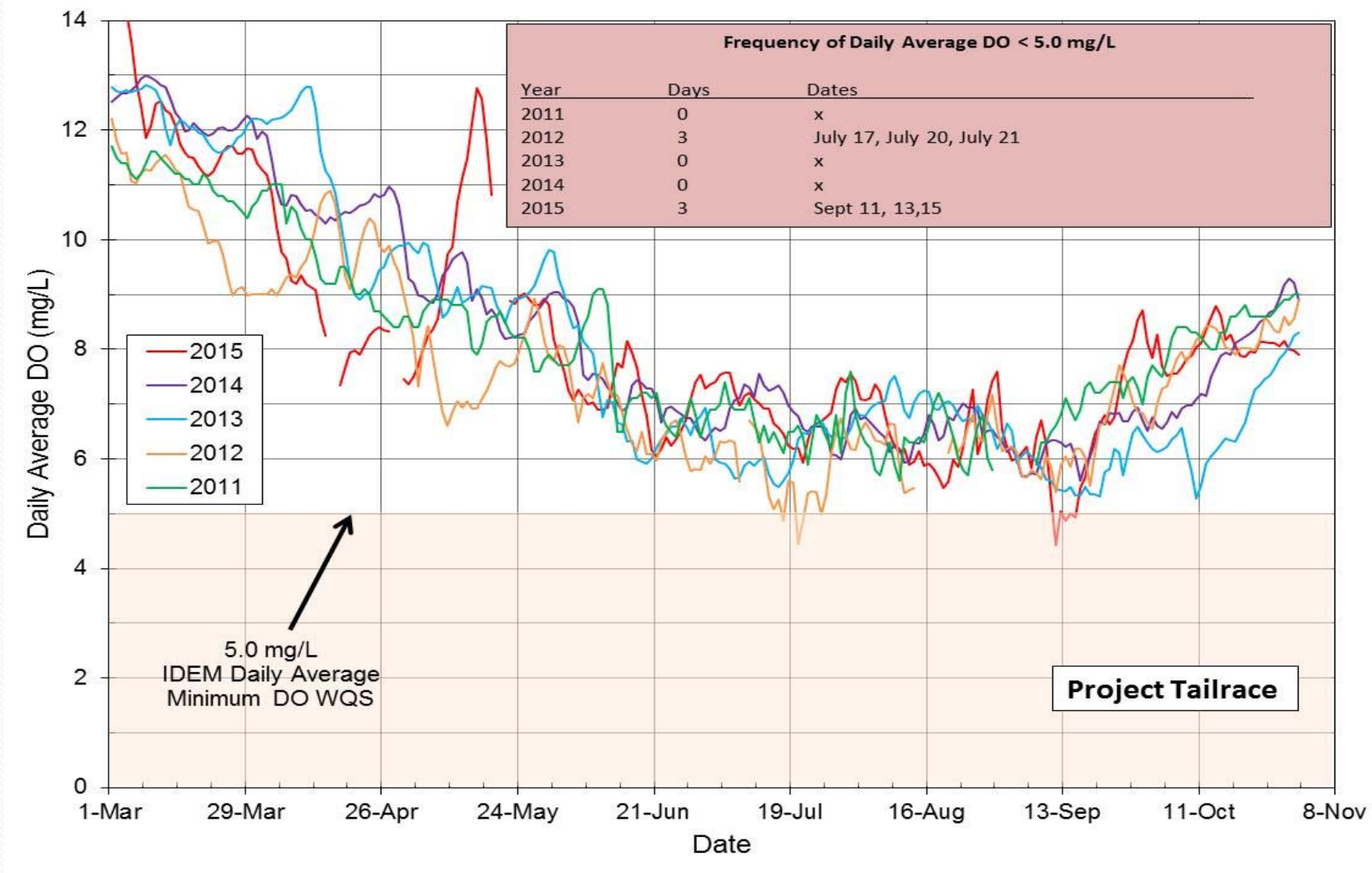
Results of Continuous Monitoring

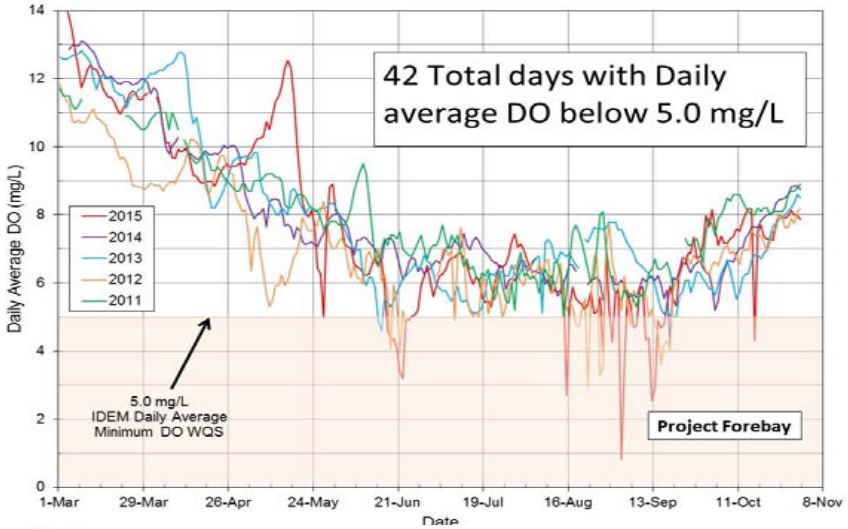
Tailrace Daily Average Water Temperatures, 2011 - 2015

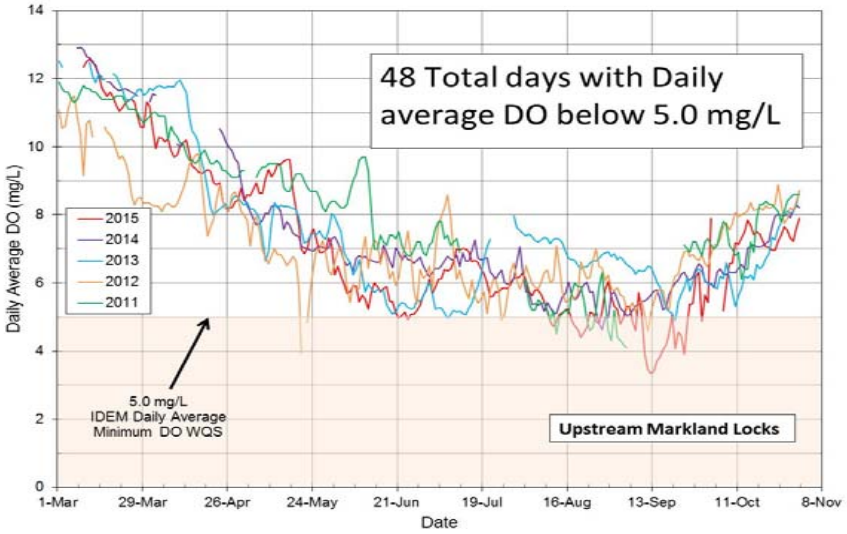


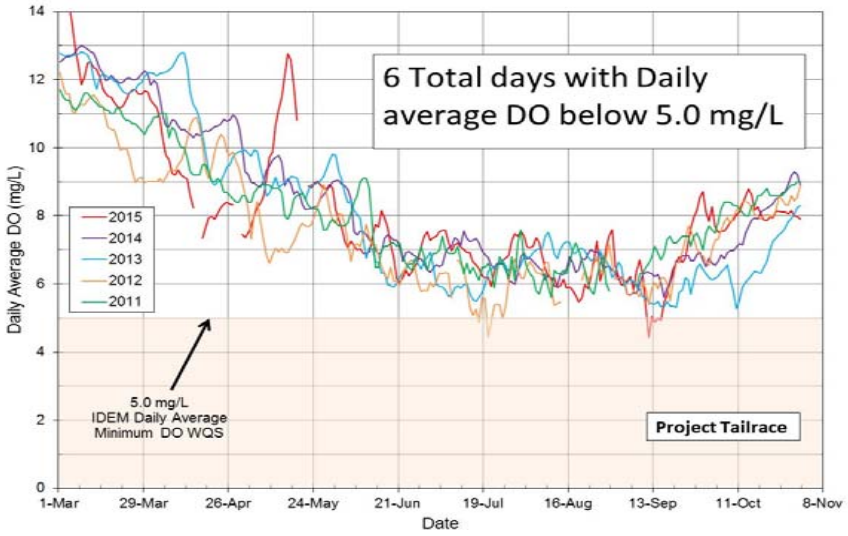
Markland Tailrace Daily Average DO, 2011 - 2015

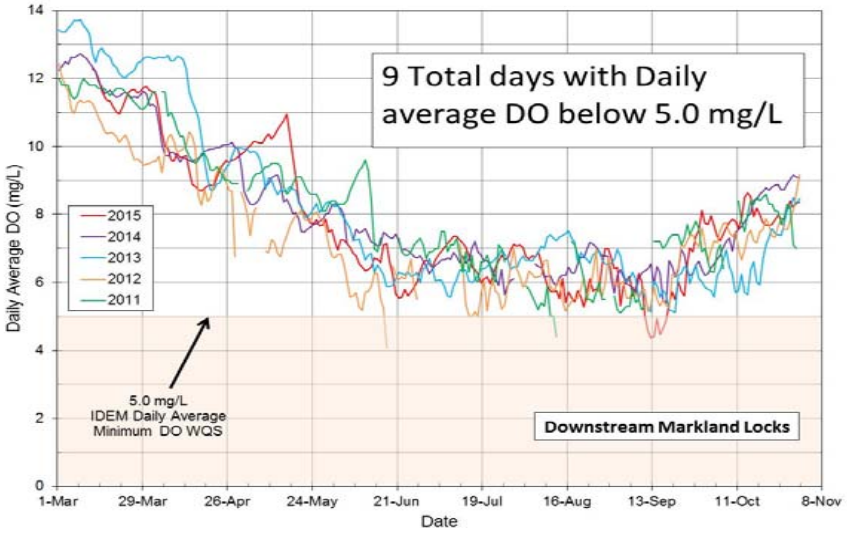


Daily Average DO at the 4 Markland Sites, 2011 - 2015









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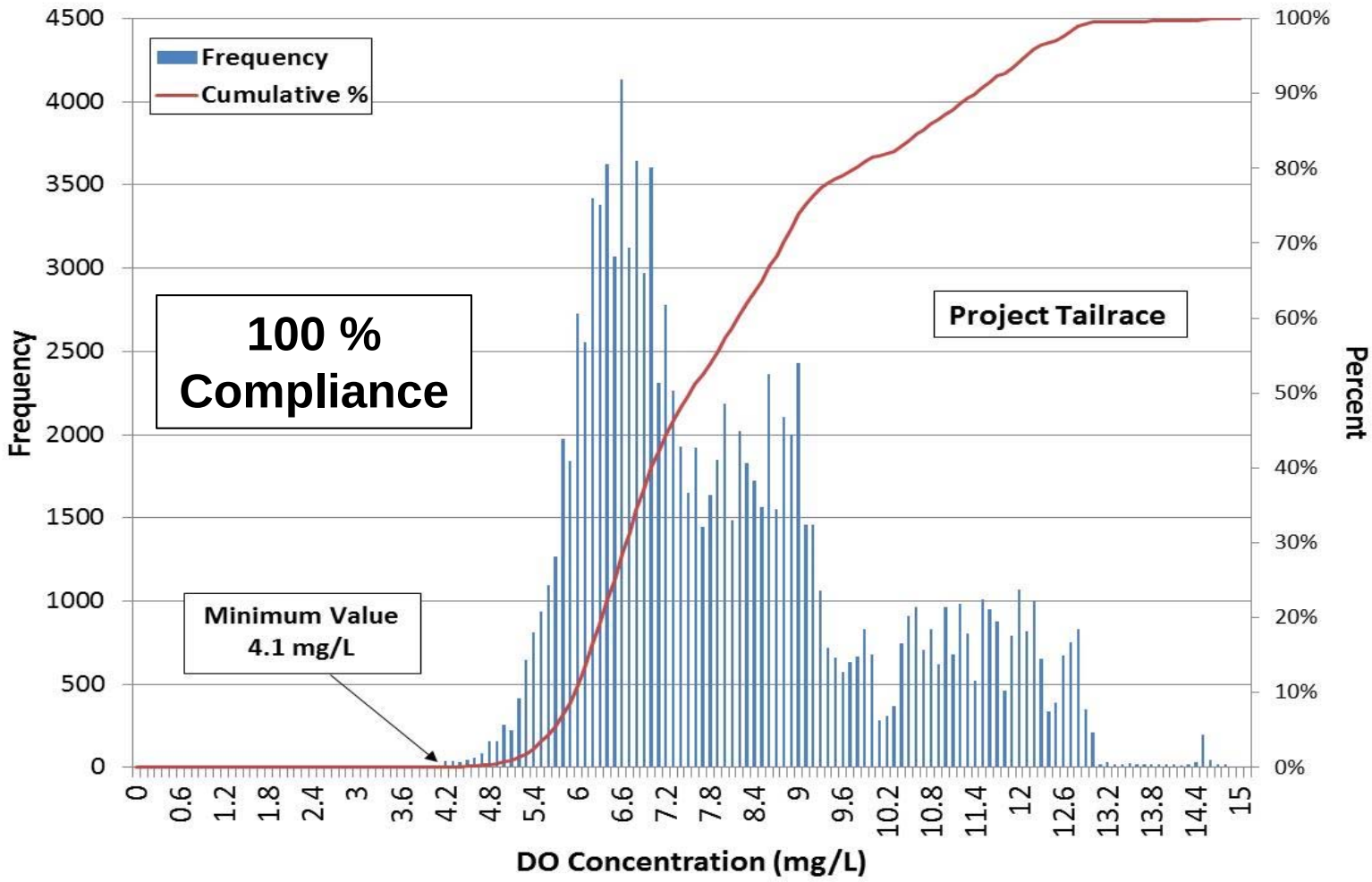
Tailrace DO: Frequency Distribution of Approved Data 2011-2015



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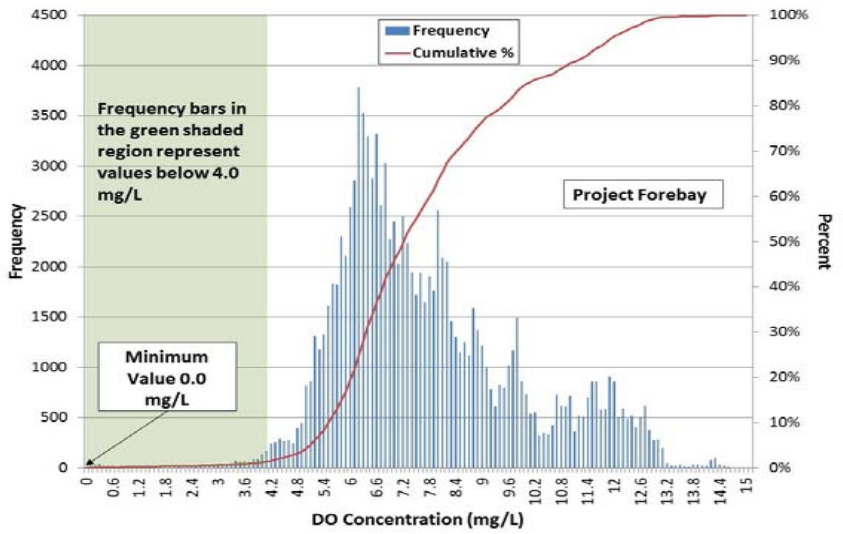
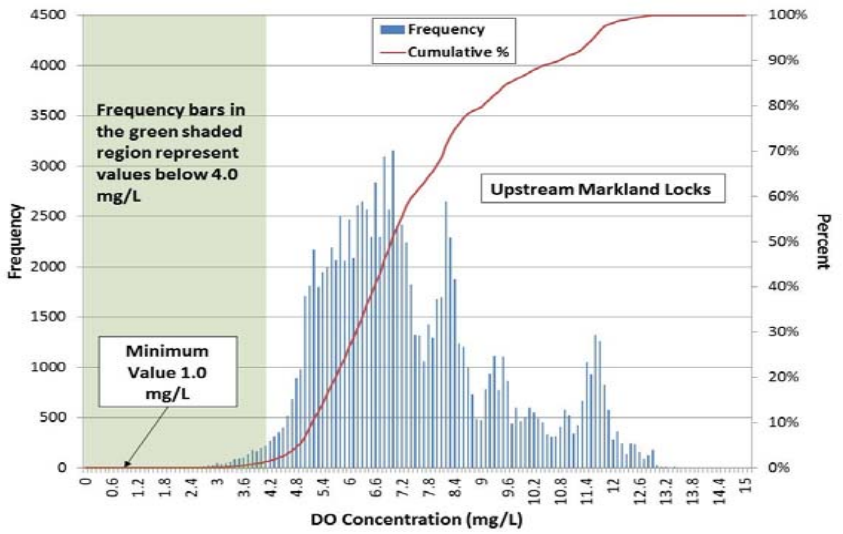
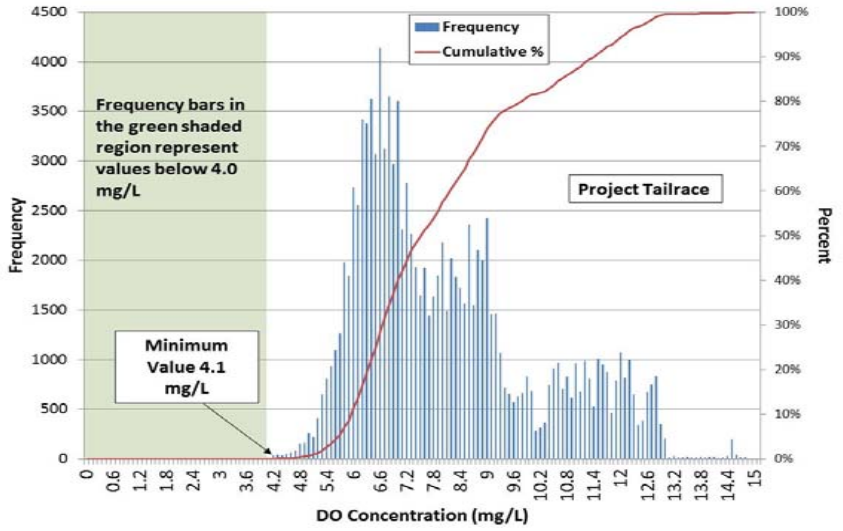
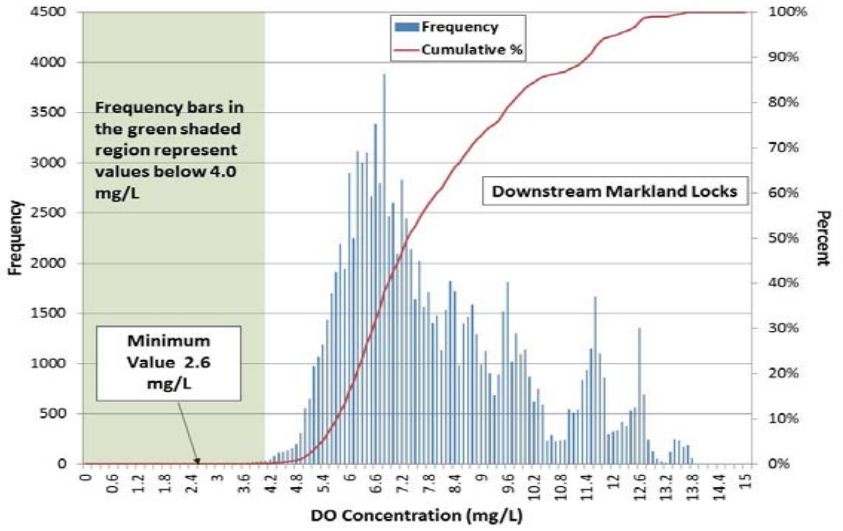
All 4 Markland Sites: Frequency Distribution of Approved Data 2011-2015









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Hydro Tailrace Continuous Monitoring DO Statistics

- Five monitoring seasons combined data:
  - 114,857 individual Markland tailrace DO readings
  - 1,196.4 days represented (March – October)
- 100% compliance with instantaneous DO of 4.0 mg/L
- 6 total days with daily average DO < 5.0 mg/L
  - 2 days where mean DO was < 4.9 mg/L; (Min. 4.4 mg/L on July 20, 2012 and September 11, 2015)

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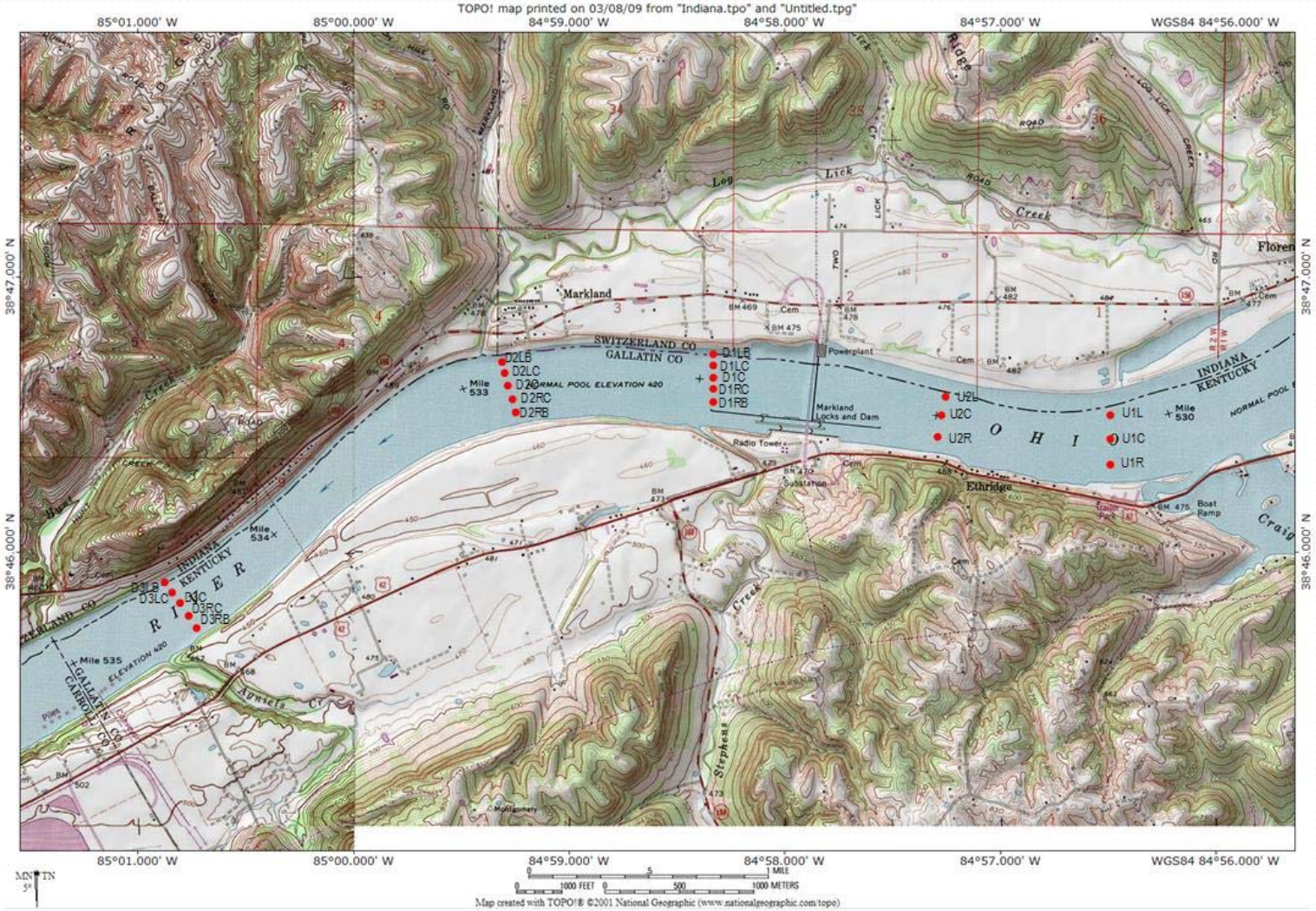
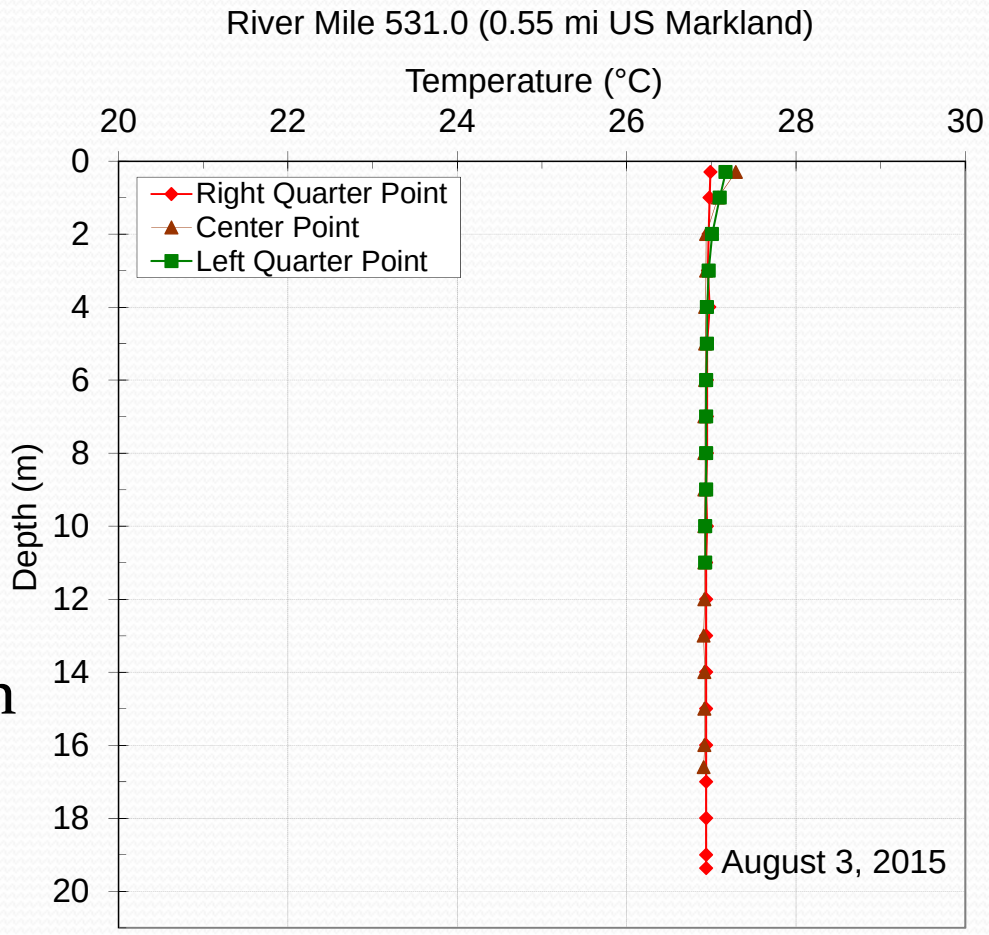
River Transect Water Quality Vertical Profiles



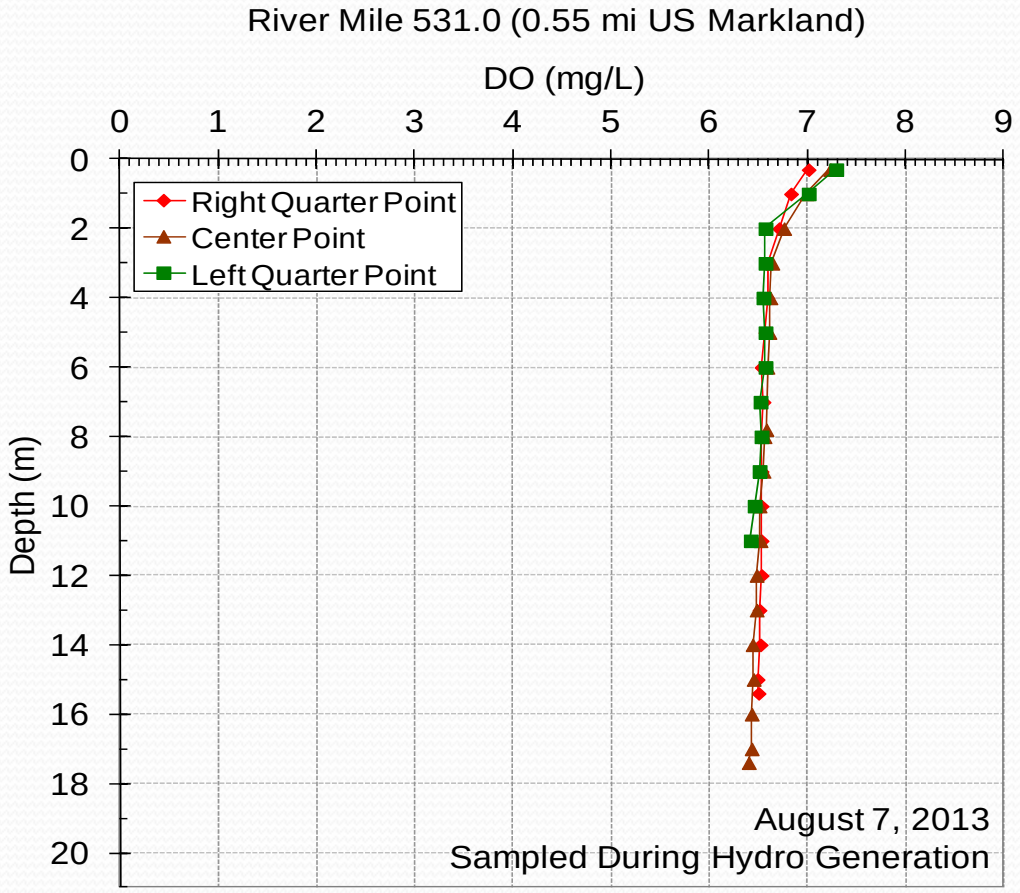
Vertical Profiles: Water Temperature

- Profile temperatures always met Ohio River mainstem WQS
- Markland Reservoir vertical profiles consistently show near-isothermal conditions, which ensures downstream temperatures will be similar



Vertical Profiles: Dissolved Oxygen

- Profile DO concentrations always met Ohio River mainstem WQS
- In low flow scenarios, upstream DO saturation was typically enhanced in the upper water column due to influence of atmospheric exchange and daytime photosynthesis

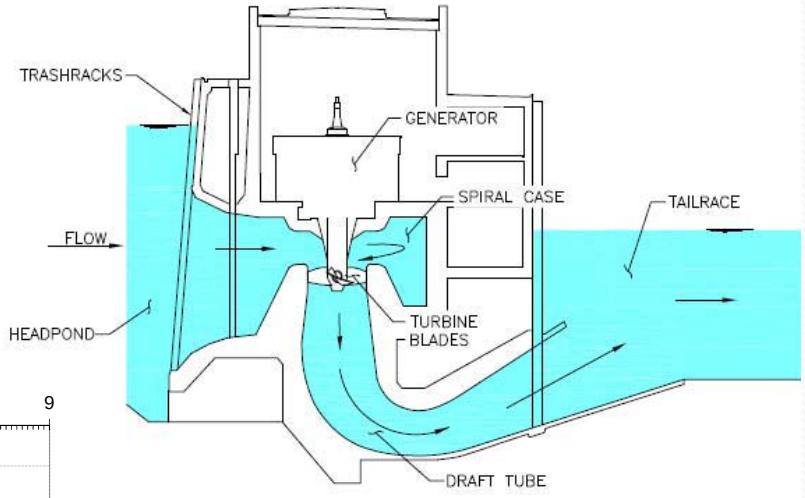


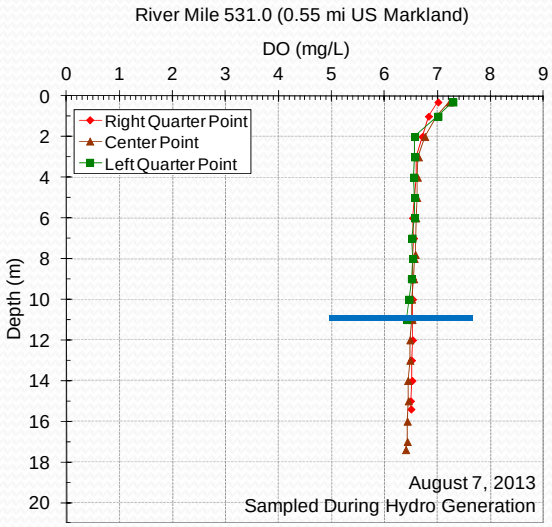
Markland Generation Releases – Influence on Water Quality As Demonstrated by Transect Profile Sampling

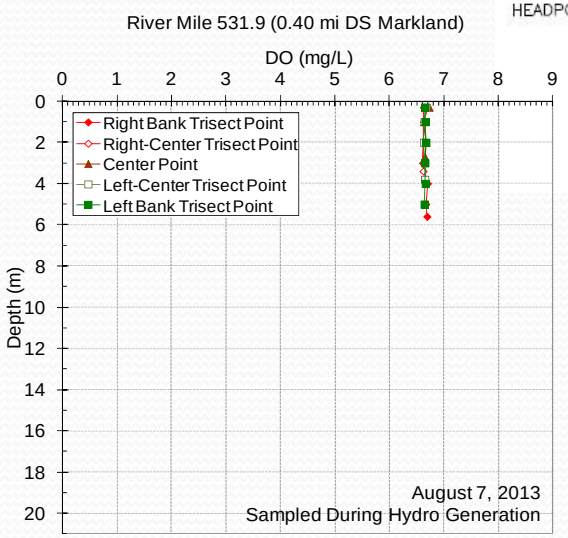
Generation releases result in a depth-integrated tailwater DO

- Upstream surface (0.3 m) DO: 7.2 mg/L
- Upstream profile (0.3 to 11 m) average DO: 6.7 mg/L

- Tailwater profile average DO: 6.7 mg/L
- Tailwater surface DO: 6.7 mg/L



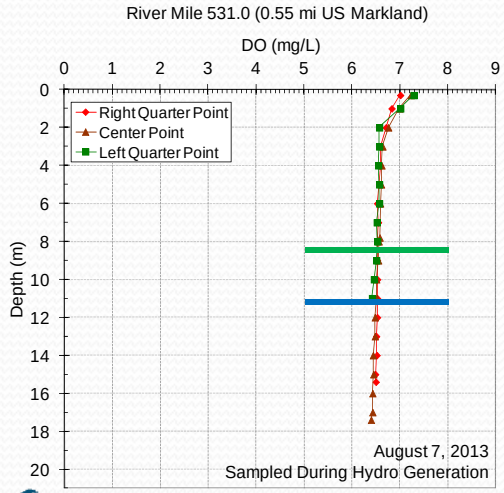




Minimal DO Boost from Tainter Gate Spillage

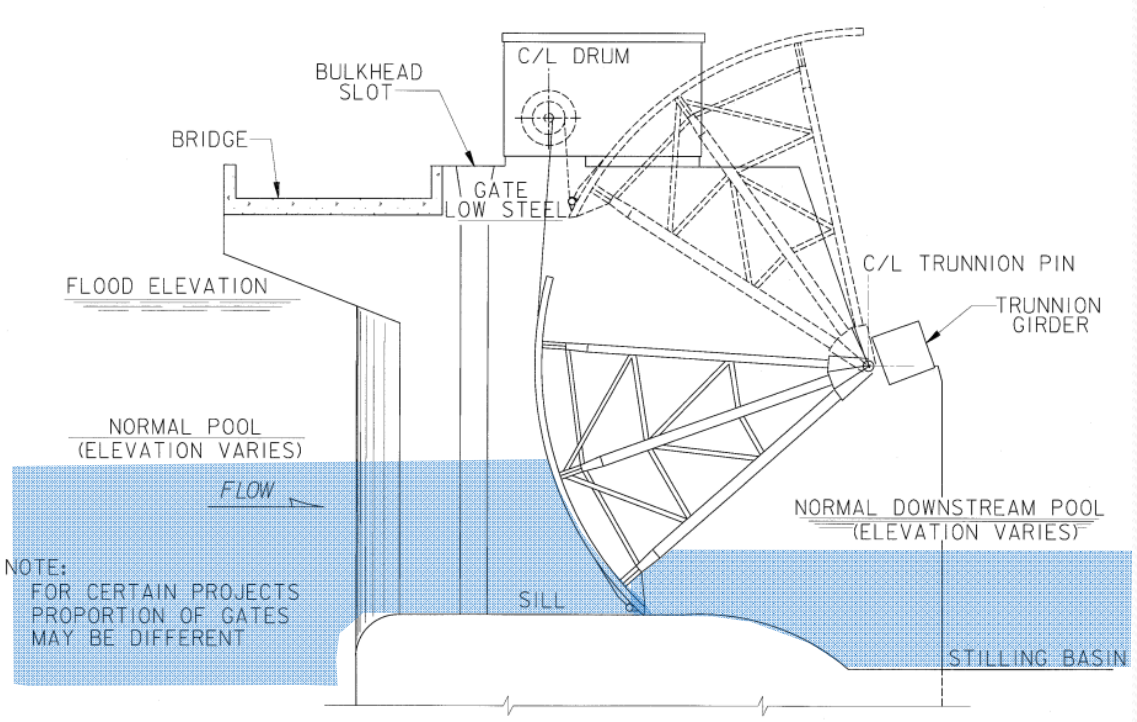
Markland pool	455 ft msl
Tainter gate bottom sill	427 ft msl
Profile depth equivalent	28 ft or 8.5 m

Spillage DO reflects US water column averaged DO from the top ~1/3 of the water column, increased by a minor, DO saturation and flow-dependent reaeration component.



"A ***submerged*** hydraulic jump below a gated structure has minimal oxygen transfer."

Hettiarachchi et al. (1997)



Low Flow Tainter Gate Spillage

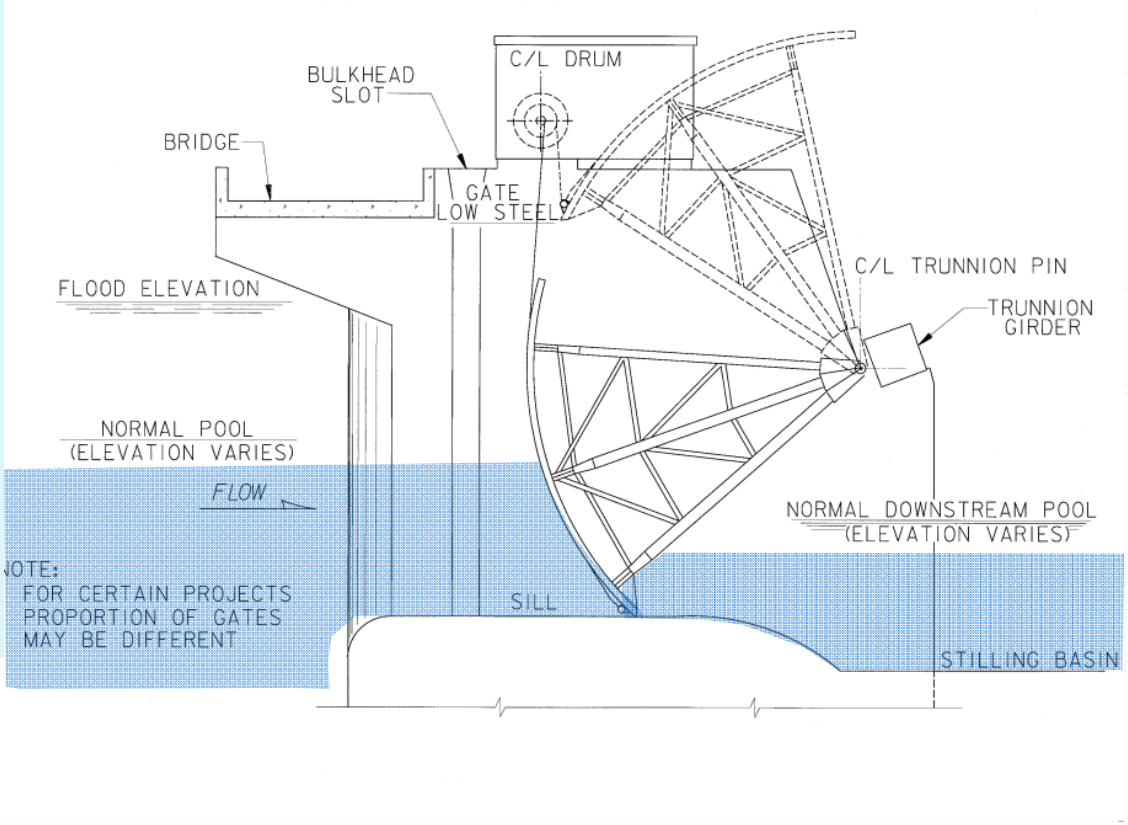
Spillage releases result in downstream [DO] consistent with minor reaeration of a depth-integrated release from the top ~1/3 of the water column

<u>Example Conditions – Markland Spillage</u>

Average Upstream Profile DO:
6.7 mg/L,
Percent DO saturation: 84%

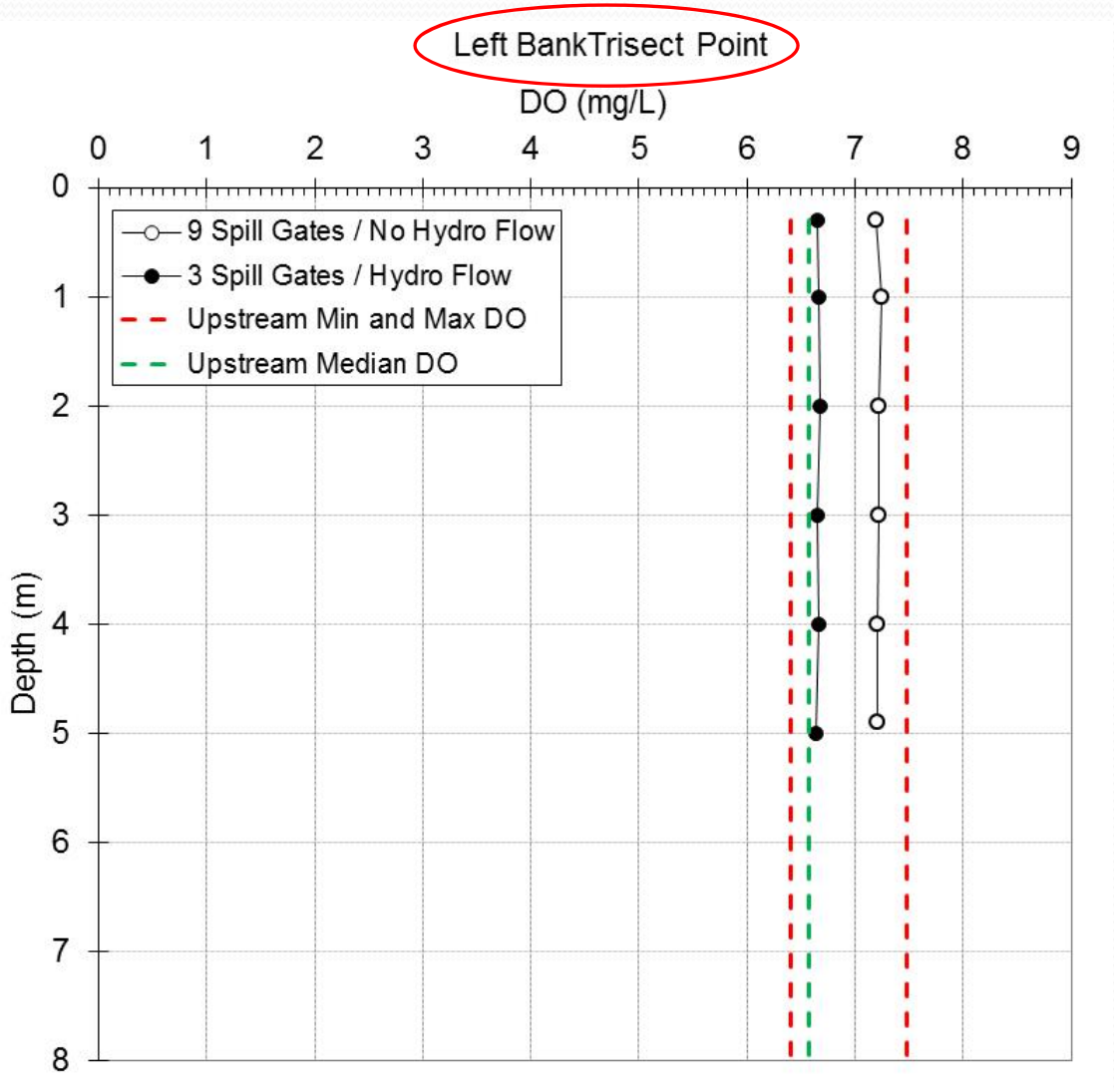
Downstream DO:
7.1 mg/L
Percent DO saturation: 90%

Net increase of 0.4 mg/L, 6% increase in saturation



Comparing Generation Release to Gate Spillage DO

- Based on 2011-2015 channel transect data, the relative increase in DO from spillage was typically 0.3 to 0.5 mg/L.
- Even with generation-dominated flows, downstream DO met or exceeded the upstream water column median DO



Low-Flow Channel Transect Profiling – Spillage Aeration Assessment from Observations With and Without Hydro Generation

- Under low flows, Tainter gates are typically set open at 1 foot; additional gates will then be opened at 1 foot sequentially as needed
- Typically observe 0.3 to 0.5 mg/L increase in DO from Tainter gate underflow releases compared to hydro generation flow releases
- Hydro generation shutdown can lead to localized low DO water upstream when trash accumulation is substantial

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Site-Specific Considerations

Characterizing Spillage: Markland spillways lack a hydraulic jump to enhance reaeration

Markland

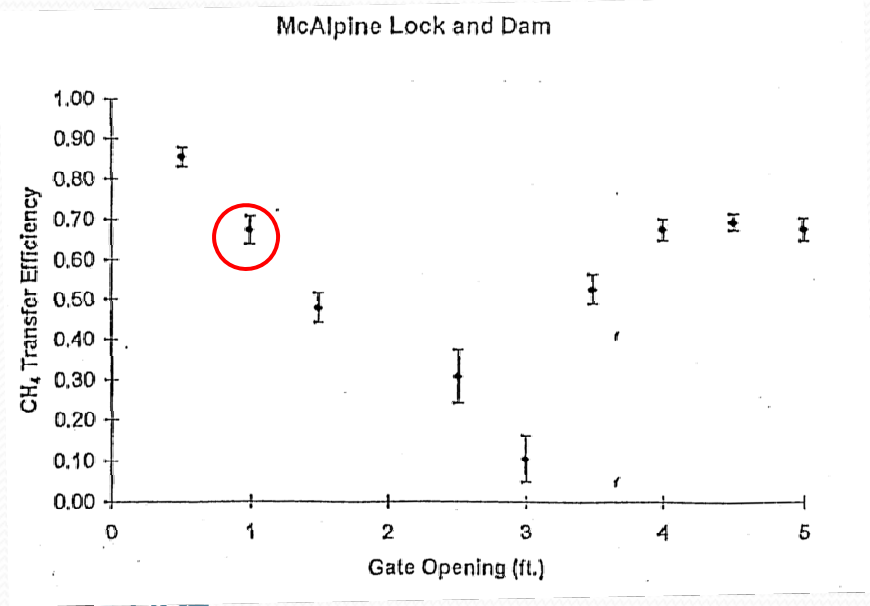
McAlpine, Lower

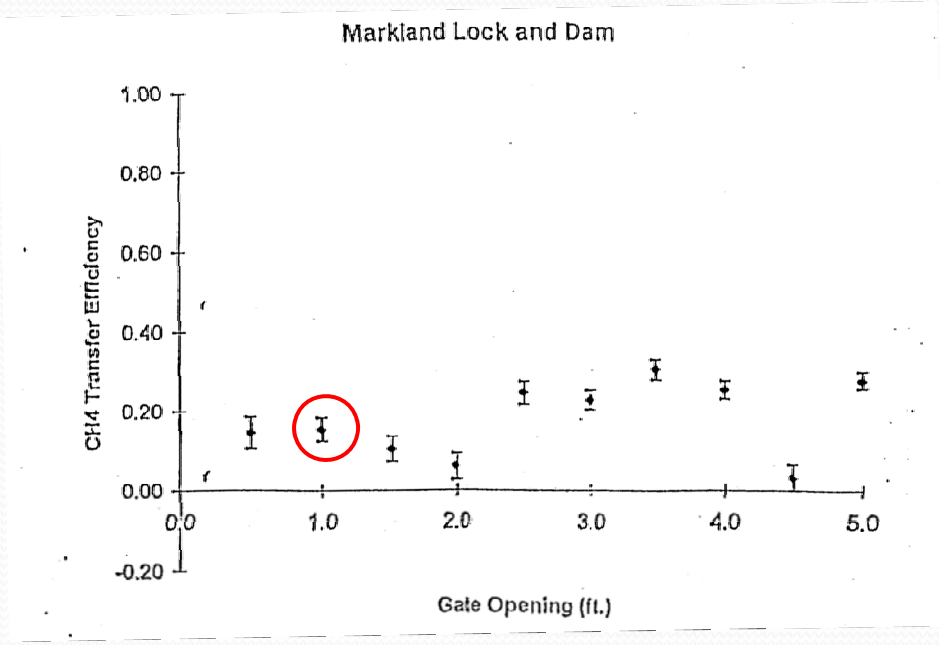
Same date (9/22/15) Google Earth photos

Re-Aeration Potential

- Empirically determined gas transfer efficiency and 95% C.I.

(Hettiarachchi et al. 1997)





Local and Transient Effects of Debris on Water Quality

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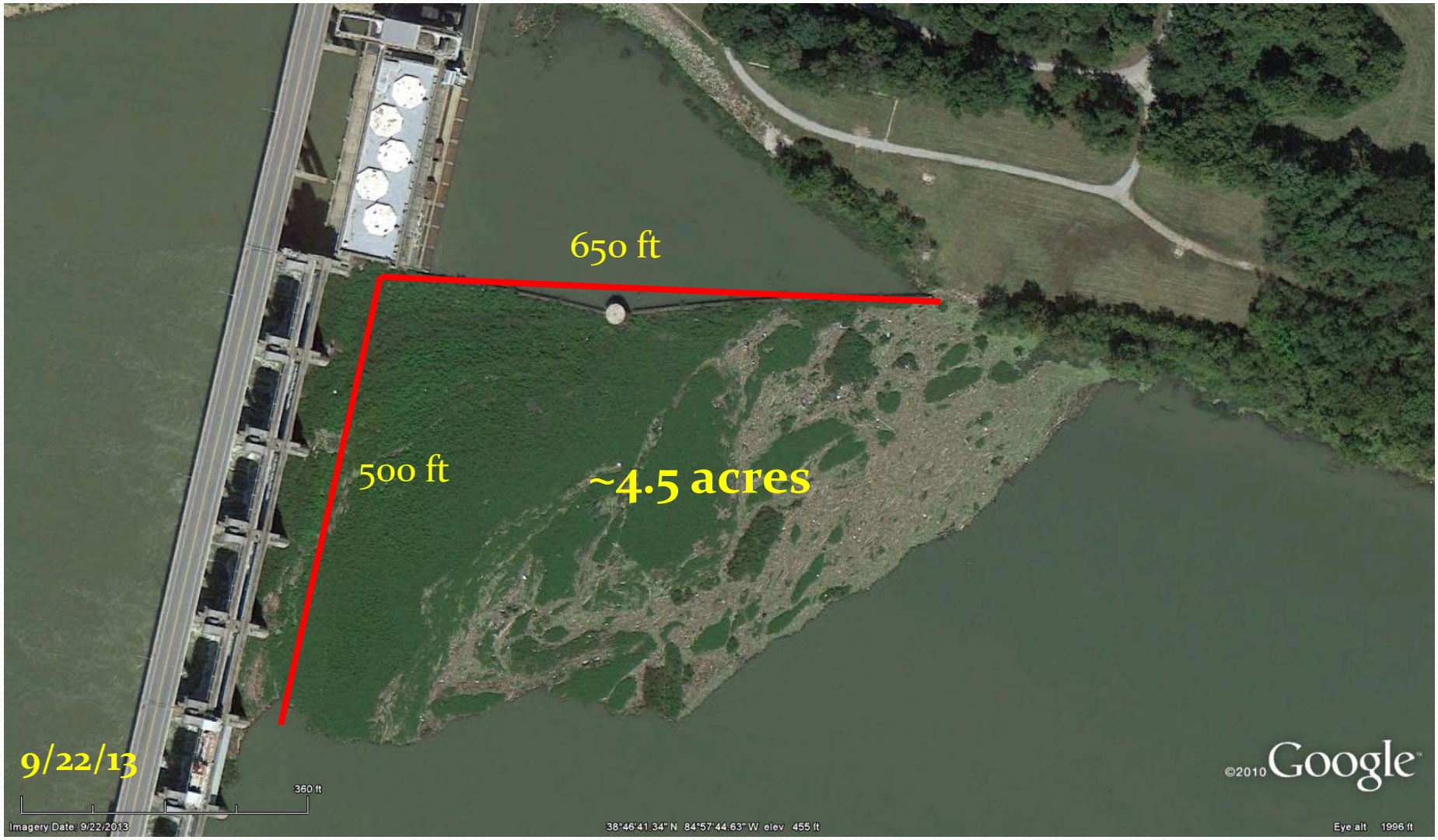
650 ft
500 ft
~4.5 acres
9/22/13
360 ft
Imagery Date: 9/22/2013
38°46'41.34" N 84°57'44.63" W elev 455 ft
Eye alt 1996 ft
©2010 Google

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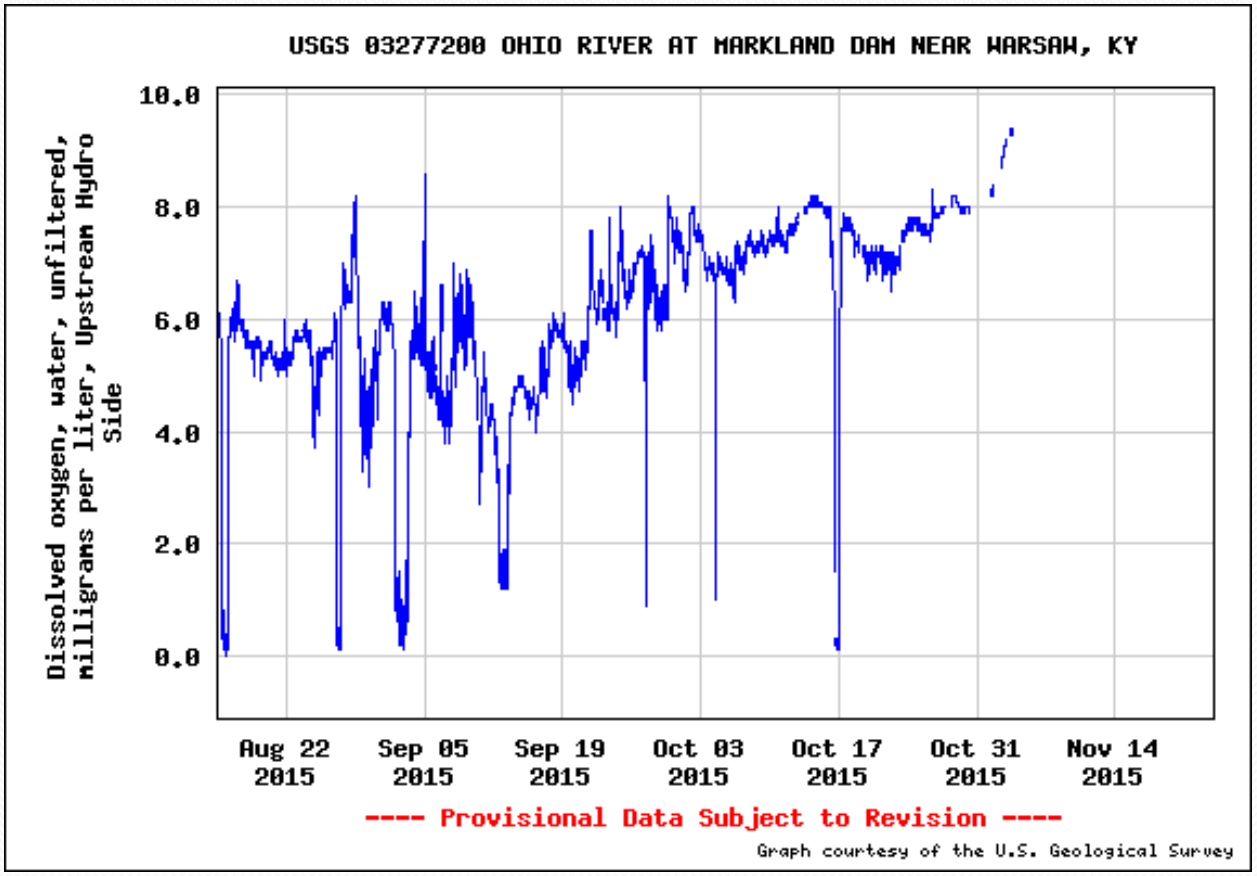
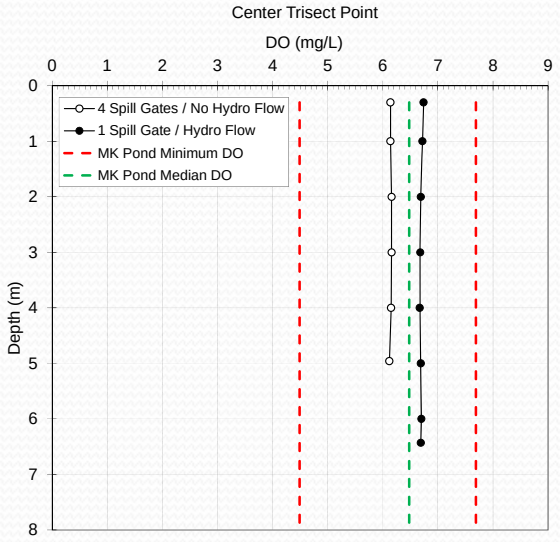
Markland Forebay DO and Generation Shutdowns, 2015



3-Mile Downstream Transect During Spillage-Only Flow vs Generation Flow, August 27, 2015



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Five-Year Study Findings

- Instantaneous WQS of 4 mg/L DO met without exception in hydro tailwaters (114,857 readings)
- Hydro tailwaters met the daily average DO WQS of 5 mg/L 99.5 percent of the time (maximum among monitoring sites)
- Daily average DO below 5 mg/L only observed in summers of 2012 and 2015
  - 2012: 3 days with < 5 mg/L average; 2 days had a mean DO of 4.9 mg/L, with one day averaging 4.4 mg/L
  - 2015: 3 days with < 5 mg/L average; 2 days had a mean DO of 4.9 mg/L, with one day averaging 4.4 mg/L

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Perspective After 5-Year Study

- The instantaneous DO WQS (4 mg/L) was ALWAYS met
- Exceptionally infrequent and relatively brief circumstances when daily average DO WQS not met
- WQ from Tainter gate spillage not “substantially different” from generation release WQ
- Localized water quality impairment attributed to high-BOD water release from accumulated debris can be triggered by hydro shutdowns

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Benefits of Markland Hydropower

- As a renewable and emissions-free source of energy, hydro generation provides reliable, carbon-free electric power 24/7 (except when flow-limited).
- Markland generation is base-loaded. Replacement power would likely be derived from regional generation sources having CO_2 and other emissions.

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2016 Proposed State Water Quality Compliance Plan and Schedule

- Submitted to agencies for consultation May 31, 2016
- Duke to file Plan & Schedule w/ FERC July, 2016
- IDEM implementation under authority of 401 WQC
- Duke requesting full Plan implementation in 2017

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Compliance Plan and Schedule Elements

- Continued USGS Monitoring, June 1 – October 31
  - Tailrace DO compliance
  - Forebay WQ trending
- Provision for independent accuracy checks of USGS instrumentation
- Interim triggers for hydro operation curtailment
  - < 5 mg/L (daily average) trigger
  - < 4 mg/L (instantaneous) trigger
  - Potential for future turbine aeration removing triggers
- Provisions for electric grid emergencies, long-lived degraded water quality episodes

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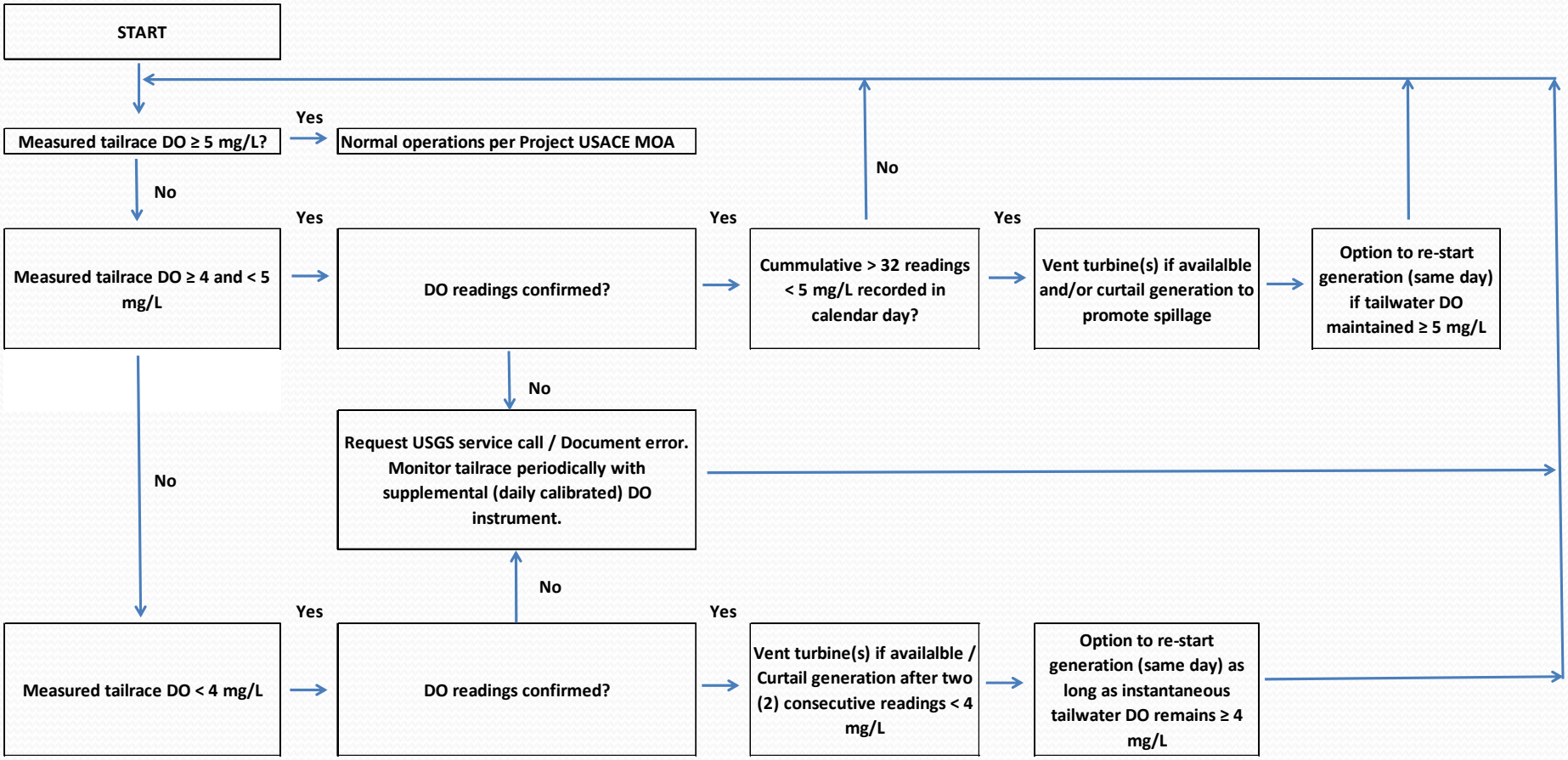
Flowchart: Interim hydro operational response to tailrace DO concentration



Rationale of Plan Elements

- ***June – October monitoring term***:

  Five-year minimum tailwater DO, March through May = 6.5 mg/L (Five-year June minimum = 5.3 mg/L)

- ***Independent DO checks***:

  Ability to overcome out-of-calibration conditions and typical 1-2 day response by USGS

- ***Interim triggers for generation curtailment***:

  Triggers to curtail hydro generation nullified when WQ from replacement, aerated Markland units (if implemented) is demonstrated to approximate WQ from Tainter gate spillage

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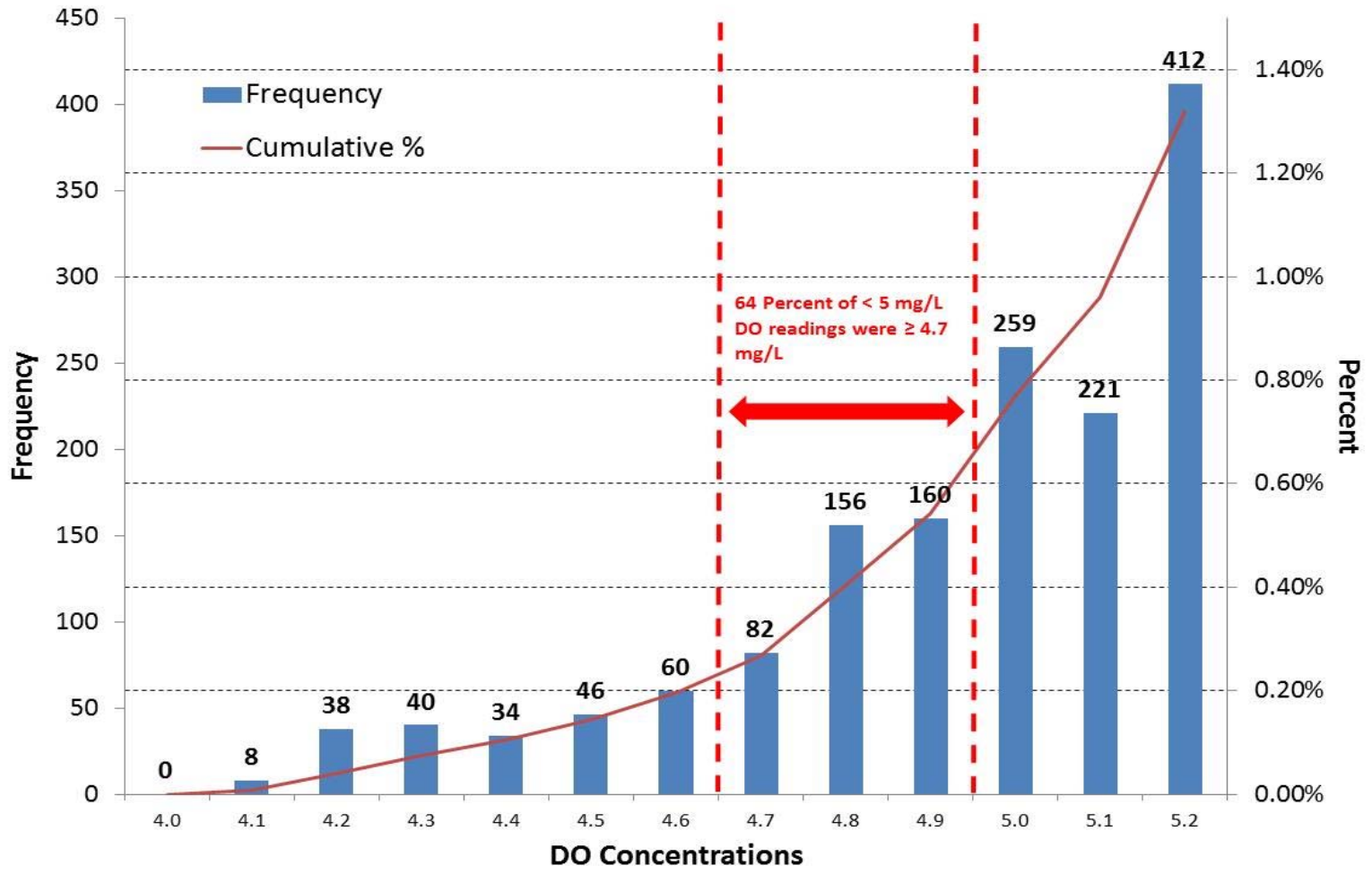
Rationale, continued

Why set the daily average trigger at >32 cumulative (4 mg/L ≤ DO < 5 mg/L) readings?

Historical data distribution shows this will be protective to the extent practical.



Rationale, continued

***Why set the < 4 mg/L trigger at two successive readings*?**

- Due to relative improbability of occurrence, the approach can screen out spurious data
- Avoids prompting a USACE response in opening gates based on a single number
- Allows opportunity for independent verification of apparent low tailrace DO

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Acknowledgements

- USGS, Kentucky Water Science Center
  - Mike Griffin
  - Tom Ruby
  - Molly Lott
- USACE, Markland Locks and Dam
  - Gary Birge, Markland Lockmaster
- Duke Energy, Markland Project
  - Tami Styer
  - Andy Leininger
  - Kyle Meyer
  - Phil Sexton
  - Bill Chanley
  - Glenn Long
  - Courtney Flowe

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