Pumped Storage Project Considerations
Alden Webinar Series
January 29, 2013

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• Questions and Audio
• Availability of slides and recording
• Q&A period

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Agenda

- Introduction: Pumped Storage and Renewable Energy (Ron Grady, HDR)
- Generating Equipment (Dr. Juliusz Kirejczyk, HDR)
- The Licensing Process (Pat Weslowski, Louis Berger)
- Pumped Storage Hydraulics (Andy Johansson, Alden)
- Fish Protection Considerations (Steve Amaral, Alden)

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Pumped Storage and Renewable Energy Integration = Strategic Flexibility

Ron Grady, P.E.

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The Challenge: Balancing Transmission System Operations

• Maintain system reliability by continuously balancing supply and demand
• Follow the short-, medium-, and long-term variation in load with a fleet of flexible and dispatchable resources
• Call on operating reserves to accommodate large net load ramping events
Grid-Scale Energy Storage Solutions

- Grid-scale storage enables development of double-digit levels of wind penetration
- Europe integrates variable energy with big transmission, conventional hydro, and carbon-free pumped storage
- Changing US market for system reserves and grid reliability services
Wind Integration

As variable energy resources increase, grid operators have become increasingly concerned about their ability to maintain system stability.

- Wind generation can change suddenly, increasing the balancing requirements of dispatchable resources
- Wind peak generation often occurs during off-peak periods, reducing its energy value by not supporting peak loads
- Low load and/or transmission congestion can lead to wind output curtailments

NERC: “Net load in the future will result in a need for greater system flexibility.”

Courtesy of Bonneville Power Administration & Puget Sound Energy
Denmark and Grid Reliability

- 30% wind penetration in the generation mix
- No native load balancing
- Balancing services provided via interconnects:
  - Strong interconnections with Norway, Sweden, and Germany
  - Utilizes energy storage and flexible energy options in neighboring balancing areas
  - Excess wind is exported and stored in Norwegian hydropower reservoirs
Western Denmark
Wind Output and Net Electricity Flows

January 2007
MWh/h

Source: Energinet.dk (Denmark's system operator)
Load and Wind on BPA System

December 24-31, 2007 (Total Installed Wind of 1,300 MW)

BPA Balancing Authority Load & Total Wind Generation, Last 7 days

Installed Wind Capacity (1,300 MW)

Actual Wind Generation

Winter Peak Load December 27, 2007

Based on 5-min readings from the BPA SCADA system for points 45583, 79687
Balancing Authority Load in Red, Wind Generation in Blue
BPA Technical Operations: Roy Ellis (rcellis@bpa.gov)

Courtesy of Bonneville Power Administration
Why Energy Storage?

- Attenuates generation volatility and physical availability
- Aligns peak generation to peak loads
- Reduces imbalance due to scheduling challenges
- Moderates transmission congestion and improves system reliability
- Enables further penetration of variable generating resources
Bulk and Distributed Energy Storage Technologies

System Ratings
Installed systems as of November 2008

Storage System Ratings
Real-Time Operations Scale

ALDEN
Solving Flow Problems Since 1894
Pumped Storage is the Best Partner

Hydro pumped storage balances variable generation, turning *celebrity* into *certainty*
Hydroelectric Pumped Storage

• What is it?
  – An efficient means to store energy when the demand for power is low and to generate power with the stored energy when the demand is high.

• How does it work?
  – Water is stored in an upper and lower reservoir.
  – During periods of low power demand, water is pumped from the lower reservoir to the upper reservoir.
  – During high demand periods, water from the upper reservoir is released through turbines to the lower reservoir, generating power.

More importantly: Pumped storage is a system operations/transmission tool.
Alternative Project Profiles

NOTE: CHOICE OF UPPER INTAKE DEPENDS ON UPPER RESERVOIR CONFIGURATION.

Courtesy Electric Power Research Institute
Definition Sketch of Project Profiles

<table>
<thead>
<tr>
<th>Legend</th>
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<tr>
<td>A</td>
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Courtesy Electric Power Research Institute
Pump-Turbines: Three Modes of Operation

- Normal Generation
- Pumping Operation
- Synchronous Condensing (Spinning in air)
# Pumped Storage Development Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Approx. Duration</th>
<th>Schedule (Years)</th>
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<tbody>
<tr>
<td><strong>Study Phase</strong></td>
<td></td>
<td></td>
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<tr>
<td>Reconnaissance Study</td>
<td>2 to 3 Months</td>
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<tr>
<td>Prefeasibility Study</td>
<td>4 to 8 Months</td>
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<tr>
<td>Feasibility Study &amp; Concept Design</td>
<td>10 to 15 Months</td>
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<tr>
<td><strong>Initial Design &amp; Tender</strong></td>
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<tr>
<td>Additional Site Characterization</td>
<td>3 to 4 Years</td>
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<tr>
<td>Major PH Equipment Selection</td>
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<td></td>
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<tr>
<td>Initial Design Phase &amp; Spec Dev</td>
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<tr>
<td>Construction Tender Process (1)</td>
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<tr>
<td><strong>Final Design &amp; Engr Support (2)</strong></td>
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<tr>
<td>Regulatory Phase (ILP)</td>
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<tr>
<td>Pre-Application Activities (3)</td>
<td>As Req’d</td>
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<tr>
<td>File NOI &amp; PAD</td>
<td>1 Year</td>
<td></td>
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<tr>
<td>Scoping / Process Plan</td>
<td></td>
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<tr>
<td>Study Plan Development</td>
<td></td>
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<tr>
<td>Studies &amp; Application Dev</td>
<td>1 - 2 Years</td>
<td></td>
</tr>
<tr>
<td>Post Filing Activities</td>
<td>1.5 Years</td>
<td></td>
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<tr>
<td>License Order</td>
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</tr>
<tr>
<td><strong>Construction</strong></td>
<td>5 to 6 Years</td>
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**Notes:**
1. Assumes construction bid documents are released in advance of final design.
2. Assumes engineering continues through tendering process as well as construction.
3. Pre-Application activities could be advanced depending on the owner's appetite for risk prior to completion of the feasibility study.
Considerations for Evaluating Pumped Storage Project Potential

- Favorable market conditions
- Favorable geology and seismology
- Favorable environmental and regulatory setting
- Favorable topography maximizing operating head, minimizing water conductor length relationship and suitable for embankment construction
- Unit operating range
- Unit submergence
- Available existing infrastructure (roads, transmission, etc.)
- Closed loop vs. open loop and adequate available water source
- Available construction materials
- Adequate overburden above tunnels
Equipment and Layout Considerations

- Underground vs. shoreline powerhouse
- Operational objectives and desired performance
- Selection of unit type (single speed vs. variable speed)
- Selection of number of units
- Unit speed optimization
- Transient analysis
- Powerhouse sizing considerations
Operational Characteristics

• Standstill to full generation usually in less than 3 minutes
• From 100% pumping to 100% generation usually in less than 6 to 10 minutes
• From 100% generation to 100% pumping in approximately 6 to 10 minutes
• Load following capabilities (in generation mode) that can respond in seconds
• Pump load is relatively fixed due to synchronous motor – step function changes (single speed machines)
• Variable speed technologies are available and offer significantly greater benefit at a incrementally higher cost
Advantages of Single Speed and Variable Speed Pumped Storage Units

<table>
<thead>
<tr>
<th>Single Speed Pump-Turbine</th>
<th>Variable Speed Pump-Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lower equipment cost by ~30%</td>
<td>• Wider head range operation</td>
</tr>
<tr>
<td>• Smaller powerhouse size</td>
<td>• Flatter and higher generating performance curve</td>
</tr>
<tr>
<td>• Slightly lower O&amp;M costs</td>
<td>• Regulation in pumping</td>
</tr>
<tr>
<td></td>
<td>• Wider generating operating range</td>
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</tbody>
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Generating Equipment

Juliusz Kirejczyk

HDR
Overview

• Generating equipment currently in operation represents technical level of the 1960’s and 1970’s

• Recent advances
  – Draw on accumulated experience
  – Profit from computational design methods
  – Offer the possibility of variable speed operation
Why Variable Speed?

(+) Economically attractive way of controlling grid frequency
  • Long time scale (minutes, hours) by regulation of pumping power
  • Short time scale (seconds) by using inertia of rotating parts as energy storage

(-) Higher equipment cost (about 30%)
Power Regulation

Pumping

- Range of regulation
  60% to 100%

Variable Speed

Constant Speed

Diagram showing the range of regulation from 60% to 100% for both constant and variable speed pumping.
Power Regulation
Generating

Higher efficiency

Wider operating range

[Graph showing efficiency and generating head with constant and variable speed operations]

ALDEN
Solving Flow Problems Since 1894
Variable Speed Equipment

• Pump-turbines – the same as for constant speed
• Electrical part – addition of AC excitation with frequency converter
  – Converter capacity:
    about 10% of motor-generator rating
  – Typical range of speed variation:
    ± 4% to ±8%
Experience with Variable Speed Pumped Storage Equipment

• Over 20 years of reliable operation
• Several dozens of units in service worldwide
  – Maximum capacity 395 MVA
• About one dozen units currently in construction
  – Maximum capacity 475 MVA
Available options:

• Single speed
  – Time-proven method
  – Lower cost

• Variable speed
  – Possibility of balancing effects of large-scale wind and solar generation
The Licensing Process

Pat Weslowski

The Louis Berger Group
The Challenge: Obtaining a License from The Federal Energy Regulatory Commission (FERC)

- Overview of regulatory process
- Strategic decisions
- Stakeholder consultation
- Steps to help manage timeframes and costs

Copies of the regulations at 18 CFR Part 4 and 5 and flow charts for the Integrated, Traditional, and Alternative Licensing Processes are available at FERC.gov/industries/hydropower
The Challenge: Overview of Regulatory Process – Pre-filing Steps

• Preliminary Permit Stage (3 years)
  – Assessing the feasibility
  – Agency/Stakeholder consultation
  – Preparing the Pre-Application Document (PAD) and Notice of Intent (NOI)

• Successive Permits (3 more years)
  – Adequacy of progress reports (actually making progress is important)
  – Meeting filing deadlines
The Challenge: Overview of Regulatory Process – Pre-filing Steps

• Pre-Application Document (PAD)
  – Readily available existing information (baseline)
  – Strategic studies to augment existing information
  – Decision of whether to include study plans in PAD
  – Stakeholder meetings
  – Strategic decision on which process to use; however assume new pumped storage facilities will use the default Integrated Licensing Process (ILP).
Processes for Hydropower Licenses

Integrated Licensing Process (ILP)
5.5 years before expiration for relicense

Pre-Application Activity

- Applicant files NOI and Pre-Application Document
  Applicant may request use of TLP or ALP
  \(\text{Sections 5.5, 5.5.5, 5.6}\)

- Comments on use of TLP or ALP, if requested
  \(\text{Section 5.3}\)

- Initial Tribal Consultation Meeting
  \(\text{Section 5.7}\)

- Commission notices NOI/PAD and issues Scoping Document 1 (SD1)
  Commission acts on TLP or ALP requests
  \(\text{Section 5.8}\)

- Commission holds scoping Meetings/Site Visit
  Discuss issues, mgmt obj, existing info, info needs, process plan, and schedule
  \(\text{Section 5.8}\)

- Comments on PAD, SD1 and Study Requests
  \(\text{Section 5.9}\)

- Applicant Files Proposed Study Plan
  \(\text{Sections 5.11, 5.10}\)

- Study Plan Meetings(s) (informal resolution of study issues)
  \(\text{Section 5.11}\)

- Comments on Proposed Study Plan
  \(\text{Section 5.12}\)

- Applicant files revised Study Plan for Commission approval
  File reply comments within 15 days
  \(\text{Section 5.13}\)

- Commission issues Study Plan Determination
  \(\text{Section 5.13}\)

- No Disputes
  \(\text{Section 20}\)

- Mandatory conditioning agencies file notice of study disputes
  \(\text{Sections 5.14, 5.14}\)

- Determination on Study Dispute
  \(\text{Section 5.14}\)

- First season studies and Study Review:
  1) Applicant files initial study report 2) Study meeting 3) Requests for study plan modification
  \(\text{Section 5.15}\)

- Second season studies, if needed, and Study Review (same as first season)
  \(\text{Section 5.15}\)

- Applicant’s Preliminary Licensing Proposal
  (not later than 150 days before application)
  \(\text{Section 5.36}\)

- Comments on Applicant’s Preliminary Licensing Proposal
  Additional Information Requests, if needed
  \(\text{Section 5.36}\)
The Challenge: Overview of Regulatory Process – Pre-filing Steps (assumes ILP)

- FERC issues scoping document
- FERC conducts scoping meetings and site visit
- FERC comments on PAD, scoping documents and study requests
- Applicant Prepares Proposed Study Plan and Revised Study Plan
- FERC issues Study Plan Determination
- Applicant Field Studies
The Challenge: Overview of Regulatory Process – Pre-filing Steps (assumes ILP)

• Preliminary Licensing Proposal
  – Preparation of Exhibits A, B, C, D, E
    • A - Project Description
    • B – Project Operations
    • C – Project Construction Schedule
    • D – Project Costs
    • E – Environmental Report
    • F - Drawings and Plans
    • G – Project Boundary and Land Ownership
  – Agency/Stakeholder consultation
The Challenge: Overview of Regulatory Process – Post-filing Steps (assumes ILP)

- Final License Application (tendering notice)
- FERC conducts an adequacy review
- FERC issues deficiency and/or additional information requests
- FERC issues acceptance notice
- FERC issues Ready for Environmental Analysis notice
- FERC prepared draft/final National Environment Policy Act (NEPA) documents
The Challenge: Overview of Regulatory Process – Post-filing Steps (for all processes)

• FERC issues license – but not until
  – A Water Quality Certification has been issued
  – Endangered Species Act (ESA) consultation is completed and biological opinion has been issued
  – A Programmatic Agreement with the State Historic Preservation Officer as been signed (if there are historic properties)
The Challenge: Strategic Decisions

- Which process to use
  - Given the complexity of pumped storage one would assume the ILP
- To do studies for the PAD
  - When there are obvious information that stakeholders want
- To include study plans in the PAD
- The degree of candor in the filings – how much information about operations to provide.
The Challenge: Stakeholder Consultation

- Needs to reflect due diligences in identifying stakeholders and tribes
- Needs to present real opportunities to review and comment
- Needs to adhere to the rigid timeframes in the ILP
The Challenge: Steps to Help Manage Timeframes and Costs

• Consult early and often with both FERC and stakeholders
• Consider the appropriate seasons for protocols and other studies
• Use FERC’s Environmental Assessment/Environmental Impact Statement guidance documents
• Strive for internal consistency between study reports and license applications
• Be thorough to avoid time consuming Additional Information Requests (AIRs).
Pumped-Storage Hydraulics

Andy Johansson

Alden
Pumped-Storage Hydraulics

• Where?
  – Lower Reservoir/Supply
  – Upper Reservoir
  – Pump Turbines
  – Penstock

• Why?
  – New Facility
  – Site changes over time
  – Increased capacity
  – Changes in expected water levels
Pumped-Storage Hydraulics

• Tools:
  – Accurate Physical and Computational Fluid Dynamics (CFD) Modeling
    • Confirm Performance of Pump Turbines
    • Provide information on how changes will impact hydraulics
    • Develop modifications to mitigate long term operational and maintenance concerns
  – Modeling Options
    • Computational Fluid Dynamics (CFD) Models
      – Cost and Schedule advantages
      – More information typically available
    • Physical Models
      – Able to predict phenomena CFD is not capable of simulating
        » Vortex Activity
Pumped-Storage Hydraulics

- Hydraulic Phenomena of Interest:
  - Vortex Formation (Lower and Upper Reservoirs)

Free Surface Vortex Classification
Pumped-Storage Hydraulics

- Hydraulic Phenomena of Interest:
  - Vortex Formation (Lower and Upper Reservoirs)

  - Adverse Vortex activity can result in unacceptable hydraulics and air entrainment impacting flow, head, power, cavitation, increased vibration and noise.
Pumped-Storage Hydraulics

• Hydraulic Phenomena of Interest:
  – Velocity Distribution and Swirl (at the pump/turbines)

\[
\theta = \tan^{-1} \frac{V_t}{U} = \tan^{-1} \frac{\pi n d}{U}
\]

where:

- \(d\) = diameter of pipe at swirl meter {ft}
- \(n\) = revolutions of swirl meter {revolutions / second}
- \(Q\) = flow {ft\(^3\)/s}
- \(U\) = average axial velocity {ft/s}
- \(V_t\) = tangential velocity near pipe wall {ft/s}
Pumped-Storage Hydraulics

• Hydraulic Phenomena of Interest:
  – Velocity Distribution and Swirl (at the pump/turbines)

– Velocity Non-uniformity and swirl can change performance characteristics and cause uneven loading of rotating elements
Pumped-Storage Hydraulics

- Hydraulic Phenomena of Interest:
  - Headloss (Civil Structures)

  – Increased Headloss can impact efficiency
Pumped-Storage Hydraulics

• Hydraulic Phenomena of Interest:
  – Scour, Sedimentation and Debris (Lower and Upper Reservoirs)
  – Adverse Scour, Sedimentation and Debris can impact O&M cost and safety
Pumped-Storage Hydraulics

• Conclusions:
  – Accurate hydraulic model studies can be very useful tools to evaluate hydraulic phenomena at pumped-storage facilities.
    • Physical Models
    • Numeric Models
    • Combined Physical/Numeric Modeling Approaches
  – Can be used to provide information on how changes will impact hydraulics
    • Changes that have occurred over time
    • Operational Changes (Increased flow capacity, water levels)
  – Can be used to develop modifications to mitigate long term operational and maintenance concerns
Fish Protection Considerations

Steve Amaral
Alden
Issue

• Fish in the vicinity of upper and lower reservoir intakes may be entrained through turbines or impinged on trash racks

• Risk of entrainment and impingement will depend on:
  – Project design and operation
  – Environmental and hydraulic conditions
  – Biological factors (species, size, movement patterns)

• Potential impacts resulting from entrainment and impingement will depend on:
  – Magnitude of losses or other effects (e.g., migration delays)
  – Existing population levels (i.e., depressed or healthy)
  – Life history strategy and biology of species of interest (i.e., resident species vs. diadromous)

• Mitigation through fish protection systems or modified project operation
Entrainment and Impingement Risk

- Type of water body used for upper and lower reservoirs (rivers, natural lakes, man-made reservoirs)
- Intake location and design (depth, bar rack spacing)
- Intake approach velocities and hydraulic zone of influence
- Water temperature, turbidity, and other environmental conditions that may influence fish behavior and ability to avoid entrainment and/or impingement
- Fish size and swimming capabilities
- Diel activity and migration behaviors
Potential Impacts

- Transfer of fish from one reservoir to another
- Loss of fish due to turbine/pump mortality
- Mortality from impingement on bar racks (as influenced by approach velocities and bar rack spacings)
- Migration delays in rivers due to changes in hydraulic conditions and entrainment
Mitigation Alternatives and Effectiveness Studies

- Fish protection systems designed to reduce entrainment and impingement
  - Narrow-spaced bar racks, screening systems
  - Barrier nets
  - Behavioral deterrents (sound, strobe lights, air bubble curtains)

- Modified project operation
  - Reduced pumping at night
  - Reduced generation during day

- Multi-year performance monitoring and protection system modifications
Northfield Mountain

- Upper reservoir: man-made (no public access)
- Lower reservoir: Connecticut River (Turners Falls impoundment)
- Units: 4 reversible pump/turbines with combined 1119 MW generating capacity
- Head range: 753 – 825 ft
- Flow capacity: 15,200 cfs pumping; 20,000 cfs generating

- Primary fish issue: Entrainment of Atlantic salmon smolts during pumpback operations
- Fish protection measures: seasonal guide net (April 1 – June 15, until 2015), 650 ft long with ¾ square mesh; pumping limited to three units or less
- Effectiveness: 93.3% guidance of tagged smolts (NUSCO 1999); some impingement reported for non-tagged smolts
Ludington

- Upper reservoir: man-made
- Lower reservoir: Lake Michigan
- Units: 6 Francis reversible pump/turbines with combined generating capacity of 1,872 MW
- Head range: 290 – 370 ft
- Flow capacity: 66,600 cfs pumping; 76,000 cfs

- Primary fish issue(s): Entrainment and mortality of Lake Michigan fish (primarily alewife, yellow perch, and salmonids) during pumpback operations

- Fish protection measures: 2.5-mile long seasonal barrier net (April – October); 19-mm bar mesh on offshore panels and 12.7 mm bar mesh on inshore panels

- Effectiveness: 62 to 100% for fish > 5 inches in length (1996 data); 95.7% for all target species combined (Reider et al. 1997)
Richard B. Russell

- Upper reservoir: Richard B. Russell Lake
- Lower reservoir: J. Strom Thurmond Lake
- Units: 4 conventional turbines (combined 328 MW capacity) and 4 reversible pump/turbines (combined 320 MW capacity)
- Head range: 136 to 166 ft
- Flow capacity: 30,000 cfs pumping; 60,000 cfs generating

- Primary fish issue(s): Entrainment of lower reservoir fish during pumpback operations; species of primary interest include blueback herring, threadfin shad, gizzard shad, striped bass, white bass, hybrid bass, walleye, sauger, and yellow perch
- Fish protection measures: Ultrasonic sound deterrent system (blueback herring); overhead lighting along shorelines to attract fish away from intake; intake screening overlays (2 inches on center); rock berm to improve hydraulic conditions (reduce fish attraction); pumping restrictions during specified seasonal periods; no daytime pumping
- Effectiveness: Reductions in entrainment rates were observed after all of the fish protection measures were implemented (Nestler et al. 1999)
Muddy Run

- Upper reservoir: man-made
- Lower reservoir: Susquehanna River (Conowingo Impoundment)
- Units: 8 Francis reversible pump/turbines
- Rated head (generation): 412 ft
- Flow capacity: 28,000 cfs pumping; 32,000 cfs generating

- Primary fish issue(s): Entrainment of fish during pumpback operations, including resident, anadromous, and catadromous species
- Fish protection measures: No specific measures have been implemented to reduce entrainment
- Effectiveness: N/A
References


Northfield Mountain study reports and documents (current relicensing activity):
http://www.northfieldrelicensing.com/NorthfieldRelicensing/Lists/Documents/AllItems1.aspx


Muddy Run study reports and documents (current relicensing activity):
Summary

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Questions

Please use the Q&A tab in LiveMeeting

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Pat Weslowski
Andy Johansson
Steve Amaral

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