

Evaluating Water System Hydraulics

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This document provides a general summary of the requirements of the Vermont Water Supply Rule, Chapter 21 of the State of Vermont Environmental Protection Rules (the Rule) that relate to distribution hydraulic conditions, a definition of commonly used terms, and information about planning, conducting, and reporting on pressure tests, hydrant flow tests, hydraulic grade line evaluations, and hydraulic models. General background information regarding these different evaluations may be found in AWWA M17 Fire Hydrants: Installations, Field Testing and Maintenance and AWWA M32 Computer Modeling of Water Distribution Systems.

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Regulatory Requirements

The Rule establishes regulatory requirements for public drinking water systems in Vermont. Appendix A, Part 8.1.1 of the Rule requires distribution systems associated with Public Community Water Systems to be designed to maintain a minimum hydraulic pressure of 20 psi throughout the system during worst-case, peak operating conditions, such as a fire-flow event experienced during maximum system demand conditions (or peak hourly flow conditions for systems that do not provide fire protection). The normal working pressure in the distribution system should be approximately 60 psi and not less than 35 psi. Static pressures should be maintained at less than 100 psi (per Appendix A, Part 7.3.1 of the Rule).

Terms and Definitions

Fire Flows: Flows produced by a fire hydrant for fire-fighting purposes. Fire flow requirements are established Appendix A, Part 7 and Part 8 of the Rule.

Fire Hydrant: Hydrant designed, constructed, and maintained to provide fire protection flows in accordance with Appendix A of the Rule.

Flushing Hydrant: Hydrant used for routine operation and maintenance activities, not used to provide fire flow.

Hydrant Flow Tests: Field tests performed to characterize fire-flow and residual hydraulic pressure capabilities of existing or newly constructed infrastructure.

Hydraulic Grade Line: Representation of pressure changes throughout a water system with respect to vertical head, storage tank elevation and pump-station capacity, and friction and minor losses within the distribution system.

Hydraulic Model: Computerized simulations performed to predict hydraulic conditions within a water system during various operating conditions and validated through collection of empirical flow and pressure data collected from the water system being modeled.

Maximum Flow Event: The greatest volumetric rate of water moved through the water system in a situation (e.g., peak hourly flow, hydrant flow, pump operating cycle, etc.)

Peak Hourly Flow: Calculated rate (gallons per minute) based on meter data using maximum volume of water entering distribution in one (1) hour during a 24-hour period. In the absence of meter data, peak hourly flow shall be calculated by multiplying the MDD by a peaking factor. A peaking factor of five has been commonly used in the absence of meter data for a specific water system. Justification of the use of different peaking factors must be specifically approved by the Division.

Pressure Tests: Field tests performed to measure and record hydraulic pressure data

from a water system.

Service Area Boundary: The geographic extent that a water system can provide service to while meeting the flow, pressure, and water quality standards established in Rule, without requiring installation of additional pumping, treatment, and/or storage facilities.

When are Hydraulic Evaluations Required?

Water system hydraulic evaluations are typically required in three different situations:

Construction Permit Applications: Per Subchapter 21-4 of the Rule, a construction permit must be obtained prior to modification of a public water system. Construction permit applications must meet the requirements of Appendix A, Part 1 of the Rule. Applications proposing modifications to existing infrastructure or construction of new storage, pump station, or distribution infrastructure must include technical information that demonstrates the proposed modifications will meet the requirements established in the Rule. Depending on the specific project, this may necessitate an evaluation of the distribution system's existing hydraulic conditions and evaluation of how the proposed project will impact the hydraulic conditions.

Evaluations Required by the Division: The Division performs routine sanitary survey inspections and issues permits to operate for public water systems throughout Vermont. Based on system-specific information, including the existing water system's service area and the infrastructure design, records pertaining to the operations of the water system, and customer complaints received, the Division may require a system to evaluate its existing hydraulic conditions under average, maximum, and peak operating conditions to determine whether minimum pressure requirements specified by the Rule are maintained under all conditions of flow and if vulnerabilities for contamination of the system exist. Note: Maximum and peak operating conditions may not occur during fire flow (e.g., peak operating conditions may occur during a booster pump cycle).

Evaluations to Support Infrastructure Improvements and Asset Management: Evaluation of hydraulic conditions may be necessary and required as part of planning for infrastructure improvements to a public water system and/or as part of an Asset Management Plan or Asset Management Program. In this situation, hydraulic evaluations are performed to evaluate and identify existing operating conditions, confirm the capabilities and limitations of the water system's existing infrastructure, develop a service area boundary and map, and to prioritize and strategically plan for infrastructure maintenance and replacement. For proposed infrastructure improvements projects, an evaluation of the hydraulic conditions with the proposed infrastructure improvements may also be required. Public water systems expecting growth may be required to evaluate hydraulic conditions with the estimated demand increase from the expected growth for a time period consistent with Appendix A, Part 2 of the Rule.

Evaluation Components

This section explains the reporting and documentation needed to complete a hydraulic evaluation. If there is uncertainty regarding the need for a Test Plan, whether a Hydraulic Grade Line Evaluation is appropriate for the Water System being evaluated, or any other requirements related to the hydraulic evaluation, the Water System or Consulting Engineer shall contact the Division prior to beginning the hydraulic evaluation.

Step 1 - Test Plans: When being performed at the direction of the Division (such as through a sanitary survey or permit to operate condition), a test plan shall be submitted to the Division for review and approval prior to performing the evaluation (performing field testing and/or developing a hydraulic model). The plan submitted to the Division must describe the purpose of the proposed evaluation, proposed locations, dates, operating conditions to be evaluated, proposed equipment to be used, limitations of proposed equipment, and other operational data to be considered during this evaluation (including but not limited to, water elevations in storage tanks, meter data, and operational status of pressure/flow controlling valves). Should the system experience seasonal variations in historical water demand these variations should be factored into the test plan as appropriate. Following Division approval of Step 1, Steps 2 and 3 shall be completed.

Steps 2a and 2b - Pressure Test and Hydrant Flow Test Reports: Pressure Tests and Hydrant Flow Tests events, including timeframes and duration of testing, shall be documented in a written report. The written report shall summarize test activities, data collected during testing, results, and identify any pressure standards and deficiencies identified during this testing, including, backflow, negative pressure data, and any pressure conditions that do not meet the requirements of the Rule. Flow testing written reports shall also document the flows that can be provided while meeting the requirements of the Rule. Acceptable report templates for Pressure Test and Hydrant Flow Test can be found in the AWWA Manual M17.

Either Step 3a or 3b must be performed.

Step 3a - Hydraulic Grade Line Evaluation Reporting: Hydraulic Grade Line Evaluations must be performed by a Vermont-Licensed Professional Engineer experienced with public water systems and applicable regulations. The Vermont-Licensed Professional Engineer must provide a signed and sealed letter report to the Division upon completion. All calculations, survey data, and supporting information are to be provided as attachments to the letter report. The evaluation must include identification of any deficient aspects of infrastructure. Relevant technical details included in the section titled "Technical Details" of this document shall be included in the report.

Step 3b - Hydraulic Model Reports: Hydraulic Models, and associated reports, must be prepared by a Vermont-Licensed Professional Engineer experienced with public water systems and applicable regulations. Hydraulic Model reports must describe the

purpose for developing the model and the data used to develop, calibrate, and validate the model. Results of calibration/validation activities and results from model simulations, including discussion of any deficiencies identified during this evaluation, must be included in the report submitted to the Division. Technical details for hydraulic models begin on Page 7 of this document.

Further Description of Evaluation Components

Pressure Tests (Step 2)

- Pressure tests are performed to characterize hydraulic pressures in portions of a distribution system during specified water system operating conditions. Typically, a pressure test involves installing either a mechanical pressure gauge or pressure transducer equipped with a chart recorder or datalogger and leaving the instrument set up to record pressure data for a specified period of time. The specified period of time should include the typical periods of maximum demand flows for the system, such as typical peak hourly flow conditions.
- Data is to be used to characterize both high-pressure and low-pressure conditions. Pressure transducers and recorders may also be used to investigate and characterize transient condition pressure wave/surge events (e.g., water hammer).
- Systems without fire hydrants may be requested to install pressure chart recorders or transducers at: flushing hydrants; pressure regulating valves, including pressure reducing valves (PRVs) and pressure sustaining valves; pump stations; and selected service connections.
- Elevation data associated with monitoring equipment must be reported with pressure data. Accuracy of elevation data is critical and must be reported with the data; discussion of accuracy and justification, as it relates to purpose of the testing, must be provided in the report submitted. Data quality and uncertainties with the data that has been collected must be documented.

Hydrant Flow Tests (Step 2)

- Hydrant Flow Tests are performed to characterize the flow rates fire hydrants can produce. This testing may be performed to demonstrate that hydrants installed on mains that do not meet current technical standards outlined in Appendix A, Part 8.1.2 of the Rule are capable of providing at least 500 gpm for two hours while maintaining a minimum pressure of 20 psi throughout the entire distribution system (as required by Appendix A, Part 7.0.1(a) and Part 8.1.1 of the Rule).
- Typically testing involves installing at least one pressure transducer/datalogger at a location of concern in the system (e.g., a location where low-pressure conditions may exist such as the highest elevation water service or a high usage area),

connecting a flow meter to a hydrant, flowing the hydrant, and recording the flow and residual pressure data from nearby hydrant(s).

- Elevation data associated with monitoring equipment must be reported with pressure data. Accuracy of elevation data is critical, and discussion of the quality and uncertainties of the data must be included in the report. Differences in elevation between monitoring locations must be accounted for in calculations and documented.
- Identification of pressure monitoring location(s) and justification for selection of hydrant(s) where flow testing occurred must be documented (e.g., expected lowest residual pressure).
- Flow testing should be conducted during routine operating conditions during times that are representative of expected maximum occupancy (for systems with seasonal variations in occupancy), and representative of typical maximum water use demands, including peak hourly flows.
- The pressure drop between the static and residual pressures should be at least 10 psi. If the pressure drop was less than 10 psi, testing should be repeated with an additional flow hydrant.

Hydraulic Grade Line Evaluation (Step 3a)

- This evaluation is a study created through means other than modeling software that characterizes pressure conditions based on elevations of pumps, storage tanks, piping, service connections, distribution pipe materials, pump performance curves.
- This evaluation is appropriate for applications involving very small populations served and which are in a geographically compact service area involving limited pumping facilities.
- Hydraulic Grade Line calculations must consider the following: infrastructure elevations; typical operating water levels in storage facilities; pipe lengths, material(s), and diameter(s); flow rates (permitted maximum daily demand (MDD), metered MDD, other measured peak flow, and average daily demand (ADD)); pump capacities; and description of friction losses (including pipe length equivalents for valves (open/closed)). Relevant technical details are described in the section titled “Technical Details Regarding Hydraulic Grade Line Evaluations and Hydraulic Model Reports” of this document.

Hydraulic Models (Step 3b)

- Hydraulic models are developed to characterize conditions throughout a distribution system. Models can be used for a variety of purposes, including: planning for expansion or future improvements projects; defining service area boundaries;

evaluating storage tank draw and fill patterns; evaluating fire-flow capabilities; and evaluating flow characteristic conditions (C-values) of existing pipe infrastructure. The section titled “Technical Details” of this document provides general guidelines and accepted practices for developing, calibrating (using pressure study data), and reporting on hydraulic models for public water systems. Note, the requirements for a specific model will vary based on the purpose of the model and specific characteristics of the system being evaluated. This guidance is oriented toward the development of a static (steady-state) model for systems that provide fire protection flows. Dynamic (extended-period simulation) models may be utilized, as appropriate, but may require the Water System to consider different approaches when collecting basic data as part of a pressure study. The section titled “Technical Details Regarding Hydraulic Grade Line Evaluations and Hydraulic Model Reports” of this document includes technical information and expectations specific to development and reporting for hydraulic models.

- Hydraulic Models and associated reports must be prepared by a Vermont-Licensed Professional Engineer experienced with public drinking water systems and associated regulations. A report must be prepared and submitted to the Division. The reports must include the following: the purpose of the model; assumptions and data used to develop, calibrate, validate, and evaluate the model; results from model simulations; and potential future uses of the model. Reports must also include topographic figures that depict the spatial distribution of drinking water infrastructure, service connections, and flow nodes used in the model. Additional details are presented in the section titled “Technical Details Regarding Hydraulic Grade Line Evaluations and Hydraulic Model Reports” of this document.

Technical Details Regarding Hydraulic Grade Line Evaluations and Hydraulic Model Reports

This section provides details regarding the Division’s expectations for hydraulic model reports submitted to support evaluations of public drinking water systems in Vermont. The Division expects that hydraulic models will typically be developed for public community water systems that provide (or plan to provide) fire protection flows, public community water systems that are planning for future growth, evaluating water system deficiencies, or as part of an Asset Management Plan. Details regarding model development, calibration, and recommendations are presented below. Relevant technical details included in this section shall be included in the Hydraulic Grade Line Evaluations.

Model Development

- The report must describe the purpose of the model, type of model developed (static/steady-state, dynamic/extended-period simulation, etc.), the assumptions made, and the data inputs used to develop the model.
- The report must include a description of the water system’s infrastructure. This

description must provide a detailed discussion of infrastructure that directly affects hydraulic conditions, including storage facilities, pump facilities, specialty valves (e.g., pressure and flow control valves), location and elevation of this infrastructure, and related operational process controls, such as motor soft-starts, SCADA settings used to control timing of pumping/tank filling operations, etc.

- The report must describe how source water production and water use demand flows were simulated and calibrated in the model. This discussion must outline whether the water system is planning for future growth, and if so, indicate how future growth was considered in development of the model. Discussion of the ADD and MDD flows for the water system for both the current state and in the design year considered for the model (please refer to Appendix A, Part 2 of the Rule for the appropriate design year period). This discussion must also include evaluation of the metered data available, a description of how metered data was used to develop model, and the methodology used to simulate water use demands throughout the distribution system, including description of how demand flows were assigned to nodes in the model. Identification and discussion of large demand users connected to the water system must be included.
- Models developed for Wholesale and Consecutive Water Systems must include a node at each consecutive connection. Model simulations should consider both meter data obtained from the consecutive connection and the water use allocation provided by the Wholesaler to the Consecutive system.
- Discussion of assumptions must include: operating water level elevations for storage facilities (should be minimum water level for normal operations); settings for specialty valves (e.g., pressure reducing valves); operational status of treatment facilities (including clearwells), pumping facilities, and sources; friction factors for distribution piping; and operational settings/controls in the model (e.g., describe the conditions that open/close control valve(s), or settings to control pump operations).
- The report must include description of the basis used to model the water system's pipe diameters, materials, friction losses, and operating conditions.
- The report must include a Map / Figure that depicts the elevations and geographic distribution of water system infrastructure (including distribution piping, pressure reducing valves/other specialty valves, storage facilities, pump facilities); locations of flow nodes used in the model; and identification of fire hydrants used for flow and pressure testing. Datum for any elevations used should be provided. Note: topographic map and/or plans and profiles may be used, as appropriate, to meet this requirement.

Model Calibration / Validation

- All models must be calibrated based on empirical flow and pressure data collected from the water system. Pressure tests and hydrant flow tests should be planned,

performed, and documented in accordance with the Division's recommendations. Empirical data used to calibrate/validate the hydraulic model must be less than 3 years old; use of older empirical data must be specifically approved by the Division.

- Fire hydrant flow tests must be performed when modeling systems that provide fire protection; these tests must consider the minimum fire protection flow requirements in the Rule, fire flow ratings established for the water system by the Insurance Services Office (ISO), and fire flow testing data from ISO.
- Field testing programs must be planned to include test sites that are representative of each pressure zone served by the system. The number of hydrants tested in each pressure zone should take in to consideration the number of service connections, the length and diameter of pipe, changes in elevation, and other factors that may impact local water pressure.
- Boundary conditions and water system operational data including tank and clearwell water level elevations, treatment facility production flows, pump operations including source pumps, and other appropriate water system operating conditions must be recorded before the field testing, during testing, and after testing, and discussed in the hydraulic model report provided to the Division.
- The Report must provide a comparison of field data and the results of model simulations. The goal is 5% or less difference between the pressures generated by the model simulations and empirical pressure data. If a 5% or less difference cannot be achieved, the report shall discuss why. The discussion shall include description of the precision of the equipment/instruments used during empirical data collection, of potential effects of differences between model simulations and field data, and implications for the quality of analysis provided by the model (i.e., impact to the conclusions that can be drawn from the model based on level of calibration achieved and precision of equipment/instruments used.)

Results and Recommendations

- This section of the report shall describe simulations performed with the calibrated model, including simulations at current year and design year ADD and MDD flow conditions (refer to Appendix A, Part 2.1 of the Rule for the appropriate design year).
- For water systems that provide fire protection flows, simulations shall be performed using fire flows of 500 gpm for two (2) hours (per Appendix A, Part 7.0.1 of the Rule) and using ISO Ratings, as appropriate, based on storage and flow capacities of existing infrastructure. Fire flows should be simulated during maximum day demand flow conditions at both the current year and design year.
- Simulations shall be performed to represent both existing infrastructure conditions and conditions that would exist if proposed improvements were completed. For

example, model simulations could be performed to evaluate benefits of replacing specific segments of existing aged pipe, and with new pipe to create looped segments.

- The report shall describe results of model simulations, including discussion of any atypical conditions (e.g., high velocity flows, high losses) that were simulated, including discussion of any simulated hydraulic conditions that don't meet the requirements of the Rule. The discussion shall include the likely, or suspected, root cause of each atypical and/or unacceptable condition simulated, including brief discussion(s) of solution(s) to correct each situation.
- The report shall include recommendations for current and future uses of the model, including discussion of how the model may be used to plan for future water system operations and maintenance. Discussion shall also include details regarding model ownership and updates.
- Model reports shall include excerpts of model outputs, field data obtained during model calibration, and data used to develop the model (including metered data and data related to operational settings of water system equipment) in appendices.
- The report shall include a map that establishes a Service Area Boundary for the Water System based on model results, representing the geographic area the Water System can serve while meeting the requirements of the Rule without the addition of pumping facilities and/or storage facilities.