FINAL REPORT

Steam Trap Evaluation Phase 2

Massachusetts Program Administrators and Energy Efficiency Advisory Council

Date: March 8, 2017

Acknowledgments

This report required substantial engagement by the Massachusetts Program Administrators and their steam trap-related service providers. The DNV GL team led by ERS wishes to thank the following participants in this report's development:

Sam Alpert, GDS

Anthony Carloni, National Grid

Jennifer Chiodo, Cx Associates

David Gaudet, National Grid

Sue Haselhorst, ERS

Cameron Kinney, ERS

Tony Larson, National Grid

Jon Maxwell, ERS

Erik Mellen, Eversource

Mike Mills, Eversource

Ralph Prahl, Ralph Prahl Associates

Mark Sevier, National Grid

Chad Telarico, DNV GL

Table of contents

List of figures

List of tables

1 EXECUTIVE SUMMARY

Prescriptive and custom steam trap repair and replacement projects are large and increasing contributors to the Massachusetts Program Administrators' (PAs') statewide energy savings portfolio, and currently represent the fourth-largest natural gas energy savings measure.[1] The PAs increased their promotion of the measure in 2016, especially the prescriptive portion, because it is a cost-effective measure that is perceived as underutilized by customers. At the same time, evaluators have observed that savings realization rates for steam traps vary widely at the project level, in both prescriptive and custom programs.

DNV GL completed a Phase 1 steam trap evaluation in 2015, which resulted in an increase in measure effective useful life (EUL) from 3 to 6 years, and a recommendation to initiate a Phase 2 study to develop a methodology for producing more consistent results for custom steam trap savings and a new prescriptive steam trap deemed savings value. This report details findings and conclusions from the Phase 2 Steam Trap Evaluation, led by ERS on behalf of DNV GL (DNV GL team).

1.1 Overview of objectives and approach

The objectives of the evaluation are as follows:

1. Improve the accuracy and consistency of the custom savings equation for steam trap repair and replacement by developing an algorithm that the DNV GL team will use in ex post evaluations and recommend to the PAs for estimating the steam trap savings in custom applications. The expectation is that all PAs will converge on this approach, which is referred to in this document as the revised savings equation.
2. Use participant representative data to update the deemed savings value for prescriptive steam trap replacement measures.

The general approach entailed consulting a variety of industry experts (including the "steam trap stakeholder group" of PA implementers) as well as incorporating program participant data and secondary research findings to establish a theoretical basis for a revised savings equation. We completed primary data collection activities and site-specific savings calculations, and empirically derived values for the most uncertain variables of the revised savings equation. We used the revised savings equation in conjunction with average program participant characteristics to calculate a revised deemed savings value for prescriptive replacements. Based on our findings and conclusions, we recommend a number of changes to the custom savings tool that will moderately impact the overall measure savings.

1.2 Key findings, conclusions, and recommendations

The findings, conclusions and recommendations are summarized as follows:

1.2.1 Conclusions

- A review of custom steam trap projects from 2013 and 2014 revealed that PAs were using analogous but ultimately different methodologies and assumptions to calculate savings for each steam trap.
  - We developed a custom savings tool for statewide use by the PAs.

[1] Boilers, pre-rinse spray valves, and insulation were the top three and thermostats were fifth. *Massachusetts 2013 Prescriptive Gas Impact Evaluation, Steam Trap Evaluation Phase 1: Final*, Massachusetts Gas Program Administrators and Massachusetts Energy Efficiency Advisory Council, by DNV GL (KEMA, Inc.), June 17, 2015, p. 1.

- Our review of the existing methods found that, in some instances, the savings equation had an unnecessary amount of complexity.
  - We reviewed input parameters from the savings equation on an individual basis, using expert interviews and secondary research. We then chose to keep, modify, add, remove, or omit these input parameters from the revised savings formula. Notable revisions include the modification of the condensate return and leak factors and removal of the repair/replace factor.
  - We have made methodological simplifications to the revised tool in an effort to reduce the chance of field staff misinterpreting the operating status of an individual trap. These simplifications include reducing the number of variables and respective options for selected variables. In particular, the reduction of leak factor options from 4 to 2 non-zero options in a pick list should minimize the opportunity to misinterpret a trap, and yield more consistent savings estimates among the PAs.
- There are 2 input parameter values that are difficult to observe in the field or estimate with engineering judgement, and are often associated with high uncertainty.
  - We empirically derived these parameters (trap operating status leak factors and condensate return factor) using the billing analysis results from a number of custom projects.
- With comparable input variables, the revised savings equation estimates 13% less savings for sites that were used to empirically derive the most uncertain values.
- Adopting the revised custom savings tool statewide will provide an opportunity for PAs to maintain uniformity and consistency in the estimation of steam trap savings across the state, while moderately improving the tool's predictive ability and reducing the variability of the estimates.
- We found that the methodology and assumptions used to generate the existing deemed value are unrepresentative of the typical customer.
  - We used trap-level details from the custom project trap inventory to characterize an average high- and low-pressure trap. We used the average input parameters in the revised savings equation to generate annual per-trap savings, and then blended these based on their frequency of observed occurrence to arrive at a new single value we judged to be representative of the current market.

1.2.2 Recommendations

- The DNV GL team recommends that all PAs use the revised custom savings tool for custom projects installed in 2017 and going forward.
- The DNV GL team recommends using a single revised deemed savings value of 12.2 MMBtu/year for prescriptive steam trap replacements. This value is lower than the prior value of 25.7 MMBtu/yr. The new revised deemed savings value should be applied retrospectively to 2016 prescriptive projects, and prospectively from 2017 going forward.

1.2.3 Considerations

- The unique nature of steam trap projects relative to other efficiency measures calls for a more measure-specific approach in record keeping of completed projects. At the program level, an emphasis should be placed on tracking the following data points for custom projects at each individual site:
  - Dates: survey, repair/replacement (i.e., installation), post-installation inspection

- Trap counts: facility total, inspected total, repair/replace, confirmed repair/replace
- Savings: tracked, vendor, workbook, confirmed workbook

- We identified two areas for which savings estimates could possibly be improved in later studies:

1. Conducting further research into leak statuses and pressurized hours of operation, as a function of both specific trap types and their applications. Such refinement would further reduce custom savings variability, but due to the method used in this study, would not be expected to materially change the program-level savings.
2. Using prescriptive-specific participant firmographic data in modeling deemed savings. Profile data were available and used from the custom participants to estimate the deemed savings value. If prescriptive participants characteristically differ, this can affect the average savings represented by the deemed value.

2 INTRODUCTION

Prescriptive and custom steam trap repair and replacement projects are among the most cost-effective natural gas energy saving measures in the state, and are currently the fourth largest natural gas contributor to the Massachusetts Program Administrators' (PAs') state-wide energy savings portfolio. The PAs are looking to increase the promotion of the measure (with an emphasis on the prescriptive track), as it is perceived by many to be underutilized by customers. At the same time, the realized savings have been observed to vary widely at the project level for both custom and prescriptive programs. In an effort to increase the accuracy of future estimates, the Phase 1 steam trap evaluation made program level recommendations regarding overall incentive structure and measure life.[2] It also identified the need for this Phase 2 study to develop a methodology to produce more consistent results for custom and deemed savings.

This report details the overall efforts of the Phase 2 steam trap evaluation, including the establishment of the theoretical basis for the selection of an energy savings equation as well as the research provided to support the optimal selection of parameters based on market research and data analysis.

The DNV GL team has engaged with the existing "steam trap stakeholder group" of PA implementers to ensure that the methodology can accommodate current and/or future program designs, and provide research to support the expanded marketing of the program.

The objectives of the Phase 2 steam trap evaluation are as follows:

1. Improve the accuracy and consistency of the custom savings equation for steam trap repair and replacement by developing an algorithm that the DNV GL team will use in ex post evaluations and recommend to the PAs for estimating the steam trap savings in custom applications. The expectation is that all PAs will converge on this approach, which is referred to in this document as the revised savings equation.
2. Use participant representative data to update the deemed savings value for prescriptive steam trap replacement measures.

The remainder of this report details:

- Methods we used to accomplish this evaluation
- Findings regarding:
  - Screening disposition
  - Billing analysis results
  - Parameter calibration
  - Deemed savings estimate
- Conclusions and recommendations

[2] It recommended keeping both prescriptive and custom incentives and increasing the measure life from three to six years. *Massachusetts 2013 Prescriptive Gas Impact Evaluation Steam Trap Evaluation Phase 1*, DNV GL, June 17, 2015

3 METHODS

The overall methodology of developing the custom savings calculator and deemed savings value consisted of two distinct activities: data collection and analysis.

Data collection

- **Stakeholder group engagement** – The DNV GL team engaged the steam trap stakeholder group to help refine the research approach, provide expert input and guidance, and ensure that the project methodology was in step with current and future program designs.
- **Secondary research** – We reviewed a selection of other states' technical resource manuals (TRMs) to determine how other governing bodies assess steam trap savings compared to Massachusetts.
- **Pre-installation vendor ride-alongs** – We joined multiple steam trap survey vendors during pre-project inspections to assess the methodologies employed on-site, and understand how trap-level characteristics are captured and eventually turned into actual energy savings estimates. Three different site visits were conducted for this task.
- **Program year 2013–2014 steam trap participant data** – Project files and billing data from 2013 and 2014 program participants were collected, screened, and used throughout the evaluation to ensure that the results produced were characteristic and representative of the Massachusetts steam trap program participants. Participant data was gathered for 70 unique sites.
- **Post-installation phone interviews** – We identified a selection of 2013–2014 program participants for phone interviews, and screened each facility for the feasibility of using a weather-normalized billing analysis to accurately characterize gas savings at the site. The intent of the phone screening was to eliminate facilities where changes may have occurred concurrently with the steam trap project that would affect the outcome of the billing analysis. Phone interviews were completed for 55 different facilities.
- **Post-installation on-site evaluations** – We conducted on-site visits to follow up with a selection of the facilities screened over the phone, to confirm the trap-level parameters as well as facility-level characteristics, including boiler combustion efficiency and maintenance practices. Post-installation site visits were conducted at seven different facilities.

Analysis

- **Refine formula structure** – We modified the steam trap loss equation's parameters based on the interviews and secondary research, to simplify and increase the accuracy of the semi-prescriptive calculator in order to develop a more consistent and accurate custom savings equation.
- **Trap-level savings calculation** – Trap-level savings were replicated using the original, PA-specific savings formula for each of the 9,450 steam traps from the participant's trap survey inventories. 2,659 (28%) of these traps had savings associated with them.
- **Site-specific billing analyses** – After screening participants for billing analysis feasibility, we conducted weather-normalized billing analyses to observe the actual impact of steam trap projects at a number of facilities.

- **Engineering algorithm refinement** – Excluding the most uncertain variables, the DNV GL team assigned values to every savings calculation parameter using expert judgment. The variables associated with the highest uncertainty (i.e., condensate return and leak factors) were defined empirically using the results of the billing analyses in a parameter calibration analysis. This method entailed adjusting the identified variables in the savings algorithm with the goal of matching calculated savings to the qualified billing analysis results while minimizing the statistical uncertainty of the calculated savings and realization rate-equivalent values. After screening projects the final basis for this exercise was 24 projects and 4,750 inventoried traps (of which 1,332 included savings).
- **Deemed savings estimation** – We used the refined engineering algorithm with program population representative input assumptions to define a single deemed savings value. We used median values for continuous variables and weighted averages for discrete variables.

3.1 Formula structure refinement

We drew on findings from a number of different sources in order to refine the existing savings algorithm(s) into one that would be more consistent across the state and more accurate. Each of the existing or proposed equation inputs was individually reviewed and then marked to be kept, modified, added, removed, or omitted. Table 3-1 provides a summary of each the existing calculation input's status; an in-depth examination of each input can be found in the appendix.

Table 3-1. Current custom savings equation variables

Variable Status	Variables
Keep	Trap pressure, enthalpy of saturated steam and liquid, trap type/orifice size, open/closed system status, boiler efficiency
Modify	Condensate return factor,[1] leak factors,[1] hours of operation
Add	Annual gas usage flag
Remove	Repair/replace factor, steam system loss factor, flash steam heat recovery
Omit	Condensate pressure factor, lighting interactivity factor

[1] Condensate return factor (CR) and leak factors (LF1, LF2) have been identified as candidates for parameter calibration

The proposed custom equation for steam traps is as follows:

$$Energy\ loss\ (\frac{Btu}{yr}) = \frac{60 \times a \times P^{0.97} \times LF \times C_D \times \left(h_g - h_f\right) \times CR \times \frac{hr}{yr}}{\eta}$$

where,

60 = Empirically derived factor in Grashof equation ($lb_m/(in^{0.06}\text{-}lb^{0.97}\text{-}hr)$)

0.97 = Empirically derived factor in Grashof equation (unitless)

a = Area of orifice at throat (sq. in), from field observation of trap model number & lookup

P = Pressure in steam line at trap (psia), from field data

LF = Leak factor (0–100%) to discount for partially obstructed orifices or non-ideal steam flow, entered as one of five different values from trap status pick list based on field observation. Each trap will be designated as OK, not in service (NIS), plugged, leaking or blowing by. OK, NIS and plugged traps are 0% by definition (yielding no savings) while the leaking and blowing by are established in the analysis below.

C_D = Discharge coefficient (70%) to account for trap hole not being a perfect orifice, generalized value from secondary research

h_g,h_f = Enthalpy of saturated steam and liquid, respectively (Btu/lbm) associated with the specified steam pressure

CR = Condensate return factor (30%–100%) accounts for energy returned from condensate line. Value is 100% if there is no condensate return system or a single value calculated from analysis described below.

hr/yr = Hours per year that trap is functioning (deemed value). On of 9 pre-determined values, with selection from a list based on field observation of trap application.

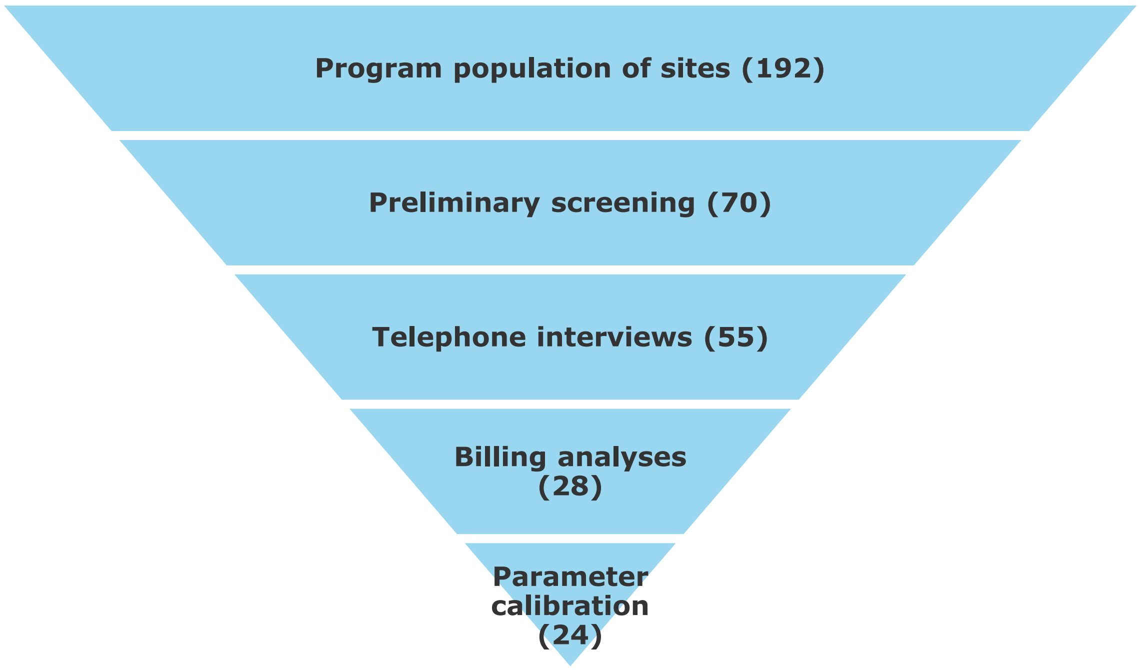
η = Overall steam generator marginal combustion plus heat exchange efficiency (80%). Fixed value from secondary research

The leak factors and condensate return factors were identified as the variables with the most uncertainty within the equation, and therefore were the focus of the parameter calibration in the algorithm refinement section. The four parameters CD, η, CR, and LF are present in every trap calculation and multiplicative with one another. If the assumed value of CD or η is incorrect, the research on CR and LF will inherently correct for this.

3.2 Individual site assessments

The calibration of the model depended on steam trap site-specific project data and billing data. However, not all of the projects were included in the final calibration. Figure 3-1 illustrates the site counts for each stage in the screening process.

Figure 3-1. Site screening process flow



Program population of sites

The DNV GL team requested the project tracking data for every facility that performed steam trap upgrades in project years 2013 and 2014. The 2013/2014 tracking data set contained an assortment of 252 custom and prescriptive gas projects (including non-trap projects) completed at 192 unique sites. We also requested the natural gas billing data for every facility from 2012 through 2015.

Preliminary screening

We screened each facility using criteria to validate the use of billing data to assess trap savings via a weather-normalized billing analysis. To ensure that the impact of steam trap projects could be recognized within the billed usage, only facilities with tracked savings that were higher than 5% of their annual usage (the "savings fraction" which is based on a 12-month annual average) were included for initial consideration. The facilities that had one or more steam trap projects with a total tracked savings greater than 5% of their annual usage were accepted, as were sites with multiple measures (not limited to steam traps) where the total savings was greater than 5% of their annual usage and the steam trap project(s) accounted for at least 90% of the total tracked savings. Next, we reviewed projects with a savings fraction just below 5% (approximately 4.9%) of the average annual consumption.

This preliminary screening phase resulted in a preliminary count of 105 custom and prescriptive steam trap projects at 70 sites. Project files were obtained for each of the custom projects (which included savings calculation worksheets), while trap counts and installation dates were provided for prescriptive projects.

Trap-level details were pulled from every custom savings workbook into a master spreadsheet, where the tracked savings were replicated with the existing algorithm used by each PA. Replicating the savings for every site proved difficult, as some applications used the vendor savings (algorithm unknown) over the PA savings while others took an average of the two values. Additionally, some sites did not repair every trap marked for repair in the inventory, which the tracking savings had been updated to reflect. The differences between the tracking, vendor, and replicated workbook savings necessitated using all three values for the sake of comparison.

Telephone interviews

The DNV GL team conducted telephone interviews with contacts at each facility in order to determine whether the difference in billed usage could be wholly attributed to the steam trap project or not. We asked facility staff about other measures or equipment that may have been installed, notable changes in production, occupancy or scheduling, fuel switches, or any other event that may have spurred a change in steam and/or gas usage at the approximate time of the project (±1 year from project date). Sites that confirmed that there had been some other change to the facility at the approximate time of the project that would affect natural gas usage were removed from consideration for the billing analysis phase. After repeated attempts at recruiting every site in the population, interviews were completed for 55 out of the 70 sites. The 15 sites for which interviews weren't completed were excluded, along with 14 sites for which other site activity contaminated the billing data, leaving 41 for billing analysis consideration.

Billing analyses

Weather-normalized billing analyses were completed for each of the remaining sites. Pre- and post-project gas consumption was regressed against actual heating degree days (HDDs) and then normalized against typical TMY3 data from the nearest weather station. We reviewed each individual billing analysis and ensured that the regressions were reasonable by comparing gas usage and HDD profiles against each other. Adjustments were made on an individual site basis by shifting degree-day base temperatures as well as pre- and post-project billing periods. Billing analyses were removed from consideration for parameter calibration if the analysis yielded indeterminate results by way of billing data anomalies or gas consumption that was found to be predominately production-based. Of the 41 sites screened with a weather-normalized billing analysis, 28 met the criteria for parameter calibration. Out of the 28 sites, 4 were prescriptive projects and did not have trap level details to be used in the parameter calibration analysis. Thus, the final site count for the parameter calibration portion is 24.

3.3 Parameter calibration

The majority of assumptions in the revised savings equation were identical or close to the existing approach assumptions. However, the values for the condensate return factor and leak factors were calculated empirically using the best fit approach described in this section. These factors are difficult to observe in the field and potentially vary widely.

The DNV GL team used the revised savings equation and trap-level parameters to calculate the revised savings estimates, which were then totaled by site and compared to the billing analysis results of each qualified site. The comparisons consisted of creating a ratio similar to a realization rate: the ratio of the ex post savings (billing analysis results), to that of the tracking savings (or, in this case, our revised savings). We compared the billing analysis results to both the various ex ante values (tracking, vendor, and workbook savings) and the newly developed revised savings by generating both savings-weighted and unweighted realization rate-equivalent values, plotting them, and calculating the relative precision of each value.

Using the status listed for each trap in the master inventory, we created a conditional statement assigning the "updated" leak factors based on the older status. Value ranges were assigned to each of the three parameters to be calibrated (CR, LF1, and LF2) along with the overall weighted and unweighted realization rate-equivalent values. We then used Excel's evolutionary solver package to adjust the targeted parameters from the formula in Section 3.1 (CRF, LF1, and LF2) within the specified engineering constraints (e.g., the factors cannot be less than 0 or greater than 1) with the goal of minimizing the statistical uncertainty of the overall weighted realization rate-equivalent value. The evolutionary solving method is designed to find a near-optimal solution for non-smooth, nonlinear functions by iterating specified variables using a nondeterministic, random sampling mechanism confined to the specified constraints. Numerous permutations were executed with the solver until we arrived at a set of three parameter values deemed to be optimal.

3.4 Deemed savings value

The deemed savings estimate was calculated by using participant averages as the input parameters to the revised savings equation. The participant averages were derived from the custom project trap inventory imported from the project files into the master spreadsheet. This approach is generally preferred to averaging the overall per-trap savings value, as it allows for a combination of continuous and discrete variables. For continuous variables (such as orifice size), the individual trap values were averaged without weighting them. For discrete variables the individual values were aggregated using a weighted average (based on steam trap counts). After arriving at an updated savings estimate using participant average custom characteristics, the DNV GL team corroborated the findings for prescriptive use by reviewing the realization rate-equivalent values for four prescriptive projects that had passed through the site screening phase.

4 FINDINGS

This section discusses the results of the evaluation.

4.1 Screening disposition

Table 4-1 provides an overview of the final site dispositions, categorically broken down by the reasons sites were removed from the final analysis.

Table 4-1. Final site dispositions

Final disposition	Count
Removed from analysis	42
No survey completed	15
Production, occupancy, or schedule changes	3
Other projects completed	9
Fuel switch	2
Production based usage	8
Inconsistent billing pattern	5
Cleared survey and BA screening	28
Custom	24
Prescriptive	4
Total	**70**

In more detail, sites were dropped from the initial population for the following reasons:

- We were unable to complete interviews for 15 sites.
- 14 sites were removed because the site contact indicated that there had been some type of change at the facility affecting gas usage within the billing analysis window of the project.
- An additional 13 sites were removed during the billing analysis review, as the evaluators found either that gas usage was largely production-based, or that there were too many inconsistencies within the billing data to establish an accurate regression against weather data.

There were 28 sites that passed through the overall screening process. Four were prescriptive projects with no trap-level details, leaving 24 sites to be used in our parameter calibration analysis.

The next several exhibits illustrate the degree to which the final sample of projects used in the parameter calibration analysis reflects population characteristics. Overall, we believe there is low likelihood of significant attrition bias associated with the firmographic variables evaluated beyond possibly the two issues noted below. Table 4-2 provides a breakdown of the facility classification types throughout the evaluation screening process, including both custom and prescriptive projects.

Table 4-2. Facility types through screening process

Facility type	Population	Surveyed	Passed phone screening	Passed BA screening
Com – other	5	3	1	-
Health care	14	12	8	5
Hotel	2	1	1	1
Industrial	13	11	9	3
Multifamily	3	1	-	-
Municipal	9	6	5	5
Office	5	4	3	3
School	19	17	14	11
Total	**70**	**55**	**41**	**28**

There is a relatively similar distribution of projects by facility type between the sites used in the calibration and the initial population, with two exceptions. The final counts for health care and industrial sites are low relative to other categories. Site surveys revealed that many health care facilities were either undergoing facility expansions or doing other project work within the timeframe of the steam trap project. This is not expected to be a characteristically significant concern with respect to attrition. While 9 of 11 industrial facilities passed the phone survey screening phase, the majority did not pass the billing analysis screening due to production-based gas usage. There was obvious non-weather and likely production-driven gas use volatility in the majority of the industrial sites. Collecting production data and analyzing performance as a function of it was beyond the scope, thus they were removed. This aspect could be a minor vulnerability in the analysis.

Table 4-3 provides a breakdown of the initial site count and tracking savings compared to the final site numbers and tracking savings used in the parameter calibration analysis.

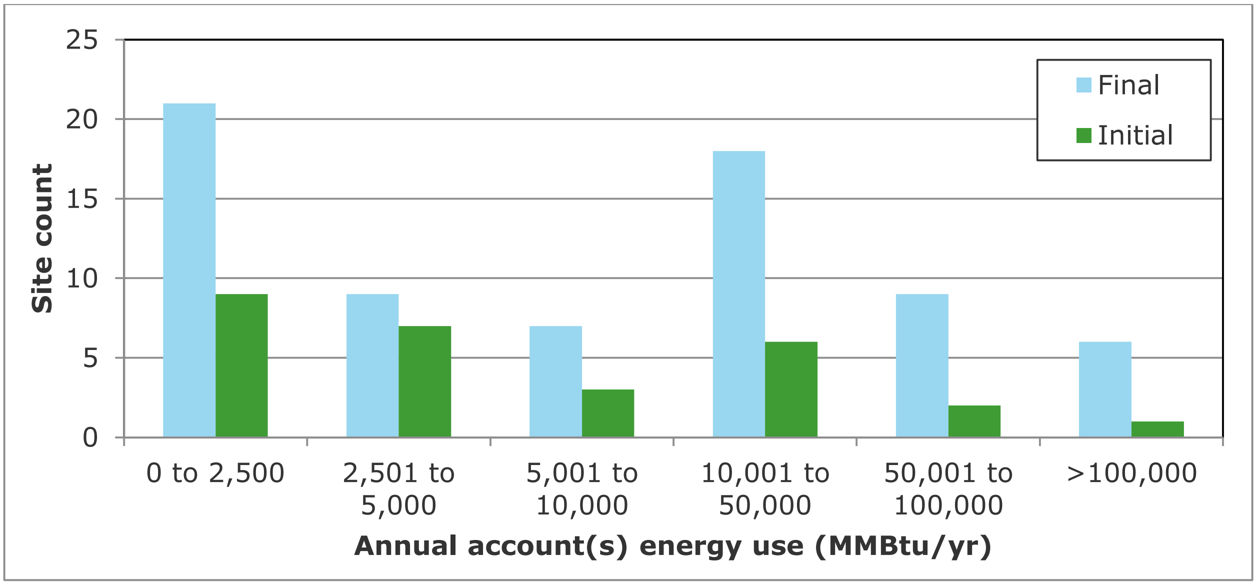
Table 4-3. Initial and final site counts and savings by program administrator

PA	National Grid	Eversource	Total
Total sites	61	9	70
Sites for BA calibration	22	2	24
Total tracked savings (therms)	895,805	192,207	1,088,012
BA calibration tracked savings (therms)	338,541	33,457	371,997
Final % of sites	36%	22%	34%
Final % of savings	38%	17%	34%

The similar percentage of sites and percentage of savings indicates that attrition did not disproportionately screen out very small or very large saver, a good sign.

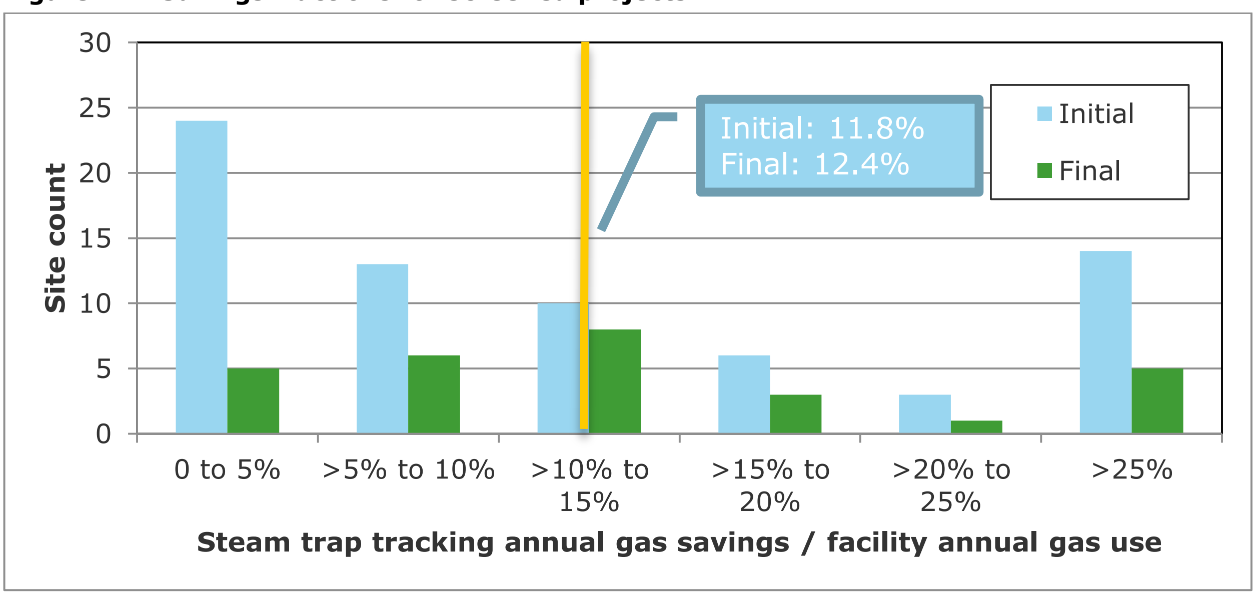
Figure 4-1 illustrates the breakdown of the annual energy use per facility, comparing the initial and final counts used in the parameter calibration analysis.

Figure 4-1. Annual energy use per premise



While energy intensity is not directly related to the realized steam trap savings at a given facility, the chart illustrates that the sites used in the evaluation approach were representative of the initial population. Figure 4-2 illustrates the breakdown of the tracked savings as a fraction of the annual energy use at each facility.

Figure 4-2. Savings fractions for screened projects



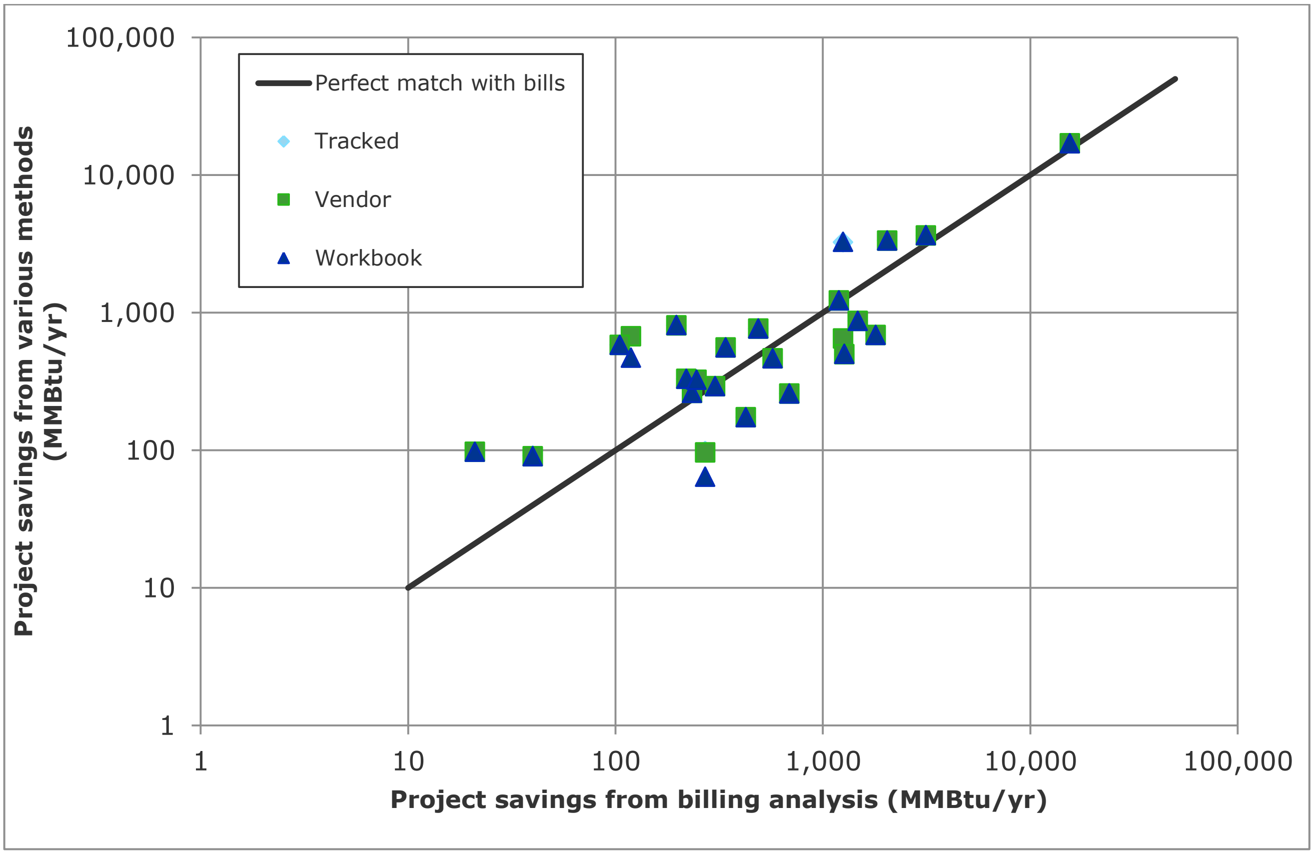
The average savings fraction for the initial population was 11.8% while the average for the final sample was 12.4%. The majority of bins have representative counts, although the final numbers are low relative to the smallest savings bins. The 0 to 5% bin has low final numbers because the majority of sites in that bin were either health care facilities that had multiple projects occurring within the timeframe of the steam trap project, or industrial facilities with production-based usage that didn't screen out of the billing analysis phase.

The >25% bin is conspicuous, considering that this bin is the second largest by count, yet technical reviewers are expected to flag sites with savings fraction of 25% or higher. We did not remove projects at any point in the site screening phase due to projects exceeding an annual energy use threshold. Of the 5 sites that did pass through the screening process, 3 were prescriptive while the other 2 had realized savings below 25% of the annual energy use. Those 2 sites remained in the >25% bin as the identifier was tracked savings rather than realized savings. Only custom projects were used in the parameter calibration analysis.

4.2 Billing analysis results

Results from the initial billing analyses of the 24 sites can be found in Figure 4-3 and Table 4-4. In the figure, the x-axis and y-axis are reversed compared to normal realization rate convention; the x-axis is the billing analysis result and the y-axis shows the 3 tracking results. Both axes use a logarithmic scale in order to include all sites used in the final analysis.

Figure 4-3. Tracking, vendor and workbook savings compared to billing data



This figure compares the ex ante savings from various sources (tracked, vendor, and replicated workbook) with the results of our weather-normalized billing analyses for the 24 custom projects that passed the screening process. While the source savings for most of the facilities match one another, there are a few facilities for which we were unable to match replicated savings with either the tracking or vendor savings. These sites were kept in the sample and all 3 source savings values are used as a means of comparison.

Table 4-4. Realization rate-equivalent values

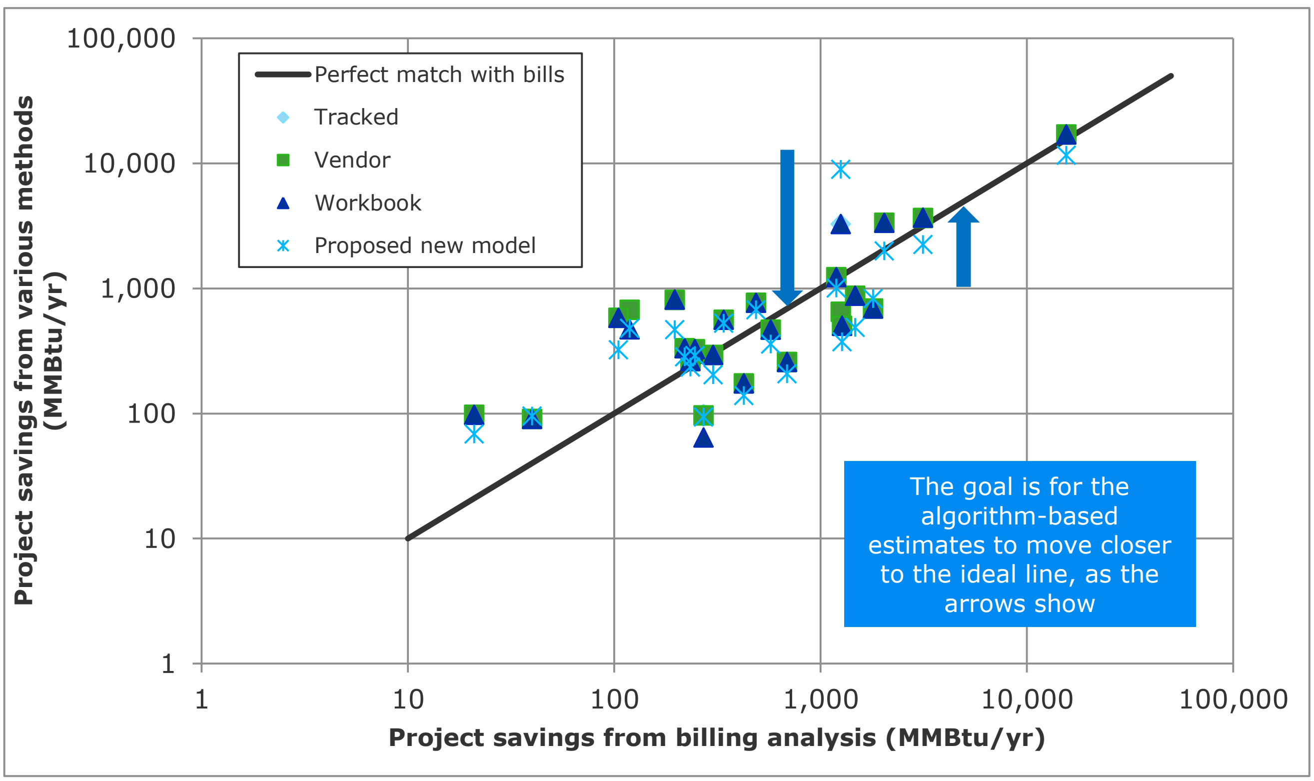
Savings source	Total BA savings/ source savings	Relative precision
Tracked	86.2%	73.1%
Vendor	92.7%	78.3%
Workbook	86.6%	73.6%

The realization rate-equivalent values in Table 4-4 are weighted by savings, as these values are of the most importance. The simple average of the realization rate-equivalent values was calculated to be 107% against tracking savings, indicating that larger projects were more likely than smaller ones to have overestimated savings compared to the bills. The goal of the evaluation approach is to bring the overall savings closer to the billing analysis estimate while reducing the uncertainty (increasing the relative precision) of the estimate.

4.3 Parameter calibration

Through the parameter calibration analysis, we were able to empirically derive the most uncertain variables in the steam trap revised savings equation using the billing analysis results of the 24 custom projects that passed through the screening process. The modeled savings calculated using the recommended equation and empirically derived values can be found in Figure 4-4 and Table 4-5.

Figure 4-4. Modeled savings compared to billing data



As was the case in Figure 4-3, the axes in Figure 4-4 use a logarithmic scale in order to include all sites used in the final analysis. The snowflake data points represent the updated savings values calculated using the revised algorithm and newly calibrated leak factors and condensate return factor. As noted in the chart, for the new algorithm to be an improvement, the points need to generally move closer to the ideal line. The majority of estimates do this.

Table 4-5. Realization rate-equivalent values with proposed savings

Savings source	Total BA savings/ source savings	Relative precision
Tracked	86.2%	73.1%
Vendor	92.7%	78.3%
Workbook	86.6%	73.6%
Proposed new model	98.5%	68.4%

The snowflake plots of Figure 4-4 show an overall realization rate-equivalent value moderately closer to that of any of the initial savings estimates and with a lower level of uncertainty. The net effect is an average savings estimate that is 12.5% less than the tracking savings, a corresponding 12.3% higher realization rate-equivalent value, and a modestly improved variability, as measured by relative precision. The average realization rate-equivalent value of projects used in the parameter calibration analysis is significantly higher, indicating that savings could be underestimated for the "average" site. While this number is relevant to the evaluation results, we are more concerned with the overall program savings compared to the results of each average site.

Resultant values from the parameter calibration analysis are shown in Table 4-6.

Table 4-6. Parameter calibration results

Parameter	Initial value(s)	Revised value
Condensate return	30.0%	36.3%
Low leak factor	11%–26%	26.4%
High leak factor	34%–100%	54.9%

It is important to point out in Table 4-6 that prior to consolidating the leak factors into two values, the PAs did not use consistent leak factors, as their overall algorithms differed in how trap status was assessed.

4.4 Deemed savings estimate

With the custom tool refinement complete, the DNV GL team next determined the participant average values for each of the site specific inputs required for the revised savings equation. The participant average input values were computed using a combination of population- and sample-based estimates and engineering parameters as shown in Table 4-7 . These participant average inputs and engineering parameters were used in the revised savings equation to calculate the participant average savings for the deemed savings.

Table 4-7. Deemed savings calculation parameters

Parameter		Value		Basis
a	Trap orifice area	0.25	in.	Population median
p	Pressure	22	psia	Population median, low pressure systems
p	Pressure	101	psia	Population median, medium-high pressure systems
h_f	Enthalpy, sat. liquid	196	Btu/lb_m	Engineering parameter, at low pressure
h_g	Enthalpy, sat. steam	1,156	Btu/lb_m	Engineering parameter, at low pressure

h_f	Enthalpy, sat. liquid	295	Btu/lb_m	Engineering parameter, at specified med-high pressure
h_g	Enthalpy, sat. steam	1,186	Btu/lb_m	Engineering parameter, at specified med-high pressure
hr/yr	Annual hours trap pressurized	2,802	hr/yr	Sample weighted average
η	Boiler combustion + HX efficiency	80.0	%	Population median & engineering judgment
Cd	Discharge coefficient	70.0	%	Sample weighted average
CR	Condensate return factor	36.3	%	Sample analysis
LF	Leak factor	36.9	%	Sample weighted average from analysis
LPIR	Low pressure trap incidence rate	90.0	%	Population observation
RoF	Rate of failure in bulk installations	50.0	%	Industry standard value

The revised deemed savings estimate is 47% of the ex ante value currently used by program staff as shown in Table 4-8.

Table 4-8. Deemed savings value

Parameter	Current value (MMBtu/yr)	Revised recommended value (MMBtu/yr)
Per trap savings	25.7	12.2

Table 4-9 presents an analysis of the sources of the differences between the current deemed and revised savings value. As a first step, we attempted to replicate the current deemed savings value using the inputs and approach presented in the Massachusetts TRM,[3] which relies on a using a look-up table organized by orifice size and pressure. We were unable to replicate the current deemed value and it appears to overstate the TRM algorithm savings significantly and accounts for most of the difference between the current and revised deemed value. The next step reports the change introduced by the new revised savings equation, accounting for about 4% of the discrepancy between the two values. The calibration step in concert with more accurate mapping of the population has a positive effect on savings.

Table 4-9. Discrepancies between the existing and proposed deemed values

Calculation method	Calculated savings value (MMBtu/yr)	Percent of Discrepancy
TRM specified (existing deemed)	25.7	N/A
TRM using the TRM method	8.5	-127%
Revised savings equation	8.2	-2%
Updated with population-specific and billing analysis calibrated results.	12.2	+29%

As the table illustrates, there is a significant and unexplained deviation between the deemed value noted in the TRM and the value computed using the TRM methods, which accounts for most of change in the new deemed savings value. The difference introduced by the revised savings equation reflecting participant population characteristics actually increases the unit savings, primarily due to an increase in hours of operation.

3 Massachusetts Electric and Gas Energy Efficiency Program Administrators (2012). *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures.;* Page 360, Footnote 721

The 4 prescriptive projects that cleared the survey and billing analysis screening criteria yielded an overall realization rate-equivalent value of 19% and an average realization rate-equivalent value of 35%, which corroborates the results of the updated deemed value. Furthermore, the total tracked savings values for these 4 projects represented 85% of the total weather-normalized pre-project annual usage. Notably, these comparisons are merely suggestive, and too small a sample to be considered representative.

5 CONCLUSIONS AND RECOMMENDATIONS

Our conclusions, recommendations, and considerations are summarized as follows:

5.1 Conclusions

- A review of custom steam trap projects from 2013 and 2014 revealed that PAs were using analogous but ultimately different methodologies and assumptions to calculate savings for each steam trap.
  - We developed a custom savings tool for statewide use.
- Our review of the existing methods found that, in some instances, the savings equation had an unnecessary amount of complexity.
  - We reviewed input parameters from the savings equation on an individual basis, using expert interviews and secondary research. We then chose to keep, modify, add, remove, or omit these input parameters from the revised savings formula. Notable revisions include the modification of the condensate return and leak factors and removal of the repair/replace factor.
  - We have made methodological simplifications to the revised tool in an effort to reduce the chance of field staff misinterpreting the operating status of an individual trap. These simplifications include reducing the number of variables and respective options for selected variables. In particular, the reduction of leak factor options from 4 to 2 non-zero options in a pick list should minimize the opportunity to misinterpret a trap, and yield more consistent savings estimates among the PAs.
- There are 2 input parameter values that are difficult to observe in the field or estimate with engineering judgement, and are often associated with high uncertainty.
  - We empirically derived these parameters (trap operating status leak factors and condensate return factor) using the billing analysis results from a number of custom projects.
- With comparable input variables, the revised savings equation estimates 13% less savings for sites that were used to empirically derive the most uncertain values.
- Adopting the revised custom savings tool statewide will provide an opportunity for PAs to maintain uniformity and consistency in the estimation of steam trap savings across the state, while moderately improving the tool's predictive ability and reducing the variability of the estimates.
- We found that the methodology and assumptions used to generate the existing deemed value are unrepresentative of the typical customer.
  - We used trap-level details from the custom project trap inventory to characterize an average high- and low-pressure trap. We used the average input parameters in the revised savings equation to generate annual per-trap savings, and then blended these based on their frequency of observed occurrence to arrive at a new single value we judged to be representative of the current market.

5.2 Recommendations

- The DNV GL team recommends that all PAs use the revised custom savings tool for custom projects installed in 2017 and going forward.

- The DNV GL team recommends using a single revised deemed savings value of 12.2 MMBtu/year for prescriptive steam trap replacements. This value is lower than the prior value of 25.7 MMBtu/yr. The new revised deemed savings value should be applied retrospectively to 2016 prescriptive projects, and prospectively from 2017 going forward.

5.3 Considerations

- The unique nature of steam trap projects relative to other efficiency measures calls for a more measure-specific approach in record keeping of completed projects. At the program level, an emphasis should be placed on tracking the following data points for custom projects at each individual site:
  - Dates: survey, repair/replacement (i.e., installation), post-installation inspection
  - Trap counts: facility total, inspected total, repair/replace, confirmed repair/replace
  - Savings: tracked, vendor, workbook, confirmed workbook
- We identified two areas for which savings estimates could possibly be improved in later studies:
  3. Conducting further research into leak statuses and pressurized hours of operation, as a function of both specific trap types and their applications. Such refinement would further reduce custom savings variability, but due to the method used in this study, would not be expected to materially change the program-level savings.
  4. Using prescriptive-specific participant firmographic data in modeling deemed savings. Profile data were available and used from the custom participants to estimate the deemed savings value. If prescriptive participants characteristically differ, this can affect the average savings represented by the deemed value.

APPENDIX A. DISCUSSION OF VARIABLES

This section provides an in-depth examination of each input for the custom savings equation, sorted by the status of each variable decided upon by evaluation staff.

Keep

- **Trap pressure (P)** – This is an identifiable property during site visits that has significant variance within a single system, which is critical for calculating savings.
- **Enthalpy of saturated steam and liquid (h_g, h_f) –** This is an extensive property associated with the steam trap pressure and can be determined in a lookup table.
- **Trap type/orifice size (a)** – This is another parameter that can be identified during the site visit (via trap model number) and is critical for calculating savings.
- **Trap venting to atmosphere** – This variable ties into the system condensate return factor (mentioned below) but at the trap level. Most steam systems utilize a condensate return line to recover energy to the boiler and prevent "waste" heat from escaping through the building envelope. The revised savings algorithm should allow for the ability to override this system wide factor if a trap is shown to vent directly to atmosphere.
- **Boiler combustion efficiency (η)** – Current savings calculations use a default value of 80%. Combustion tests from the facilities in which on-site visits were conducted all yielded boiler efficiency values within 5% of this value. Seeing as the range on this value is relatively limited, we have chosen to keep this value as fixed and instead will focus on parameters with much higher variability.

Modify

- **Condensate return or open system (CR)** – The governing equation assumes that steam is discharged through the building envelope into the atmosphere. If a trap discharges into a condensate return system, then some of the energy in that discharge is returned to the boiler and will keep "wasted" heat from passing through the envelope, which will significantly affect savings estimates. If there is no condensate return line, the value is 100% and the factor has no effect on the savings estimate. If there is condensate return, which is typical, the current value employed by one PA's model uses a factor of 30% (discounting savings by 70%). This value is theorized to range anywhere from 30%–100%. The high variability of this value makes it a great candidate for parameter calibration later on.
- **Trap status/leak factor (LF)** – These values are subject to the most uncertainty. Program staff, vendors, and experts alike have all advocated for a number of changes to the leak factors, including the following:
  - Reducing the maximum leak rate to less than 100%
  - Adding a "Not in Service" option
  - Reducing the number of leak status options – The existing custom tool has six different statuses (four non-zeros) including OK, Plugged, Partial Leak, Full Leak, Partial Blow-by, and Full Blow-by. The number of partial leak rate options exceeds the level of resolution practical to expect from field staff and leaves the tool open to the interpretation of the steam trap surveyor. In order to minimize the likelihood of a trap being interpreted incorrectly, and with the endorsement of interviewed

experts, we have chosen to reduce the number of non-zero status options to two. The values for these two leak factors are highly uncertain, impossible to inspect, and significantly affect savings and thus are prime candidates for parameter calibration.

- **Annual hours (hr/yr)** – Based on past experience, experts and stakeholder both recommended retaining pick list of hours associated with specified trap applications rather than direct entry of hours, which would be theoretically more precise. This past lesson learned eliminated confusion regarding field staff entering system rather than trap hours exposed to steam or highly variable estimates that had no sound basis. The values are:
  - Air Handling Unit 1,700 hr/yr
  - Drip Leg 8,760 hr/yr (process), 5,100 hr/yr (heating)
  - Flash Tank 8,760 hr/yr
  - Heat Exchanger 4,380 hr/yr (process), 1,700 hr/yr (heating)
  - Humidifier 1,700 hr/yr
  - Radiator 1,700 hr/yr
  - Reheat Coil 1,700 hr/yr
  - Unit Heater 1,700 hr/yr

Add

- **Total gas bill data** – There is a consensus among the program staff that a cross-check against the annual facility gas usage to anchor savings to reality should be required. At least one PA already does this check formally, and another does it informally. It was agreed that this should be helpful to add a warning flag for high savings to the standardized calculator used by PAs to review vendor applications. The appropriate fraction of savings relative to the annual gas usage that should trigger flagging is likely in the range of 20-30%. We coded a 20% threshold.[4]

Remove

- **Repair/replace factor** – This value was intended to serve as an indirect measure-life discount factor, penalizing the savings for traps that are repaired rather than fully replaced. There is a consensus among the stakeholders and other industry professionals that this should no longer be used.

  There is still a need in the tool to identify how traps will be fixed as that will impact project costs and payback, but linking a discount factor into the savings algorithm will be done away with.[5]

- **Steam system loss factor** – Used by some PAs as a 5% reduction in overall efficiency due to the size and complexity of a steam system. This value will be removed from the equation, as it is not significantly affected by the change in steam use caused by trap repair. There is potential for this value to be looked at in future studies in conjunction with pipe insulation, envelope improvements, or other heat-load related measures, but like combustion efficiency, the variability is minimal so we will not focus on it too intently.

- **Flash steam heat recovery** – Flash steam is created when condensate passes from the pressurized trap into a lower pressure return line. This characteristic discounts trap savings even further than the condensate return factor by recovering flash steam energy by way of a heat recovery device. In order

[4] After discussion with PA stakeholders the group decided not to include the element in the version distributed to vendors.

[5] Also, review of the two PA's savings algorithms found that while one PA was reducing savings by 30% for trap repairs, the other PA was doing the opposite by giving a 30% bonus to traps that were being replaced.

for a facility to have a viable flash steam heat recovery system, there must be sufficient high pressure condensate and there must also be a suitable low pressure application for the recovered flash steam. Of the 9,450 steam traps included in the program trap inventory, none included this feature. Experts corroborated findings that the rate of incidence was very rare. For this reason we will be removing it from the revised custom savings equation.

Omit

- **Condensate back pressure** – Some condensate systems are slightly pressurized relative to atmospheric pressure, either unintentionally (e.g., a low-pressure system with back-ups or highly excessive leaks) or rarely, intentionally (e.g., a high-pressure industrial system that uses the condensate return system as a low-pressure supply). This factor would reduce savings by virtue of less steam leaking since there is a smaller pressure differential between the trap and condensate return line. This value is not used in the existing savings formula and will not be added to the revised formula. Field experts indicated that pressurized condensate is rare and unless part of the design, hard to detect during a survey. [6]
- **Lighting interactivity factor** – The high incidence of lighting projects in past years gives rise to concerns about the interactive heating effects affecting the results of a weather normalized billing analysis used to calculate steam trap savings. During the site interviews, we inquired with facility staff about the installation of other energy-related projects within the time frame of the steam trap project. Of the 24 projects used in the parameter calibration analysis, 8 sites confirmed that they had performed lighting upgrades in recent memory. Five of those sites indicated that the project had occurred over a year's time before or after the steam trap project took place. We investigated the potential impacts of lighting interactivity effects for the three remaining sites using an LPD reduction method. The calculation yielded a total heating penalty value less than 9% of the combined tracking savings for the 3 sites and less than 1% of the total overall savings used in the parameter calibration analysis. The results indicate that this parameter will not have any sort of meaningful effect on their results. This value is not used in the existing savings formula and will not be added to the revised formula.

[6] While difficult to identify, a good indicator of back pressure is an abnormally high failure rate among traps. This would be a candidate for future research.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter, and greener.