Snow-Melting System

Feasibility Study

November 7, 2018

City of Berlin
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Energy · Environment · Enterprise

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1.0 Executive Summary

The City of Berlin has commissioned a study to investigate options for the development of a snow-melting system that would keep streets and sidewalks clear of snow and ice during the winter season. This system would provide a major boost to downtown accessibility and attractiveness during the winter months, and provide an economic driver for redevelopment and streetscape projects currently in the planning stages. This system is part of an overall strategy to revitalize the Berlin downtown, and would leverage local renewable energy resources to spur this revitalization.

Other communities, notably Holland, Michigan, have installed similar systems with success, and have leveraged their systems to promote downtown redevelopment and broader branding and economic development, attracting businesses and tourists. This study evaluates the current snow management practices, available local renewable energy resources, snow-melting system designs, predicted performance, estimated capital costs, life cycle costs, and project qualitative and quantitative benefits.

1.1 Existing Snow Management Practice

Berlin's Public Works Department (PWD) is responsible for managing over sixty miles of paved streets, as well as sidewalks and several municipal parking lots. In the winter, this includes plowing roads and snow removal for priority areas. After the winter season, sand buildup from snow management practices must be removed from the downtown streets and sidewalks.

The overall costs for these activities downtown is estimated at $117,720 per year. Even with this effort and expenditure, there are times when the condition of downtown roads and sidewalks present negative impacts to businesses simply due to the logistics and realities around snow management efforts. Further, there are unavoidable impacts from sand and salt applied throughout the winter, and into the spring until cleanup can be accomplished.

1.2 Snow-Melting System Options Considered

This study evaluated various options for supply of heat from local renewable resources to a snow-melting system, snow-melting system design approaches, and varying operational and economic performance associated with each option.

The ultimate focus of the study is a system with the following key components.

- Snow-melting system below the streets, sidewalks, and municipal parking lots of downtown, covering an initial area of approximately 381,000 ft^2
    - Main system piping runs allowing for increase of snow-melting system square footage to over 600,000 ft^2 in the future
- Interconnection to condenser water supply line to cooling towers at Burgess BioPower, and 1,800 ft^2 pump house for the system pumps, back boilers, and balance of plant systems

- Three variable speed system pumps providing approximately 3,850 gpm at a minimum supply temperature of 85°F (one spare and two operating in parallel), with room to add 2 additional system pumps for future expansion
- Propane backup boiler capacity of 28.5 mmBtu/hr for freeze protection, and the ability to boost system temperatures by 15°F for increased system performance under peak conditions, with room to add additional boiler capacity in the future
- Propane backup generator to ensure power can be maintained at all times for system pumps

The study identified that a system designed around the condenser water from the Burgess BioPower plant would provide satisfactory performance for snow-melting in downtown Berlin. Further, it was identified that the Burgess BioPower facility has far more waste heat available than is required for the downtown snow-melting system. This waste heat is currently being exhausted to the atmosphere, and is a local resource from renewable energy that can be captured for local benefit. The initial proposed scope of approximately 381,000 ft^2 would only use about 8% of the waste heat available from the power plant. Thus, there is substantially more heat available that would allow for future expansion of a snow-melting system beyond the initial scope considered.

1.3 Conclusions and Additional Considerations

This study evaluated various options for supply of heat from local renewable resources to a snow-melting system, snow-melting system design approaches, and varying operational and economic performance associated with each option. The ultimate focus of the study is a system with key components listed above in Section 1.2. Such a system has the ability to keep the downtown streets and sidewalks free from snow during the winter season. The system would provide a marked improvement over current snow management practices in terms of time to clear and remove snow from streets and sidewalks. This is expected to promote activity in the downtown area, vastly improve walking conditions, extend the street and sidewalk life, and reduce manual snow clearing of building fronts and custodial costs from clean-up of salt, sand, and snow tracking inside buildings.

A snow-melting system as described and serving the initial scope of approximately 381,000 ft^2 would have a capital cost of approximately $8.3 Million. The heat from this system is essentially free since it is residual heat that is being exhausted from the power plant. This provides major benefits from a sustainability and annual operation and maintenance cost perspective. It is estimated that the cost to operate the system will be on the order of $70,000 annually. It is anticipated that this project would be completed in concert with an overall redevelopment of downtown road and sidewalk infrastructure, and the construction costs identified above are only for the increased cost to add a snow-melting system to a downtown streetscape project’s scope.

The snow-melting system will provide a host of benefits to the City of Berlin and project stakeholders, including the following key items:

- Approximately $110,000 in annual snow management costs
- Approximately $500,000 in annual thermal REC revenue based on current REC values
- Reduction of approximately 9 million gallons per year of makeup water for the cooling tower at the Burgess BioPower plant
- Reduction of approximately 75 metric tonnes of annual CO_2 equivalent greenhouse gas emissions, and avoidance of approximately 6,700 metric tons of CO2 equivalent each year by operating with the renewable energy source instead of #2 fuel oil
- Improved downtown safety for residents, business owners, customers, and tourists
- Improved cleanliness of downtown without waiting until spring cleanup of sand and salt
- Improved life of downtown road and sidewalk infrastructure investments
- A draw to the downtown which will support downtown businesses, and improved conditions for consumers during winter months, which will improve business traffic
- A unique marketing feature for the City of Berlin, and use of a local renewable resource to drive economic development and downtown revitalization

The following considerations are recommended as the City of Berlin pursues a snow-melting system for its downtown:

- Consideration should be given to the delineation of responsibilities for the system between the City of Berlin and Burgess BioPower. The pump house will likely be sited adjacent to the power plant, and would directly tie-in to their condenser system. For these reasons, Burgess may be better suited to operate the pump house equipment.
- The extent of the allowance for future expansion. The system as evaluated in this study has been setup to allow for expansion from approximately 381,000 ft^2 to approximately 600,000 ft^2. Consideration should be given to the total scope of what future expansions may or may not entail, and this will help with final design.
    - The City should discuss what arrangement would be offered to private landowners for any expansion of the system. Holland shares in the cost of expansion with private landowners for the snow-melting portion of the expansion.
- Collaboration with Burgess BioPower, the City, and downtown stakeholders will be key to implementation of the system. There are a number of funding opportunities and vehicles available to assist with implementing this system, and some of these opportunities require varying ownership structures.
- The City could discuss whether it would consider charging a use or operations and maintenance fee on a square foot basis to help recover the cost of the system. Survey responses from business owners were generally non-committal on whether they would be willing to pay a service fee. It seemed that those who responded may be willing to do so, depending on the fee and level of value they ultimately see from the system.
    - Survey of Holland Michigan business owners were nothing but positive, and there were no complaints noted about their use fee, which is $0.45 / ft^2 / yr for

the sidewalk areas in front of landowner properties, and any private areas that are covered.

- This type of project is a very forward thinking project with regard to maximizing the overall efficiency of power generation in the US, and should be recognized for this attribute and as a model for future power plant development. The heat exhausted from power generation plants provides a major opportunity for development of sustainable energy systems for buildings, snow-melting systems, and other projects which can turn wasted energy into a local resource to provide benefit.
- Any new buildings constructed downtown could consider installing low-temperature hydronic heating systems. This approach to hydronic heating design is becoming best practice, as it allows for the use of condensing boilers and maximum building efficiency. Additionally, it provides the opportunity for any new building to connect to the snow-melting system and use high efficiency water-to-water heat pumps for building space heating. Converting existing heating systems in existing buildings to hydronic heating is typically not economically feasible unless a building is undergoing a substantial renovation.

2.0 Snow-Melting Feasibility Scope and Purpose

The City of Berlin has commissioned a study to investigate options for the development of a snow-melting system that would keep streets and sidewalks clear of snow and ice during the winter season. The goal of this system is to provide a major boost to downtown accessibility and attractiveness during the winter months, and to provide an economic driver for redevelopment and streetscape projects currently in the planning stages. This system is part of an overall strategy to revitalize the Berlin downtown, and would leverage local renewable energy resources to spur this revitalization.

Other communities, most notably Holland, Michigan, have installed similar systems with success, and have leveraged their systems to promote downtown redevelopment and broader branding and economic development, attracting businesses and tourists. This study evaluates the current snow management practices, available local renewable energy resources, snow-melting system designs, predicted performance, estimated capital costs, life cycle costs, and project qualitative and quantitative benefits.

3.0 Snow Management Practice

3.1 Current Snow Management Practice

Berlin's Public Works Department (PWD) is responsible for managing over sixty miles of paved streets, as well as sidewalks and several municipal parking lots. In the winter this includes two distinct phases of operations; (1) plowing roads and (2) subsequent snow removal for priority areas. In addition, after the winter season, sand buildup from snow management practices must be removed from the downtown streets and sidewalks.

Berlin provided cost data for its snow plowing, removal, and clean-up practices, based on historical equipment and material use and labor costs. A snow-melting system has the potential to eliminate the need for these snow management practices in the downtown area, reducing operating costs and allowing snow management efforts to be focused on other prioritized areas.

3.1.1 Snow Plowing

The PWD plows over sixty miles of paved streets and approximately 16 miles of city sidewalks. Snow plowing operation generally begins after 3 to 5" of snow has accumulated, though ultimately the decision to begin plowing is left to the discretion of the PWD supervisor during regular business hours and is initiated by the Police Dept. during non-business hours. Several factors may be considered by responsible personnel. Snow clearing is continued until the end of the snow event.

The PWD employs several front end loaders, graders, and sidewalk tractors equipped with plows to clear roads, as well as several salt trucks for spreading salt and sand. Plowing vehicles operate on set plowing routes and will typically plow streets for the duration of a snow event. Plowing in the downtown area will typically be avoided until 5:00 PM, if a snow event occurs during the day, in order to avoid vehicles that park along the street. Snow banks are typically pushed to one side of the road, blocking some parking spaces in the downtown area until snow removal can be completed.

Estimated snow plowing costs for the downtown area are presented in Table 1. Estimated costs are based on a typical snow event, requiring 10 hours of plowing roads and sidewalks, and consuming 200 lbs of salt and 400 lbs of sand city-wide. Snow plowing operations, when falling outside of standard operating hours of 7:00 AM to 3:00 PM, incur overtime costs for the work force. The downtown area represents approximately 3.6% percent of the total surface area cleared, and costs for clearing the downtown area are estimated proportionately to the total cost of clearing during a snow event. The annual costs are based on 10 snow events, which is typical for a given year.

Table 1: Downtown Snow Plowing Costs

Description[1]	Cost per Snow Event[2]	Annual Cost (10 Snow Events)
Mobile Equipment: (8) loaders, (2) graders, (2) sidewalk tractors, (1) salt truck	$200	$2,000
Materials: 7 tons salt, 14 tons sand	$665	$6,650
Labor: (15) men	$235	$2,350
Administrative Costs (15% of subtotal)	$165	$1,650
TOTAL	***$1,264***	***$12,650***

Note 1: Equipment costs include fuel, maintenance, and hourly depreciation costs of operation.
Note 2: Costs for clearing the downtown area are estimated as a percentage of the overall snow clearing effort based on the surface area cleared.

3.1.2 Snow Removal

The PWD focuses its snow removal efforts on the downtown area encompassed by Main Street and Pleasant Street. After snow plowing, the PWD supervisor determines whether there is enough snow to warrant removal. Snow removal always occurs at night, typically between the hours of 12:00 AM and 7:00 AM, when traffic is low. Ordinances prevent vehicles from parking along the downtown streets during these hours. Snow removal will usually occur on the night following a snow event, however, if a snow event occurs late in the day or overnight, snow removal may take place on the following night. This occasionally creates a day in which snow is piled up downtown before and before being removed the following night.

For downtown snow removal, the PWD typically employs a loader, snow blower, sidewalk tractors, a bulldozer, salt truck, and several dump trucks. Sidewalk tractors are used to push snow away from sidewalks and into the street. A snow blower and loader are used to load snow into dump trucks, where they are taken to designated snow dump area. A bulldozer is used to manage the snow dump site.

Estimated costs for snow removal efforts downtown are presented in Table 2. Estimated costs are based on the typical equipment, materials, and labor force used. Annual snow removal costs are based on 10 snow events requiring snow removal.

Table 2: Downtown Snow Removal Costs

Description	Cost per Snow Event	Annual Cost (10 Snow Events)
Mobile Equipment: (1) loader, (1) snow-blower, (2) sidewalk tractors, (1) bulldozer, (10) dump trucks, (1) salt truck	$4,399	$43,990
Materials: 6 tons salt, 12 tons sand	$554	$5,540
Labor: (19) men	$3,809	$38,090
Administrative Costs (15% of subtotal)	$1,314	$13,140
TOTAL	***$10,076***	***$100,760***

3.1.3 Spring Clean-Up

Sand build-up from winter season snow management practices must be removed during the spring. This involves employing a sweeper truck and sidewalk tractor or pickup truck to collect and remove sand. The sweeper truck sweeps the downtown area twice per week for four weeks for the spring clean-up.

Estimated costs for spring clean-up are presented in Table 3. Estimated costs are based on the typical equipment and labor force used.

Table 3: Spring Clean-up Costs

Description	Cost for Spring Clean-up
Mobile Equipment: (1) sweeper truck, (1) sidewalk tractors, (1) truck	$2,000
Labor: (3) men	$1,750
Administrative Costs (15% of subtotal)	$560
TOTAL	***$4,310***

3.2 Additional Snow Removal Opportunity Costs

Snow removal is limited to the early A.M. hours when there is no traffic, otherwise traffic would obstruct the effort. During a significant snow event, the snow removal crew will work from 12:00 AM to 7:00 AM. The downtown streets and sidewalks are the first priority. If the crew is able to complete the downtown area, the second priority is the City schools, particularly bus routes and student pedestrian paths. Beyond these priorities are truck routes, other community facilities, and additional city streets.

Currently cost and man-power considerations limit snow plowing and removal efforts to only certain snowfall events, and downtown use considerations limit when snow removal can be completed. If the City had more funds to dedicate to these efforts the plowing and snow removal efforts would be more frequent. A snow-melting system would provide the following improvements for the downtown area with regard to opportunity cost:

- Currently, plowing does not occur for every snowfall. The snow-melting system will address all snowfall events, as opposed to those over 3” or more.
- The snow-melting system will all but negate the need for the current snow removal work by the Public Works Dept. in the downtown area. This will allow the workforce to focus on the other snow removal priorities with snow removal around schools being the next priority. The snow-melting system will free up parking spaces and providing safe vehicle and pedestrian access to downtown more quickly than current removal operations. Downtown occupancy and business activity dictates that snow removal take place over night (between 12:00 PM and 7:00 AM), and thus, the time to removal depends on when a snowfall occurs. Late night/early morning snow storm snow banks are often not removed from the downtown until the next night leaving business patrons to negotiate the snow banks for an entire business day before they are removed. Snowstorms in and around major shopping days have the biggest negative impact.
- PWD staff that form the snow removal crew also have other, everyday duties that must be put on hold while attending a snow event. A snow-melting system would allow PWD staff to tend to their everyday duties.

3.3 GHG Emissions

The City of Berlin uses over 7,500 gallons of diesel fuel on average each year in its mobile equipment during snow management efforts in the downtown area. Combustion of this fuel results in the direct emission of 78 metric tons of CO_2 equivalent each year, which could be offset by a snow-melting system. Factors for CO_2 equivalent were obtained from the EPA and include CO_2, as well as CH_4 and N_2O adjusted for their 100-year global warming potentials relative to CO_2.

3.4 Salt and Sand Impacts

Berlin uses salt and sand for de-icing streets and sidewalks, and to provide better traction for both vehicles and pedestrians. The City uses up to 2,000 tons of salt and 4,000 tons of sand each year, of which over 5% is applied to the downtown area. While salt and sand improve safety on streets and sidewalks during wintery conditions, they can have negative impacts on health and the environment.

Contaminates from road salt dissolve and are carried away by runoff, where they enter groundwater or surface water. Sodium and chloride can seep into water supply wells through groundwater. While not toxic, salt can affect the taste of water, and is costly to remove. Sodium and chlorides can be particularly harmful to aquatic life and vegetation. Salt is also very corrosive to metals, causing both cosmetic and structural damage to vehicles, reinforced concrete, etc.

Sand use on roads can significantly increase airborne particulate matter, especially PM_{10} as vehicles grind the sand into a fine dust and kick it up into the air, which deteriorates air quality. Particulate matter causes health hazards for those with respiratory problems like asthma. This is compounded in the downtown area where there is increased pedestrian traffic. Sand can also clog storm water piping and catch basins as runoff carries it away before it can be swept up. Sand also negatively impacts the environment as it can increase turbidity of water or settle out on the stream beds, both of which hurt aquatic life.

Another key aspect is the impact on businesses that rely on pedestrian traffic in the winter. The salt and sand tracked into shops, businesses, and dining establishments necessitate frequent cleaning by staff to ensure clean and safe conditions, and to minimize the impacts to floors and equipment from abrasive and corrosive sand and salt. All of these impacts can be significantly reduced by a snow-melting system.

4.0 Snow-Melting System and Heat Supply

This study evaluated various options for supply of heat from local renewable resources to a snow-melting system, snow-melting system design approaches, and varying operational and economic performance associated with each option. The ultimate focus of the study is a system with the following key components. This section of the report provides a description of this system as outlined, the various options considered, and key aspects of the options that led to the identification of the system as outlined.

Key Components of System

- Snow-melting system below the streets, sidewalks, and municipal parking lots of downtown, covering an initial area of approximately 381,000 ft^2
    - Main system piping runs allowing for increase of snow-melting system square footage to over 600,000 ft^2 in the future
- Interconnection to condenser water supply line to cooling towers at Burgess BioPower, and 1,800 ft^2 pump house for the system pumps, back boilers, and balance of plant systems
- Three variable speed system pumps providing approximately 3,850 gpm at a minimum supply temperature of 85°F (one spare and two operating in parallel), with room to add 2 additional system pumps for future expansion
- Propane backup boiler capacity of 28.5 mmBtu/hr for freeze protection, and the ability to boost system temperatures by 15°F for increased system performance under peak conditions, with room to add additional boiler capacity in the future
- Propane backup generator to ensure power can be maintained at all times for system pumps

4.1 Snow-Melting System

4.1.1 System Type and Description

Hydronic snow-melting systems circulate warm water through tubing embedded in the sidewalk and street slabs to melt surface snow and ice. There are a multitude of options for how a snow-melting system could be designed, with key considerations including: heat source and cost, transfer fluid, potential operating temperatures, approach to system controls, and desired performance of the system. Two options were considered as the potential local renewable heat source to supply the system: a standalone wood boiler plant, and waste heat from condenser system at the existing Burgess BioPower facility. The existing Burgess BioPower facility was selected as the heat source, and this selection has the effect of driving a number of the remaining system design considerations. Section 4.4 provides an overview of the stand-alone wood boiler plant option.

As stated, the warm water from the condenser system at Burgess BioPower will be circulated to the downtown area. Water will be circulated across the Androscoggin river to the north end of the downtown area by 24 inch HDPE piping mains. HDPE piping will split into two mains, each with a supply and return line, traveling underneath Main Street and Pleasant Street to serve multiple snow-melting zones. The HDPE piping assumed is PE4710 DR-11 piping, which has rated pressure of approximately 168 psig at 100°F. The system design velocities have been kept low to minimize pressure loss and reduce pumping energy required. Surge pressure is not anticipated to impact the maximum operating pressure allowable.

For each zone, a 3 inch HDPE supply and return line will tee off of the mains to valve-less HDPE manifolds. Flow to the manifolds themselves will be set using a balancing valve installed at each return manifold. Manifolds will be installed underneath the sidewalks, with the shutoff and balancing valves accessible from a valve box. Because the manifold outlets are valve-less, they must be balanced by using similar loop lengths from each outlet. The loop tubing is made of a crosslinked polyethylene (PEX) material, 1 inch in diameter, and is flexible enough to bend into different layout patterns. The standard PEX tubing is has a pressure rating of 160 psig at 73.4°F, and that drops to 100 psig at 180°F. Typical zone layouts are provided in Appendix A.

For sidewalk construction, PEX tubing will be installed in a compactable layer of sand, with pavers installed over the sand layer. The base layer is compacted prior to installing the tubing. Wire mesh is placed over the compacted base layer and tubing laid out and fixed to the wire mesh. After installation of the tubing, a compactable sand bed is applied to provide 2 inches of cover above the tubing, and pavers installed over top. A cross-sectional diagram of sidewalk construction is presented in Figure 1.

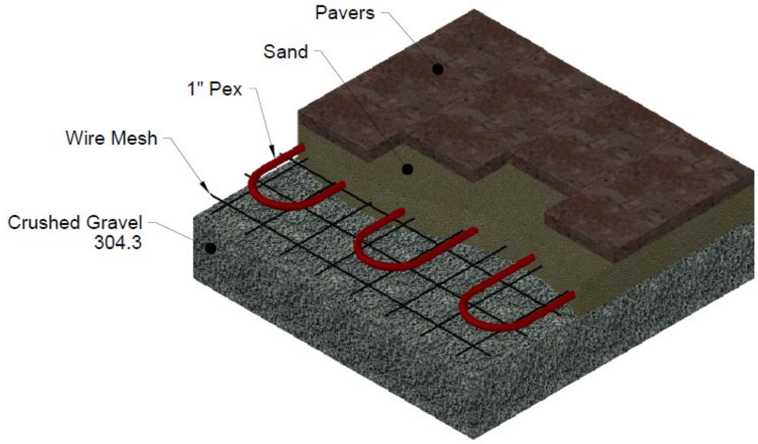


Figure 1: Sidewalk Cross-sectional Diagram

For street and parking lot construction, PEX tubing will be installed in a compactable layer of sand or stone dust, and asphalt courses installed over the sand/stone dust layer. As with the sidewalk construction, base layers should be compacted before placement of the tubing. It is important during installation of the asphalt courses that water be circulated through the tubing to protect the PEX tubing. A cross-sectional diagram of construction is presented in Figure 2. Detailed cross sections for sidewalk and street and parking lot construction are provided in Appendix A.

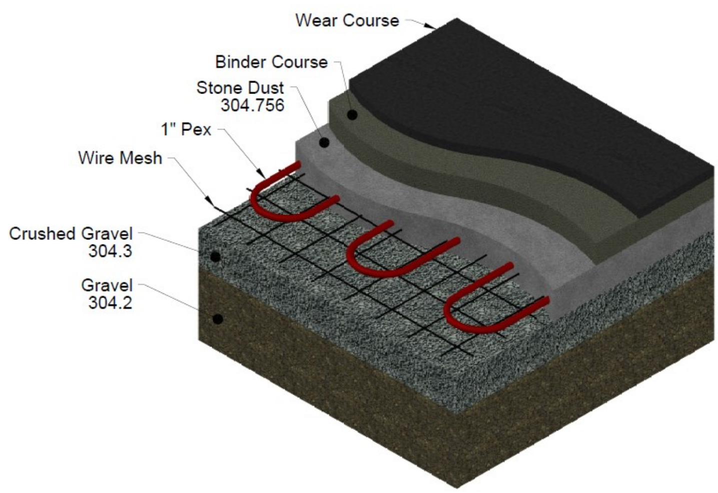


Figure 2: Street / Parking Lot Cross-sectional Diagram

4.1.2 Areas Served by Snow-Melting System

The snow-melting system will serve the streets and sidewalks in the downtown area, from the intersection of Main Street and Pleasant Street with Exchange Street north to the point at which Main Street and Pleasant Street intersect. This will include the intersecting streets in between Main and Pleasant Streets: Exchange Street, Green Street, Mechanic Street, Mason Street, and High Street. Three municipal parking lots are also included in the scope of this snow-melting system: the lot between Pleasant Street and Cole Street near Mechanic Street and the additional lot across Cole Street, as well as the lot between Pleasant Street and Cole Street across from the Rite Aid. A site map showing the areas served by the snow-melting system is provided in Appendix A. The total area covered by the system is approximately 381,000 square feet. A summary of the areas by surface type is presented in Table 4. Streets and parking lots are assumed to have similar construction, with the main anticipated difference being thicknesses in paving or base layers.

Table 4: Summary of Snow-Melting System Surface Area

Surface Type	Surface Area (ft^2)
Sidewalks	88,000
Streets	214,000
Parking Lots	79,000
Total	***381,000***

4.2 SYSTEM PERFORMANCE

4.2.1 Factors Affecting Performance

System performance is driven by system design and construction, and outdoor weather conditions. Design parameters such as tube sizing, spacing, available water temperature, and sidewalk or road construction will all affect how much heat can be delivered to the surface. Outdoor conditions like air temperature and wind speed, drive how quickly heat is removed from the surface.

System Design Factors

Common tube spacing for snow-melting systems are 6, 9, or 12 inch on center, though any spacing may be chosen. Tube spacing at 12 inches and above can create uneven surface heating, leaving strips of snow on the surface between tubes. Spacing is often a trade-off between additional heat flux to the surface and additional cost in added length of tube, more zones. A comparison of 6 and 9 inch tube spacing to 12 inches is presented in Table 5.

Table 5: Tube Spacing

Tube Spacing	Additional Heat Flux	Additional Tube Length Needed
12”	-	-
9”	5 - 10%	33%
6”	10 - 20%	100%

Tube sizing does not significantly affect system performance in terms of heat flux or melting capability. However, larger tube sizing does allow for longer lengths of tubing per zone, allowing each zone to cover more area. Given the potential scale of this project, it is recommended that a tube size of at least 1 inch be used to minimize the number of zones.

Road or sidewalk construction makes perhaps the most significant impact on snow-melting performance. Thermal conductivity of the materials chosen and depth of bury of the tubing determine the resistance to heat from the circulating water reaching the surface.

Water temperature available for the snow-melting system is another significant factor in overall system performance. Higher water temperatures will generate more heat to the surface, providing better performance. Return temperatures in the Burgess condenser loop are relatively low compared to many snow-melting systems, and thus, maximizing the available temperature to the system is critical to overall performance.

The design temperature drop — the difference between entering water temperature and leaving water temperature — through the snow-melting loop can also affect overall performance. Larger temperature drops equate to a lower average loop temperature, and therefore an overall lower heat output. This is less of a concern if the entering water temperature is high and tightly controlled, however, in this case the system is largely limited by the condenser loop temperature. A temperature drop of 25°F is common for hydronic snow-melting systems, however, a lower temperature drop, 15°F, would increase average circulating fluid temperature. The drawback is that a higher flow rate is required with a lower temperature drop. This requires a larger pump and uses more pumping energy.

It is common to install insulation underneath snow-melting systems to reduce heat loss and improve system response. However, this case is unique in that heat from the available source (Burgess) has no direct cost and is practically unlimited. There is limited benefit in reducing heat loss. In common snow-melting systems, insulation also allows the system to react more quickly once water begins to circulate, as it prevents the thermal mass of the surrounding earth from absorbing heat from the system. However, in this case it is recommended that water constantly be circulated through the system during the entire winter season, limiting any warm up period required. For these reasons, it is assumed that insulation would not be installed underneath the snow-melting system since it would add significant cost. Since insulation is not assumed, losses through the ground underneath the system need to be considered when selecting the water flow rates.

Outdoor Conditions

Outdoor conditions significantly affect the heat flux through the surface, and will affect the surface temperature and snow-melting performance. In addition to the heat required to melt snow, heat is lost through the surface due to convection losses, radiant losses, and evaporation of snowmelt. Convection is driven by outdoor air temperature and wind speed. Lower air temperatures and higher wind speeds pull heat from the surface at a higher rate. Radiant losses are driven by the difference between the relatively warm sidewalk or street surface, and the colder surrounding environment. A small portion of the snowmelt runoff will also evaporate from the surface, pulling heat from the slab.

If snow fall exceeds the rate in which the system can melt it, then snow accumulates on the surface. This has the effect of insulating the surface from convection, radiation, and evaporation losses, and allows the snow-melting system to melt accumulated snow at a faster rate. A table of snow melting rates for sidewalk is presented in Table 6. This table shows both snow-free and snow-covered surface conditions.

Table 6: Snow Melting Rate of Sidewalk at Varying Outdoor Conditions

Snow Melting Rate (in/hr)								
Wind Speed	**Surface Condition**	**Outdoor Air Temperature**						
		0°F	**5°F**	**10°F**	**15°F**	**20°F**	**25°F**	**30°F**
0	Snow-free	0.8	0.9	0.9	1.0	1.1	1.1	1.2
	Snow-covered	1.0	1.1	1.1	1.2	1.2	1.2	1.2
5	Snow-free	0.2	0.3	0.5	0.6	0.7	0.9	1.0
	Snow-covered	1.1	1.1	1.1	1.2	1.2	1.2	1.2
10	Snow-free	0.0	0.0	0.0	0.3	0.5	0.7	0.9
	Snow-covered	1.0	1.1	1.1	1.2	1.2	1.2	1.2

Note: Melting rate is based on a tube spacing of 9 inches on center and an entering water temperature of 85°F with a temperature drop of 15°F.

Operating Sequence

Snow-melting systems are usually designed to provide heat to the surface only when there is a need for snow-melting. During periods when there is no snow fall, the slab is allowed to stay cold or at a minimum set-back temperature to conserve heating costs. This often results in a lag time in which the slab must be brought up to temperature before snow-melting can begin. With the potential to utilize waste heat from Burgess, there would be no direct heating cost (i.e. fuel expense), and therefore the system could be operated continuously during the winter season. For most of the winter season, this would provide some level of heat stored in the slab, causing snow to melt immediately upon contact with the ground. During extended periods of very cold weather (outdoor temperatures below 0°F), the surface temperature of the street or sidewalk may drop below 32°F. In these conditions, snow melting would not begin until a small layer of snow has accumulated on the surface. To illustrate this concept, a temperature gradient through a cross-section of the typical street construction is shown in Figure 3. At outdoor weather conditions of 15°F and 5 mph wind speeds, the slab stores enough heat to melt 0.5 inches of snow. Conversely, at 2°F and 5 mph wind speeds, this same amount of heat is required to warm the slab before snow-melting begins.

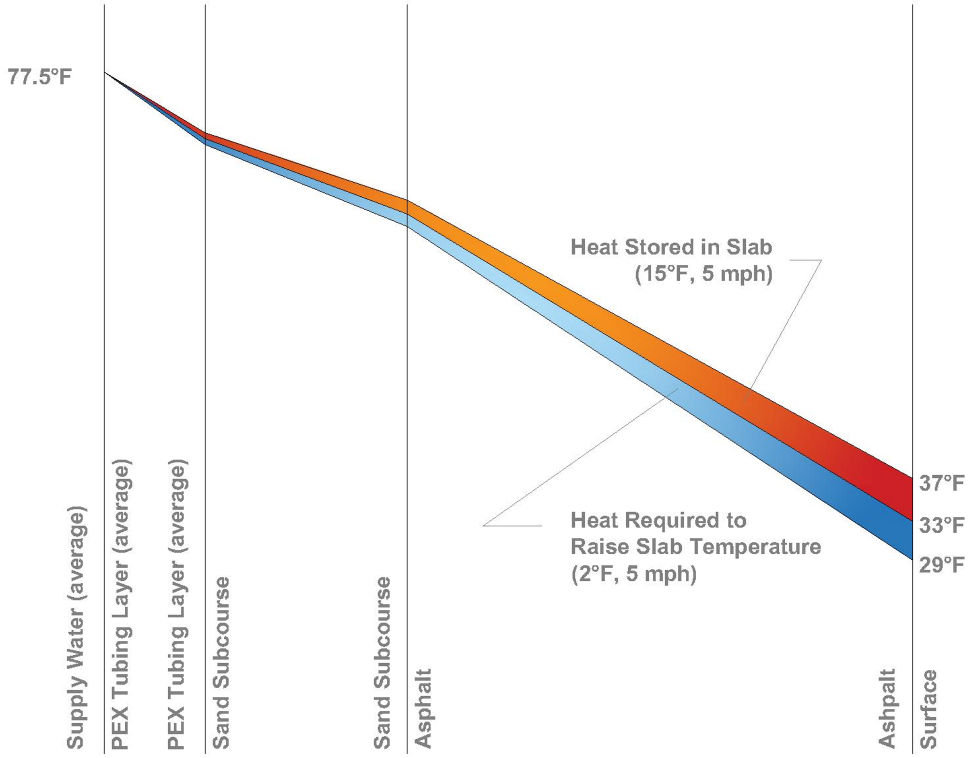


Figure 3: Temperature Gradient of Typical Street Cross-Section

Note: During snow-melting, the surface temperature of the slab is slightly above 32°F.

With a constant water flow rate, fixed speed pumps could be utilized to serve the snow-melting system. However, it is recommended that consideration be given to utilizing pumps with variable frequency drives (VFDs), which would reduce pump speed to achieve the desired flow rate. This would reduce the pumping energy costs. VFDs could also be operated to adjust flow based on a desired temperature drop in the system, which may optimize pumping energy. Note, however, that this style of operating would be based on the blended return water temperature from all zones. The zones themselves may see different heating demands based on factors such as shading, cross-section design (e.g. sidewalk vs. street), uneven snow accumulation, runoff, etc. Additional care would need to be given to ensure that this operation would not leave some zones underserved.

4.2.2 Predicted Performance

System performance was analyzed through modeling based on ASHRAE guidelines. ASHRAE establishes a steady state energy balance at the snow-melting surface based on atmospheric conditions. This heat balance is defined by the following equation for heat flux through the surface, q_0:

$$q_0 = q_s + q_m + A_r(q_h + q_e)$$

The sensible heat flux, q_s, is the heat flux required to raise the temperature of falling snow to the melting temperature. The latent heat flux, q_m, is the heat flux required to melt the snow. The heat flux, q_h, includes both convective heat losses to the ambient air and radiative losses to the surroundings. The evaporative heat flux, q_e, takes into account heat lost from the surface through evaporation of melted snow. The snow-free area ratio, A_r, represents the percentage of the slab surface that is free of snow. When there is snow-cover on the surface, snow insulates the surface from convective, radiative, and evaporative losses.

The amount of heat that the snow-melting system can deliver to the surface is also dependent upon the thermal resistance of the slab. Sidewalk construction uses 2-inch concrete pavers in addition to the sub-layer of sand. The pavers provide less thermal resistance than the 5 inches of asphalt used in street and parking lot paving. This will result in higher heat flux through the surface, and therefore better performance from the snow-melting system in sidewalks as compared to the street.

Predictive performance of the system was evaluated using historical weather data provided by the NOAA's Global Historical Climatology Network for Berlin, NH. Data obtained included historical daily temperatures, precipitation, and snow records for the previous 10 years. A summary of this weather data is presented in Table 7. Historical daily snowfall data for this time period is provided in Appendix B. Over the previous ten years, snow events with snowfall greater than 3 inches, enough to warrant snow removal, occurred an average of 11 times per year. The lowest hourly temperature recorded occurred on January 18, 2013 and was -33°F. The longest sustained stretch of cold weather during this period lasted three days from January 16 – 18, 2009, in which average daily temperatures remained well below zero, and lows reached -25°F or below each day. These days were not accompanied by snowfall, but must be considered for freeze protection in the event that Burgess is not operating.

Table 7: Berlin, NH Weather Data Summary, 2008 – 2017

Year	HDDs	Min. Recorded Hourly Temperature (°F)	Snowfall (ft)	Peak Daily Snowfall (in)	Days with Snowfall > 3"
2008	8,288	-18	7.3	22	16
2009	8,697	-26	7.3	14	10
2010	7,777	-10	8.9	12	14
2011	7,621	-18	5.9	13	13
2012	6,873	-13	6.7	8	11
2013	8,067	-33	7.1	14	9
2014	8,716	-18	6.6	12	8
2015	8,633	-22	4.5	12	12
2016	7,911	-17	10.6	8	8
2017	8,210	-19	9.6	19	15
Average	***8,079***	***-19***	***7.5***	***13.4***	***11.6***

Note: Data obtained from the NOAA's Global Historical Climatology Network for Berlin, NH (Station ID: USC00270690).

Intense snow events may have snowfall rates reaching up to 3 inches per hour at peak intensity, however, these snowfall rates are short-lived and average rates for the duration of the event are typically less than 1.0 inch per hour. For most snow events, average snowfall rates are less than 0.5 inches per hour. The NOAA's National Operational Hydrologic Remote Sensing Center provides comprehensive snow observations, analyses, and data sets. Hourly snowfall data for numerous snow events for Berlin were pulled from these data sets for evaluation, and two are displayed here. The first shows an intense snow event, with 19 inches of snowfall, which occurred on March 15, 2017. This was the largest snowfall event since 2008. Snowfall rates exceeded 2 inches per hour at peak intensity, but averaged less than 1 inch per hour for the duration of the event.

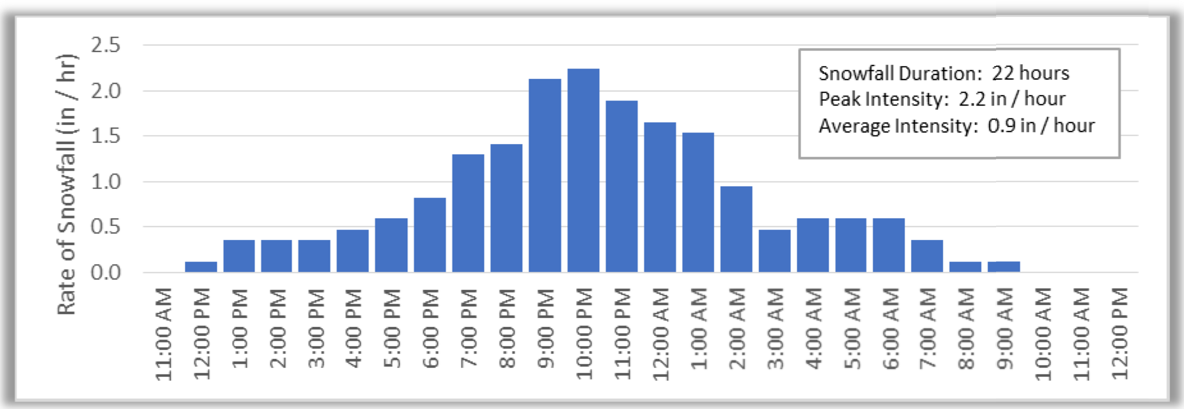


Figure 4: Intense Snow Event, March 15, 2017, 19" Snowfall

The second data set shows a moderate snow event with 8 inches of snowfall, which occurred on December 30, 2016. Peak intensity for this snow event was 0.9 inches per hour, and the average snowfall rate was 0.4 inches per hour.

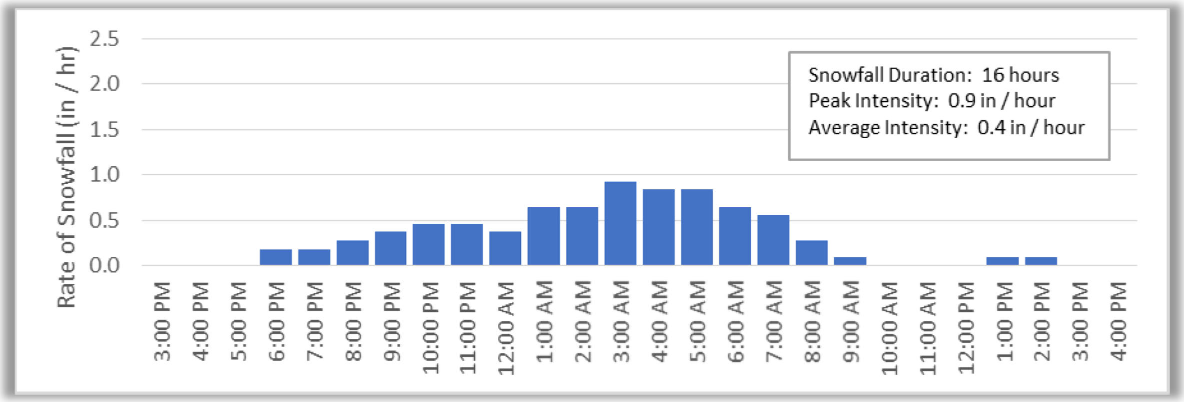


Figure 5: Moderate Snow Event, December 30, 2016, 8" Snowfall

Performance of the snow-melting system for sidewalk and street/parking lot zones is assessed based on the time to melt snow from the end of a snow event. Predicted performance versus historical snowfall and outdoor conditions for sidewalk and street construction are presented in Figure 6 and Figure 7. Average snowfall rates for snow events were modeled depending on total snowfall for the event, with rates ranging from 0.4 inches per hour for snow events less than 5" of total snowfall, up to 1.0 inches per hour for snow events above 15 inches of total snowfall. Predicted performance for the snow-melting system are also provided in Appendix B.

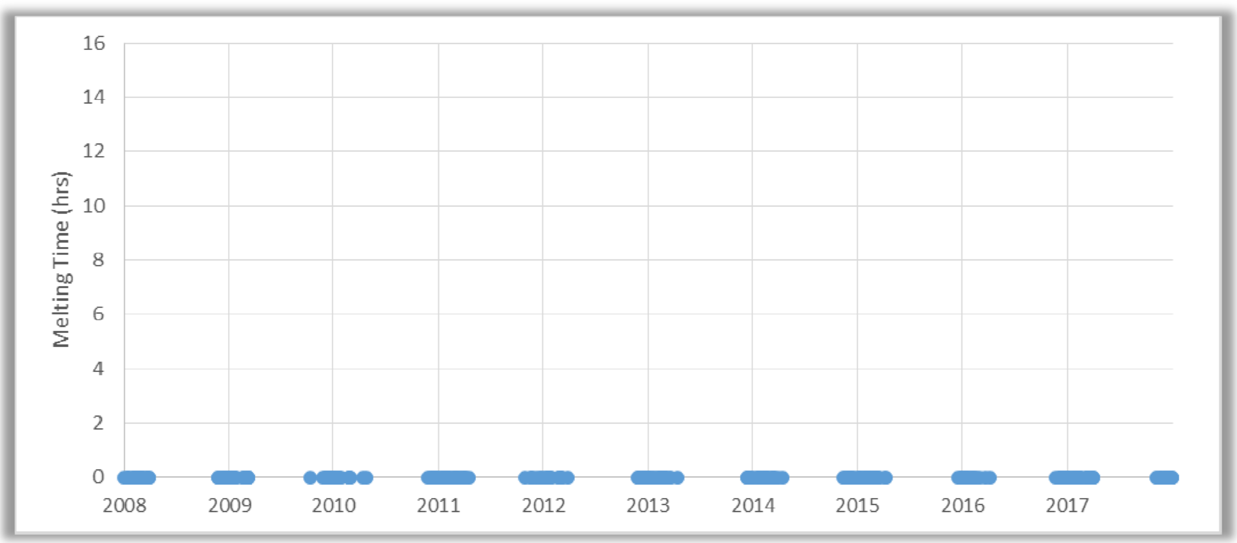


Figure 6: Sidewalk Predicted Performance vs. Historical Snow Events

Note: Note: Performance is based on an average snowfall rates and outdoor temperatures and 10 mph winds. Sidewalk construction consists of 2" of cover with sand/fill above PEX tubing and 2" of concrete pavers.

Sidewalk melting time for all events is shown as zero, as it is not expected that snow would accumulate for any significant amount of time when examining the historical snowfall events of the previous ten years. This is supported by anecdotal reports from the system in Holland, MI, in which it was reported that snow doesn't accumulate on their surfaces except in the most extreme cases. Melting time for streets and parking lots is expected to be greater due to the increased thermal resistance of road construction and low condenser water temperatures.

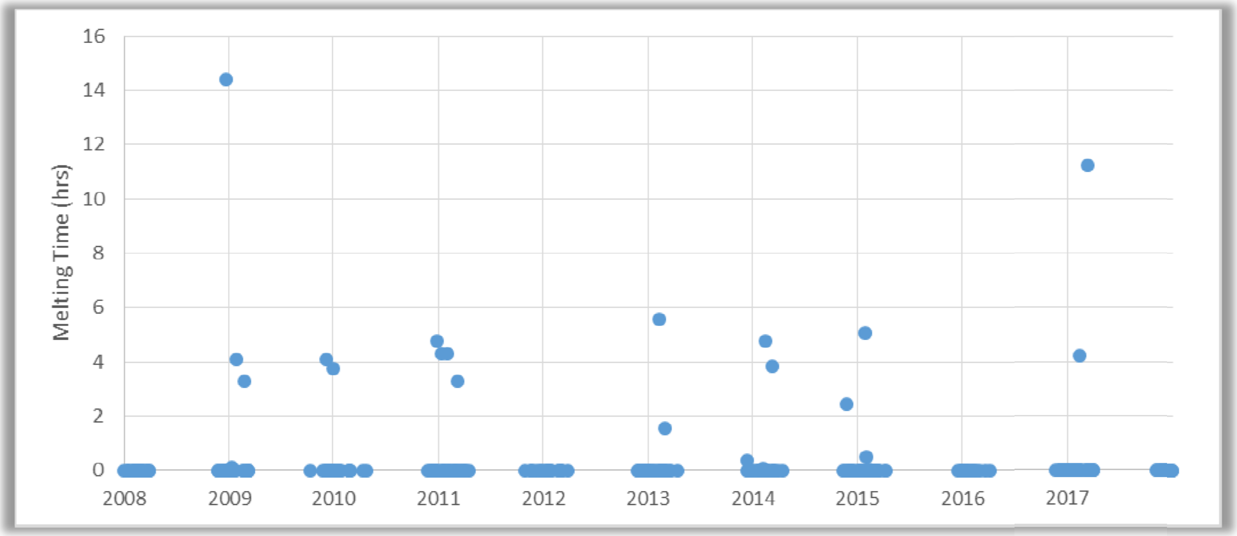


Figure 7: Street / Parking Lot Predicted Performance vs. Historical Snow Events

Note: Performance is based on an average snowfall rates and outdoor temperatures and 10 mph winds. Street and parking lot construction consists of 2" of cover with sand/fill above PEX tubing and 5" of asphalt.

Current practice for snow plowing is to begin once snowfall accumulation reaches 3 to 5 inches, though discretion is left to the senior foreman on duty. Snow plowing routes take approximately 4 hours to complete, which means roads are plowed once every 4 hours or more. For example, at a snowfall rate of 1 inch per hour, 4 inches of snow will have accumulated by time the operator completes their route and starts again. For the downtown area, roads typically are not plowed until after 5:00 PM when vehicles have vacated the area. Snow is not removed from downtown until the early morning hours after the snow event, and depending on the timing of the event, may not be removed until the following early morning hours. In nearly all cases, a snow-melting system would outperform current practice.

For street surfaces, predictive performance models show that the snow-melting system may allow significant snow accumulation during large snow events. Snow accumulation that exceeds expectations for melting time can be mitigated by temporarily boosting the supply water temperature. Conventional fuel boilers are recommended to be installed with the system to provide backup heat for freeze protection in the event that Burgess BioPower is down for an extended period of time during the winter. These boilers can also be utilized to boost the supply temperature for the snow-melting system. The installed capacity needed to provide freeze protection for the system would have the ability to boost supply temperatures by 15°F. Predicted performance versus historical snowfall and outdoor conditions for street construction with a boosted supply temperature is presented in Figure 8. From this figure, it can be seen that boosting supply temperature could have a significant impact on melting times for intense snow events.

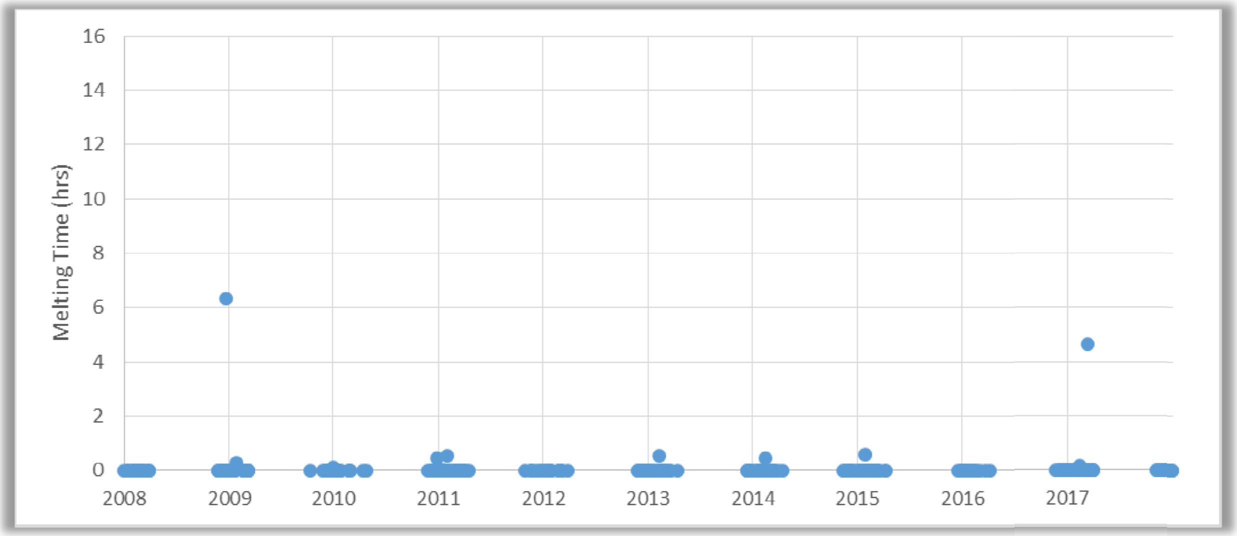


Figure 8: Street / Parking Lot Predicted Performance vs. Historical Snow Events, with Supply Water Temperature Boosted by 15°F

Note: Performance is based on an average snowfall rates and outdoor temperatures and 10 mph winds. Street and parking lot construction consists of 2" of cover with sand/fill above PEX tubing and 5" of asphalt.

4.2.3 Thermal Load Analysis

Thermal load on the system will primarily be driven by outdoor weather conditions. During active snow-melting, surface temperatures remain fairly constant, near the melting point of snow, and thus thermal load on the system is similarly constant. When there is no snow, thermal load on the system fluctuates, primarily with air temperature and wind speed. During periods of very low outdoor temperatures, slab surface temperatures can drop below the freezing point, and thermal loads can be higher than during active snow-melting.

Design heating demand for the system is based on thermal load during active snow-melting and the total surface area served. Thermal loads may be higher during periods of cold weather without snow, however, because there is no immediate need for the heat, it is not necessary to design the system to meet these heating loads. A summary of the design heating demands for the system, based on the snow-melting areas identified, is presented in Table 8.

Table 8: Design Heating Demand Summary

Surface	Surface Area (ft^2)	Design Demand[1] ($Btu/hr/ft^2$)	Design Demand (mmBtu/hr)
Sidewalk	88,000	127	11.2
Street / Parking Lot	293,000	61	17.8
Total	***381,000***		***28.9***

Note 1: Design heating demands include a 1.25 increase factor to account for ground and edge heat losses. Please note that the limiting factors on design demand are the condenser water temperature (85°F), and the construction cross-section. These values do not consider boosted condenser water temperatures by fossil boilers.

In order to estimate the total thermal energy use during a heating season, models of daily average thermal load were generated using historical daily weather data. A demand model based on the 2016-17 heating season is presented in Figure 9. This model shows the fluctuations in thermal load across the season, with peak loads over 30 mmBtu/hr.

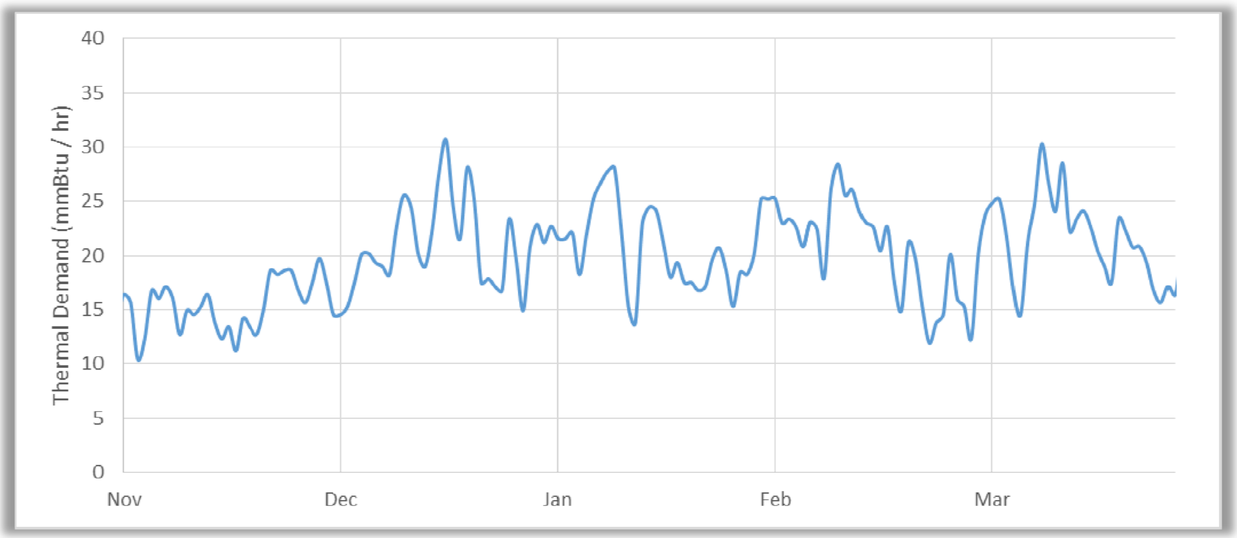


Figure 9: Daily Average Thermal Demand, 2016-17 Heating Season

Note: Estimated heating demand represents the daily average. Actual heating demand fluctuates above and below throughout the course of a 24-hour period.

A summary of total heating demand for the heating season is presented in Table 9. For the surface areas identified in this study, and a heating season from November through March, total heating demand is over 72,000 mmBtu. This heating demand offsets an equivalent amount of heat that would have to be rejected at the cooling tower at Burgess. This demand also has the potential to generate over 21,000 thermal renewable energy credits. Renewable energy credits are discussed further in Section 5.2.

Table 9: Total Heating Demand Summary

Year	Length of Heating Season (days)	Total Heating Demand (mmBtu)	REC Generation Potential
2008	152	73,644	21,584
2009	151	74,714	21,898
2010	151	70,193	20,572
2011	151	71,115	20,843
2012	152	66,202	19,403
2013	151	73,341	21,495
2014	151	77,029	22,576
2015	151	76,154	22,319
2016	152	70,028	20,524
2017	151	74,326	21,784
Average		***72,675***	***21,300***

Note 1: Length of heating season is based on operation from November 1st to March 31st.
Note 2: Total heating demand is based on the identified total surface area of 381,000 ft², and includes a 1.25 increase factor to account for ground and edge heat losses.

4.3 BURGESS BIOPOWER

Burgess BioPower is a 75 MW (gross) biomass-fired power plant, located just on the other side of the Androscoggin River from the northeast end of downtown Berlin. Burgess, like most power plants, utilizes a process in which steam is used to drive a turbine to generate electricity. Steam at the end of the process is converted back into water before being pumped back to the boiler. Steam is condensed by a recirculating water loop which picks up heat from the turbine exhaust and rejects it at an induced draft cooling tower. Cooling is primarily achieved through evaporation of a portion of the returning water. Heat rejected at the cooling tower is waste-heat, rejected to the atmosphere during evaporation. A snow-melting system would provide a productive use for a portion of the heat rejected.

4.3.1 Thermal Energy Availability

Condenser water temperature varies seasonally, mostly due to outdoor weather conditions. The condenser loop water is supplied to the condenser at 70 – 75°F and returned to the cooling tower at 85 – 95°F during the winter season. During the summer these temperatures are higher. Burgess provided condenser loop water temperature trend data for the time period 9/01/2016 – 8/31/2017. Outlet water temperature data is presented in Figure 10. The system maintains an average flow rate of 50,000 gallons per minute to the condenser. A small portion of the condenser loop flow is split off to serve auxiliary equipment cooling, and tie back into the condenser outlet. Outlet temperatures from the auxiliary cooling loop average approximately 7°F lower than condenser outlet. This lowers the temperature of the condenser outlet water available to be used for snow-melting, however, because the relative flow is much lower, it is not considered to be significant. Total heat rejected at the cooling tower is estimated at 430 mmBtu per hour based on the reported average temperature delta across the cooling tower and the stated average flow rate.

Burgess has two planned outages each year, in April and October, each lasting about a week. These outages are marked by the significant drop in condenser water outlet temperature in Figure 10. Other drops in temperature are a result of plant load reductions or unplanned outages to address maintenance items in the plant. During the winter season in 2016-17, Burgess was offline for a total of six days. During these periods, the plant's condenser water temperature dropped, but typically some heat was still being extracted from the plant as it cooled.

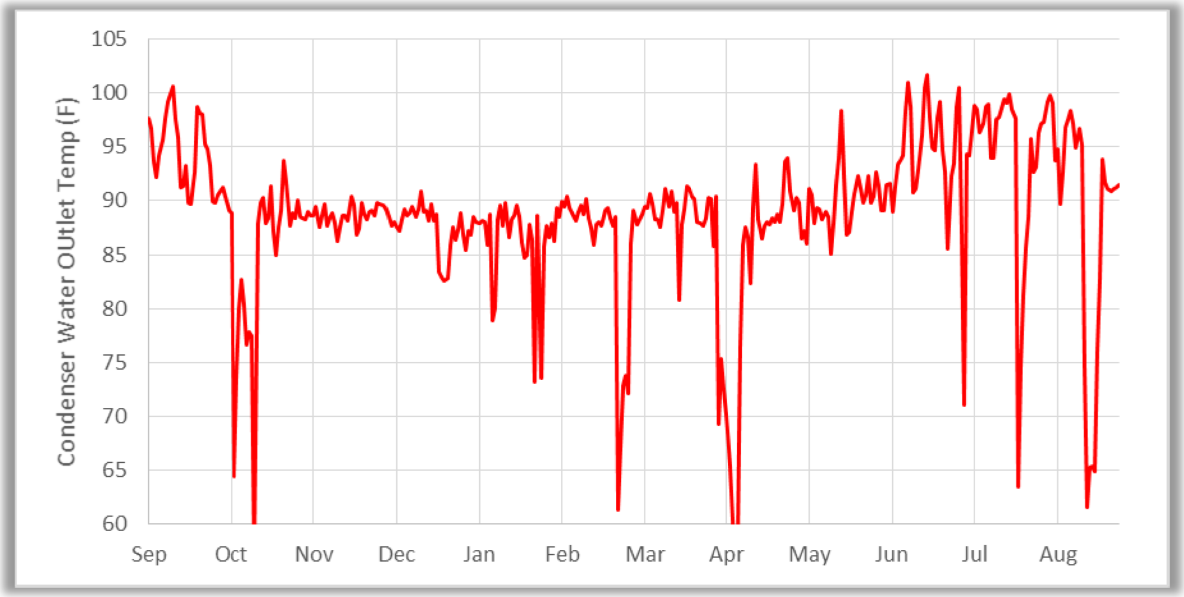


Figure 10: Cooling Tower Supply & Return Water Temperature

Note: Spikes lower in condenser water outlet temperature are a result of planned or unplanned reductions in plant output.

The cooling tower has four cells each with an induced draft fan. These fans can be operated at two speeds, low and high. In the winter, Burgess only needs to operate one fan at the high speed setting, while the other three are operated at the low speed setting. During the summer, typically all four are operating at the high speed setting. It is not expected that fan operation would change based on the relatively small amount of heat used by the snow-melting system.

In addition to the condenser loop, heat is lost through a continuous blowdown system on the boiler. The boiler blowdown discharge point is located on the east wall of the boiler building, at ground level. Blowdown runs to a flash tank and then to drain. The temperature reading on the flash tank measured 200°F on the date of the site visit. Burgess provided boiler makeup water trend data for the time period 9/01/2016 – 8/31/2017. This provides a reasonable proxy for blowdown rates, as blowdown is the primary source of water loss in the boiler system. A chart of boiler makeup water rates is presented in Figure 11. Makeup water typically ranged from 15 to 25 gallons per minute, with an average of 16 gallons per minute.

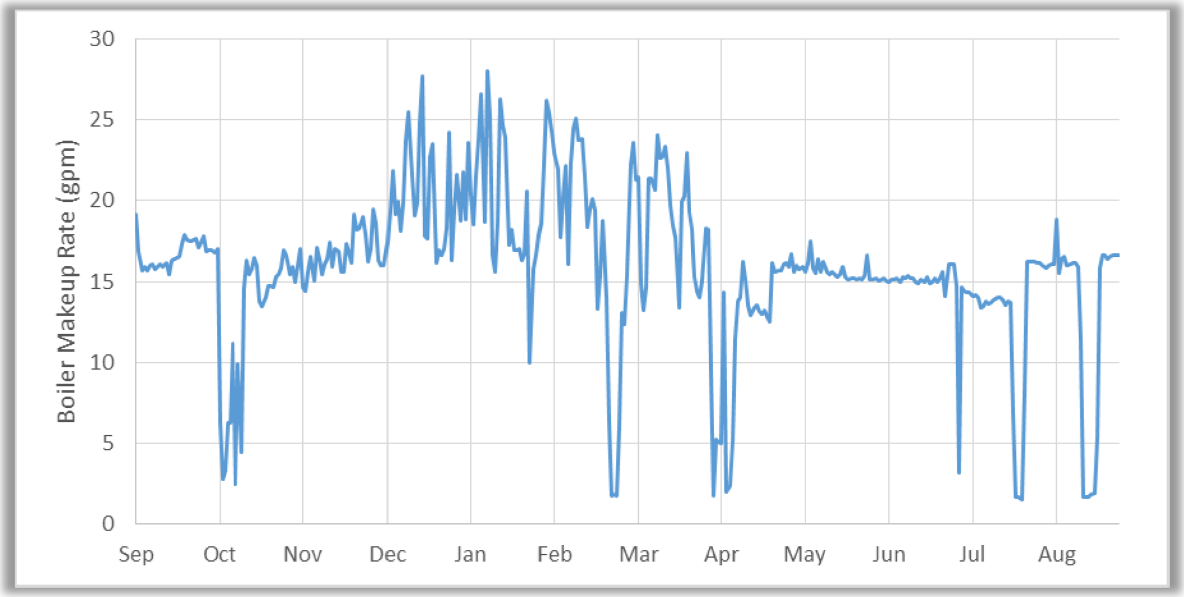


Figure 11: Boiler Makeup Water Rate

Note: Boiler makeup rate is used to approximate the blowdown rate. Large drops in boiler makeup water rate are a result of planned or unplanned outages.

A heat exchanger could be installed to capture some of the heat lost in blowdown. Based on a 10°F approach in the heat exchanger and an inlet blowdown temperature of 200°F, an additional 790,000 Btu/hr could potentially be provided to the snow-melting system. With the expected flow rate of nearly 4,000 gallons per minute for the snow-melting system, capturing heat from blowdown would have the potential to boost the supply water temperature by 0.4 – 0.7°F.

4.3.2 Snow-Melting System Interface with Burgess BioPower

Interconnection

Two options for interconnection with the condenser system were considered: a direct connection which would circulate condenser water directly through the snow-melting system, and an indirect connection which would circulate water through a heat exchanger connected to the snow-melting system.

With the direct connection option, hot water would be pulled off and put back into the condenser return (cooling tower supply) line through use of a closely-spaced tee type arrangement. This will keep the snow-melting system hydraulically separated from the condenser loop, allowing the snow-melting system pump(s) to operate without interfering with the condenser loop. This arrangement would allow the snow-melting system to pull heat out of the condenser loop before it reaches the cooling tower. Because return from the snow-melting system is injected back into the condenser loop before the cooling tower as well, it is not necessary to achieve the full temperature drop achieved by the cooling tower.

With the indirect connection option, hot water would also be pulled from the condenser return line through use of a closely spaced tee arrangement. A heat exchanger would be utilized to physically separate the snow-melting system loop from the condenser loop.

For purposes of this study, the direct connection option is carried forward as the preferred option. Direct connection provides the advantage of being able to utilize the full temperature range of the condenser return water. For the indirect connection option, a 5°F approach is likely as close as is economically reasonable and requires a relatively large heat exchanger. In addition to the added capital costs and maintenance item, the temperature difference is significant enough to affect performance of the snow-melting system. The drawbacks identified with using a direct connection are that scale or debris from the cooling tower will be circulated throughout the snow-melting system, potentially creating issues for valves and fittings within the system. It should be noted, however, that the snow-melting system operated in Holland, Michigan circulates condenser water directly with little to no issues.

Pump House

A 30 ft by 60 ft pump house would be constructed at the end of Community Street and would house the main distribution pumps for the snow-melting system. Supply and return piping from the condenser system tie-in would be piped underground to the pump house. Two 75 HP pumps with VFDs, and operating in parallel, would supply the snow-melting system with warm water.

Backup Boilers

Three condensing propane boilers, each sized at 9.5 mmBtu/hr, would be installed in the pump house for backup heat in the event that the power plant is offline for an extended period of time. These boilers are necessary to provide freeze protection to the system during extremely cold weather because the snow-melting system does not use glycol, which would adversely impact the heat transferring capabilities of the system, and require separation from the condenser water. The boilers would be controlled to maintain a lower supply setpoint temperature of 50°F to the system when there is no snow. The boilers were sized based on the lower setpoint supply temperature when the power plant was down for an extended period, and outdoor conditions of -35°F and 10 mph winds.

In addition to freeze protection, the boilers would also be capable of supplying enough heat to the system for snow-melting. Because the use of the backup boilers has a fuel cost, it is expected they would only be operated to maintain the minimum supply temperature to the system when not providing heat for active snow-melting.

The backup boilers can also be used for boosting supply water temperature if increased heat output is desired from the system. This may be desired during extreme snowfall events, to meet the desired performance in terms of melting time. The three backup boilers have the capacity to boost the supply water temperature by 15°F at the design flow rate nearing 4,000 gpm. This would increase the snow-melting system heat output by nearly 30%.

4.3.3 Androscoggin River Crossing

The Androscoggin River separates the Burgess BioPower plant from downtown Berlin. Warm water for the snow-melting system must be piped across this river. Two viable options have been identified for this crossing: a utility bridge to cross above the river, or directional drilling underneath the river.

A utility bridge spanning the river would be 170 feet long and 8 feet wide. Concrete supports would be required on either side of the river. The pipe bridge would be constructed from galvanized steel, and painted.

Directional drilling under the river with HDPE supply and return pipes has the advantage of no additional maintenance after installation, and no visual impact to the river view. The cost of installation is highly dependent upon soil conditions, particularly if ledge is present, which is expected.

Both options have been identified as having reasonably similar overall costs, and either could be implemented. Discussion with the NH Department of Environmental Services (NHDES) indicated a Wetlands Permit would not be required for any of the proposed alternatives as described. The prefabricated pipe bridge may require a "Permit by Notification" for construction of the bridge supports, but would require further design details for clarification.

4.3.4 Added System Benefits

The primary benefit to Burgess provided by the snow-melting system is that the heat rejected through the system reduces the heat that must be rejected through the cooling tower. This has the potential to reduce water consumption (through less evaporation), and thus makeup water required for the cooling tower. Based on trend data of condenser inlet and outlet temperatures, and the flow rate, heat rejection at the cooling tower is estimated at 430 mmBtu per hour. The snow-melting system is expected to use 10 to 30 mmBtu per hour throughout the winter season, which represents 2.3% to 7.0% of the total heat typically rejected at the cooling tower when operating at plant capacity. This equates to approximately 20 to 60 gpm in reduced evaporation and makeup at the cooling tower. Over the course of a 151 day heating season, from November through March, water consumption could be expected to be reduced by approximately 9 million gallons at a cost savings to Burgess BioPower of $4,600.

With the proximity of a potential pump house to the plant parking lot at Burgess, a snow-melting system could also provide Burgess with the opportunity to provide snow-melting to its own parking lot for employees and visitors as well.

4.4 Alternate Heat Source Considered – Stand-Alone Biomass Boiler

An initial Phase I Analysis for this project considered both a stand-alone biomass boiler plant and the Burgess BioPower plant as main options for the heat source for the facility. Burgess BioPower was selected as the option on which to focus for this study for the following reasons:

upfront costs of a biomass boiler plant, the annual cost of wood fuel for supplying heat to the snow-melting system, and the operating and maintenance costs of a stand-alone biomass boiler plant.

This type of system could still be considered as an alternative to using waste heat from Burgess BioPower, or to be used in the event that Burgess BioPower is no longer able to supply heat to the snow-melting system for some reason.

As needed, a biomass boiler plant could be erected near the snow-melting system pump house and tied in to the system via underground piping. The design heating demand for the snow-melting system is approximately 29 mmBtu/hr. This load could be met with a level of redundancy by two 600 hp biomass boilers. One means of operation for this plant in order to minimize energy costs yet keep the system in a state of readiness would be to operate one boiler constantly throughout the heating season, and fire the second boiler when weather forecasts call for snowfall or extreme weather.

A hot water thermal storage tank is recommended to provide some short term peaking capacity and to provide a heat sink during low load periods, thus limiting boiler cycling and improving system efficiency. Wood chips would be fed to the boiler from a wood storage bunker as needed by an automated wood reclaim and handling system.

It is expected that wood chips costs would range from $20 to $60 per green ton (about $3.00 – $9.00 per mmBtu output). In addition to the fuel costs, it is also expected that the Berlin would need to dedicate manpower equivalent to ½ FTE during the heating season to manage the boiler plant, schedule deliveries, etc. This system would be expected to use on the order of 10,000 tons of wood per year, with a total annual operating cost of approximately $475,000. This value assumes $40/ton green wood chips, and $75,000 in annual operating and maintenance costs for the plant. In order to sustainably supply this amount of wood use, a minimum of 1,000 acres would need to be sustainably harvested annually. This is calculated using a value of 10 tons of sustainable growth annually per acre. Please note that this acreage value does not identify the extent of the landscape acreage that would be required to sustainably supply this system, as an acre of forest would need to be harvested on a sustainable schedule (not annually).

High-level estimates for a biomass boiler plant based on similar sized installations are in the range of $5 – $9 Million. This includes cost for two boilers, wood fuel storage and handling equipment, and the boiler plant building.

5.0 Financial Analyses

5.1 Costs

5.1.1 Snow-Melting System Capital Costs

The following capital cost estimates for the snow-melting system include costs for connection to the Burgess system, a pump house and backup boiler system, and the snow-melting system distribution piping, PEX tubing, valves, etc. Cost estimates include all equipment labor, materials, and professional services associated with the design and installation of the system. The following cost estimates do not include costs associated with street or sidewalk paving, and any downtown streetscape projects. It is assumed that this project would be completed in conjunction with an overall streetscape project downtown, and this cost estimate is designed to be able to allow the City to understand the cost adder to include this project with an overall streetscape project. Cost estimates were established based on budget quotes from manufacturers, vendors, and service providers. A summary of capital costs is presented in Table 10. A detailed capital cost estimate for the system is provided in Appendix C.

Table 10: Snow-Melting System Capital Cost Summary

Item	Cost	Cost/SF
General Conditions	$719,500	$1.89
Pumphouse Building / Plant Connection Site Work	$507,600	$1.33
Pumphouse/Plant Connection Mechanical Systems	$586,500	$1.54
Pumphouse Backup Energy Systems	$882,700	$2.32
River Crossing - Directional Drilling or Pipe Bridge	$415,000	$1.09
Snowmelt System in Downtown	$3,025,300	$7.94
Construction Contingency	$613,600	$1.61
Contractor Profit/OH/Markup	$920,500	$2.42
Professional Services	$613,600	$1.61
Total	**$8,284,500**	**$21.74**

The cost per unit area for the system and the areas identified equates to approximately $21.74 per square foot. However, not all costs scale linearly with changes to the scope of areas served. Certain costs are fixed (e.g. the pump house building or connection to the condenser piping) and others may only change slightly (e.g. changes to backup boiler sizing). Approximately $3.7 Million of the costs are reasonably fixed, and $4.6 Million are directly determined by the area covered by the system. The incremental square foot cost for the snow melting system is presented in Table 11 and is $12.14 per square foot.

Table 11: Incremental Cost for Changes in Scope of Snow-Melting System

Scope of Area Served (ft^2)	Incremental Cost to Change Scope ($\$/ft^2$)
381,000	$12.14

5.1.2 Operating Costs

A summary of estimated operating and maintenance costs of the snow-melting system is presented in Table 12. The primary operating cost for the system is for the electric energy to operate the main pumps. To provide the required flow of nearly 4,000 gallons per minute, two 75 HP pumps are required. It is recommended that the pumps be operated with VFD's to maximize the efficiency and reduce the pumping energy required.

Additionally, in the event that the plant is offline during a snow event, backup boilers may be required to provide heat to the system. In order to meet the design load of the system, the backup boilers would consume approximately 330 gallons of propane per hour. For purposes of estimating operating costs, it is assumed that the boilers would operate for a maximum of 48 hours per heating season.

Costs are also carried for 10 hours per week of staff time to tend to routine maintenance items in the pump house and for the system at large. This time includes items such as blowdown of the dirt separator, monitoring performance, and other routine checks of the system. An allowance of $15,000 is budgeted for parts and maintenance.

Table 12: Estimated Operating and Maintenance Costs

Electric Energy Cost	Propane Fuel Cost	Labor Cost	Maintenance & Parts Cost	Water Avoided Cost	O & M Total Costs
$29,400	$24,000	$6,600	$15,000	($4,600)	**$70,400**

5.1.3 Avoided Snow Management Costs

Avoided snow management practices for the downtown include the plowing of downtown streets and sidewalks, snow removal, and spring clean-up of sand from the previous winter. Costs avoided include manpower, fuel costs, equipment hours, and associated administrative costs. A summary of the avoided costs is presented in Table 13. A detailed breakdown of avoided costs is provided in Appendix C.

Table 13: Avoided Snow Management Costs Summary

Description	Annual Cost
Snow Plowing	$12,650
Snow Removal	$100,760
Spring Cleanup	$4,310
Total	***$117,720***

5.1.4 Downtown Streetscape Order of Magnitude Costs

It is beyond the scope of this study to develop an estimate of costs for a rehabilitation of downtown streets and infrastructure. However, it is very useful to understand the order of magnitude of the snow-melting system costs in comparison with the road, sidewalk, and parking that would need to occur. Thus, a per square footage cost has been developed for each typical cross-section/area type expected on the project. The approximate per square foot number for construction of each section type is presented in Table 14.

Table 14: Unit Costs for Typical Section Areas

Typical Section	Surface Area (ft^2)	Unit Cost ($\$/ft^2$)	Unit Cost w/ Area-Based Snow-melting Cost ($\$/ft^2$)
Sidewalks	88,000	$15.54	$27.73
Streets	214,000	$10.25	$22.98
Parking Lots	79,000	$8.56	$21.28

Notes: This table shows unit costs for the typical sections when they are built as part of a large infrastructure project. Unit costs are intended to include general conditions, contingencies, OH, profit, etc. Please see Appendix C for a detailed breakdown. The snow-melting system added costs are intended only to be those that are area-based. Fixed costs for the system are not included in these unit values. Appendix C provides a breakdown of the value used to determine area-based costs for the snow-melting system.

The total cost for new sidewalks, roads, and parking lots for the areas identified downtown is identified as approximately $4.3 Million. This is for approximately 1.3 miles of road (and sidewalks) and the identified parking lots. Please note that this is a very general estimate based on total square footages and is not based on a specific design incorporating traffic calming measures, plantings, and other streetscape or infrastructure improvements. The snow-melting system cost is estimated at an additional $8.3 Million, of which approximately $3.7 Million does not directly vary based on the area served, and is generally fixed in order to serve the identified areas and provide future expansion potential.

5.2 POTENTIAL FUNDING SOURCES

5.2.1 Renewable Energy Credits

The State of New Hampshire is unique among states in that its RPS includes a provision for thermal renewable energy credits (REC). A Class I thermal REC is generated for every 1 MWh of use thermal energy delivered and metered by a qualifying generator. This project would provide useful thermal energy from the Burgess Power facility. The following discusses the eligibility of this project for Class I Thermal RECs in accordance with the NH Puc 2500 rules, and the strategies for capturing this revenue source.

Eligibility

Puc 2505.08 specifies that for a facility to be qualified as a combined heat and power (CHP) facility to generate Class I or Class III electric RECs and Class I Thermal RECs, the facility must meet all applicable rules for both electric generation and useful thermal generation facilities, provide a description of the system efficiency, and install meters for measuring useful thermal energy. There is no specific requirement for efficiency, only that the total system efficiency must be disclosed.

Since the plant has an input of greater than 100 mmBtu/hr, the emissions limits for electric and thermal are the same. Therefore, the facility would not have to change its emissions controls or stack testing methods. The emissions limits are:

- 0.02 lb/mmBtu particulate matter (PM)
- 0.075 lb/mmBtu NOx

A stack test for PM is required prior to the first quarter in which the facility intends to generate Class I Thermal RECs. NOx is measured by continuous emissions monitors, and the quarterly average NOx emissions rate must be provided to the PUC in order to gain initial eligibility for Class I Thermal RECs.

In order to maintain compliance with both the electric and thermal emissions limits, continuous NOx monitoring must be in place, and stack testing for PM must be conducted annually or every 3 years, if granted by the department after 3 successful annual stack tests. For the purposes of Thermal eligibility, it is assumed that if the facility is in compliance with PM limits and stack testing for electric generation, it would be able to commence production of Thermal RECs at any time.

Metering

Metering can either take place using steam or hot water. In the case of this project, the metering would be in the water lines feeding the snowmelt system. Care should be taken to use meters which either meet EN 1434-1 accuracy requirements for hot water, or else 3% accuracy for steam, in order to avoid being assessed the penalty for meter accuracy, which can be up to 5%. The metering system will need to measure flow, supply temperature, and return temperature. The metering system requires a computer that will meet specified accuracy with regard to the calculation, and it is critical that the system include backup of the metering data.

Ownership of the RECs

The facility which actually does the conversion of biomass into electricity or useful thermal energy “the source” is most appropriately the owner/generator of the Thermal RECs. Another applicant may apply on behalf of the source, but this would require the source’s cooperation with regard to the emissions controls and stack testing. The distinctions in this case are not well defined in the PUC rules. It is likely easiest for this project if the power plant were to be the owner/generator of the RECs.

5.2.2 Grants and Loans

There are a number of funding opportunities that could help make this project a reality. Several key among these are listed here, and basic descriptions of the opportunity for each are identified. This is not an all-inclusive list, and it is recommended that this report be used to define the project for potential foundations and other funders to identify additional sources.

BUILD Grant

The Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grants program has replaced the pre-existing Transportation Investment Generating Economic Recovery (TIGER) grant program. The BUILD grants are for investments in surface transportation infrastructure and are to be awarded on a competitive basis for projects that will have a significant local or regional impact. Eligible entities are state and local governments, or agencies of state and local governments.

Projects for BUILD target merit criteria that include safety, economic competitiveness, quality of life, environmental protection, state of good repair, innovation, partnership, and additional non-Federal revenue for future transportation infrastructure investments.

The stated intent of BUILD grants is to prioritize projects in rural areas that align well with the selection criteria, and particularly projects that improve/deploy other infrastructure, such as broadband.

This grant can fund up to 100% of project costs in rural areas, and the maximum award is $25 Million. Past awards for TIGER grants have included a number of streetscape projects in rural areas that have provided economic development, traffic calming/safety, environmental, quality of life, and other benefits.

It is recommended that an application for a BUILD grant for the Berlin downtown that includes the snow-melting system would encompass an overall streetscape project providing a host of safety, economic development, state of good repair, and other benefits.

NH Renewable Energy Fund

The NH Renewable Energy Fund (REF) is derived from ACPs and is managed by the New Hampshire PUC. Each fall the PUC solicits proposals for renewable energy projects which will result in the production of RECs as well as other benefits to the people of New Hampshire such as job creation, energy cost savings, and energy efficiency.

The amount of funding available varies each year. In 2017, the total amount of funding available was $800,000, in 2016 it was $1,000,000, in 2015 it was $750,000, and in 2014 it was $2,000,000. The minimum grant request is $150,000, and up to the total grant value may be requested.

USDA Rural Development Community Facilities Program

The program, administered by the USDA, provides funding in the form of loans and grants to develop community facilities in rural communities. The program is open to public bodies, and community-based nonprofit corporations. The program is primarily geared towards loans, which can have terms of up to 40 years. Grant funding awards are determined with preference for smaller communities with lower household income relative to state medians.

Opportunities with Third-Parties / Public-Private-Partnerships

There are a number of financing vehicles and tax credit options available to entities other than a municipality. Even though the snow-melting system would be a City project, there are ownership structures or agreements that can be leveraged to access these funding mechanisms. The following are several funding opportunities that could be considered if the City were to partner with local stakeholders or businesses on the project. Please note that some of these opportunities require non-profit structures, and some require for-profit businesses in order to access them.

New Market Tax Credit

The New Market Tax Credit (NMTC) Program allows private investors to claim a tax credit against their federal income tax for investments made in eligible projects through Community Development Entities. The tax credit is a total of 39 percent of the amount invested, and is claimed over 7 years. The net result to the project is typically on the order of a 20% reduction in project costs, and the exact percentage depends on the size of the project investment and the fees charged.

One key caveat is that the project owner must be a non-profit entity. It is not uncommon for a non-profit entity to be established with board representation by a municipality and local stakeholders to implement a project. After the seven-year period of the tax credit, the infrastructure can be turned over to the municipality as appropriate.

For more details on the NMTC option, it is recommended that the City discuss the project with an entity like the Northern Forest Center, which has a history of placing NMTC projects.

USDA Rural Energy for America Program (REAP)

REAP is administered by the USDA and provides grant and/or loan funding to for-profit businesses for energy projects in rural areas. Grant funding of up to $500,000 per project can be used to cover up to 25% of total project costs. Additionally, the REAP program offers loans that could cover the remainder of the project. The City is not eligible for this funding, but could potentially pursue third-party ownership of the system by a for-profit business meeting the definition of a small business.

Accelerated Depreciation

Ownership by a for-profit business can allow for the opportunity to capture accelerated depreciation benefits. Exact qualifications for this project would need to be determined, but it is anticipated that accelerated depreciation of 5 years or less would be able to be achieved for eligible property that is part of this project. The ownership structure helps to determine the value of this tax benefit, but this credit may be able to be passed through to investors with large tax liabilities, depending on the structure of the project.

5.3 LIFE CYCLE COST ANALYSIS

A summary of the estimated first year net operating savings for the snow-melting system is presented in Table 15. Net operating savings are based on the avoided cost savings of the downtown snow management operations and estimated value of RECs generated, less the O&M costs associated with the system. The magnitude of operating savings is heavily dependent on how the REC value is applied, but the project still offers operating savings over current practice even when not considering RECs.

Table 15: First Year Net Operating Savings

O&M Costs	Avoided Snow Management Costs	Value of RECs Generated	First Year Net Operating Savings
($70,400)	$117,720	$521,846	$569,166

Note 1: First year net income with REC value of $24.50/MWh

Life cycle costs were analyzed over a period of 25 years at varying funding levels. Electric and fuel prices were forecast using energy price indices based on Department of Energy forecasts and provided in the National Institute of Standards and Technology's (NIST) 2018 Annual Supplement to NIST Handbook 135. Pro-forma cash flow analyses are provided in Appendix D. The analysis assumes that the financed portion of the project is financed at a rate of 5% over a 15-yr period. Analyses use a discount rate of 3%. A summary of the life cycle cost analysis is presented in Table 16.

Table 16: Life Cycle Cost Analysis Summary

Grant Funding Level	Snow-Melting System	Assumed Grant Funding	Project Costs Financed	First Year Net Operating Savings	25-Year Net Present Value
0%	$8,284,500	$0	$8,284,500	$569,166	($2,186,848)
30%	$8,284,500	$2,485,350	$5,799,150	$569,166	$757,376
60%	$8,284,500	$4,970,700	$3,313,800	$569,166	$3,701,601
90%	$8,284,500	$7,456,050	$828,450	$569,166	$6,645,826
100%	$8,284,500	$8,284,500	$0	$569,166	$7,627,234

5.4 Life Cycle GHG Reduction

GHG reductions are achieved by the reduction in fuels costs associated with avoided snow management practices. A snow-melting system for the downtown area would have the potential to reduce diesel fuel use by over 7,500 gallons per year, reducing GHG emissions by 78 metric tonnes. Over a 25-year period this equates to a reduction of nearly 2,000 metric tonnes of CO_2 equivalent. A summary of life cycle GHG reduction is presented in Table 17.

Table 17: Life Cycle GHG Reduction Summary

Life Cycle Period	Reduction of Diesel Fuel Use (gallons)	Reduction of GHG Emissions (mtonne CO2eq)
25 Years	189,400	1,955

Note: CO2 equivalent includes CO_2, and both CH_4 and N_2O adjusted for their 100-year global warming potential relative to CO_2.

6.0 Qualitative Assessment

6.1 Road Life Expectancy

Winter weather is tough on asphalt pavements. Asphalt is much more brittle in cold weather, leaving it more susceptible to cracking, especially in extremely cold weather. Most damage during the winter season is caused by freeze-thaw cycles. Freeze-thaw cycles occur when slab temperatures fluctuate above and below freezing. Water seeps through cracks in asphalt to the subgrade material. The subgrade is meant to drain away, but in the winter the moisture freezes. Significant water introduction through cracks in the asphalt can cause heaving of the subgrade as water freezes and expands. When the ice melts as temperatures rise, the surface is weakened and more susceptible to damage. Salt can exacerbate this problem as salt lowers the freezing point of water and can cause the freeze-thaw cycles to continue even at lower temperatures. Examples of road damage and repairs in the downtown area are presented in Figure 12.

Figure 12: Downtown Berlin Road Damage and Repairs

A snow-melting system would keep subgrade materials above the freezing point at all times during the winter season, significantly reducing risk of freeze-thaw conditions. Over the life of the road, maintenance and repair costs are expected to be greatly reduced. As a result, the need for the ultimate replacement of the pavement system should be pushed further into the future providing additional substantial benefit to the life cycle cost. This concept is illustrated in Figure 13, which compares pavement conditions over time. Nearing the end of a pavements useful life, deterioration increases rapidly, significantly increasing the cost of maintenance. A snow-melting system would have the effect of extending this curve, and therefore extending the life of the pavement and lowering average maintenance costs during its life.

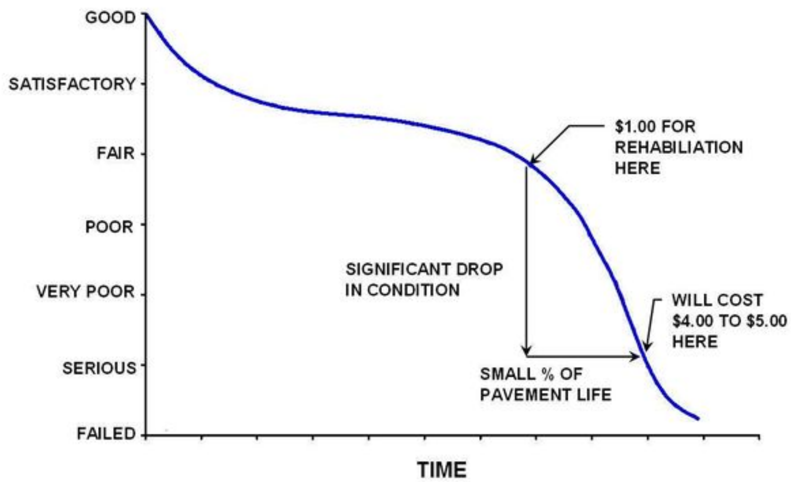


Figure 13: Typical Pavement Life Cycle Curve

Source: Federal Aviation Administration
https://www.faa.gov/airports/central/airport_compliance/pavement_maintenance/

6.2 Survey of Berlin Businesses

An informal survey of several businesses in downtown Berlin was conducted to identify levels of interest, potential benefits, and concerns of a snow-melting system.

6.2.1 Safety

Improved safety was identified by all survey participants as a critical benefit of a snow-melting system. Slips and falls from icy conditions are a common occurrence downtown. Participants identified that snow banks can block passage on sidewalks requiring pedestrians to walk down the road until an access point can be reached. It was further identified that snow banks cause visibility concerns for both pedestrians and motorists as they block sight lines for vehicles entering and exiting parking lots.

Participants also identified an additional benefit of a downtown snow-melting system related to health and safety, which is improved air quality for pedestrians. Leftover sand from the winter season remaining in the streets is ground to a fine dust and kicked up in the air, creating health hazards for those with respiratory difficulties.

6.2.2 Custodial

Most businesses spend a significant amount of time and money in keeping business entrances and parking free of snow, estimates ranged from 15 to 100 hours per winter season. For those with their own parking lots and building access, plowing services are typically hired to clear parking lots and sidewalks.

Downtown foot traffic tracks sand and salt into businesses, requiring frequent cleaning. Salt and sand can be particularly harmful to wood floors, which are susceptible to abrasion, and carpet, which is easily stained. Snow is also tracked into facilities creating additional slipping hazards.

6.2.3 Parking

Survey participants note that there is a noticeable reduction in customer traffic on days with poor walking and parking conditions. Parking on Main Street in particular was identified as affecting overall pedestrian traffic downtown. Snow banks are piled up on one side of the street reducing convenient parking and blocking pedestrian access to businesses on that side of the street.

6.3 Survey of Holland Businesses

An informal survey of several businesses within the areas served by the snow-melting system in Holland, MI was conducted to identify the perception of their system. Overall, Holland businesses are very happy with their snow-melting system. Safety, particularly for the elderly, downtown aesthetics during the winter season, and increased business were all emphasized as valuable additions that the snow-melting system brings to their downtown area. It was noted that the snow-melting system encourages residents to walk or jog, or otherwise spend time downtown.

6.3.1 Description of Holland System and Operations

Holland, Michigan has been running a snow-melting system in the downtown using waste heat from their municipally-owned power plant since the 1980's. The system currently covers over 600,000 square feet of surface area, which is mostly sidewalks and a four-block section of downtown streets. Over the past several years, Holland has transitioned from its aging coal-fired power plant to a new natural gas-fired combined cycle electric plant. As part of the natural gas plant project, Holland included an 80 mmBtu/hr natural gas boiler specifically to ensure backup capacity for the snow-melting system. Further, the power plant is run in the winter to ensure that 95^{o}F condenser water is sent out to the system. The following is a link to a brochure with a detailed description of the snow-melting system:

https://www.cityofholland.com/sites/default/files/fileattachments/snowmelt_brochure_8-2017.pdf

Discussions with Holland staff were conducted during the study to identify their impressions of the system and the operations of the system. The system itself is maintained by the City of Holland. The City charges an annual operations and maintenance fee of $0.45 per square foot for the areas served for business owners. This area includes the sidewalks in front of their businesses, and any privately owned areas that may be connected. The City offers to cover 50% of the installation cost of new sections of the system that are in private areas. The City has seen the installation as very reliable over its more than 30-year history. City staff stated that the system has been used as a major marketing tool for the City and the downtown in particular. City staff were asked what would be the reaction if the system were no longer maintained, and the response was that this would not be an option due to the popularity of the system. That the City has made major investments at the power plant specifically for the snow-melting system provides an indication of its value to the City.

7.0 Conclusions and Additional Considerations

This study evaluated various options for supply of heat from local renewable resources to a snow-melting system, snow-melting system design approaches, and varying operational and economic performance associated with each option. Such a system has the ability to keep the downtown streets and sidewalks free from snow during the winter season. The system would provide a marked improvement over current snow management practices in terms of time to clear and remove snow from streets and sidewalks. This is expected to promote activity in the downtown area, vastly improve walking conditions, extend the street and sidewalk life, and reduce manual snow clearing of building fronts and custodial costs from clean-up of salt, sand, and snow tracking inside buildings.

Key Components of System

- Snow-melting system below the streets, sidewalks, and municipal parking lots of downtown, covering an initial area of approximately 381,000 ft^2
    - Main system piping runs allowing for increase of snow-melting system square footage to over 600,000 ft^2 in the future
- Interconnection to condenser water supply line to cooling towers at Burgess BioPower, and 1,800 ft^2 pump house for the system pumps, back boilers, and balance of plant systems
- Three variable speed system pumps providing approximately 3,850 gpm at a minimum supply temperature of 85°F (one spare and two operating in parallel), with room to add 2 additional system pumps for future expansion
- Propane backup boiler capacity of 28.5 mmBtu/hr for freeze protection, and the ability to boost system temperatures by 15°F for increased system performance under peak conditions, with room to add additional boiler capacity in the future
- Propane backup generator to ensure power can be maintained at all times for system pumps

A snow-melting system as described and serving the initial scope of approximately 381,000 ft^2 would have a capital cost of approximately $8.3 Million. The heat from this system is essentially free since it is residual heat that is being exhausted from the power plant. This provides major benefits from a sustainability and annual operation and maintenance cost perspective. It is estimated that the cost to operate the system will be on the order of $70,000 annually. It is anticipated that this project would be completed in concert with an overall redevelopment of downtown road and sidewalk infrastructure, and the construction costs identified above are only for the increased cost to add a snow-melting system to a downtown streetscape project's scope.

The snow-melting system will provide a host of benefits to the City of Berlin and project stakeholders, including the following key items:

- Approximately $110,000 in annual snow management costs
- Approximately $500,000 in annual thermal REC revenue based on current REC values
- Reduction of approximately 9 million gallons per year of makeup water for the cooling tower at the Burgess BioPower plant
- Reduction of approximately 75 metric tonnes of annual CO_2 equivalent greenhouse gas emissions, and avoidance of approximately 6,700 metric tons of CO2 equivalent each year by operating with the renewable energy source instead of #2 fuel oil
- Improved downtown safety for residents, business owners, customers, and tourists
- Improved cleanliness of downtown without waiting until spring cleanup of sand and salt
- Improved life of downtown road and sidewalk infrastructure investments
- A draw to the downtown which will support downtown businesses, and improved conditions for consumers during winter months, which will improve business traffic
- A unique marketing feature for the City of Berlin, and use of a local renewable resource to drive economic development and downtown revitalization

The following considerations are recommended as the City of Berlin pursues a snow-melting system for its downtown:

- Consideration should be given to the delineation of responsibilities for the system between the City of Berlin and Burgess BioPower. The pump house will likely be sited adjacent to the power plant, and would directly tie-in to their condenser system. For these reasons, Burgess may be better suited to operate the pump house equipment.
- The extent of the allowance for future expansion. The system as evaluated in this study has been setup to allow for expansion from approximately 381,000 ft^2 to approximately 600,000 ft^2. Consideration should be given to the total scope of what future expansions may or may not entail, and this will help with final design.
    - The City should discuss what arrangement would be offered to private landowners for any expansion of the system. Holland shares in the cost of expansion with private landowners for the snow-melting portion of the expansion.
- Collaboration with Burgess BioPower, the City, and downtown stakeholders will be key to implementation of the system. There are a number of funding opportunities and vehicles available to assist with implementing this system, and some of these opportunities require varying ownership structures.
- The City could discuss whether it would consider charging a use or operations and maintenance fee, on a square foot basis, to help recover the cost of the system. Survey responses from business owners were generally non-committal on whether they would

be willing to pay a service fee. It seemed that those who responded may be willing to do so, depending on the fee and level of value they ultimately see from the system.

- Survey of Holland Michigan business owners were nothing but positive, and there were no complaints noted about their use fee, which is \$0.45 / ft^2 / yr for the sidewalk areas in front of landowner properties, and any private areas that are covered.

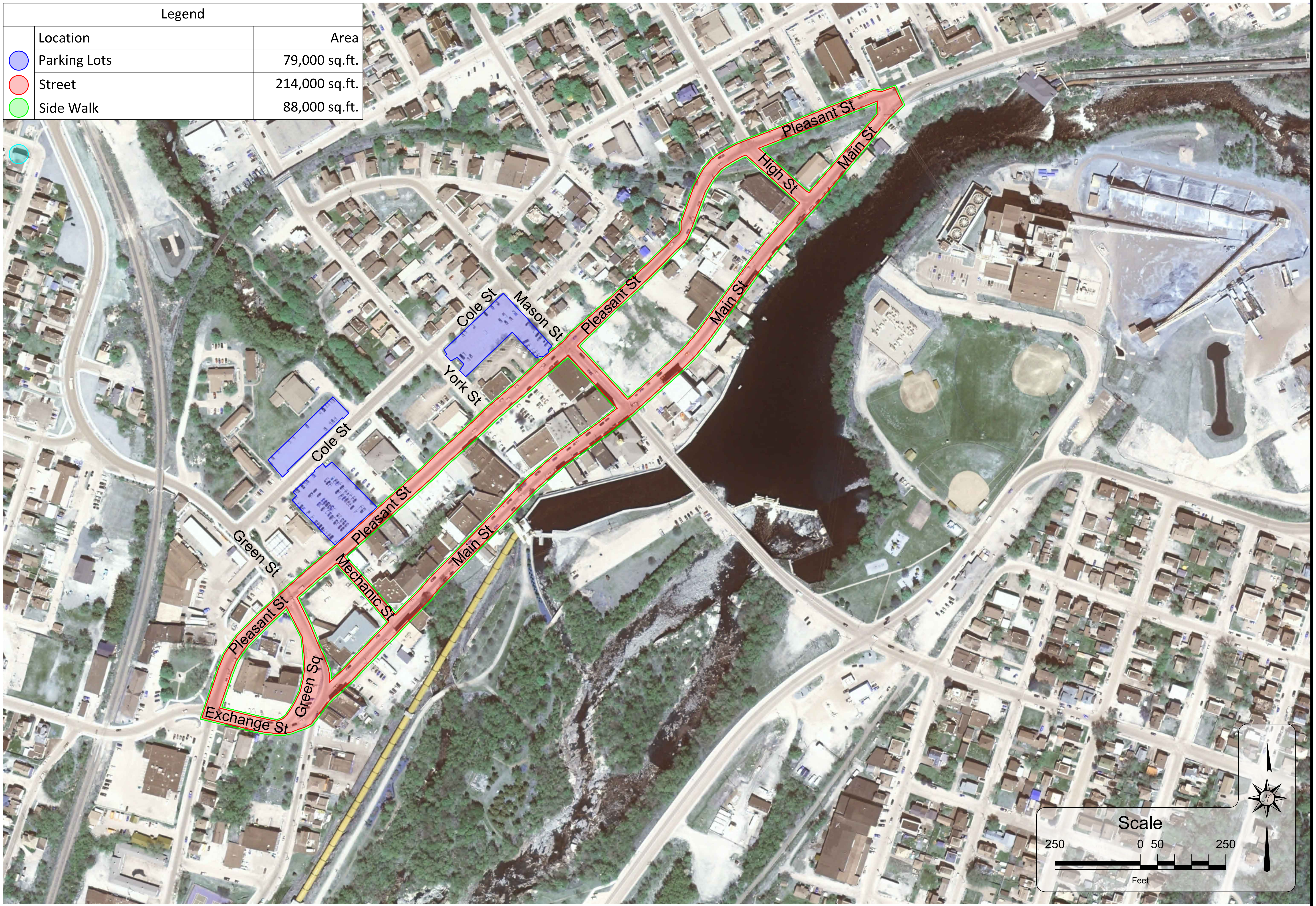
- This type of project is a very forward thinking project with regard to maximizing the overall efficiency of power generation in the US, and should be recognized for this attribute and as a model for future power plant development. The heat exhausted from power generation plants provides a major opportunity for development of sustainable energy systems for buildings, snow-melting systems, and other projects which can turn wasted energy into a local resource to provide benefit.
- Any new buildings constructed downtown could consider installing low-temperature hydronic heating systems. This approach to hydronic heating design is becoming best practice, as it allows for the use of condensing boilers and maximum building efficiency. Additionally, it provides the opportunity for any new building to connect to the snow-melting system and use high efficiency water-to-water heat pumps for building space heating. Converting existing heating systems in existing buildings to hydronic heating is typically not economically feasible unless a building is undergoing a substantial renovation.

Appendix A

System Drawings & Schematics

- A.1: Snow-Melting System Areas Scope
- A.2: Snow-Melting System Layout
- A.3: Pump House Layout
- A.4: Snow-Melting System Manifold Layout
- A.5: Typical Sidewalk Zone Layout
- A.6: Typical Street Zone Layout
- A.7: Sidewalk and Street Cross Section Details
- A.8: Burgess BioPower Connection Schematic
- A.9: Typical Manifold Connection Schematic

Legend		
	Location	Area
(blue)	Parking Lots	79,000 sq.ft.
(red)	Street	214,000 sq.ft.
(green)	Side Walk	88,000 sq.ft.



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Snow-Melting System Scope

Berlin, NH

Date: 9/24/18

A.1

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Snow-Melting System Layout
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A.2

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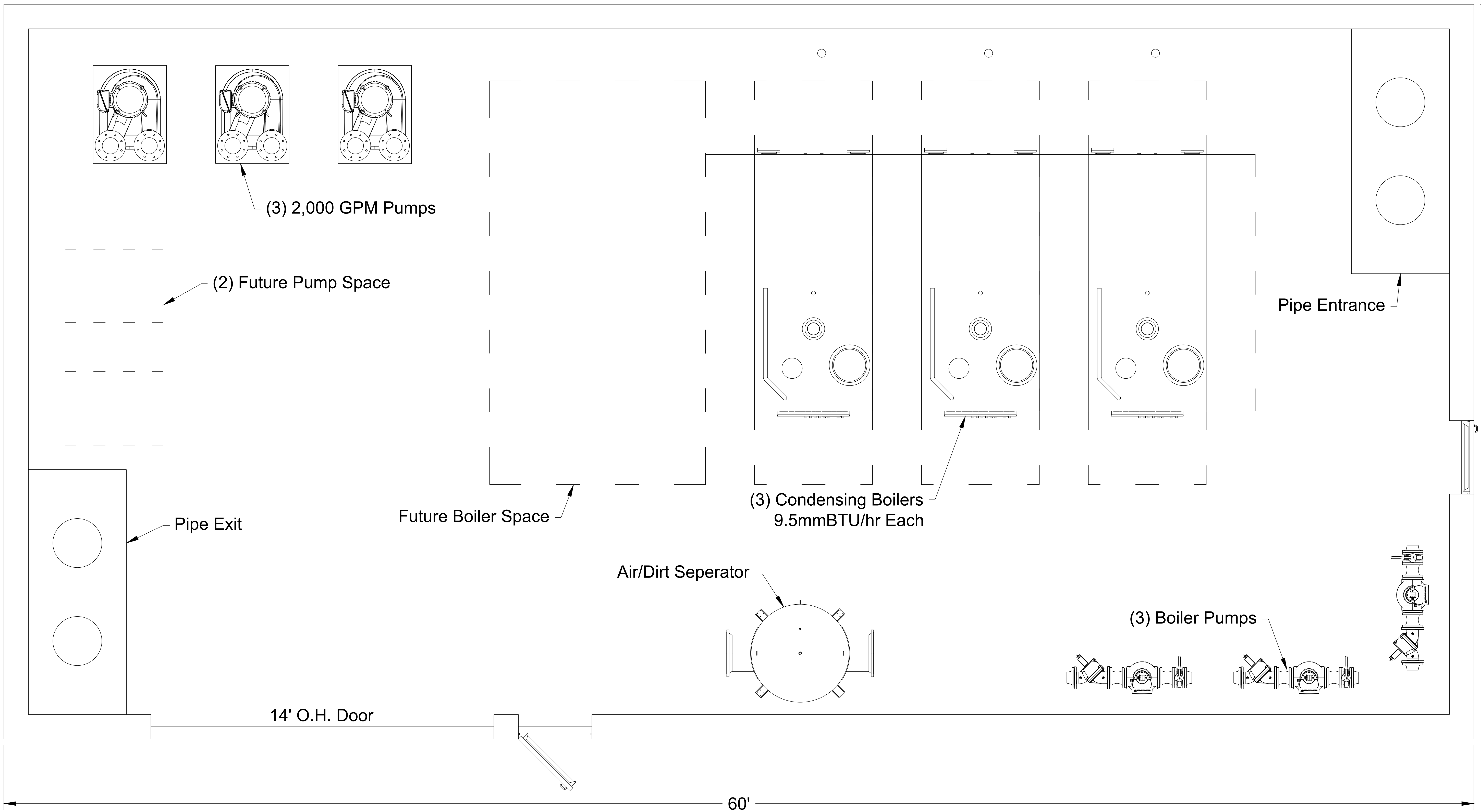

Pump House Layout

Scale: 1" = 4'-0"

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Pump House Layout
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A.3

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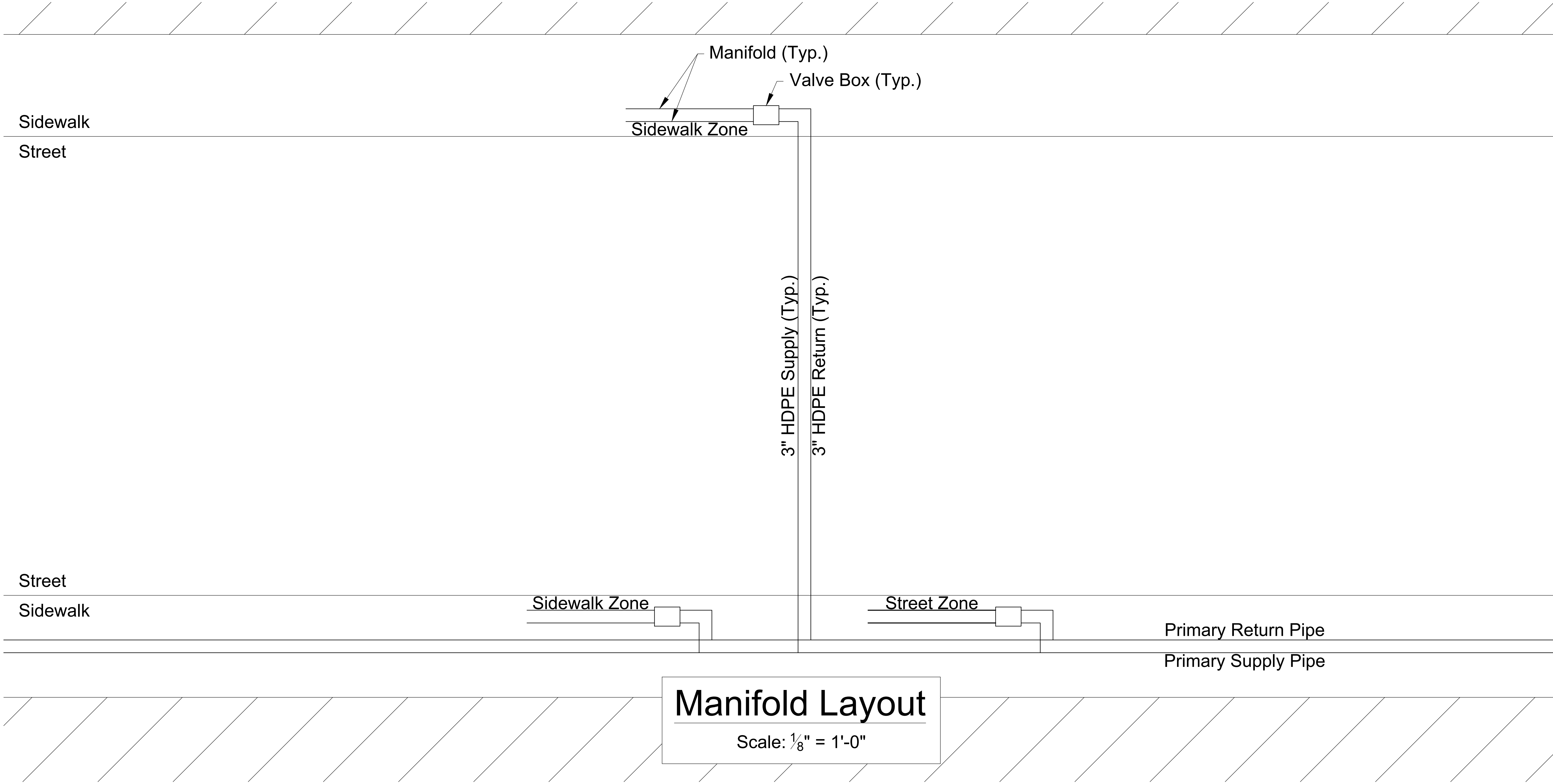
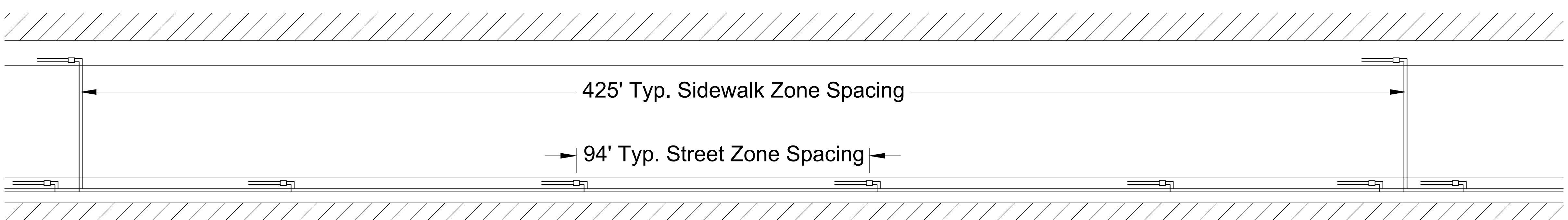


Manifold Layout

Scale: ⅛" = 1'-0"



Manifold Spacing

Scale: 1" = 40'-0"

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Snow Melting System Manifold Layout
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A.4

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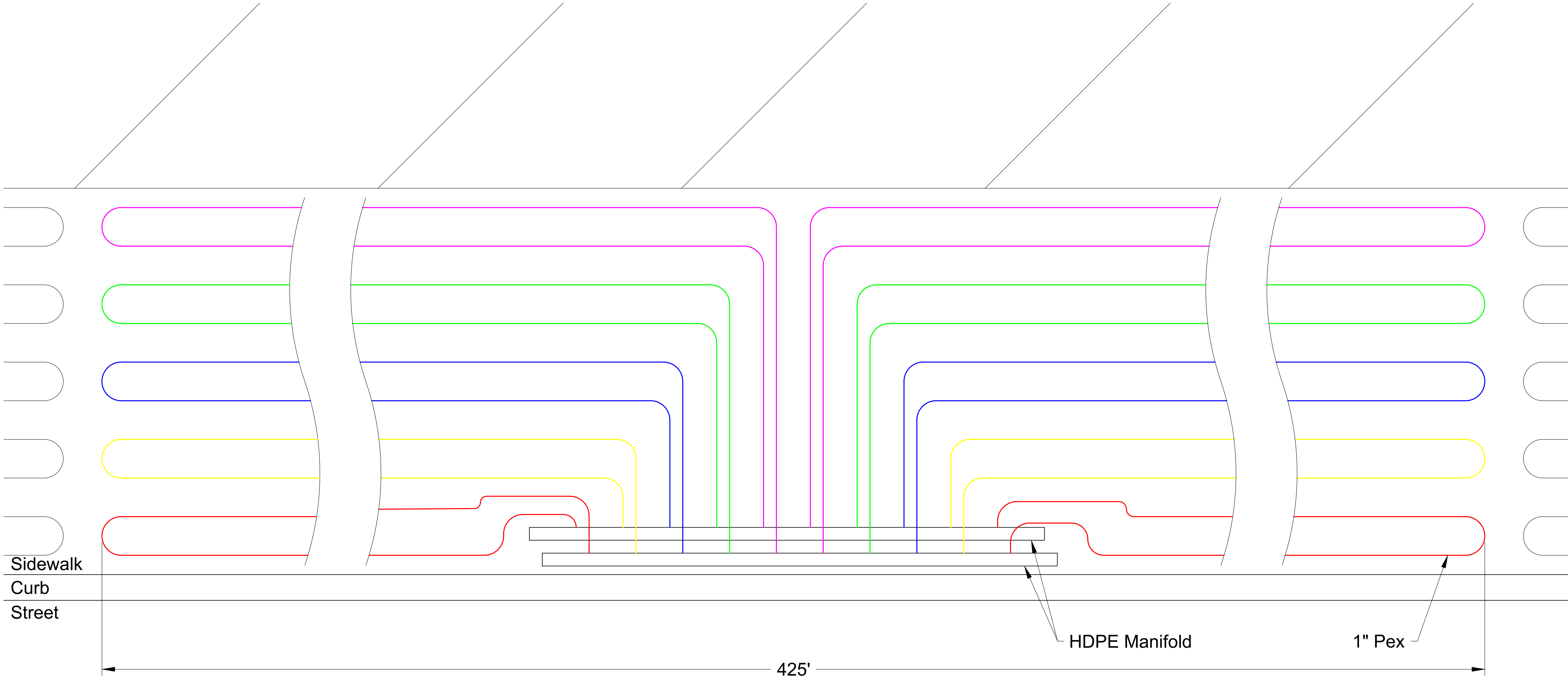

Typical Sidewalk Zone Layout

Scale: 1" = 2'-0"

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Typical Sidewalk Zone Layout
Berlin, NH
Date 9/24/18

A.5

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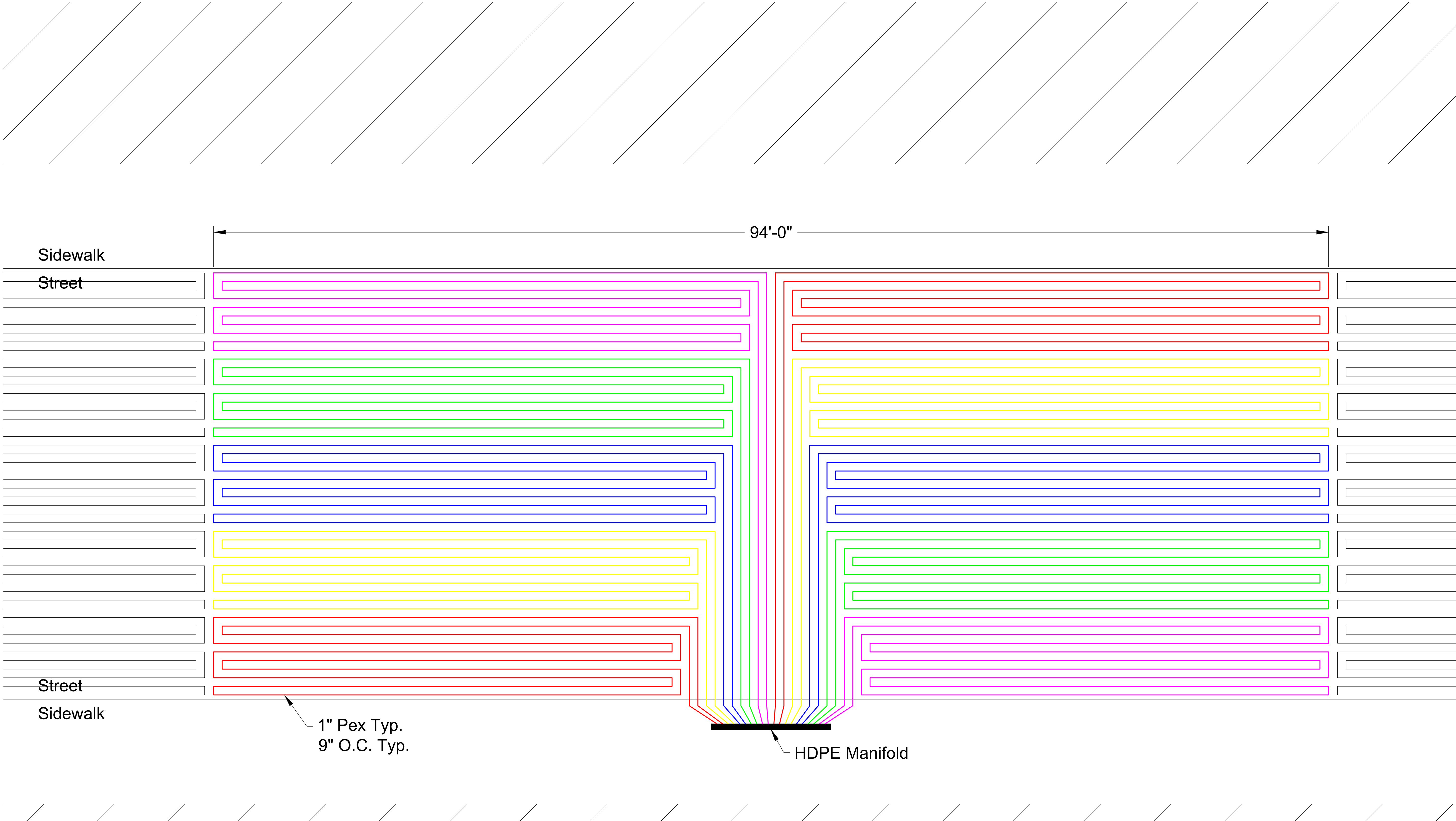

Typical Street Zone Layout

Scale: $\frac{1}{8}$" = 1'-0"

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Typical Street Zone Layout
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A.6

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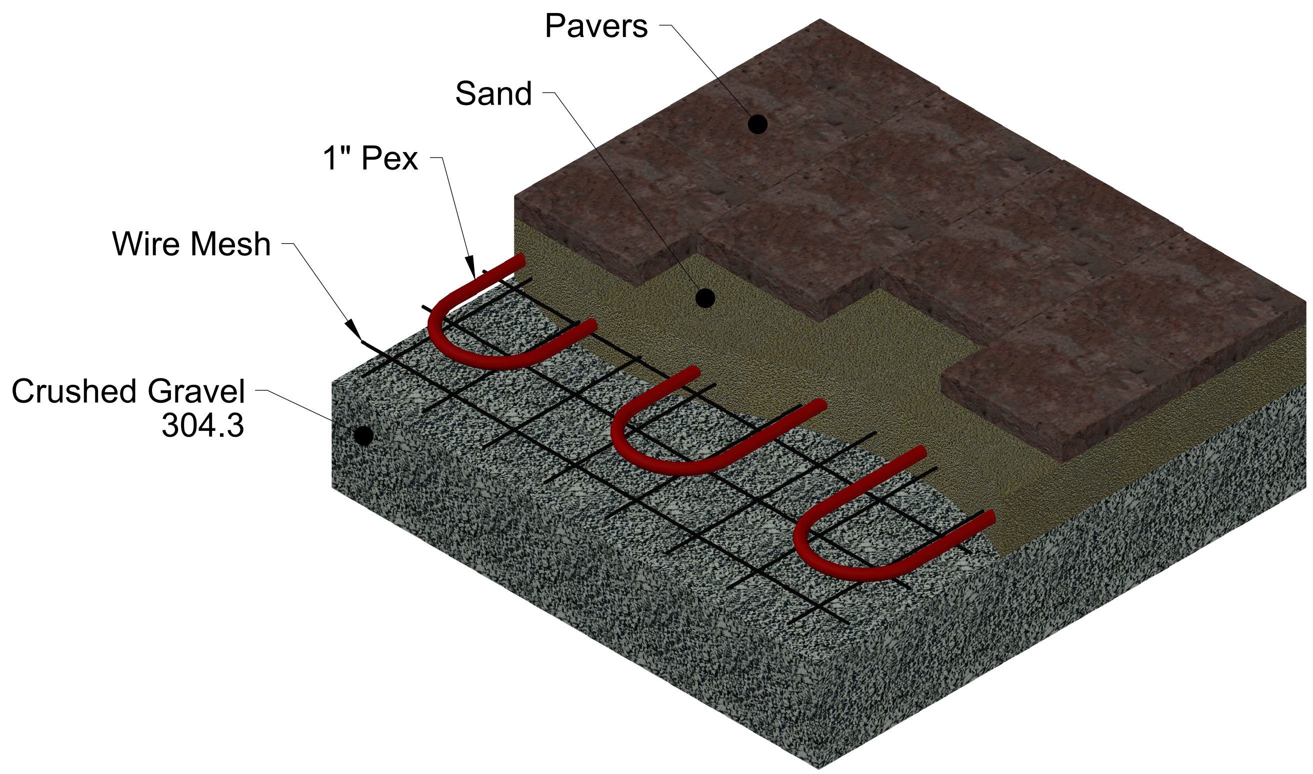

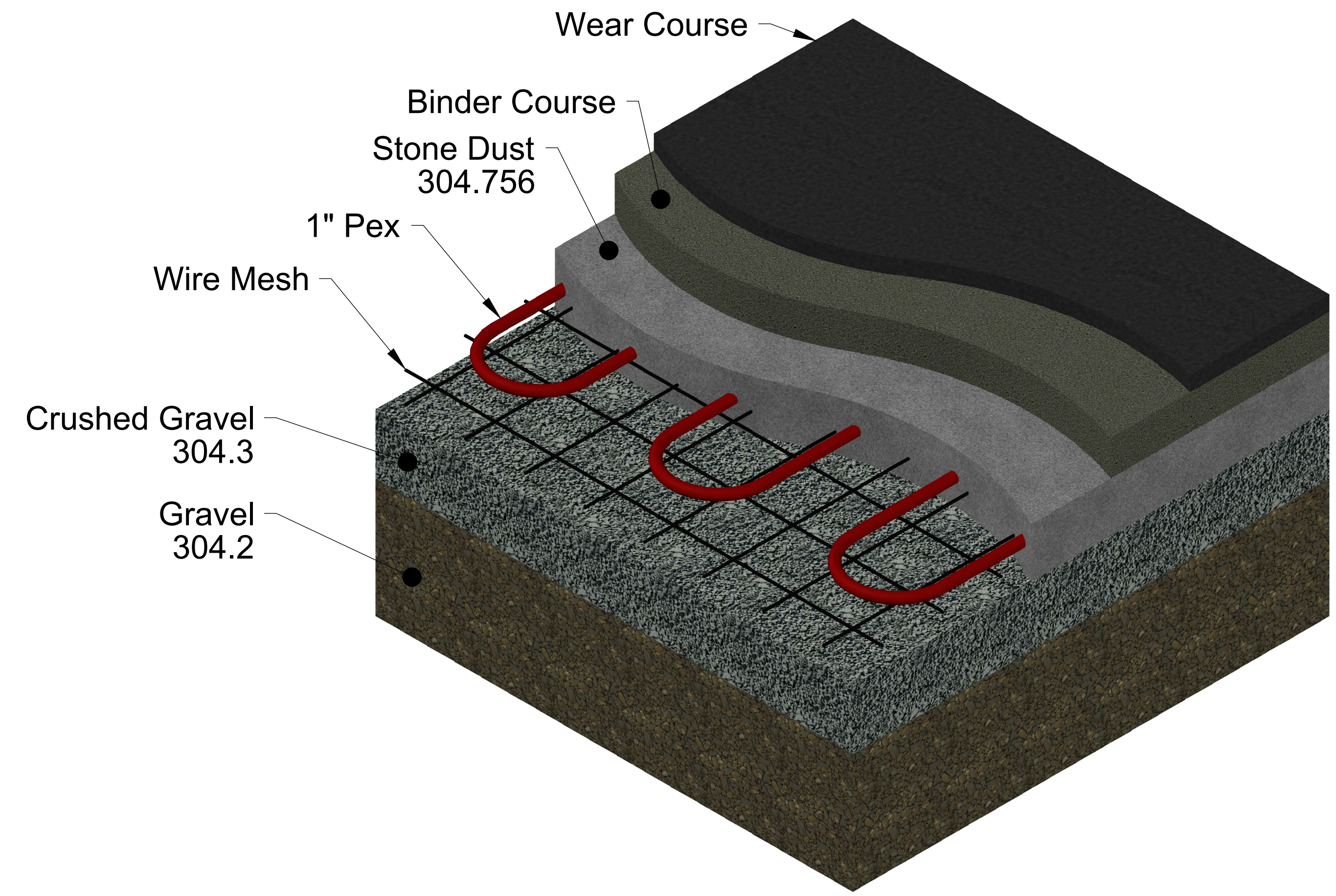

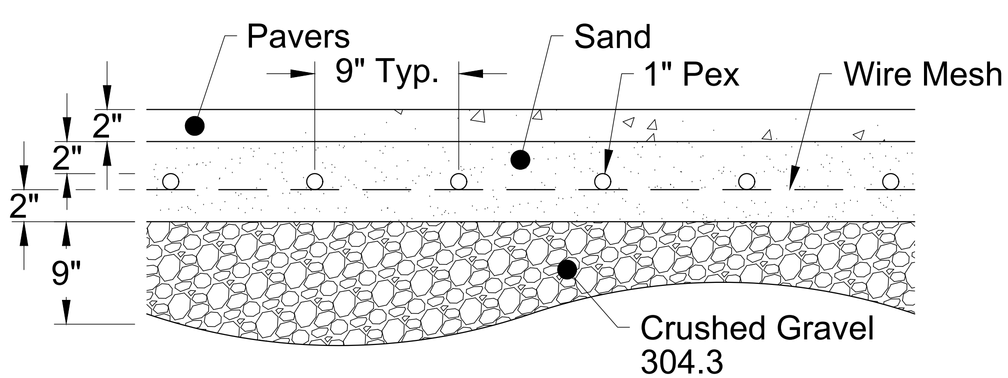

Side Walk

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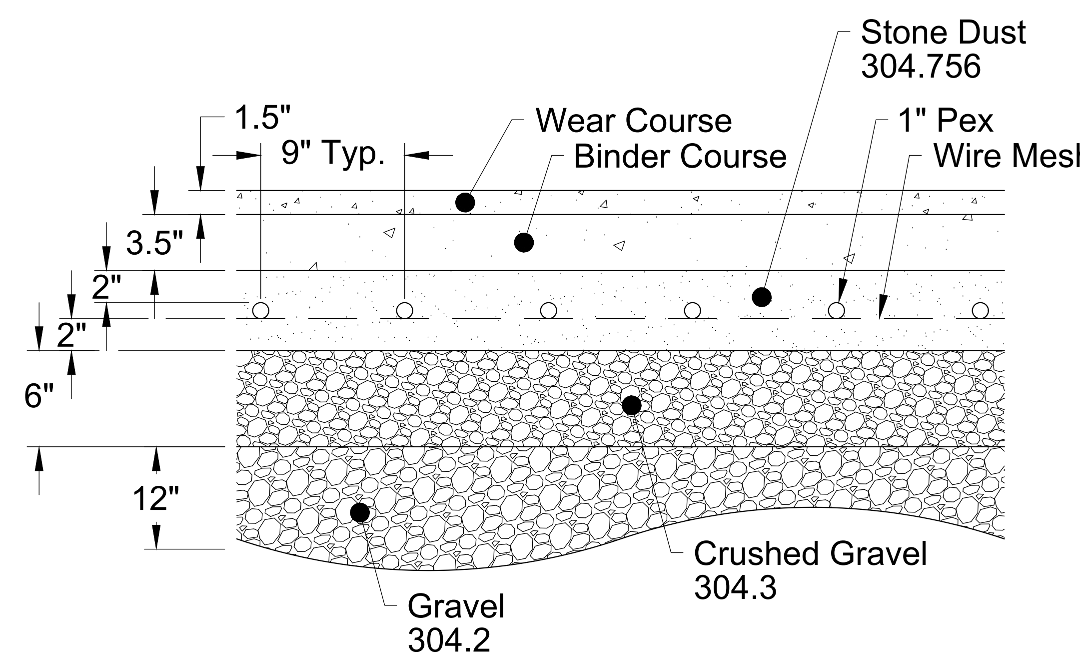

Note: Parking lot/light duty, use Road Way but go to only 8" crushed gravel under the stone dust.

Road Way

Scale: NTS

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Cross Section Details
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A.7

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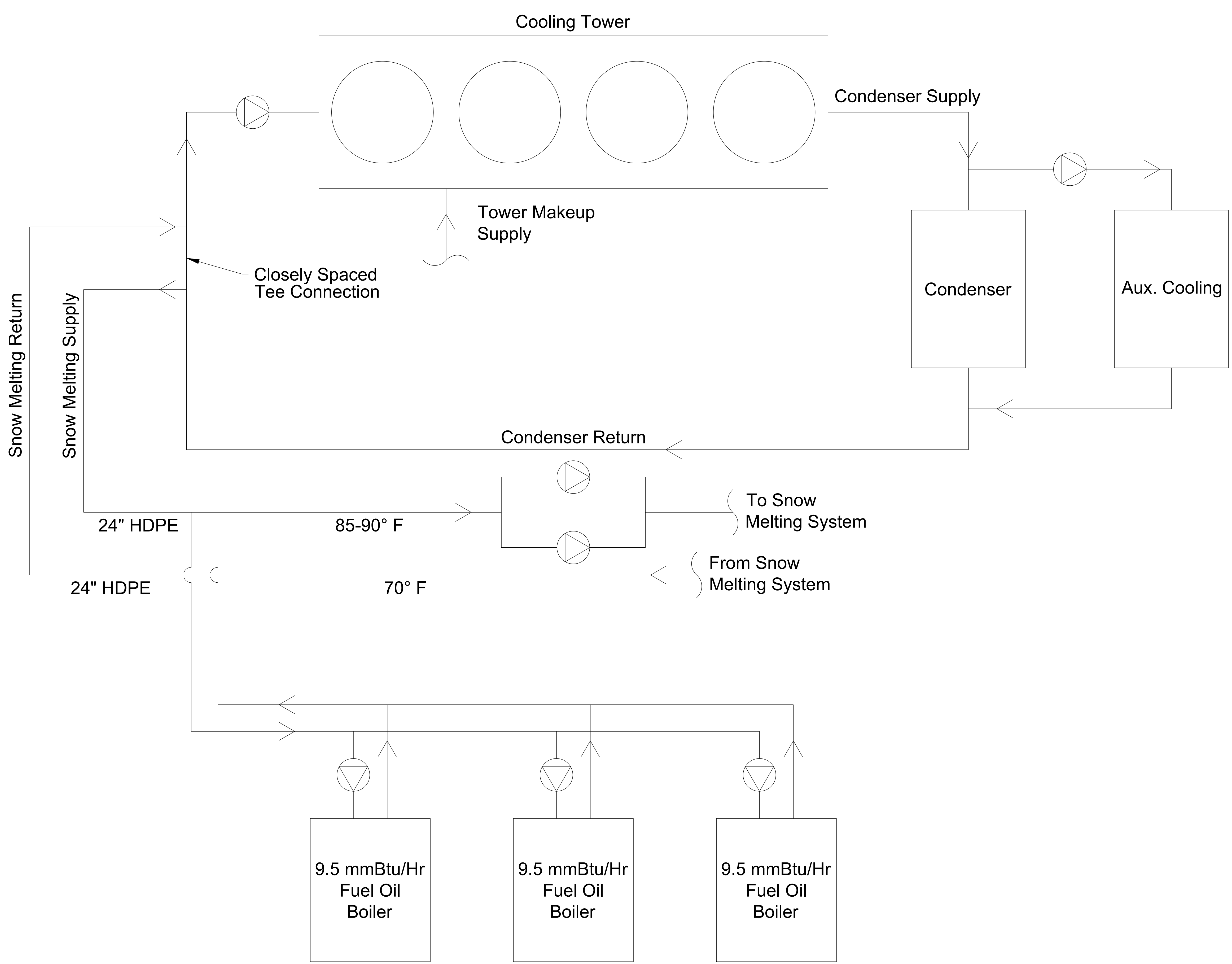

Burgess Biopower Connection Schematic

Scale: NTS

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Burgess Biopower Connection Schematic
Berlin, NH
Date 9/24/18

A.8

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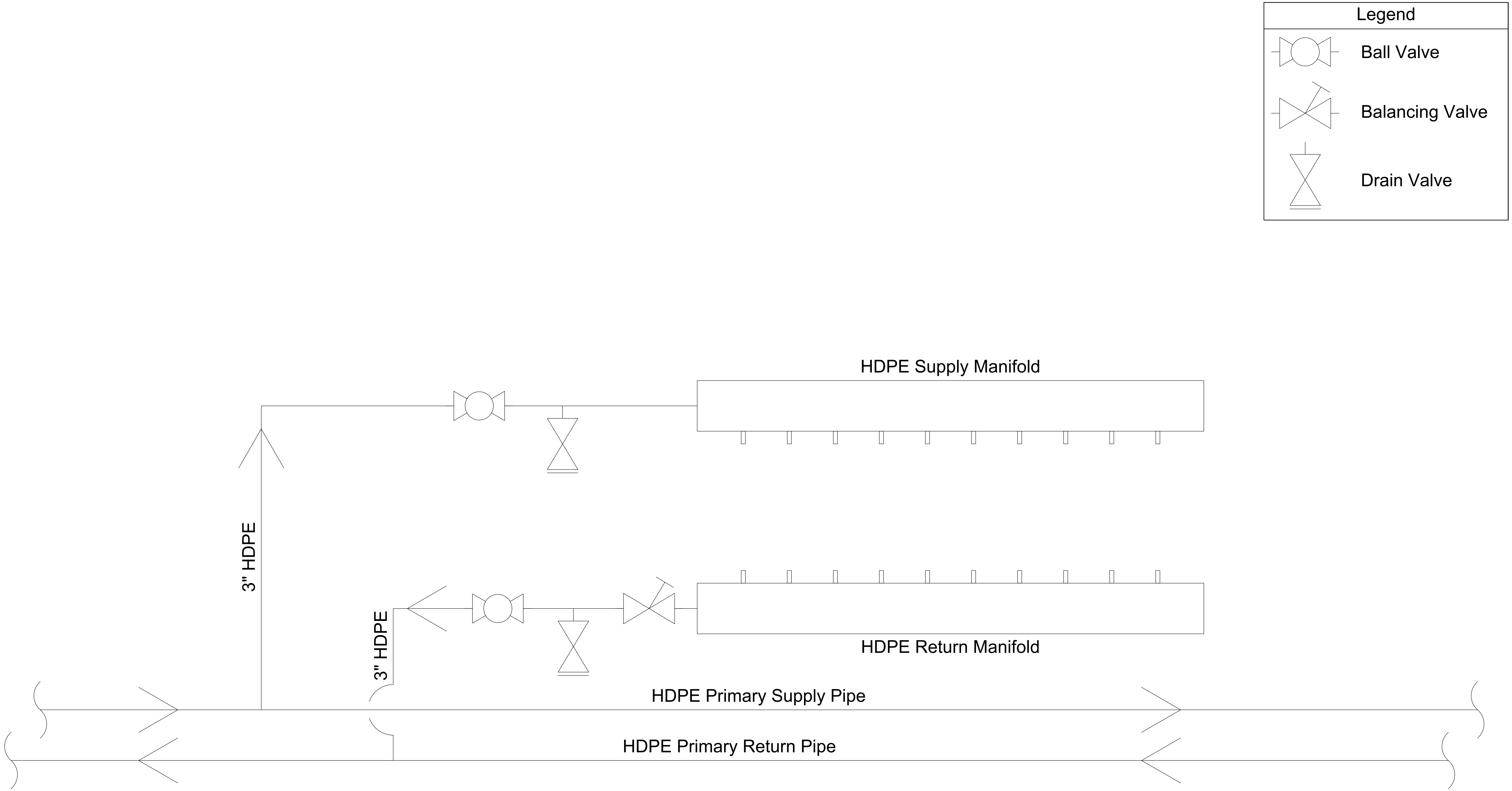

Typical Manifold Connection Schematic

Scale: NTS

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Typical Manifold Connection Schematic
Berlin, NH
Date 9/24/18

A.9

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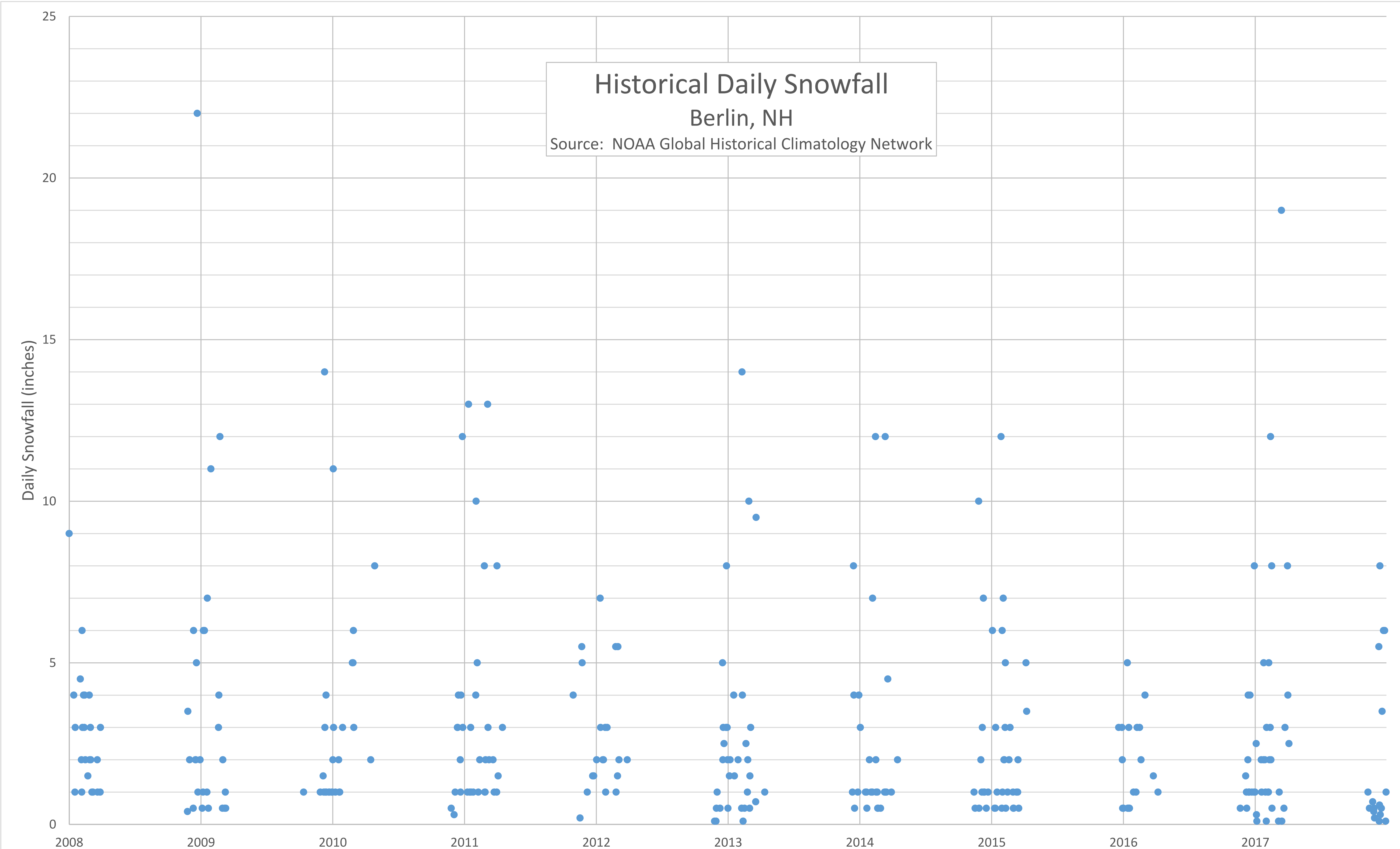
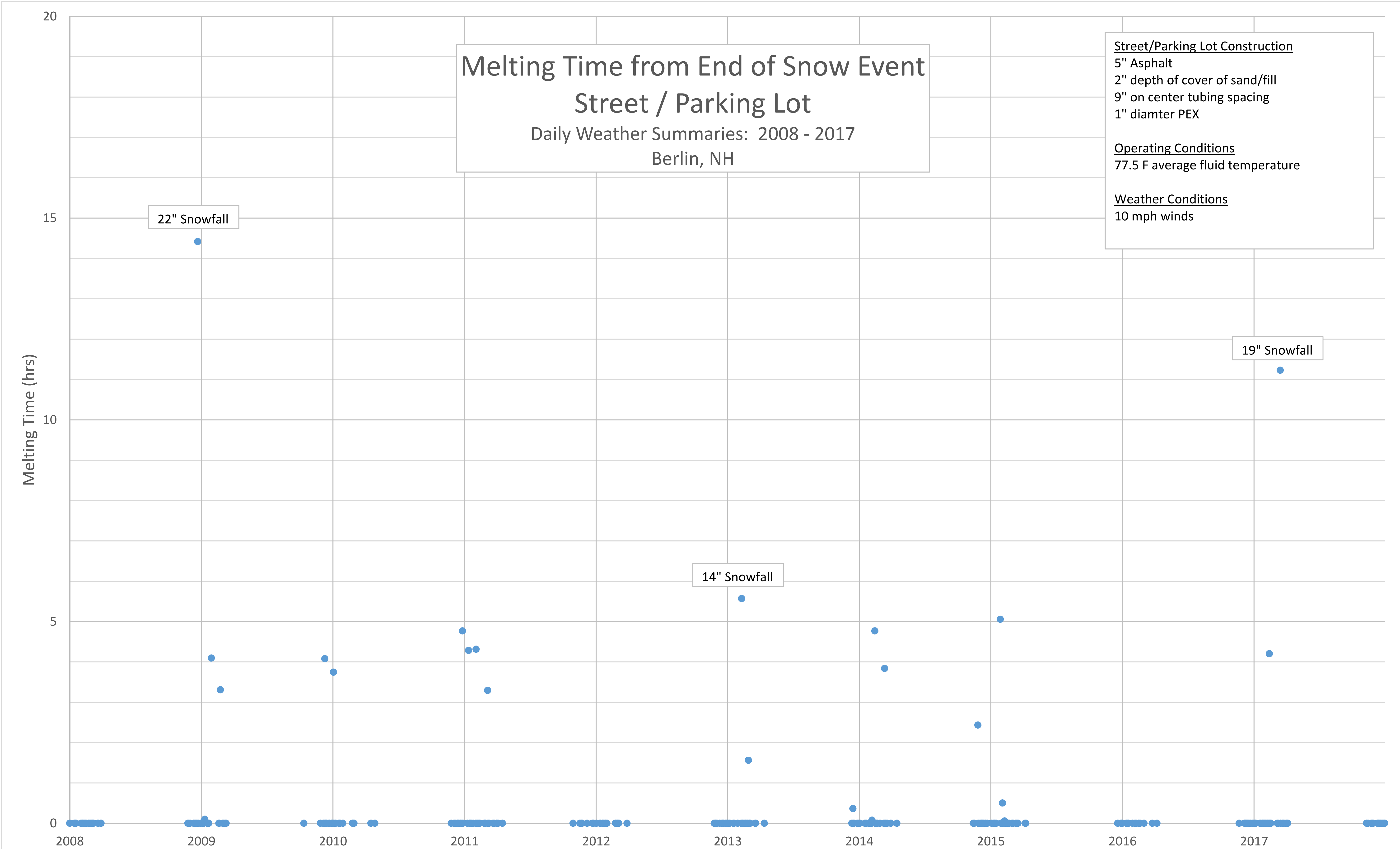
Appendix B

Historical Data and Predicted System Performance

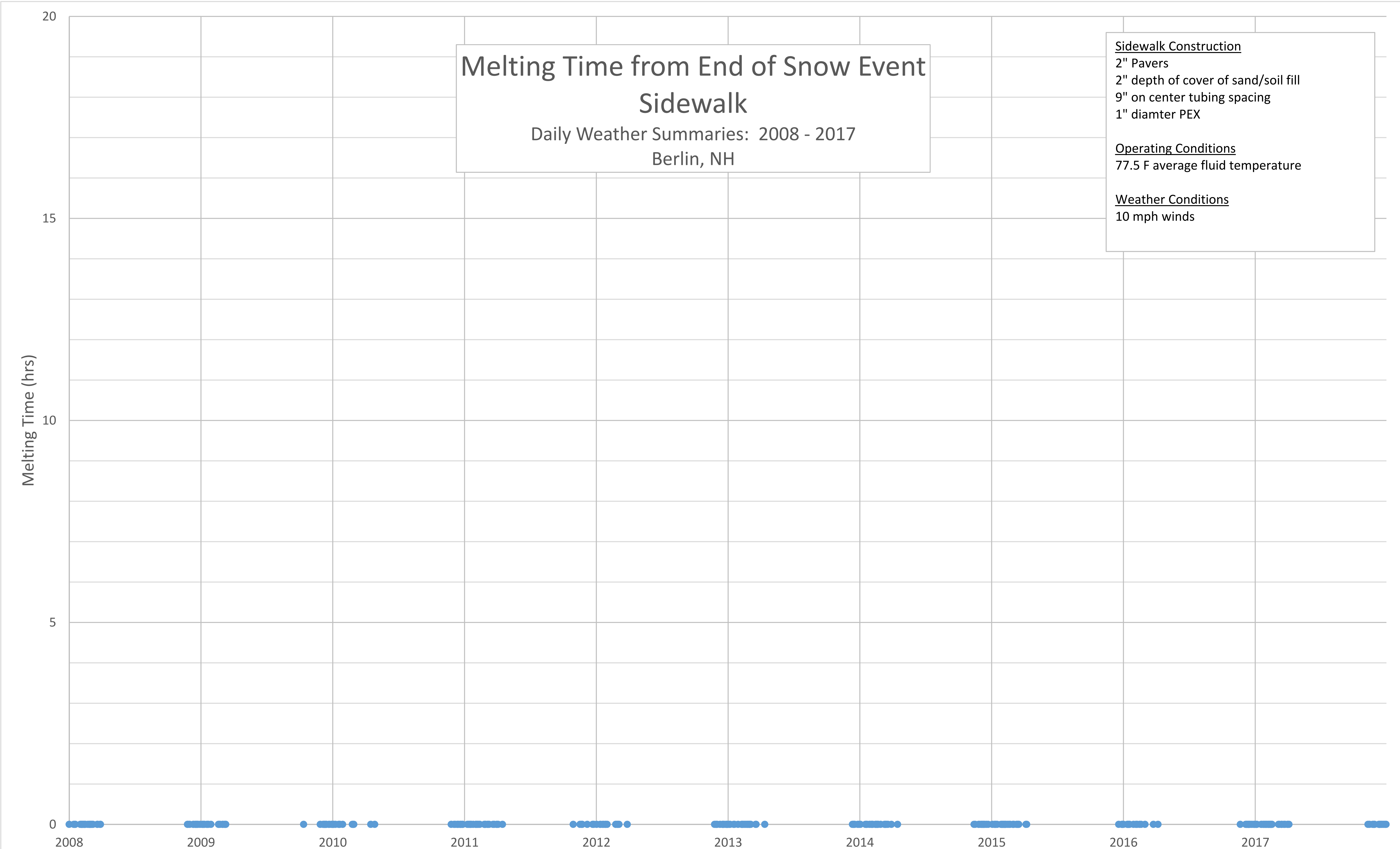
- B.1: Historical Daily Snowfall Data
- B.2: Street/Parking Lot Melting Time from End of Snow Event, 77.5°F average water temperature
- B.3: Sidewalk Melting Time from End of Snow Event, 77.5°F average water temperature
- B.4: Street/Parking Lot Melting Time from End of Snow Event, 90°F average water temperature
- B.5: Sidewalk Melting Time from End of Snow Event, 90°F average water temperature



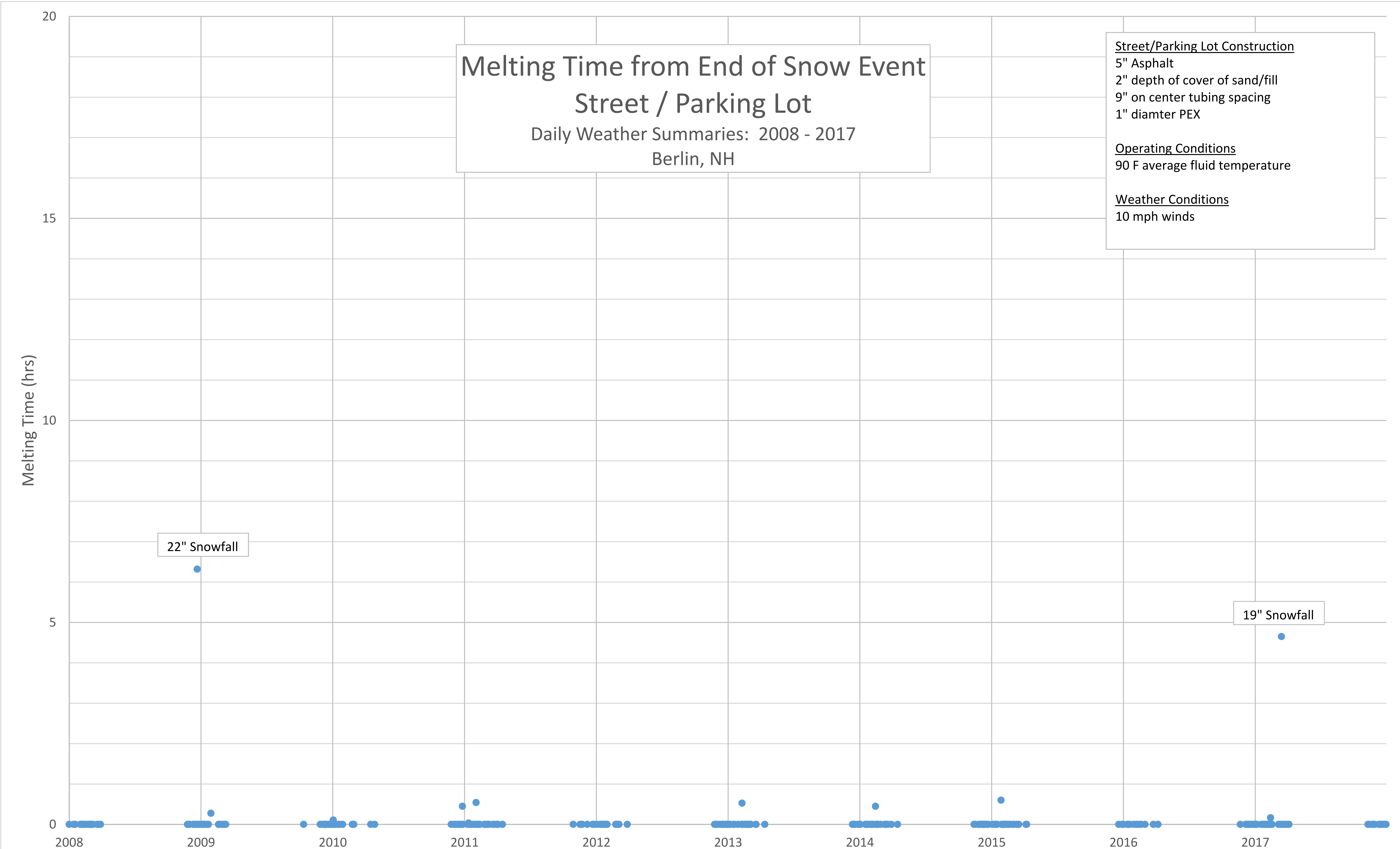
Historical Daily Snowfall
Berlin, NH
Source: NOAA Global Historical Climatology Network
Daily Snowfall (inches)
0
5
10
15
20
25
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017



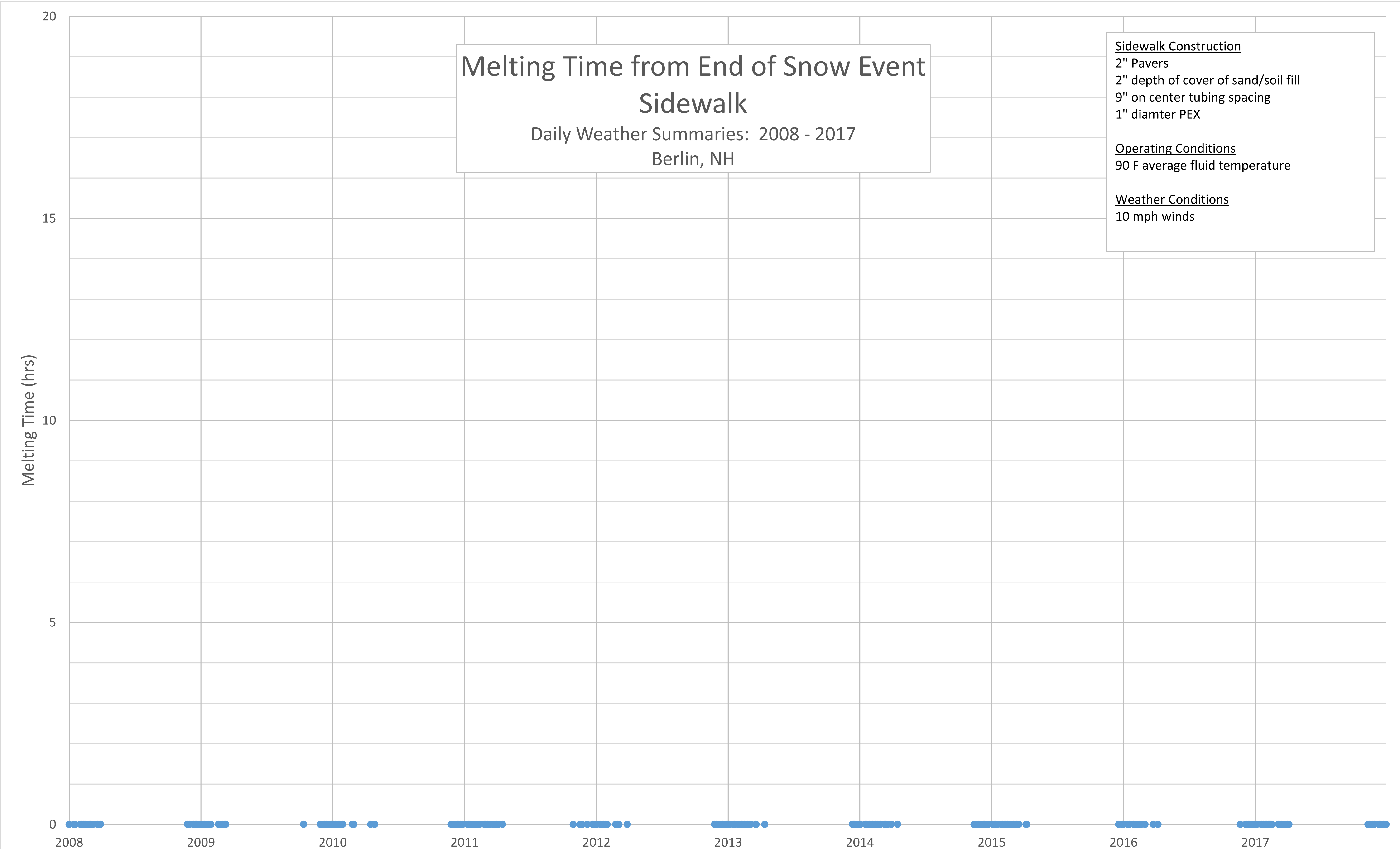
Melting Time from End of Snow Event
Street / Parking Lot
Daily Weather Summaries: 2008 - 2017
Berlin, NH
Street/Parking Lot Construction
5" Asphalt
2" depth of cover of sand/fill
9" on center tubing spacing
1" diamter PEX
Operating Conditions
77.5 F average fluid temperature
Weather Conditions
10 mph winds
22" Snowfall
19" Snowfall
14" Snowfall
Melting Time (hrs)
0
5
10
15
20
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017



Melting Time from End of Snow Event
Sidewalk
Daily Weather Summaries: 2008 - 2017
Berlin, NH
Sidewalk Construction
2" Pavers
2" depth of cover of sand/soil fill
9" on center tubing spacing
1" diamter PEX
Operating Conditions
77.5 F average fluid temperature
Weather Conditions
10 mph winds
Melting Time (hrs)
20
15
10
5
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017



Melting Time from End of Snow Event
Street / Parking Lot
Daily Weather Summaries: 2008 - 2017
Berlin, NH
Street/Parking Lot Construction
5" Asphalt
2" depth of cover of sand/fill
9" on center tubing spacing
1" diamter PEX
Operating Conditions
90 F average fluid temperature
Weather Conditions
10 mph winds
22" Snowfall
19" Snowfall
Melting Time (hrs)
20
15
10
5
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


Melting Time from End of Snow Event
Sidewalk
Daily Weather Summaries: 2008 - 2017
Berlin, NH
Sidewalk Construction
2" Pavers
2" depth of cover of sand/soil fill
9" on center tubing spacing
1" diamter PEX
Operating Conditions
90 F average fluid temperature
Weather Conditions
10 mph winds
Melting Time (hrs)
0
5
10
15
20
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

Appendix C

Cost Estimates

- C.1: Labor, Materials, and Equipment Packages for Existing Snow Plowing, Removal, and Spring Cleaning
- C.2: Snow Melting System Capital Cost Estimate
- C.3: Area Based Unit Costs for Construction

Labor, Materials, and Equipment Packages for Existing Snow Plowing, Removal, and Spring Cleaning

Overall Inputs and Assumptions

Item Description	Value	Units
Equipment salvage value	10%	percent
Maintenance cost as percentage of depreciation	50%	percent
Consumables (oil/grease, etc.) cost as percentage of fuel cost	10%	percent
Fuel cost	$3.15	$/gal
Employee benefits as percentage of wage	35%	percent
Overtime pay increase	50%	percent
Salt cost	$75.00	$/ton
Sand cost	$8.65	$/ton
Administrative costs as percentage of total	15%	percent

Snow Removal Event

Equipment Type	Replacement Cost	Life (hours)	Hourly Depreciation ($/hr)	Hourly Maintenance Cost ($/hr)	Straight Time Loaded Labor Cost ($/hr)
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Snow-blower	$150,000	10,000	$13.50	$6.75	$28.92
SW Tractor	$120,000	10,000	$10.80	$5.40	$27.96
SW Tractor	$120,000	10,000	$10.80	$5.40	$27.96
Bull Dozer	$300,000	10,000	$27.00	$13.50	$28.92
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
10 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
6 Wheeler	$160,000	15,000	$9.60	$4.80	$28.34
Salt Truck	$160,000	15,000	$9.60	$4.80	$28.34
Laborer	-	-	-	-	$27.49
Mechanic	-	-	-	-	$31.16
Mechanic	-	-	-	-	$31.16
Hourly Totals			**$187.95**	**$93.98**	**$544.17**

Item (units)	Value
Fuel use (gals)	700
Event duration (hrs)	7
Salt use (tons)	6
Sand use (tons)	12
Event OT labor cost ($)	$0
Event ST labor cost ($)	$3,809
Event consumables cost ($)	$221

Event Cost	**$10,076**
Total Annual Cost (10 events)	**$100,760**

Snow Plowing (City-wide) Event

Equipment Type	Replacement Cost	Life (hours)	Hourly Depreciation ($/hr)	Hourly Maintenance Cost ($/hr)	Straight Time Loaded Labor Cost ($/hr)
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Loader	$225,000	10,000	$20.25	$10.13	$28.92
Grader	$225,000	15,000	$13.50	$6.75	$28.34
Grader	$225,000	15,000	$13.50	$6.75	$28.34
SW Tractor	$120,000	10,000	$10.80	$5.40	$27.96
SW Tractor	$120,000	10,000	$10.80	$5.40	$27.96
Salt Truck	$160,000	15,000	$9.60	$4.80	$28.34
Mechanic	-	-	-	-	$31.16
Mechanic	-	-	-	-	$31.16
Hourly Totals			**$220.20**	**$110.10**	**$434.58**

Item (units)	Value
Fuel use (gals)	650
Event duration (hrs)	10
Salt use (tons)	200
Sand use (tons)	400
Downtown area (%)	3.6%
Event OT labor cost ($)	$6,519
Event ST labor cost ($)	$0
Event consumables cost ($)	$205

Event Cost	**$1,264**
Total Annual Cost (10 events)	**$12,650**

Spring Cleanup Annual

Equipment Type	Replacement Cost	Life (hours)	Hourly Depreciation ($/hr)	Hourly Maintenance Cost ($/hr)	Straight Time Loaded Labor Cost ($/hr)
Sweeper	$150,000	15,000	$9.00	$4.50	$28.34
SW Tractor	$120,000	10,000	$10.80	$5.40	$27.96
Truck	$40,000	15,000	$2.40	$1.20	$28.34

Item (units)	Value
Fuel Use (gal)	342
Total use - Sweeper (hrs)	32
Total use - SW Tractor (hrs)	22
Total use - Truck (hrs)	8
Total OT labor cost ($)	$0
Total ST labor cost ($)	$1,749
Total consumables cost ($)	$108

Total Annual Cost	**$4,310**

City of Berlin - Budget Estimate - General Breakdown
Snow-melting System Installation

Cost Estimate Narrative:

The cost estimate is a budgetary/planning level estimate. It is based on the feasibility study layout of the snowmelt system by Wilson Engineering Services, PC. The estimate covers the cost of a snowmelt system that is constructed in conjunction and concurrently with an overall downtown streetscape project. The purpose of this estimate is to identify the increased total cost of a streetscape project for a snowmelt system including: interconnection to Burgess Power condenser water system, pumphouse with backup electric and boiler systems, main run HDPE piping systems, snowmelt system specialties, junction boxes, manifolds, and valving. Costs associated with street, parking lot, and sidewalk base courses, paving, and pavers are estimated separately.

	Initial Buildout Total Coverage Area, sf	*381,000*
Item	**Cost**	**Cost/SF**
General Conditions	$719,500	$1.89
Pumphouse Building / Plant Connection Site Work	$507,600	$1.33
Pumphouse/Plant Connection Mechanical Systems	$586,500	$1.54
Pumphouse Backup Energy Systems	$882,700	$2.32
River Crossing - Directional Drilling or Pipe Bridge	$415,000	$1.09
Snowmelt System in Downtown	$3,025,300	$7.94
Construction Contingency	$613,700	$1.61
Contractor Profit/OH/Markup	$920,500	$2.42
Professional Services	$613,700	$1.61
Total	**$8,284,500**	**$21.74**

Fixed Cost for Snowmelt System (not area based)	***$3,657,837***	***$9.60***
Area Based Cost for Snowmelt System	***$4,626,663***	***$12.14***

City of Berlin - Budget Estimate Division Summary
Snow-melting System Installation

Cost Estimate Narrative:
The cost estimate is a budgetary/planning level estimate. It is based on the feasibility study layout of the snowmelt system by Wilson Engineering Services, PC. The estimate covers the cost of a snowmelt system that is constructed in conjunction and concurrently with an overall downtown streetscape project. The purpose of this estimate is to identify the increased total cost of a streetscape project for a snowmelt system including: interconnection to Burgess Power condenser water system, pumphouse with backup electric and boiler systems, main run HDPE piping systems, snowmelt system specialties, junction boxes, manifolds, and valving. Costs associated with street, parking lot, and sidewalk base courses, paving, and pavers are estimated separately.

	Snowmelt SF	*381,000*
Division	**Cost**	**Cost/SF**
Division 01 - General Requirements	$719,500	$1.89
Division 02 - Existing Conditions	$0	$0.00
Division 03 - Concrete	$48,500	$0.13
Division 04 - Masonry	$94,500	$0.25
Division 05 - Metals	$48,000	$0.13
Division 06 - Rough Carpentry and Sheathing	$45,000	$0.12
Division 07 - Thermal & Moisture Protection	$2,700	$0.01
Division 08 - Openings	$5,500	$0.01
Division 09 - Finishes	$0	$0.00
Division 10 - Specialties	$0	$0.00
Division 11 - Equipment	$50,000	$0.13
Division 12 - Furnishings	$0	$0.00
Division 13 - Special Construction	$415,000	$1.09
Division 14 - Conveying Equipment	$0	$0.00
Division 23 - Mechanical	$4,076,200	$10.70
Division 26 - Electrical	$295,000	$0.77
Division 31 - Earthwork	$256,700	$0.67
Division 32 - Exterior Improvements	$55,000	$0.14
Division 33 - Site Utilities	$25,000	$0.07
Subtotal	*$6,136,600*	*$16.11*
Contingency (10%)	$613,700	$1.61
Contractor Markup / Profit / OH (15%)	$920,500	$2.42
Professional Services (A/E, Permits, CM) (10%)	$613,700	$1.61
Project Cost Estimate	**$8,284,500**	**$21.74**

Alternates

Alt 1 -	$0
Alt 2 -	$0
Alt 3 -	$0
Alt 4 -	$0

Project Berlin Snow-melting System and Pumphouse / Plant Connection
Sq. Ft. 381,000
Date October 2, 2018

	Estimate	# Units	Units	Unit Rate	Cost/SF
Division 01 - General Requirements					
Project Supervision - Superintendent and Project Manager	$192,000	30	wks	$6,400	
Lodging / Per Diem	$103,500	30	wks	$3,450	
Construction Fencing - Pumphouse and plant connection only	$24,000	30	wks	$800	
Silt Fence - Pumphouse and plant connection only	$5,000	1,000	lf	$5	
Bond and insurance	$240,000	4	percent	-	
Construction Trailer and Temp Facilities	$105,000	30	wks	$3,500	
Miscellaneous	$50,000	1	ls	$50,000	
Division Total	$719,500				$2
Division 02 - Existing Conditions					
Miscellaneous					
Division Total	$0				$0
Division 03 - Concrete					
Pumphouse concrete, slab, footer, foundation walls, pads	$45,000	100	cy	$450	
Flatwork for pumphouse access	$3,500	10	cy	$350	
Miscellaneous					
Division Total	$48,500				$0
Division 04 - Masonry					
Insulated block with rebar, grout, and wire - installed - pumphouse	$94,500	2,700	sf	$35	
Miscellaneous					
Division Total	$94,500				$0

Project Berlin Snow-melting System and Pumphouse / Plant Connection
Sq. Ft. 381,000
Date October 2, 2018

	Estimate	# Units	Units	Unit Rate	Cost/SF
Division 05 - Metals					
Steel truss and structural steel - pumphouse	$45,000	1,800	sf	$25	
Miscellaneous	$3,000	1	ls	$3,000	
Division Total	$48,000				$0
Division 06 - Rough Carpentry and Sheathing					
Roof sheathing, insulation, EPDM, etc. for complete roofing system for pumphouse	$45,000	1,800	sf	$25	
Miscellaneous					
Division Total	$45,000				$0
Division 07 - Thermal & Moisture Protection					
Foundation insulation for pumphouse	$2,700	180	lf	$15	
Miscellaneous					
Division Total	$2,700				$0
Division 08 - Openings					
Doors and OH Door for pumphouse	$5,500	1	ls	$5,500	
Miscellaneous					
Division Total	$5,500				$0
Division 09 - Finishes					
Miscellaneous					
Division Total	$0				$0
Division 10 - Specialties					
Miscellaneous					
Division Total	$0				$0
Division 11 - Equipment					
100-ton crane rental	$50,000	10	days	$5,000	
Miscellaneous					
Division Total	$50,000				$0

Project Berlin Snow-melting System and Pumphouse / Plant Connection
Sq. Ft. 381,000
Date October 2, 2018

	Estimate	# Units	Units	Unit Rate	Cost/SF
Division 12 - Furnishings					
Miscellaneous					
Division Total	$0				$0
Division 13 - Special Construction					
Prefabricated 24" Pipe Bridge	$415,000	1	ls	$415,000	
Miscellaneous					
Division Total	$415,000				$1
Division 14 - Conveying Equipment					
Miscellaneous					
Division Total	$0				$0
Division 23 - Mechanical					
Condensing boilers (CB-CFCL 8000 or similar)	$366,000	3	units	$122,000	
Propane tank (18,000 gallons) and LP evaporator	$250,000	1	units	$250,000	
75 hp pumps for district system	$41,300	3	units	$13,750	
Boiler pumps (7.5 hp)	$10,500	3	units	$3,500	
6" butterlfy vavles in pumphouse	$16,200	18	units	$900	
8" butterfly vavles in pumphouse	$14,400	8	units	$1,800	
8" check vavles in pumphouse	$10,800	3	units	$3,600	
16" butterlfy valves in pumphouse	$42,000	6	units	$7,000	
24" spirotherm	$49,000	1	units	$49,000	
Pumphouse and boiler room piping and fittings	$150,000	1	ls	$150,000	
Boiler installation	$65,000	1	ls	$65,000	
24" Inline Mag Meter, RTDs, thermowells, BTU computer, and export to FTP	$19,000	1	ls	$19,000	
Mechanical for connection to condenser water	$175,000	1	ls	$175,000	
Snowmelt system materials, 3" HDPE manifolds, pex piping, fittings, wire ties, etc.	$1,750,000	1	ls	$1,750,000	
Welded wire mesh	$61,000	381,000	sf	$0	
Access boxes	$204,000	120	units	$1,700	
HDPE piping for supply and return mains	$450,000	1	ls	$450,000	
Mechanical installation - labor, fusion machine rental, tools, consumables	$402,000	30	wks	$13,400	
Miscellaneous					
Division Total	$4,076,200				$11

Project Berlin Snow-melting System and Pumphouse / Plant Connection
Sq. Ft. 381,000
Date October 2, 2018

	Estimate	# Units	Units	Unit Rate	Cost/SF
Division 26 - Electrical					
250 kW Emergency Generator, ATS, Installation	$175,000	1	units	$175,000	
Electrical for building (600 amp, 480V, 3ph service and panel, and low-voltage sub-panel)	$85,000	1	ls	$85,000	
Pumphouse monitoring system (based off packaged industrial controls platform (Redlion or similar))	$35,000	1	ls	$35,000	
Miscellaneous					
Division Total	$295,000				$1
Division 31 - Earthwork					
Excavator, operator, consumables - Pumphouse / Plant Connection	$48,000	30	days	$1,600	
Building / utilities construction labor - Pumphouse / Plant Connection	$50,400	30	days	$1,680	
Increased base materials for snow-melting over typical sections	$158,300	293,000	sf	$0.54	
Miscellaneous					
Division Total	$256,700				$1
Division 32 - Exterior Improvements					
Paving (subgrade, basecourse, binder, surface) - repair pumphouse/plant	$30,000	2,000	sf	$15	
Miscellaneous (curbs, grass, etc. for pumphouse/plant repair)	$25,000	1	ls	$25,000	
Division Total	$55,000				$0
Division 33 - Site Utilities					
1" waterline, meter, BFP, connection for pumphouse	$10,000	1	ls	$10,000	
Sewerline and fittings / connection for pumphouse	$15,000	1	ls	$15,000	
Miscellaneous					
Division Total	$25,000				$0

Project Berlin Snow-melting System and Pumphouse / Plant Connection
Sq. Ft. 381,000
Date October 2, 2018

	Estimate	# Units	Units	Unit Rate	Cost/SF
Subtotal	$6,136,600				$16.11
Contingency (10%)	$613,700	0.10			
Contractor Markup / Profit / OH (15%)	$920,500	0.15			
Professional Services (A/E, Permits, CM) (10%)	$613,700	0.10			
Total Project Estimate	$8,284,500				$22
Alt 1 -					
Miscellaneous					
Total	$0				
Alt 2 -					
Miscellaneous					
Total	$0				
Alt 3 -					
Miscellaneous					
Total	$0				
Alt 4 -					
Miscellaneous					
Total	$0				

City of Berlin - Square Footage Based Costs
Typical Section Costs with and witout Snow-melting

Cost Estimate Narrative:

This cost estimate sheet is developed to provide order of magnitude unit costs per square foot construction of several types of downtown surfaces in Berlin, NH when completed as part of a major overall downtown streetscape project. The purpose of this estimate is to identify the general order of magnitude increase in cost to add snow-melting systems to these sections. The snow-melting costs are limited to only the incremental area-based costs of a snow-melting system. The main heat source, pumping, river crossing, and other fixed infrastructure costs are not included in these per square foot unit costs.

Road Paving Section							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Estimated Cost/unit**	**Cost/SF**
Hot Bituminous - 403.11	5	0.42	145	0.030	tons	$115.00	$3.47
Base Course - 304.3	6	0.50		0.019	cy	$36.00	$0.67
SubBase - 304.2	12	1.00		0.037	cy	$30.00	$1.11
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$5.00
						Total Cost per SF	**$10.25**

Concrete Paver Section							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Average Cost/unit**	**Cost/SF**
Concrete Pavers				0.111	sy	$81.00	$9.00
Granular Fill - 304.1	5	0.42		0.015	cy	$35.00	$0.54
Base Course - 304.3	9	0.75		0.028	cy	$36.00	$1.00
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$5.00
						Total Cost per SF	**$15.54**

Parking Lot Paving Section							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Estimated Cost/unit**	**Cost/SF**
Hot Bituminous - 403.11	4	0.33	145	0.024	tons	$115.00	$2.78
Base Course - 304.3	6	0.50		0.019	cy	$36.00	$0.67
SubBase - 304.2	12	1.00		0.037	cy	$30.00	$1.11
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$4.00
						Total Cost per SF	**$8.56**

Road Paving Section With Snowmelt Area-Based Variable Costs							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Average Cost/unit**	**Cost/SF**
Hot Bituminous - 403.11	5	0.42	145	0.030	tons	$115.00	$3.47
Granular Fill - 304.1	5	0.42		0.015	cy	$35.00	$0.54
Base Course - 304.3	6	0.50		0.019	cy	$36.00	$0.67
SubBase - 304.2	12	1.00		0.037	cy	$30.00	$1.11
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$5.00
Snowmelt system area-based variable costs							$12.19
						Total Cost per SF	**$22.98**

Concrete Paver Section With Snowmelt Area-Based Variable Costs							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Average Cost/unit**	**Cost/SF**
Concrete Pavers				0.111	sy	$81.00	$9.00
Granular Fill - 304.1	5	0.42		0.015	cy	$35.00	$0.54
Base Course - 304.3	9	0.75		0.028	cy	$36.00	$1.00
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$5.00
Snowmelt system area-based variable costs							$12.19
						Total Cost per SF	**$27.73**

Parking Lot Paving Section Area-Based Variable Costs							
Item	**Thickness, in**	**Quantity, ft^3/SF**	**Density, lb/ft^3**	**Pricing Quantity, Unit/SF**	**Units**	**Estimated Cost/unit**	**Cost/SF**
Hot Bituminous - 403.11	4	0.33	145	0.024	tons	$115.00	$2.78
Granular Fill - 304.1	5	0.42		0.015	cy	$35.00	$0.54
Base Course - 304.3	6	0.50		0.019	cy	$36.00	$0.67
SubBase - 304.2	12	1.00		0.037	cy	$30.00	$1.11
General Conditions, Utilities, Curbs, Plantings, Contingency, Professional Services, Profit, OH, Etc.							$4.00
Snowmelt system area-based variable costs							$12.19
						Total Cost per SF	**$21.28**

Appendix D

Life Cycle Cost Analysis

- D.1: 25-Year Life Cycle Cost Analysis
- D.2: 25-Year Life Cycle Cost Analysis w/ 30% Grant Funding
- D.3: 25-Year Life Cycle Cost Analysis w/ 60% Grant Funding
- D.4: 25-Year Life Cycle Cost Analysis w/ 90% Grant Funding
- D.5: 25-Year Life Cycle Cost Analysis w/ 100% Grant Funding

25-Year Life Cycle Cost Analysis
0% Grant Funding

Input Variables	Value	Units
Project Cost	$8,284,500	$
Grant Funding	$0	$
Project Costs Financed	$8,284,500	$
Financing Interest Rate	5%	percent
Financing Term	15	years
O&M Costs	$70,400	$/yr
Avoided Snow Management Costs	$117,720	$/yr
Thermal REC Generated	72,675	mmBtu
Thermal REC Value	$7.18	$/mmBtu
General Inflation Rate	2.7%	percent
Real Discount Rate	3%	percent

Year	O&M Costs	Avoided Snow Management Costs	REC Value	Net Operating Savings	Financing Cost	Present Value of Cash Flow
1	$ (70,400)	$ 117,720	$ 521,846	$ 569,166	$ (798,148)	$ (228,982)
2	$ (72,054)	$ 121,438	$ 521,846	$ 571,229	$ (798,148)	$ (220,309)
3	$ (76,873)	$ 128,316	$ 521,846	$ 573,289	$ (798,148)	$ (211,951)
4	$ (79,728)	$ 134,624	$ 521,846	$ 576,741	$ (798,148)	$ (202,618)
5	$ (81,821)	$ 139,719	$ 521,846	$ 579,744	$ (798,148)	$ (194,049)
6	$ (84,914)	$ 144,691	$ 521,846	$ 581,622	$ (798,148)	$ (186,777)
7	$ (88,179)	$ 148,906	$ 521,846	$ 582,573	$ (798,148)	$ (180,541)
8	$ (91,268)	$ 153,242	$ 521,846	$ 583,820	$ (798,148)	$ (174,268)
9	$ (94,393)	$ 157,380	$ 521,846	$ 584,833	$ (798,148)	$ (168,393)
10	$ (97,315)	$ 161,629	$ 521,846	$ 586,160	$ (798,148)	$ (162,471)
11	$ (100,327)	$ 166,336	$ 521,846	$ 587,855	$ (798,148)	$ (156,478)
12	$ (103,357)	$ 171,531	$ 521,846	$ 590,019	$ (798,148)	$ (150,356)
13	$ (106,883)	$ 176,162	$ 521,846	$ 591,125	$ (798,148)	$ (145,202)
14	$ (110,524)	$ 181,661	$ 521,846	$ 592,983	$ (798,148)	$ (139,707)
15	$ (113,430)	$ 186,947	$ 521,846	$ 595,363	$ (798,148)	$ (134,065)
16	$ (117,646)	$ 191,994	$ -	$ 74,348	$ -	$ 47,721
17	$ (121,190)	$ 197,982	$ -	$ 76,792	$ -	$ 47,854
18	$ (124,840)	$ 203,328	$ -	$ 78,488	$ -	$ 47,486
19	$ (128,598)	$ 209,242	$ -	$ 80,643	$ -	$ 47,369
20	$ (132,956)	$ 215,762	$ -	$ 82,806	$ -	$ 47,223
21	$ (137,364)	$ 222,035	$ -	$ 84,671	$ -	$ 46,880
22	$ (141,493)	$ 228,030	$ -	$ 86,537	$ -	$ 46,518
23	$ (146,273)	$ 234,658	$ -	$ 88,386	$ -	$ 46,128
24	$ (150,665)	$ 241,479	$ -	$ 90,814	$ -	$ 46,014
25	$ (154,733)	$ 248,496	$ -	$ 93,763	$ -	$ 46,125
					25-Yr Net Present Value	**$ (2,186,848)**

Notes:

1. All prices are presented in real terms.
2. Electric and propane costs are escalated based on energy price indices presented in the 2018 Annual Supplement to NIST Handbook 135 - Table Ca-1.
3. Depreciated value of capital expenditures at end of 25-year period are not considered.

25-Year Life Cycle Cost Analysis
30% Grant Funding

Input Variables	Value	Units
Project Cost	$8,284,500	$
Grant Funding	$2,485,350	$
Project Costs Financed	$5,799,150	$
Financing Interest Rate	5%	percent
Financing Term	15	years
O&M Costs	$70,400	$/yr
Avoided Snow Management Costs	$117,720	$/yr
Thermal REC Generated	72,675	mmBtu
Thermal REC Value	$7.18	$/mmBtu
General Inflation Rate	2.7%	percent
Real Discount Rate	3%	percent

Year	O&M Costs	Avoided Snow Management Costs	REC Value	Net Operating Savings	Financing Cost	Present Value of Cash Flow
1	$ (70,400)	$ 117,720	$ 521,846	$ 569,166	$ (558,703)	$ 10,462
2	$ (72,054)	$ 121,438	$ 521,846	$ 571,229	$ (558,703)	$ 12,161
3	$ (76,873)	$ 128,316	$ 521,846	$ 573,289	$ (558,703)	$ 13,748
4	$ (79,728)	$ 134,624	$ 521,846	$ 576,741	$ (558,703)	$ 16,507
5	$ (81,821)	$ 139,719	$ 521,846	$ 579,744	$ (558,703)	$ 18,694
6	$ (84,914)	$ 144,691	$ 521,846	$ 581,622	$ (558,703)	$ 19,770
7	$ (88,179)	$ 148,906	$ 521,846	$ 582,573	$ (558,703)	$ 19,990
8	$ (91,268)	$ 153,242	$ 521,846	$ 583,820	$ (558,703)	$ 20,422
9	$ (94,393)	$ 157,380	$ 521,846	$ 584,833	$ (558,703)	$ 20,627
10	$ (97,315)	$ 161,629	$ 521,846	$ 586,160	$ (558,703)	$ 21,043
11	$ (100,327)	$ 166,336	$ 521,846	$ 587,855	$ (558,703)	$ 21,691
12	$ (103,357)	$ 171,531	$ 521,846	$ 590,019	$ (558,703)	$ 22,623
13	$ (106,883)	$ 176,162	$ 521,846	$ 591,125	$ (558,703)	$ 22,740
14	$ (110,524)	$ 181,661	$ 521,846	$ 592,983	$ (558,703)	$ 23,342
15	$ (113,430)	$ 186,947	$ 521,846	$ 595,363	$ (558,703)	$ 24,236
16	$ (117,646)	$ 191,994	$ -	$ 74,348	$ -	$ 47,721
17	$ (121,190)	$ 197,982	$ -	$ 76,792	$ -	$ 47,854
18	$ (124,840)	$ 203,328	$ -	$ 78,488	$ -	$ 47,486
19	$ (128,598)	$ 209,242	$ -	$ 80,643	$ -	$ 47,369
20	$ (132,956)	$ 215,762	$ -	$ 82,806	$ -	$ 47,223
21	$ (137,364)	$ 222,035	$ -	$ 84,671	$ -	$ 46,880
22	$ (141,493)	$ 228,030	$ -	$ 86,537	$ -	$ 46,518
23	$ (146,273)	$ 234,658	$ -	$ 88,386	$ -	$ 46,128
24	$ (150,665)	$ 241,479	$ -	$ 90,814	$ -	$ 46,014
25	$ (154,733)	$ 248,496	$ -	$ 93,763	$ -	$ 46,125
					25-Yr Net Present Value	**$ 757,376**

Notes:

1. All prices are presented in real terms.
2. Electric and propane costs are escalated based on energy price indices presented in the 2018 Annual Supplement to NIST Handbook 135 - Table Ca-1.
3. Depreciated value of capital expenditures at end of 25-year period are not considered.

25-Year Life Cycle Cost Analysis
60% Grant Funding

Input Variables	Value	Units
Project Cost	$8,284,500	$
Grant Funding	$4,970,700	$
Project Costs Financed	$3,313,800	$
Financing Interest Rate	5%	percent
Financing Term	15	years
O&M Costs	$70,400	$/yr
Avoided Snow Management Costs	$117,720	$/yr
Thermal REC Generated	72,675	mmBtu
Thermal REC Value	$7.18	$/mmBtu
General Inflation Rate	2.7%	percent
Real Discount Rate	3%	percent

Year	O&M Costs	Avoided Snow Management Costs	REC Value	Net Operating Savings	Financing Cost	Present Value of Cash Flow
1	$ (70,400)	$ 117,720	$ 521,846	$ 569,166	$ (319,259)	$ 249,907
2	$ (72,054)	$ 121,438	$ 521,846	$ 571,229	$ (319,259)	$ 244,631
3	$ (76,873)	$ 128,316	$ 521,846	$ 573,289	$ (319,259)	$ 239,447
4	$ (79,728)	$ 134,624	$ 521,846	$ 576,741	$ (319,259)	$ 235,633
5	$ (81,821)	$ 139,719	$ 521,846	$ 579,744	$ (319,259)	$ 231,437
6	$ (84,914)	$ 144,691	$ 521,846	$ 581,622	$ (319,259)	$ 226,317
7	$ (88,179)	$ 148,906	$ 521,846	$ 582,573	$ (319,259)	$ 220,521
8	$ (91,268)	$ 153,242	$ 521,846	$ 583,820	$ (319,259)	$ 215,112
9	$ (94,393)	$ 157,380	$ 521,846	$ 584,833	$ (319,259)	$ 209,646
10	$ (97,315)	$ 161,629	$ 521,846	$ 586,160	$ (319,259)	$ 204,557
11	$ (100,327)	$ 166,336	$ 521,846	$ 587,855	$ (319,259)	$ 199,861
12	$ (103,357)	$ 171,531	$ 521,846	$ 590,019	$ (319,259)	$ 195,603
13	$ (106,883)	$ 176,162	$ 521,846	$ 591,125	$ (319,259)	$ 190,681
14	$ (110,524)	$ 181,661	$ 521,846	$ 592,983	$ (319,259)	$ 186,392
15	$ (113,430)	$ 186,947	$ 521,846	$ 595,363	$ (319,259)	$ 182,537
16	$ (117,646)	$ 191,994	$ -	$ 74,348	$ -	$ 47,721
17	$ (121,190)	$ 197,982	$ -	$ 76,792	$ -	$ 47,854
18	$ (124,840)	$ 203,328	$ -	$ 78,488	$ -	$ 47,486
19	$ (128,598)	$ 209,242	$ -	$ 80,643	$ -	$ 47,369
20	$ (132,956)	$ 215,762	$ -	$ 82,806	$ -	$ 47,223
21	$ (137,364)	$ 222,035	$ -	$ 84,671	$ -	$ 46,880
22	$ (141,493)	$ 228,030	$ -	$ 86,537	$ -	$ 46,518
23	$ (146,273)	$ 234,658	$ -	$ 88,386	$ -	$ 46,128
24	$ (150,665)	$ 241,479	$ -	$ 90,814	$ -	$ 46,014
25	$ (154,733)	$ 248,496	$ -	$ 93,763	$ -	$ 46,125
					25-Yr Net Present Value	**$ 3,701,601**

Notes:
1. All prices are presented in real terms.
2. Electric and propane costs are escalated based on energy price indices presented in the 2018 Annual Supplement to NIST Handbook 135 - Table Ca-1.
3. Depreciated value of capital expenditures at end of 25-year period are not considered.

25-Year Life Cycle Cost Analysis
90% Grant Funding

Input Variables	Value	Units
Project Cost	$8,284,500	$
Grant Funding	$7,456,050	$
Project Costs Financed	$828,450	$
Financing Interest Rate	5%	percent
Financing Term	15	years
O&M Costs	$70,400	$/yr
Avoided Snow Management Costs	$117,720	$/yr
Thermal REC Generated	72,675	mmBtu
Thermal REC Value	$7.18	$/mmBtu
General Inflation Rate	2.7%	percent
Real Discount Rate	3%	percent

Year	O&M Costs	Avoided Snow Management Costs	REC Value	Net Operating Savings	Financing Cost	Present Value of Cash Flow
1	$ (70,400)	$ 117,720	$ 521,846	$ 569,166	$ (79,815)	$ 489,351
2	$ (72,054)	$ 121,438	$ 521,846	$ 571,229	$ (79,815)	$ 477,101
3	$ (76,873)	$ 128,316	$ 521,846	$ 573,289	$ (79,815)	$ 465,146
4	$ (79,728)	$ 134,624	$ 521,846	$ 576,741	$ (79,815)	$ 454,758
5	$ (81,821)	$ 139,719	$ 521,846	$ 579,744	$ (79,815)	$ 444,180
6	$ (84,914)	$ 144,691	$ 521,846	$ 581,622	$ (79,815)	$ 432,864
7	$ (88,179)	$ 148,906	$ 521,846	$ 582,573	$ (79,815)	$ 421,052
8	$ (91,268)	$ 153,242	$ 521,846	$ 583,820	$ (79,815)	$ 409,802
9	$ (94,393)	$ 157,380	$ 521,846	$ 584,833	$ (79,815)	$ 398,666
10	$ (97,315)	$ 161,629	$ 521,846	$ 586,160	$ (79,815)	$ 388,071
11	$ (100,327)	$ 166,336	$ 521,846	$ 587,855	$ (79,815)	$ 378,030
12	$ (103,357)	$ 171,531	$ 521,846	$ 590,019	$ (79,815)	$ 368,583
13	$ (106,883)	$ 176,162	$ 521,846	$ 591,125	$ (79,815)	$ 358,623
14	$ (110,524)	$ 181,661	$ 521,846	$ 592,983	$ (79,815)	$ 349,442
15	$ (113,430)	$ 186,947	$ 521,846	$ 595,363	$ (79,815)	$ 340,838
16	$ (117,646)	$ 191,994	$ -	$ 74,348	$ -	$ 47,721
17	$ (121,190)	$ 197,982	$ -	$ 76,792	$ -	$ 47,854
18	$ (124,840)	$ 203,328	$ -	$ 78,488	$ -	$ 47,486
19	$ (128,598)	$ 209,242	$ -	$ 80,643	$ -	$ 47,369
20	$ (132,956)	$ 215,762	$ -	$ 82,806	$ -	$ 47,223
21	$ (137,364)	$ 222,035	$ -	$ 84,671	$ -	$ 46,880
22	$ (141,493)	$ 228,030	$ -	$ 86,537	$ -	$ 46,518
23	$ (146,273)	$ 234,658	$ -	$ 88,386	$ -	$ 46,128
24	$ (150,665)	$ 241,479	$ -	$ 90,814	$ -	$ 46,014
25	$ (154,733)	$ 248,496	$ -	$ 93,763	$ -	$ 46,125
					25-Yr Net Present Value	**$ 6,645,826**

Notes:
1. All prices are presented in real terms.
2. Electric and propane costs are escalated based on energy price indices presented in the 2018 Annual Supplement to NIST Handbook 135 - Table Ca-1.
3. Depreciated value of capital expenditures at end of 25-year period are not considered.

25-Year Life Cycle Cost Analysis
100% Grant Funding

Input Variables	Value	Units
Project Cost	$8,284,500	$
Grant Funding	$8,284,500	$
Project Costs Financed	$0	$
Financing Interest Rate	5%	percent
Financing Term	15	years
O&M Costs	$70,400	$/yr
Avoided Snow Management Costs	$117,720	$/yr
Thermal REC Generated	72,675	mmBtu
Thermal REC Value	$7.18	$/mmBtu
General Inflation Rate	2.7%	percent
Real Discount Rate	3%	percent

Year	O&M Costs	Avoided Snow Management Costs	REC Value	Net Operating Savings	Financing Cost	Present Value of Cash Flow
1	$ (70,400)	$ 117,720	$ 521,846	$ 569,166	$ -	$ 569,166
2	$ (72,054)	$ 121,438	$ 521,846	$ 571,229	$ -	$ 554,591
3	$ (76,873)	$ 128,316	$ 521,846	$ 573,289	$ -	$ 540,380
4	$ (79,728)	$ 134,624	$ 521,846	$ 576,741	$ -	$ 527,800
5	$ (81,821)	$ 139,719	$ 521,846	$ 579,744	$ -	$ 515,095
6	$ (84,914)	$ 144,691	$ 521,846	$ 581,622	$ -	$ 501,712
7	$ (88,179)	$ 148,906	$ 521,846	$ 582,573	$ -	$ 487,895
8	$ (91,268)	$ 153,242	$ 521,846	$ 583,820	$ -	$ 474,699
9	$ (94,393)	$ 157,380	$ 521,846	$ 584,833	$ -	$ 461,672
10	$ (97,315)	$ 161,629	$ 521,846	$ 586,160	$ -	$ 449,242
11	$ (100,327)	$ 166,336	$ 521,846	$ 587,855	$ -	$ 437,419
12	$ (103,357)	$ 171,531	$ 521,846	$ 590,019	$ -	$ 426,242
13	$ (106,883)	$ 176,162	$ 521,846	$ 591,125	$ -	$ 414,603
14	$ (110,524)	$ 181,661	$ 521,846	$ 592,983	$ -	$ 403,792
15	$ (113,430)	$ 186,947	$ 521,846	$ 595,363	$ -	$ 393,605
16	$ (117,646)	$ 191,994	$ -	$ 74,348	$ -	$ 47,721
17	$ (121,190)	$ 197,982	$ -	$ 76,792	$ -	$ 47,854
18	$ (124,840)	$ 203,328	$ -	$ 78,488	$ -	$ 47,486
19	$ (128,598)	$ 209,242	$ -	$ 80,643	$ -	$ 47,369
20	$ (132,956)	$ 215,762	$ -	$ 82,806	$ -	$ 47,223
21	$ (137,364)	$ 222,035	$ -	$ 84,671	$ -	$ 46,880
22	$ (141,493)	$ 228,030	$ -	$ 86,537	$ -	$ 46,518
23	$ (146,273)	$ 234,658	$ -	$ 88,386	$ -	$ 46,128
24	$ (150,665)	$ 241,479	$ -	$ 90,814	$ -	$ 46,014
25	$ (154,733)	$ 248,496	$ -	$ 93,763	$ -	$ 46,125
					25-Yr Net Present Value	**$ 7,627,234**

Notes:
1. All prices are presented in real terms.
2. Electric and propane costs are escalated based on energy price indices presented in the 2018 Annual Supplement to NIST Handbook 135 - Table Ca-1.
3. Depreciated value of capital expenditures at end of 25-year period are not considered.

Appendix E

Key Values and Assumptions

- E.1: Key Values and Assumptions

Key Values and Assumptions

Description	Value	Units	Source
Sidewalk surface area	88,000	ft^2	WES
Street / parking lot surface area	293,000	ft^2	WES
Sidewalk design heating demand	127	$Btu/hr/ft^2$	WES
Street design heating demand	61	$Btu/hr/ft^2$	WES
Edge/back losses as percentage of surface heat flux	25%	percent	WES
Design temperature drop	15	°F	WES
Design flow rate	3,865	gpm	WES
Asphalt thermal conductivity	0.66	Btu/hr/ft/°F	WES
Concrete paver thermal conductivity	1.13	Btu/hr/ft/°F	WES
Sand/stone dust thermal conductivity	1.08	Btu/hr/ft/°F	WES
PEX thermal conductivity	0.22	Btu/hr/ft/°F	WES
Electric energy cost	0.13	$/kWh	WES
Diesel fuel cost	$3.15	$/gal	WES
Propane cost	$1.50	$/gal	WES
Misc. labor cost	$30	$/hr	WES
CO_2 emitted during combustion of diesel	10.21	kg/gal	EPA
CH_4 emitted during combustion of diesel	0.00144	kg/gal	EPA
N_2O emitted during combustion of diesel	0.00026	kg/gal	EPA
CH_4 100-year Global Warming Potential	25	* CO_2	IPCC
N_2O 100-year Global Warming Potential	298	* CO_2	IPCC