TARGET CENTER
Re-Roofing Investment Analysis

February 11, 2008

Prepared for

Minneapolis
City of Lakes

Prepared by

The Kestrel
Design Group, Inc.

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I) EXECUTIVE SUMMARY

The purpose of this investigation was to evaluate the costs and benefits of a number of green roof options for re-roofing the main event roof of the Target Center, located downtown Minneapolis, MN. While the Target Center has a total of 30 roofs on 5 different levels, only the 115,000+/- square foot (s.f.) main event center high roof was included in the scope of this study because the other roofs are too small for a green roof to be a viable option (see drawings G-1 and G-3).

An interdisciplinary team including green roof and sustainable design experts, roofing system experts, architects, an AEG representative, structural engineers, and Minneapolis CPED representatives conducted a lifecycle cost-benefit analysis of the following alternatives:

- Conventional fully adhered PVC **white roof**
- **Extensive green roof – 13.4 pounds per square foot (lb/s.f.)** (1.4 inch growing medium depth)
- **Extensive green roof – 17.4 lb/s.f.** (2” growing medium depth)
- **Extensive green roof – 22 lb/s.f.** (2.5 inch growing medium depth)
- **Extensive green roof – 39 lb/s.f.** (6 inch growing medium depth)
- Combination of **white roof** (83.5% of roof area) with **22 lb/s.f. extensive green roof** perimeter (16.5% of roof area)

In the process of analyzing the above scenarios and structural results, the following scenario was also added to cost-benefit analysis:

- Combination of 1**7.4 lb/s.f. extensive green roof** 83.5% of roof area) with **22 lb/s.f. extensive green roof** perimeter (16.5% of roof area)

All of the above scenarios would have the same roofing membrane

and would be designed to achieve an insulation thermal resistance value of R-36. The existing EPDM roof assembly has an insulation value of R-18. All green roof weights provided are saturated weights and include weight of roofing assembly. All analysis assumes that the existing rigging loads will be maintained.

Conventional Roof: Fully Adhered or Mechanically Fastened PVC White Roof

This scenario represents a conventional roof. The current roof at the Target Center is a loose laid single ply EPDM membrane with gravel ballast. International Building Council (IBC) codes will no longer allow for a loose laid gravel ballast roof at this site, so a fully adhered or mechanically fastened PVC Roof is the closest possible option for re-roofing if a traditional roof similar to the existing roof is desired.

Extensive Green Roof – 13.4 lbs/s.f. (1.4 inch Growing Medium Depth)

This scenario represents the deepest green roof profile possible if the goal is to build a green roof that is no heavier than the existing roof. Only a limited number of green roof manufacturers provide green roof systems that are this light (2 that we know of) and plant diversity will be limited to 4 to 6 very hardy species at this depth. With such a thin soil profile and limited water holding capacity, this scenario will require permanent irrigation, whereas the other scenarios analyzed will only need irrigation during extended drought periods once they mature.

Extensive Green Roof – 17.4 lb/s.f. (2" growing medium depth)

This scenario evaluates a 17.4 lb/s.f. extensive green roof because it is the deepest green roof possible throughout the roof, adding 5 pounds per square foot to the current roof load to account for a reduction in snow load requirements since the time of the installation of the existing roof, and leaving one pound per square foot of the structural capacity gained from decreased snow load requirements for acoustical improvements. The existing roof assembly weighs 13.4 pounds per square foot, so, with an added 5

pounds per square foot for the decrease in snow load requirements, of which one pound per square foot is reserved for acoustical improvements, under the new building code a green roof that weighs 17.4 pounds per square foot is comparable in structural loading to the existing roof.

This depth allows for increased plant vigor as well as greater plant diversity than the 13.4 lb/s.f. green roof, typically 8-11 species. Greater plant diversity allows for more resilience, colors and blooming periods.

Extensive Green Roof – 22 lb/s.f. (2.5 inch Growing Medium Depth)

This scenario represents the minimum saturated green roof weight with a 1" water holding capacity. A 24 hour 1" rain event is a typical water quality volume and comprises approximately 90% of the average annual rainfall, including first flush rainfall events, which contribute most to water quality problems. This green roof depth will allow for more plant species diversity and is also more widely available than either the 13.4 lb/s.f or 17.4 lb/s.f. green roof options.

Structural modifications estimated at a cost of $500,000 would be needed to accommodate this scenario.

Extensive Green Roof – 39 lb/s.f. (6 inch Growing Medium Depth)

This scenario allows for greater plant species diversity, resilience, and stormwater holding capacity but significantly exceeds current structural capacity. Additional structural capacity needed for this scenario is estimated at $17,000,000.

Combination of White Roof with 22 lb/s.f. Extensive Green Roof Perimeter

This scenario includes a band approximately 35' wide of extensive green roof (total approximately 19,000 s.f, or 16.5% of the roof) at the roof perimeter where pavers are currently located and structural capacity is higher, allowing for a maximum 22 lb/s.f. green roof

without structural re-inforcement. The inner 96,000 s.f., the remaining 83.5% of the roof, where gravel ballast roof is currently installed and structural capacity is lower, would be a conventional PVC white roof.

Combination of 17.4 lb/s.f. Extensive Green Roof with 22 lb/s.f. Extensive Green Roof Perimeter

This scenario includes a band approximately 35' wide of 22.5 lb/s.f (2.5" growing medium depth) extensive green roof (total approximately 19,000 s.f, or 16.5% of the roof) at the roof perimeter where pavers are currently located and structural capacity is higher, allowing for a maximum 22 lb/s.f. green roof without structural re-inforcement. The inner 96,000 s.f., the remaining 83.5% of the roof, where gravel ballast roof is currently installed and structural capacity is lower, would be a 17.4 lb/s.f green roof. This green roof will provide the maximum possible stormwater holding capacity, plant diversity, and landscape resilience within the existing structural capacity.

Executive Summary Distillation of Summary and Recommendations (see pages 23-25 for full Summary, Conclusions, and Recommendations)

Due to the lightness of the anticipated acoustic enhancements (1 psf), it would be ***possible to accommodate both a green roof and improved acoustics*** under several of the green roof options analyzed within the existing structural capacity: 13.4 lb/s.f. green roof, 17.4 lb/s.f. green roof, and 17.4 lb/s.f./22 lb/s.f. green roof combination.

If the Target Center IS likely to be in operation 20 more years, we recommend installation of a hybrid 17.4 lb/s.f. green roof (83.5 %of roof)/22 lb/s.f. green roof (16.5% of roof), as both the economic and ecological benefits of the green roof will outweigh those of the conventional roof. This green roof scenario will provide the maximum possible stormwater holding capacity, plant diversity, and landscape resilience within the existing structural capacity.

If the Target Center IS NOT likely to be in operation for at least another 20 years, lifecycle cost comparison of the factors included in this study (not including marketing value or watershed wide stormwater benefits of the green roof) favors a conventional roof, but ecological benefits of the greenroofs still outweigh those of the conventional roof, so the Owner will need to prioritize decision making factors.

More detail on the costs and benefits of the seven re-roofing scenarios evaluated is presented below.

II) PROJECT SCOPE AND BACKGROUND

The purpose of this investigation was to evaluate the costs and benefits of a number of green roof options for re-roofing the main event roof of the Target Center, located downtown Minneapolis, MN. While the Target Center has a total of 30 roofs on 5 different levels, only the 115,000+/- square foot (s.f.) main event center high roof was included in the scope of this study because the other roofs are too small for a green roof to be a viable option (see drawings G-1 and G-3).

This report has culminated from a series of 3 team meetings that have included Kristin Guild, Acting Manager Business Development, and Andrea Petersen, Project Coordinator, from Minneapolis CPED; Tom Reller, Target Center Director of Operations; Frank Anderson and Tim McCarron, Architects with Leo A Daly; Chuck Ault and Pete Siessenbuettel, Structural Engineers with Leo A Daly; Jim Roed, Structural Engineer with Ericksen Roed and Associates; Gary Patrick, Roofing Consultant with INSPEC; Rick Carter, Sustainable Design Consultant with LHB Engineering, and Peter MacDonagh and Nathalie Hallyn, Landscape Architects and Green Roof Consultants with The Kestrel Design Group; as well as conversations and written correspondence with roofing and green roof contractors, and FM Global, AEG's insurance company for the Target Center; and the consultants' previous extensive green roof experience in the Twin Cities and Europe.

The team conducted a lifecycle cost-benefit analysis of the following 6 alternatives for the main roof:

- Conventional fully adhered PVC **white roof**
- **Extensive green roof – 13.4 pounds per square foot (lb/s.f.)** (1.4 inch growing medium depth)
- **Extensive green roof – 17.4 lb/s.f.** (2 inch growing medium depth)
- **Extensive green roof – 22 lb/s.f.** (2.5 inch growing medium depth)

- **Extensive green roof – 39 lb/s.f.** (6 inch growing medium depth)
- Combination of **white roof** with **22 lb/s.f. extensive green roof perimeter**

In the process of analyzing the above scenarios and structural results, the following scenario was also added to cost-benefit analysis:

- Combination of 1**7.4 lb/s.f. extensive green roof** 83.5% of roof area) with **22 lb/s.f. extensive green roof** perimeter (16.5% of roof area)

All of the above scenarios would have the same roofing membrane and would be designed to achieve an insulation thermal resistance value of R-36. The existing EPDM roof assembly has an insulation value of R-18. All green roof weights provided are saturated weights and include weight of roofing assembly. All analysis assumes that the existing rigging loads will be maintained.

Conventional Roof: Fully Adhered or Mechanically Fastened PVC White Roof

This scenario represents a conventional roof. The current main event roof at the Target Center is a loose laid single ply EPDM membrane with gravel ballast. International Building Council (IBC) codes will no longer allow for a loose laid gravel ballast roof at this site, so a fully adhered or mechanically fastened PVC Roof is the closest possible option for re-roofing if a traditional roof similar to the existing roof is desired.

1.5” deep extensive green roof on private Minneapolis residential garage, Minneapolis MN, installed 2004, image by The Kestrel Design Group, Xeroflor green roof system

Extensive Green Roof – 13.4 lbs/s.f. (1.4 inch Growing Medium Depth)

This scenario represents the deepest green roof profile possible if

the goal is to build a green roof that is no heavier than the existing roof. See drawings G-1, G-3, G-4, G-6, and G-7.

Only a limited number of green roof manufacturers provide green roof systems that are this light (2 that we know of) and plant diversity will be limited to 4 to 6 very hardy species at this depth. With such a thin soil profile and limited water holding capacity, this scenario will require permanent irrigation, whereas the other scenarios analyzed will only need irrigation during extended drought periods once they mature.

Ford green roof, Dearborn, MI, approximately 19 lb/s.f. total weight (green roof only, without roofing membrane weight, is 15 lbs/s.f.), image by Don Russell, Xero Flor

Extensive Green Roof – 17.4 lb/s.f. (2" growing medium depth)

This scenario evaluates a 17.4 lb/s.f. extensive green roof because it is the deepest green roof possible throughout the roof, adding 5 pounds per square foot to the current roof load to account for a reduction in snow load requirements since the time of the installation of the existing roof, and leaving one pound per square foot of the structural capacity gained from decreased snow load requirements for acoustical improvements. The existing roof assembly weighs 13.4 pounds per square foot, so, with an added 5 pounds per square foot for the decrease in snow load requirements, of which one pound per square foot is reserved for acoustical improvements, under the new building code a green roof that weighs 17.4 pounds per square foot is comparable in structural loading to the existing roof.

This depth allows for increased plant vigor as well as greater plant diversity than the 13.4 lb/s.f. green roof, typically 8-11 species. Greater plant diversity allows for more resilience, colors and blooming periods. Typical concept drawings will be the same as those for the 13.4 lb/s.f. green roof but will have deeper growing medium.

Extensive Green Roof – 22 lb/s.f. (2.5 inch Growing Medium Depth)

This scenario represents the minimum saturated green roof weight with a 1" water holding capacity. A 24 hour 1" rain event is a typical water quality volume and comprises approximately 90% of the average annual rainfall, including first flush rainfall events, which contribute most to water quality problems. This green roof depth will allow for more plant species diversity and is also more widely available than either the 13.4 lb/s.f or 17.4 lb/s.f. green roof options.

Structural modifications estimated at a cost of $500,000 would be needed to accommodate this scenario.

Typical concept drawings will be the same as those for the 13.4 lb/s.f. green roof but will have deeper growing medium.

4" Deep extensive green roof at the Minneapolis Central Library, Minneapolis MN, installed 2004, image by The Kestrel Design Group

Extensive Green Roof – 39 lb/s.f. (6 inch Growing Medium Depth)

This scenario allows for greater plant species diversity, resilience, and stormwater holding capacity but significantly exceeds current structural capacity. Additional structural capacity needed for this scenario is estimated at $17,000,000.

See drawings G-1, G-3, and G-5.

6" deep extensive green roof at the Green Institute, Minneapolis MN, installed 2004, image by The Kestrel Design Group

Combination of White Roof with 22 lb/s.f. Extensive Green Roof Perimeter

This scenario includes a band approximately 35' wide of extensive green roof (total approximately 19,000 s.f, or 16.5% of the roof) at the roof perimeter where pavers are currently located and structural capacity is higher, allowing for a maximum 22 lb/s.f. green roof without structural re-inforcement. The inner 96,000 s.f., the remaining 83.5% of the roof, where gravel ballast roof is currently

installed and structural capacity is lower, would be a conventional PVC white roof.

See drawings G-2 and G-3. Sections will be the same as those for the 13.4 lb/s.f. green roof but will have deeper growing medium.

Combination of 17.4 lb/s.f. Extensive Green Roof with 22 lb/s.f. Extensive Green Roof Perimeter

This scenario includes a band approximately 35' wide of 22.5 lb/s.f (2.5" growing medium depth) extensive green roof (total approximately 19,000 s.f, or 16.5% of the roof) at the roof perimeter where pavers are currently located and structural capacity is higher, allowing for a maximum 22 lb/s.f. green roof without structural re-inforcement. The inner 96,000 s.f., the remaining 83.5% of the roof, where gravel ballast roof is currently installed and structural capacity is lower, would be a 17.4 lb/s.f green roof. This green roof will provide the maximum possible stormwater holding capacity, plant diversity, and landscape resilience within the existing structural capacity.

See drawings G-1 and G-3. Sections will be the same as those for the 13.4 lb/s.f. green roof but will have deeper growing medium.

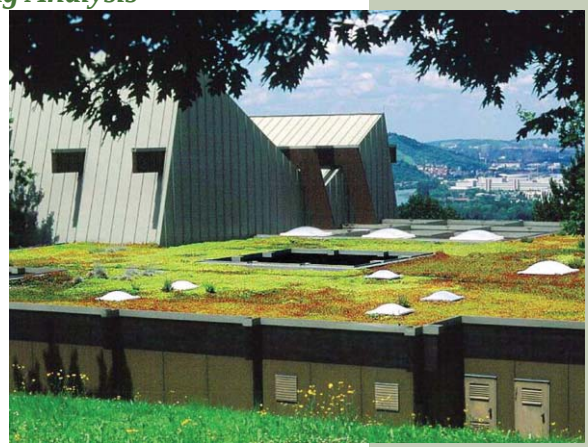
III) LIFECYCLE COST COMPARISON

The lifecycle cost of each of the 7 scenarios evaluated for this study was compared using a Life Cycle Cost (LCC) Calculator developed by the ATHENA Institute for Sustainable Materials. LCC is a method for evaluating project investment alternatives over a selected period of time to determine which alternative is the more economical option. "It is particularly suited to determining whether the higher initial cost of an investment is justified by reduction in future costs (e.g. operating, maintenance, repair, or replacement costs)" (ATHENA Institute, 2007). Input required into the calculator includes data such as estimated capital costs, maintenance costs, effects on operating costs, lifespan, investment period, inflation rates, discount rate, and end of life residual value.

LCC results are expressed as Net Present Value (NPV) at the end of the chosen study period. "The larger the NPV – other things being equal – the more attractive the investment. ***In the case of a roof investment analysis it is unlikely that the roof will generate a positive NPV and hence, the roof with the least negative NPV is the better investment outcome."*** (ATHENA Institute, 2007)

German green roof in 1976 and more than 30 years later, photo credit: Zinco

A) LCC Input for Target Center Re-Roofing Analysis



1) Study period
Net present value was calculated for each scenario for a 16 year study period and for a 20 year study period.

2) Roof size
While the Target Center has a total of 30 roofs on 5 different levels, only the main event center 115,000+/- square foot high roof was included in the scope of this study. The other roofs are too small for a green roof to be cost-effective or functional.

3) Project Initiation Year
Project initiation year was assumed to be 2009.

4) Capital Costs
Estimated capital costs entered into the LCC for each

scenario include all costs for re-roofing, including materials and installation costs for roofing membrane, green roof and irrigation material and installation costs (where applicable), electronic leak detection cost (for green roof only), 2 year start-up maintenance cost (for green roof scenarios only), structural re-inforcement (required only for 22 lb/s.f. and 39 lb/s.f green roofs) and cost of 20 year single source warranty.

5) Applicable Discount (Hurdle) Rate

This is the cost of borrowing money, i.e. the interest rate of a loan. A discount rate of 0% was used because money used to pay for re-roofing will not be borrowed money.

6) Annual Maintenance Cost

a. PVC White Roof

This is the estimated cost to fix/maintain things not covered by the warranties and includes such things as cleaning roof drains, cleaning and resealing joints, fixing flashings and seams, replacing pavers that are past the warranty, etc. for the 20 year project study period averaged to an annual cost.

b. Green Roofs

Estimated green roof annual maintenance cost includes white roof maintenance cost plus cost for water to irrigate green roof during periods of extended drought (assumed at 2” per year except for the 13.4 lb/s.f. green roof), and cost to inspect and maintain plantings (estimated at 2 site visits per year based on comparable project experience). Water cost for the 13.4lb/s.f. green roof, which will need more irrigation due to its very limited water-holding capacity and soil depth, was based in 10” of irrigation per year.

Green roof maintenance costs decrease significantly after the initial 2 year establishment period. Annual maintenance cost entered into the lifecycle model is the cost per year after the first 2 years of start-up maintenance. The additional maintenance costs during the first 2 years of startup maintenance are included in the capital costs.

Estimated cost of cisterns to hold enough roof runoff

to water green roof 1" is about 3 times the estimated cost of municipal water for 20 years of watering the green roof, so this estimate is based on using potable water for roof irrigation. If the City desires to harvest water in cisterns for demonstration and water stewardship incentives, the cost of cisterns could replace part of the cost of water to irrigate included in the annual maintenance cost.

7) Lifespan

Conventional PVC white roof lifespan was estimated to be ***20 years*** based on local experience and roofing studies that cite typical lifespans of 12-20 years for PVC roofs. As of 2008, some PVC roof providers have started offering 25 to 30 year warranties, indicating that with recent improvements in PVC roofing technology, a conventional PVC roof installed in 2009 could last longer than PVC roofs installed in the past, i.e. longer than the 20 years estimated in this life cycle cost benefit analysis.

Green roof lifespan was estimated to be ***40 years*** based on proven performance in Europe as documented below:

- "Green roofs have been proven to protect the roofing membrane against ultra-violet radiation, extreme temperature fluctuations, and puncture or physical damage from recreation or maintenance. The second "Building Failure/Damage Report' issued by the German Government in 1988, identifies roof greening as a solution to flat roof membrane failure." Liesecke 1989 In "Greenbacks from Green Roofs: Forging a New Industry in Canada"
- According to an international literature review by the Toronto and Region Conservation "German literature indicates that, based on observation of installations in Germany, green roofs will at least double the lifespan of the roofing membrane to 40 or 50 years (Porsche and Kohler, 2003; Krupka, 2001). Porsche and Kohler (2003) also note that membranes beneath some older green roof installations in Berlin have even lasted 90 years without requiring

replacement." (Toronto and Region Conservation, 2007).
• Switzerland has green roofs that are 90+ years old.
• Experience with green roofs in Germany appears to prove the performance of their green roof technology, as even after 35 years of experience with green roof technology, German regulations still strongly encourages use of green roof technology.
• "According to Penn State's Dr. Dave Beattie, by late 2002, 15% of all of Germany's flat roofs are now greenroofs, with 22% of Stuttgart's roofs being greenroofs, and all new roof construction will require greenroofs (personal communications, September, 2002). In 1989, twenty-seven cities had established zoning districts that require greenroofs to be installed on flat roofs. Such a requirement on flat-roofed industrial buildings was included in Stuttgart's 1989 Law of Building Book (The London Ecology Unit, 1993).
• Since 1982, the greenroof industry in Germany has grown an average of 15-20% (www.peck.ca).
• Since 1984 Munich has included greenroofs in its building ordinance, and in the subsequent 15 years approximately 4.2 million square feet of rooftops have been greened. In 1992 a direct subsidy program was started, providing $3.13 per square foot ($33.70/m^2), paying up to 50% of the capital cost of installing a greenroof (Charlie Miller publication, 1998). By 1996, over 10 million square meters of greenroofs were constructed in Germany alone (Green Roofs For Healthy Cities)" (from: http://www.greenroofs.com/Greenroofs101/industry_support.htm)

8) Stormwater Utility Fee
The City of Minneapolis offers stormwater utility fee credits to property owners who use Low Impact Development Techniques to reduce the negative watershed effects of stormwater runoff from hard surfaces on their sites. The surface area of the green roof is subtracted from the surface area on which the stormwater utility fee is

based. Based on the 2008 stormwater utility rates of $10.26 per Equivalent Stormwater Unit (ESU), 115,000 square foot (s.f.) of green roof on a 128,000 s.f. site, and a runoff coefficient of 1, the Target Center could receive a ***$9254.12 per year stormwater utility fee credit*** for a 115,000 s.f. green roof. Stormwater utility rates are predicted to be raised considerably in the coming years. If this happens, stormwater credit savings from the green roof would also significantly increase.

9) Energy Useage

A green roof thermal performance model developed for use with ESP-r used to model cooling showed that, presumably due to building configuration and roof R-value, cooling energy savings for both the extensive green roof as well as from the white roof compared to the current roof membrane are minimal, estimated to be comparable, around 1% savings for cool roofs as well as for extensive green roofs. For white roofs, cooling benefits decrease somewhat over time as the roof membrane gets dirty: solar reflectance decreases somewhat after about 3 years and then stabilizes to 60-85% (General Services Administration, 2000). Modeling represents stabilized solar reflectance values. Modeling results are shown in Table 1 on the following page.

10) General Price Inflation Factor

The calculator's default annual inflation rate of 2.72% was used. This is the average US general price inflation between Jan/97 and Jan/07 (www.inflationdata.com)

11) End of Life Residual Value

End of Life Residual Value represents the value remaining in a roof system at the end of the study in today's $. For the purpose of this evaluation, it was estimated as:

- PVC membrane value of $0.20 per s.f.
- Insulation value of $1.00 per s.f.

Table 1: Estimated Cooling Energy Savings

Insulation R-Value	**Roof Type**	**Consumption (kWh)**	**% Savings**	**Total savings ($)**
18	Existing Roof	504779.34	-	-
36	New Black Roof with R-36	502902.12	0.37	$1,676
36	Extensive Green Roof <25 lbs/s.f.+/-	500158.09	0.92	$4,168
36	Green Roof (higher LAI) ≥25 lbs/s.f.+/-	499110.56	1.12	$5,074
36	White Roof (albedo = 0.71)	500201.62	0.91	$4,122

Notes:

- Percentage savings was calculated with respect to existing roof.
- LAI = Leaf Area Index, ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows, varies with plant species and health as well as growing medium depth.
- Total savings estimated based on 2007 usage

• Material cost of growing medium and plants estimated based on local bids from previous projects at $1.60/sf for 13.4 lb/s.f. green roof; $1.86 per s.f. for 17.4 lb/s.f. green roof; $2.08 for the 22 lb/s.f green roof; and $3.59 per s.f. for 39 lb/s.f. green roof.

12) Periodic Salvage Value
Periodic Salvage Value represents positive cash flow recurring at regular intervals (i.e at replacement intervals) due to the salvage of non-replaced materials (e.g. the reuse of ballast or insulation materials); material salvage or reuse estimated here as:
• PVC membrane value of $0.20 per s.f.
• Insulation value of $3.50 per s.f. (assuming 80-90% of insulation can be left in place)
• Material cost of growing medium and plants estimated based on local bids from previous projects at $1.60/sf for 13.4 lb/s.f. green roof; $1.86 per s.f. for 17.4 lb/s.f. green roof; $2.08 for the 22 lb/s.f green roof; and $3.59 per s.f. for 39 lb/s.f. green roof.

B) LCC Output

Net present value at the end of the study period for this re-roofing analysis depends primarily on the duration of the study period chosen in relation to the estimated roof lifespans. For a 16 year study period, a conventional white roof scenario is the best economic investment based on the factors entered into the LCC. For a 20 year study period, the green roof scenarios for the 13.4 lb/s.f. green roof, the 17.4 lb/s.f. green roof, and the hybrid 17.4 lb/s.f./22 lb/s.f. green roof are the better economic investments based on the factors entered into the LCC.

Table 2 on pages 18-20, “Comparison Summary Chart”, compares LCC input and output as well as unquantified advantages and disadvantages for each of the scenarios side by side.

Table 2: Comparison Summary Chart

	Conventional PVC White Roof	**13.4 lb/sf Green Roof**	**17.4 lb/sf Green Roof**	**22 lb/s.f. Green Roof**	**39 lb/s.f. Green Roof**	**White/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; White Reflective Roof in Center**	**Green/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; 17.4 lb/s.f. Green Roof in Center**
Growing Medium Depth	NA	1.4”	2”	2.5”	6”	None on 86.5% of roof/ 2.5” on 13.5% of roof	2” on 86.5% of roof/ 2.5” on 13.5% of roof
Estimated Water Holding Capacity**	None	0.55”	0.76”	1.00”	2.22”	1.00” only in green roof band	0.80”
Pros	• Lower design, initial installation, and maintenance costs • Faster construction time • Heat island effect mitigation* • Proven 20 year roof performance • Weighs less than original roof system	• Stormwater benefits to Mississippi River* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value* • Potential for longer lifespan** • Acoustic insulation* • No additional structural capacity needed	• Stormwater benefits to Mississippi River* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value* • Potential for longer lifespan** • Establishment period shorter than for green roof with less growing medium • More stormwater benefits than for green roof with less growing medium • More growing medium allows for more plant species diversity, soil water holding capacity and rooting space, so plants will be more vigorous, which will enhance aesthetics and in some cases also wind resistance. • More widely available than 13.4 lb/s.f. system • Acoustic insulation* • No additional structural capacity needed	• Stormwater benefits to Mississippi River* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value* • Potential for longer lifespan** • Establishment period shorter than for green roof with less growing medium • More stormwater benefits than for green roof with less growing medium • More growing medium allows for more plant species diversity, soil water holding capacity and rooting space, so plants will be more vigorous, which will enhance aesthetics and in some cases also wind resistance. • More widely available than 13.4 lb/s.f. system • Acoustic insulation*	• Stormwater benefits to Mississippi River* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value * • Potential for longer lifespan** • Establishment period than shorter than for green roof with less growing medium • More stormwater benefits than for green roof with less growing medium • More growing medium allows for more plant species diversity, soil water holding capacity and rooting space, so plants will be more vigorous, which will enhance aesthetics and in some cases also wind resistance. • More widely available than 13.4 lb/s.f. system • Acoustic insulation*	• Lower design, initial installation, and maintenance costs • Stormwater benefits to Mississippi River* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value* • Establishment period shorter than for green roof with less growing medium • More stormwater benefits than for green roof with less growing medium • More growing medium allows for more plant species diversity, soil water holding capacity and rooting space, so plants will be more vigorous, which will enhance aesthetics and in some cases also wind resistance. • More widely available than 13.4 lb/s.f. system • Acoustic insulation*	• Stormwater benefits to Mississippi River maximized within existing structural capacity* • Lower stormwater utility fee • Aesthetic amenity* • Heat island effect mitigation* • Air quality benefits* • Marketing value* • Potential for longer lifespan** • Establishment period shorter than for green roof with less growing medium • More stormwater benefits than for green roof with less growing medium • More growing medium allows for more plant species diversity, soil water holding capacity and rooting space, so plants will be more vigorous, which will enhance aesthetics and in some cases also wind resistance. • More widely available than 13.4 lb/s.f. system • Acoustic insulation* • No additional structural capacity needed

	Conventional PVC White Roof	**13.4 lb/sf Green Roof**	**17.4 lb/sf Green Roof**	**22 lb/s.f. Green Roof**	**39 lb/s.f. Green Roof**	**White/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; White Reflective Roof in Center**	**Green/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; 17.4 lb/s.f. Green Roof in Center**
Cons	• Negative effects on stormwater • Shorter estimated lifespan	• Higher design, installation, maintenance, and replacement costs • Longer construction time • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects • There are fewer green roof manufacturers who offer green roof systems this light (only 2 that we know of) than offer the heavier ones	• Higher design, installation, maintenance, and replacement costs • Longer construction time • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects	• Higher design, installation, maintenance, and replacement costs • Longer construction time • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects • Heavier than existing roof	• Higher design, installation, maintenance, and replacement costs • More weeding required long term than on green roof with less growing medium • Longer construction time • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects • Heavier than existing roof	• Higher design, installation, maintenance, and replacement costs for green roof • Longer construction time for green roof • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects	• Higher design, installation, maintenance, and replacement costs • Longer construction time • No local 20 year extensive green roof projects; but many 40-50 year projects in similar European climates, even several 90+ year projects
Stormwater Utility Fee Savings (compared to conventional roof)	$0 per year	$9254.12 savings per year	$9254.12 savings per year	$9254.12 savings per year	$$9254.12 savings per year	$1528.94 per year	$9254.12 savings per year
Energy Savings (of compared to existing roof)	$4122 per year	$4168 per year	$4168 per year	$4168 per year	$5074 per year	$4168 per year	$4168 per year
Estimated Roof Lifespan	20 years***[a]	40 years*** [b]	40 years*** [b]	40 years*** [b]	40 years*** [b]	20 years*** [a]	40 years*** [b]
Total Installed Capital Cost	115,000 s.f. at $10.50/s.f. = $1,207,500	115,000 s.f. at $22.50/s.f. + leak detection cost = $2,637,500.00	115,000 s.f. at $23.90/s.f. + leak detection cost = $2,798,500.00	115,000 s.f. at $24.24/s.f. + leak detection cost + structural re-inforcement costs =$3,337,600	115,000 s.f. at $26.50/s.f. + leak detection cost + structural re-inforcement costs =$20,097,500	19,000 s.f. at $24.24/s.f. + 96,000 s.f. at $10.50 per s.f. + leak detection cost (green roof only) =$1,478,560	115,000 s.f. at $23.95/s.f. + leak detection cost = $2,803,775
Structural Re-inforcement Cost	None needed	None needed	None needed	$500,000	$17,000,000	None needed	None needed

	Conventional PVC White Roof	13.4 lb/sf Green Roof	17.4 lb/sf Green Roof	22 lb/s.f. Green Roof	39 lb/s.f. Green Roof	White/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; White Reflective Roof in Center	Green/Green Hybrid: 22 lb/s.f. Green Roof in Current Paver Location; 17.4 lb/s.f. Green Roof in Center
Est. Annual Maintenance Cost	$2,300 per year	$9,750 per year	$9,750 per year	$9,750 per year	$9,750 per year	$3,531 per year	$9,750 per year
Periodic Salvage Value	$425,000	$610,065	$639,879	$664,724	$838,638	$465,024	$643,960
End of Life Residual Value	$138,000	$322,565	$352,379	$377,224	$551,138	$177,524	$356,460
Estimated Replacement Cost	115,000 s.f. at $10.50/s.f. = $1,207,500	115,000 s.f. at $22.50/s.f. + leak detection cost = $2,637,500.00	115,000 s.f. at $23.90/s.f. + leak detection cost = $2,798,500.00	115,000 s.f. at $24.24/s.f. + leak detection cost =$2,837,600	115,000 s.f. at $26.50/s.f. + leak detection cost =$3,097,500	19,000 s.f. at $24.24/s.f. + 96,000 s.f. at $10.50 per s.f. + leak detection cost (green roof only) =$1,478,560	115,000 s.f. at $23.95/s.f. + leak detection cost = $2,803,775
Net present value for 16 year study period****	-$958,586	-$2,067,564	-$2,182,768	-$2,683,691	-$19,032,008	-$1,162,737	-$2,181,766
Net present value for 20 year study period****	-$2,260,123	-$1,987,264	-$2,097,270	-$2,593,875	-$19,032,008	-$2,851,405	-$2,095,565
Green Roof Payback Period*****	NA	20 years	20 years	None	None	None	20 years

*Not quantified as a financial benefit – see report for more information

**This is the water storage capacity when soil is dry; stormwater treatment capacity will vary depending on factors such as soil moisture content before rainfall event and rainfall rate.

*** [a] Conventional PVC roof estimated lifespan is based on local experience and roofing studies that cite typical lifespans of 12-20 years for PVC roofs. As of 2008, some PVC roof providers have started offering 25 to 30 year warranties, indicating that with recent improvements in PVC roofing technology, a conventional PVC roof installed in 2009 could last longer than PVC roofs installed in the past, i.e. longer than the 20 years estimated in this life cycle cost benefit analysis.

*** [b] While Minneapolis does not yet have any extensive green roofs more than 20 years old, European green roofs typically last 40-50 years – see report for more information.

****In the case of a roof investment analysis, the roof with the least negative Net Present Value (NPV) is the better investment income.

*****Payback Period = defined as time when green roof net present value surpasses that of a white roof and applies to a 20 year study period only. For a 16 year study period, the conventional roof is more favorable than all green roof scenarios throughout the study period. I.e. there is no green roof payback period during a 16 year study period. Due to the significant impact of capital costs and lifespan on comparative Net Present Value, the payback period depends on the length of study period selected. Because the primary financial advantage of the green roof over the white roof at this site is the estimated lifespan difference with a 20 year study period, the green roof becomes more cost effective at the end of the study period, i.e. 20 years, the time at which the lifecycle cost model calculates that the conventional white roof would need to be replaced while the green roof does not yet need to be replaced if the estimated white roof lifespan is 20 years and the green roof lifespan is 40 years.

IV) ANALYSIS FACTORS NOT INCLUDED IN LIFECYCLE COST COMPARISON

A. Additional Green Roof Advantages

Green roofs provide several other ecological as well as private and public economic benefits that were not incorporated into the LCC for various reasons, including:

1) Marketing Value

Team meeting discussions concluded that with the marketing value of a green roof, the Target Center is likely to be able to attract more events to the Target Center and thereby increase its revenue. The potential marketing value has not been incorporated into the LCC because it is difficult to quantify before the green roof is installed. However, though hard to quantify beforehand, after a green roof was installed, it would be feasible to estimate how much additional revenue the Target Center brought in due to the green roof. Such an estimate would be useful for educational purposes for future green roof projects.

2) Downstream Stormwater Benefits

In addition to the stormwater utility fee reduction quantified in the LCC, green roofs will also provide ecological benefits by ***reducing the negative effects of hard surfaces like traditional roofs on stormwater quality, volume, rate, and temperature on the receiving waterbody, in this case, the Mississippi River.*** At 115,000 square feet, ***almost 3 acres***, this green roof has potential for mitigating stormwater runoff from a significant amount of impervious surface in a ***downtown location where space does not permit use of other Low Impact Development Techniques*** to mitigate for the negative effects of hard surfaces on receiving waterbodies. ***Though difficult to quantify in the LCC, positive impacts on local water bodies are valuable in a City that prides itself on its legendary waterbodies: The City of Lakes in the Land of 10,000 Lakes.***

3) Acoustic Insulation
Due to their mass, green roofs can attenuate sound transmission: the substrate tends to block lower frequencies while the plants block higher frequencies. Tests have shown that a 5" layer of substrate can reduce sound by 40 dB; 8" can reduce sound by 46dB (Minke 1982 in Peck et al 1999). While acoustic insulation benefits from a green roof could reduce sound transmission through the roof, they will not improve sound quality of performances for events within the building.

4) Demonstration value
As part of its efforts to protect its legendary water resources, including the Mississippi River which receives stormwater runoff from the Target Center site, the City of Minneapolis is promoting use of green roof technology as well as other low impact development techniques where appropriate. Installation of a green roof at the Target Center can provide demonstration value to help further promote green roof technology throughout the City of Lakes.

5) Aesthetic Amenity
Vegetation on the green roof would be a visual amenity for tenants looking down onto the Target Center Roof from surrounding buildings.

6) Heat Island Effect Mitigation
Both the white roof and the green roof will provide heat island effect mitigation benefits.

7) Air quality benefits
Green roofs are associated with air quality improvements such as mitigation of nitrous oxides and volatile organic compounds as well as reductions in airbourne particulates. These air quality improvements directly benefit millions of urban residents who suffer from asthma or other breathing ailments and also decrease smog (Peck et al, 1999).

B. Additional Green Roof Disadvantages

1) Insurance Companies' Lack of Experience with Green Roofs

One potential disadvantage of green roofs is that though they are a well established technology in Europe and a rapidly growing technology in Minneapolis, the technology is relatively new in the Minneapolis area, so U.S. insurance companies have limited experience dealing with green roofs and may be wary of this new technology. Education is key to overcoming potential insurance hurdles. Some key issues to address in this process include:

• The single largest roof related exposure for the insurance industry is damage resulting from hail. Even growth medium depths as shallow as two or three inches will serve to protect the roof covering from hail damage. A green roof will virtually eliminate the insurance company's exposure to hail damaged roofing materials. Damage to plants after a hail storm can completely heal after five or six weeks.

• The insurance company will likely be concerned about the fire hazard dead plants would pose. However, any dead foliage would burn very rapidly leaving several inches of growth medium that is made up of mostly gravel that the Underwriting Laboratories considers to be a class A fire rated roof covering in built up roof assemblies.

• Help them separate the exposures covered under warranty from those that will be covered under insurance. Leaks and plant failure will be warranty issues.

FM Global, AEG's insurance company for the Target Center, is currently the only insurance company that ***does already address green roofs,*** so they are likely to be less wary of green roofs than insurance companies that have never come across green roof projects or have never had to think about how green roofs affect their policies. FM Global has developed preliminary design guidelines for insured green roofs that include several components (minimum 3" depth, galvanized materials for a metal roof,

minimum roof slope) that may not be financially feasible for a Target Center green roof. FM Global green roof policy guidelines also require a 40 lb snow load rather than the 35 lb dictated by the modified code requirements. However, FM Global may be willing to waive some of these guidelines. For example, a representative has indicated in conversation that it would be very unlikely that they would require a 3” growing medium depth if this would require additional structural capacity. While conversations with FM Global to date about the potential of a green roof at the Target Center have been positive, FM Global will need to review and approve the design once it is complete, and without having gone through the design process yet, we cannot in good conscience guarantee that we will not encounter road blocks along the way that could raise the insurance premiums.

Table 2 on pages 18-20, “Comparison Summary Chart”, compares LCC input and output as well as unquantified advantages and disadvantages of each scenario side by side for each of the scenarios evaluated.

V) SUMMARY AND CONCLUSIONS

• The primary benefits of the ***Conventional PVC White Roof*** are lower costs for design, initial installation and maintenance.

• Due to the lightness of the anticipated acoustic enhancements (1 psf), it would be ***possible to accommodate both a green roof and improved acoustics*** under several of the green roof options analyzed within the existing structural capacity: 13.4 lb/s.f. green roof, 17.4 lb/s.f. green roof, and 17.4 lb/s.f./22 lb/s.f. green roof combination.

• Advantages of the ***green roof*** scenarios are stormwater benefits (runoff volume and rate reduction, water quality benefits, and runoff temperature reduction), longer estimated lifespan, educational and demonstration value, and marketing value for attracting arena acts.

• ***Increasing green roof depth*** slightly increases capital costs, but also increases stormwater holding capacity and plant vigor. Increase in plant vigor is expected to be the greatest between the 13.4 lb/s.f. (1.4" growing medium depth) and the 22 lb/s.f. (2.5" growing medium depth) green roofs.

• The ***13.4 lb/s.f. (1.4" growing medium depth) green roof,*** which weighs the same as the existing roof, is the lightest of the scenarios analyzed and slightly less costly than the heavier green roof options but also has the lowest stormwater holding capacity, plant diversity and vigor, and green roof system market availability. With such a thin soil profile and limited water holding capacity, this scenario will require permanent irrigation, whereas the other scenarios analyzed will only need irrigation during extended drought periods once they mature.

• The ***17.4 lb/s.f. (2" growing medium depth) green roof*** is the deepest green roof possible throughout the roof without adding structural reinforcement and will therefore provide the maximum

possible plant health, plant diversity and stormwater holding capacity without the cost of additional structural capacity.

• The ***22 lb/s.f. (2.5" growing medium depth) green roof*** will provide greater plant diversity, landscape resilience, and green roof system market availability (and therefore potential for more competitive bids) than either the 13.4 lb/s.f. or the 17.4 lb/s.f. green roofs, and the 22 lb/s.f. green roof is also the threshold for 1" water holding capacity. A 24 hour 1" rain event is a typical water quality volume and comprises approximately 90% of the average annual rainfall, including first flush rainfall events, which contribute most to water quality problems. Structural re-inforcement estimated at a cost of $500,000 would be required for this green roof scenario.

• The ***39 lb/s.f. (6" growing medium depth) green roof*** scenario allows for greater plant species diversity, landscape resilience, and stormwater holding capacity but significantly exceeds current structural capacity. Estimated cost of structural re-inforcement needed for this scenario is $17,000,000: more than five times the cost of the green roof itself.

• A combination of ***96,000 s.f. +/- (83.5% of the roof) white roof*** with a ***19,000 s.f. +/- perimeter (16.5% of the roof area) of 22 lb/ s.f. green roof*** would not require any additional structural support, because the area of the proposed green roof has higher structural capacity than the remainder of the roof. Due to an estimated lifespan of 20 years, this scenario was comparable to the conventional roof scenario in that estimated Net Present Value compared favorably to all the green roof scenarios in the 16 year study period but not in the 20 year study period. The green roof perimeter increases the capital cost of this scenario compared to the conventional roof scenario so that the Net Present Value of this scenario is slightly less than that of the conventional roof scenario.

• A ***combination*** of (a) a ***22 lb/s.f. green roof*** (2.5" growing medium depth) in the perimeter of the roof (total approximately 19,000 s.f, or 16.5% of the roof) where structural capacity of the roof is 22 lb/s.f. with (b) a ***17.4 lb/s.f. green roof*** in the inner

96,000 s.f., the remaining 83.5% of the roof, where maximum structural capacity of the roof is 17.4 lb/s.f. will provide the ***maximum possible stormwater holding capacity, plant diversity, and landscape resilience within the existing structural capacity***. Life cycle cost-benefit analysis of this scenario is very similar to that of the 17.4 lb/s.f. green roof, with marginally higher economic cost of the 17.4 lb/s.f. green roof balanced out by marginally higher end of life residual value for the combination green roof, and resulting in a NPV $1,705 higher at the end of a 20 year study period for the combination roof than for the green roof that is 17.4 lb/s.f. throughout as a result of inflation on the end of life residual value. Ecological stormwater benefits to the Mississippi River are also marginally higher for the combination roof (0.04" higher water holding capacity).

• Estimated cost of ***cisterns*** to hold enough roof runoff to water green roof 1" one time is about 3 times the estimated cost of municipal water for 20 years of watering the green roof.

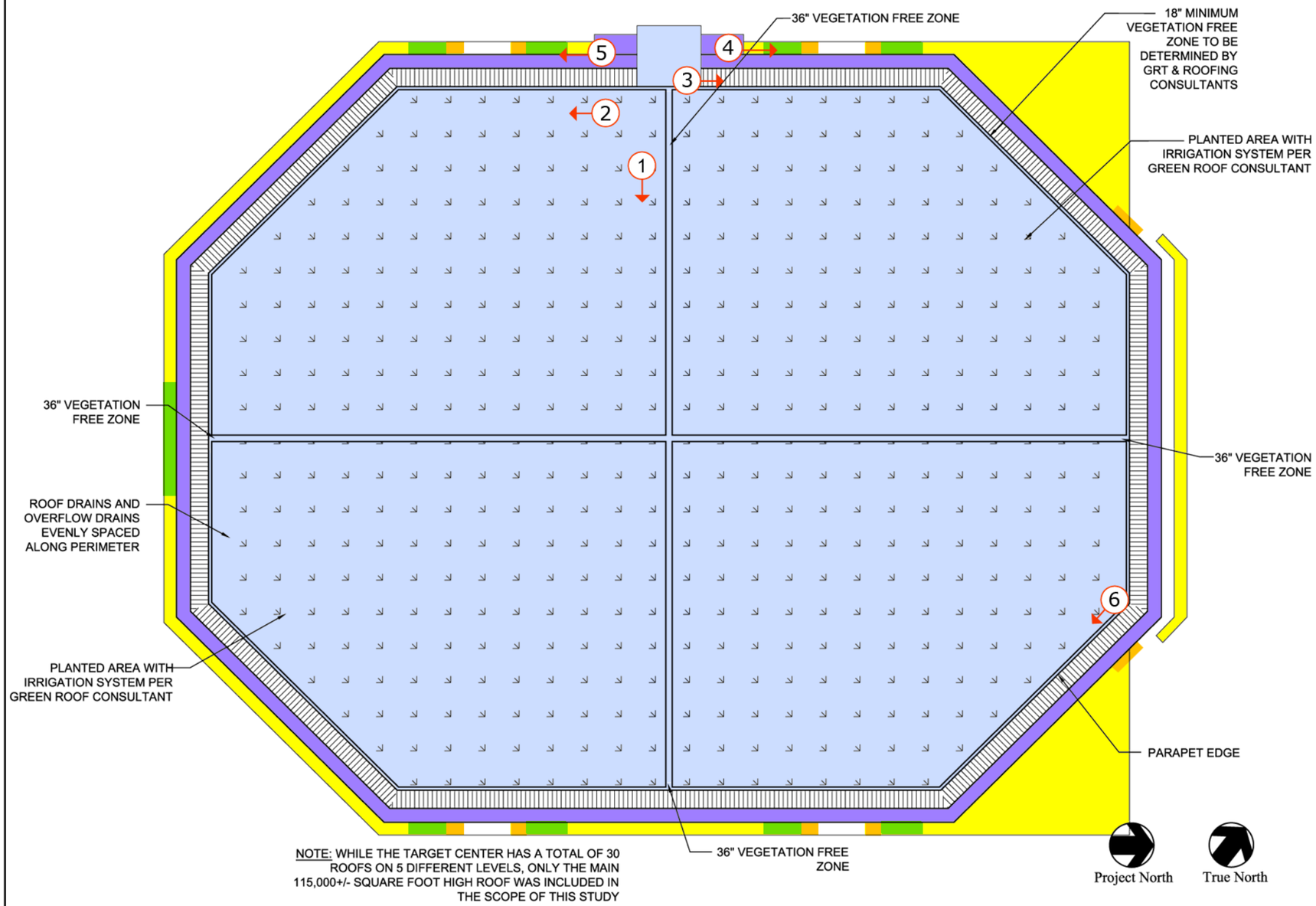
VI) RECOMMENDATIONS

If the Target Center IS likely to be in operation 20 more years, we recommend installation of a hybrid 17.4 lb/s.f. green roof (83.5 %of roof)/22 lb/s.f. green roof (16.5% of roof), as both the economic and ecological benefits of the green roof will outweigh those of the conventional roof. This green roof scenario will provide the maximum possible stormwater holding capacity, plant diversity, and landscape resilience within the existing structural capacity.

If the Target Center IS NOT likely to be in operation for at least another 20 years, lifecycle cost comparison of the factors included in this study (not including marketing value or watershed wide stormwater benefits of the green roof) favors a conventional roof, but ecological benefits of the greenroofs still outweigh those of the conventional roof, so the Owner will need to prioritize decision making factors.

VII) APPENDIX: TYPICAL CONCEPT DRAWINGS

G-1) Green Roof Concept and Context Plan
G-2) Combination of White and Green Roof Concept and Context Plan
G-3) Typical Building Section
G-4) Typical Planted in Place Green Roof: 1.4” Growing Medium
G-5) Typical Planted in Place Green Roof: 6” Growing Medium
G-6) Typical Pre-Grown Green Roof: 1.4” Growing Medium
G-7) Typical Pre-Grown Green Roof with Irrigation Dripline



NOTE: WHILE THE TARGET CENTER HAS A TOTAL OF 30 ROOFS ON 5 DIFFERENT LEVELS, ONLY THE MAIN 115,000+/- SQUARE FOOT HIGH ROOF WAS INCLUDED IN THE SCOPE OF THIS STUDY

LEGEND

- ROOF LEVEL A (MAIN ROOF OVER ARENA)
  - APPROXIMATELY 115,000 SQ. FT.
  - 80% OF TOTAL ROOF AREA
- ROOF LEVEL B (UPPER RING ROOF)
- ROOF LEVEL C
- ROOF LEVEL D
- ROOF LEVEL E (MEZZANINE LEVEL ROOFS)
- SLOPED METAL PANEL
- (1) EXTERIOR PHOTO LOCATIONS

(1) ROOF LEVEL A

(2) ROOF LEVEL A

Green Roof
Concept & Context Plan G-1

0' 5' 15' 25' 50' 100'

NOTE: BACKGROUND DRAWINGS BY KMR ARCHITECTS

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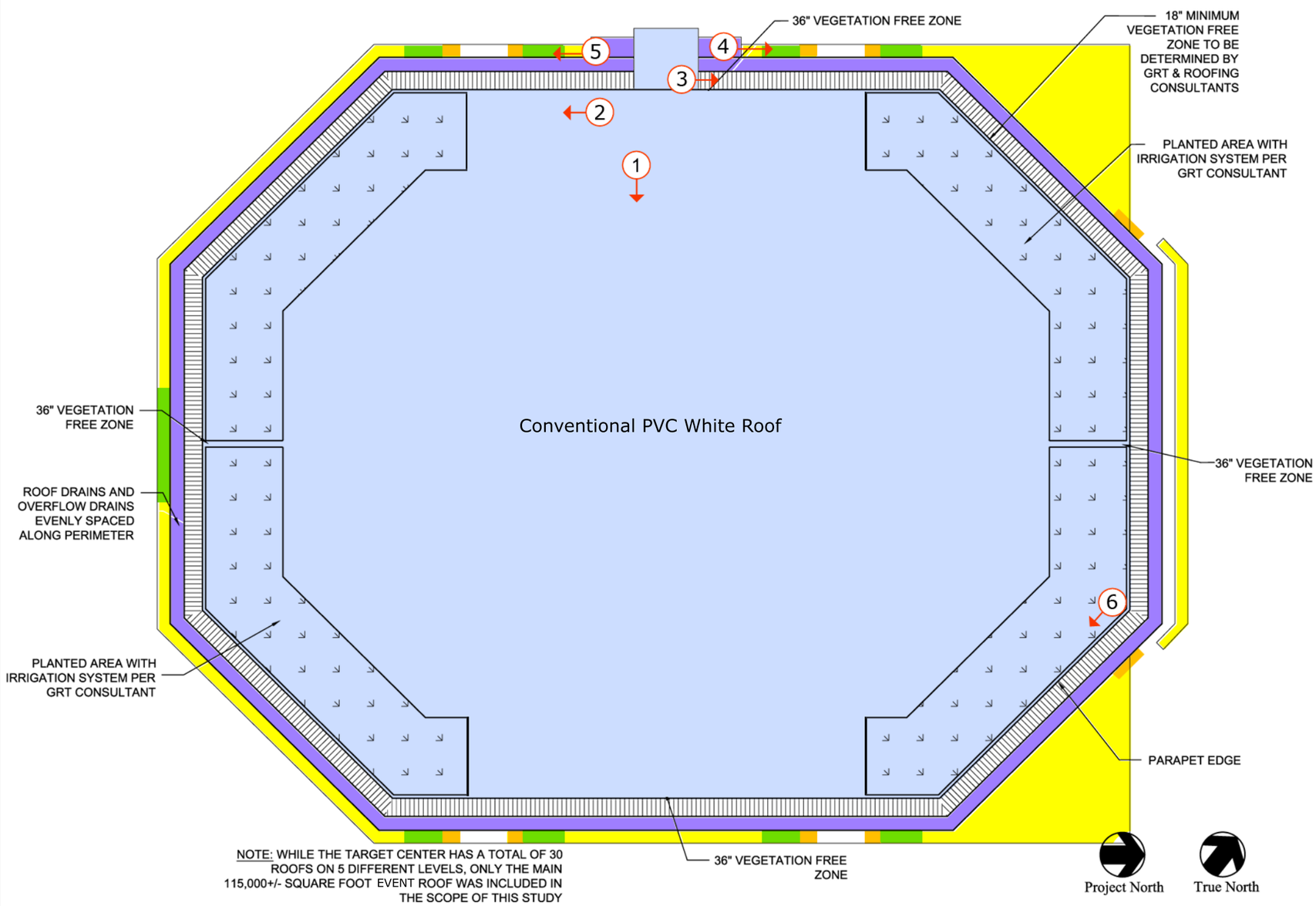

NOTE: WHILE THE TARGET CENTER HAS A TOTAL OF 30 ROOFS ON 5 DIFFERENT LEVELS, ONLY THE MAIN 115,000+/- SQUARE FOOT EVENT ROOF WAS INCLUDED IN THE SCOPE OF THIS STUDY

LEGEND

- ROOF LEVEL A (MAIN ROOF OVER ARENA)
  - APPROXIMATELY 115,000 SQ. FT.
  - 80% OF TOTAL ROOF AREA
- ROOF LEVEL B (UPPER RING ROOF)
- ROOF LEVEL C
- ROOF LEVEL D
- ROOF LEVEL E (MEZZANINE LEVEL ROOFS)
- SLOPED METAL PANEL
- (1) EXTERIOR PHOTO LOCATIONS

(1) ROOF LEVEL A

(2) ROOF LEVEL A

Combination of White & Green Roof Concept & Context Plan G-2

0' 5' 15' 25' 50' 100'

NOTE: BACKGROUND DRAWINGS BY KMR ARCHITECTS

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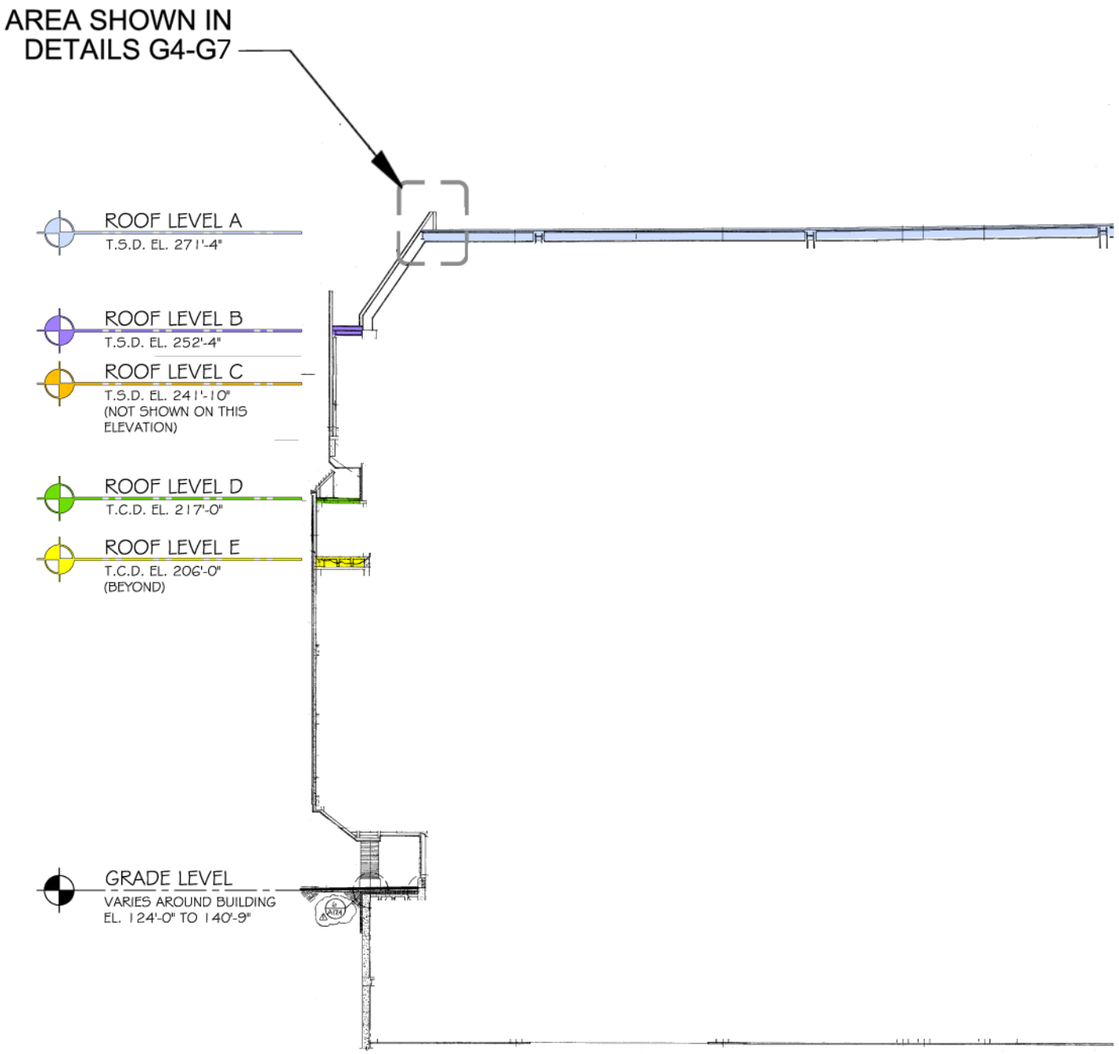

3 ROOF LEVEL B

4 ROOF LEVEL C

5 ROOF LEVEL D & E

6 ROOF LEVEL C & E

Typical Building Section G-3

NOTE: BACKGROUND DRAWINGS BY KMR ARCHITECTS

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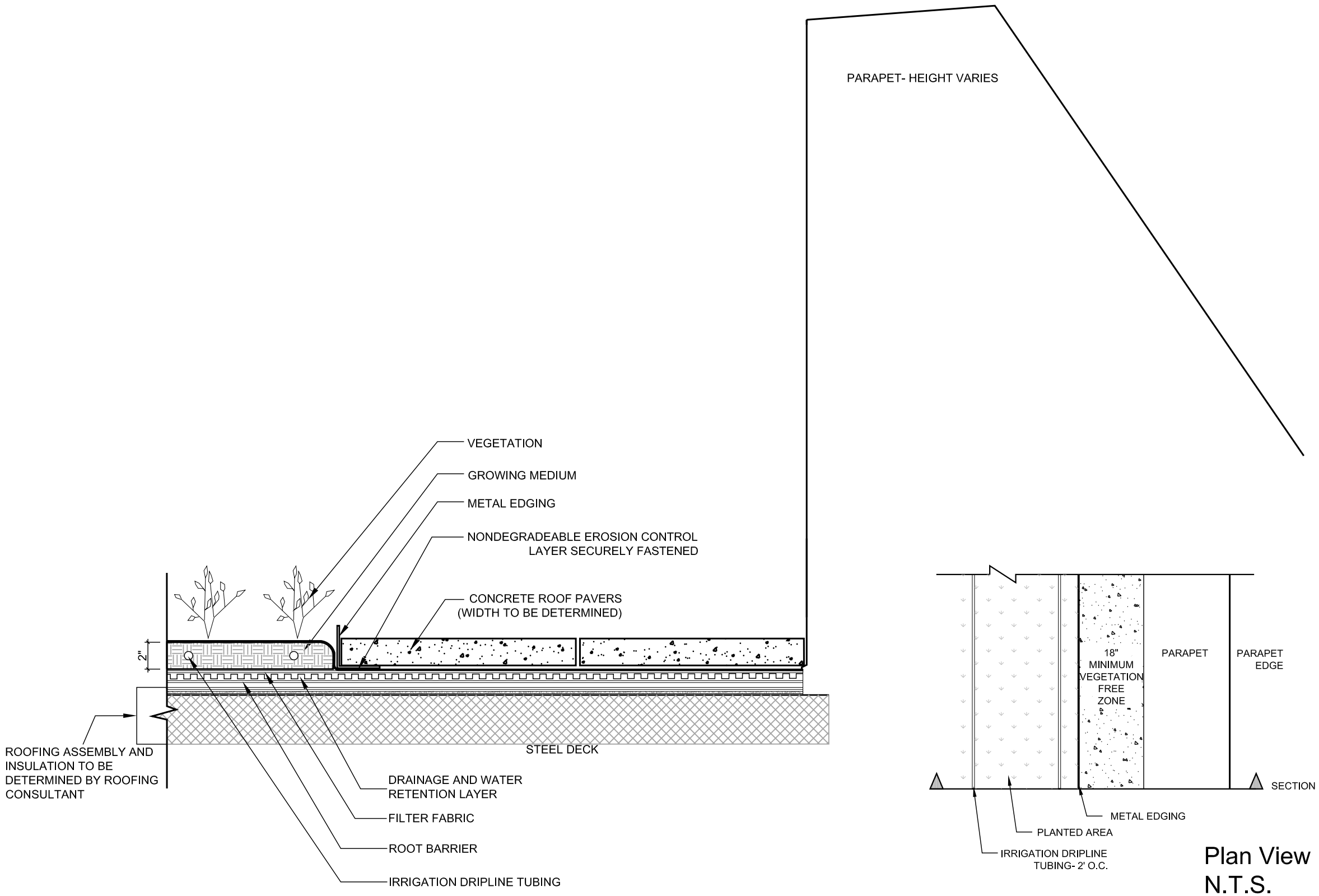

Plan View
N.T.S.

1
G-4

TYPICAL PLANTED IN PLACE GREEN ROOF- 1"-4" GROWING MEDIUM

Section
Scale:1-1/2"=1'-0"

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Project No.: 07432
Drawn by: AJW
Checked by: NH
Date: 2/01/2008

Revisions:

Date/Initials/Description

07432/CAD/07432_Details.dwg

0 4" 8" 1'

Scale:1-1/2"=1'-0"

TARGET CENTER Re-Roofing Analysis
Minneapolis, Minnesota

GREEN ROOF TYPICAL PLANTED IN PLACE CONCEPTUAL DETAIL

G-4

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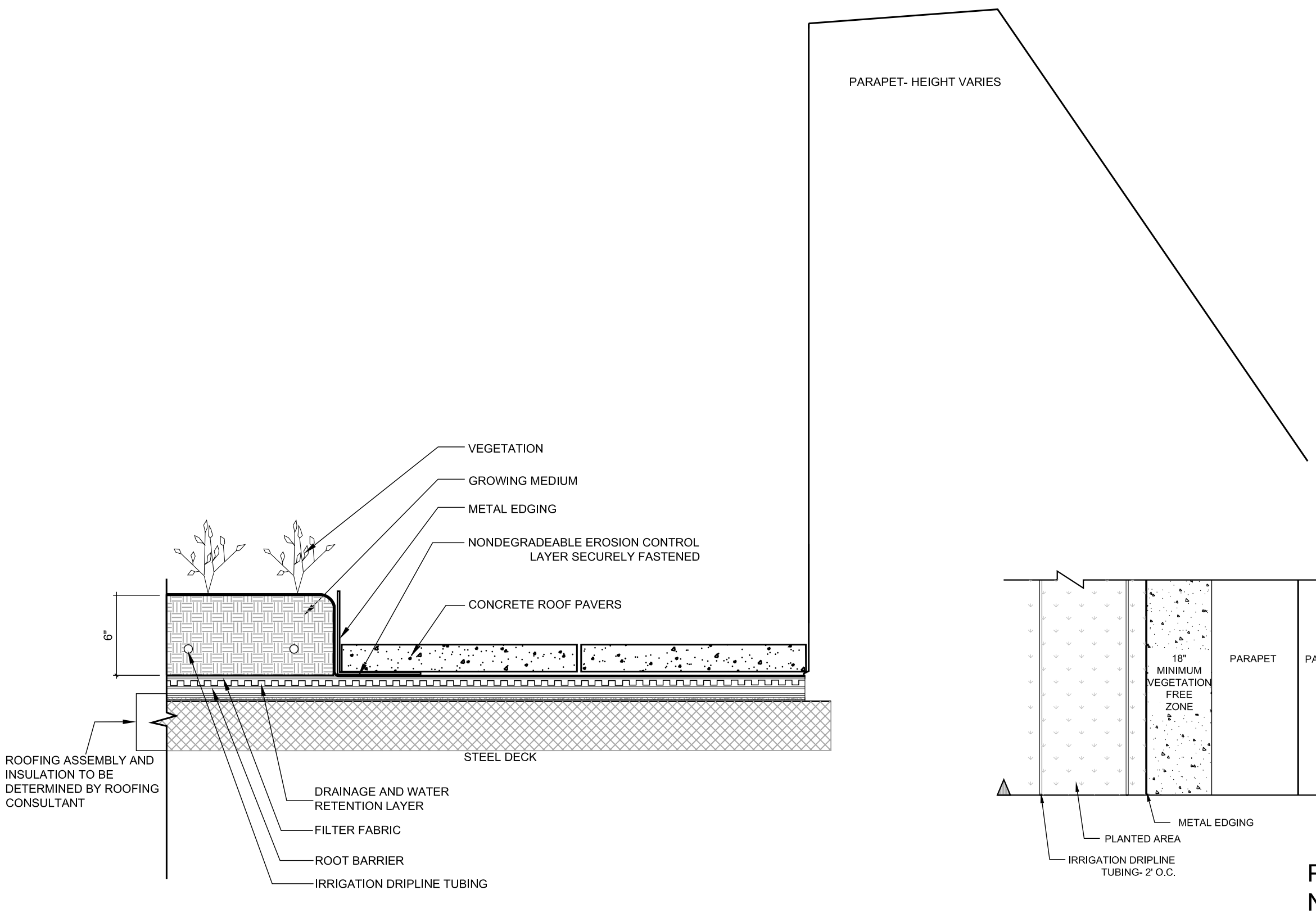

Plan View
N.T.S.

1
G-5

TYPICAL PLANTED IN PLACE GREEN ROOF- 6" GROWING MEDIUM

Section
Scale:1-1/2"=1'-0"

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07432/CAD/07432_Details.dwg

0 4" 8" 1'
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TARGET CENTER Re-Roofing Analysis
Minneapolis, Minnesota

GREEN ROOF TYPICAL PLANTED IN PLACE CONCEPTUAL DETAIL

G-5

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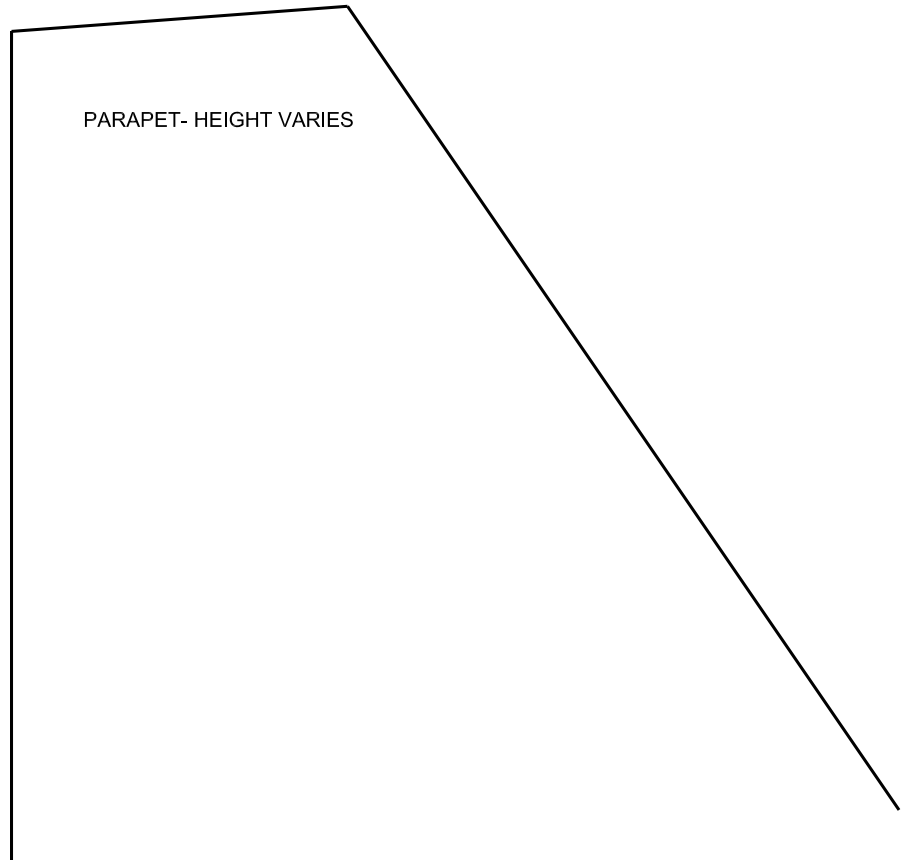

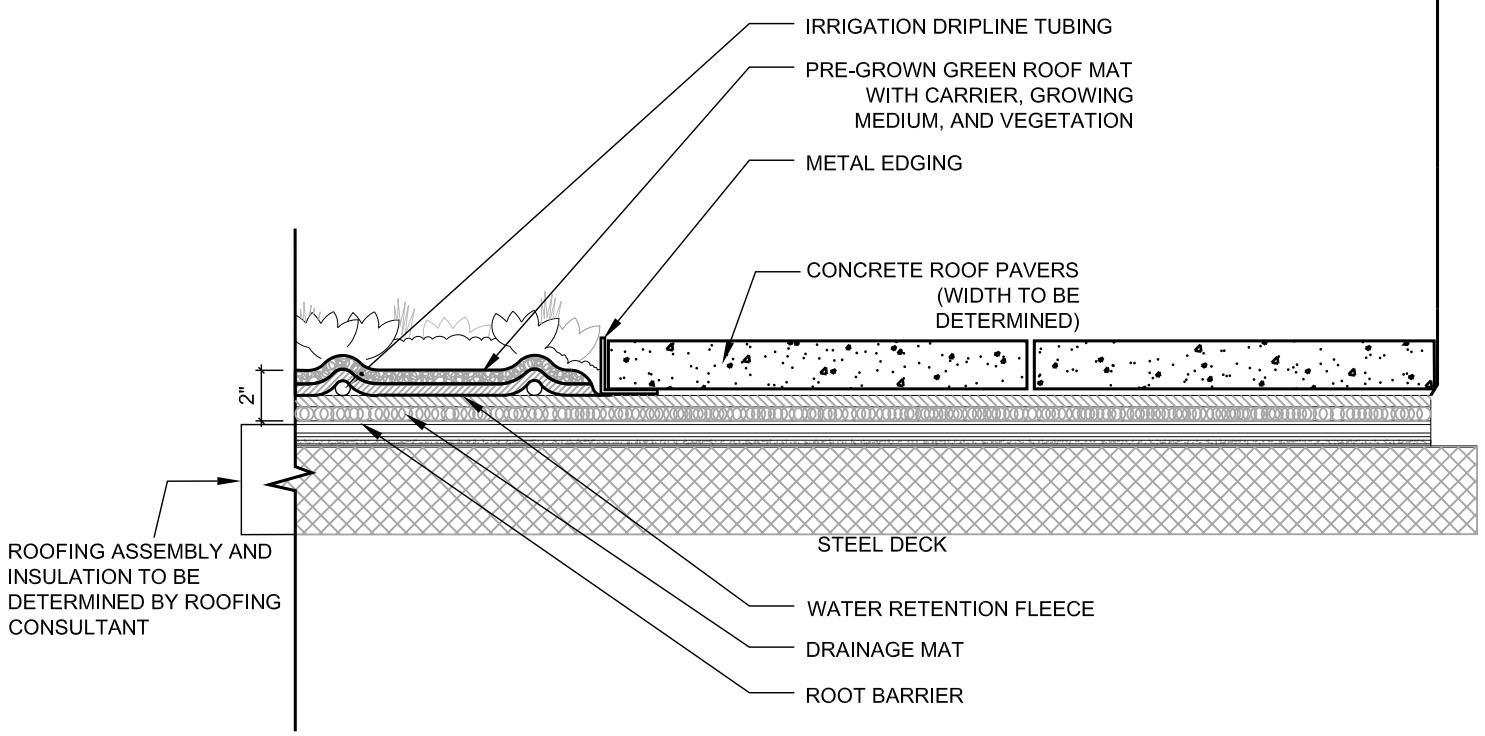

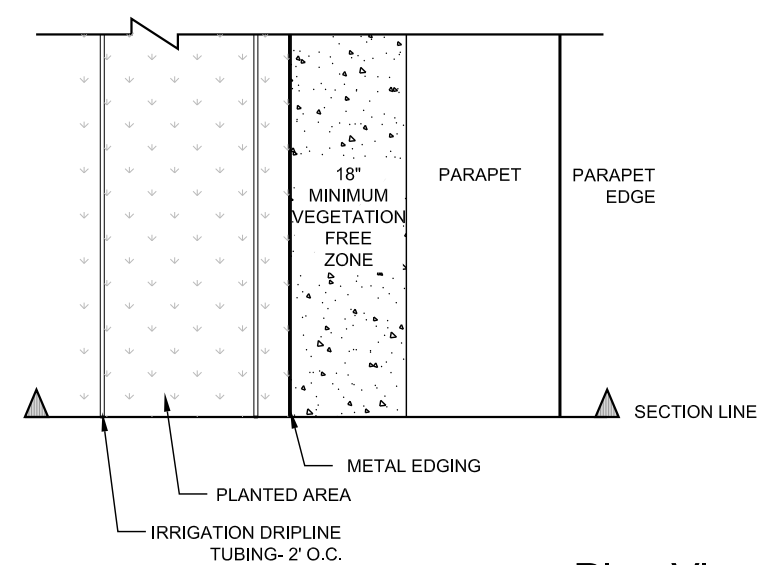

Plan View
N.T.S.

1
G-6

TYPICAL PRE-GROWN GREEN ROOF- 1"- 4" GROWING MEDIA

Section
Scale:1-1/2"=1'-0"

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Date: 2/01/2008

Revisions:

Date/Initials/Description

07432/CAD/07432_Details.dwg

0 4" 8" 1'
Scale:1-1/2"=1'-0"

TARGET CENTER Re-Roofing Analysis
Minneapolis, Minnesota

GREEN ROOF
TYPICAL PRE-GROWN
CONCEPTUAL DETAIL
G-6

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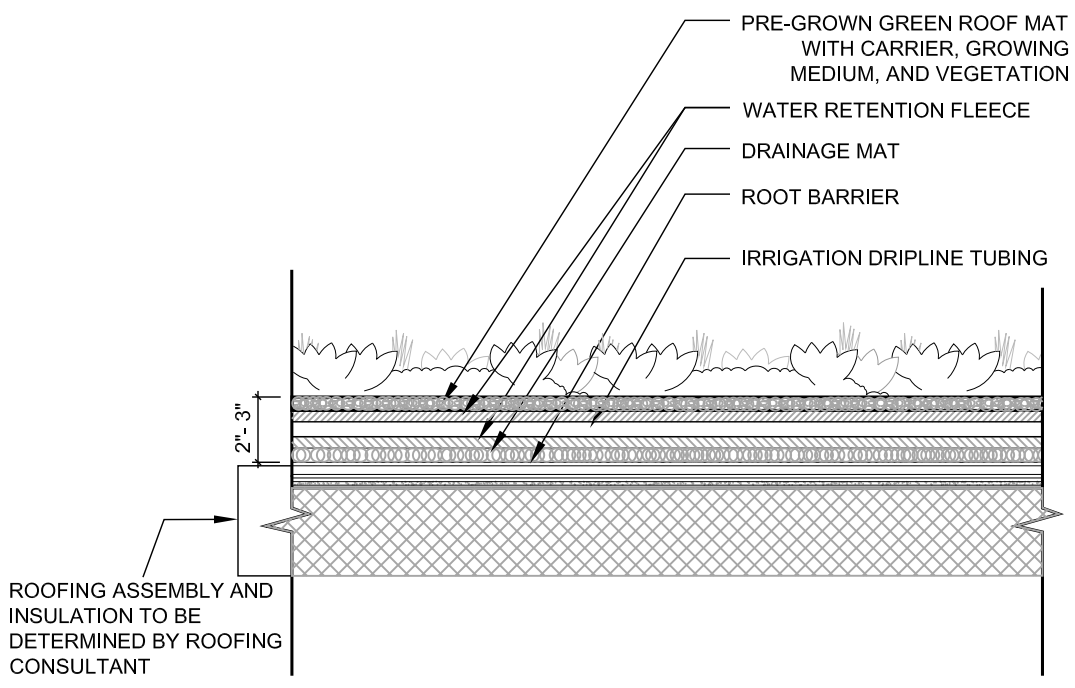
NOT FOR CONSTRUCTION



1
G-7

TYPICAL PRE-GROWN GREEN ROOF WITH IRRIGATION DRIPLINE

Longitudinal Section
Scale:1-1/2"=1'-0"

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0 4" 8" 1'
Scale:1-1/2"=1'-0"

TARGET CENTER Re-Roofing Analysis
Minneapolis, Minnesota

GREEN ROOF TYPICAL PRE-GROWN W/ IRRIGATION CONCEPTUAL DETAIL **G-7**

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