## DESIGN NARRATIVE FOR VERTICAL LOOP GROUND SOURCE SYSTEM

Prepared by Andy Baker, PE, YourCleanEnergy LLC Updated for Four Building Project on October 28, 2022

Design of the Ground Source Heat Pump System for the Seward District Heat System is based on the following criteria recommended by IGSHPA (International Ground Source Heat Pump Association); from the $CO_2$ heat pump manufacturer Mayekawa; from standard mechanical engineering design practice, and from previous YCE/EDC project experience with ground source heat pump system in Seldovia, and the $CO_2$ heat pump system at the Alaska SeaLife Center. Design criteria for this project is as follows:

- Vertical loop field should provide 2.5 to 3 gm of source flow per ton of heating capacity (IGSHPA).

- Vertical loop field is 92% submerged and can be modeled as a lake loop, with a recommended total loop length of 300 ft per ton of heating capacity (IGSHPA).

- Velocity thru vertical loops at design flow must be high enough to ensure turbulent flow, meaning a Reynolds Number of 2500 or greater. Anti-freeze concentration must be considered (IGSHPA).

- Double ¾" HDPE SDR11 loops will be inserted down a 6" diameter sch 40 steel casing driven down into the gravel formation; the casing will then be extracted. The existing 4" diameter PVC screened test well (installed in 2015) will have a single loop of 1" HDPE SDR11 piping installed in its water column to equal depth of the ¾" HDPE loops.

- Ground water monitoring data shows that the water table begins at @20 ft below grade; and that warm ocean tides influence the first 220 ft of the water table: therefore, vertical loops will extend 240 ft below grade for this project. Monitoring data suggest an annual average groundwater temperature of 46°F in the first 220 ft of the water table where the wellfield will be located.

- Velocity thru supply and return manifolds must be at least 2 fps at design flow to ensure proper flushing of trapped air from the system (IGSHPA). Once the system is commissioned, air will be removed from the main source loop with air release valves in the Library.

- Velocity in the HDPE source main from Library to vertical loop field should not exceed 6 fps at maximum design flow, to avoid high friction loss and pumping energy. Anti-freeze concentration and source flow temperature must be considered in calculating friction loss and pumping energy.

- The $CO_2$ heat pump units can receive source flows from 26 gpm to 78 gpm, with a mid-range of 54 gpm being optimal for fixed flow pumping (Mayekawa Unimo performance calculator).

**Estimation Of Design Heat Load (@5F Outdoor Air Temp ) To Be Served:**

Economy Project = Two $CO_2$ Heat Pumps serving Library + City Annex + system heat losses = 480,000 BTU/hour = 40 tons

Three Building Project = Four $CO_2$ Heat Pumps serving City Hall + City Annex + Library + system heat losses = 720,000 BTU/hour = 60 tons

Four Building Project = Five $CO_2$ Heat Pumps serving City Hall + City Annex + Library + Fire Hall + system heat losses = 852,000 BTU/hour = 71 tons

**Determine Optimal Source Flow Into Heat Pump Units**:

To ensure adequate heat transfer in a heat pump unit from a closed loop geothermal system, IGSHPA recommends a source entering flow rate of 2.5 to 3.0 gpm per ton of heating capacity. For the Economy Project of 40 tons, this would equate to 100 gpm to 120 gpm of total source flow entering the heat pumps. For the Three Building Project of 60 tons, this would equate to 150 gpm to 180 gpm of total source flow entering the heat pumps. For the Four Building Project of 71 tons, this would equate to 178 gpm to 218 gpm of total source flow entering the heat pumps.

The Mayekawa Unimo heat pump units will accept a range of 26 gpm to 78 gpm of source flow per unit. The more source flow delivered to the units, the more heat capacity the units can deliver on the load side for a fixed set of operating conditions. Energy modeling of the $CO_2$ heat pumps using the Mayekawa performance simulator shows that for example, for a 40°F source entering temperature: increasing the source flow rate from 30 gpm (currently used at ASLC) to the mid-range target of 54 gpm will increase heat output from each heat pump by 5,105 BTU/hr; increase heating COP from 2.39 to 2.43; and raise the source leaving temperature from 32.2°F up to 35.5°F. This is a significant improvement in heat pump performance for a very small increase in source side pumping energy.

For this project, the source flow rate for each heat pump will be fixed at the mid-range 54 gpm. This will allow fewer heat pumps to operate to cover modulating heat loads; and avoid the need for modulating source flow in real time with expensive VFDs, source side flow meters, and additional programming of the HPPC. The fixed flow rate of 54 gpm at each heat pump is close to optimal in matching wellfield flow rates within the flow capacity of the vertical loop field.

| Loop Description | 1 HP Target Flow (gpm) | 2 HP Target Flow (gpm) | 3 HP Target Flow (gpm) | 4 HP Target Flow (gpm) | 5 HP (gpm) |
|---|---|---|---|---|---|
| Well Field Supply Loop 100 | 85 | 125 | 162 | 180 | 218 |
| Source Side Loops 201 thru 205 | 54 | 108 | 162 | 216 | 270 |

The table above shows that for the 4 HP and 5 HP operations there will be a small amount of back-cycling of source flow to the heat pumps, this will cause a very slight cooling in source temperature. However it is expected that the slight cooling of source from the back-cycling will be easily offset by increased heat gains from the vertical loops as they will see a higher Reynolds Number that ensures more turbulence and heat transfer from ground water into the loops. See the section later in this memo on Reynolds Number.

**Selection Of Heat Transfer Fluid:**

The heat pump manufacturer Mayekawa requires freeze protection of source side fluid down to 15°F. A similar freeze protection is preferred in the 4" insulated supply and return mains between the wellfield and the Library. There is no back up generation available at the Library and the source and a power outage of several hours on occasion can be expected. The source mains will be buried approximately 5 ft below grade and will be wrapped continuously with one inch of R8 insulation. Depth of frozen ground can reach 6 ft or more during winter season in Seward.

The most common heat transfer fluids used in ground source systems are propylene glycol (PG) and methanol. Either a 25% by volume PG solution, or a 20% by volume methanol solution would provide the required freeze protection need for this project. Non-toxic propylene glycol (25% by volume) is the selected choice for this project for two important reasons. First, the vertical loop field is adjacent to Resurrection Bay which is a pristine marine ecosystem regulated by both state and federal environmental agencies. A solution of 25% PG in the closed loop ground system is both non-toxic to marine organisms and biodegradable over time should a leak occur in the source mains, well field manifolds, or vertical loops. Methanol has known toxicity to marine organisms. Second, the Mayekawa Unimo heat pumps are not rated as explosion proof, making PG a clear choice over methanol which is flammable and can asphyxiate an operator if leaked inside a closed room. There is a slight penalty in heat transfer and pumping energy by using 25% PG over 20% methanol, however for this project the benefits of PG in terms of operator safety and environmental safety are well justified.

A $CO_2$ monitor with audible and visible alarm will be installed with air sampler tube 18" above the floor near the heat pumps. The alarm will be enabled when the concentration of $CO_2$ exceeds 2,000 ppm. The $CO_2$ monitor will also send an alarm signal to the HPPC which will display the alarm in the web-based operator screens and record the event.

**Selection Of Piping Material and Size For Vertical Ground Loops:**

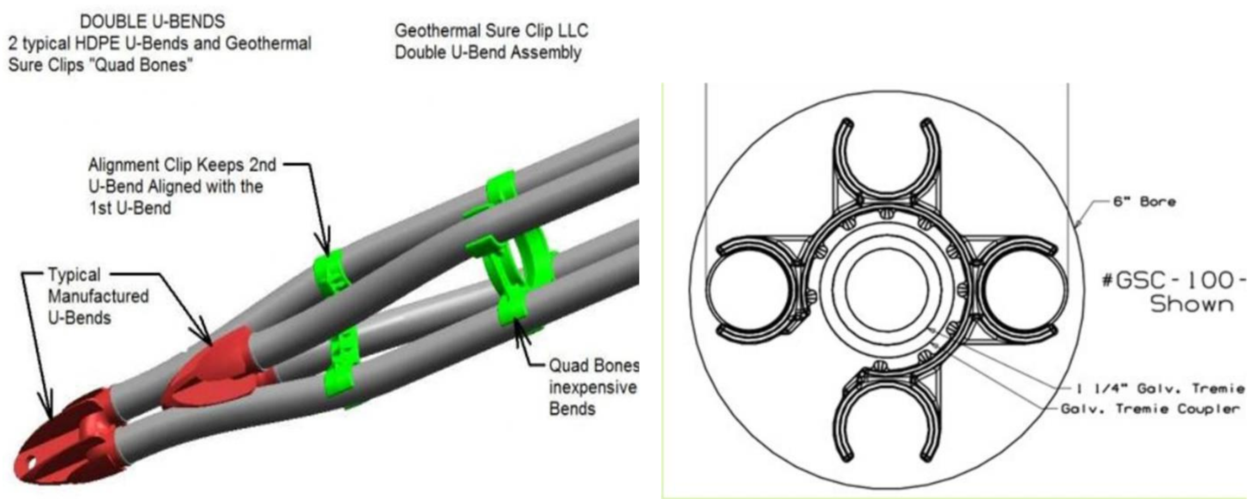
Per IGSHPA recommendations, vertical loops should be made from PE4710 SDR11 HDPE (160 psi rating) with nominal diameter of ¾" or 1" size:

¾" HDPE SDR11 has ID of 0.848" and OD or 1.05"

1" HDPE SDR11 has ID of 1.062" and OD of 1.315"

To optimize return on cost of borehole drilling, double vertical loops (2 circuits per hole) will be used to dip vertical loops into the warm and horizontally moving tidal water table that exists from 20ft below grade to 240 ft below grade. The driller of the 2015 test hole (Denali Drilling) had success with driving a 6" Schedule 40 steel casing down 300 ft in the shoreside sand gravel formation, and then extracting the same steel casing with dual hydraulic jacks.

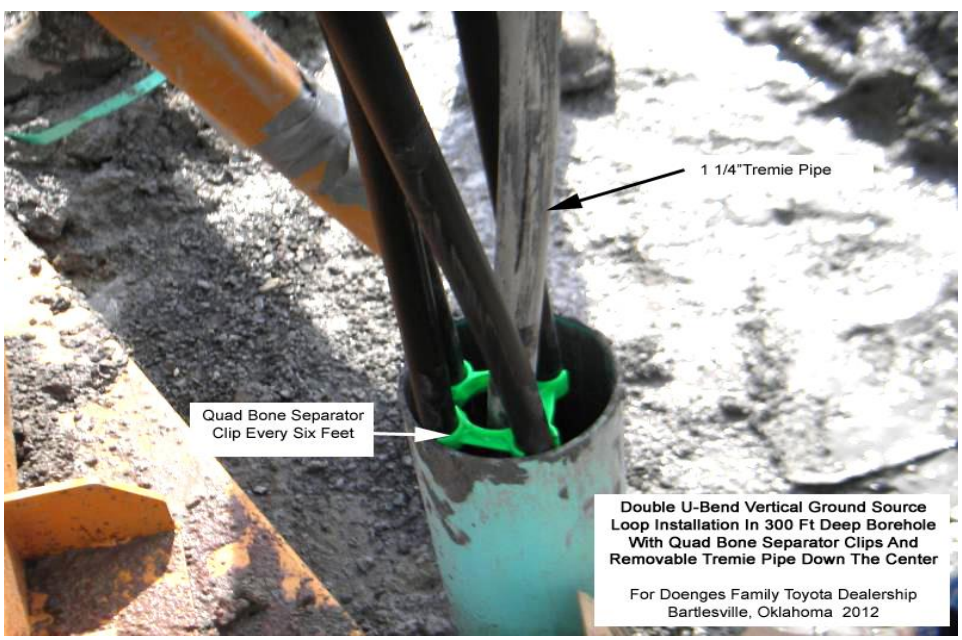
To limit the thermal influence of one vertical loop pipe on another in the same borehole, an innovative plastic spacer clip shall be installed every 6 ft as the double loops are inserted downhole. These plastic clips are known as "quad bones" and they effectively maintain a spacing of 2" to 3" between each of the four pipes along the entire depth of the borehole. This optimizes the total heat transfer possible from the double loops, especially in a fully saturated tidal subsurface condition that exists under the waterfront in Seward. Below are images from the manufacturer of the "quad bone" clips:




While it is possible to insert double loops of ¾" size with quad bone spacers down a 6" Schedule 40 steel casing of 240 ft depth, this could be very difficult and even risky if using 1" HDPE with a quad bone spacer. 1" HDPE SDR11 pipe is much stiffer and the clearance between outside pipe wall and casing is so close that the double loop assembly could be pulled out or stretched out due to friction when extracting the steel casing. Therefore, using ¾" SDR11 HDPE double loops with a properly sized quad bone spacer (Model No. GSC-75-4) to secure four ¾" pipes is the preferred choice for this project.

A proven and successful method of installing double loops with quad bone spacers down a 6" casing is to make use of an electric powered de-coiler that allows both loops to be smoothly and uniformly uncoiled into the borehole. The quad bone clips are inserted every six feet along the loops as the they are inserted. In this project the ground water table is only 20 ft below grade level. The vertical loops must be first filled with water before insertion downhole into the casing, otherwise the buoyant force from air in the loops will prevent them from sinking. To overcome the buoyant force of the HDPE pipe material, a heavy steel rebar of about five ft length must be attached to the bottom u-bend of the double loops.

The total depth of casing must be 245 ft to accommodate the 5 ft long rebar weight followed by 240 ft of loop inserted below grade. The loops must have an additional ten feet of pipe sticking above grade when fully inserted (to allow attachment to manifold), this requires the total loop length to be 250 ft. Following are two job site photos showing installation of double vertical HDPE geothermal loops (with quad bone spacers) into steel casing using a power de-coiler:

**Estimate total length of below grade vertical loop required:**

IGSHPA recommends approximately 300 ft of loop piping for each ton of heating capacity for a submerged closed loop system. This recommendation was used to determine the optimal number of boreholes in the well field, each borehole having a double loop of ¾" HDPE pipe to depth of 240 ft below grade:

Economy Project (Library + Annex): = heating capacity of 40 tons. 30% of source heat will be heat recovery from the existing boiler room and new heat pump room inside the Library; 70% of source heat will come from the ground source field.

40 tons x 0.7 x 300 ft of loop piping per ton = 8,400 ft of vertical loop piping recommended

8,400 ft of loop piping / 480 ft loop piping per circuit = 17.5 circuits *** use 18 circuits ***

Use 8 boreholes with double ¾" loops plus one additional 1" loop down existing test hole. For simplicity, the 1" HDPE down test hole will be considered roughly equivalent hydraulically to two ¾" circuits down the same hole.

16 circuits of ¾" HDPE + 1 circuit of 1" HDPE = approximately 18 circuits (loops) of ¾" HDPE pipe.

Three Building Project (Library + Annex + City Hall): = heating capacity of 60 tons. 20% of source heat will be heat recovery from the existing boiler room and new heat pump room inside the Library; 80% of source heat will come from the ground source field.

60 tons x 0.8 x 300 ft of loop piping per ton = 14,400 ft of vertical loop piping recommended

14,400 ft of loop piping / 480 ft loop piping per circuit = 30 circuits needed *** choose 30***

Use 15 boreholes with double ¾" loops plus one additional 1" loop down existing test hole. For simplicity, the 1" HDPE down test hole will be considered roughly equivalent hydraulically to two ¾" circuits down the same hole.

30 circuits of ¾" HDPE + 1 circuit of 1" HDPE = approximately 32 circuits (loops) of ¾" HDPE pipe.

Four Building Project (Library + Annex + City Hall + Fire Hall): Heating capacity of 71 tons. Approximately 17% of source heat will be heat recovery from the existing boiler room and new heat pump room inside the Library; approximately 83% of source heat will come from the ground source field.

71 tons x 0.83 x 300 ft of loop piping per ton = 17,680 ft of loop piping recommended

17,680 ft of loop piping / 480 ft of loop per circuit = 36.8 circuits needed *** choose 36 ***

36 circuits x 480 ft loop piping per circuit = 17,280 ft of loop piping in design = acceptable

Use 18 boreholes with double ¾" loops plus additional loop down existing test hole. For simplicity, the 1" HDPE down test hole will be considered equivalent hydraulically to two ¾" circuits down the same hole.

36 circuits of ¾" HDPE + 1 circuit of 1" HDPE = approximately 38 circuits (loops) of ¾" HDPE pipe.

**Reynolds Number - Flow in Vertical Loops Must Be Turbulent For Good Geo Heat Exchange**:

IGSHPA recommends having a Reynolds Number of 2500 or greater in vertical ground loops at design flow to ensure there is turbulent profile for good heat exchange between the pumped 25% propylene glycol heat transfer solution and the HDPE pipe wall. For this design, the flow of ground and tidal water outside and around the vertical loop pipes is assumed to be laminar. However, the horizontal movement of subsurface water table due to tidal action, especially near high and low tides, will provide enhanced heat transfer in comparison to the same loops installed as coils in a stagnant and colder lake bottom.

For simplicity, the ground source system in this project is considered similar to a lake loop system since 440ft of each 480 ft long vertical loop will be completely submerged under the water table.

The Reynolds Number is a parameter expressing the magnitude of turbulence near the wall of a pipe filled with fluid. Reynolds Number of 2300 or less indicates laminar flow in the pipe. 3500 or more indicates there is clearly turbulence in the pipe. The greater the flow, the higher the Reynolds Number and turbulence, and the greater the transfer of heat thru the pipe wall. Higher flows also means more pipe friction loss and pumping energy required. The goal of vertical loop design is to choose the number of vertical loops such that the source flow in each loop has a Reynolds Number of at least 2500 under design conditions.

Climate Master has compiled a useful chart for ¾" and 1" SDR HDPE pipe showing velocity and Reynolds Number for 25% PG flowing at 30°F. This is cooler than our minimum expected source return temperature of 36F; using this table suggests a conservative design that will yield proper heat exchange in the vertical loops. See below that for ¾" SDR11, a Reynolds Number of 2554 is achieved when flow reaches 4 gpm (velocity of 2.21 feet per second):

Water-to-Water System Design Guide

Part III: Source Side Design / Closed Loop Installatic

**Table 3-3b: Polyethylene Pressure Drop per 100ft of Pipe**
**Antifreeze (30°F [-1°C] EWT): 25% Propylene Glycol by volume solution**

| Flow Rate | 3/4" IPS SDR11 | | | 1" IPS SDR11 | | | 1-1/4" IPS SCH40 | | | 1- |
|---|---|---|---|---|---|---|---|---|---|---|
| | PD (ft) | Vel (ft/s) | Re | (ft) | Vel (ft/s) | Re | PD (ft) | Vel (ft/s) | Re | PD |
| 1 | 0.42 | 0.55 | 636 | 0.14 | 0.35 | 507 | 0.04 | 0.21 | 389 | 0.02 |
| 2 | 1.41 | 1.10 | 1271 | 0.48 | 0.70 | 1013 | 0.15 | 0.43 | 798 | 0.07 |
| 3 | 2.86 | 1.66 | 1919 | 0.98 | 1.06 | 1534 | 0.30 | 0.64 | 1187 | 0.15 |
| 4 | 4.74 | 2.21 | 2554 | 1.63 | 1.41 | 2041 | 0.50 | 0.86 | 1595 | 0.24 |
| 5 | 7.01 | 2.76 | 3190 | 2.41 | 1.76 | 2548 | 0.74 | 1.07 | 1985 | 0.36 |
| 6 | 9.64 | 3.31 | 3826 | 3.31 | 2.11 | 3054 | 1.02 | 1.29 | 2393 | 0.49 |
| 7 | 12.62 | 3.87 | 4473 | 4.33 | 2.47 | 3575 | 1.34 | 1.50 | 2782 | 0.64 |
| 8 | 15.94 | 4.42 | 5109 | 5.47 | 2.82 | 4082 | 1.69 | 1.72 | 3190 | 0.81 |
| 9 | 19.59 | 4.97 | 5745 | 6.73 | 3.17 | 4589 | 2.07 | 1.93 | 3580 | 1.00 |
| 10 | 23.56 | 5.52 | 6380 | 8.09 | 3.52 | 5095 | 2.49 | 2.15 | 3988 | 1.20 |

Climate Master – Water To Water System Design Guide - 2007

<u>Economy Two Building Project</u>: For the 40 ton (480,000 BTU/hr) heat load of the Economy Project (2 heat pumps + 2 bldg district heat system), the optimal flow rate of 25% PG source flow is 85 gpm. Per above table, at least 4 gpm per ¾" HDPE vertical loop is needed to generate turbulent flow and good heat exchange in the loops. To calculate the flow rate in each of vertical loops:

85 gpm / 18 circuits = 4.72 gpm per circuit = Reynolds No. approx. = 3,190 = good turbulence

Additional performance can be expected from the Economy Project with source flow = 108 GPM; this flow equates to the optimal mid-range of 54 gpm of source flow thru 2 heat pumps

108 GPM / 18 circuits = 6 gpm per circuit = Reynolds No. approx. = 3,826 = excellent turbulence

<u>Three Building Project</u>: For the 60 ton (720,000 BTU/hr) heat load of the Base Project (4 heat pumps + 3 bldg district heat system), the optimal flow rate of 25% PG source flow is 180 gpm. Per above table, at least 4 gpm per ¾" HDPE vertical loop is needed to generate turbulent flow and good heat exchange in the loops. To calculate the flow rate in each of vertical loops:

180 gpm / 32 circuits = 5.62 gpm per circuit = Reynolds No. approx. = 3,600 = good turbulence

<u>Four Building Project</u>: For the 71 ton (852,000 BTU/hr) heat load (Four building district heat system served by five heat pumps), the optimal flow rate of 25% PG source flow is 218 gpm. Per above table, at least 4 gpm per ¾" HDPE vertical loop is needed to generate turbulent flow and good heat exchange in the loops. To calculate the flow rate in each of vertical loops:

218 gpm / 38 circuits = 5.74 gpm per circuit = Reynolds No. approx. = 3,700 = good turbulence

**<u>Layout Of Vertical Loop Wellfied In City Waterfront Park</u>**

See YCE Drawing C3.0. Boreholes will be in two parallel rows between the paved bike path and the Branson Pavillion. The east row is closest to the ocean and will have one more borehole than the west row. All boreholes will be 6" diameter and drilled with equal spacing of 20 ft between boreholes to avoid thermal influence of one set of vertical loops upon another. The east and west rows are staggered from each other again to avoid thermal influence from the east to west to east tidal flow anticipated in the water table below.

**<u>Source Mains From Library To Wellfield Manifold</u>**

The source return and supply mains will carry the total source flow from the Library to the wellfield manifold, and then from the opposite end of the manifold back to the Library. There is a 25 ft drop in grade elevation from Library to the manifold. If this source loop is pressurized to 30 psi at the Library heat pump room for normal operation, the maximum static pressure in the source mains would occur at the wellfield and be about 41 psi. These mains are selected to be 4" HDPE SDR 17 with pipe inside diameter of 3.94" and 125 psi pressure class. The project specifications require these lines be pressure tested with air at 100 psi for a 24-hour period after installation. The source main piping will have 1" urethane insulation wrap (R8) and a heavy HDPE jacket around the insulation. The pipe is specified to be Polycor, as manufactured by Thermacor in Corvallis, OR, or approved equal. The pipe is supplied in 40 ft lengths with 12" of pipe exposed at either end to allow butt fusion welded joints in the field. Once fused, the two ft length at the joint is fitted with an insulated joint kit that provides a permanent water-tight seal. All fittings specified for the 4" HDPE source main have a long sweep radius of 13.5 inches to minimize hydraulic losses.

For the Two Building Project, the return from Library is approximately 700 ft (536 ft plus an additional 164 ft along the well field - at which point the pipe class transitions to heavier wall SDR 11 for the manifold piping). The SDR 17 source supply main back to the Library begins where the SDR 11 supply manifold ends. The total length of 4” SDR 17 supply main is approximately 566 ft (30 ft along manifold + 536 ft to Library.

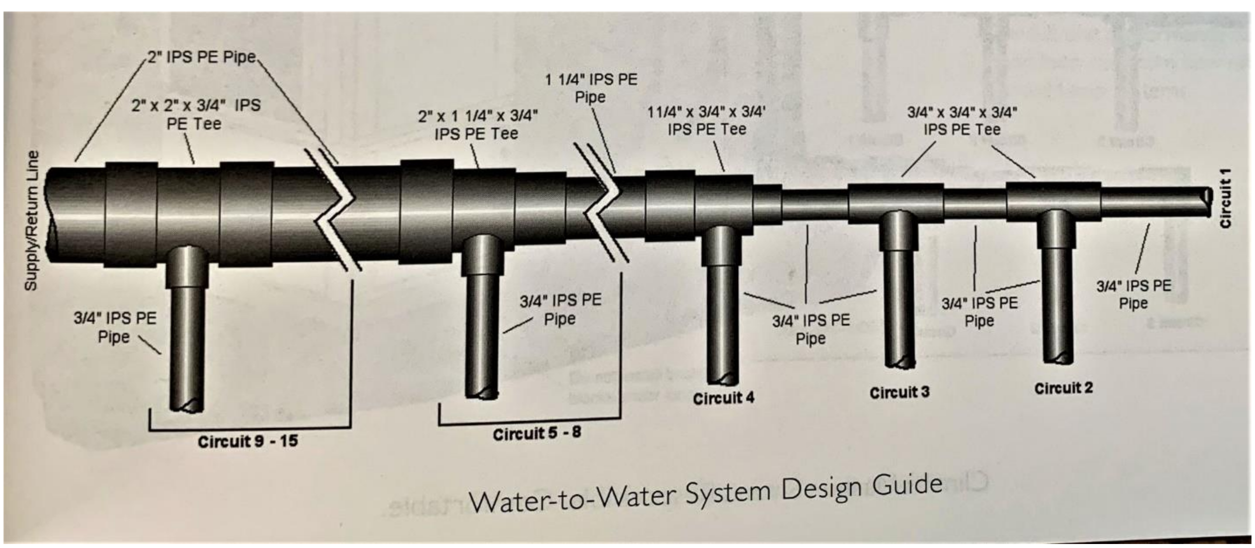
For the Three Building Project, the total length of 4” SDR17 4” in the source main loop is approximately 1,266 ft. This length of 4” SDR17 includes eight 90° sweep elbows, eight 22.5° sweep elbows, and two 7.75° sweep elbows.

For the Four Building Project, there is an additional 40 ft of 4” SDR 17 supply main along the well field. The total length of 4” SDR17 4” in the source main loop is approximately 1,306 ft. This length of 4” SDR17 includes eight 90° sweep elbows, eight 22.5° sweep elbows, and two 7.75° sweep elbows.

**Return & Supply Manifolds For Vertical Loop Circuits**

The return and supply manifolds that lie horizontal and parallel along the wellfield are also part of the source main loop. The manifolds are SDR11 HDPE and have pipe diameters which continually increase or decrease along the length of the manifolds as flow is delivered to, and received from, the circuits of loop piping. IGSHPA recommends that a velocity of at least 2 feet per second be reached in all sections of the manifolds under design conditions so that air can be flushed out of the vertical loop field and back to the heat pump room where air release valves can remove it.

The manifold must be designed so that as flow is added or removed by circuits that join the manifold from either side, the velocity in pipe sections is greater than 2 fps but less than 4 fps (when possible) at the design flow condition for the vertical loop field. Below is an example of custom designed manifold from the Climate Master geothermal system design guide that shows the manifold diameter changing along its length to accommodate the addition (or subtraction) of flow from circuits that join it:



To design the manifold headers for this project so that air is flushed out at the design flow (180 gpm for Three Building Project; 218 gpm for the Four Building Project) a table was made showing flows along the manifold header:

| Borehole No. | Flow per BH At Design Flow (gpm) | Exact Pipe Dia to give 2FPS (in) | Nominal SDR11 Pipe Size Selected | Pipe ID Of Selection (in) | Velocity w/Selected Pipe (fps) |
|---|---|---|---|---|---|
| 1 | 9.47 | 1.391 | 1 1/4" | 1.358 | 2.10 |
| 2 | 18.95 | 1.967 | 1 1/2" | 1.554 | 3.21 |
| 3 | 28.42 | 2.409 | 2" | 1.920 | 3.15 |
| 4 | 37.89 | 2.782 | 2" | 1.920 | 4.20 |
| 5 | 47.37 | 3.110 | 3" | 2.830 | 2.42 |
| 6 | 56.84 | 3.407 | 3" | 2.830 | 2.90 |
| 7 | 66.32 | 3.680 | 3" | 2.830 | 3.38 |
| 8 | 75.79 | 3.934 | 4" | 3.630 | 2.35 |
| 9 | 85.26 | 4.173 | 4" | 3.630 | 2.64 |
| 10 | 94.74 | 4.399 | 4" | 3.630 | 2.94 |
| 11 | 104.21 | 4.614 | 4" | 3.630 | 3.23 |
| 12 | 113.68 | 4.819 | 4" | 3.630 | 3.52 |
| 13 | 123.16 | 5.015 | 4" | 3.630 | 3.82 |
| 14 | 132.63 | 5.205 | 4" | 3.630 | 4.11 |
| 15 | 142.11 | 5.387 | 4" | 3.630 | 4.41 |
| 16 | 151.58 | 5.564 | 4" | 3.630 | 4.70 |
| 17 | 161.05 | 5.735 | 4" | 3.630 | 4.99 |
| 18 | 170.53 | 5.902 | 4" | 3.630 | 5.29 |
| 19 | **180.00** | 6.063 | 4" | 3.630 | **5.58** |
| 20 | 189.47 | 6.221 | 4" | 3.630 | 5.87 |
| 21 | 198.95 | 6.375 | 4" | 3.630 | 6.17 |
| 22 | 208.42 | 6.525 | 4" | 3.630 | 6.46 |
| 23 | **217.89** | 6.671 | 4" | 3.630 | **6.76** |

The supply and return manifolds are parallel and identical except that they are reversed from each other. The return manifold begins with the transition from 4” SDR 11 and terminates at the opposite end with the smallest diameter pipe (1¼” SDR11). The supply manifold begins with the smallest diameter pipe (1 ¼” SDR11), and then transitions to 4” SDR11 at the opposite end of the field. For the Three Building Project, the manifold length is approximately 182 ft; for the Four Building Project the manifold length is approximately 222 ft. There is 10 ft of manifold pipe between the locations along the manifold where ¾” side tees connect to the borehole circuits from either the west or east row of vertical loops.

## Sequence Of Operations For Pumping Glycol Thru The Ground Source System

The flow rate of glycol thru the ground source system will be modulated by the Heat Pump System Controls in accordance with the number of heat pumps running. The more heat pumps running, the greater the quantity of source heat that will be needed from the vertical loop well field.