VII. Residential Hot Water Distribution

1.0 Background

The purpose of this PBMP analysis is to address the waste of water that occurs in a typical household between the time one turns on a tap or a fixture and when the water arrives at the same location at the desired useful hot water temperature. The key question that needs to be answered in order to properly frame the discussion is:

How much water can or should be wasted while waiting for hot water to arrive?

The amount of water that is wasted is directly related to the volume and temperature of water that is in the pipe between the source of hot water and point of need, i.e., the fixture or appliance. That volume of waste can be either cold or warm water. That water is not at the desired useful hot water temperature at the beginning of the hot water event and can vary from practically zero to many gallons.

The amount of water waste also relates to time and energy. For a given flow rate, the smaller the volume that needs to be purged from the line, the less the wait. Less wait generally increases customer satisfaction.

Energy is used in buildings both to pressurize and heat the water. When needed, cold water is pressurized, e.g., using well pumps in remote locations and using pumps to lift the water in tall buildings. The energy so-consumed needs to be accounted for in the building and in the water and wastewater treatment systems. The energy required for heating the water is based on the delivery volume, the use volume, the volume of water that cools off between hot water events and on the efficiency of the water heater. The configuration of the hot water distribution system – length, diameter, environmental conditions, insulation, etc. – is directly related to its water delivery performance and to the energy needed to support this level of performance.

Every gallon that is not wasted while waiting for hot water to arrive means that a gallon does not need to be delivered to the water-using customer and that same gallon does not need to be treated as wastewater. The energy intensity of the water use cycle has been studied by the California Energy Commission (CEC). In their staff report (CEC-Klein, 2005), the CEC reported that energy intensity can vary from 2,000 to 20,000 kilowatt-hours/million gallons (kWh/MG). In northern California the typical energy intensity is roughly 4,000 kWh/MG and in southern California it is roughly 13,000 kWh/MG. Saving a gallon of water - hot or cold - in southern California typically saves more energy than in northern California.

1.1 What is a Hot Water Event?

Before going further, we need to define a hot water event. A typical hot water event is depicted in Figure 1. Each hot water event has three phases: delivery, use, and cool down. When a fixture valve is opened, hot water leaves the water heater and heads through the hot water piping toward the fixture. Ideally, we want this delivery time to be as short as possible. In practice, there are probably two parts to the delivery phase. The first part is technical or structural and depends
upon the plumbing system configuration, the location of the pipes, the volume of the water in the pipes between the water heater and the fixture, whether the piping is insulated, the fixture flow rate, the temperature of the water in the pipes compared to the temperature in the water heater, etc. The second part is behavioral and depends upon when the occupant decides the water is hot enough to use and “gets in.” The behavioral waste can be significantly longer than the structural waste.

![Figure 1. Hot Water Event Schematic](image)

The delivery phase may be short at some fixtures and long at others. It may be short or long at the same fixture depending on when hot water was last needed on the same line serving the fixture elsewhere in the building. Some people hover near the fixture, checking to see when it is hot enough, while others know from experience that it takes a long time, so they leave, returning when they are good and ready! From the occupant’s point of view this may appear to be totally random and hard to “learn”, in which case their behavior may likely default to the worst case condition at all fixtures.

The use phase needs to be whatever length it takes to perform the task for which hot water is desired. The cool down phase begins the moment the fixture is turned off. If the time until the next hot water event is short enough, the water in the pipes all the way back to the water heater will be hot enough to use. If it is too long, water coming from the water heater for that next event will be run down the drain until water hot enough to use arrives at the fixture.

At the fixture, hot water is generally mixed with cold water to reach the desired useful hot water temperature. The thermostat on the water heater needs to be set high enough to overcome the heat losses in the piping system and still provide water that is hot enough to be mixed with cold water at the furthest fixture to obtain the highest desired useful hot water temperature. For purposes of the experiments, 105°F was arbitrarily selected as the nominal useful hot water temperature. The actual useful hot water temperature depends in large part on the purpose of the hot water event: rinsing hands, taking a shower, sterilizing dishes, etc.
1.2 Recent Research

What follows is a synopsis of what was learned from the CEC-sponsored research into hot water flow (CEC-Hiller, 2005).

The Delivery Phase

The CEC learned three things about the delivery phase:

1. During the delivery phase, hot water acts differently than cold water
2. Low flow rates (< 1 gpm) waste much more water than high flow rates (> 4 gpm).
3. At typical fixture flow rates (1-3 gpm), sharp (standard) 90° elbows increase turbulence, heat loss and water waste

Perhaps one of the most surprising things researchers learned is that it is possible for significantly more water to come out of the pipe before hot water gets from the water heater to the fixture than is actually in the pipe. During the tests, their researcher found that the temperature sensor on the first turn was getting hot sooner than was theoretically possible assuming perfect plug flow. The difference in time was significant. To determine what was actually occurring, the researcher used his hands to feel the pipe and found that there was a thin stream of hot water riding on top of the cold water that was running many feet ahead of the plug of hot water coming from the water heater. After some time, mixing would occur, but until that happened, there was a much greater surface area of hot water touching both the cold water and the relatively cold pipe than would normally have been expected.

This is depicted in the top portion of Figure 2. At the beginning of a hot water event, the cold water is much more viscous than the hot water. The length of the thin stream of hot water could be more than 20 feet long and would go around the elbows. The volume of water that would come out of the pipe (or past a given temperature sensor) before hot water arrived could be twice the volume that was in the pipe.

This condition was most prevalent at flow rates less than 1 gpm. Such low flow rates are typical of commercial lavatory sinks, low flow showers and the hot water portion of the flow in a single lever faucet when the valve is opened halfway between hot and cold. In fact, for a given length of pipe in a given environment there is a flow rate at which hot water will never get to the fixture.

As the flow rate increased into the range typical of many sinks and showers (1-3 gpm), the thin stream gave way to a more normal mixing front, which is depicted as a long bullet (see Figure 2). The length of the bullet was several feet ahead of the hot water plug. The extra volume of water that came out of the pipe before hot water arrived was generally 10 to 50 percent more than the volume of water in the pipe. The waste was larger for a given flow rate in the hard-piped test rig that had standard elbows than it was in the flexible pipe test rig which used wide-radius bends in the pipe itself to make the 180 degree turns.
At higher flow rates, typical of those found in garden or Jacuzzi tubs, some laundry sinks, washing machines and dishwashers, researchers saw what looked like plug flow, the idealized type of flow covered in engineering school. In these cases, the length of the much shorter bullet was only a very short distance ahead of the hot water plug (see bottom illustration in Figure 2). The extra volume of water that came out of the pipe before hot water arrived was generally much less than 10 percent more than the volume of water in the pipe. This condition was seen some of the time at high flow rates in the hard-pipe test rig with hard elbows. It was seen much more often and at lower flow rates in the flexible test rig with wide-radius bends.

The Use Phase

Researchers learned four things about the use phase:

- Uninsulated flexible PEX-Al-PEX\(^{67}\) piping has a greater temperature drop at a given flow rate than does copper piping of the same nominal diameter. Insulating the pipes minimized the difference.
- The temperature drop at a given flow rate is less in \(\frac{1}{2}\)-inch piping is less than in \(\frac{3}{4}\)-inch piping.
- The temperature drop over a given distance is greater at low flow rates than at high flow rates. There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm.
- Insulation decreases the temperature drop at a given flow rate.

Figure 3 shows the comparison between nominal \(\frac{3}{4}\)-inch PEX-Al-PEX and \(\frac{3}{4}\)-inch copper piping over a length of 100 feet. The figure is based on steady-state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F. The

---

\(^{67}\) PEX piping is cross-linked polyethylene and Al is Aluminum. PEX-Al-PEX is a type of PEX pipe that has a layer of aluminum sandwiched between two layers of PEX.
water in the uninsulated PEX-Al-PEX pipe lost more temperature at the same flow rate than did the water in the copper pipe. This additional heat loss is probably due to a combination of two effects: first, the nominal ¾-inch PEX-Al-PEX pipe has a larger surface area than the nominal ¾-inch copper pipe - once it is hot, there is more surface area to lose heat. Second, because the PEX-Al-PEX has a larger internal diameter than the copper piping, the face velocity of the water in the PEX-Al-PEX is slower and the rate of heat loss is greater than it is in copper. Once the pipes were insulated, the difference in temperature drop essentially disappeared.

Figure 3. Comparison of Nominal ¾-Inch PEX-Al-PEX and ¾-Inch Copper Piping

The CEC did not have enough funding to run tests on ½-inch PEX-Al-PEX. Based on the fact that uninsulated copper performed better than PEX-Al-PEX, and with insulation, the performance was very similar, it is possible to use the performance of copper pipe at ½-inch and ¾-inch (with and without insulation) as a reasonable first order proxy to better understand what generally happens in hot water piping.

Figure 4 compares the performance of nominal ½-inch and ¾-inch diameter copper piping, both insulated and uninsulated. As in the prior figure, the graph is based on steady-state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F over a length of 100 feet.

At a given flow rate, the temperature drop in ½-inch nominal piping is less than in ¾-inch nominal piping. This is due to the increased face velocity of the water, which reduces the heat loss rate. The issue is that frictional losses increase exponentially with increased face velocity and results in increased pressure drop over a given length.
The temperature drop over a given distance is greater at low flow rates than at high flow rates. At 2.5 gpm, the highest flow rate allowed for showerheads, the temperature drop in uninsulated copper piping is between 2° and 2.5°F. At 1 gpm, the temperature drop in uninsulated pipe climbs to between 4.5° and 5.5°F. At 5 gpm, the temperature drop goes down to roughly 1°F, and the difference between ½- and ¾-inch diameter essentially goes away.

There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm. At 0.5 gpm, the temperature drop more than doubles. As discussed earlier, the curve will get even steeper if the flow rate is reduced still further and for a given length at some low flow rate, hot water will never reach the fixture. The same thing would happen if length was increased while flow rate was held constant, or if the piping was located in a higher heat loss environment, say in damp soil under a slab or between buildings in a campus situation.

As shown in Figure 4, insulation reduces the heat loss overall. For a given flow rate, insulation causes the temperature drop to be roughly halved. Insulation also reduces the difference in temperature drop between ½- and ¾-inch diameter piping.

The Cool Down Phase

Three things were learned about the cool down phase:

- If the time between hot water events is long enough, the pipes cool down to below the useful hot water temperature for the next hot water event.
- Larger diameter pipes cool down more slowly than smaller diameter pipes.
- Insulation extend the time it takes for the pipes to cool down to a given temperature.
The first point seems obvious, since if you wait long enough, the temperature of the water in the pipes will eventually reach equilibrium with the ambient temperature surrounding the pipes. The real question is: how long does it take to cool down to a non-useful hot water temperature? This depends upon the starting temperature of the water in the pipes, the diameter of the pipes, the amount of pipe insulation, the environmental conditions in which the pipes are located, and the temperature of water needed for the next hot water event.

Figure 5 compares how long it took for the water in ¾-inch diameter copper pipes to cool down from a given starting temperature to 105°F. The ambient temperature surrounding the pipes was between 65° and 70°F and the pipes were located in air. Without insulation, it took between 5 and 22 minutes for the temperature to reach 105°F. The hotter the water began, the longer it took.

Figure 5. Time Required for ¾-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation

When ½-inch wall thickness and ¾-inch wall thickness insulation was added, it took significantly longer for the water to cool down to 105°F. Use of the ¾ inch thick insulation (>R-4) roughly tripled the cool down time. The ½-inch wall thickness insulation did almost as well.

Figure 6 compares how long it took for the water in ½-inch diameter copper pipes to cool down from a given starting temperature to 105°F. As with the tests on ¾-inch diameter pipe, the ambient temperature surrounding the pipes was between 65° and 70°F and the pipes were located in air. Without insulation, it took between 5 and 20 minutes for the temperature to reach 105°F, almost exactly the same as for the uninsulated ¾-inch piping. Use of the ¾-inch thick insulation (>R-4) roughly doubled the cool down time. The ½-inch wall thickness insulation did almost as well.
Although the time it took the water in the uninsulated pipes to cool down was very similar for the ½-inch and ¾-inch diameter pipes, when insulation was added, the water in the ¾-inch pipes took roughly 1.5 times as long to reach the same temperature as the ½-inch pipes.

If the pipes were located in a colder environment, such as in a crawl space or an attic, at night or early in the morning, or throughout much of the winter, they would have cooled down much more quickly. If the pipes were in a high heat loss environment, such as in the damp soil under a concrete slab, they would cool off even faster. If the ambient temperature were higher, such as in an attic in the middle of a summer afternoon, it would take much longer to cool down. (On the other hand, the water in the cold water pipes might be too hot to use!)

### 2.0 Improving Hot Water Events

The concept behind the original elements in the PBMP was to save water. From the research results provided above, it is possible to define improvements in hot water events that save both water and energy and increase customer convenience and satisfaction. The key to understanding how to improve a hot water event is recognizing that unless the water in the pipes is hot enough to use at the fixture where it is desired, it always takes more water than is in the pipe to get the water to the fixture at the desired temperature.

The volume of water in the pipes between the source of hot water and the fixture(s) that is not hot enough for the next hot water event determines the minimum volume of water that will be wasted before water that is hot enough to use arrives at the fixture(s). (Conversely, if you know the maximum amount of water or time that you want to waste while waiting for hot water to arrive, you can back calculate the volume of water that will be in the pipe.) Once you know the volume, you can determine the maximum length for any pipe diameter, or any configuration of multiple pipe diameters. Other factors, such as the temperature of the water in the pipes at the
start of the event, the temperature of the hot water coming from the water heater, the additional restrictions in the plumbing run (joints, abrupt changes in direction, valves and other fitting) that increase the “effective length” of the pipe, the ambient temperature surrounding the pipe, other environmental conditions, etc., increase the volume of water that comes out of the pipe before hot water arrives at the fixture.

Before going into the details, it is necessary to introduce the concept of “trunks, branches and twigs”. A twig serves one fixture, a branch serves more than one twig and a trunk serves many twigs or a combination of branches and twigs. These descriptions apply to plumbing in single family and multifamily residential applications as well as to non-residential applications. While a slight departure from the terms used in the plumbing industry, this nomenclature has proven useful in discussing how to improve hot water events.

According to the research, water is wasted:

1. Based on the volume of water between the source of hot water and the fixture.
2. At low flow rates (really low face velocities). The lower the flow rate, the more water that is wasted.
3. When there are restrictions to flow in the piping.

According to the research, energy is wasted:

1. When water is wasted. This is true both in the building (pressurizing and heating) and in the water use cycle.
2. When overcoming the heat losses in the piping. The longer the pipe, the larger the diameter, the slower the face velocity, the less the insulation, the worse the ambient environment surrounding the pipes, the more energy that is lost.

The goal is to improve hot water events. Figure 7 depicts an improved hot water event.
Improving the Delivery Phase

Improving the delivery phase means getting hotter water more quickly by minimizing the waste of water, energy and time. For a given fixture flow rate, there are three ways to do this:

- Reduce the volume of water in the pipe
- Reduce the number of restrictions to flow
- Increase the flow rate

Reducing the volume of water in the piping between the source of hot water and the fixture means paying attention to both the diameter and the length. Smaller diameters and shorter lengths contain less water. However, for a given flow rate, the pressure drop due to friction is larger in smaller diameter pipes. If not carefully engineered, it is possible to reduce the pressure at the fixture to a point where the fixtures will not operate properly or provide the desired effect. The problem is exacerbated at low municipal water pressures and longer length piping.

One of surprising results of the research was the impact of standard elbows on the waste of water. In the tests on copper piping, standard radius elbows were used to make the changes in direction. There were no couplings on the straight sections, but there were two elbows at each end to change direction 180 degrees. There was also a tee to create a well for the temperature sensor. In the tests on PEX-AL-PEX, the pipe itself was bent to make the changes in direction, so that there were no elbows. In addition, there were no tees for the temperature sensors (a new method had been found to insert them directly into the pipe). In short, the “effective length” of the PEX-AL-PEX was much shorter than it was in the copper piping.
The general solution is to reduce the effective pipe length as much as possible. The first step is to reduce the actual length as much as practical, then reduce the restrictions to flow that increase the pressure drop in the line disproportionately to their actual length. The idea is to make the pipe appear like a “super highway” to the water. To do this, the number of joints (couplings, elbows, tees and valves) between the source of hot water and the fixtures need to be minimized.

The configuration with the fewest joints would be one with a smooth, flexible pipe running from the water heater to the fixture. The minimum is two connections, one at the water heater and one at the fixture and no shut off valves. Since we generally want to be able to turn off the water on each individual line, and most code jurisdictions require it, the practical minimum is four connections (two connections at the shut off valve, one on each side).

While this sounds good, in buildings with many hot water fixtures and appliances and only one water heater, this would mean that the water heater would need to have as many outlets as the number of fixtures. It is not likely, however, that water heater manufacturers would be willing to produce such a design!

Assuming that water heaters will continue to have one outlet for the hot water exiting the heater, then there will be a main trunk line coming out of the water heater. This trunk line can be short or long, but there needs to be a tee to get water from the trunk line into the branch lines or twigs. In general, there is more pressure drop when the water makes a 90 degree turn through a tee than if it made the same turn through an elbow. The fewest joints would be on a line that had one tee. This means that the fixture was served by a twig attached directly to the trunk. From the trunk line, the practical minimum number of connections is still four; one at the tee, two at the shut off valve and one at the fixture.

A tee can be defined as a one-port manifold. There are three joints for this type of tee. Each requires labor to make the joint and each joint is a potential source of leaks. It is common to use tees with the same dimension on all three joints. However, when a twig is connected to a trunk, the through diameter will be larger by one or more sizes than the diameter of the joint serving the twig (for example ¾-inch through diameter trunk line serving a ½-inch diameter twig. For a given flow rate at the fixture served by the twig, the face velocity of the water in the twig is greater than the face velocity of the water in the trunk line. This results in somewhat less pressure drop than if the water went through the 90 degree turn in a tee with equal dimensions.

It is possible to reduce the number of joints (and labor and potential leaks) by joining two or more tees into a manifold. If manufactured correctly, this reduces the number of joints by two for every additional “tee” connected to the manifold. Most of these manufactured multi-port tees already have smaller diameter openings compared to the trunk line, providing an additional benefit for their use.

Figure 8 compares the radius of various elbows. The larger the radius of the bend, the more it appears to the water like a banked curve on a race track, and the less resistance there is to flow. Using larger radius bends also results in the use of less piping.

Internal elbows, such as those used in PEX or PEX-Al-PEX systems have the most restriction to flow. External standard elbows such as those used in copper and CPVC systems are next. Two
45 degree external elbows are next, but because of the extra joints, are not quite as good as sweep elbows. Wide radius elbows provide the least restrictions. Making these elbows with flexible piping (copper, PEX, PEX-Al-PEX, CPVC) means that no joints are needed for the elbows. Based on the radius of the elbows in the tests by the CEC, it appears that the radius should be no less than 10 times the nominal diameter (larger is better), but this really needs to be further tested.

**Figure 8. Changing Directions Smoothly**

It is also possible to improve the delivery phase by increasing the flow rate. The research showed that moving water faster got it there sooner and at a higher temperature. It is possible to see this effect at tub/shower combinations where the flow rate through the tub spout is greater than it is through the shower (when the tub spout diverter is used). Even though hot water will get to the tub/shower combination sooner with somewhat less water waste, you still waste the water if you run it down the drain. One solution to this dilemma is to find a way to prime the trunk line serving the fixture shortly before hot water is desired and then turn on the fixture. The only water that needs to be drained is the volume that is between the trunk line and the fixture. The smaller that volume, the quicker the hot water will arrive.

**Improving the Use and Cool Down Phases**

Insulation is the best way to improve a hot water event during the use and cool down phases. Assuming you have already improved performance by reducing the volume of water in the pipe, reducing the effective pipe length and getting the hot water to the fixture more quickly, then the insulation will help maintain the temperature during the event and reduce the rate at which the pipes cool down when the fixture is turned off.

The benefits during the use phase are primarily energy related; once the hot water is at the fixture, the flow rate is what it is. What can change is the amount of hot water that is needed to reach the desired mix temperature. The energy benefit derives from the fact that there are fewer
heat losses in the piping for the water heater to overcome. Referring again to Figure 7, the red line shows the improved hot water event and the black line shows the typical event. During the use phase, the temperature indicated by the black line was hot enough to create the desired mixed temperature. In the improved event, the temperature indicated by the red line is hotter. Since the water at the fixture is hotter than it would have been without the insulation, then less hot water is needed to reach the same mixed temperature.

There are three ways to capture the energy benefit. One is to keep the temperature of the water heater the same and change the mix temperature. This will reduce the volume of hot water used. If the water heater is of the tank type, standby losses will remain the same, but total available hot water will effectively increase since there will be more hot water in the tank to mix with cold water. If the water heater is tankless, there will be no changes to overall capacity. Second is to reduce the temperature setting of the water heater. For tank-type gas-fired water heaters this will reduce the standby losses roughly two percent for every degree the tank temperature is reduced. For tankless water heaters this will increase the effective capacity so that more fixtures can be used simultaneously. The third way is to combine both strategies. While lowering the tank temperature provides the greatest energy benefits, the consumer benefits from any of the three options.

The longer the distance between the source of hot water and the fixture, and the slower the flow rate, the greater the benefit of the insulation. Looking back at Figure 4, insulation will become even more important if the trend to lower fixture flow rates continues. We already have many sink and shower fixtures with flow rates less than 1 gpm (rated at 80 psi). For a given amount of insulation on the pipes, the temperature drop will increase as the flow rate is decreased. If we do not simultaneously reduce the volume of water in the pipes between the source of hot water and the fixture, the potential water and energy savings benefits will be reduced and might actually be reversed.

In the cool down phase, insulation increases the time that the pipes stay hot enough to use for the next hot water event, thereby increasing the likelihood that the temperature in the pipes is hot enough for the next use. There are four major issues.

- Where is the location of the hot water event in relation to the source of hot water?
- How long is the time until the next hot water event?
- What is the temperature of the hot water needed for that subsequent event?
- What is the volume of water in the pipe that eventually cools down?

Going back to trunks, branches and twigs, all hot water distribution systems have some combination of these. The worst configuration from the water and energy perspective is to have a high volume system characterized by long, large diameter trunks, long, large diameter branches and long twigs. The best configuration would be a low volume system characterized by short, small volume trunks, no branches and short twigs. To achieve this configuration means carefully determining the location of all fixtures in relationship to one water heater, or having multiple water heaters as will be described in the section on Point-of-Use Water Heaters. The next best system would be to have a reasonable volume trunk and short twigs. This provides for greater
flexibility in the relationship between the water heater(s) and the fixtures, while still minimizing the volume of water in each twig.

Standard main and branch systems generally have large volume trunks, medium volume branches and relatively small volume twigs. The distance (volume) from the water heater to the fixtures varies from close to far (small volume to large volume). If the first hot water event is close to the water heater, then hot water will flow through the trunk line to the branch line to the twig serving that fixture. If the next hot water event is located at the far end of the trunk line, then the source of hot water will be the point on the trunk line where the water branched off to serve the first event, assuming, of course, that the water in the pipe hasn’t cooled to below the temperature needed for the second hot water event. If the first hot water event was at the furthest fixture, then the hot water would already be at the branch line serving the closest fixture, assuming that the time between hot water events is short enough that the temperature in the pipes was still hot enough.

Once the temperature in the pipes drops below the desired temperature for the next hot water event, it is necessary to replace all of the water in the pipes that is not hot enough with water that is. As was discussed earlier, at a minimum, this will be the volume of water that is in the pipe between the source of hot water and the fixture. The amount that needs to be removed can be significantly more than this, both for structural reasons and for behavioral ones…if people have to wait long enough, they leave, coming back to see if the water is hot when they are good and ready to do so.

While the examples given above are based on single family dwellings, the principles are equally applicable to multi-family and non-residential applications. For example, in multi-family buildings with recirculation systems, depending on how the plumbing is configured, there may be a branch line serving each apartment or there may be individual twigs serving each fixture off a trunk line.

The time between hot water events, the location of the next hot water event and the temperature needed for the next hot water event are all unknowns. They are essentially random and the possibilities are practically infinite. However, all of the possibilities default into two choices; either the temperature of the water in the pipes is hot enough for the next hot water event or it is not. Since it is unknown what the desired temperature for the next event will be, it makes sense to design systems to provide for hottest typical event, say 105°F to 110°F, suitable for a shower.

The volume of water in the pipes is determined by the location of the fixtures and appliances in relationship to the water heater(s). The greater the length, the higher the flow rate and the more fixtures served by the same pipe, the greater the volume that pipe needs to be. Plumbing codes must be followed when determining the diameter of the pipes supply hot water to the fixtures. The purpose of good engineering and the codes is to ensure that there is enough pressure at each fixture so that it operates properly under a variety of conditions.

Given these considerations, the volume of water on the supply side of a hot water distribution system is effectively predetermined. As shown earlier in Figures 5 and 6, the same amount of insulation keeps a larger diameter pipe hotter longer than a smaller diameter pipe. However, the
larger the diameter, the more water that will eventually cool down if the time between hot water events is long enough. The energy it took to heat this water will effectively be lost.

A balance needs to be struck between the volume of the water that is in the supply piping and the fact that the energy it took to heat that water will be lost when the water in the pipes eventually cools down (which it will always do if the time between hot water events is long enough). While this can be addressed relatively easily in new construction (or a major remodel where the piping configuration can be changed), it is much harder to do so in retrofit.

Single trunk and branch systems are the simplest to fix and the ones where the benefits in terms of water and energy will be greatest. This is because once the trunk line is primed with hot water, the volume to the fixture is reduced to what remains in the branch and twig that serves the fixture. Since all fixtures are served by some combination of branches and twigs that emanate from the main trunk line, all fixtures will benefit to a greater or lesser degree by priming the main trunk line.

The most difficult plumbing configuration to fix will be manifold systems. These systems are characterized by a trunk line of some volume, hopefully small, and twigs serving individual fixtures. If there are many fixtures with relatively large volume twigs, there will be many problem areas that need to be addressed.

In new construction, it is possible to address both the location of the fixtures and the layout of the plumbing that will serve those fixtures. Stacking hot water fixtures, locating them back-to-back and grouping them close together and near the water heater minimizes the total plumbing required. This is true for the hot and cold water supply as well as for the drain system. However, efficiently locating the plumbing fixtures is often not the primary criteria when designing a building layout.

The key to reducing the waste of water for the next hot water event is to minimize the volume of water between the source of hot water and the fixture that is not hot enough to perform the task at hand. Insulated trunk lines, which are relatively large in diameter, stay hot a relatively long time. Once the trunk line is hot enough, then the volume of water between the trunk line and the individual fixtures becomes the next critical value. The smaller the volume of the water contained in these sections of pipe, the less water that will be wasted at the beginning of the next hot water event.

3.0 Technologies and PBMPs

3.1 Point-of-Use Water Heaters

The principle behind point-of-use water heaters is to locate the heater(s) close to each fixture or appliance so that when hot water is desired, the waste of water, energy, and time until hot water arrives is minimized. Each point-of-use water heater needs to be sized properly for the one or more fixtures that it will serve. Many people are familiar with the devices that are intended to heat a small amount of water at the kitchen sink. While appropriate for that use, they are not capable of supplying one or more gallons per minute of hot water for continuous use at a sink or
shower and they do not have the capacity to provide the hot water for a dishwasher or washing machine cycle.

Hiller (ASHRAE-Hiller, 2005) reports that beyond a certain distance, adding another water heater may be more energy-efficient than running the plumbing from a single water heater. This conclusion is based on the results of laboratory tests that studied the heat loss characteristics of ½- and ¾-inch piping. This paper compares the energy lost in the piping to the energy lost by the water heater, both over the course of the day. Hiller found that larger diameter pipe, less insulation on the pipe, and more efficient water heaters translate into a shorter distance before the energy losses from another water heater are equal to the energy losses of the intervening piping. This was true for both trunk and branch piping layouts and for recirculation system layouts.

The CEC approaches the question somewhat differently. In the 2005 Title 24 Building Energy Efficiency Standards Residential Compliance Manual (CEC-Shirakah, 2005) a point-of-use hot water distribution system is one with no more than eight (8) feet of horizontal distance between the water heater and hot water fixtures, except in the laundry. The CEC considers this type of distribution system to be somewhat more efficient than the standard hot water distribution system. To get credit for this when building a house, there can only be one such system in the building - one water heater serving all fixtures and appliances.

There are several issues with installing point-of-use water heaters. These have been well described by Klein (IAPMO-Klein, 2005b) as follows:

1. The cost of running gas piping or electrical wiring to each point-of-use water heater instead of running plumbing pipe to the same location. In general it always costs less to install the same length of plumbing.
2. The cost of installing additional flues if gas is the water heating fuel.
3. The related problems of how to install a flue for the island sink in the kitchen when the floor is a slab-on-grade.
4. The cost of each additional water heater. If the additional water heater(s) serve loads such as a shower, then they need to be essentially the same capacity as the single water heater that is generally chosen to serve an entire house. This capacity either needs to be in a tank with a volume large enough to provide hot water for the intended application or it needs to be in the form of a tankless water heater with a burner or element large enough to keep up with the hot water demand. Small tank water heaters may be an option for remote sinks, but if they need to serve a shower, dishwasher or a washing machine, the volume need increases rather quickly. For example, to supply enough hot water for a 10 minute shower, the tank needs to have 30 gallons of stored hot water. If the shower is longer, the tank needs to be larger. In the tankless case, assuming 55°F incoming cold water and 120°F outgoing hot water, it takes roughly 10 kW electric or 40,000 Btu gas to continuously heat 1 gpm. This flow rate is fine for most sink uses, but it is not enough for a shower, which needs roughly 2 gpm. This doubles the instantaneous energy consumption.
5. The space required by each water heater. Typical practice in single family residential applications in California is to install the water heater in the garage. In multi-family applications, either a large mechanical room serving many individual dwelling units or a smaller mechanical room in each individual apartment is used. In commercial buildings,
there is generally a mechanical room. As an example, a typical tank-type water heater needs roughly 10 square feet of space, including the walls that surround it. At sales prices for single family homes of more than $200 per square foot, this means that the value of the space for the water heater is more than $2,000. While tankless water heaters take up much less space, the space they take within the building needs to be considered.

6. Finally, the future maintenance that will be needed by each water heater. Most homeowners don’t adequately maintain the one water heater they have today. Should they be expected to properly maintain more than one?

Do multiple water heaters make sense? The short answer is that it depends on an interrelated set of variables. The variables include the volume of hot water or flow rate that is needed at each fixture and appliance, the distance between fixtures or groups of fixtures and appliances, and the intermittency of the use pattern. The more intermittent and the smaller the demand in flow rate or volume, and the further the fixtures are apart, the more a point-of-use water heater makes sense.

3.2 Recirculating Hot Water Systems

The primary alternative to point-of-use water heaters is to install a recirculating hot water system. There are several issues with installing hot water circulation systems. These have been well described by Klein (IAPMO-Klein, 2005b and 2005c)

There are six types of recirculation systems:

1. Thermosyphon (gravity convection with no pump),
2. Continuously pumped systems,
3. Timer controlled,
4. Temperature controlled,
5. Time and temperature controlled, and
6. Demand controlled.

**Thermosyphon**-based recirculation systems use the temperature difference between the hot and cold water and the height of the building to drive the water around the loop. They work because heat is lost from the time the water leaves the water heater until it returns at some colder temperature to the water heater, often 5–10°F less than when it left the water heater. It takes energy to reheat the water; how much depends on the heat loss and the flow rate, which is in the range of 0.5–1 gpm. Pipe insulation is often neglected, which means that there is even more heat loss as the water moves around the loop.

A **continuously pumped** recirculation system is thermally very much like a thermosyphon system, with the addition of a small pump that runs 24 hours per day. In most residential systems the pump draws roughly 40 watts. In multifamily and commercial systems the pump can draw significantly more energy.

In **timer-controlled** recirculation systems a timer determines the hours of operation of the pump. This has the effect of reducing the costs of operating the recirculation system in proportion to
reduced hours of operation. In residential applications, a timer is often set to run for all of the waking hours, or roughly 16 hours per day. In this case, it would use roughly two-thirds as much energy as the continuously pumped system for both the pump operation and for heating the water needed to maintain the temperature in the loop.

Another method of controlling the pump is to install an aquastat, which is a method of temperature control similar to that used in an automobile radiator. The aquastats that are often used in single family applications are set to open when the temperature rises to 95°F and to close when the temperature drops to 115°F—a 20°F bandwidth. Assuming that the minimum desired hot water temperature is 105°F, the temperature in the recirculation line is colder than desired at least half the time. A better choice from a water temperature perspective would be to use an aquastat with a minimum set point of more than 105°F. However, with a bandwidth of 20°F, the lowest water heater setting must be above 125°F, otherwise the pump will never shut off. An aquastat controlled system can be installed without a timer, and if set up properly, will run roughly half the time, or 12 hours a day. If set up incorrectly with the water heater temperature too low to overcome the temperature drop in the recirculation loop, the upper temperature limit of the aquastat will never be reached and the pump will continue to run 24 hours a day.

Time- and Temperature-Controlled recirculation system combine the use of a timer and an aquastat. Assuming a 16-hour time clock, the aquastat will allow the pump to come on roughly half that time, or eight hours per day.

Demand control is the last method of operating a recirculation system. This system uses one or more consumer-activated devices (button, remote, flow switch, door switch, motion sensor) located where convenient near the hot water fixtures to “tell” the pump to come on. A thermosensor, looking for a small (5–10°F) rise in temperature above the ambient pipe temperature, tells the pump to shut off. In typical residential applications, the pump is activated 10–20 times and runs for 10–20 minutes a day, the duration depending on the configuration of the plumbing system (volume and restrictions). Unlike typical recirculation systems which usually have a ½ inch diameter return line, demand controlled systems have a return line that is no smaller than ¾ inch. This is to accommodate the higher velocity found in demand pumps, since they are intended to “prime the line” quickly and then shut off.

Given the same plumbing layout (meaning the same diameter trunk line supplying hot water to the fixtures and same volume in the lines serving each fixture), all of these systems will waste the same amount of water at the beginning of a hot water event. The difference in these systems is in the energy it takes to keep the trunk line primed with hot water.

Rosenthal (Rosenthal, 2005) measured water savings using a time and temperature controlled retrofit water circulation system. The small pumps were located in the room that was determined to have the longest wait for hot water. Based on a sample of ten single family homes, Rosenthal found that the average decrease in water waste per hot water use event in these test rooms was 2 gallons (68 percent). There was a large variation in the water waste, however, and therefore the savings per household varied significantly as well. The smallest measured decrease was 0.8 gallons and the largest was 5.4 gallons. The percent reduction in waste was also very variable, ranging from 5 to 96 percent. Rosenthal then estimated whole house savings from the savings
measured in the test room. Based on this estimate, the potential water savings compared very favorably with the savings from high efficiency washing machines and from showerhead replacements. Although the water utility does not see the entire benefit, Rosenthal points out that the customer benefits from the savings in both water and wastewater costs. The study did not measure the energy costs or savings from using these time and temperature controlled circulation systems. Although most customers were satisfied with the system’s performance, some pointed out that they often had warm water in the cold water lines and had to run this out before they could get cold water. Rosenthal plans to start a new study in 2006 with Proposition 50 funding to look at this question.

As documented the articles and papers by various green building programs and more recently by the U.S. Environmental Protection Agency (U.S. EPA-Chinery, 2006), demand controlled circulation is the most energy-efficient. In fact, demand controlled circulation systems use less energy, and waste less water than current practice where water is run down the drain at the beginning of a hot water event. Green building programs such as the City of Austin, Build-It-Green and the U.S. Green Building Council’s LEED for Homes all give the most credit for using a demand controlled circulation. EPA released a draft report in early June 2006 (the final report is due to be released in late June) that recognizes demand controlled pumping as suitable for inclusion in Energy Star for homes programs. The EPA is in the process of defining a category for all circulation systems.

The EPA report states that demand controlled pumping systems can conservatively save 15 percent of the daily hot water consumption when used in retrofit or new construction on trunk and branch systems where no special consideration has been given to optimizing the plumbing layout or to insulating the pipes. This reduction in water consumption translates to energy savings equivalent to a 12-17 percent energy factor coefficient enhancement to the water heater.

When demand controlled circulation is combined with Structured Plumbing, in which the volume of water in the branches or twigs serving individual fixtures has been minimized (less than 10 feet of ½ inch diameter or less piping) and all hot water pipes have been insulated with at least R-4 pipe insulation, the water and energy savings will be even larger. The EPA conservatively estimates that water savings will increase to 20 percent of the daily hot water use (due primarily to the small volume in the twigs) and an additional savings will be due to the insulation on the piping, which increases the likelihood that the water in the pipes will be hot enough for the next hot water event. The combined energy savings are estimated to be equivalent to a 27 to 42 percent increase in the energy factor of the water heater.

The California Department of Water Resources recently awarded a Proposition 50 grant to Lawrence Berkeley National Laboratory to compare the performance of Structured Plumbing systems to standard plumbing systems. The study will work with one or more builders so that different plumbing configurations can be applied to the same floor plan and the water and energy performance of each type measured. This study will begin in the second half of 2006.

3.3 Hot Water Pipe Insulation

The benefits of hot water pipe insulation were discussed earlier in this report. The research results were based on relatively mild ambient temperatures surrounding the pipes. These
temperatures are close to the temperature found in most buildings, 65°-70°F. This means that hot water piping should be insulated even when the pipes are located within the conditioned building envelope.

In general, it will be much more difficult to insulate the pipes in retrofit than it will be in new construction. This is due primarily to the fact that hot water pipes are often buried, hidden in walls or floors or are located in other hard-to-reach places such as crawl spaces. However, given the benefits, wherever possible, they should be insulated. The focus of any retrofit insulation effort should be to insulate the main trunk line(s) that serve(s) many fixtures. Then focus on insulating the longest, most used branches and twigs. These recommendations apply to all building types.

Insulation of all hot water pipes should be required in new construction for all building types.

If the cold water pipes run in locations where they get warm or hot, they should also be insulated. The idea is to deliver hot water to the hot fixtures and cold water to the cold water fixtures, not lukewarm water to either of them.

4.0 California Potential

There is a large base of existing buildings in California with water- and energy-inefficient hot water distribution systems. There is also a large number of new buildings constructed each year also with water- and energy-inefficient hot water distribution systems.

Klein (ASHRAE-Klein, 2005) estimated the magnitude of the waste and therefore the benefit for the United States. This paper estimated the scope of losses of water and energy caused by the poor design and installation of hot water distribution systems. The emphasis was on residential buildings, both single family and multifamily. The purpose for the estimate was to assess whether or not the waste of water, energy and time associated with waiting for hot water to arrive at fixtures was large enough to warrant further study and possible remediation. The base year for the estimates was 2005.

The paper estimated that the daily waste of water was 10 gallons per household per day, recognizing that the standard deviation around this number is quite large. This level of waste is roughly 17 percent of daily average hot water consumption and is consistent with the waste report by Rosenthal. This volume of wasted water while waiting for hot water to arrive results in a waste of energy in each home as well. If the water is heated electrically, the energy waste is 2.9 kWh per household per day. If it is heated with natural gas, the energy waste is 0.14 therms per household per day.

The waste of water was estimated to be 415 billion gallons (almost 1.3 million acre-feet) in 2005, continuing to grow proportional with household growth unless something was done specifically to prevent that waste. The paper looked at the United States as a whole and did not separate out California. The number of households in California is roughly 10 percent of the national total. Assuming that the average plumbing configuration is the same as the national average, and that behavior while waiting is essentially the same, then roughly 40 billion gallons (123,000 acre-feet) of the waste occurs in California.
The energy consequences of this waste depend on the relative amount of water heating that is done by natural gas or electricity. In California, this is roughly 85 percent natural gas (or propane) and 15 percent electric. Applying these percentages to the waste of water, the energy impact is 476,000,000 therms and 1,740,000,000 kWh per year.

Costs can be estimated assuming $0.005 per gallon for water and wastewater costs combined, $1.00 per therm for natural gas and $0.10 per kWh for electricity, all of which are conservative given today’s prices.

The total cost in California in 2005 can then be estimated to be at least $850 million ($200 million for water and wastewater, $476 million for natural gas and $174 million for electricity). There are additional costs associated with the inefficient operation of multifamily circulation systems and non-residential applications, which brings the total estimated costs to more than $1 billion per year for existing residential applications.

Nationally, the waste is growing by at least the rate of growth in the number of households or roughly one percent per year. In California, the rate of growth of new dwelling units (single family, multifamily and manufactured) is estimated to be approximately 130,000 per year through 2025. Conservatively assuming that the average waste per household remains the same, (in fact the waste is likely to be larger, since dwelling unit square footage is increasing), the expected increase in water waste will be 475 million gallons (1,475 acre-feet) per year. These water and energy inefficiencies cost Californians $10 million ($68 per household) per year.

To express it differently, every year that serious improvements in construction practices are delayed will result in an increase in annual waste of about 1,475 acre-feet of water. In the 20 years from 2005 to 2025, the waste will grow to 9.5 billion gallons (29,000 acre-feet) per year, an increase almost 25 percent on the current waste occurring in existing homes. The total waste is growing even faster when ones takes into account the other non-residential buildings that are being constructed in California.

5.0 Possible Actions

5.1 Single Family - New Construction

Water providers have the opportunity to dramatically impact the future water efficiency of hot water distribution systems in single family (SF) new construction by requiring that all new plumbing be installed to take advantage of what has been learned about how to improve performance. In general, new homes are being built with structural water waste that is significantly larger than the average waste in existing households, as discussed above. The costs and potential savings are proportional to the actual waste. The key to obtaining future water savings is to improve the hot water distribution systems so that the volume wasted at the beginning of each hot water event is minimized. Minimizing the water waste will also reduce water and wastewater treatment agency expenditures on embedded energy costs while also reducing the energy costs for water heating.
One strategy is to require that all builders change the layout of their houses so that all hot water fixtures are located within less than a given number of plumbing feet of a single water heater. While the concept of better plumbing fixture layouts should be encouraged through incentives such as points in a green building program, water providers risk a great deal of strong resistance from builders and consumers if it is mandated. Similarly, mandating more water heaters, given the additional installation costs and other issues, should be avoided. Where appropriate, water providers can encourage the use point-of-use water heaters.

The installation of Structured Plumbing systems is the most cost-effective and buildable strategy in single family new construction, since it requires the fewest changes to standard practice. A Structured Plumbing system includes a properly sized trunk line located such that the distance from the trunk line to each fixture is no more than 10 feet of ½ inch diameter or smaller piping. All hot water lines must be insulated. In most cases there will be a dedicated return line from the last fixture back to the water heater, but there are some circumstances in which the cold water line may be used as the return. The pump used to circulate the water must be demand controlled, not continuously operated or controlled by time, temperature, or time and temperature. As of June, 2006 there are at least three manufacturers of demand controlled pumping systems: ACT Inc., Metlund Systems (www.gothotwater.com); TACO (www.taco-hvac.com); and Uponor Wirsbo (www.wirsbo.com).

Installing Structured Plumbing in new construction often requires no more piping (even including the dedicated return line that is recommended) and labor than typical plumbing installations, the only difference is the layout for where the pipes are located. There are additional costs for pipe insulation, but sometimes it may be possible for the pipes to be buried in attic insulation for much of their length, and the cost of insulation for this portion of the system is zero. For purposes of this paper it can be assumed that there will be an additional cost for the installed pipe insulation of $100. The primary additional costs are for the demand controlled pump and the activation mechanisms and for the additional outlet where the pump is to be connected. These costs range from $325 to $725. What is essential to note is that there is practically no increase in cost to install the piping, the pipe insulation and the extra outlet in a Structured Plumbing configuration. If this is done, then the homeowner has a choice of including the pump and activation mechanisms in the original purchase or of waiting until after they have lived in the house for some time and completing the system as a retrofit. Since the plumbing was laid out efficiently, the retrofit will have the same performance characteristics as if it were installed during construction.

Structured Plumbing systems can either be mandated or encouraged. Mandated programs are often difficult to implement, but once past the political battle prior to adoption, they generally provide the most savings at the least cost. The most effective strategy will probably be to start by developing a joint incentive program with the local energy utility that is responsible for selling the energy used for water heating. The program should include assistance with plumbing layouts before the builders have the plumbers bid on the projects, work with the plumbers so they understand how to bid and install the systems properly, discussions with the local building officials so they understand how the systems meet the code requirements, validation that the systems were installed properly and measurement that they perform as intended. A feedback loop needs to be established so that customer satisfaction, and water and energy performance are tracked and improvements made to the program to maximize the benefits at the lowest delivered...
cost. After a few years of incentives, it will then be much easier to make the use of Structured Plumbing a requirement.

Given the water and corollary energy issues in Southern California, there is a confluence of events that strongly indicates that a large scale program should be started in all growing communities south of the Tehachapi Mountains. The reason for this focus is that the embedded energy in the water is generally the greatest in Southern California, so the ancillary benefits to the state are the largest. Similar programs should be started in all growing communities in the state.

5.2 Single Family - Retrofit

While there are many more existing homes that have inefficient plumbing systems than what is built new each year, the key to a retrofit program is to identify the homes with the greatest structural waste without spending a great amount of money doing so. The key is to identify those homes with single trunk and branch plumbing configurations, since priming the trunk line with hot water will reduce the waste to the amount remaining in the branches and twigs serving individual fixtures. The next best homes to target are those with two trunk lines, one of which serves the kitchen and the master bathroom, the two most used hot water rooms in a house. The City of San Diego Water Department will be testing a simple audit technique in the Proposition 50 program that they will implement in the second half of 2006, where they will also demonstrate and measure the water and energy performance of demand controlled pumps.

Demand controlled pumps are the only type of circulation pump that will save the customer both water and energy. There are two other types of pumps sold for use in retrofit, both of which have time and temperature based controls. Neither of them saves energy because they need to run many hours per day to provide hot water when needed by the occupants. If the number of hours is restricted, then whenever hot water is needed between circulation cycles, the water savings are reduced.

The water and energy savings from a retrofit program are likely to be somewhat less than that attainable in a new construction program. The reason for this is that it is extremely unlikely that such a program can or would attempt to reconfigure or insulate the existing piping. Even with this caveat, a retrofit program can be cost effective. The cost to retrofit with a demand controlled pump is between $300 and $700 depending on the model and features. In addition to the cost of the pump and activation mechanisms, there is installation, which takes about one hour if there is electricity available under the sink (e.g., kitchen) and another hour if it is necessary to run a short line from the outlet near the bathroom sink to a location down under the cabinet.

As in new construction, the program should be run in cooperation with the local energy utilities, to share both program costs and benefits. One way to think of the magnitude of the incentives is to look at the joint programs that were run to support the introduction of high-efficiency clothes washers. Since the water savings are similar, the incentives should be similar.

5.3 Multi-Family - Retrofit and New Construction
There are two types of multi-family buildings, those with central water heaters and circulation systems and those with individual water heaters serving each dwelling unit. In existing multifamily buildings with central systems, unless the circulation loop is non-existent or inoperative, the savings are primarily energy and the role for water providers is limited. In those buildings with individual water heaters serving each dwelling unit, the plumbing systems must be looked at the same way as would be done in a single family home. The key is to identify those buildings with single trunk and branch systems that serve the whole apartment and to install a demand controlled circulation pump at the furthest fixture from the water heater on the trunk line that serves the most used fixtures. Also, install insulation on the pipes if they are accessible.

In new construction or major renovation, programs should assist the builder or developer with the design of the plumbing layout in order to minimize the volume of water between either the circulation loop and the fixtures or the water heater and the fixtures. The concept of Structured Plumbing should be fully employed, adjusted as applicable to the type of water heating system. In buildings with central hot water, the activation mechanism will probably need to be a flow control, rather than the buttons or motion sensors that are typically used in single family homes. An excellent example of how to implement this concept in a major renovation can be found in a 35 unit apartment building owned by Bob Mayer in San Francisco (Mayer, 2006, personal communication). He plans to complete the renovations in late 2006 and will be measuring the water and energy performance.

Even though many of the savings to be found in multifamily buildings are energy, not water, it still makes sense to share programs with the energy utilities. Working closely with multifamily building owners, operators, management companies and developers will be key to the success of these programs. Builder, plumber and code official education need to be part of the program as will validation of system performance and feedback to the program designers so that the program can be improved.

5.4 Non-Residential - New Construction and Retrofit

Most of the efforts to understand how to improve hot water distribution systems have gone into residential applications, so less is known about non-residential situations. Point-of-use water heaters have greater application in buildings that are more spread out. This is particularly true when the hot water demand is both small and intermittent. When non-residential applications looks like those found in single and multifamily residences, then the solutions will probably be similar as well.

Recent discussions with the Food Service Technology Center indicate that there are many opportunities to save water by improving the plumbing systems in food service facilities. Improving the plumbing will result in the more the rapid availability of hot water at kitchen and lavatory sinks, which will help the industry meet its health code requirements.
6.0 Cost Effectiveness

Based upon the potential savings per household data presented in Section 4.0 and the rough costs for new construction and retrofit installations discussed in Section 5.0, the cost effectiveness of the two scenarios was determined to be approximately as follows:

Estimated lifetime savings: 10 gallons per day per household x 365 days x 25 year life = 91,250 gallons = 0.28 acre-feet of water

Approximate cost: $425 to $825 per installation
Cost per acre-foot saved: $1,500 to $2,900

It appears that, by itself, the cost of the saved water does not justify an incentive program that pays for the entire cost of a residential installation. However, by coupling such a program with similar incentive programs that might be offered by water and/or wastewater utilities, feasibility may be achieved. However, structured plumbing requirements are being “written into” various green building programs today. Therefore, the implementation of a BMP directed at these voluntary green building programs would have minimal cost to the water utilities and could achieve savings in a large number of new residential dwelling units in California.

7.0 Conclusions

In the quest to realize genuine water use reduction, the amount of water to be saved will depend on first developing an answer to the question posed at the beginning of this paper:

How much water can or should be wasted while waiting for hot water to arrive?

Deciding how much residual waste is acceptable after making changes to the plumbing system is the key to making significant reductions in the structural waste in buildings. Specialists in the field of residential hot water distribution know how to get the waste down to less than two cups per hot water event. Doing this will require a significant effort, but the effort will be rewarded in terms of reductions in water, wastewater, energy and air pollution and increases in customer satisfaction. As we proceed along this path, we recommend partnering with the California Energy Commission and others in the water-use aspects of their initiatives to better understand the most effective ways to obtain the potential savings represented from the technologies discussed in this paper.

Based on the evidence provided in this paper, we recommend that the PBMP relating to this topic be defined to encompass Structured Plumbing in new construction as well as encompassing the technologies contributing to it.