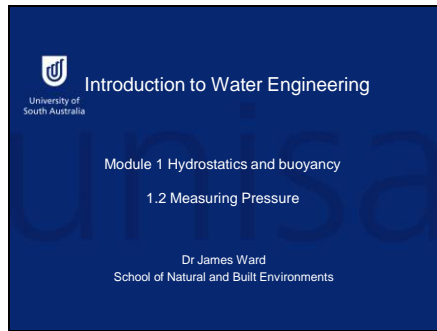


# Introduction to Water Engineering

Slide 1



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## Introduction to Water Engineering

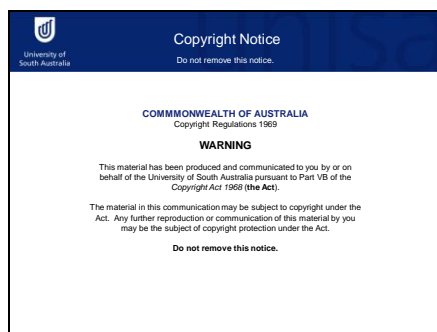
Module 1 Hydrostatics and buoyancy

1.2 Measuring Pressure

Dr James Ward  
School of Natural and Built Environments

Welcome to Module 1 and Hydrostatics and buoyancy

Slide 2



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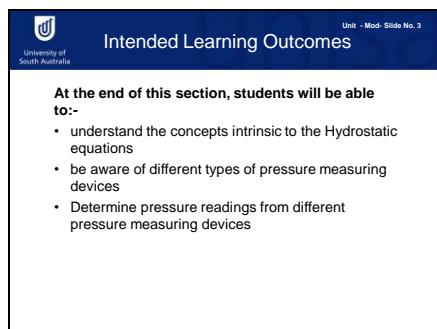
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### Intended Learning Outcomes

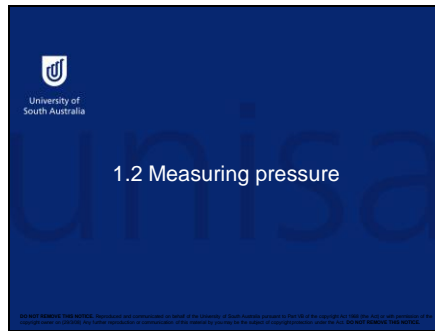
Unit - Mod- Slide No. 3

**At the end of this section, students will be able to:-**

- understand the concepts intrinsic to the Hydrostatic equations
- be aware of different types of pressure measuring devices
- Determine pressure readings from different pressure measuring devices

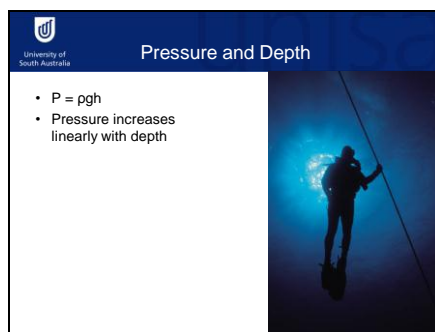
The intended learning outcomes from this presentation are to be able to understand hydrostatic equations and principles of pressure measurement using different devices.

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Now we're going to look at measuring pressure

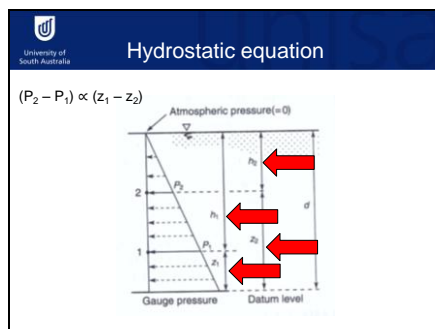
Slide 5



Just to re-cap from last week, you'll recall that there's a relationship between pressure and depth, where the pressure (P) equals density (rho) times gravity times the height (h) of the water column.

You'll also remember that pressure increases linearly with depth.

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Lets consider this figure with the water surface at the top being at atmospheric pressure, and we're interested in two points underwater, P1 and P2. There are two ways to measure the vertical distance.

Firstly, we can measure distance down from the water surface, which we denote h, like we did last week. In this case h1 is greater than h2.

Secondly, we can measure the distance up from some datum, which we denote z. When we measure it this way, z1 is less than z2.

Now, because pressure increases linearly with depth, the difference in pressure between two points is directly proportional to the distance between those points.

Image source- Les Hamill 2011, Understanding hydraulics.

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More specifically, we can express the hydrostatic equation as the equality of the P on rho g, plus Z. This relationship holds at all depths in the same body of water. A point like P2 shown here is closer to the surface, so it's got less in the pressure but more in the Z term. If you move down lower, you get less elevation in Z but increasing pressure.

We call P on rho g the pressure head, and we call Z the elevation head.

We'll refer to these terms a lot more later in the course when we look at fluids in motion.

Image source- Les Hamill 2011, Understanding hydraulics.

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When it comes to measuring pressure, a key point is the principle of equal level, equal pressure. Imagine a U-shaped tube filled with water.

In a continuous liquid of uniform density, at two points of the same elevation

(so  $Z_1 = Z_2$ ), the pressure's constant (i.e.  $P_1 = P_2$ ). We can tell this from the relationship we used before, because the pressure difference is proportional to the difference in elevation. When the difference in elevation's zero,

it means  $P_1 = P_2$ .

This is a fundamental concept in pressure measurement.

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### Stratified fluids

- Add the top layer to the bottom one (like adding weight of air to get  $P_{abs}$ )

$P_1 = \rho_1 g h_1$   
 $P_2 = \rho_1 g h_1 + \rho_2 g h_2$

Another fundamental concept involves adding pressures in layered, or stratified, liquids. Imagine now that there are two different fluids of different densities, one sitting on top of the other.

You might remember how last week we added the weight of the air sitting on top of a water body to get the absolute pressure.

It's simple – you just start with the topmost fluid, work out the pressure

at the bottom of that fluid

using  $\rho g h$

Then just add it to the pressure in the lower fluid at whatever point you're interested in,

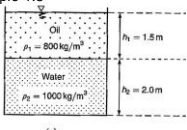
So the pressure  $P_2$  is the hydrostatic pressure of the lower fluid plus the weight of the upper one.

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### Calculating pressure of Stratified fluids

• Example 1.8



(a)

Figure 1.37 (a) Tank containing a stratified liquid, and (b) the corresponding pressure intensity diagram

Here's an example where oil's sitting on top of water in a tank. The fluid densities and heights are given in the picture. You should be able to calculate the pressure at the bottom of the oil and use it to find the pressure at the bottom of the tank. If you get stuck follow the example in the textbook.

Or watch the movie.

Image source- Les Hamill 2011, Understanding hydraulics.

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### Pressure measuring devices


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Next we're going to look at different devices to measure pressure.

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### Pressure measuring devices



- Piezometers
- Manometers
  - Simple U-tube
  - Differential U-tube
  - Inverted U-tube
- Bourdon gauge

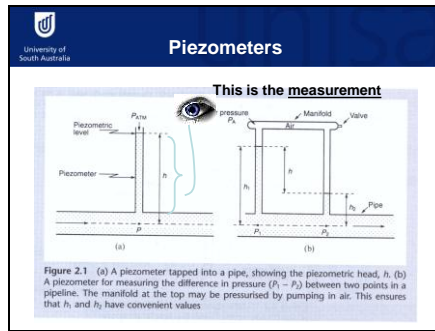
Pressure measuring devices include piezometers, manometers and the Bourdon gauge.

Piezometer [http://www.itm-soil.com.au/files/soil/W1\\_Standpipe-Piezometer.jpg](http://www.itm-soil.com.au/files/soil/W1_Standpipe-Piezometer.jpg)

Manometer [http://www.ehow.com/how\\_6901253\\_read-u\\_tube-manometer.html](http://www.ehow.com/how_6901253_read-u_tube-manometer.html)

Bourdon gauge [http://www.pchemlabs.com/files/images/gauge\\_kf25\\_1.gif](http://www.pchemlabs.com/files/images/gauge_kf25_1.gif)

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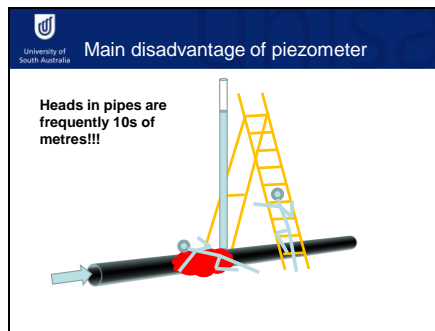


The simplest device is a piezometer, which is just a vertical tube stuck into a pipe. The fluid pushes water up the piezometer tube to a height that corresponds to the pressure in the pipe,  $P$ .

On the left is a single tube piezometer where the measurement is just the observed height of water in the tube. An alternative device is like the one on the right which has got two tubes and lets you measure the difference in pressure between two points. We'll look at these in detail later in the lecture.

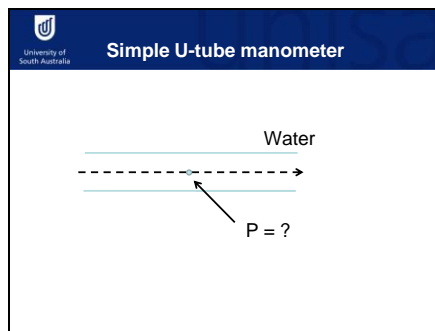
Image source- Les Hamill 2011, Understanding hydraulics.

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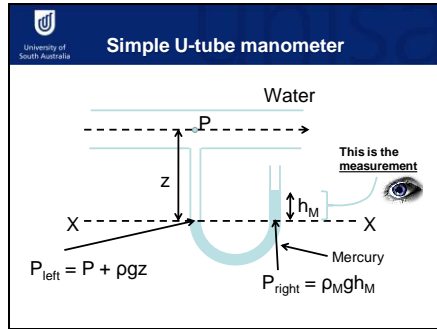
Piezometers are conceptually very simple, but in practical terms they're useless, because the pressures found in typical pipes are 10s of metres.

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Now let's look at the manometers as a tool to measure pressure in a water pipe. In a Simple U-tube manometer, a heavy fluid, like mercury is used.

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The manometer comes off the side of the pipe, and makes a U turn. The U gets filled with a heavy liquid like mercury. The key thing here is that the density of the mercury is so much greater than water that it won't be pushed as far as the basic piezometer, so it's a more practical solution. To measure the pressure, first we draw a line is drawn at the lowest we can reach that has a continuous fluid of the same type underneath.

We sometimes call this the "X-X" line.

Now as long as we know Z

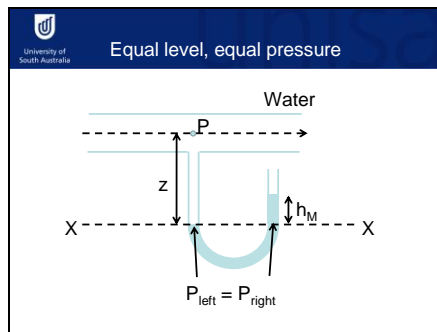
We can build up an expression for pressure on the left hand side,  $P_{left}$ , so we start at the top with the pressure  $P$ , then add  $\rho g z$  for the pressure of the water column.

Next we need to measure the height of the dense fluid in the U-tube. Let's call this  $h_M$ .

Assuming the top of the U-tube is open to the atmosphere, the pressure on the right,  $P_{right}$ , is just  $\rho_M g h_M$ .

In this case the thing we're measuring is the difference in height of the mercury between the two side of the U-tube. Now we use the "equal level, equal pressure" principle we talked about before.

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Because  $P_{left}$  and  $P_{right}$  are at the same elevation and they're connected underneath by a continuous fluid of uniform density, the equal level, equal pressure principle tells us they must be equal.

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### Manometer pressure equations

$P_{\text{left}} = P_{\text{right}}$   
 $P + \rho g z = \rho_M g h_M$   
 $P = \rho_M g h_M - \rho g z$



- Because  $\rho_M \gg \rho_{\text{water}}$ , the advantage over a simple piezometer is that the measurement is **scaled down** – i.e. you don't need as much space

So the left hand pressure's equal to the right hand pressure.

$P + \rho g z = \rho_M g h_M$

Rearranging this we can solve for pipe pressure P.

Since the density of mercury's much greater than water, the advantage of the manometer over a simple piezometer is that you don't need a huge height of tube to measure the pressure

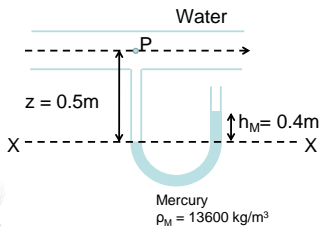
In other words the measurement is scaled down to a smaller, more practical space.

Image source  
[http://www.ehow.com/how\\_12179228\\_us-e-manometer-plumbing.html](http://www.ehow.com/how_12179228_us-e-manometer-plumbing.html)

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### Calculating pressures - Example 2.1



Water

$P$

$z = 0.5\text{m}$

X-X

Mercury  
 $\rho_M = 13600 \text{ kg/m}^3$

$h_M = 0.4\text{m}$

Here's a U-tube manometer example from the textbook. See if you can calculate the pressure on the left side and right side of the X-X line, and then rearrange the equation to solve for the pressure in the pipe, P. You've been given the density of mercury and you can assume water has a density of 1000 kg per cubic metre. You can always look up the worked solution in the textbook if you get stuck.

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### Differential U-tube manometer

$P_{\text{left}} = \rho g z_1 + P_1$   
 $=$   
 $P_{\text{right}} =$

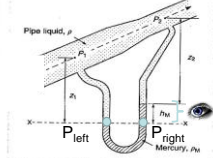


Figure 2.5 A differential U-tube manometer installed on an inclined pipeline of changing diameter. The manometer liquid in the bottom of the U-tube is mercury, the liquid above is that in the pipe.

Alright, here's another type of device to measure pressure called the differential U-tube manometer. This device determines the difference of pressures between two points in a pipe (P1 and P2).

Like before, the measurement we're interested in is the differential height of the fluid in the U-tube, which is mercury in this picture. We draw our X-X line across like we did before, and build up the picture on the left and right hand sides separately.

$P_{\text{left}} = \rho g z_1 + P_1$

Because of the equal level, equal pressure principle we know  $P_{\text{left}}$  has to equal  $P_{\text{right}}$  but  $P_{\text{right}}$ 's a little more



complicated because it's not open to the atmosphere like in the simple case we looked at before.

Now we have to consider the weight of the little bit of mercury, plus the weight of water sitting on top of that, plus the pressure in the pipe, P2.

Image source- Les Hamill 2011, Understanding hydraulics.

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### Differential U-tube manometer


$$P_{\text{left}} = \rho g z_1 + P_1$$

$$=$$

$$P_{\text{right}} = \rho_M g h_M + \rho g z_2 + P_2$$

$$\rho g z_1 + P_1 = \rho_M g h_M + \rho g z_2 + P_2$$

Therefore:  
 $(P_1 - P_2) = \rho_M g h_M + \rho g (z_2 - z_1)$



Luckily these equations can be simplified.

The first thing to do is cancel out  $P_{\text{left}}$  and  $P_{\text{right}}$  because they're equal.

Now we've got an equation relating all of the variables together.

Rearranging this we get an expression for the pressure difference,  $P_1 - P_2$ , as a function of the measured heights. It's important to note that because there are two unknowns,  $P_1$  and  $P_2$ , and only one equation, we can't do any better than working out the difference in pressure. In other words we can't use this device to work out the absolute pressure at  $P_1$  and the absolute pressure at  $P_2$ .

Image source: Microsoft clipart

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### Differential U-tube manometer

- Example 2.2

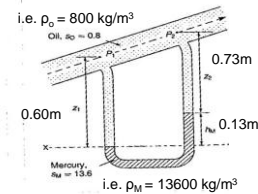


Figure 2.6

Here's an example from the textbook. This time we're looking at an oil pipeline. The density of the oil's been given as specific gravity, which means it's the density relative to water at 1000 kg per cubic meter.

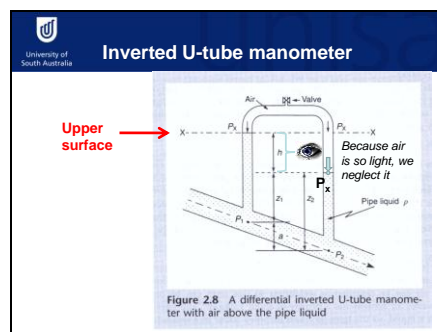
So the density of oil is 0.8 times 1000, which is 800 kg per cubic metre.

Do the same calculation for mercury

And here are all the relevant measurement lengths from the example. See if you can calculate the pressure difference,  $P_1 - P_2$ . Use the textbook if you get into trouble.

Image source- Les Hamill 2011, Understanding hydraulics.

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In the inverted U-tube manometer, the only difference is the orientation of the device, which is now sitting up above the pipe. Obviously this means we don't use dense fluids like mercury or they'd just sink down into the pipe. Ordinary air makes a pretty convenient fluid to use in this sort of device.

Just like before, we need to consider an X-X line connecting fluids, except this time we draw it at the highest point where there's a continuous fluid above the line. We can still use the equal pressure principle to say  $P_x$  on the left-hand side equals  $P_x$  on the right-hand side, but this time we're using the fact that they're connected by the air above rather than the water or mercury below.

Like we did before, we measure pressure based on the difference in observed fluid height. Strictly speaking, on the right-hand side we've got a pressure column made up of water plus a bit of air on top.

But, because air's almost a thousand times lighter than water, generally speaking we can neglect this bit of air and just imagine the pressure  $P_x$  is the same at the top of the water as it is up at the X-X line. This means it's one less calculation we have to do.

Image source- Les Hamill 2011, Understanding hydraulics.

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Inverted U-tube manometer

$P_{x(\text{left})} = P_{x(\text{right})}$

Left-hand side  
 $P_1 = P_x + \rho g z_1 + \rho g h$

Right-hand side  
 $P_2 = P_x + \rho g z_2 (+ \rho_{\text{air}} g h)$

Figure 2.8 A differential inverted U-tube manometer with air above the pipe liquid

Different pipes have different slopes, and sometimes the pressure difference is negative and sometimes it's positive. So it won't always look exactly the same as the level in this picture. Because of this, it's really important that you understand how we build up the expression for pressure and then when you're solving one of these problems, always build up the pressure equation from scratch. Hopefully this'll help you avoid common mistakes.

In the picture we've got here, we start with the X-X line where the pressures are equal, and because we're using air we can make the assumption that the right-hand side  $P_x$  is the same at the top of the water column.

Now, the expression for pressure on the left side is  $P_1$  (the pressure at the bottom) equals the weight of water above, here it's given in two heights so we add them both  $\rho g z_1$  and  $\rho g h$ , plus the pressure  $P_x$  at the top.

The expression for the right hand side is  $P_2$  equals  $\rho g z_2$  plus  $P_x$ .

If we wanted to, we could have included the weight of the air, and if the fluid was something else like a light oil, we'd need to include this here. Anyway, it's really important that you build these expressions up from the bottom.

Image source- Les Hamill 2011, Understanding hydraulics.

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Inverted U-tube manometer

Left-hand side  
 $P_1 = P_x + \rho g z_1 + \rho g h$

Right-hand side  
 $P_2 = P_x + \rho g z_2$

$P_1 - P_2 = \cancel{P_x} + \rho g z_1 + \rho g h - \cancel{P_x} - \rho g z_2$

So now it's easy to use these expressions to calculate the differential pressure,

you just subtract one from the other

And then the  $P_x$  terms cancel out because they're equal.

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### Inverted U-tube manometer

- Example 2.3
- $P_1 - P_2 = ???$

Water  
 $\rho = 1000 \text{ kg/m}^3$

$z_1 = 100 \text{ mm}$

$z_2 = 250 \text{ mm}$

$h = 90 \text{ mm}$

See if you can work out the pressure difference in this example. The fluid in the manometer's air, so you can make the simplifying assumption we made earlier. Don't forget to build up the pressure equations for  $P_1$  and  $P_2$  from scratch like we did just before, but using the geometry specific to this problem. As always, use the textbook to guide you through the example if you're having trouble.

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### Manometer sensitivity

- Example 2.4
- Sensitivity:  
How readily does the gauge respond to a given pressure difference?

Compare with Ex. 2.3

$\rho_o = 800 \text{ kg/m}^3$

Water

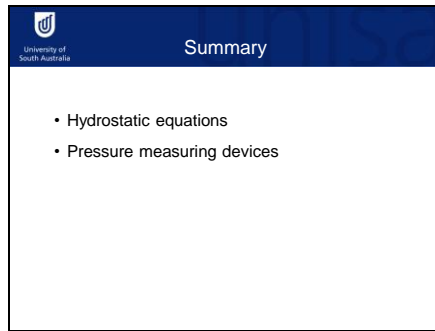
Figure 2.12

What we've seen is that the density of the fluid in the manometer dictates how far the fluid needs to move for a given pressure. For a particular pressure range, we can design a manometer to give acceptable precision and convenient size by selecting a fluid with an appropriate density. For larger pressures we need to use a dense fluid like mercury, and for smaller pressures we use a lighter fluid like oil. In this example we've got a differential U-tube manometer showing exactly the same dimensions and readings as in the previous example, again with 90 millimetres showing as the measured difference in heights.

The difference is that this time it's filled with oil instead of air. Work out the pressure difference and see whether this is a more sensitive or less sensitive gauge than the one that had air in the top. Check out the textbook if you need help.

Image source- Les Hamill 2011, Understanding hydraulics.

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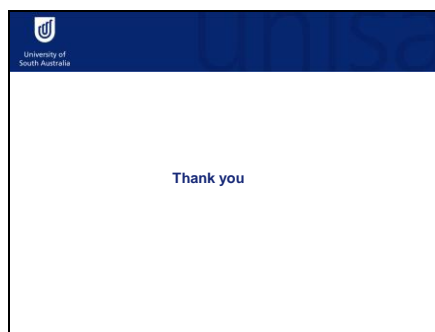
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### Summary

- Hydrostatic equations
- Pressure measuring devices

So, in summary, we've looked at hydrostatic equations and pressure measurement techniques using different types of pressure measuring devices.

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Thank you

If you have any questions or need further clarification please post a question or comment on the Discussion Forum.