7.1 Flow and Concentration

Data that comes back from the lab is usually given in a concentration. A concentration is unit per volume. Most concentrations are in milliliters per liter (volume/volume) or milligrams per liter (mass/volume). The volume is the amount of water tested, and the smaller volume, or mass is the amount of substance found in the overall volume.

Concentration can be compared to other lakes and rivers to determine there relative health. There are also known critical concentration levels that if reached certain impacts can occur such as algae growth and fish deaths. These concentrations are known from experimentation and experience. There is always a direct correlation to concentration levels and the quality of the water.

Flow is the amount of moving water in a stream or river. It is the velocity of the water multiplied by the cross sectional area of the river and is given in units of volume per time. Velocity is measured by using a flow meter. The flow meter is a small propeller that spins in moving water. The number of turns the propeller makes in a given time is used to calculate the average velocity of the water. The cross sectional area is measured or calculated. Usually it is measured at a culvert because measurements can be taken and calculated much easer and thus reduce error.

Flow is important for quantifying the amounts of substance flowing in a river. By multiplying the Flow by the Concentration we can quantify the mass or volume of substance, this is called loading and is given in units of unit (mass, volume) per time (second, day, year). Typically it is converted into gallons per day or lbs per day. Rivers that flow into lakes can greatly influence its quality. Calculating the loading identifies the greatest contributor of pollutants. For example a large river with low concentrations may be impacting the lake less than a small stream with high concentrations.

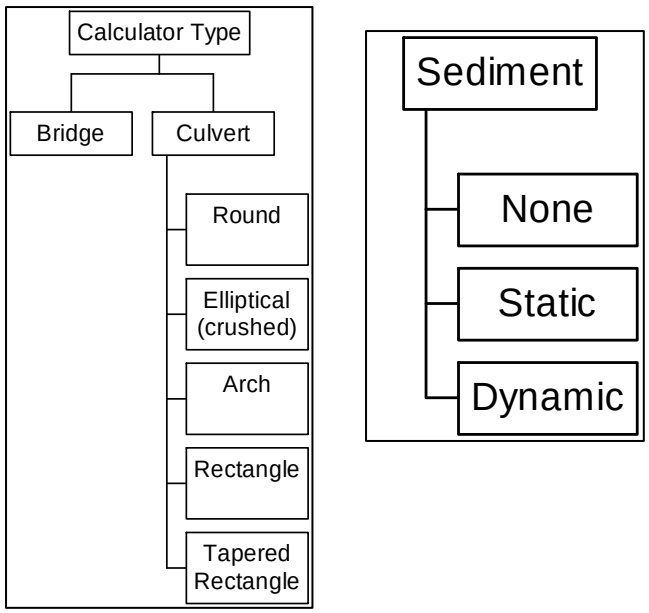
Programs were built to calculate the flow and loading for each of the sampling sites around Pelican Lake using Microsoft Excel.

7.1.1 Flow Calculators

Flow is calculated by taking the sums of the water velocities multiplied by their corresponding water cross sectional areas.

$$\textbf{Flow} = \sum \textbf{(Velocity * Cross Sectional Area)}$$

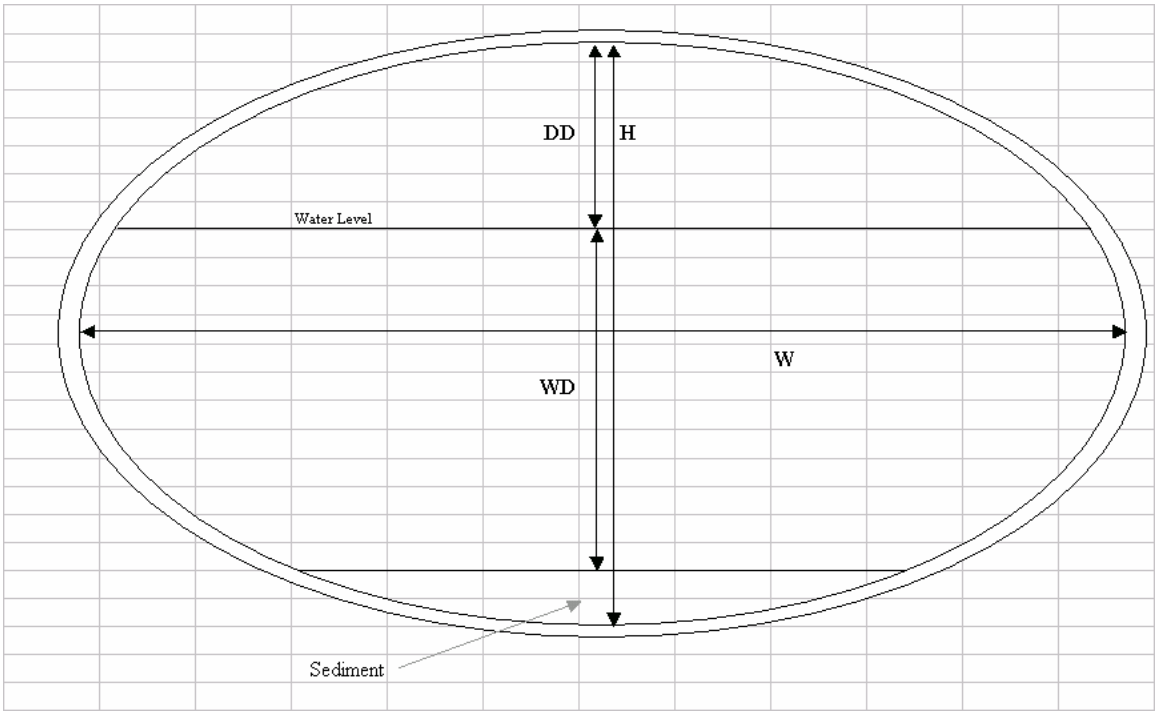
There are different calculators for each type of site shown in the chart below. There are calculators for bridges and 5 different culverts. The calculator type also depends on the sediment. Static sediment is sediment that does not move such as rock or compact gravel. Dynamic sediment is sediment that is moving thus changing the waters cross sectional area, for example, sand.



All calculations inside the flow calculator are done in standard units of feet and seconds. Therefore all measurements must be input in those units unless otherwise stated.

INCHES	FEET
1	0.0833
2	0.1667
3	0.2500
4	0.3333
5	0.4167
6	0.5000
7	0.5833
8	0.6667
9	0.7500
10	0.8333
11	0.9167
12	1.0000

Elliptical (crushed) Culverts



This calculator is used for concrete elliptical culverts and crushed culverts. While a crushed culvert is not a perfect ellipse this is usually a good approximation.

The following measurements are needed:

Depth Down (DD), Measured from the top inside of the culvert to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Height (H), Measured across the maximum vertical distance.
Width (W), Measured across the maximum horizontal distance.

H and W are constants that only need to be measured once. For culverts with dynamic sediment both the DD and WD are needed. For culverts with static sediment or with out sediment only the DD is needed.

The formula for the water cross sectional area is,

$$WaterArea = [a \bullet b \bullet \arcsin(\frac{\text{WaterDepth}}{a-1}) + (\frac{\text{WaterDepth}}{a-1})\sqrt{\frac{2 \bullet \text{WaterDepth}}{a} - \frac{\text{WaterDepth}\wedge 2}{a\wedge 2}} + \frac{\pi}{2}] -$$

$$[a \bullet b \bullet \arcsin(\frac{\text{SedimentDepth}}{a-1}) + (\frac{\text{SedimentDepth}}{a-1})\sqrt{\frac{2 \bullet \text{SedimentDepth}}{a} - \frac{\text{SedimentDepth}\wedge 2}{a\wedge 2}} + \frac{\pi}{2}]$$

Where

a = H/2
b = W/2
WaterDepth = H-DD
SedimentDepth = H-DD-WD

The first part of the equation is the area of the water and sediment. The second part is the area of the sediment. The sediments area is subtracted from the combined area leaving the water area.

If the sediment is static SedimentDepth is a constant. If there is no sediment SedimentDepth equals zero.

Generally one flow in the center of the culvert is enough for a sufficient approximation for the flow. Flow is then calculated by;

Flow = Velocity * WaterArea

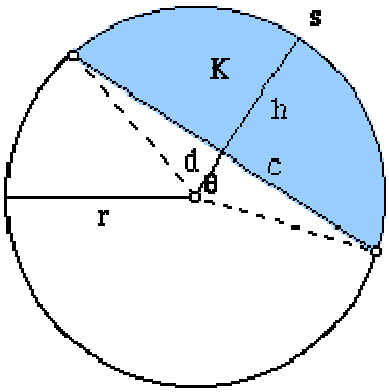
If flow is impeded by sediment or river direction then multiple velocities may be taken. Flow is then calculated by;

Flow = ∑Velocity * WaterArea / N

Where

N = number of velocities taken
∑Velocity = sum of velocities

Round Culverts



This calculator is used for round concrete and steel culverts. Only 4 of the following measurements are needed. 2 calculate Water Area and 2 to calculate Sediment Area.

s = Arc length
c = Chord Length
r = Radius (diamerter/2)
h = Height (outside radius to chord midpoint)
theda = Angle (in radians or degrees)
d = Apothem (distance from chord to center circle)
K = Area

This calculator was built Dan Erb and modified for flow calculating purposes.
http://mathforum.org/dr.math/faq/faq.circle.segment.html

The following measurements are needed:

Depth Down (DD), Measured from the top inside of the culvert to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Diameter (D), Measured across the maximum distance.

Typically the only measurement taken is the DD. WD is taken for sites with dynamic sediment. D is a constant and only need be measured once.

r = D/2
h1 = WD = D-DD
h2 = SedimentDepth = D-DD-WD

The formula for the water area is:

WaterArea = K1 – K2

Where

K1 is calculated from **r** and **h1**
K2 is calculated form **r** and **h2**

Generally one flow in the center of the culvert is enough for a sufficient approximation for the flow. Flow is then calculated by;

Flow = Velocity * WaterArea

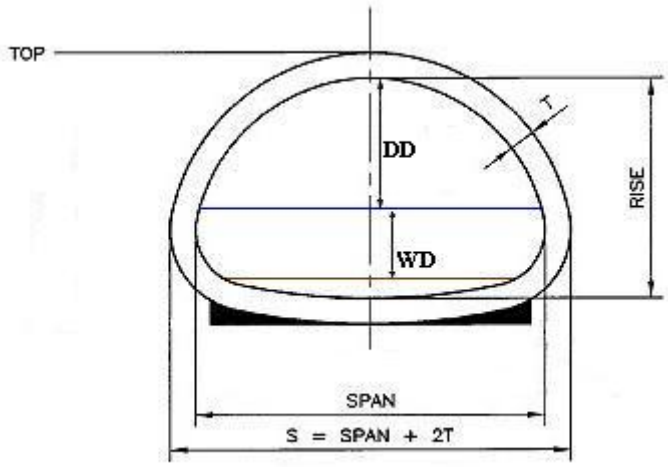
If flow is impeded by sediment or river direction then multiple velocities may be taken. Flow is then calculated by;

$$\mathbf{Flow = \sum Velocity * WaterArea / N}$$

Where

N = number of velocities taken
∑Velocity = sum of velocities

Arch Culvert



This calculator is for concrete arch pipes, also known as reinforced concrete pipes. Because of its irregular design and difficulty to take measurements an approximation chart was designed. Using a picture of a culvert and a computer program, the number of horizontal pixels was counted for every vertical pixel along the rise. Given a WD or SD (in pixels) the Default Chart will calculate the area by adding the pixels. Given the rise and span (in inches) the calculator will convert pixels into square inches.

The following measurements are needed:

Depth Down (DD), Measured from the top inside of the culvert to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Rise, Measured across the maximum vertical distance.
Span, Measured across the maximum horizontal distance.

Rise and Span are constants that only need to be measured once. Their dimensions are cross-referenced to a list of standard concrete arch pipe dimensions. Typically the only measurement taken is the DD. WD is taken for sites with dynamic sediment.

The formula for the water area is:

WaterArea = Combined Area – Sediment Area

Where:

Combined Area is selected from the Calculated Chart using the combined depth
Combined depth is: **Rise – DD**
Sediment Area is selected from the Calculated Chart using the sediment depth
Sediment depth is: **Rise – DD – WD**

The Calculated Chart is calculated using the Default Chart and the measured Rise and Span. The formulas for the area are:

Calculated WD = Default WD * Calculated Rise
Calculated SW = Default SW * Calculated Span

$$\textbf{Calculated Area} = \sum \textbf{(Calculated SW * Calculated Span)}$$

Where:

Calculated Rise = Measured Rise / Default Rise
Calculated Span = Measured Span / Default Span
Default Rise = 109 pixels
Default Span = 172 pixels

Generally one flow in the center of the culvert is enough for a sufficient approximation for the flow. Water area is divided by 144 to convert the charts units from square inches to square feet. Flow is calculated by:

$$\textbf{Flow = Velocity * WaterArea / 144}$$

If flow is impeded by sediment or river direction then multiple velocities may be taken. Flow is then calculated by:

$$\textbf{Flow} = \sum\textbf{Velocity * WaterArea / 144 / N}$$

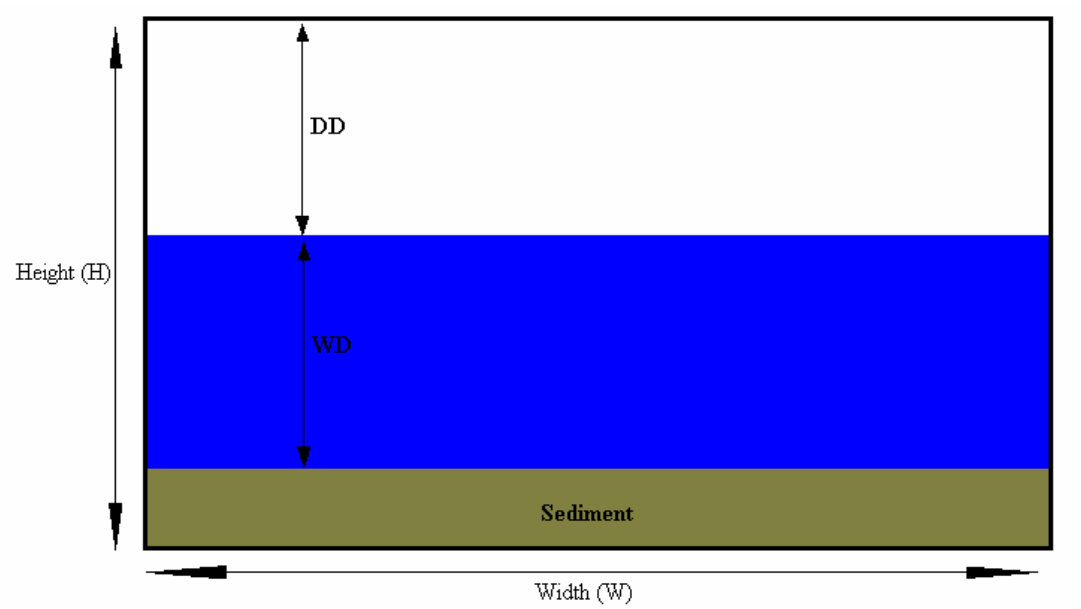
Where

N = number of velocities taken
$\sum$**Velocity =** sum of velocities

Because pixels were rounded, multiplication error causes the area to be slightly higher than it actually is. Results from this calculator were compared to known areas for the same culverts and found to be within 0 to +.8% more area. Maximum error is 109 square pixels.

Rectangular Culverts

Rectangular culverts are calculated similar to bridges but simpler. Bottoms are flat with out sediment, or near flat with sediment. It is possible for a rectangular culvert to be installed unlevel. A calculator has not been built for this scenario. However in many cases the difference in WD along the width is so little that this calculator may be used. If the difference in WD is great, then a bridge calculator may be used.



The following measurements are needed:

Depth Down (DD), Measured from the top inside of the culvert to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Height (H), Measured across the maximum vertical distance.
Width (W), Measured across the maximum horizontal distance.

H and W are constants that only need to be measured once. For culverts with dynamic sediment only the WD is needed. For culverts with static sediment or with out sediment only the DD or WD is needed. WD and W are the only measurements needed for calculations. WD can be calculated from H and DD. The easiest measurement is taken depending on the site.

The water area formula is then:

Water Area = W * WD

Where:

W = SW
WD = H – DD

Occasional only one velocity may be taken. Generally 3 to 5 are taken. Flow is then calculated by:

$$\mathbf{Flow = Velocity * WaterArea}$$

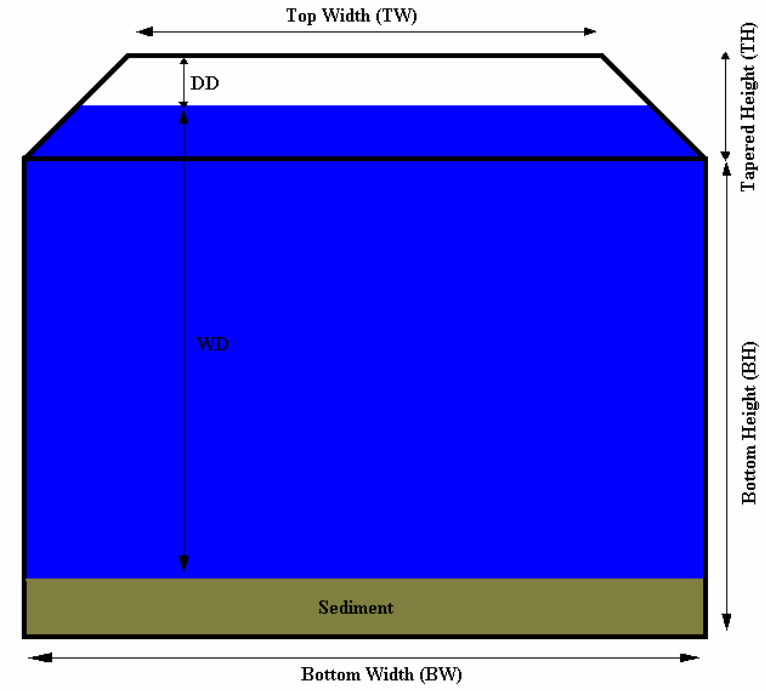
If multiple velocities are taken. Flow is then calculated by:

$$\mathbf{Flow = \sum Velocity * WaterArea / N}$$

Where:

N = number of velocities taken
$\sum$**Velocity** = sum of velocities

Tapered Rectangular Culvert



In most tapered culverts the water level never rises into the tapered height. These may be calculated in the same way as regular rectangular culverts.

The following measurements are needed:

Depth Down (DD), Measured from the top inside of the culvert to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Bottom Width (BW), Maximum horizontal distance.
Bottom Height (BH), Vertical distance from bottom to taper.
Taper Height (TH), Vertical distance of taper.
Top Width (TW), Horizontal distance across top of culvert.

BW, BH, TH, and TW are all constants than only need to be measured once. For culverts with static sediment or with out sediment only the DD is needed. The formula for the water area is a logical expression:

IF
DD < TH
THEN
Water Area = Total Area - (DD*(TW)+DD*(1/TAN(Taper))) – Sediment Area
IF
DD > TH
THEN
Water Area = BW*(Total Height-DD)) - Sediment Area

Where

Sediment Area = **BW * (TH-DD-WD)**
Total Height = BH + TH
Total Area = BW *TH – (BW-TW)/2 *TH
Taper = ARCTAN(TH/((BW-TW)/2))

Occasional only one velocity may be taken. Generally 3 to 5 are taken. Flow is then calculated by:

$$\textbf{Flow = Velocity * WaterArea}$$

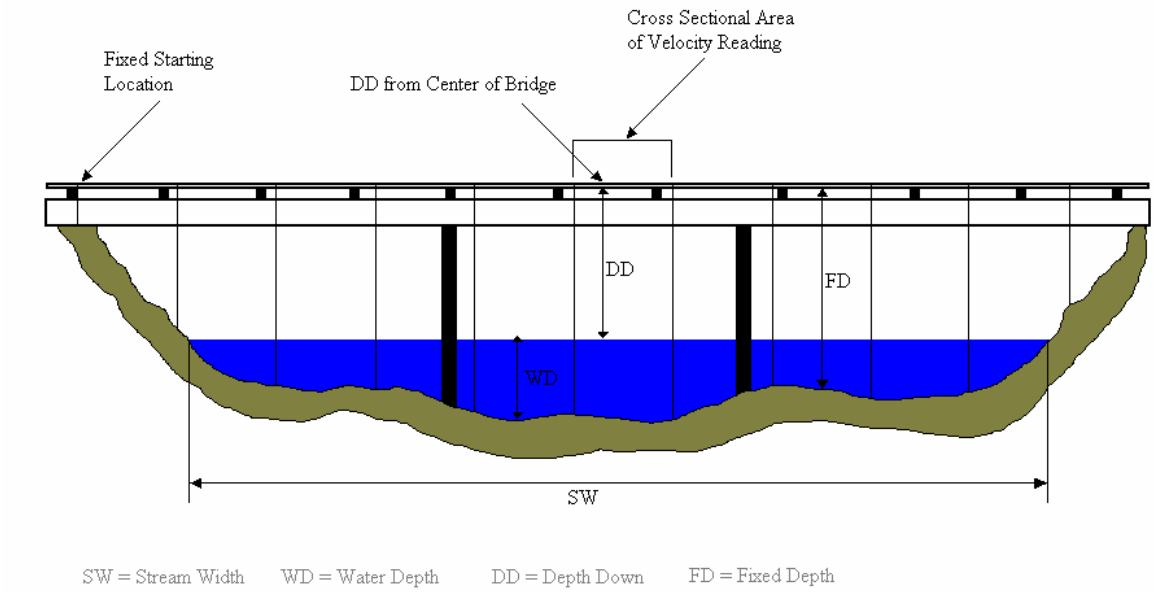
If multiple velocities are be taken. Flow is then calculated by:

$$\textbf{Flow = } \sum \textbf{Velocity * WaterArea / N}$$

Where:

N = number of velocities taken
$\sum$**Velocity =** sum of velocities

Bridges



Bridges have a fixed location to begin measurements from. This is usually a railing end, railing post, or other physical noticeable location. FD measurements are recorded for every foot along the length of the bridge from this location. Velocity readings are recorded and entered based on the distance from this location.

The following measurements are needed:

Depth Down (DD), Measured from top of railing to the water.
Water Depth (WD), Measured from the top of the water to the sediment.
Stream Width (SW), Horizontal length of stream.
Fixed Depth (FD), Measured from top of railing to sediment.

Bridges may use any combination of DD, WD, SW, and FD to calculate water area per section. A section is the water area that is multiplied by that sections velocity. Flows are calculated for each section and then added together. Section lengths depend on the length of the bridge as well as its FD and common velocities. Bridges with little change in velocity along its length tend to have larger sections. This way acceptable accuracy may be maintained while taking the least amount of velocities.

Flow is generally calculated using FD. It is important to remember that FD = DD + WD because this formula is used differently for cases were there is no water, for example when the DD > FD, WD cannot be less that zero or the water area is calculated to be much smaller that is actually is. The general formula for flow is:

$$\sum \left(\textbf{Velocity} * \left(\sum \textbf{FD} - \textbf{Section Width} * \textbf{DD} \right) \right)$$

The FD for every foot is added along the sections width yielding a FD area. The area that is not water is then subtracted. This is done for every section and the sections are added together. The velocity for areas where there is no water (DD>FD) should be entered into the calculator as 0.

Static bottom sites should have their bottoms checked for change every year. Only DD is needed for these sites. DD and FD or WD is needed for every X number of feet for dynamic bottom sites. X is the distance between measurements and is determined by the length of the bridge and the extent its bottom changes. The smaller X is the more accurate the data is. However more time sampling is required.

Take 10 flows and input the data into the correct cell location
Where there is land set flow = 0
FD = Fixed Depth = DD + WD
(from bridge railing to creek bottom)

Inches to Feet Converter			
In.	=	Ft.	This is for Exel convenience only
		0	

		0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'
Flow												
FD												

	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'	21'	22'
Flow												
FD												

	23'	24'	25'	26'	27'	28'	29'	30'	31'	32'	33'	34'
Flow												
FD												

	35'	36'	37'	38'	39'	40'	41'	42'	43'	44'	45'	46'
Flow												
FD												

	47'	48'	49'	50'	51'	52'	53'	54'	55'	56'	57'	58'
Flow												
FD												

For this site X = 2 feet. Only WD is needed for this site. WD can be calculated by

WD = FD - DD

Make a note on the field worksheet whether WD is directly measured or calculated using this formula.

For some sites the section width is equal to 1. Velocities are entered in the appropriate cells and the velocities for every other cell are calculated by averaging the velocity to the left and right. This is repeated 10000 times or until the maximum change is less than .0001 ft/sec. One cell represents 1 foot. Enter 0 where the water starts and ends.

		0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'
Flow		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FD		11.58	11.58	11.58	12.58	12.58	12.66	12.16	14.16	14.66	14.91	15.40

	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'	21'	22'
Flow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FD	15.52	14.60	15.60	15.69	15.52	16.02	16.19	16.27	16.19	16.35	16.27	16.02

	23'	24'	25'	26'	27'	28'	29'	30'	31'	32'	33'	34'
Flow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FD	16.08	15.91	15.91	15.91	15.91	15.75	15.83	15.75	15.66	15.66	15.58	15.58

	35'	36'	37'	38'	39'	40'	41'	42'	43'	44'	45'	46'
Flow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FD	15.58	15.66	15.75	15.83	16.08	15.78	16.08	15.91	15.16	15.41	15.00	15.00

	47'	48'	49'	50'	51'	52'
Flow	0.00	0.00	0.00	0.00	0.00	0
FD	13.66	12.50	12.66	12.41	11.83	11.75

Calculated Water Flow	
Sum of the row flow totals	0.00

DD	0.00

Before Values are inserted

FD data is filled in

		0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'
Flow		0	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.38	0.55
FD		11.58	11.58	11.58	12.58	12.58	12.66	12.16	14.16	14.66	14.91	15.40

	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'	21'	22'
Flow	0.73	0.76	0.79	0.83	0.86	0.89	0.95	1.01	1.08	1.14	1.20	1.16
FD	15.52	14.60	15.60	15.69	15.52	16.02	16.19	16.27	16.19	16.35	16.27	16.02

	23'	24'	25'	26'	27'	28'	29'	30'	31'	32'	33'	34'
Flow	1.12	1.08	1.04	1.00	0.99	0.97	0.96	0.94	0.93	0.81	0.69	0.58
FD	16.08	15.91	15.91	15.91	15.91	15.75	15.83	15.75	15.66	15.66	15.58	15.58

	35'	36'	37'	38'	39'	40'	41'	42'	43'	44'	45'	46'
Flow	0.46	0.34	0.38	0.43	0.47	0.52	0.56	0.49	0.42	0.34	0.27	0.20
FD	15.58	15.66	15.75	15.83	16.08	15.78	16.08	15.91	15.16	15.41	15.00	15.00

	47'	48'	49'	50'	51'	52'
Flow	0.10	0.00	0.00	0.00	0.00	0
FD	13.66	12.50	12.66	12.41	11.83	11.75

Calculated Water Flow	
Sum of the row flow totals	80.13

DD	13.00

Cells in between entered values are computed automatically

Values in orange are entered

DD is entered

Flow is Calculated

"0" is entered at water edges

Page 1

Conclusion

Site-specific worksheets were created to make field sampling and calculations easier, faster, and more accurate. Ultimately sites will be evaluated to see if any flow vs. DD correlation exists. If so, flow can be approximated given only the DD rendering these equations useless. Until a correlation can be determined these worksheets will continue to be used and improved. As new conditions warrant new calculators will be built and added to a database and this document.