Flow Monitoring Methods for Better Irrigation Management

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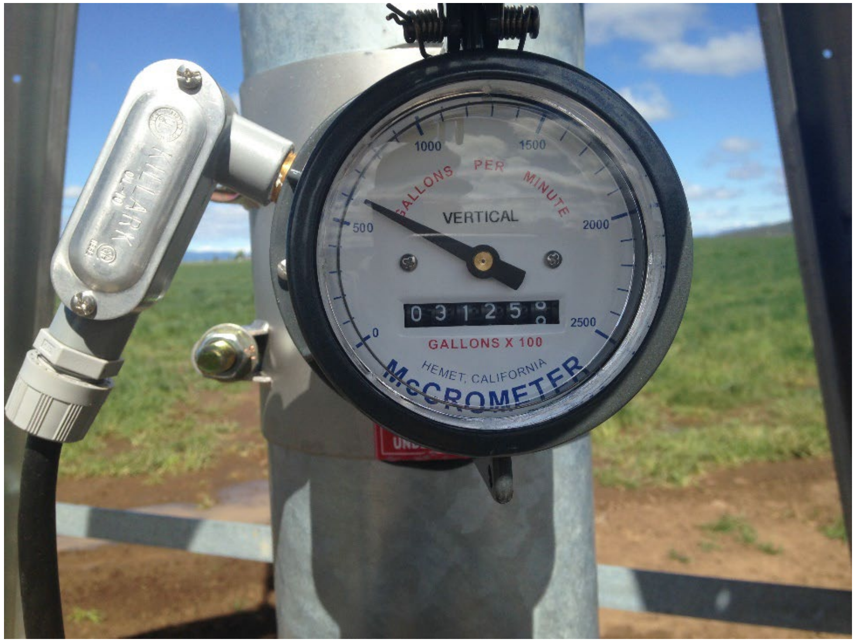
Why do water measurements matter?

- 1. Statutory requirement
- 2. Management—*If you can’t measure it, you can’t manage* it…*Chris Reilly*
  - Crop management/economics
  - Equipment management (efficiency)



Water Measurement Terms

- **Distance:** length, height or width of an object. Length between 2 points on a stream.

  Distance = expressed in:

  - Inches (in)
  - Feet (ft)

    .01 (hundredths of a foot)

    .1 (tenths of a foot)

- **Velocity:** is the rate at which water moves past a given point in a stream.

  Velocity = distance per unit time

  - Feet per Second (fps)
  - Miles per Hour (mph)

Water Measurement Terms (con't)

- Flow is an instantaneous measurement of a volume of water moving past a given point in a stream in a given time period

  Flow = volume per unit time

  - Gallons per Minute (gpm)
  - Cubic Feet per Second (cfs)
  - Acre Feet per Year (AFY)

- Time How long for an event to occur. When an event occurs. Used to calculate volume.

  Time = time of day or expressed in:

  - Seconds
  - Minutes
  - Days
  - Year

- Volume is a fixed amount of water occupying space at some point in time.

  Volume = amount of space I unit of water occupies

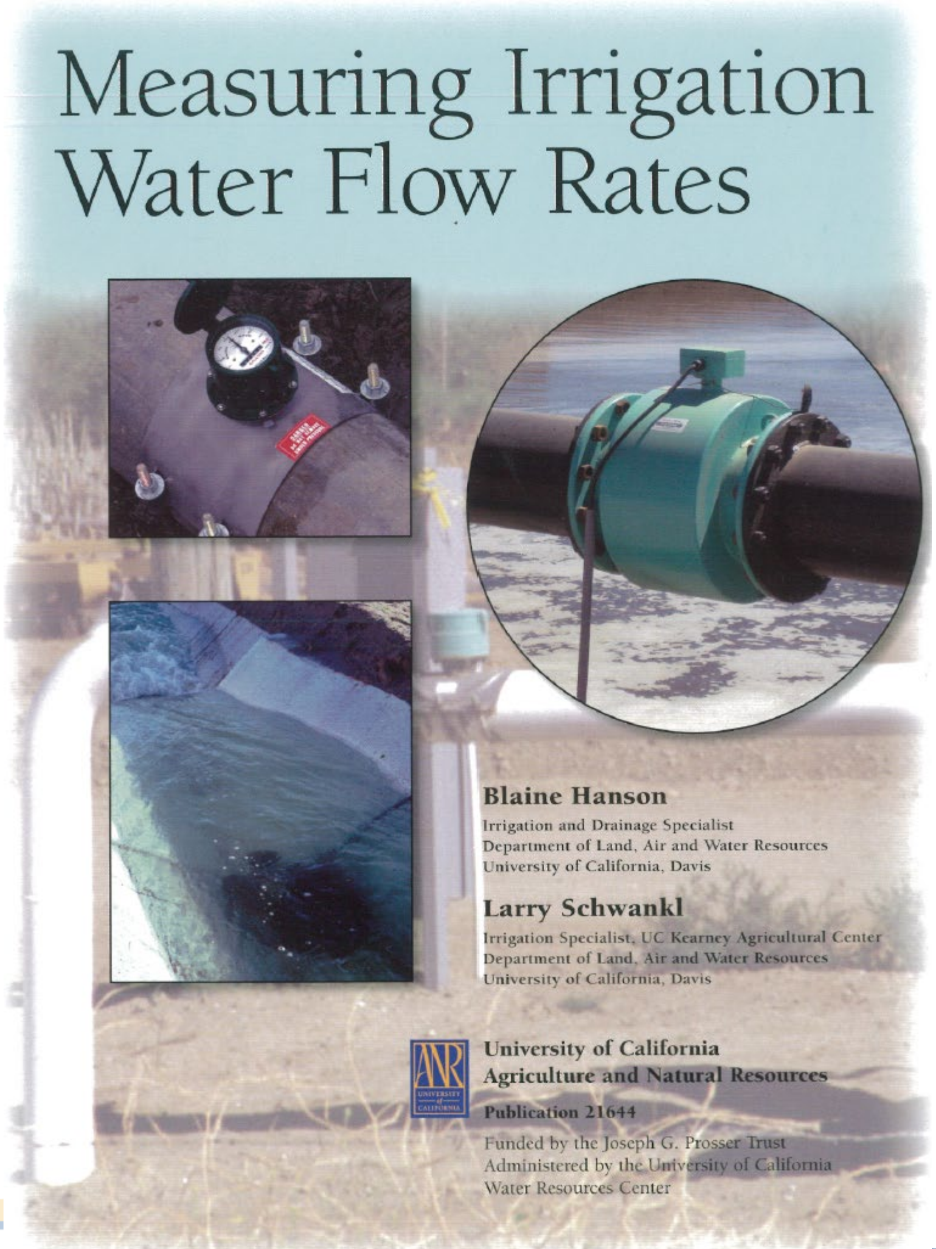
  - Gallons (gal)
  - Cubic feet (cf)
  - Acre Feet (AF)

Handful of terms and conversions to make this

- Cubic Foot per second (CFS)
  - This is a FLOW term and is equivalent to about 450 gallons per minute (448.1)
  - There are about 7.5 gallons in a cubic foot.

- Acre Foot is a (AF)
  - This is a VOLUME term and is 43,560 cubic feet of water. An acre foot of water contains 325,851 gallons (43,560 cubic feet * 7.5 gallons/cubic foot).
  - One CFS continual flow per day is equal to 1.984 (approx. 2) acre feet/day.

- **BIG HINT**!!!
  - Even though it is not what we are all mostly used to make your measurements in Engineers Rule (1/10 of foot—not inches). This will save you a headache when calculating cubic foot/second and acre feet.


Measuring Irrigation Water Flow Rates
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Flow Measurement Basics

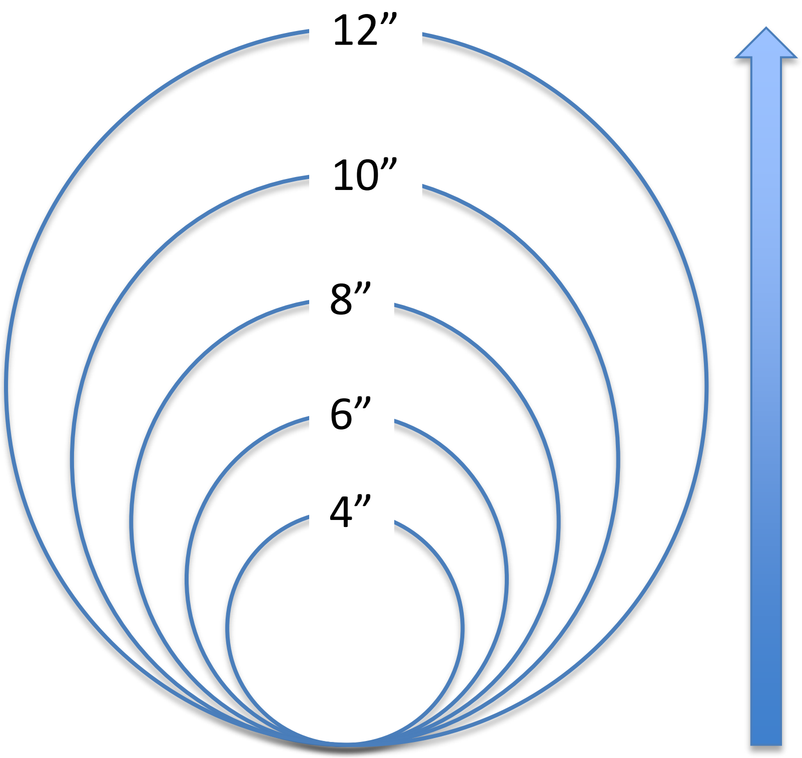
- Q = flow rate, expressed as volume of water passing through a cross section per unit time
- Q is determined by measuring two separate components:
  - Water velocity (V) in feet per second (ft/sec)
  - Cross sectional area (A) of pipe in square feet (ft^2)**

Q = V (ft/sec) x A (ft^2) = ft^3 per second (cfs)

1.0 cfs = 449 gallons per minute (gpm)

Q = flow, gpm

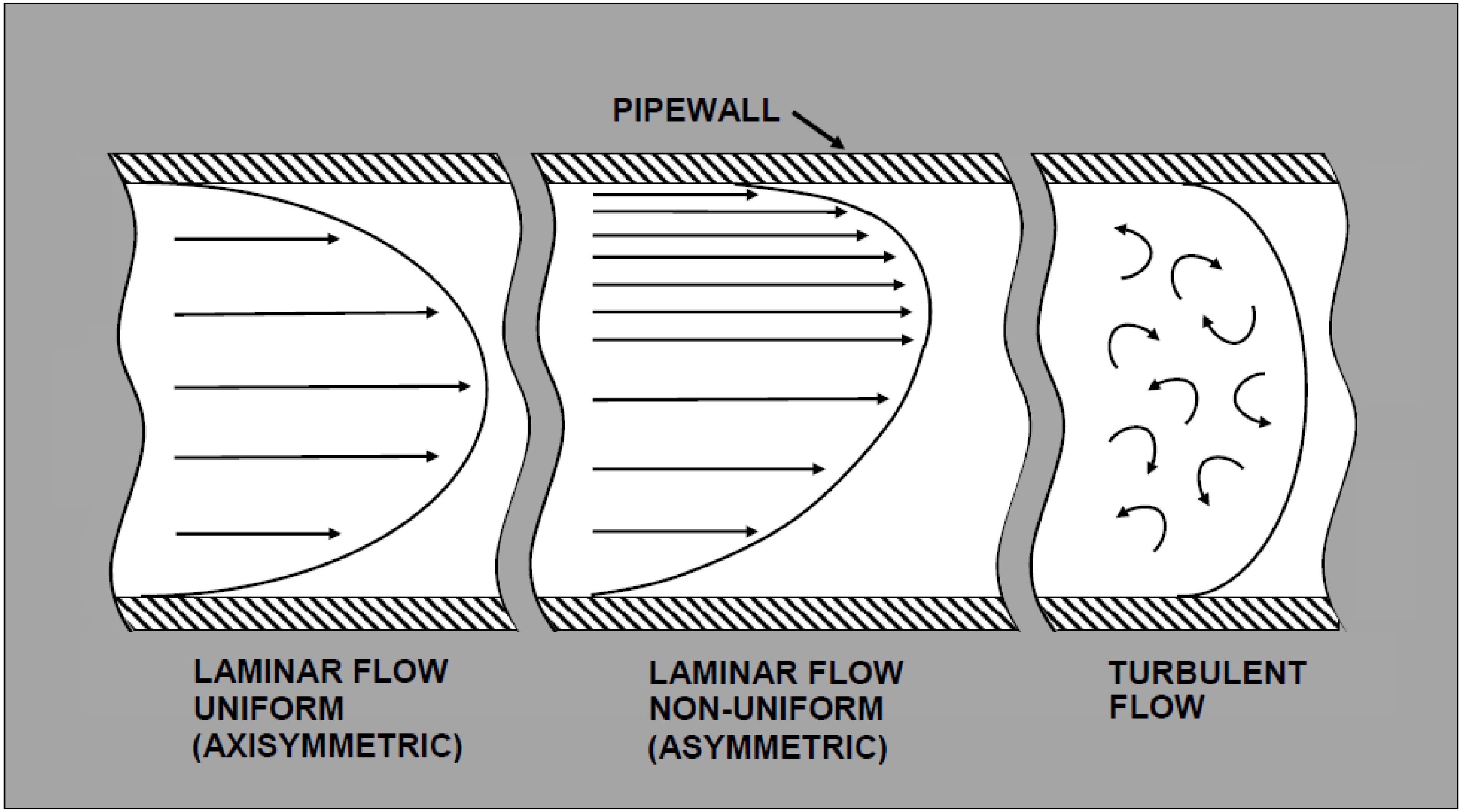
Pipe Diameter, Cross Sectional Area, and Flow Capacity Considerations for Sizing a Meter



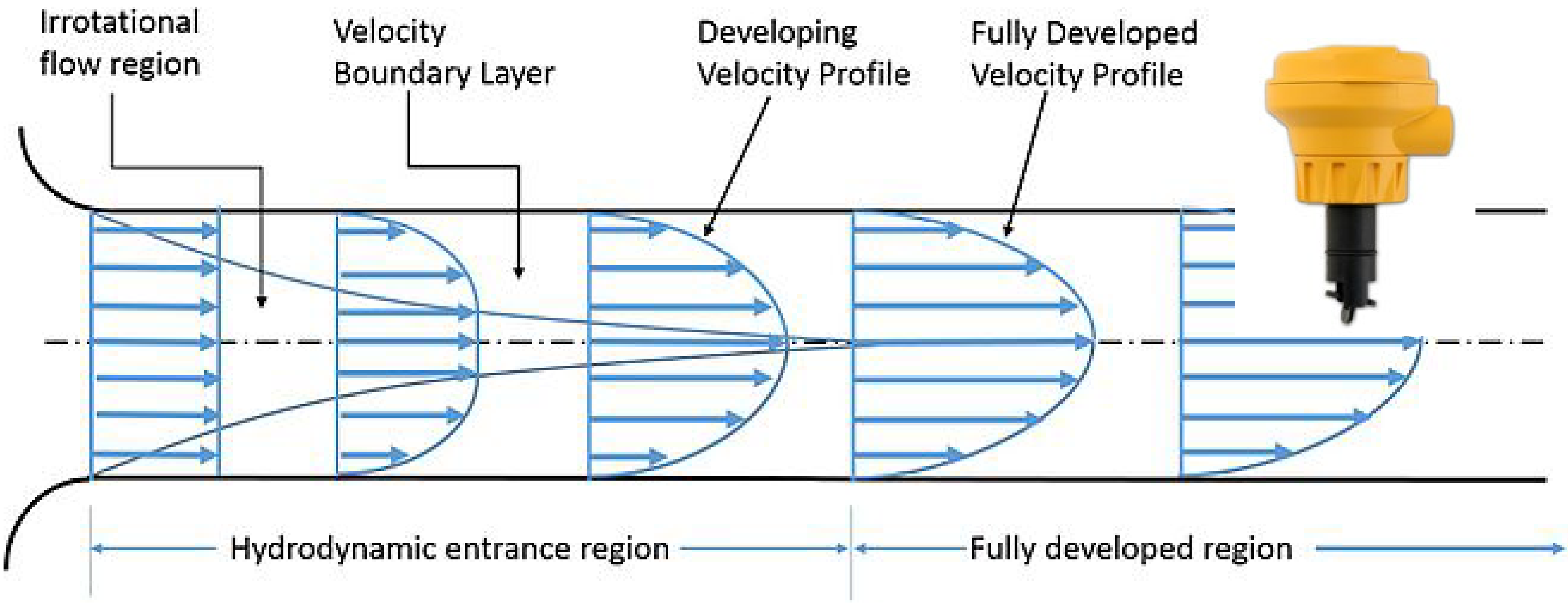
PVC Pipe Diameter (inches)	Cross Section Area (sq. inches)	Suggested Flow Range (gpm)	Mid Range Flow (gpm)
12	113.0	1800-2800	2400
10	78.5	1225-2000	1600
8	50.0	780-1250	1000
6	28.0	440-700	550
4	12.5	125-300	175

Flow Conditions Inside a Pipeline

RELIABLE FLOW MEASUREMENT REQUIRE LAMINAR FLOW (POSSIBLY UNIFORM)



Goal of a Properly Placed and Installed Flow Meter



- Laminar flow results in more accurate measurement
- General rule: > 10X pipe diameters of straight pipe above flow meter and > 5X below
- Straightening vanes may also be used upstream to achieve laminar flow in shorter pipe
- Not all meters have the same requirements

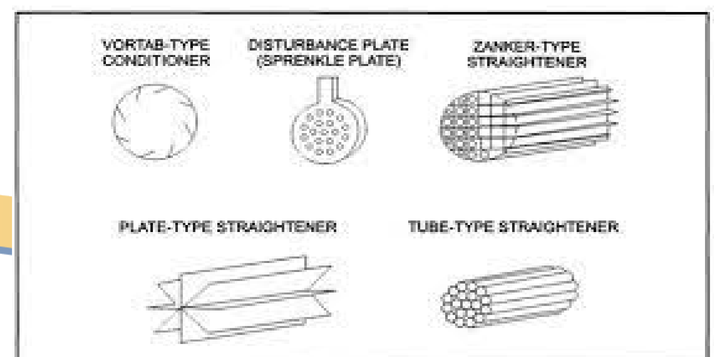
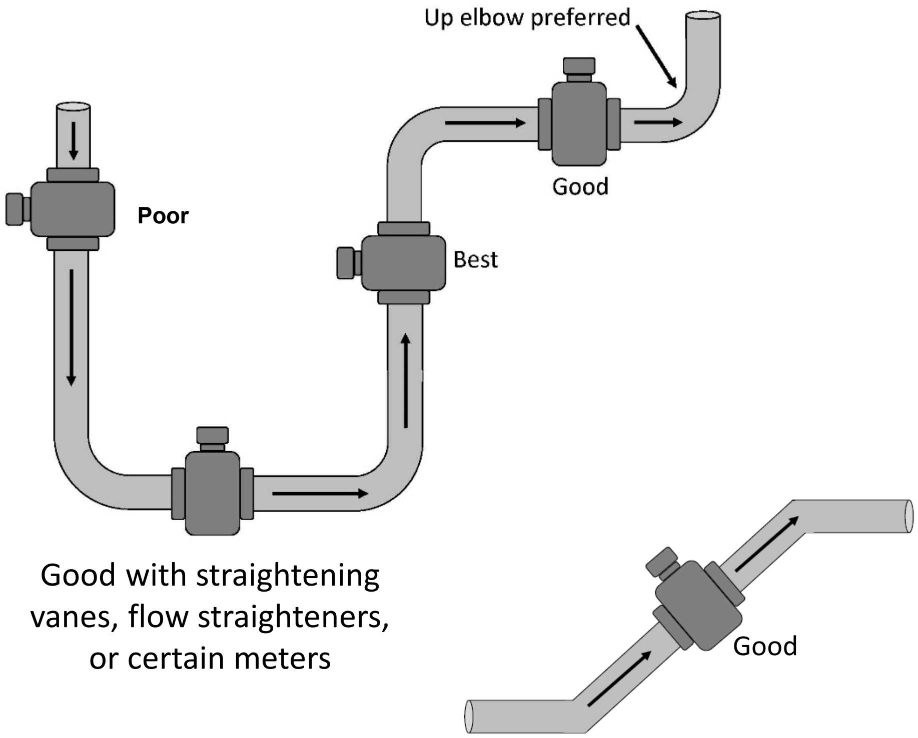
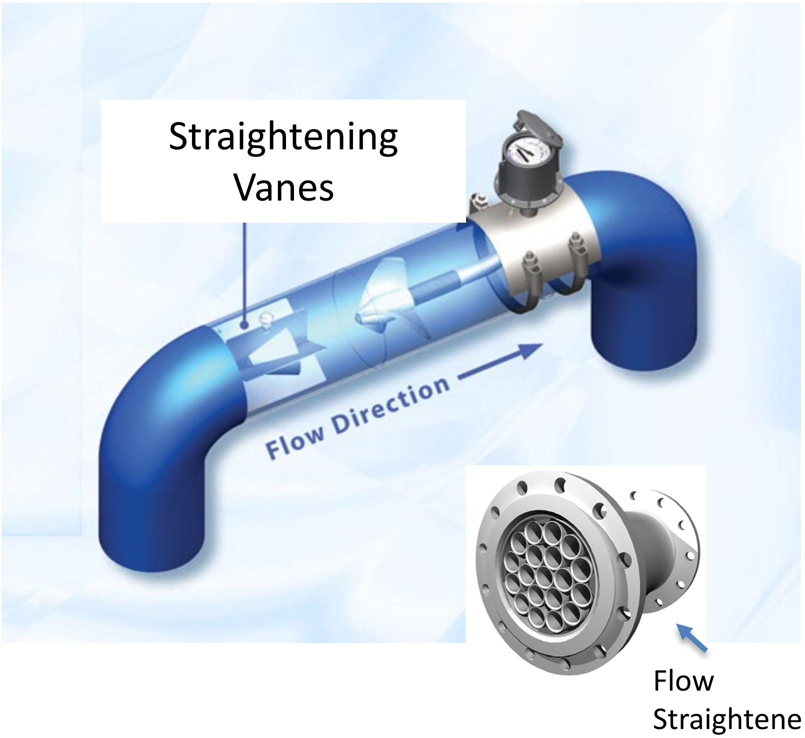


Figure 10-34. Different Types of Flow Conditioners used to Improve Flow Profiles. (Courtesy of

Steps to Help Assure Full Pipe Flow and Reduce the Risk of Measuring Turbulent Flow





Given previous slide, which flow meter installation is more likely to be accurate?

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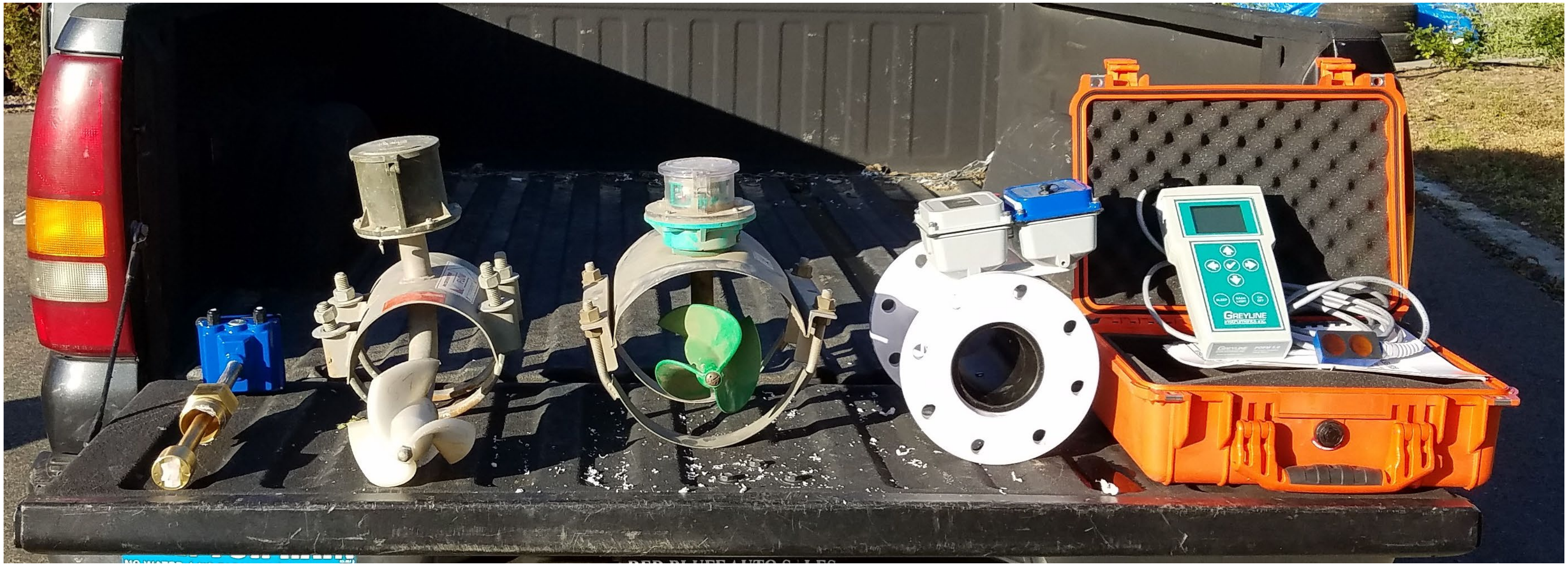
Important to calibrate correctly

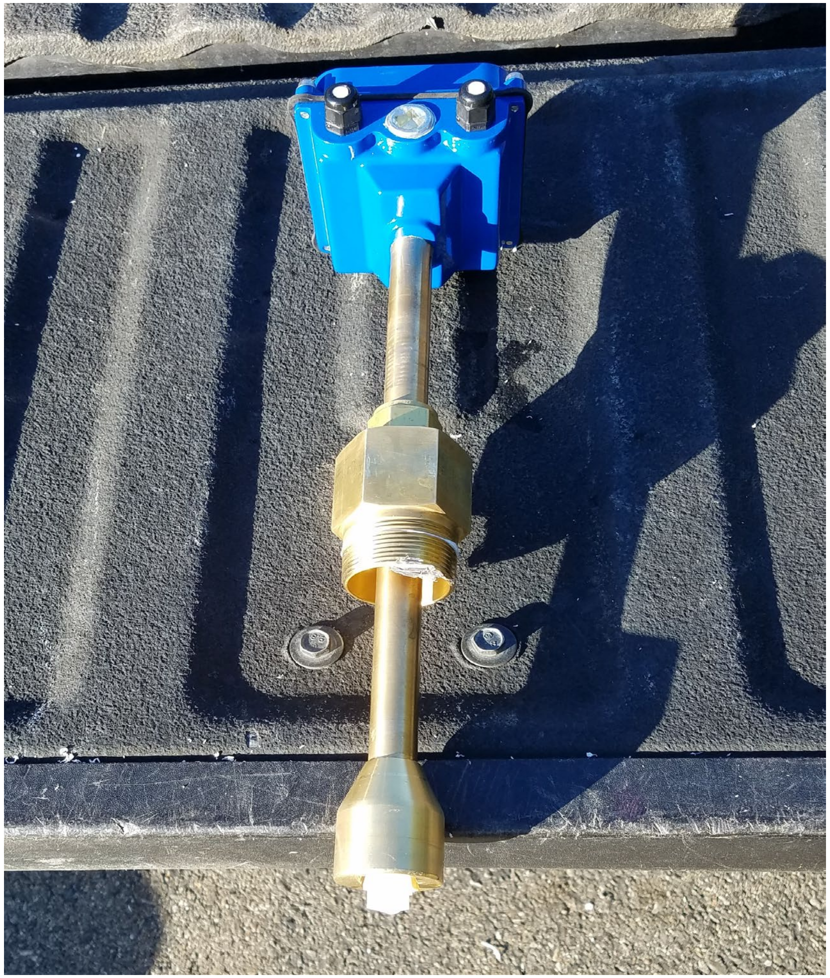
PVC Pipe Diameter (inches)	Cross Section Area (sq. inches)	Suggested Flow Range (gpm)	Mid Range Flow (gpm)
12	113.0	1800-2800	2400
10	78.5	1225-2000	1600
8	50.0	780-1250	1000
6	28.0	440-700	550
4	12.5	125-300	175

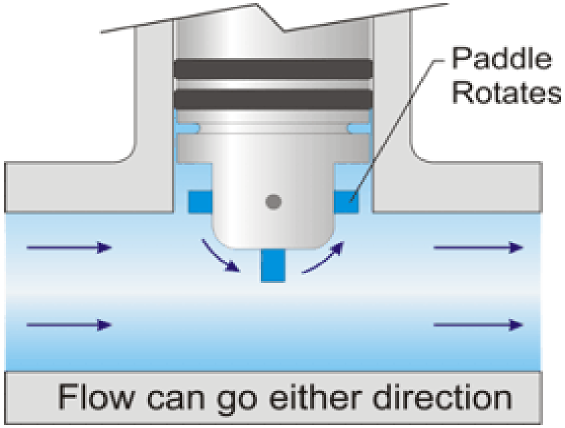
Two General Types of Flow Meters

- Point-velocity meters
- Velocity-averaging meters

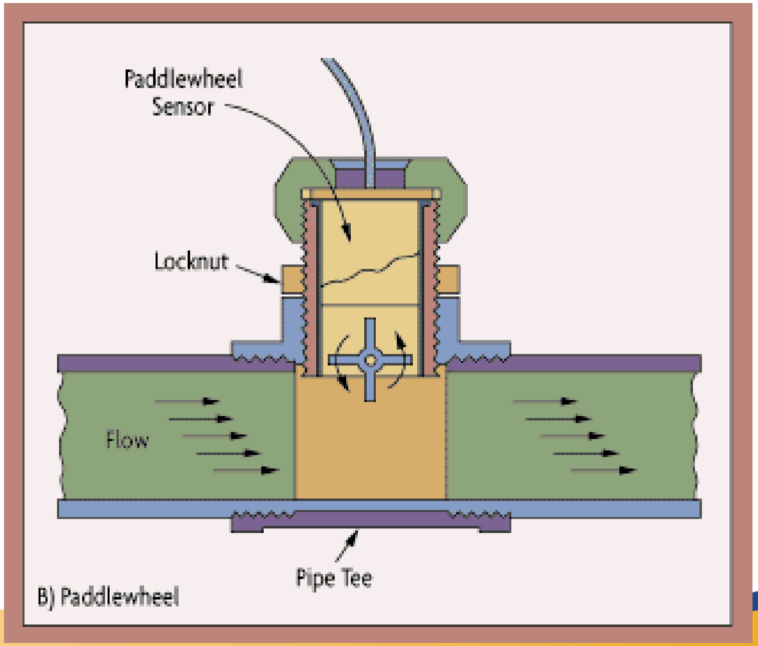


Insertion or Paddle Wheel Meters





Point-Velocity Meter

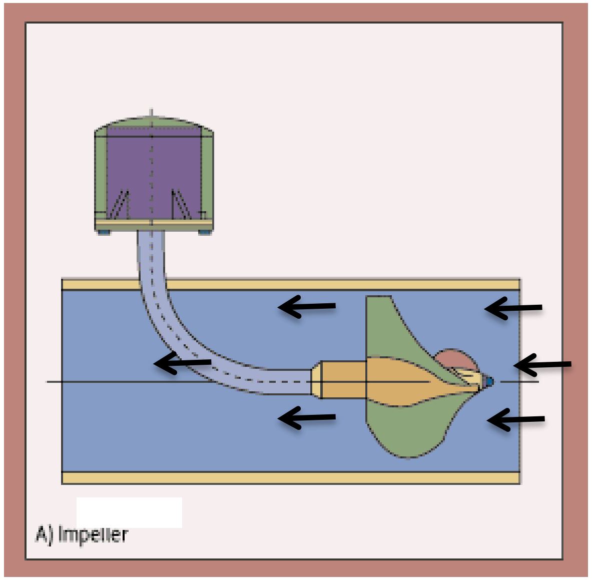



SET
≈ 3/4" - Flush
1/2" - in pipe
1.5"

Insertion or Paddlewheel Meters

- **Advantages**
  - Low cost option
  - Low power requirement
  - Suitable for high flows
  - Adequate accuracy (1-2%) with proper installation
  - Possibility to automate
  - Adequate durability
- **Disadvantages**
  - Accuracy is sensitive to proper paddle wheel insertion depth and orientation
  - Longer straight pipe section required
  - Paddle wheel can get entangled in debris
  - Moving parts subject to wear and tear from abrasion and corrosion

Impeller Meters

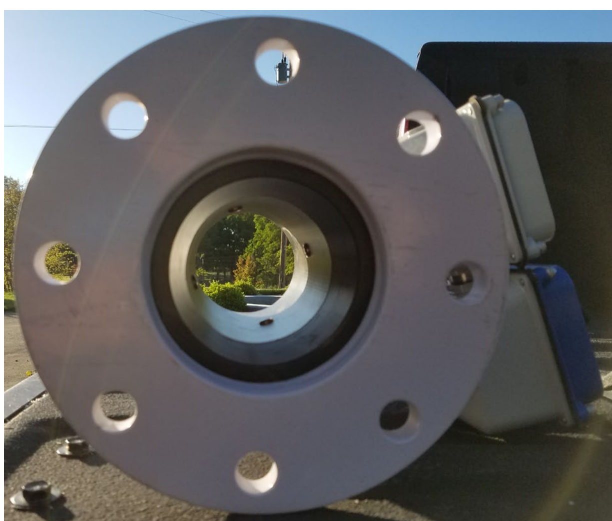


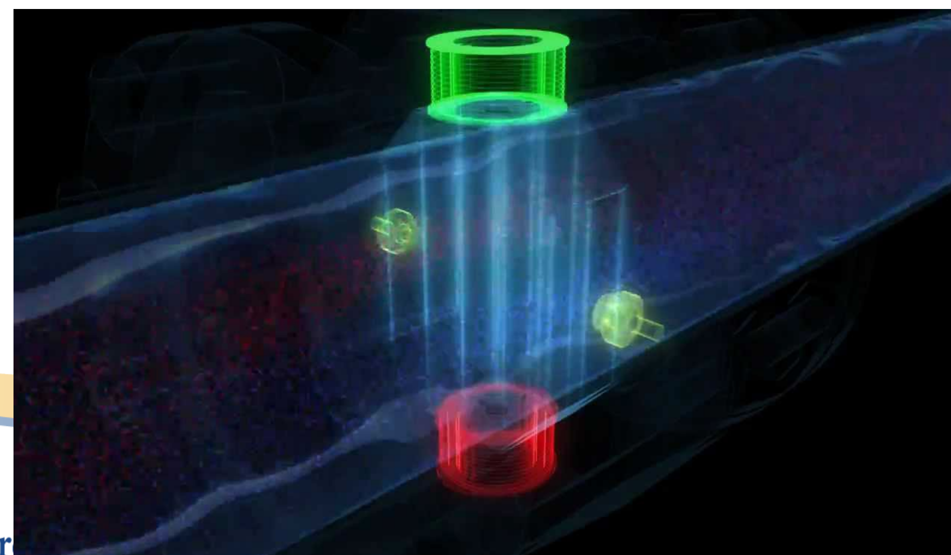
Impeller Meters

- **Advantages**
  - Among lower cost options
  - No power requirement unless automated
  - Suitable for fairly high flows
  - High accuracy (± 0.5 – 1%)
  - Possibility to automate
  - Adequate durability
- **Disadvantages**
  - Accuracy is dependent on flow conditions
  - Longer straight pipe section needed
  - Entanglement with debris can occur and affect reliability (pre-screening may be needed)
  - Moving parts subject to wear and tear from abrasion and corrosion

Electromagnetic Flow Meters

1. Two magnet coils (top and bottom) generate constant magnetic field
2. Two electrodes perpendicular to magnetic field
3. Magnetic field applies a force on the flowing water, separates positive and negative charged particles
4. Separation creates a voltage between electrodes
5. > Velocity > Separation of charges > Voltage
6. Pulsed electromagnetic field is used to alternate polarity and distinguish external electromagnetic fields

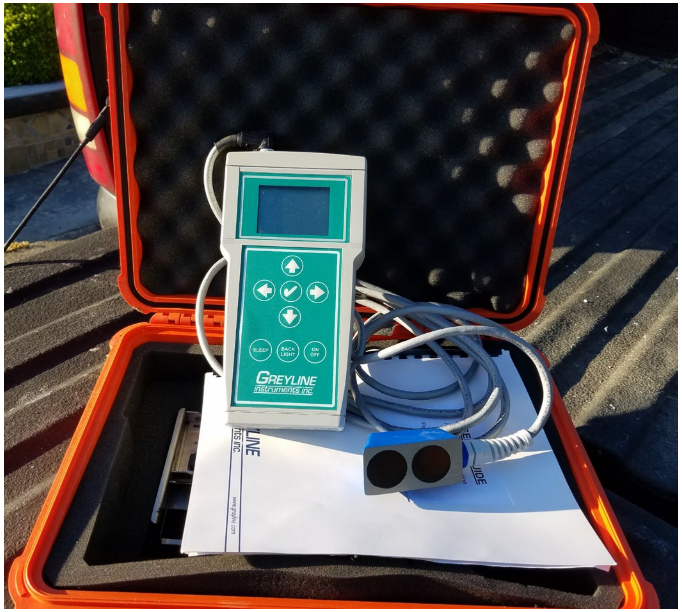




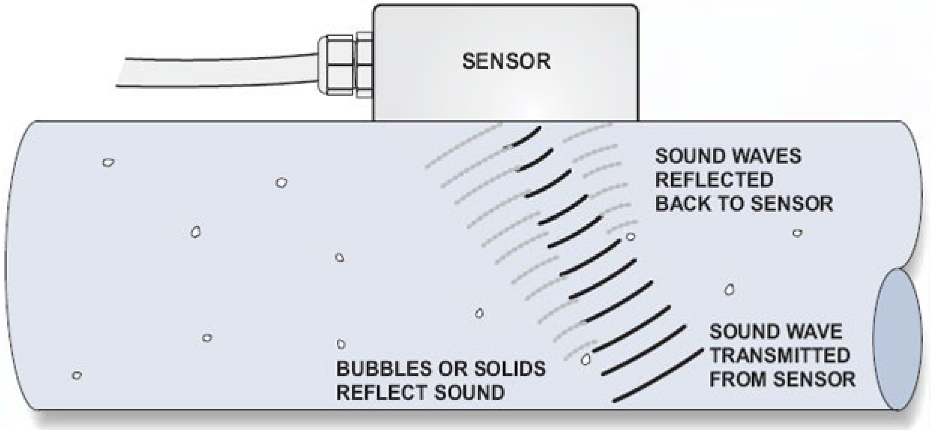
Electromagnetic Meters

- **Advantages**
  - High accuracy when installed properly (± 0.5 - 1%)
  - Accurate in clean or turbid waters
  - Greater reliability when water supply has substantial debris
  - Durability generally good
  - May need less frequent maintenance and repair
  - Possibility to automate
- **Disadvantages**
  - Higher cost option, still feasible
  - May require electricity
  - Cost likely to limit size and flow capacity in agricultural applications
  - Heavy meters may affect how it is installed and supported

Ultrasonic and Doppler Meters



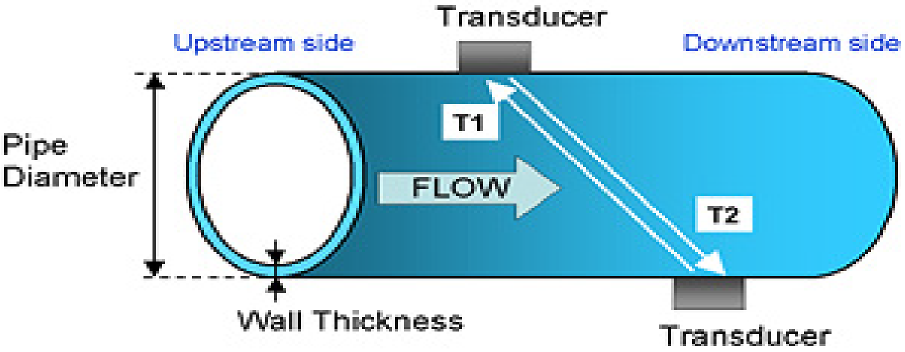
Doppler



Measurement Principle:

- Electronic transmitter/sensor sends out a voltage
- Voltage returns back to sensor
- Voltage transit time is measured
- > Transit time > Velocity > Flow

Ultrasonic



Doppler and Ultrasonic Meters

- **Advantages**
  - Easy external installation, portable use possible
  - Higher accuracy possible
  - Adaptable to very high flows (in pipes and open channels)
  - Ultrasonic can be used in all levels of water cleanliness (Doppler needs suspended sediments or air bubbles)
  - Reliable when water supply has substantial debris
  - Possible to get by with less frequent repair and calibration
  - Possible to automate

- **Disadvantages**
  - Higher cost option, especially permanent installations (~ $2000 to $5000)
  - Permanent installations will require electricity source
  - Portable device may not meet the objectives and subject to theft

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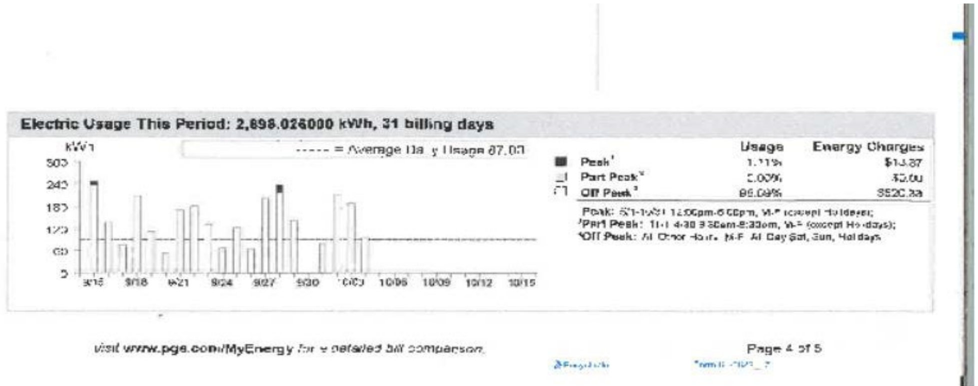
Don’t forget to consider flow/volume options associated with using your power bill

- Knowing the kWH required to pump an acre-foot of water could be useful (HINT: FLOW METER)
- Might need a pump curve
- Must have ability to get to daily energy consumption



Start Date Time	End Date Time	Usage	Usage Unit	Cost	Currency U	Avg. Temperature	Temperature Unit	Event Flag	Peak Demand	Demand U
5/21/2018 0:00	5/21/2018 0:15	3.36	KWH			65	FAHRENHEIT		13.45	KW
5/21/2018 0:15	5/21/2018 0:30	3.37	KWH			65	FAHRENHEIT		13.48	KW
5/21/2018 0:30	5/21/2018 0:45	3.38	KWH			65	FAHRENHEIT		13.54	KW
5/21/2018 0:45	5/21/2018 1:00	3.39	KWH			65	FAHRENHEIT		13.55	KW
5/21/2018 1:00	5/21/2018 1:15	3.38	KWH			61	FAHRENHEIT		13.52	KW
5/21/2018 1:15	5/21/2018 1:30	3.35	KWH			61	FAHRENHEIT		13.4	KW
5/21/2018 1:30	5/21/2018 1:45	3.35	KWH			61	FAHRENHEIT		13.4	KW
5/21/2018 1:45	5/21/2018 2:00	3.35	KWH			61	FAHRENHEIT		13.42	KW
5/21/2018 2:00	5/21/2018 2:15	3.35	KWH			59	FAHRENHEIT		13.42	KW
5/21/2018 2:15	5/21/2018 2:30	3.36	KWH			59	FAHRENHEIT		13.42	KW
5/21/2018 2:30	5/21/2018 2:45	3.35	KWH			59	FAHRENHEIT		13.42	KW
5/21/2018 2:45	5/21/2018 3:00	3.36	KWH			59	FAHRENHEIT		13.43	KW
5/21/2018 3:00	5/21/2018 3:15	3.35	KWH			59	FAHRENHEIT		13.39	KW
5/21/2018 3:15	5/21/2018 3:30	3.35	KWH			59	FAHRENHEIT		13.38	KW

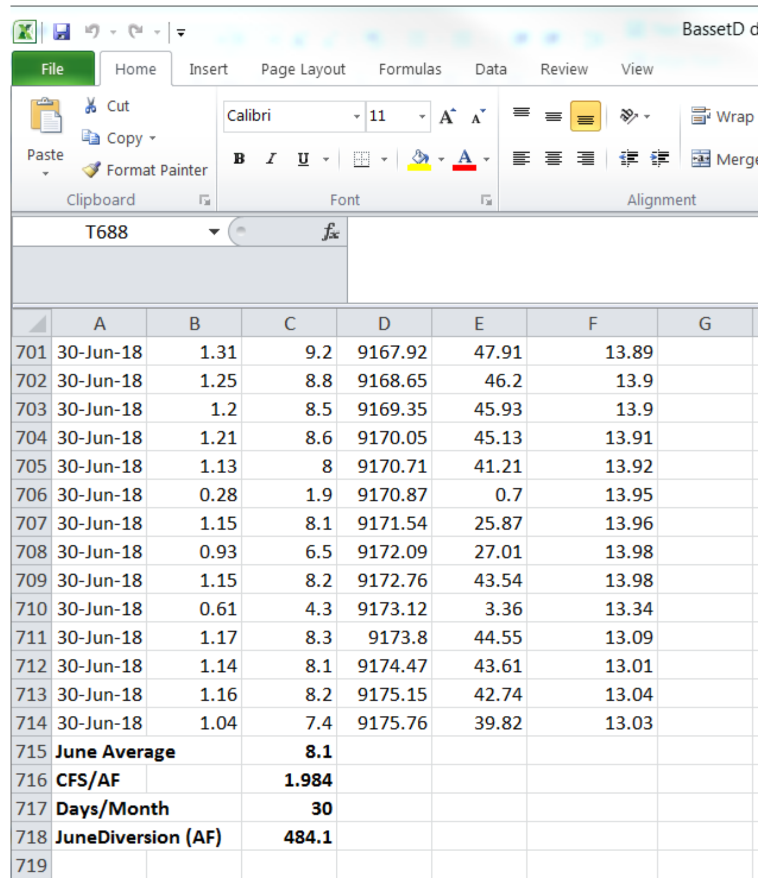
Having information can help you keep an eye on system efficiency…

Month	2020 AF		2019 AF		2018 AF		2017AF
April	0		0		0		0
May	9.9		0.015		21.4		44
June	38.8		43.13		63.6		61
July	54		46.48		72.5		54
Aug	47.1		15.28		62.2		49
Sept	26.5		36.2		35.6		49
Oct	13.7		13.5		3.3		34
Total	190		154.605		258.6		291

Meter	**190**	**154.605**	**258.6**	**291**
Total KWH	**12766**	**10021**	**15603**	**17485**
KWH/AF	**67.2**	**64.87**	**60.3**	**60.1**

Data Management

- For each diversion:
  - For greater than 1000 acre feet diversions, hourly data must be summarized (recall 24 hours/day, 30 days per month=720 data points)
  - Average Flow (Cubic Feet Per second) determined using either appropriate formula or table)
  - Volume determined (recall there are 43,560 cubic feet of water in an acre foot)
- **Summarizing this isn't that hard—just have a system**



	A	B	C	D	E	F	G
701	30-Jun-18	1.31	9.2	9167.92	47.91	13.89	
702	30-Jun-18	1.25	8.8	9168.65	46.2	13.9	
703	30-Jun-18	1.2	8.5	9169.35	45.93	13.9	
704	30-Jun-18	1.21	8.6	9170.05	45.13	13.91	
705	30-Jun-18	1.13	8	9170.71	41.21	13.92	
706	30-Jun-18	0.28	1.9	9170.87	0.7	13.95	
707	30-Jun-18	1.15	8.1	9171.54	25.87	13.96	
708	30-Jun-18	0.93	6.5	9172.09	27.01	13.98	
709	30-Jun-18	1.15	8.2	9172.76	43.54	13.98	
710	30-Jun-18	0.61	4.3	9173.12	3.36	13.34	
711	30-Jun-18	1.17	8.3	9173.8	44.55	13.09	
712	30-Jun-18	1.14	8.1	9174.47	43.61	13.01	
713	30-Jun-18	1.16	8.2	9175.15	42.74	13.04	
714	30-Jun-18	1.04	7.4	9175.76	39.82	13.03	
715	**June Average**		**8.1**				
716	**CFS/AF**		**1.984**				
717	**Days/Month**		**30**				
718	**JuneDiversion (AF)**		**484.1**				
719							

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Low-Cost Methods of Measuring Diverted Water

The California State Water Resources Control Board requires that the amount of water diverted from the surface waters of the state be reported. For many years diverters were able to estimate the amount of water they diverted and report this estimate. Legislation passed in 2010 requires that the amount of water diverted be measured. Many water right owners are seeking to comply with this regulatory requirement.

Other reasons to measure water could include the following:

- to assure that the appropriate amount is diverted
- to divide shared interest in water
- to identify opportunities to save water for other uses

This publication focuses on simple and inexpensive methods of measuring surface water to irrigate pastures and other lower-value crops where more advanced methods of measurement may not be as feasible. A simple method of estimating flow in open channels, along with installation and use of contracted rectangular and V-notch weirs, are discussed. Examples of how to apply the flow measurements are also provided.

Basic Water Measurement in Open Channels (Float Method)

The volume of water passing through a point on a stream per unit of time is used to measure stream flow. Two factors are required to determine volume (quantity) of water: cross-sectional area, generally in square feet (ft^2), and flow velocity, generally in feet per second (ft/sec). Flow is usually expressed in cubic feet per second (cfs). (For converting

Table 2. Flow over rectangular contracted weirs in cubic feet per second*

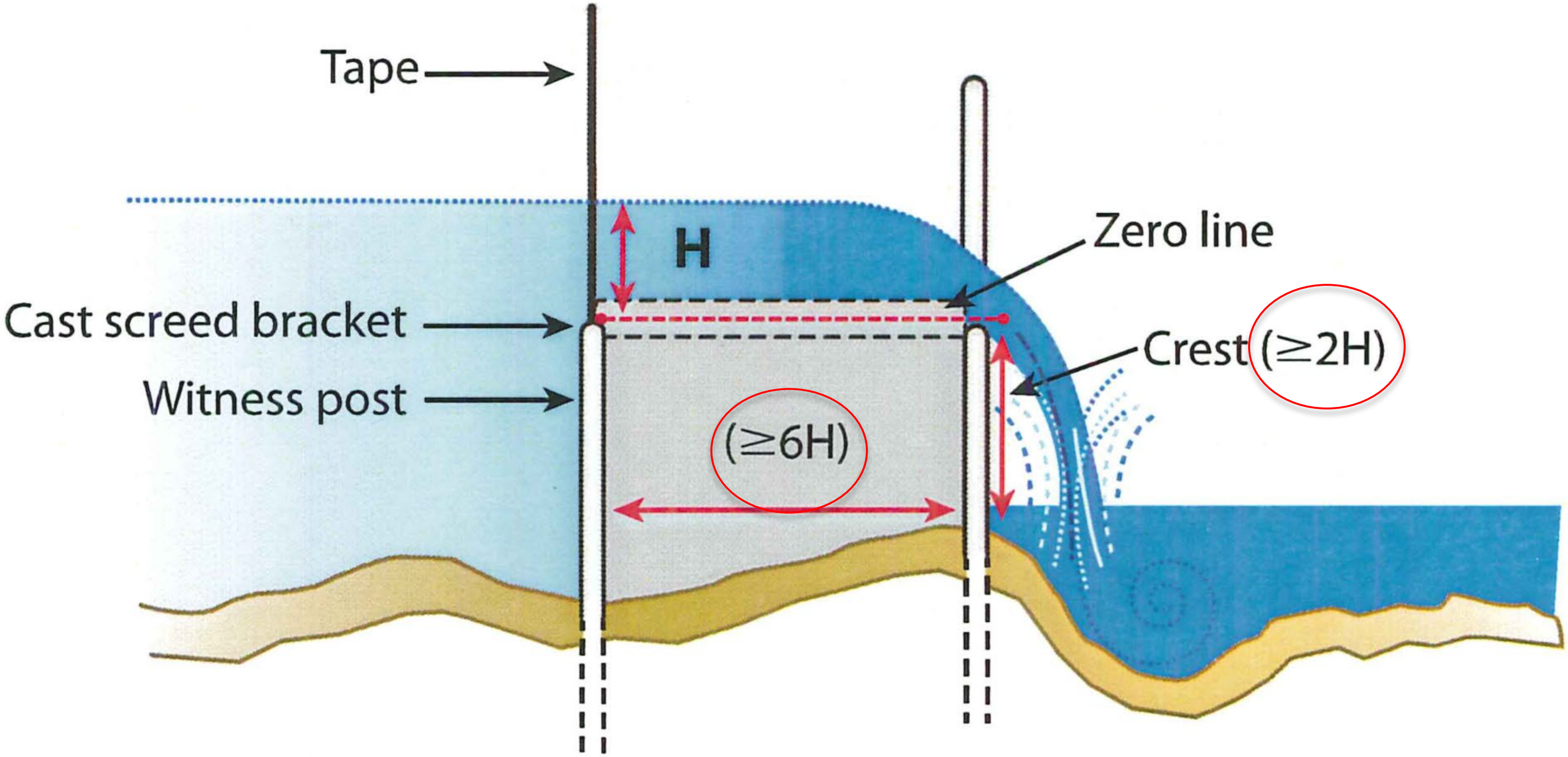
Head (H) (ft)	Head (H) (in)	Crest length (L) (ft) 1.0 ft	1.5 ft	2.0 ft	3.0 ft	4.0 ft	For each additional foot of crest in excess of 4 ft (approx.)
		Flow (cfs)					
0.10	1 3/16	0.105	0.125	0.212	0.319	0.427	0.108
0.11	1 5/16	0.121	0.182	0.244	0.367	0.491	0.124
0.12	1 7/16	0.137	0.207	0.277	0.418	0.559	0.141
0.13	1 7/16	0.155	0.233	0.312	0.470	0.629	0.159
0.14	1 11/16	0.172	0.260	0.348	0.524	0.701	0.177
0.15	1 13/16	0.191	0.288	0.385	0.581	0.776	0.196
0.16	1 15/16	0.210	0.316	0.423	0.638	0.854	0.216
0.17	2 1/16	0.229	0.346	0.463	0.698	0.934	0.236
0.18	2 3/16	0.249	0.376	0.504	0.760	1.02	0.257
0.19	2 1/4	0.270	0.407	0.546	0.823	1.10	0.278
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	0.303
0.21	2 1/2	0.312	0.472	0.632	0.954	1.28	0.326
0.22	2 5/8	0.335	0.505	0.677	1.02	1.37	0.35
0.23	2 3/4	0.358	0.539	0.723	1.09	1.46	0.37
0.24	2 7/8	0.380	0.574	0.769	1.16	1.55	0.39
0.25	3	0.404	0.609	0.817	1.23	1.65	0.42
0.26	3 1/8	0.428	0.646	0.865	1.31	1.75	0.44
0.27	3 1/4	0.452	0.682	0.914	1.38	1.85	0.47
0.28	3 3/8	0.477	0.720	0.965	1.46	1.95	0.49
0.29	3 1/2	0.502	0.758	1.02	1.53	2.05	0.52
0.30	3 5/8	0.527	0.796	1.07	1.61	2.16	0.55
0.31	3 3/4	0.553	0.836	1.12	1.69	2.26	0.57
0.32	3 13/16	0.580	0.876	1.18	1.77	2.37	0.60
0.33	3 15/16	0.606	0.916	1.23	1.86	2.48	0.62
0.34	4 1/16	0.634	0.957	1.28	1.94	2.60	0.66
0.35	4 3/16	0.661	0.999	1.34	2.02	2.71	0.69
0.36	4 5/16	0.688	1.04	1.40	2.11	2.82	0.71
0.37	4 7/16	0.717	1.08	1.45	2.20	2.94	0.74
0.38	4 9/16	0.745	1.13	1.51	2.28	3.06	0.78
0.39	4 11/16	0.774	1.17	1.57	2.37	3.18	0.81
0.40	4 13/16	0.804	1.21	1.63	2.46	3.30	0.84
0.41	4 15/16	0.833	1.26	1.69	2.55	3.42	0.87
0.42	5 1/16	0.863	1.30	1.75	2.65	3.54	0.89
0.43	5 3/16	0.893	1.35	1.81	2.74	3.67	0.93
0.44	5 1/4	0.924	1.40	1.88	2.83	3.80	0.97
0.45	5 3/8	0.955	1.44	1.94	2.93	3.93	1.00
0.46	5 1/2	0.986	1.49	2.00	3.03	4.05	1.02
0.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.06
0.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.10
0.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.13
0.50	6	1.11	1.68	2.26	3.42	4.58	1.16
0.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.20
0.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.24
0.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.26
0.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.30
0.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.33
0.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.38
0.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.41
0.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.44
0.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.49
0.60	7 3/16	1.45	2.20	2.96	4.74	6.00	1.53
0.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.55
0.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.60
0.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.63
0.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.67
0.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.72
0.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.75
0.67	8 1/16	1.71	2.59	3.47	5.26	7.05	1.79
0.68	8 3/16	1.74	2.64	3.56	5.38	7.21	1.83
0.69	8 1/4	1.78	2.70	3.63	5.49	7.36	1.87
0.70	8 3/8	1.82	2.76	3.71	5.61	7.52	1.91
0.71	8 1/2	1.86	2.81	3.78	5.73	7.68	1.95
0.72	8 5/8	1.90	2.87	3.86	5.85	7.84	1.99
0.73	8 3/4	1.93	2.93	3.94	5.97	8.00	2.03
0.74	8 7/8	1.97	2.99	4.02	6.09	8.17	2.08
0.75	9	2.01	3.05	4.10	6.21	8.33	2.12
0.76	9 1/8	2.05	3.11	4.18	6.33	8.49	2.16
0.77	9 1/4	2.09	3.17	4.26	6.45	8.66	2.21
0.78	9 3/8	2.13	3.23	4.34	6.58	8.82	2.24
0.79	9 1/2	2.17	3.29	4.42	6.70	8.99	2.29

Note: *Computed from Cone's formula: $Q = 3.247\,LH^{1.48} - [0.566\,L^{1.8} \div (1 + 2\,L1.8)]\,H^{1.9}$

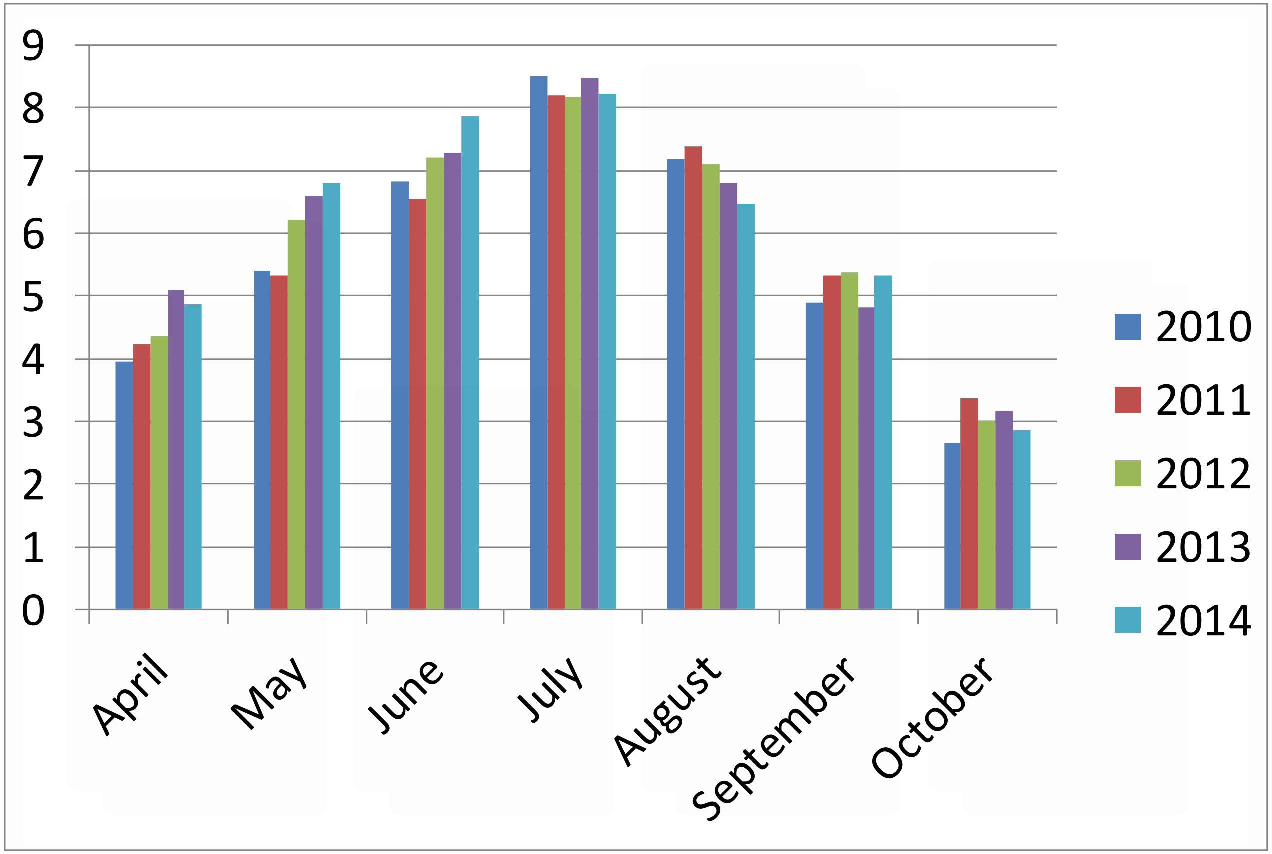
Looking at detail from the table

Head (H) (ft)	Head (H) (in)	Crest length (L) (ft)				
		1.0 ft	1.5 ft	2.0 ft	3.0 ft	4.0 ft
		Flow (cfs)				
0.60	7 3/16	1.45	2.20	2.96	4.74	6.00

Where should the measurement be taken?
How far should the water fall?



Estimated Pasture Evapo-Transpiration (ET) at Glenburn 2010-2014



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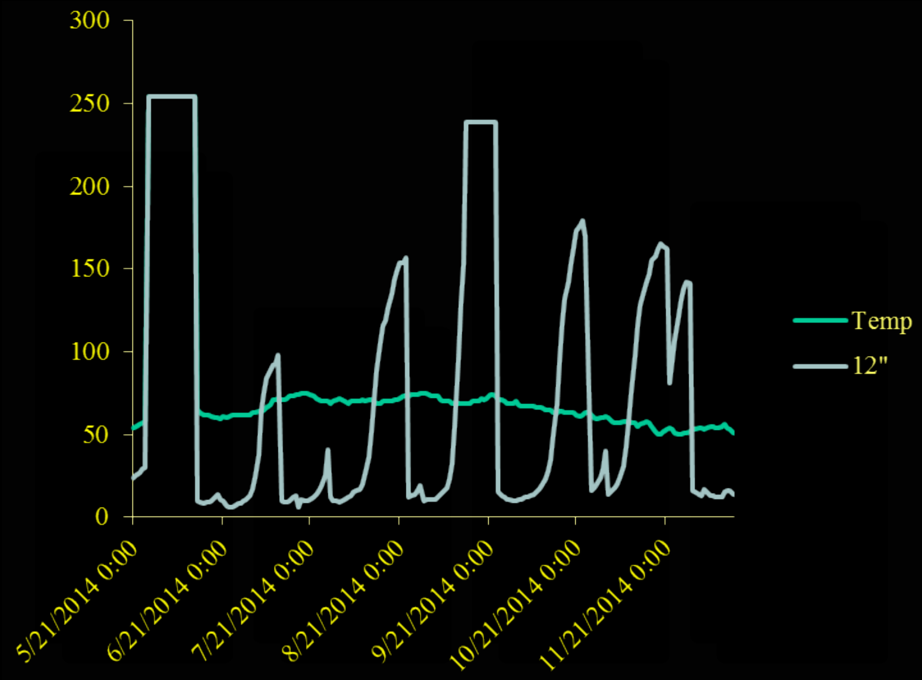
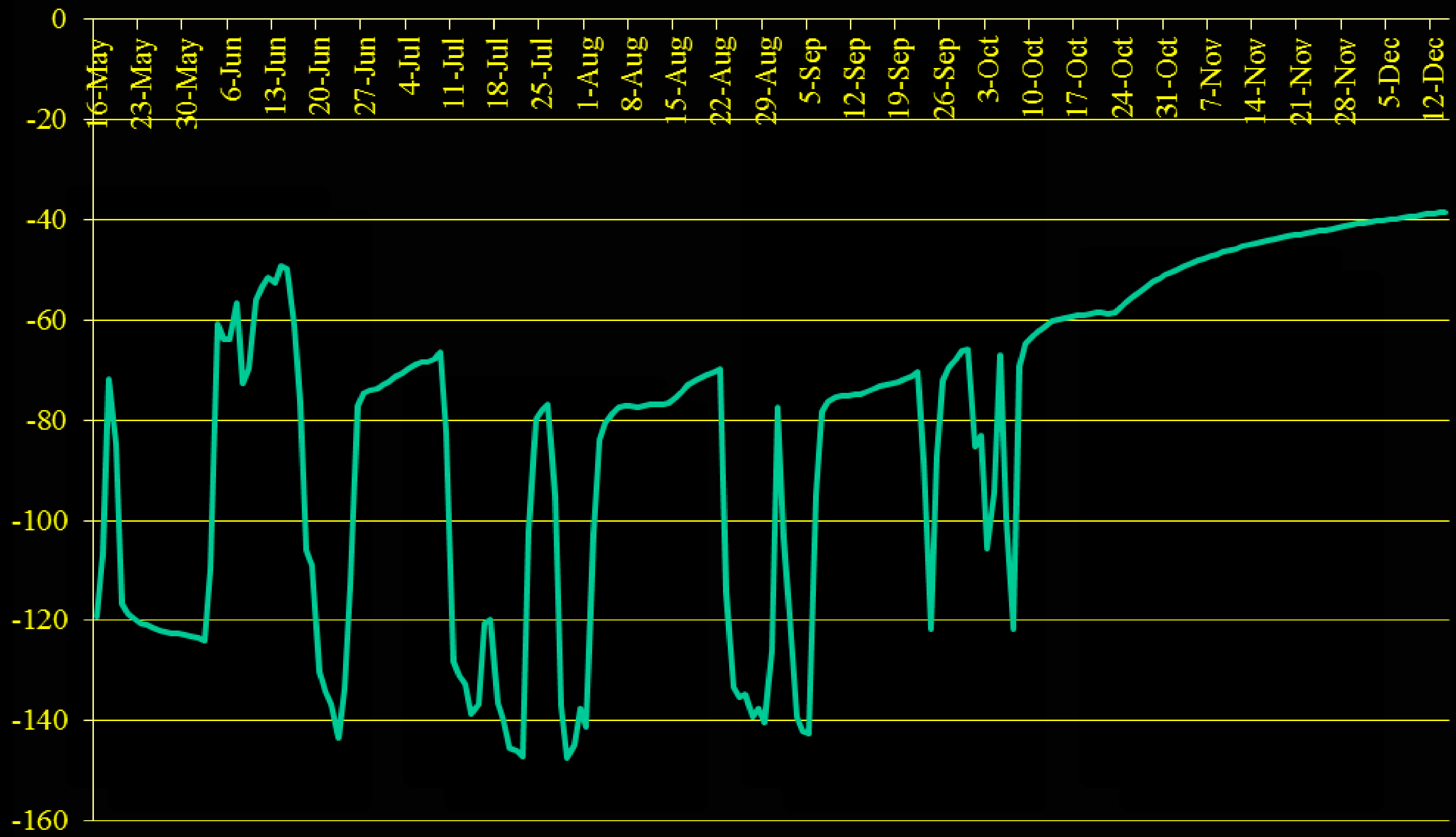
Use other Irrigation Management tools with water measurement: Soil Moisture Sensors Data 12"—Alfalfa Field-McArthur Ranch Inc



Pressure Transducer in the Well
2014 Irrigation Well Elevations, McArthur Ranch, Inc



Having flow/volume, crop requirement, soil moisture and well recharge information

- Can reduce cost
  - Applying water when it is needed
  - Apply appropriate amount of water
  - Help determine the condition of irrigation equipment
- Improve yield
- Provide insight into well recharge

Questions