MEASURING STREAMFLOW WITH ENGINEERED STRUCTURES IN OAKLAND'S SAUSAL CREEK WATERSHED

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Stream Flow Measurement Methods

There are multiple ways to measure stream flow. They vary in complexity, accuracy, resource intensity, and potential risk to personnel.

Agencies like USGS measure stream flow using automated gaging stations and rating curves.

Citizen science monitors commonly use velocity and cross-sectional area measurements.

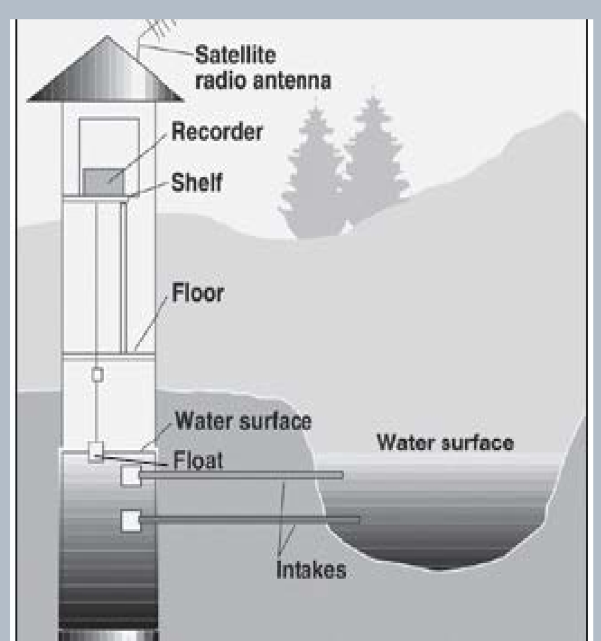

Figure 1. USGS Stream Gauge Station (Perlman, 2016)

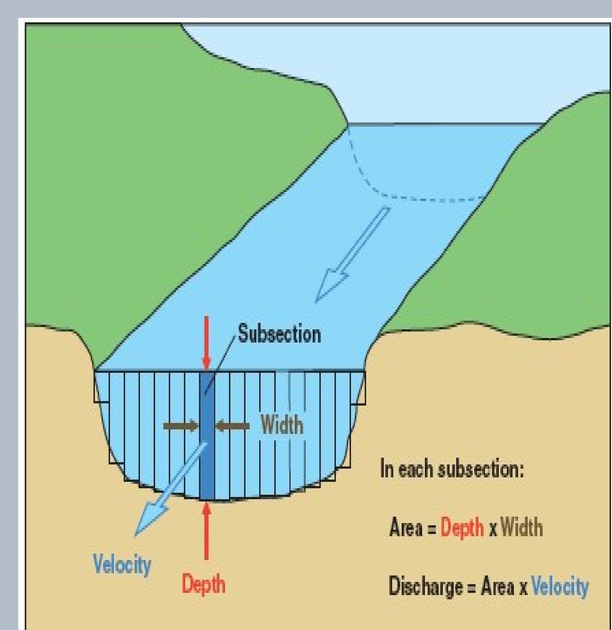

Figure 2. Cross sectional area and flow measurement (Perlman, 2016)

For the urbanized Sausal Creek Watershed and Friends of Sausal Creek (FOSC) citizen monitoring program, I am helping design a discharge monitoring approach that uses culverts and drop structures within the stream system. Found structures avoid the need for volunteer citizens to enter the stream flow and provide for rapid flow estimation through physical or photographic measurement of depth alone.

Using Found Structures for Flow Monitoring

Concrete circular culverts and concrete-lined open channel sections with drop structures are common features in urban creeks.

Empirical research shows the following estimation discharge accuracies:

- Circular culverts which are inlet controlled will have an accuracy of +/-5% (Toman, Skaugset, and Simmons, 2014).
- Rectangular concrete channelized sections leading to drop structures operate as de facto weirs and have accuracies of +/-7% (LMNO Engineering, 2015).
- Float velocity and cross-sectional area measurements have accuracies of +/- 10-20% (Herschy, 1985).
- Measurements using mechanical or electronic flow meters at multiple segments through a stream flow profile have an accuracy of +/- 5% (Whiting, 2016).

Using found structures in urban streams thus can provide acceptable levels of accuracy with minimal effort and risk to monitors; all that is required are the physical dimensions of the culvert and an accurate estimate of flow depth.

Figure 3. El Centro circular culvert

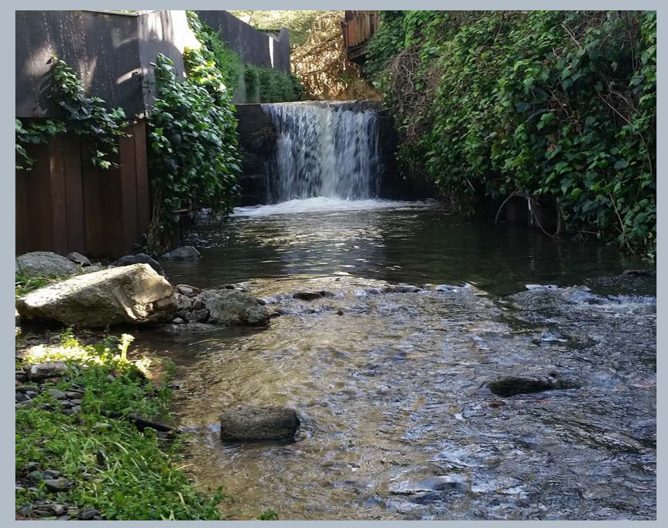

Figure 4. Barry Place drop structure

Empirical Formulae and their Application

Work by Toman, Skaugset, and Simmons (2014) has shown that discharge through an inlet-controlled circular culvert can be reliably estimated using the Henderson formula (Equation 1):

Eq 1 $Q = 0.432*g^{0.5}*H^{1.9}*D^{0.6}$.

Where Q is discharge (m^3/s), *g* = acceleration due to gravity (9.8066 m/s^2), H is water height at the entrance of the culvert (m), and D is the diameter of the culvert (m).

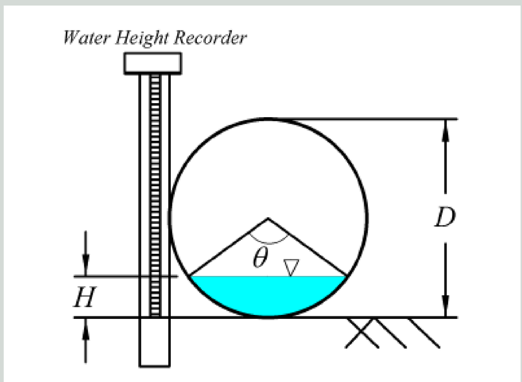

Figure 5. Culvert Cross-Section (Toman…., 2014)

The International Standards Office (ISO 1977) determined that rectangular open channel waterfalls (i.e. concrete culverted stream sections with vertical drop structures) can act as weirs for which the following formula can reliably estimate discharge (Equation 2):

Eq 2 $Q = Cg^{1/2}bh^{3/2}$

Where Q is discharge (m^3/s), b is the channel width (m), h is the water height at the edge of the drop (m), C is a coefficient of discharge (depends on the type of drop configuration, *C*=1.66 where channel side walls continue below the drop, and *C*=1.69 for unconfined flow below the drop), and *g* = acceleration due to gravity (9.8066 m/s^2).

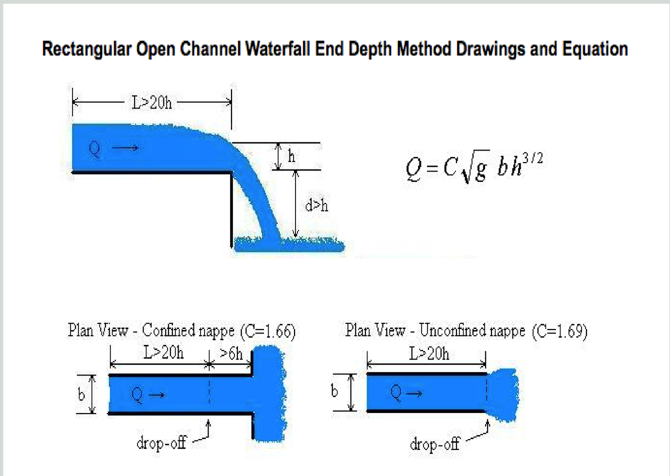

Figure 6. Rectangular Open Channel With Drop Structure (LMNO Engineering,2015)

Avoiding Low Flow Estimation Errors

When flows are low in broad circular culverts (e.g. 1.5-2m diameter) or in wide rectangular channels (e.g. 3-5m width), errors in measuring or visually estimating flow depths will lead to much bigger percentage impacts on discharge values e.g. a +1cm error for an 8cm flow depth in a circular culvert is much more significant (12.5%) than the same error with a 50cm flow depth (2%), with this error magnified by the exponent for depth in the empirical formula (becoming a variance from the actual estimates of +25% and +4% respectively for Equation 1). A solution to this problem is to install temporary V-notch weirs at the culvert inlet or in the rectangular channel at low flows to temporarily dam the flow and force it through a known channel shape (the V). Empirical studies have shown that discharge through a correctly designed and installed V-notch weir can be estimated with accuracies of around +/- 3% using Equation 3 (USBR 2001):

Eq 3 $Q = 2.49*H^{2.48}$

Where Q is discharge (ft^3/s) and H is the height of the water above the vertex of the V (ft).

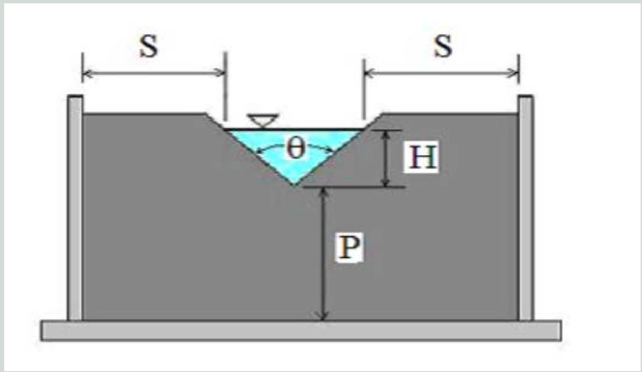

Figure 7. V-Notch weir (USBR,2001)

Figure 8. Weir would be temporarily installed on upstream side of Sausal Creek Culverts

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Benefits of Proposed Approach for Citizen Science

There are both advantages and disadvantages to using found structures for discharge measurement by volunteers and school children in an urban watershed.

Advantages:

- Low cost, does not require expensive equipment to be installed with maintenance of continuous monitoring.
- Allows for rapid data collection.
- Minimal resources needed (volunteer hours and monetary input).
- Provides reliable volumetric discharge estimates for pairing with water quality sampling or for creation of hydrographs (volunteer measures could capture rising and falling stages of flow events).
- Provides foundation for the creation of a photo monitoring app (citizens upload photos of structure showing depth at any time of day).
- Turns negative feature of urbanized creek (unsightly artificial structures) into assets.
- Avoids liability associated with physical flow measurements at medium and high flow stages.
- Can be implemented at multiple locations in watershed with culverts to develop data sets for distinct sub-areas and tributary watersheds.
- Promotes community engagement through visual cues such as painted water levels (gets people thinking of what is occurring with the water in their neighborhood)

Disadvantages:

- Depends on found locations of structures (may not be priority/ideal locations for hydrologic or water quality purposes).
- Worn, aging structures may not meet all the desired hydraulic characteristics for reliable estimates (e.g. channel approach, smooth edges, etc.).

Outreach to Middle Schools

The volunteer-based, non-profit organization Friends of Sausal Creek have been promoting community engagement in the Sausal Creek Watershed since 1996, in part through creek monitoring. This involves a significant education component through outreach to middle schools located in the most highly urbanized, lower portion of the watershed. Many of the schools have underserved youth populations that could benefit from hands-on, high impact practice STEM education activities in the watershed.

- Data collected by and for school children can be used in education programs in addition to raising awareness of the creek and its characteristics within the community.
- Mastery of time series data, algebraic formulation, geometry (of streams and culvert cross-sections), graphing, and exponents are core grade 6-8 math skills requirements.
- Stream discharge data can be used for data analysis to teach basic spreadsheet programming skills (average, max, min, etc.) and graphing (histograms and scatter plots).
- Programming of Equations 1-3 into spreadsheets and entry of field measurement data will facilitate formula construction, accurate data entry, use of functions, and chart creation through practical exercises.
- Walking field trips to nearby, accessible creek culvert locations will increase impact of classroom lessons through an experiential learning component.
- Engagement of students in paired data set collection and analysis using cross-sectional area and float velocity measurement (+/-10-20% accuracy) versus use of culverts and V-notch weir depths (+/-5% accuracy) will promote scientific literacy and critical thinking.

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