# Guidance for Appropriate Application of Hydrologic Analysis

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**3rd Hydromodification Seminar & Workshop – Modeling for Hydromodification**
**July 17, 2013**

# Overview

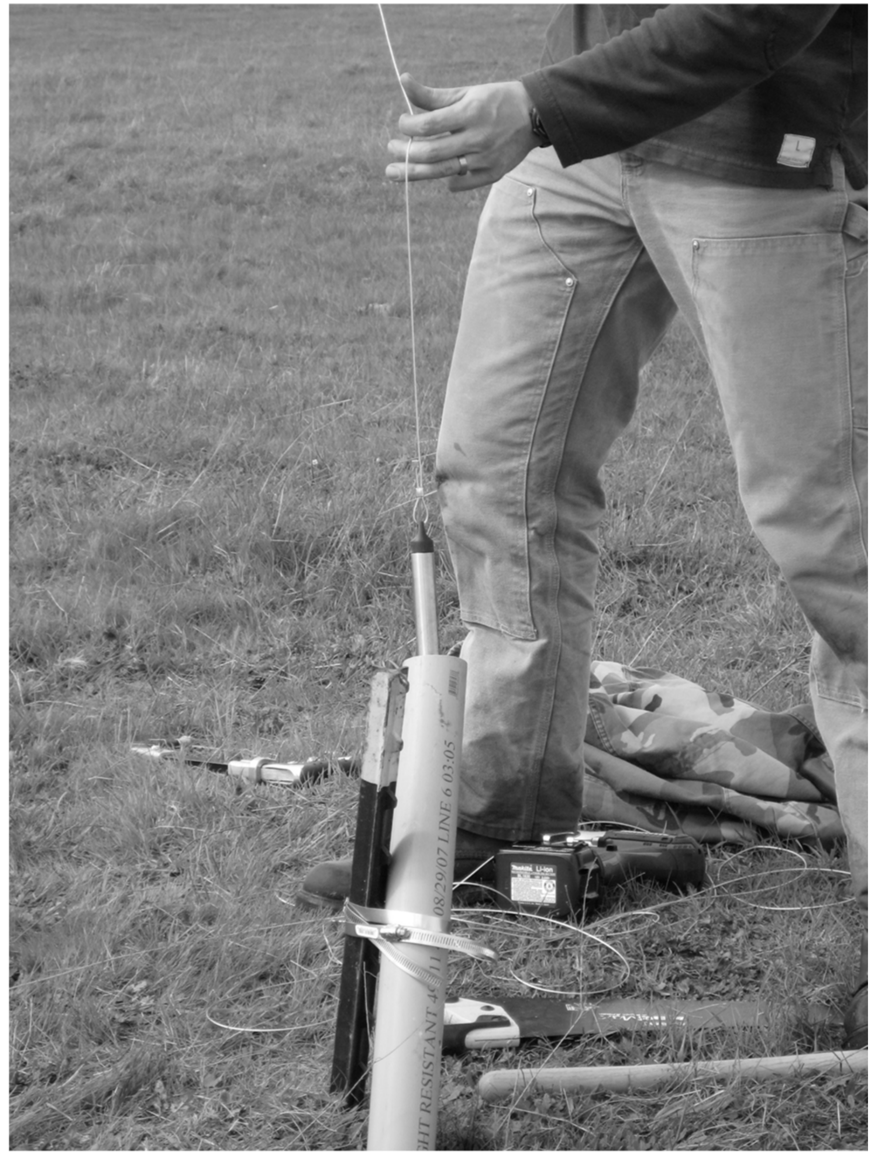
- Flow measurement
- How to estimate flow in un-gauged systems
- Considerations for hydrologic modeling (CSM)

# Flow Measurement

- **Why?**
  - We need high quality, long-term continuous flow monitoring!
  - General evaluations
  - Assessment of management measure effectiveness
  - Model calibration and validation
- **Methods**
  - Direct measurement of velocity and cross sectional area
  - Stage (height/depth) measurement - develop relationships based on channel geometry and velocity – Stage-Discharge Curves

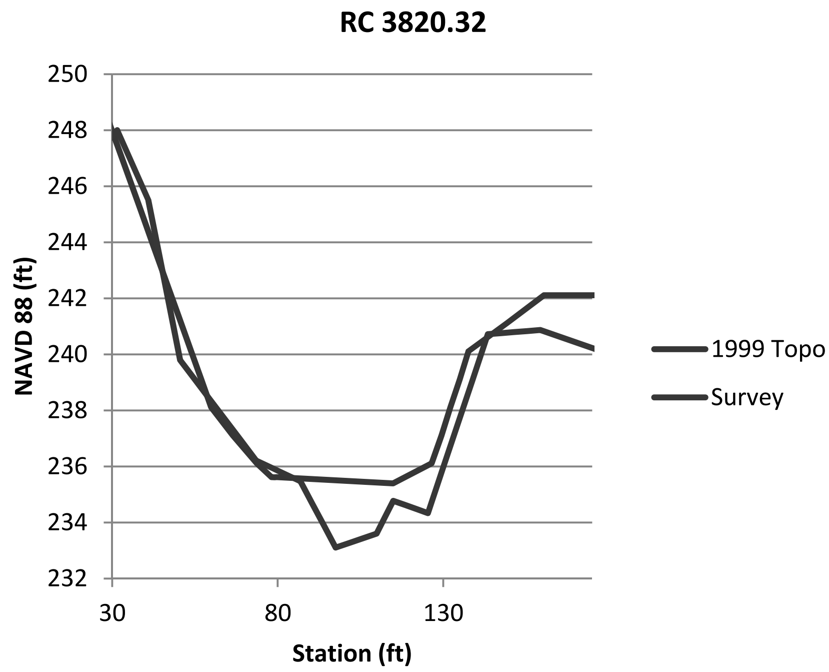
# Flow Measurement - Overview

- **Pick appropriate cross section**
- **Accurately survey cross section geometry**
- **Measure stage (water depth) and velocity profiles over a range of event-based measurements**
- **Develop Stage-Discharge relationship**
- **Continuously measure stage over long-term**
- **Convert stage to discharge (flow) using Stage-Discharge relationship**



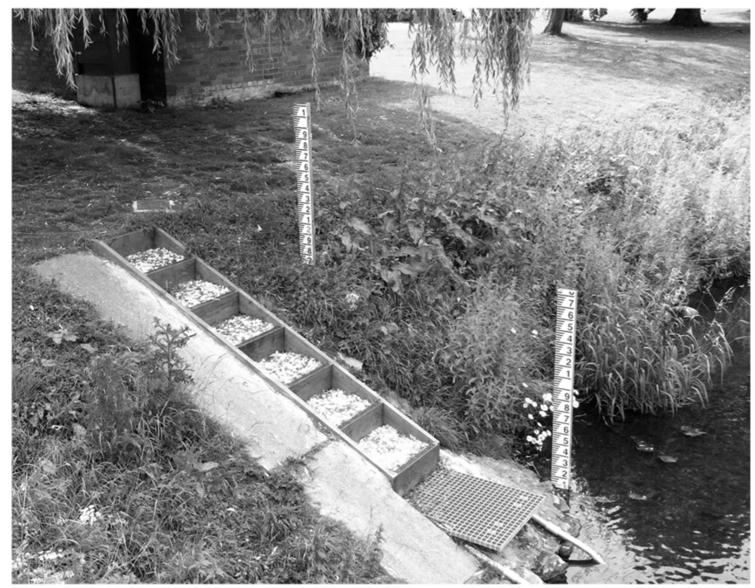
# Flow Measurement – Cross Sectional Area

- **Cross Section Measurement:**
  - **Level and staff**
  - **Total station**
  - **Survey grade RTK GPS**




# Flow Measurement – Stage / Depth

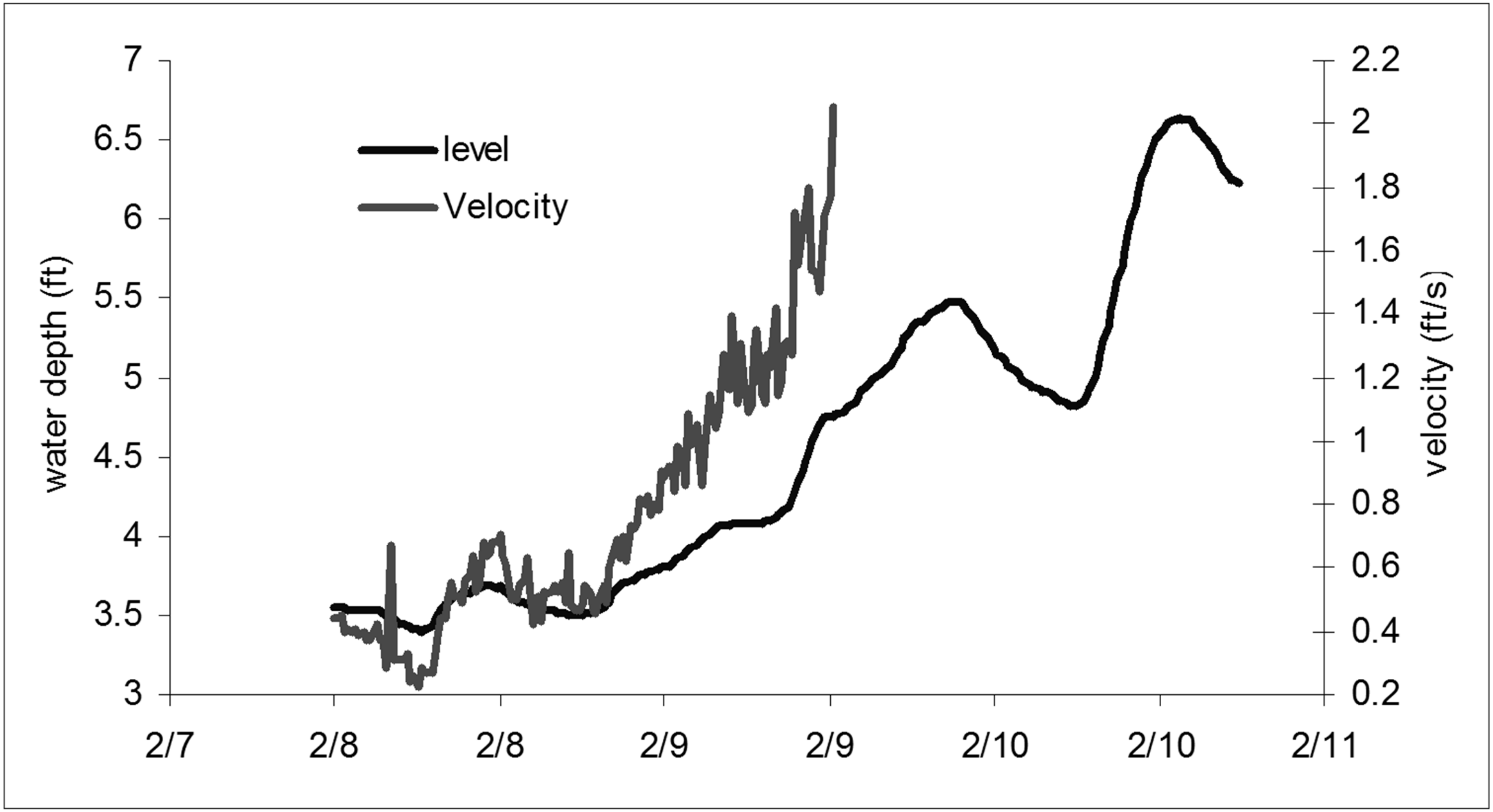
- **Stage Measurement:**
  - Pressure transducer – continuous
  - Stage board – periodic observations
  - Other mechanical methods – still used by USGS but out-dated for less permanent installations

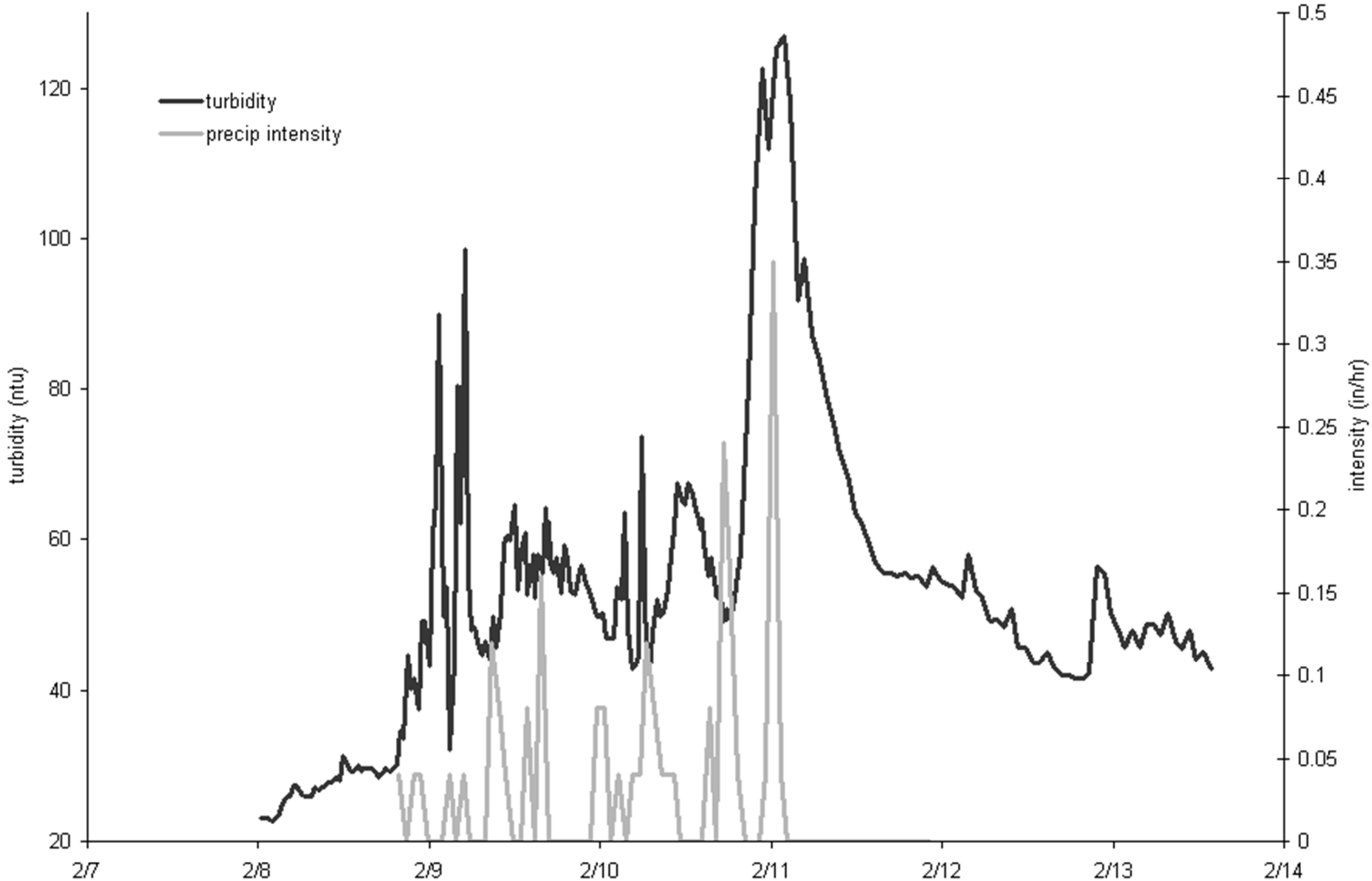
# Flow Measurement - Velocity

- **Velocity Measurement:**
  - Propeller meters
  - Acoustic electronic meters
  - Acoustic doppler current profilers

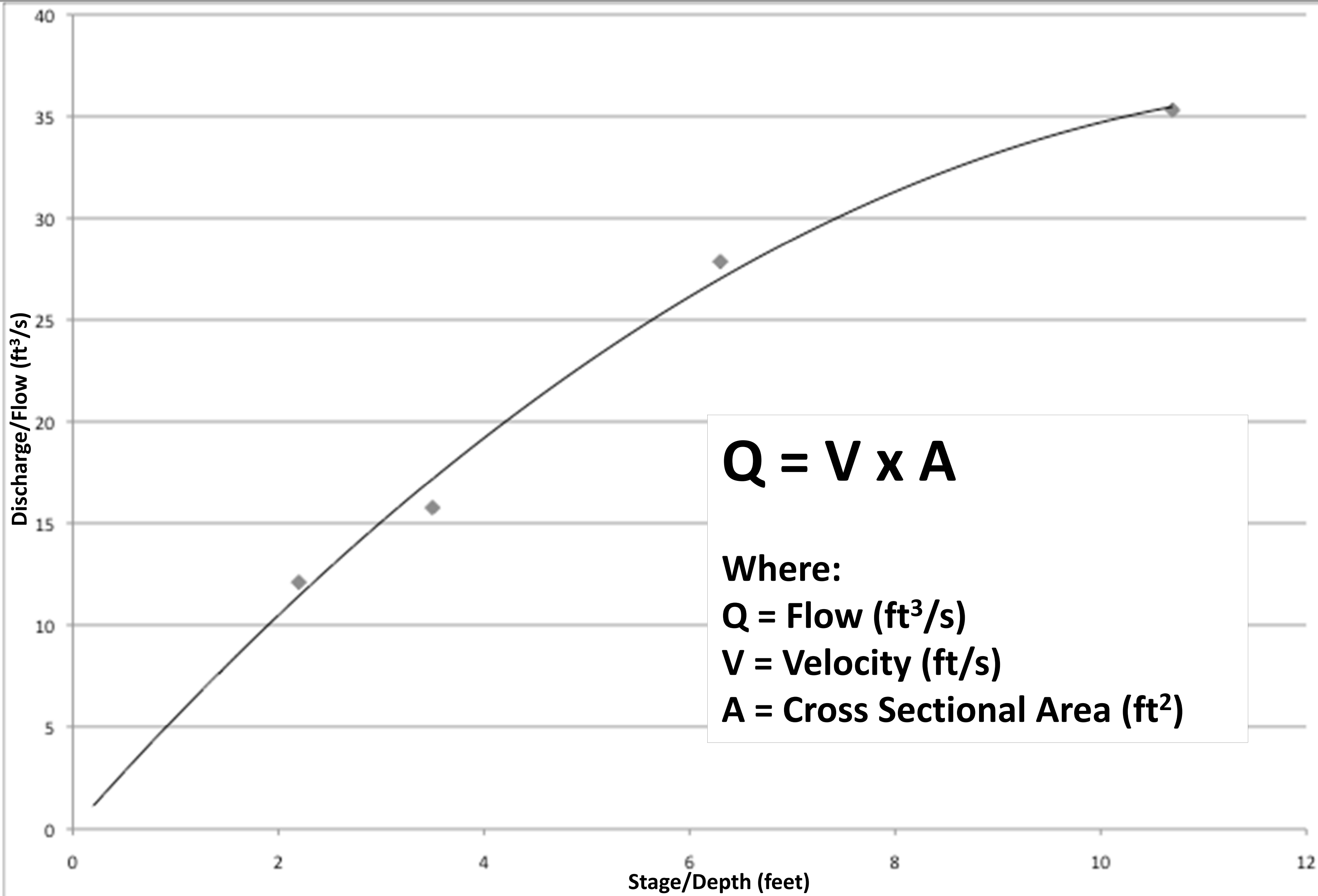
# Flow Measurement



# Flow Measurement



# Flow Measurement – Stage-Discharge Curve




**$Q = V \times A$**

**Where:**

**Q = Flow ($ft^3/s$)**

**V = Velocity (ft/s)**

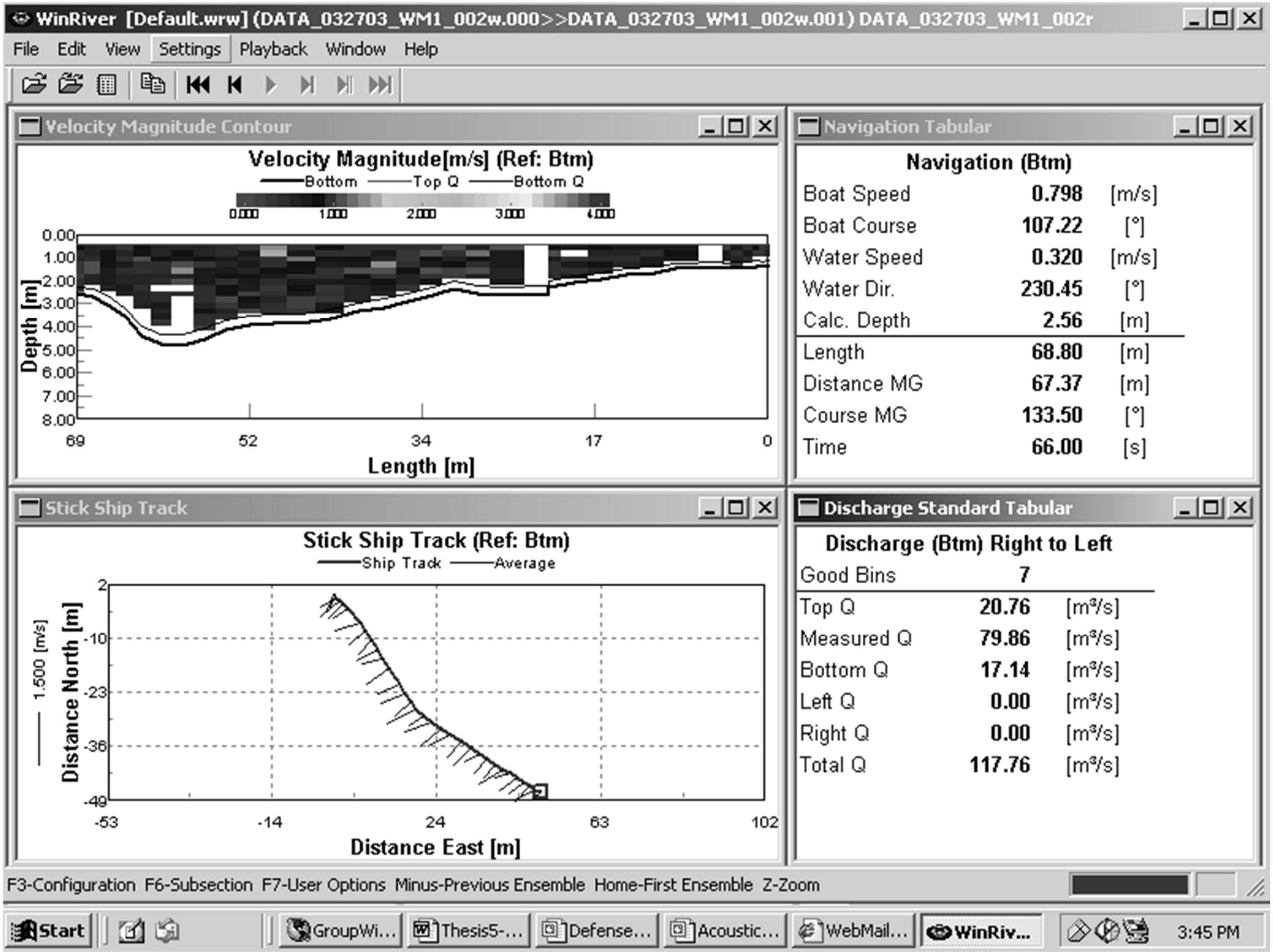
**A = Cross Sectional Area ($ft^2$)**

# Amazing!


AT&T
7:09 PM
68%
Los Angeles
hourly
73°
Tuesday 81° 63°
Wednesday 81° 63°
Thursday 81° 64°
Friday 81° 66°
Saturday 79° 66°
Sunday 82° 70°
Updated 7/16/13 7:09 PM


AT&T
7:09 PM
68%
Nottingham
hourly
61°
Tuesday 82° 57°
Wednesday 82° 57°
Thursday 81° 57°
Friday 79° 55°
Saturday 75° 55°
Sunday 77° 55°
Updated 7/16/13 7:09 PM

# Flow Measurement – Direct Measurement ADCP

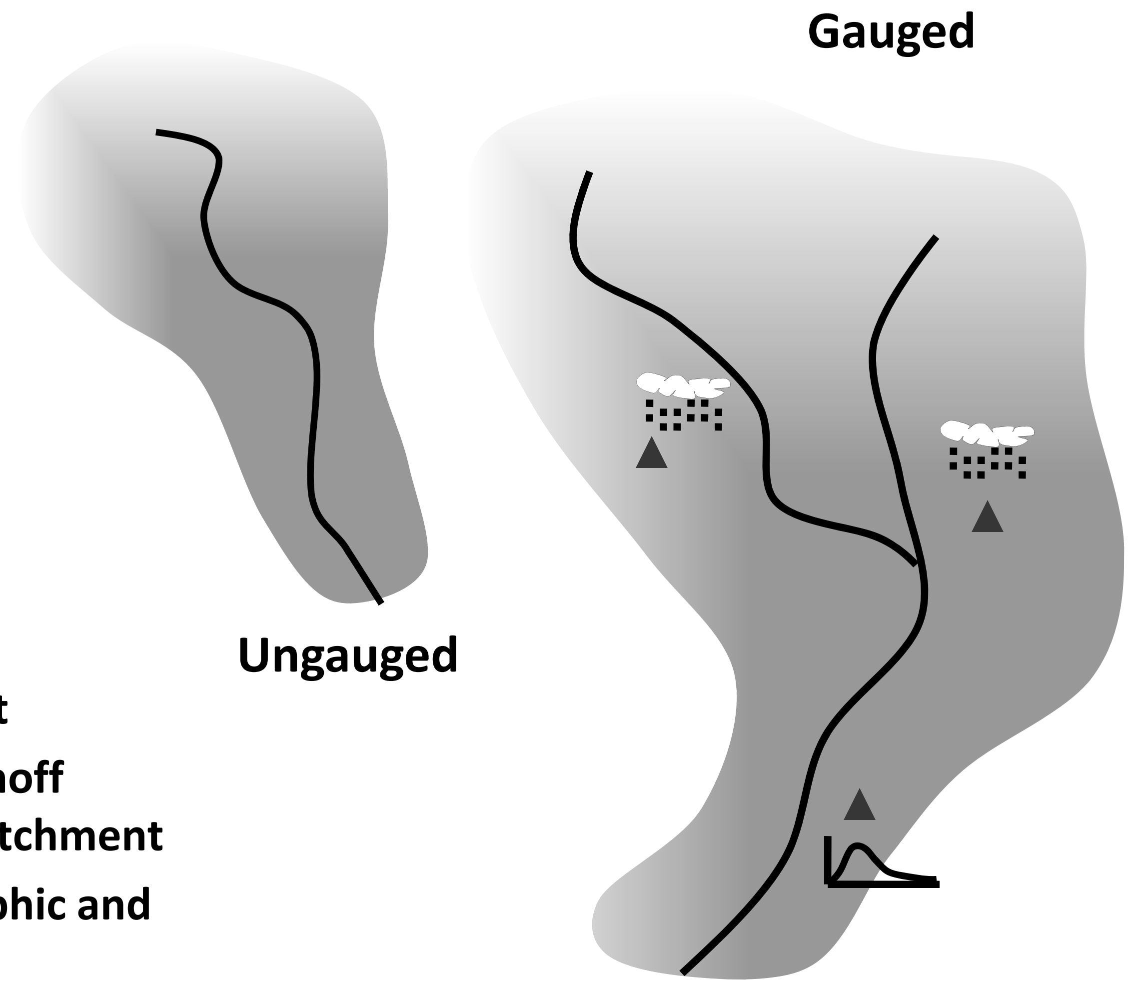


# Flow Measurement


- **Rantz, S.E., et al. (1982). *Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge.* United States Geological Survey Water-Supply Paper 2175. Washington D.C.**
- **Rantz, S.E., et al. (1982) *Measurement and Computation of Streamflow: Volume 2. Computation of Discharge.* United States Geological Survey Water-Supply Paper 2175. Washington D.C.**
- **Freeman, Lawrence A. et al. (2004). *Use of Submersible Pressure Transducers in Water-Resources Investigations*. United States Geological Survey Techniques of Water-Resources Investigations 08-A3: Reston, VA.**
- **Mueller, David S. and Wagner, Chad R. (2009). *Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat.* United States Geological Survey Techniques and Methods 03-A22. Reston, VA.**

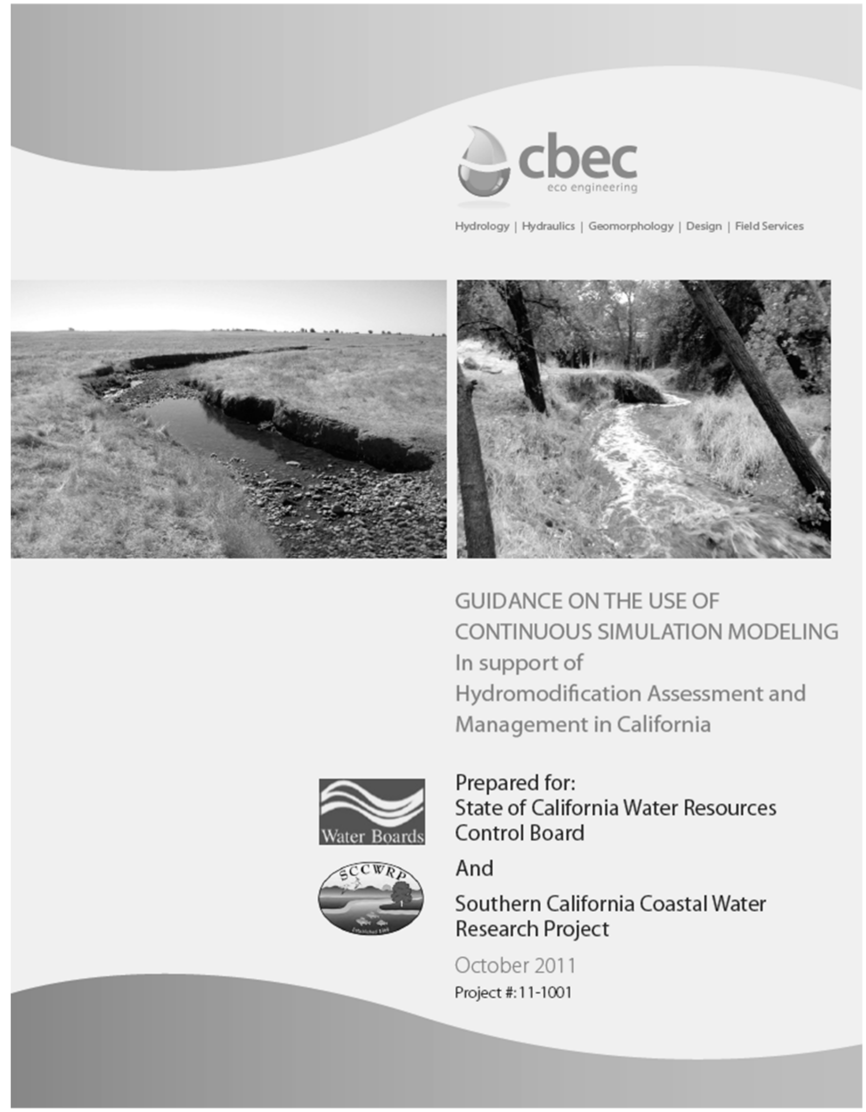
# How to estimate flow in ungauged systems

- **Data Needs:**
  - Rainfall
  - Elevation data
  - Mean Annual Precipitation
    - County drainage manual
    - PRISM maps
  - Topography
  - Land use
- **Approach**
  - Calibrate gauged catchment
  - Apply calibrated rainfall runoff parameters to ungauged catchment
  - Modify rainfall for topographic and orographic effects

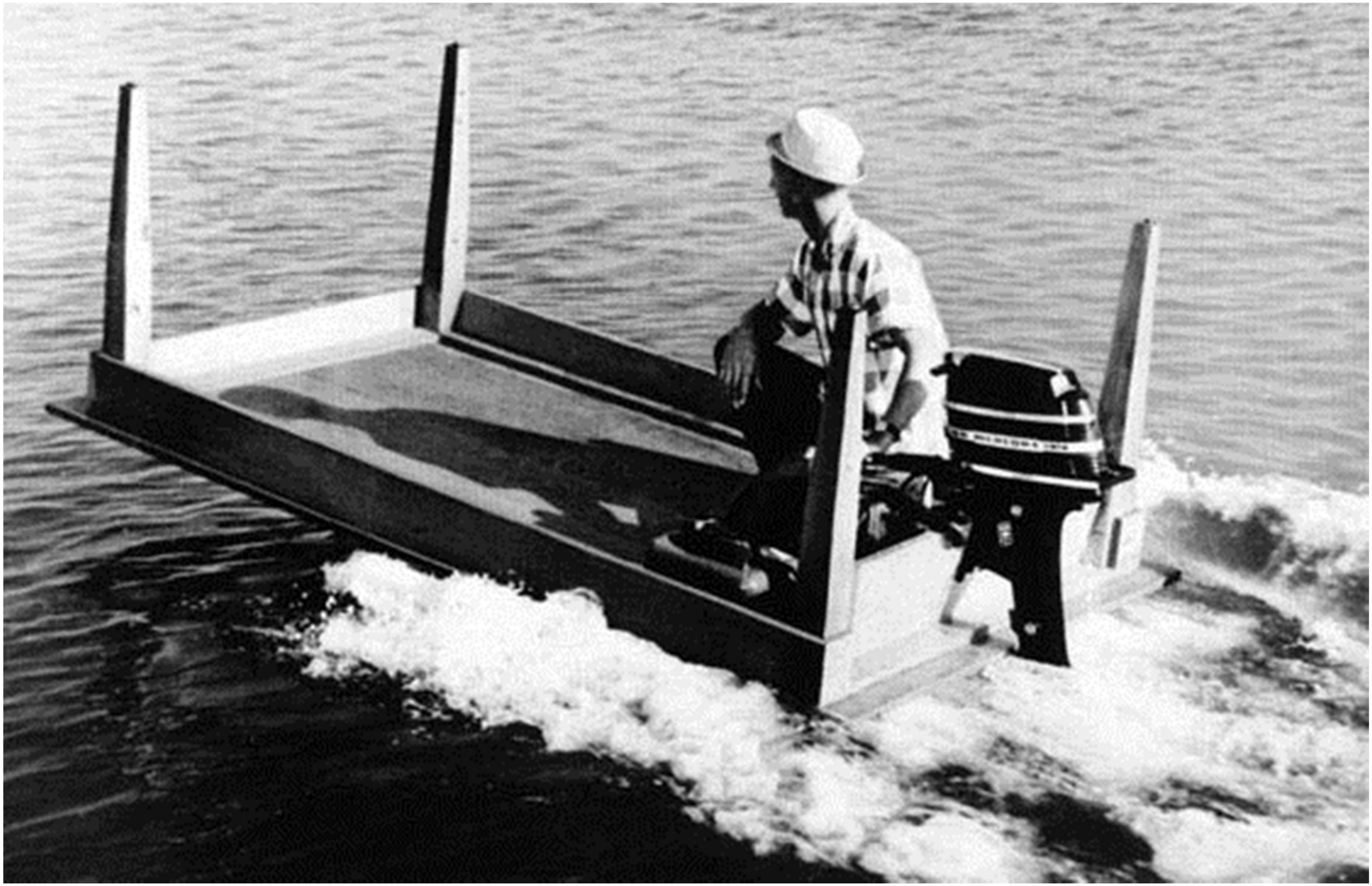


# Guidance/Considerations on use of CSM

- **Introduction and purpose:**
  - **Flow control**
  - **Modeling methodology**
- **Selection of flow ranges**
  - **Lower range – critical flow for incipient motion**
  - **Lower range – susceptibility assessments**
- **Development of evaluation criteria**
  - **Flow duration control and peak flow curve matching**
  - **Erosion potential**
- **Data requirements**
  - **Precip data**
  - **Time step**
  - **Calibration and validation**
  - **Model considerations**
  - **General tips**

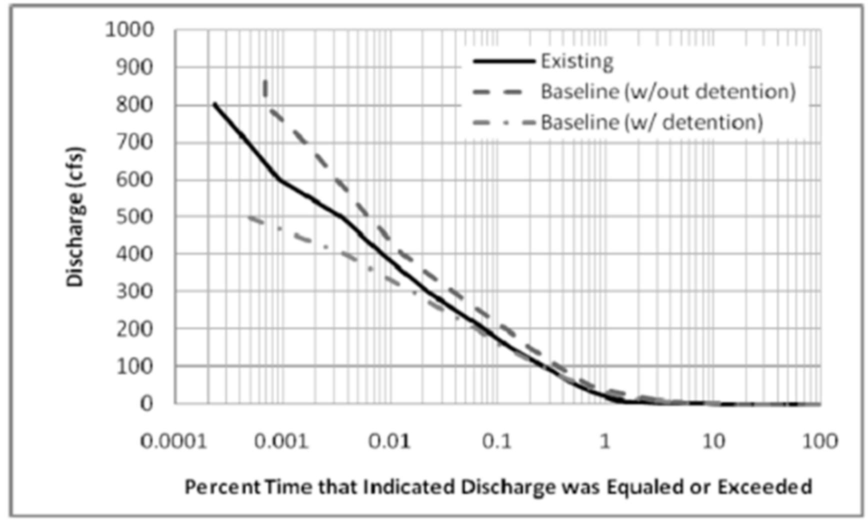


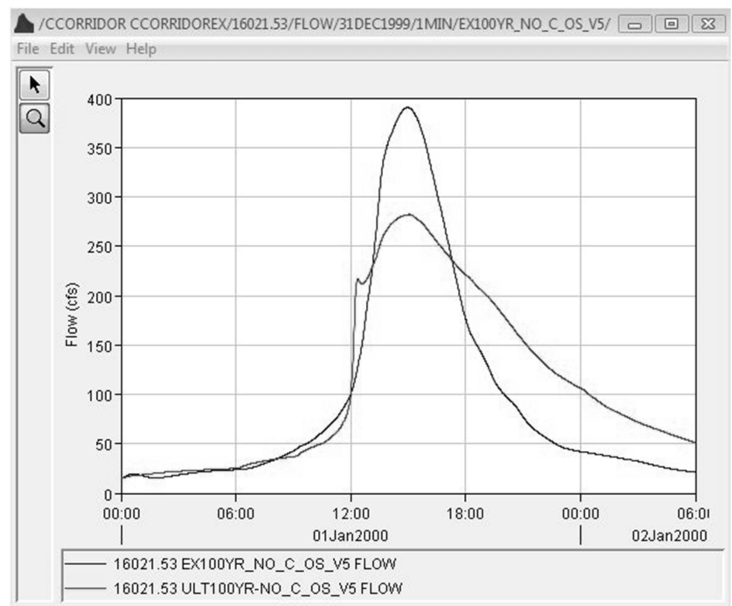
# We've Come A Long Way!



# Fundamentals – CSM vs Peak Flow

- **CSM considers the full range of flow events over long period of record – typically >30 years**
- **Peak flow modeling considers event based hydrographs for return frequency events (2-, 10-, 50-, 100-year events)**
- **Need to control both frequency and duration of flows (X% Q2 – Q10)**



# Approaches Used Elsewhere

- Alameda, Contra Costa, LA, San Diego, San Mateo, Santa Clara, San Bernardino, Ventura, Santa Rosa, Central Coast, Sacramento
- 7/11 specify CSM
- 2/10 match peak flow and volume
- 2/10 not specified
- 3/11 used HSPF
- BAHM, SAHM
- Different biases – flow duration control vs on site LID

# Continuous Simulation Modeling – Flow Ranges

- **Define flow range**

| County/Region | Lower Limit | Upper Limit |
|---|---|---|
| Santa Clara County | 10 % of $Q_2$ | 100% of $Q_{10}$ |
| Alameda County | 10 % of $Q_2$ | 100% of $Q_{10}$ |
| San Mateo County | 10 % of $Q_2$ | 100% of $Q_{10}$ |
| Contra Costa County | 10 % of $Q_2$ | 100% of $Q_{10}$ |
| San Diego: High Susceptibility | 10 % of $Q_2$ | 100% of $Q_{10}$ |
| San Diego: Medium Susceptibility | 30 % of $Q_2$ | 100% of $Q_{10}$ |
| San Diego: Low Susceptibility | 50 % of $Q_2$ | 100% of $Q_{10}$ |
| Fairfield-Suisun Suisun Urban Runoff Management Program | 20 % of $Q_2$ | 100% of $Q_{10}$ |
| Sacramento County: High Susceptibility* | 25 % of $Q_2$ | 100% of $Q_{10}$ |
| Sacramento County: Medium Susceptibility* | 45 % of $Q_2$ | 100% of $Q_{10}$ |
| Western Washington State | 50 % of $Q_5$ | 100% of $Q_{50}$ |

# Continuous Simulation Modeling – Flow Ranges

- **Why define the flow range?**

Typical stream erosion in a northern California stream (generally cohesive silty clays)
(Photo cbec, inc.)

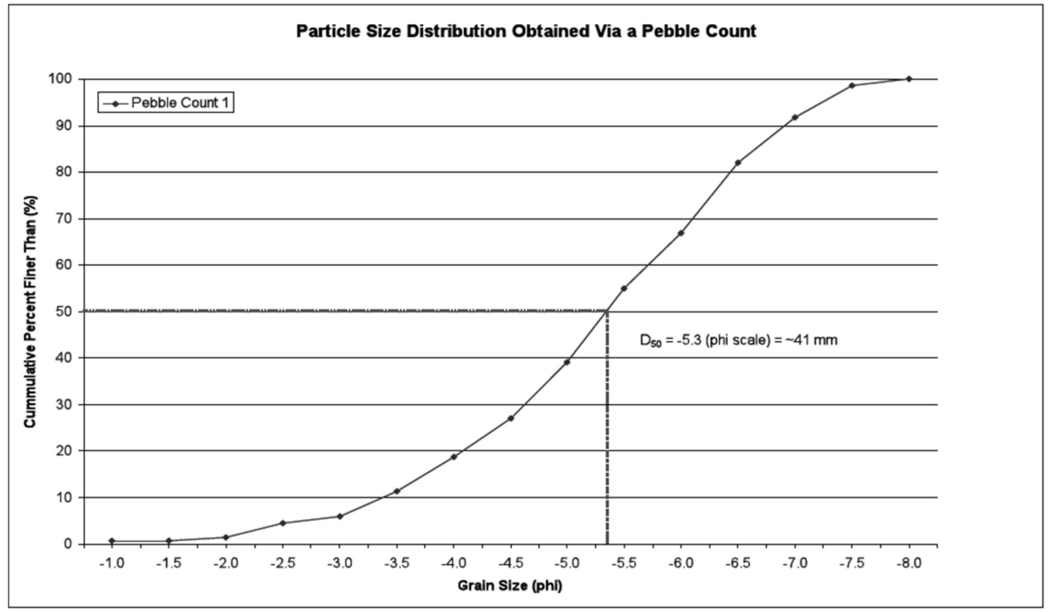
Typical stream erosion in a southern California stream (granular, non-cohesive
(Photo courtesy of Eric Stein, SCCWRP)

# Continuous Simulation Modeling – Flow Ranges

- **How to define the flow range?**
  - **Determine critical shear stress for erosion of bed and bank materials ($\tau_c$ )**
  - **Determine critical flow rate (Qc) at which critical shear stress ($\tau_c$ ) is reached and exceeded**
  - **Determine magnitude of peak Q2**
  - **Compare Qc to Q2 to establish %Q2 for lower threshold.**

# Continuous Simulation Modeling – Flow Ranges

- **How to determine critical shear stress, $\tau_c$ ?**
- ***Non-cohesive* – use Shields relationship – developed for mixtures of uniform sized sediments. For bimodal sediments (large amount of sand plus gravel) other approaches must be used**
- **Determine D50 – sample sediments (bulk or pebble count) and plot particle size distribution**




$$\tau = \rho g R s$$

$$\tau^* = \tau[(\rho_s - \rho)\, g\, D_{50}]^{-1}$$

$$\tau^*_c = 0.03 - 0.06$$

# Continuous Simulation Modeling – Flow Ranges

- **How to determine critical shear stress, $\tau_c$ ?**
- ***Cohesive* – chemical cohesion results in larger $\tau_c$**
- **Jet testing – water impinging on bank/bed creates a hole, relationships developed between depth of hole and strength of material, and hence $\tau_c$**
- **Shear vane (ASTM 2008)**
- **Literature values for materials (Fischenich, 2001)**

Typical installation of jet testing equipment in stream bank

Hole created in cohesive bank material by jet impinging on surface

# Continuous Simulation Modeling – Flow Ranges

- **How to determine critical shear stress, $\tau_c$ ?**
- **Literature values for materials (Fischenich, 2001)**

Table 2. Permissible Shear and Velocity for Selected Lining Materials[1]

| Boundary Category | Boundary Type | Permissible Shear Stress (lb/sq ft) | Permissible Velocity (ft/sec) | Citation(s) |
|---|---|---|---|---|
| *Soils* | Fine colloidal sand | 0.02 - 0.03 | 1.5 | A |
| | Sandy loam (noncolloidal) | 0.03 - 0.04 | 1.75 | A |
| | Alluvial silt (noncolloidal) | 0.045 - 0.05 | 2 | A |
| | Silty loam (noncolloidal) | 0.045 - 0.05 | 1.75 – 2.25 | A |
| | Firm loam | 0.075 | 2.5 | A |
| | Fine gravels | 0.075 | 2.5 | A |
| | Stiff clay | 0.26 | 3 – 4.5 | A, F |
| | Alluvial silt (colloidal) | 0.26 | 3.75 | A |
| | Graded loam to cobbles | 0.38 | 3.75 | A |
| | Graded silts to cobbles | 0.43 | 4 | A |
| | Shales and hardpan | 0.67 | 6 | A |
| *Gravel/Cobble* | 1-in. | 0.33 | 2.5 – 5 | A |
| | 2-in. | 0.67 | 3 – 6 | A |
| | 6-in. | 2.0 | 4 – 7.5 | A |
| | 12-in. | 4.0 | 5.5 – 12 | A |
| *Vegetation* | Class A turf | 3.7 | 6 – 8 | E, N |
| | Class B turf | 2.1 | 4 - 7 | E, N |
| | Class C turf | 1.0 | 3.5 | E, N |
| | Long native grasses | 1.2 – 1.7 | 4 – 6 | G, H, L, N |
| | Short native and bunch grass | 0.7 - 0.95 | 3 – 4 | G, H, L, N |
| | Reed plantings | 0.1-0.6 | N/A | E, N |
| | Hardwood tree plantings | 0.41-2.5 | N/A | E, N |
| *Temporary Degradable RECPs* | Jute net | 0.45 | 1 – 2.5 | E, H, M |
| | Straw with net | 1.5 – 1.65 | 1 – 3 | E, H, M |
| | Coconut fiber with net | 2.25 | 3 – 4 | E, M |
| | Fiberglass roving | 2.00 | 2.5 – 7 | E, H, M |
| *Non-Degradable RECPs* | Unvegetated | 3.00 | 5 – 7 | E, G, M |
| | Partially established | 4.0-6.0 | 7.5 – 15 | E, G, M |
| | Fully vegetated | 8.00 | 8 – 21 | F, L, M |
| *Riprap* | 6 – in. $d_{50}$ | 2.5 | 5 – 10 | H |
| | 9 – in. $d_{50}$ | 3.8 | 7 – 11 | H |
| | 12 – in. $d_{50}$ | 5.1 | 10 – 13 | H |
| | 18 – in. $d_{50}$ | 7.6 | 12 – 16 | H |
| | 24 – in. $d_{50}$ | 10.1 | 14 – 18 | E |
| *Soil Bioengineering* | Wattles | 0.2 – 1.0 | 3 | C, I, J, N |
| | Reed fascine | 0.6-1.25 | 5 | E |
| | Coir roll | 3 - 5 | 8 | E, M, N |
| | Vegetated coir mat | 4 - 8 | 9.5 | E, M, N |
| | Live brush mattress (initial) | 0.4 – 4.1 | 4 | B, E, I |
| | Live brush mattress (grown) | 3.90-8.2 | 12 | B, C, E, I, N |
| | Brush layering (initial/grown) | 0.4 – 6.25 | 12 | E, I, N |
| | Live fascine | 1.25-3.10 | 6 – 8 | C, E, I, J |
| | Live willow stakes | 2.10-3.10 | 3 – 10 | E, N, O |
| *Hard Surfacing* | Gabions | 10 | 14 – 19 | D |
| | Concrete | 12.5 | >18 | H |

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

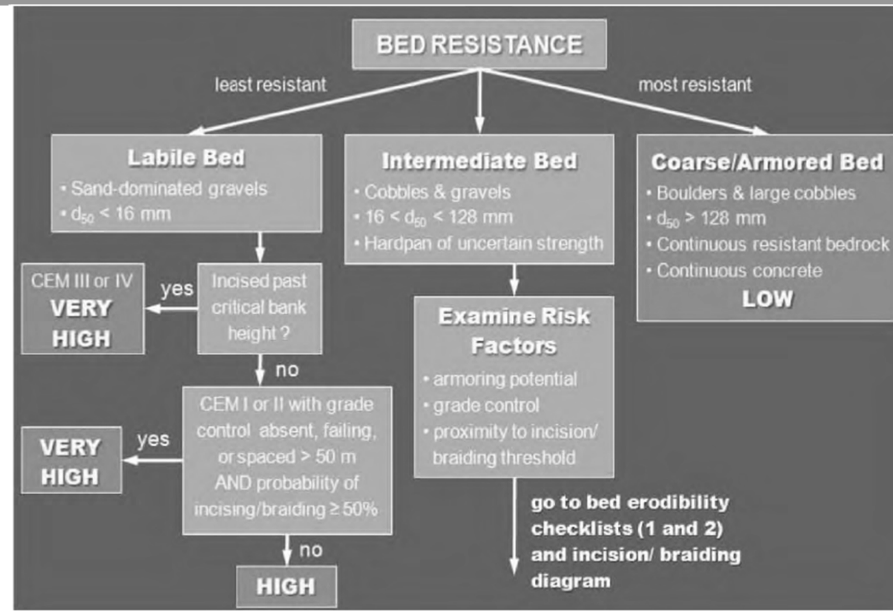

A. Chang, H.H. (1988).
B. Florineth. (1982)
C. Gerstgraser, C. (1998).
D. Goff, K. (1999).
E. Gray, D.H., and Sotir, R.B. (1996).
F. Julien, P.Y. (1995).
G. Kouwen, N.; Li, R. M.; and Simons, D.B., (1980).
H. Norman, J. N. (1975).
I. Schiechtl, H. M. and R. Stern. (1996).
J. Schoklitsch, A. (1937).
K. Sprague, C.J. (1999).
L. Temple, D.M. (1980).
M. TXDOT (1999)
N. Data from Author (2001)
O. USACE (1997).

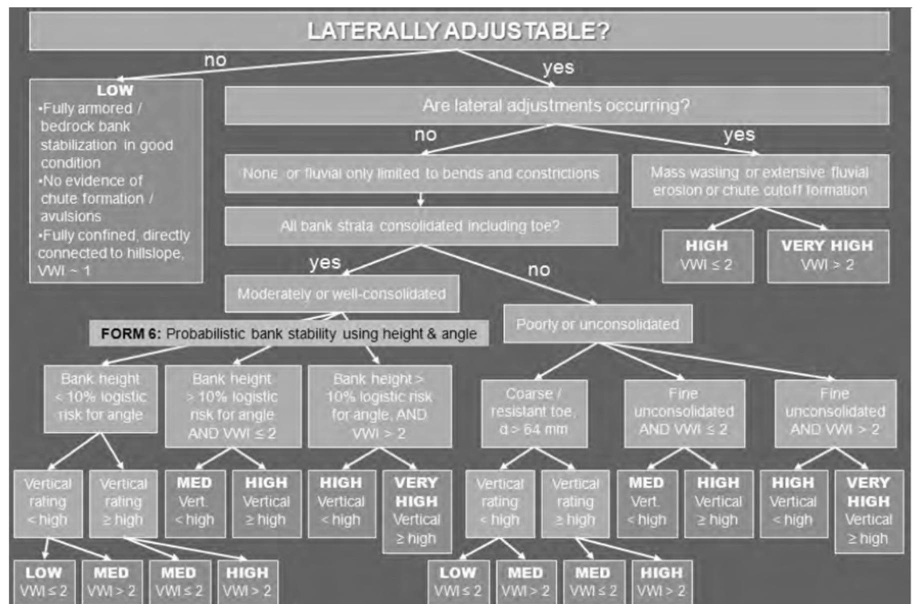

ERDC TN-EMRRP SR-29 5


Fischenich, C. 2001. Stability thresholds for stream restoration materials. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-29). U.S. Army Engineer Research and Development Center, Vicksburg, MS.

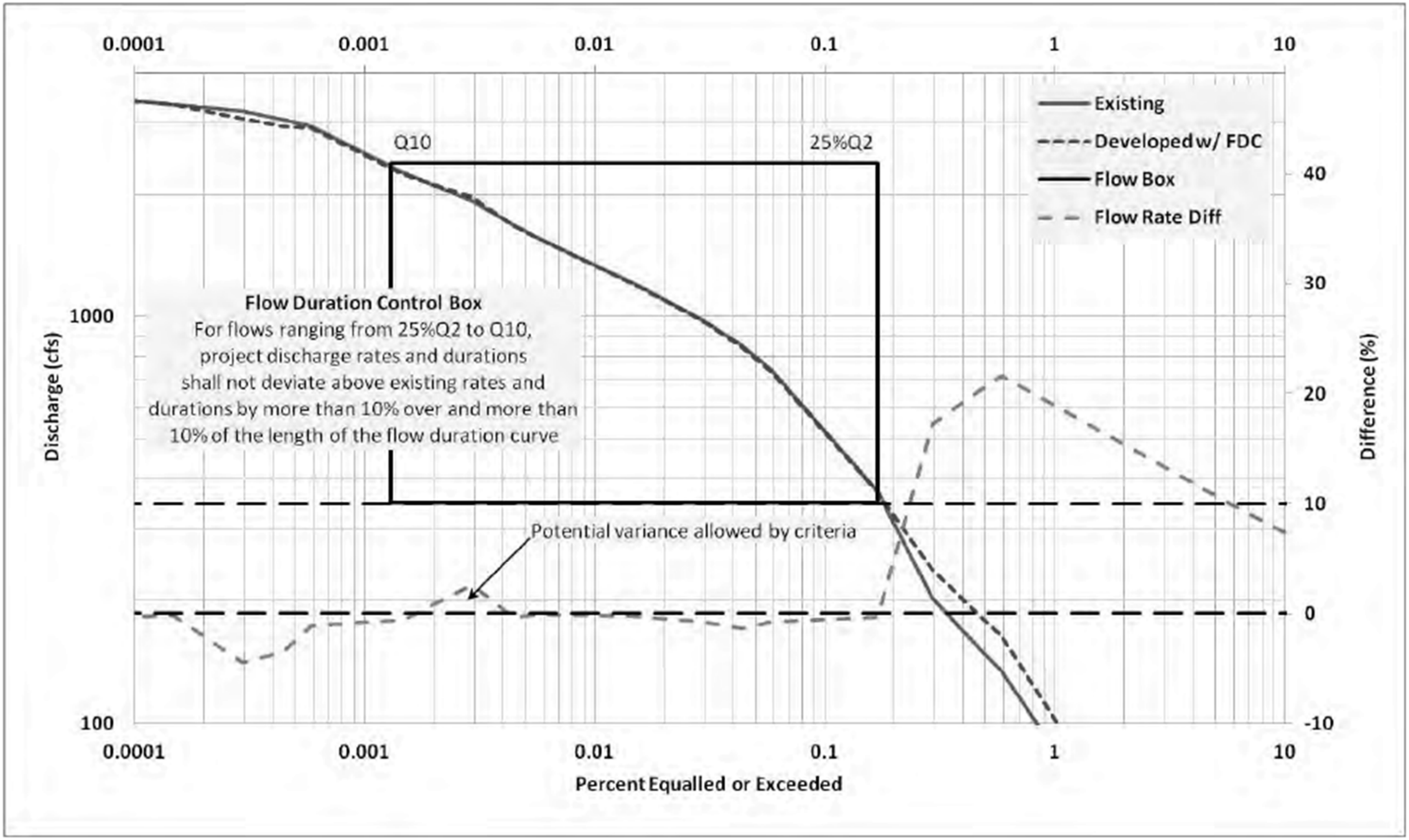
# Continuous Simulation Modeling – Flow Ranges

- **Justification for varying lower flow threshold can be based on susceptibility assessments**
- **Function of composition and condition of bed and banks**
- **Vertical and lateral assessments**
- **Bledsoe et al., 2010**



# Continuous Simulation Modeling – Evaluation Criteria



# Continuous Simulation Modeling – Evaluation Criteria

- **Erosion Potential (EP) – index to assess impact of increased flows on stream stability**
- **Based on bed mobility and integration of work (velocity and excess shear stress)**
- **EP = $W_{dev}$ / $W_{ex}$**
- **Derived from hydraulic modeling outputs**

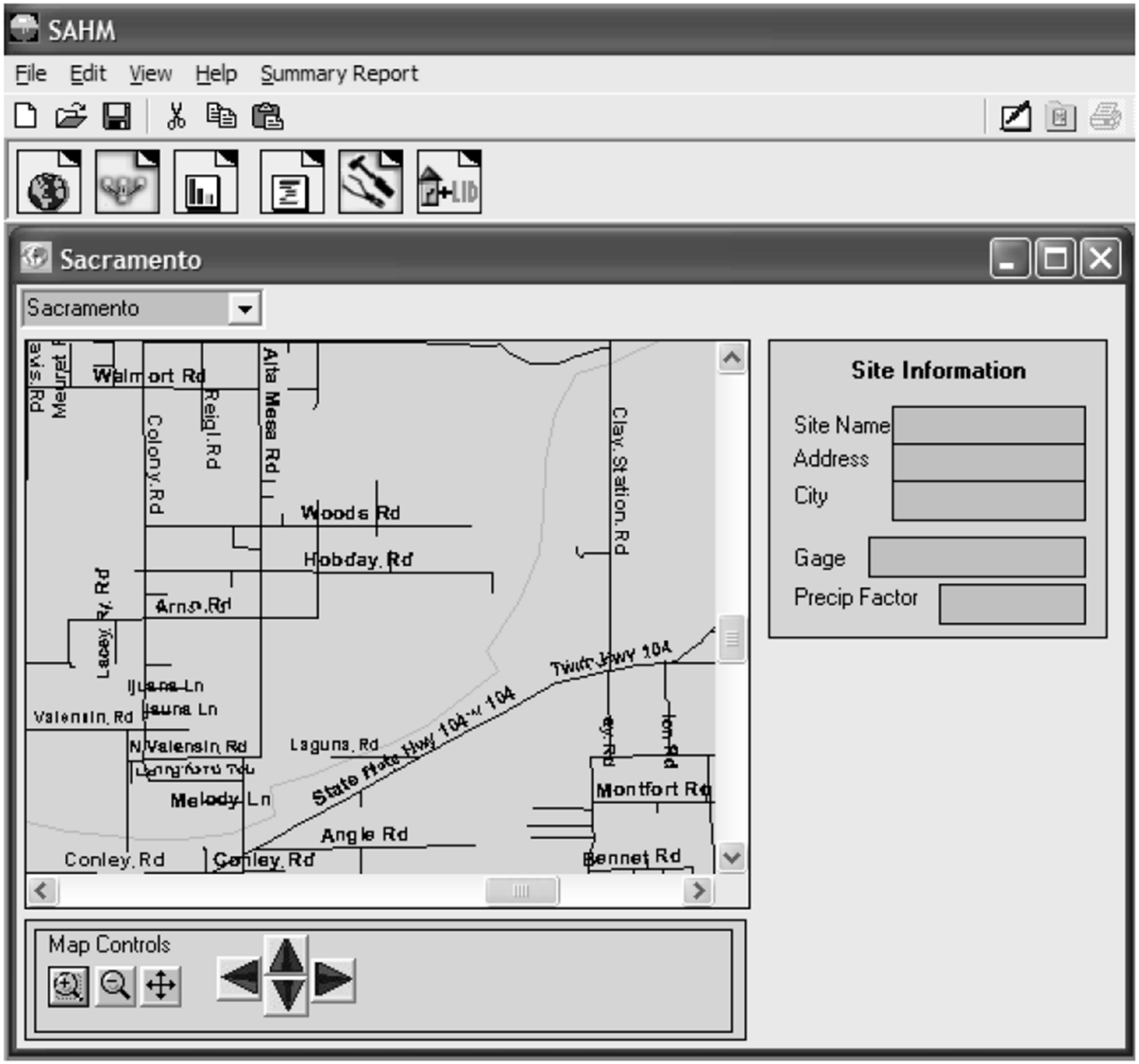
$$W = \sum_{i=1}^{n} (\tau_i - \tau_c)^s \cdot V_i \cdot \Delta t_i$$

- **More time and data intensive but perhaps more realistic in terms of channel response**
- **May result in higher discharge rates and durations that FDC matching – smaller onsite measures**

# BAHM / SAHM

- San Francisco Bay Area, Sacramento Area
- Based on Western Washington Hydrology Model – HSPF modeling platform (EPA)
- Location – local rainfall gauge, adjustment factors, soil types, slope and land use
- Calculates pre- and post-project runoff based on CSM
- User select and size mitigation BMPs
- BAHM – bias towards FDC basins
- SAHM – greater variety for other treatments

# SAHM




**Courtesy of:**

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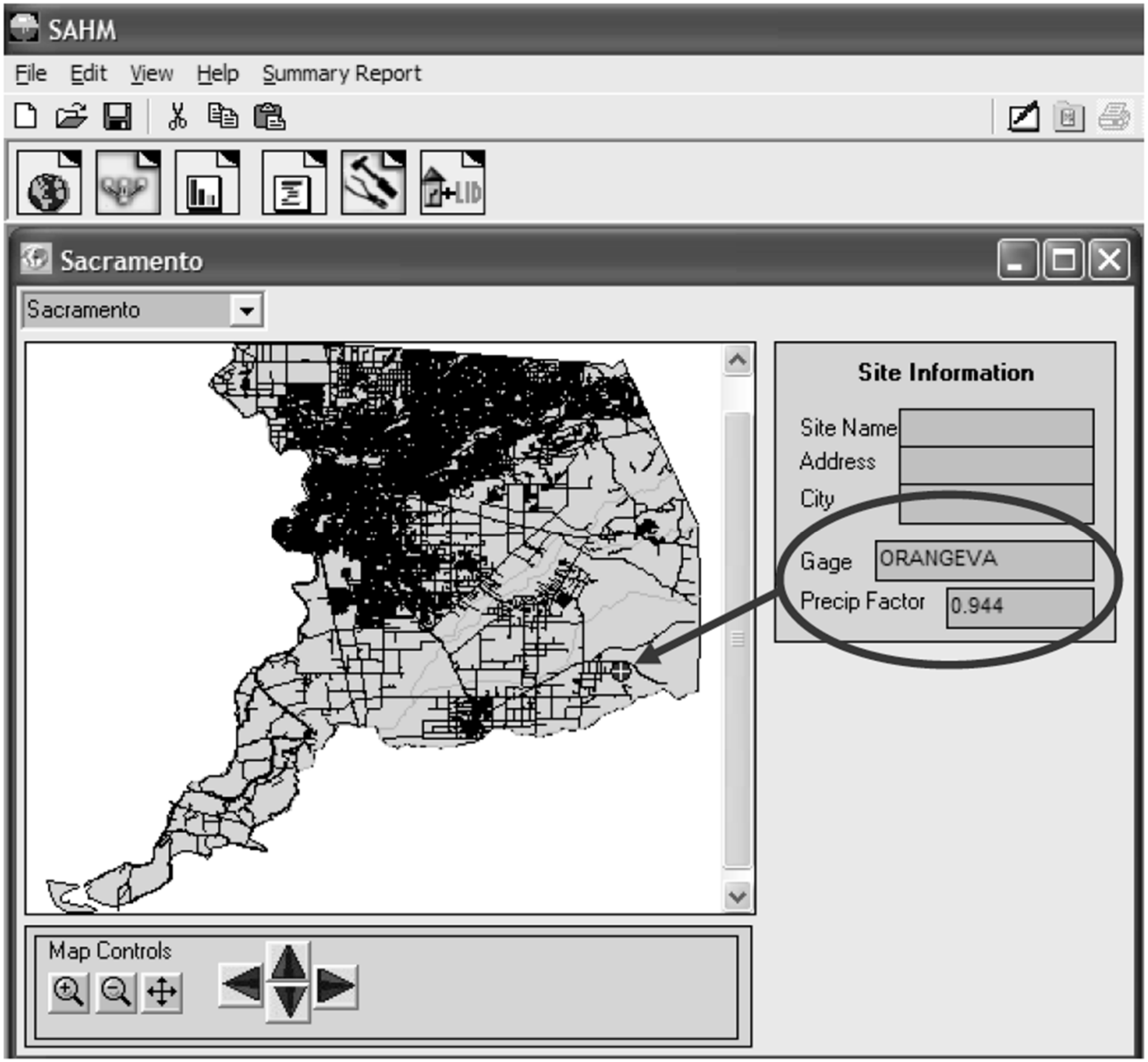
**RBF Consulting**

**Clear Creek Solutions**

# SAHM

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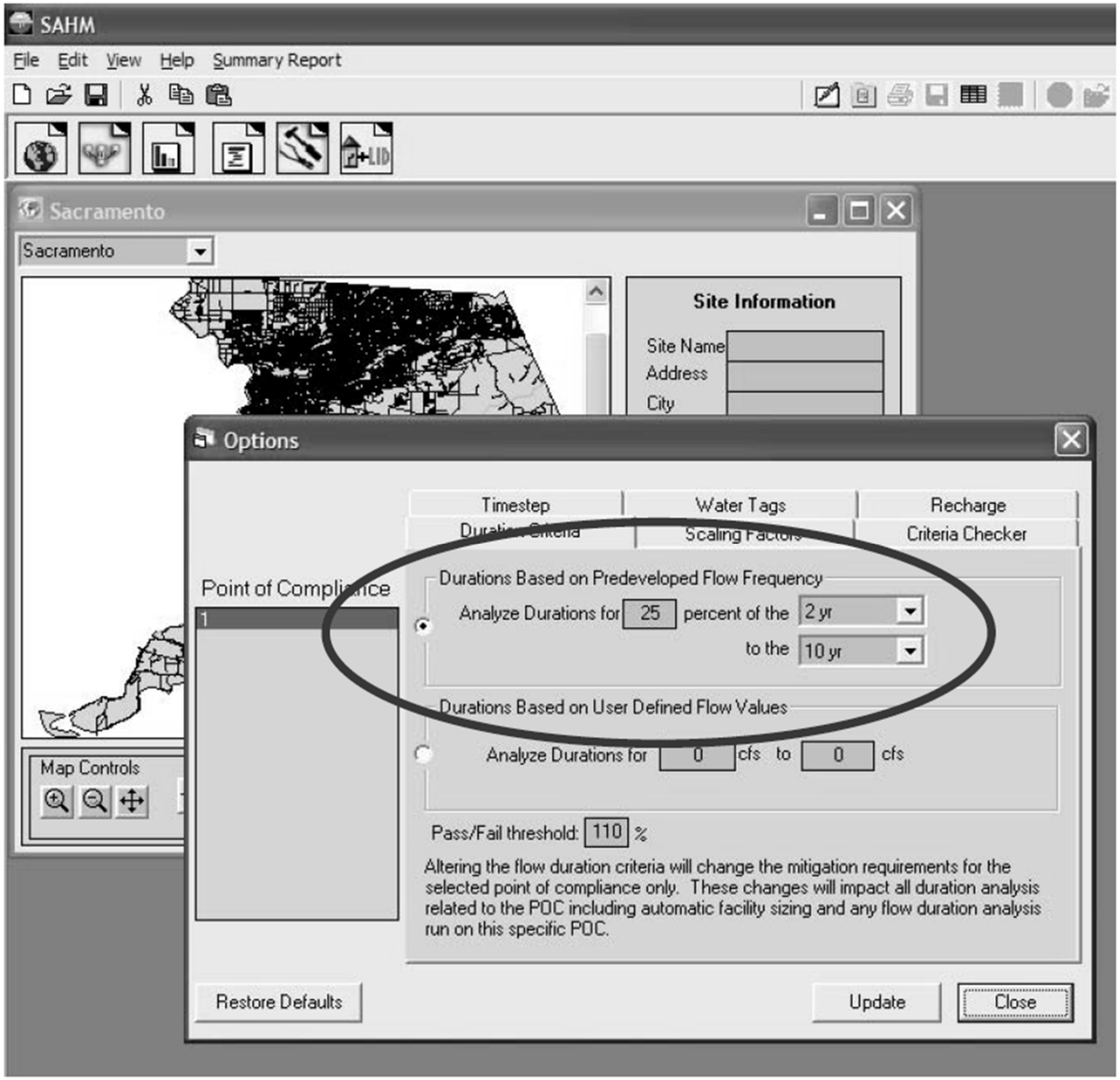


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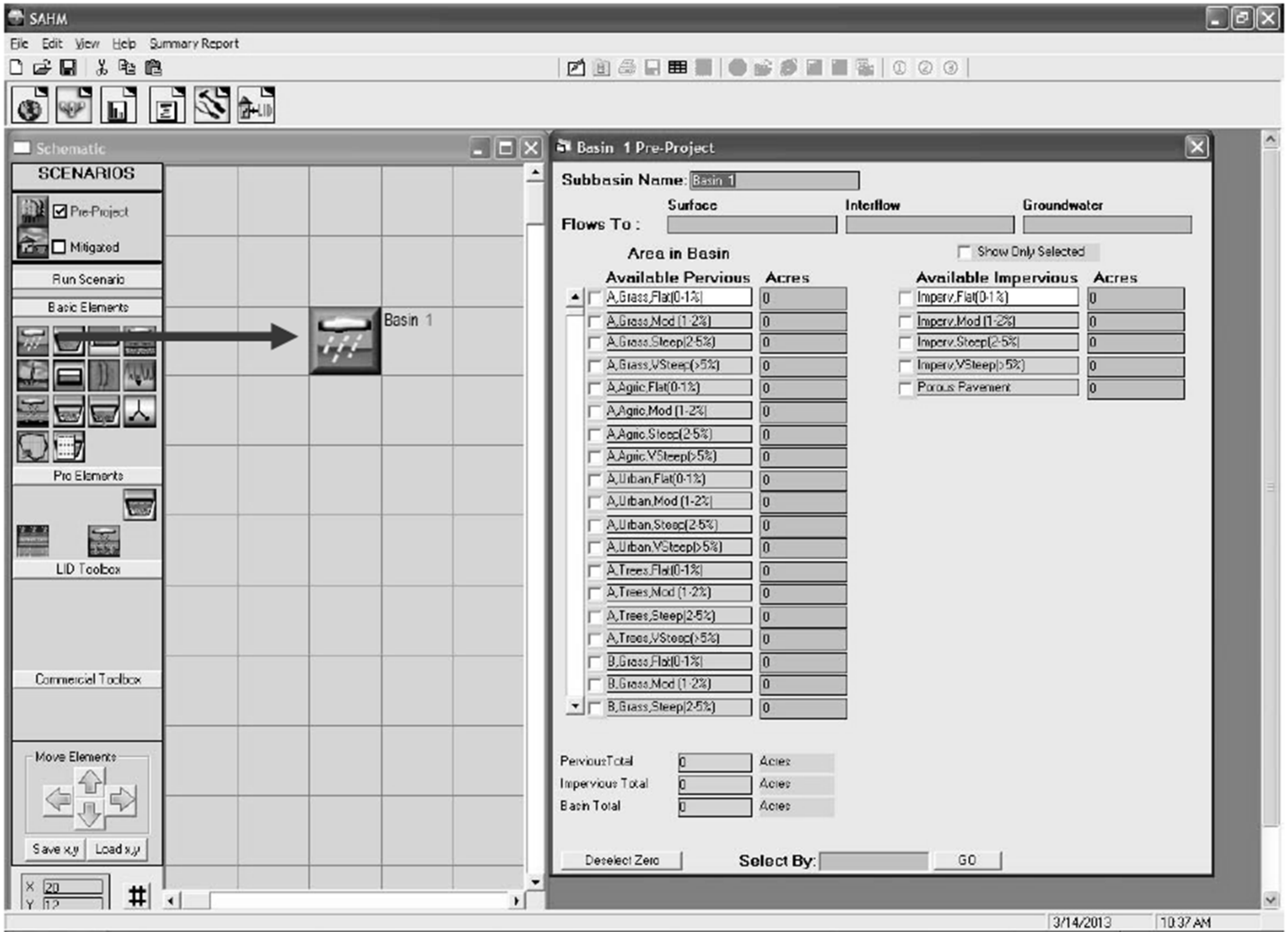


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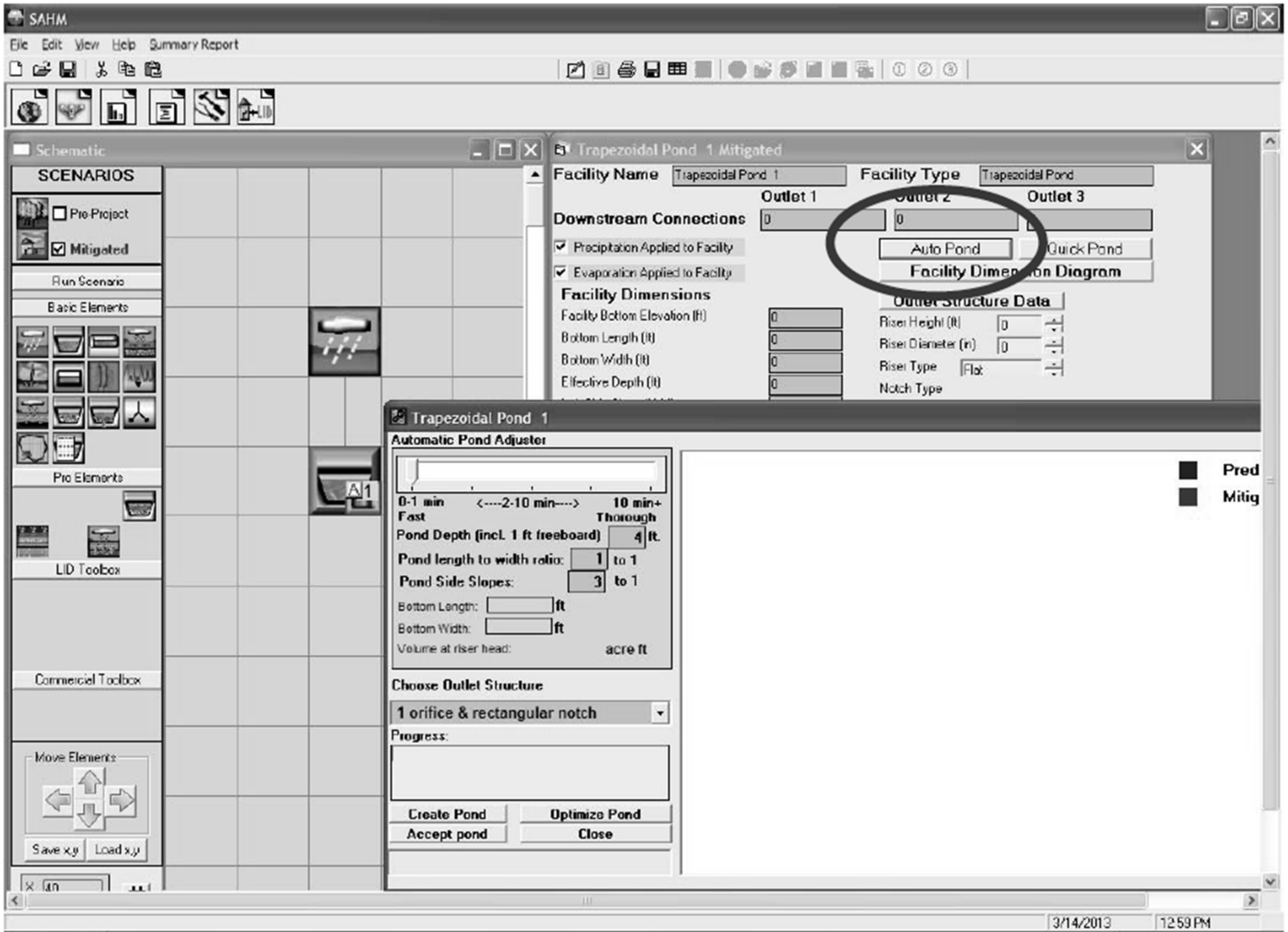


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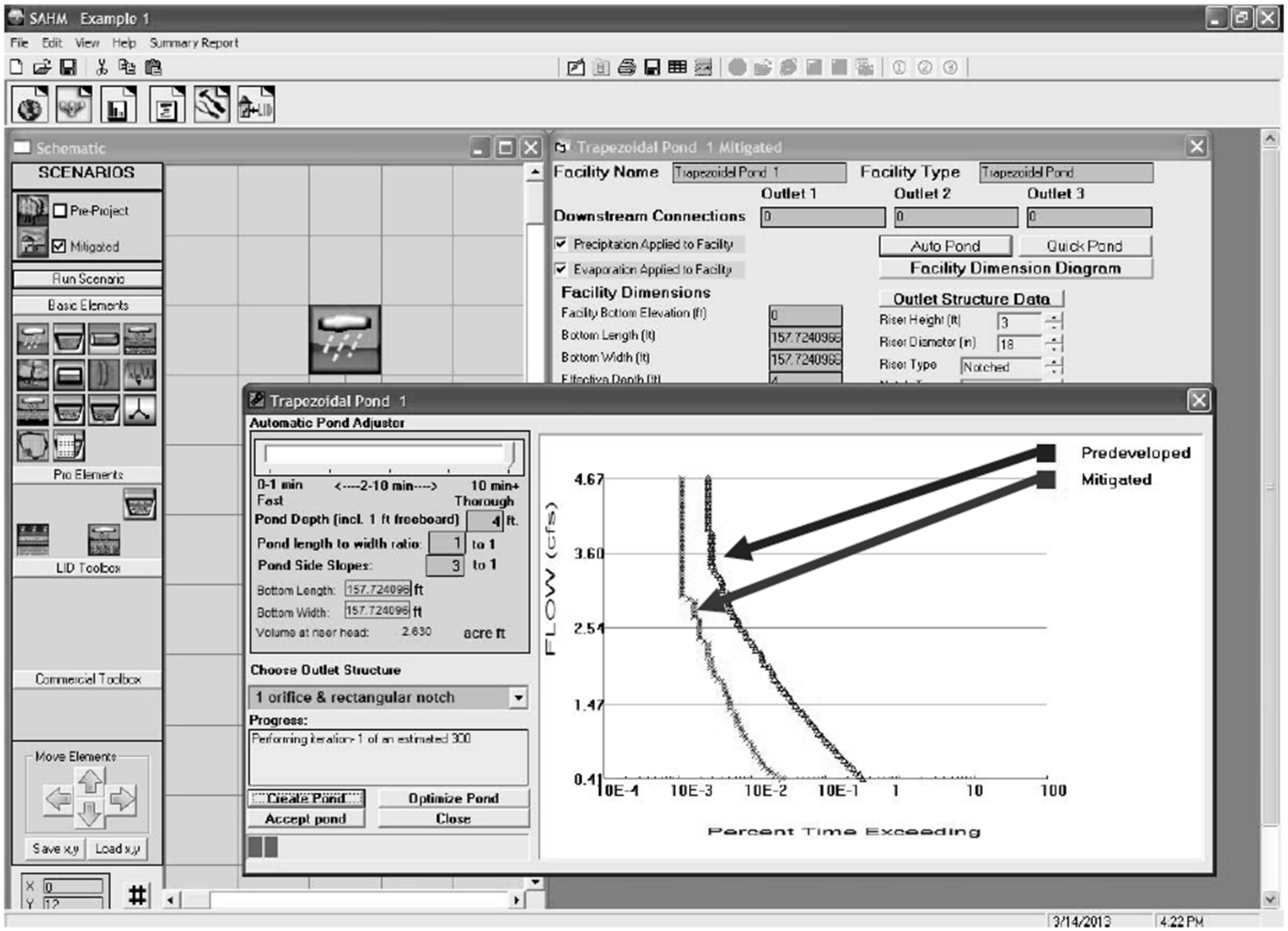


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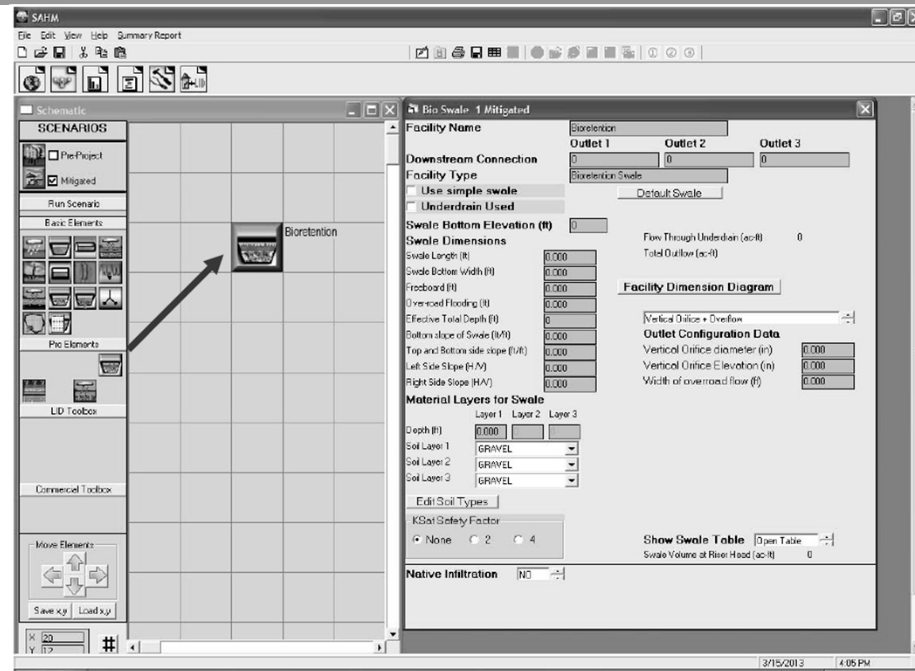
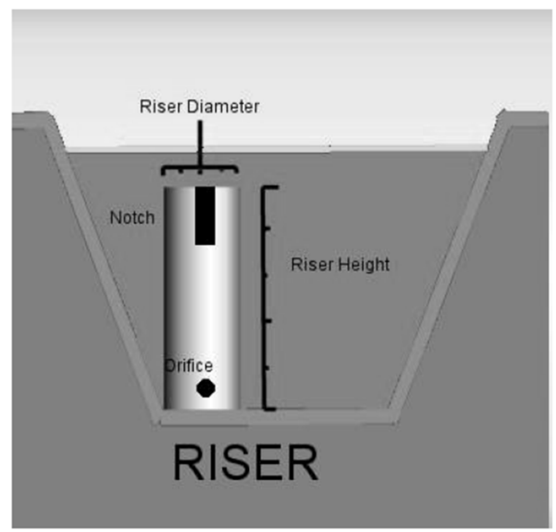
# SAHM

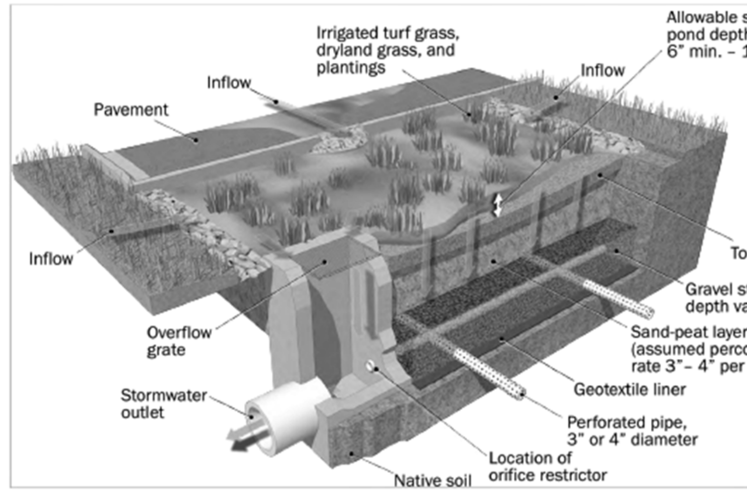
- Trapezoidal and irregular pond
- Vault
- Tank
- Gravel trench
- Sand filter
- Wetland, channel, flow splitter elements
- Bioretention/rain garden
- Outlet structure configurations
- Infiltration specification

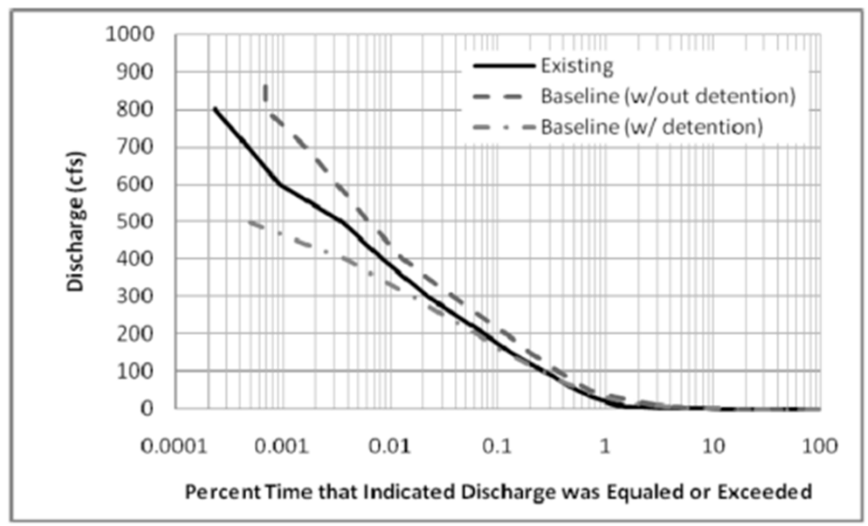


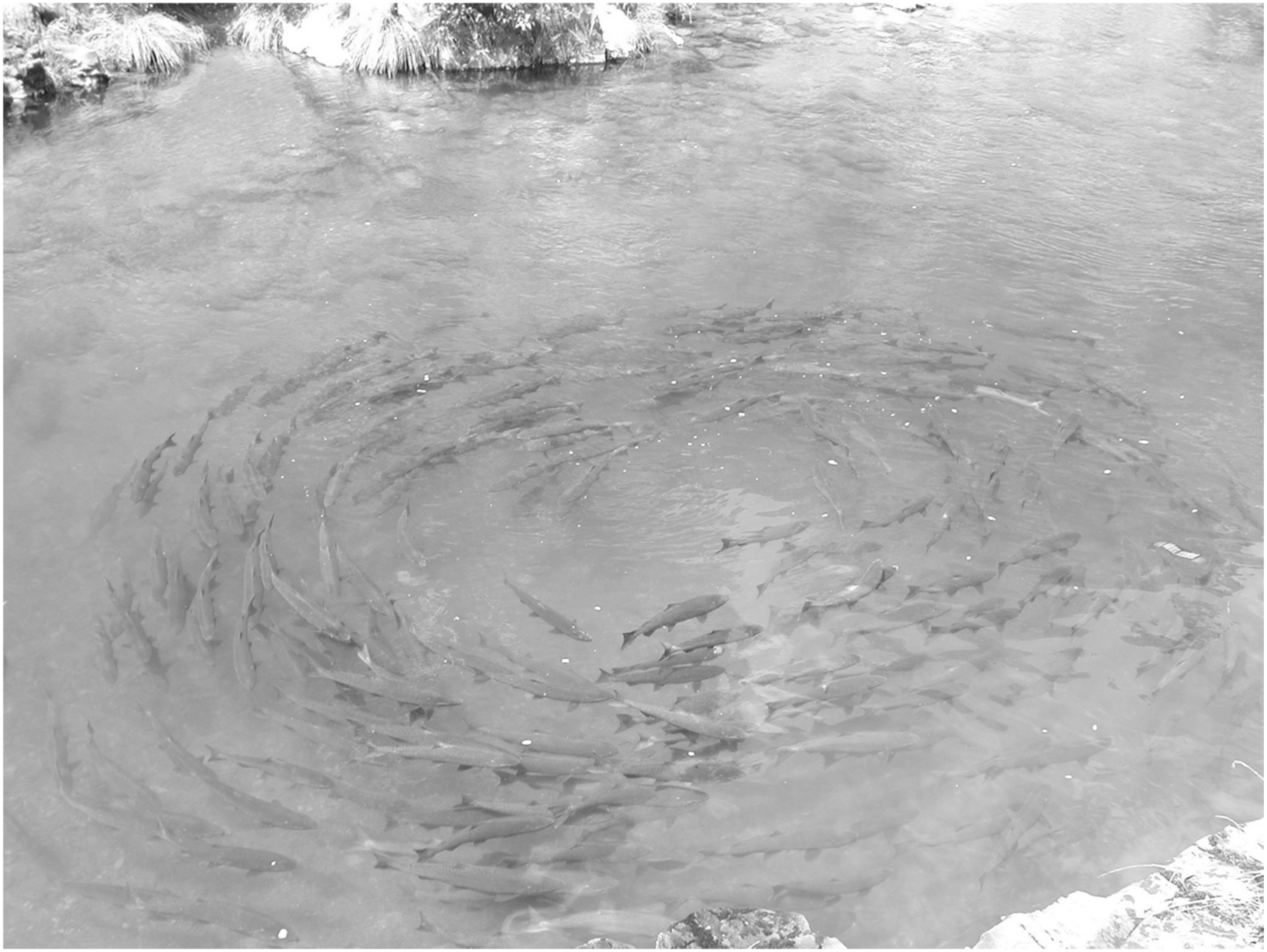
# Integrated Management Practices (IMPs)

- Contra Costa, Sacramento
- Based on sizing factors for designing IMPs
- Sizing factors – soil types, mean annual precipitation
- Range of IMPs
- Based on HSPF – soil types, vegetation, land use, rainfall, slope
- Unit area (1-acre) of impervious surface – flow duration modeled for each IMP
- IMPs sized for FDC matching for X%Q2 to Q10
- Usually lot-scale LID facilities



# Where Are We Going?

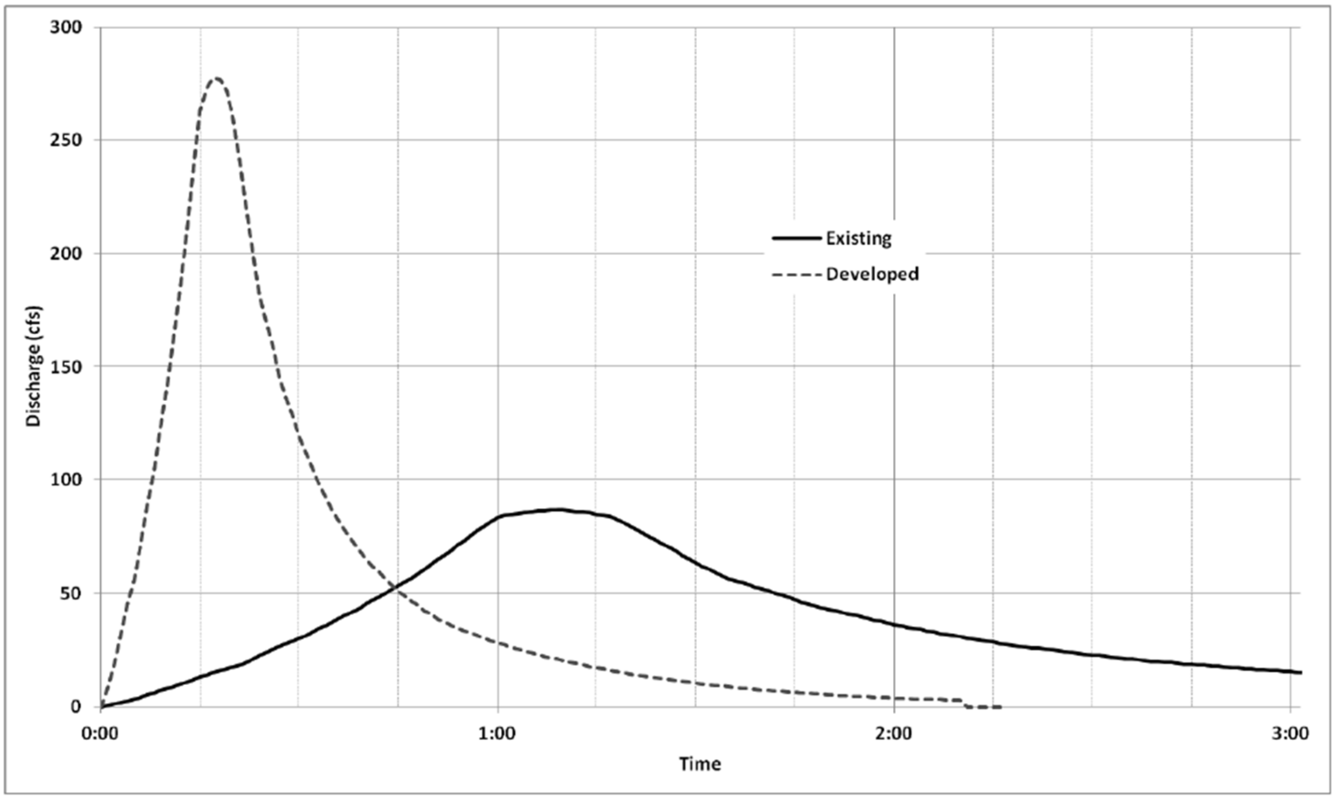


# Data Requirements for CSM

- **HSPF, HEC-HMS – SMA, BAHM/SAHM, IMPs**
- **Topo, soils, vegetation, land use, infiltration, surface runoff, soil moisture, evapotranspiration, percolation, interflow, groundwater**
- **Project CSM – County specific HMP measures must be specified**
- **IMP, BAHM/SAHM – optimization routines to size measures**
- **Precipitation – 30-50 years if possible**
  - ALERT system for individual counties (e.g., Sacramento [http://www.sacflood.org/])
  - Western Region Climate Center (WRCC [http://www.wrcc.dri.edu/])
  - NOAA National Climatic Data Center (NCDC [http://www.ncdc.noaa.gov/])
  - California Irrigation Management Information System (CIMIS [http://wwwcimis.water.ca.gov/])

# Data Requirements for CSM

- **Simulation time step – sub hourly time step preferred – time of concentration <1 hour for small sites**
- **Can produce large amounts of model output**
- **Possible to bias the results in favor of developed condition – under sampling of flashier and larger developed flows under hourly time step**



# Data Requirements for CSM

- **Hydrologic model calibration and validation**
- **Soil characteristics, land use, evapotranspiration (ET) derived from published data (soil survey, local studies, county standards, etc.)**
- **Compare modeled to measured or observed flows for overlapping periods where adequate precip, ET and flow data**
- **With paucity of data – neighboring/regional watersheds**
- **Last resort – calibration not possible – general review and comparison of CSM to standardized event-based approaches (hydrograph shapes, Annual Maximum Series, etc) – reality checks**
- **Consistency with local standards and methodologies**
- **Example – SacCalc (HEC-1) conversion to HEC-HMS-SMA**

# Data Requirements for CSM

- **Hydraulic models**
- **Needed where hydraulic routing is important – for EP or instream measures**
- **Low flows are problematic – HEC-RAS struggles – MIKE 11 much better**
- **Consider carefully topo sources – LiDAR vs ground based**
- **Channel transitions and bank markers**
- **Manning's n**
- **Selection of compliance points to represent reach and capture flow changes (downstream of points of discharge and not in backwaters)**

# Data Requirements for CSM

- **General Tips**
- **Truncate precip record to rainy seasons to reduce simulation time (especially in ephemeral systems)**
- **Hourly precip does not limit CSM from running at sub-hourly timestep**
- **Subwatersheds can be substantially smaller in developed rather than undeveloped condition. Can skew results – flashier in smaller subs – optimize existing and developed sub sizing for more meaningful comparisons**

# Thanks!

- Eric Berntsen, M.S., State Water Resources Control Board
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# Happy to talk!

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