Evaluating Stream Depletions in Small Watersheds and Headwaters of California- stream Depletion Risk Assessment Framework & Tools

High level analysis of groundwater- surface water connectivity and impact to surface waters from well pumping.

Jeff Sanchez, P.G., P.H. & Behrooz Etebari, P.G.

Overview

- Task and Background
- What is sDRAFT?
- Groundwater Basics
- Previous Efforts
- **Qualitative** Approach
  - V-BET Tool
  - Risk Zones
- **Quantitative** Approach
  - Analytical vs. Numerical Models
  - Best Analytical Model matches
- Mark West Creek- Example Application

Task

Evaluate approaches to narrow down and prioritize areas with **likely groundwater-surface water interactions** and where **groundwater diversions could impact surface flows**. Develop a **state-wide**, cookie cutter, desktop approach that can be applied in headwaters, small watersheds or areas with threatened and endangered anadromous fish habitat.

Why?

- Cannabis Policy- Board may develop additional requirements for groundwater diversions in locations where there are a significant number of groundwater diversions, or where diverters are switching from surface to groundwater, and the diversions have the potential to negatively impact surface flows. (p52)
- Many Cannabis Cultivators using wells
- Many local jurisdictions approve well permits without or with limited review (slowly starting to change)
- SGMA does not cover upland areas, only applies to High and Medium Priority alluvial basins (High and Medium= ~17% of CA; Alluvial Basins= ~38% of CA)- SGMA covers most extraction by volume, but not species impacts
- Create focused discussion in non-SGMA areas, generate background/discussion materials, engage experts in quantifying impacts

stream Depletion Risk Assessment Framework & Tools (sDRAFT)

- **Statewide** framework within which the risk of streamflow depletion by groundwater well pumping can be qualitatively and quantitively assessed. (not crop specific)
- Developed for use in upland river valleys, canyons and headwater areas, but does include some guidance for large lowland alluvial basins not covered by SGMA.
- Coarse high level approach to quickly estimate impacts to surface waters
  - Uses statewide publicly available datasets, and makes numerous simplifying assumptions
- Uses **landscape analysis** (not geology) to identify areas of likely connectivity.
- Tools are identified to simplify the process and provide consistency in application.
- **Simplifies** real-world conditions to optimize available resources

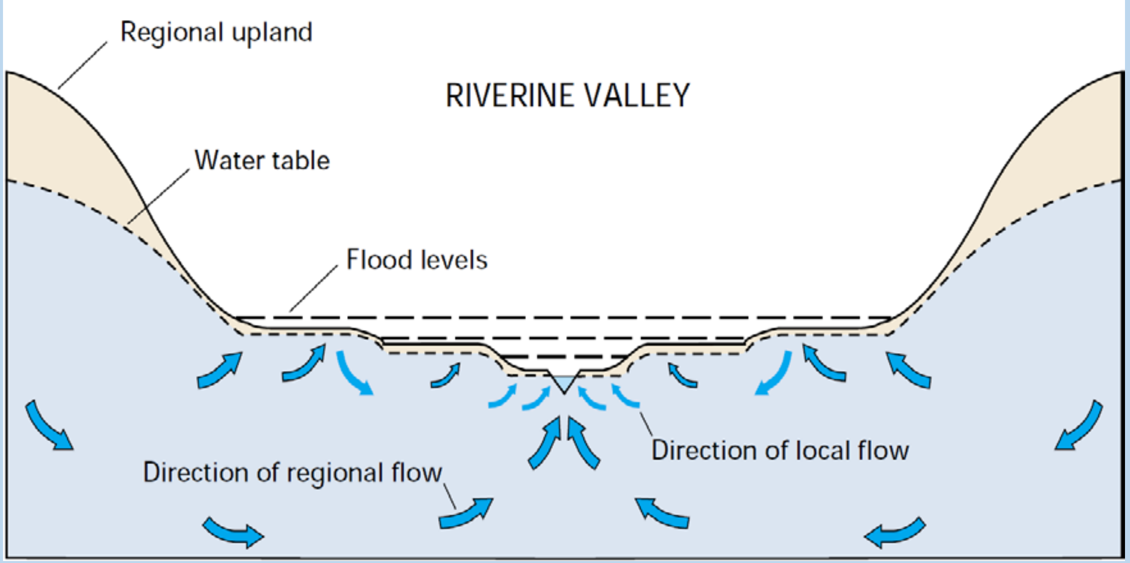
Framework: Risk Zones, Modeling Decision Chart

Tools: V-BET & Analytical Models (where/how to implement them)

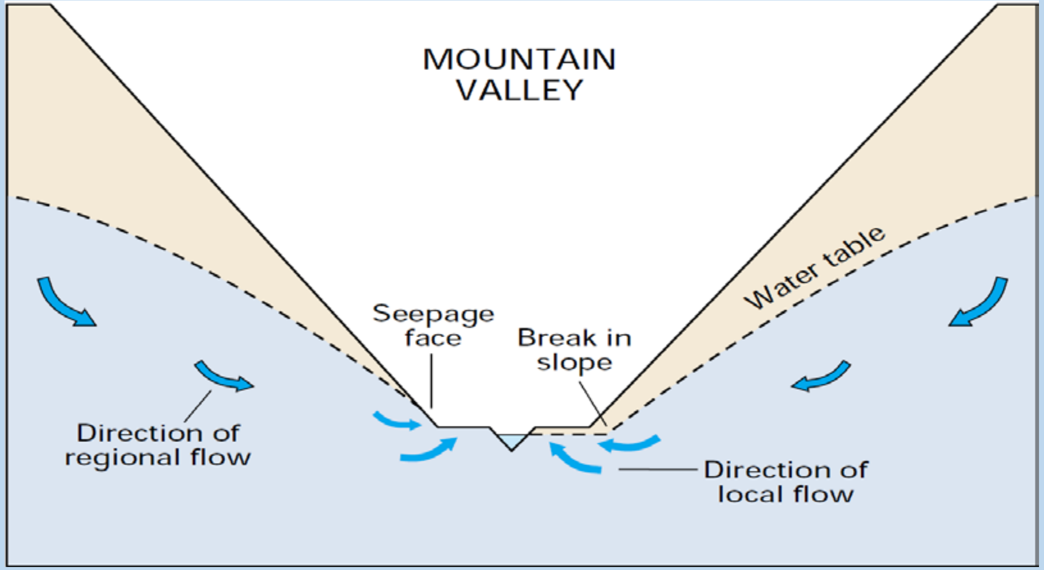
sDRAFT is in development stage and will evolve

Groundwater in the Landscape

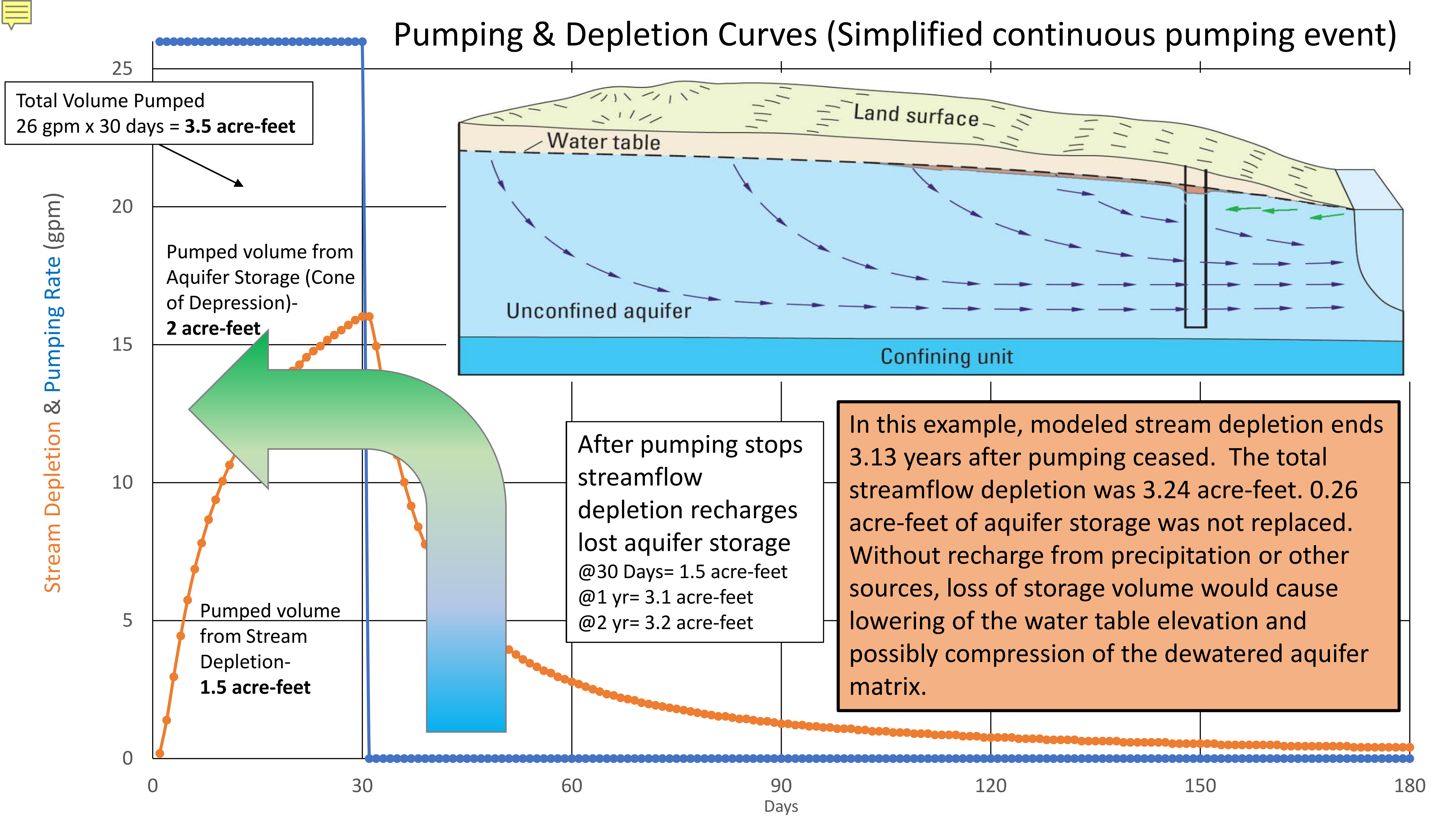
USGS CT&M 4-D2



USGS T&M 4-D2

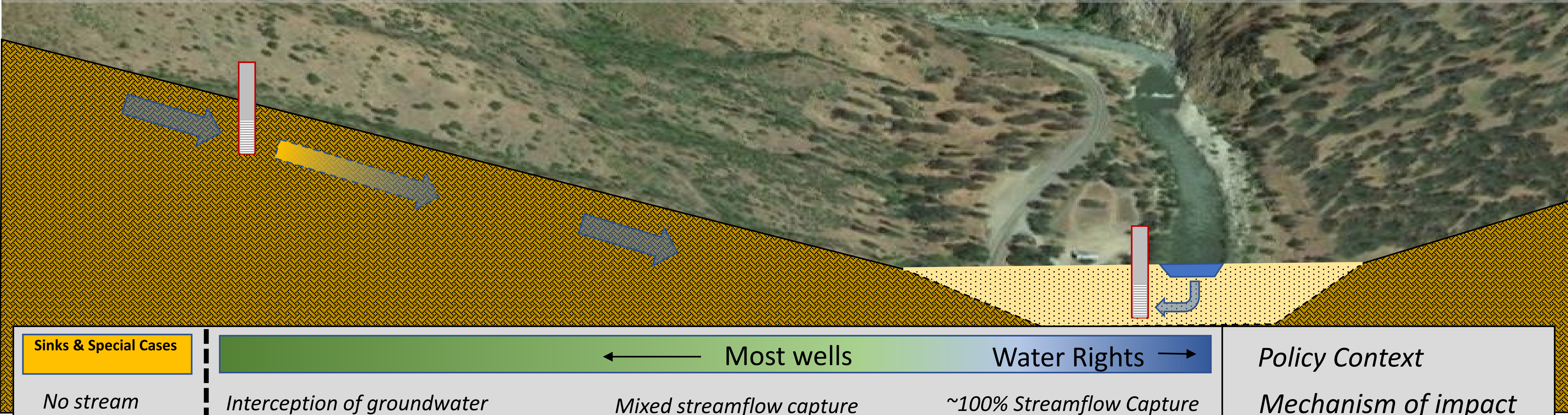


- Mimics topography but subdued in uplands
- Closest to surface (most accessible) in lowlands
- Flows from high elevation to Low elevation -or- from high pressure to low pressure
- Surface water bodies are expressions of the water table intersecting the ground surface


Pumping & Depletion Curves (Simplified continuous pumping event)
Total Volume Pumped
26 gpm x 30 days = **3.5 acre-feet**
Pumped volume from Aquifer Storage (Cone of Depression)-
2 acre-feet
Pumped volume from Stream Depletion-
1.5 acre-feet
Land surface
Water table
Unconfined aquifer
Confining unit
After pumping stops streamflow depletion recharges lost aquifer storage
@30 Days= 1.5 acre-feet
@1 yr= 3.1 acre-feet
@2 yr= 3.2 acre-feet
In this example, modeled stream depletion ends 3.13 years after pumping ceased. The total streamflow depletion was 3.24 acre-feet. 0.26 acre-feet of aquifer storage was not replaced. Without recharge from precipitation or other sources, loss of storage volume would cause lowering of the water table elevation and possibly compression of the dewatered aquifer matrix.
Stream Depletion & Pumping Rate (gpm)
25
20
15
10
5
0
0
30
60
90
120
150
180
Days

Withdrawal Impact Continuum

"All Water discharged by ***wells*** is balanced by a loss of water somewhere" - C.V. Theis 1940



Sinks & Special Cases

No stream impacts (e.g. closed basin, drains to ocean)

Most wells ← → Water Rights

Interception of groundwater discharge or Diverted Discharge

Mixed streamflow capture and interception of discharge

~100% Streamflow Capture or Induced Infiltration

Low magnitude, long duration impact (baseflow reduction)

High magnitude, short duration impact (pulse reduction)

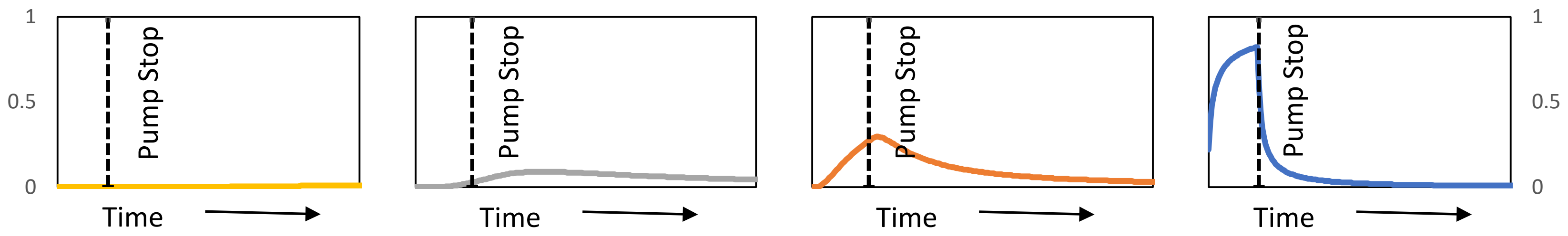
Policy Context

Mechanism of impact

Magnitude and Duration of impact

Shape of impact curve

Stream Depletion as % of pumping rate



Previous efforts informing sDRAFT development

Qualitative

Stetson Engineers Inc., 2008
Joseph Sax, 2002

- Focus on identifying areas matching legal description (4 part test); not replicating effort, considering approach and discussion, comparing results

California Geologic Survey, 2012

- Compare results to Quaternary Surficial Deposits- SoCal

- **Spatially identify** geologic units and/or areas of *likely connectivity*

Quantitative

Barlow and Leake, 2012 (Circ 1376)
Butler et al, 2001, 2007
Hunt, 1999, 2003, 2008, 2012
Hantush, 1965
Huang et al, 2018
Huggins et al, 2018
Jenkins, 1968
Zipper et al, 2018
Zlotnik and Tartakovsky, 2008
And others

- **Compare** analytical models to numerical
- Some *calculators* provided
- Mostly focus on alluvial *basins*
- Little discussion of applicability in *uplands*

Qualitative Approach- Landscape analysis to identify Valley Floor (alluvium)

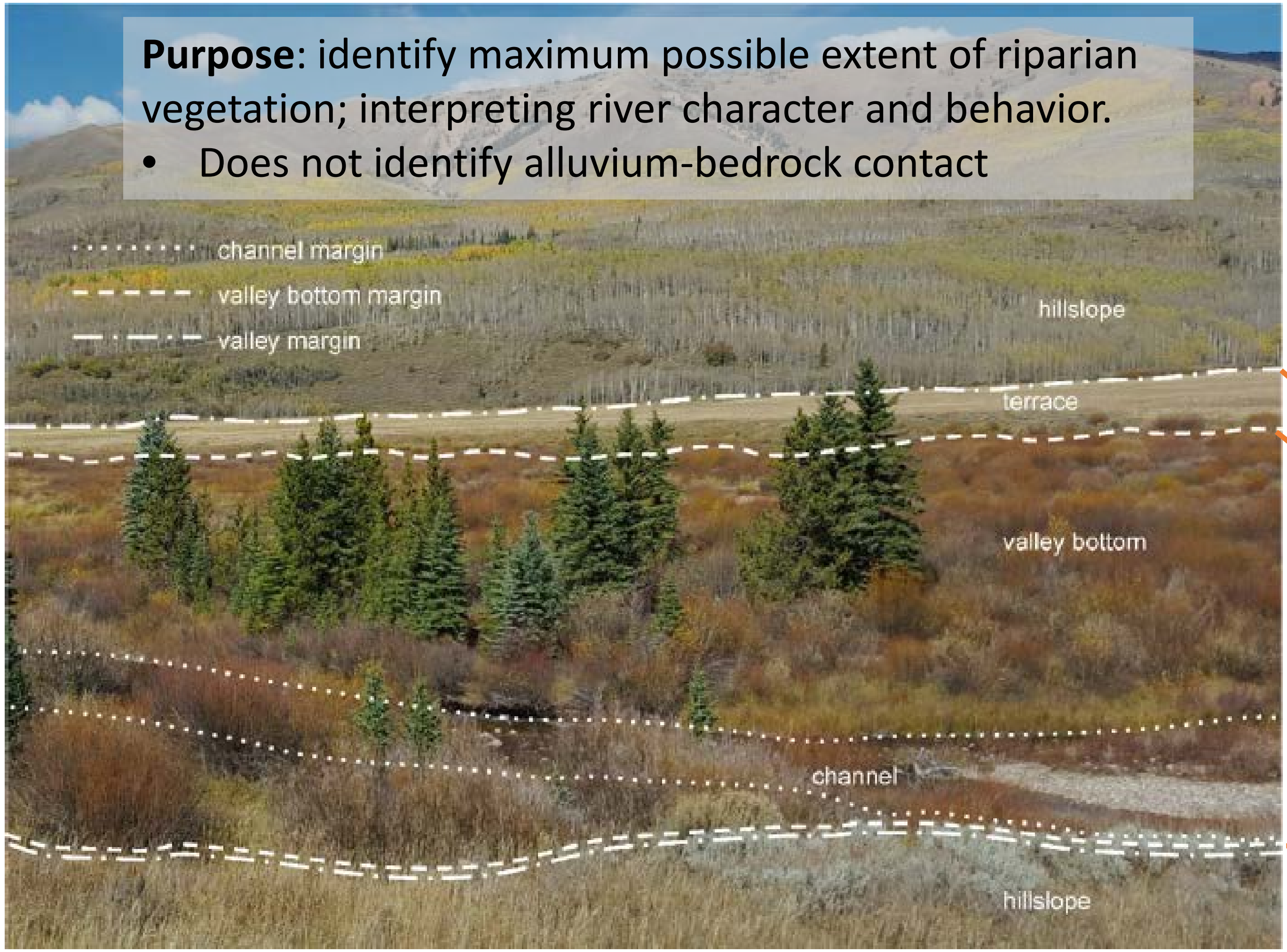
Gilbert, et al., 2016- **Valley Bottom Extraction Tool** (V-BET) {Suite of 3 tools (Network Builder, Project Builder, V-BET)}

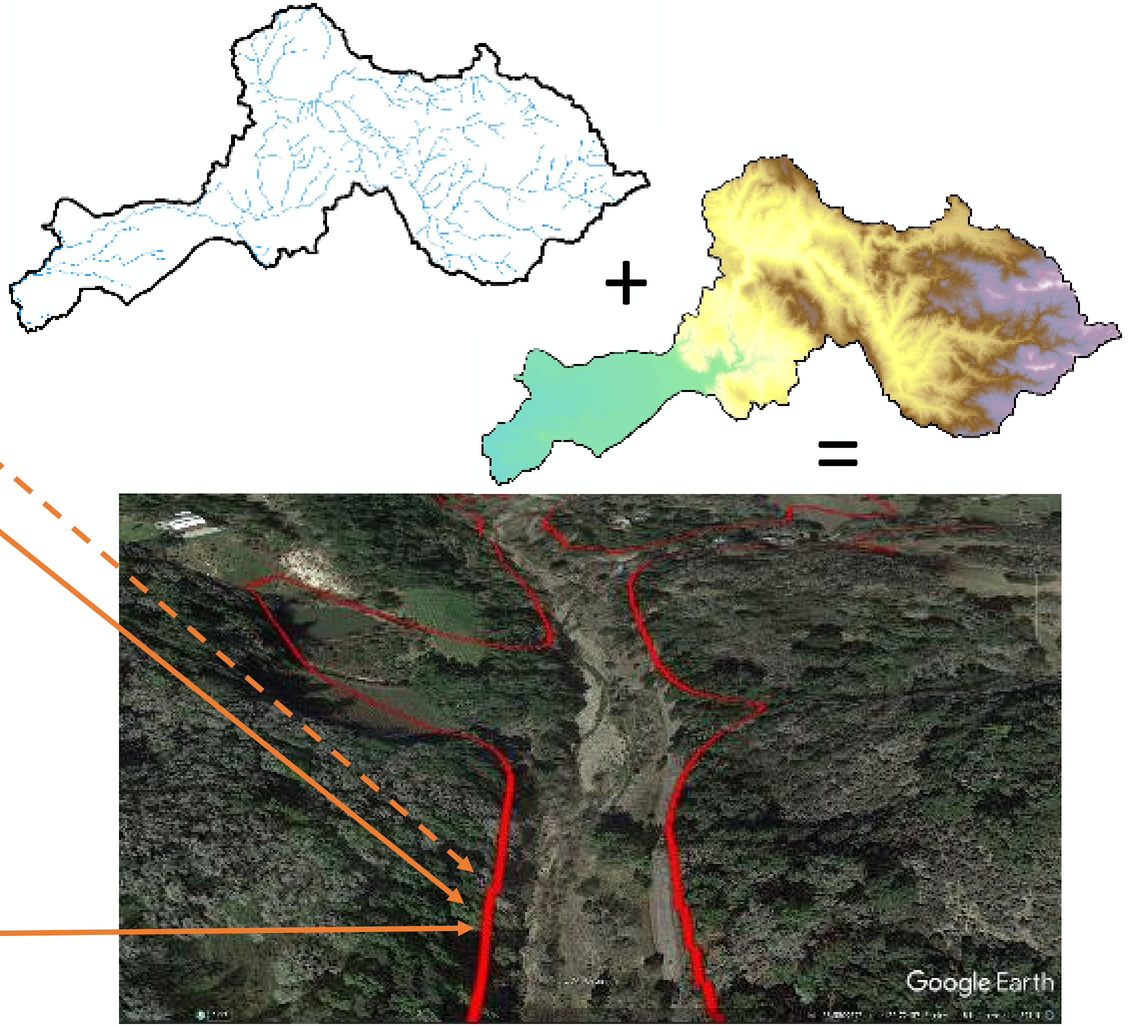
Platform: ArcGIS **Data Needs**: Topography (DEM) and Stream flowlines (NHD)

Process: Build flow network, Sub-Divides watershed based on drainage area, searches laterally from stream for slope break, generates polygon of valley bottom

Purpose: identify maximum possible extent of riparian vegetation; interpreting river character and behavior.

- Does not identify alluvium-bedrock contact





Validation- What Does V-BET identify?

1. Picked single set of input parameters and ran in 4 areas (Green Valley Ck, Mark West Ck, Sespe Ck., Ventura River)
2. Compared areas contained in Valley Bottom to Total Area of unit

Stetson Maps	Green Valley	Mark West
Recent near-stream alluvial deposits (adjacent to bedrock)	**70.4%**	**81.6%**
Stream Channel Alluvial Deposits (not adjacent to bedrock)	**88.5%**	**95.0%**
Potential Stream Depletion Area (older alluvial deposits)	25.4%	34.2%

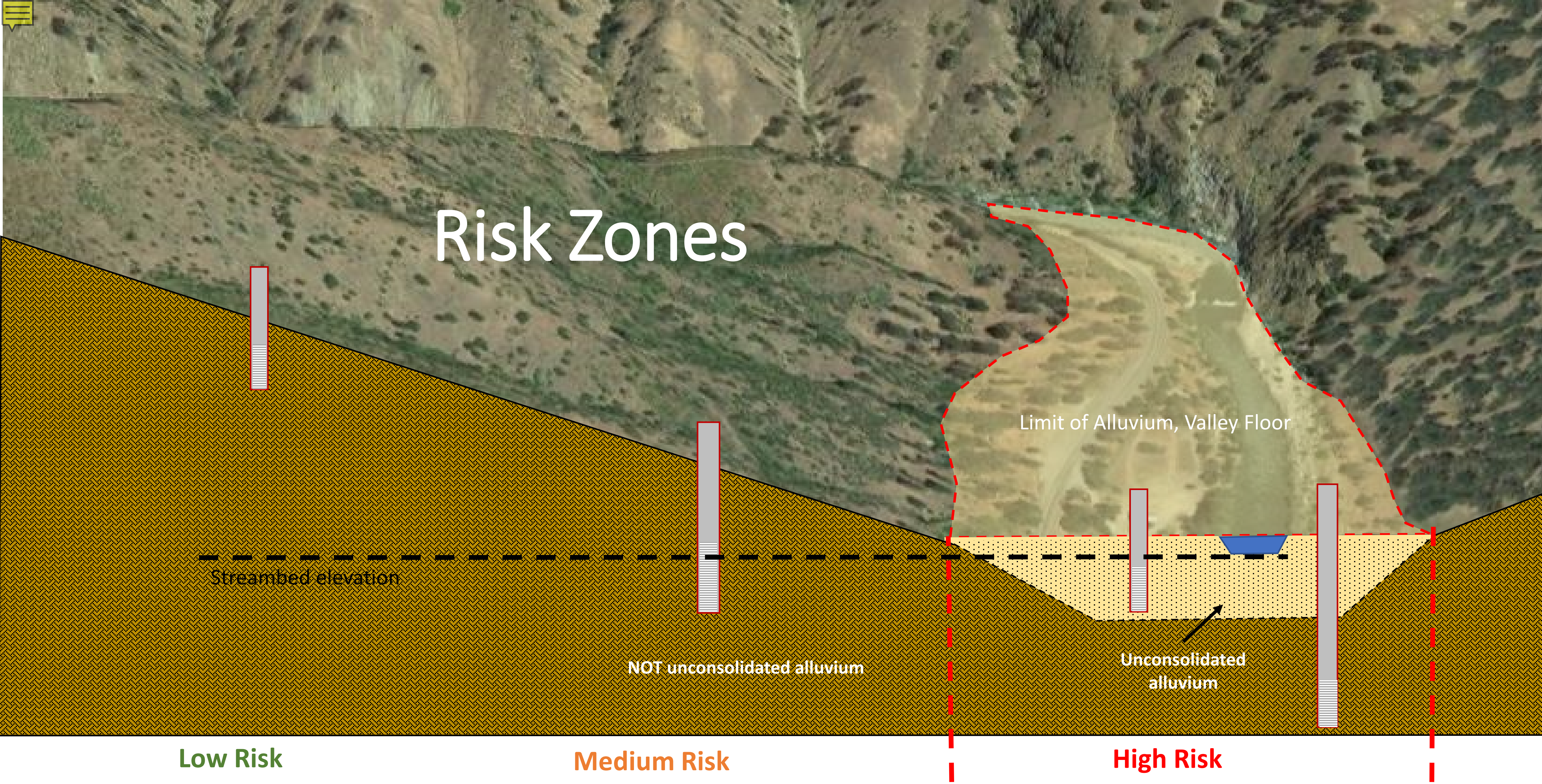
Values in these tables represent the percentage of the total unit in a watershed that falls within the Valley Bottom polygon.

Explanation of differences in results:

- Different goals behind efforts
- Differences in Stream Location (NHD vs 1:24k vs 1:100k)
- Most areas not captured by V-BET appear on valley walls when overlaid on 10-m DEM (used in V-BET)
- Compared to Stetson, V-BET does well at identifying areas of recent alluvial deposits
- Compared to Qal maps, V-BET does well at identifying more recent alluvium

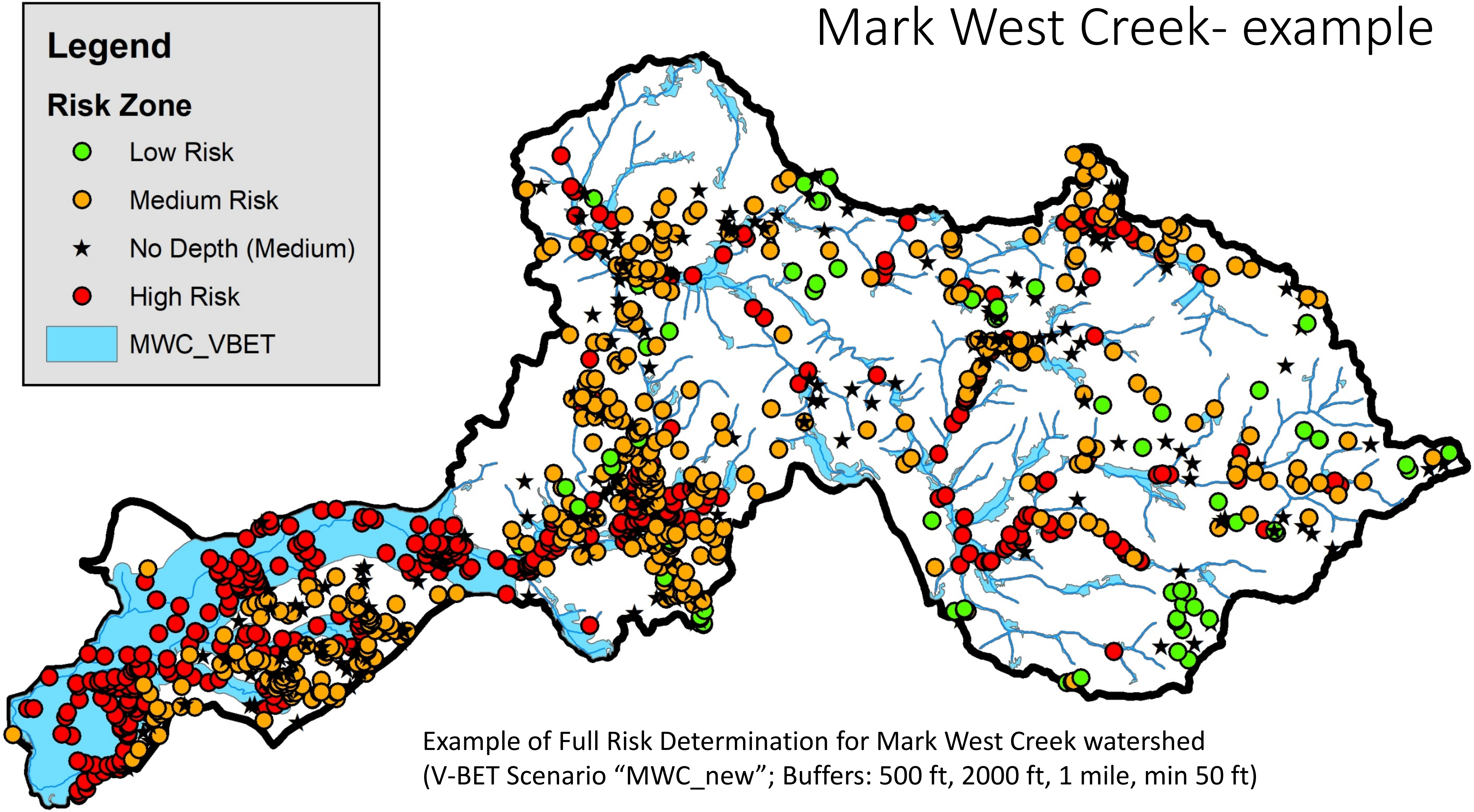
Quaternary Deposits in Southern California

Type	Age	Quaternary	Sespe Ck	Ventura River
Wash	**Qw**	Youngest	**88%**	**94%**
	Qyw	Younger	NA	NA
	Qow	Older	NA	NA
	Qvow	Oldest	NA	NA
Fan	**Qf**	Youngest	**75.9%**	**63.1%**
	Qyf	Younger	**71.4%**	NA
	Qof	Older	37.8%	27.5%
	Qvof	Oldest	NA	NA
Valley	**Qa**	Youngest	**80%**	**62%**
	Qya	Younger	**77.2%**	**45.8%**
	Qoa	Older	38%	44.2%
	Qvoa	Oldest	0%	NA
Terrace	**Qt**	Youngest	NA	**92.7%**
	Qyt	Younger	**66%**	NA
	Qot	Older	25%	NA
	Qvot	Oldest	6.4%	NA



The High Risk Zone can be defined without well information. Well location and depth are needed to separate the Medium and Low Risk Zones based on the well base in relation to streambed elevation (Low Risk wells can only intercept discharge).

Mark West Creek- example

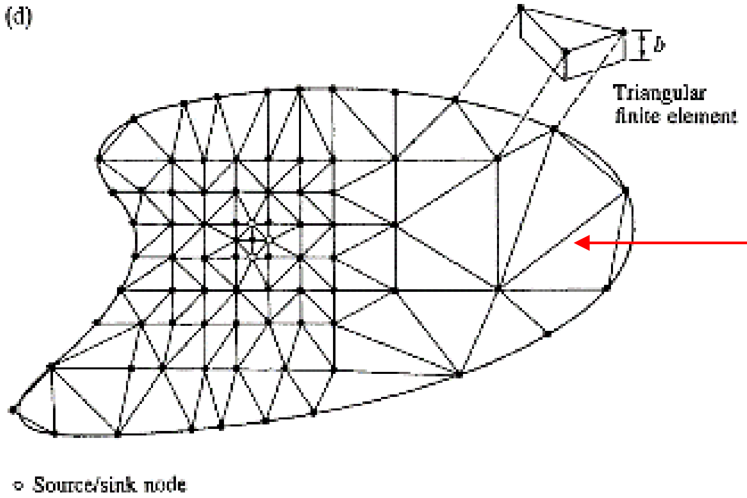


Example of Full Risk Determination for Mark West Creek watershed
(V-BET Scenario “MWC_new”; Buffers: 500 ft, 2000 ft, 1 mile, min 50 ft)

Quantitative- Comparative Modeling approach

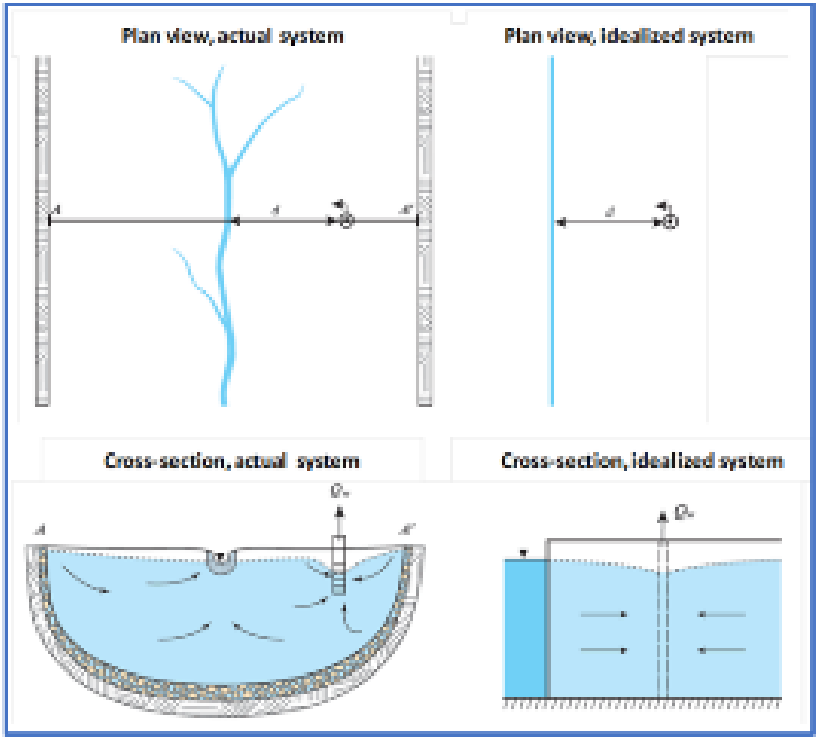
Goal: Identify Analytical models (easy to implement) to best approximate well impacts to streams (Depletion)

- Identify the conceptual analytical models with existing calculators (# layers, f/p penetration, boundaries)
- Develop a Numerical model (MODFLOW) to match the conceptual model (then vary geometry)
- Approximate the Numerical model with the analytical calculators
- Compare results to identify the best analytical model for each scenario & overall



Types of Solutions of Mathematical Models

- Analytical Solutions: h= f(x,y,z,t) (example: Glover equation)
- Numerical Solutions
  - Finite difference methods
  - Finite element methods

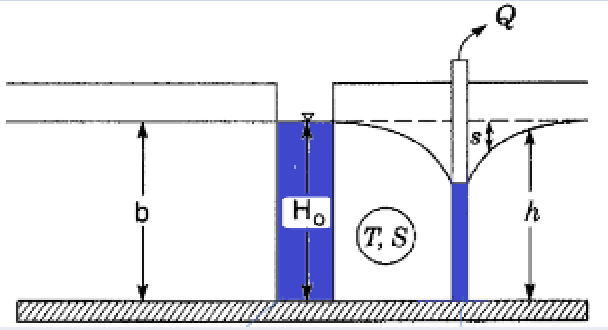


$$\iint_D \left(\frac{\partial^2 \hat{h}}{\partial x^2}+\frac{\partial^2 \hat{h}}{\partial y^2}\right) N_L\,dx\,dy = -\iint_D \left(\frac{\partial \hat{h}}{\partial x}\frac{\partial N_L}{\partial x}+\frac{\partial \hat{h}}{\partial y}\frac{\partial N_L}{\partial y}\right)dx\,dy + \int_\Gamma \left(\frac{\partial \hat{h}}{\partial x}n_x+\frac{\partial \hat{h}}{\partial y}n_y\right)N_L\,d\sigma$$

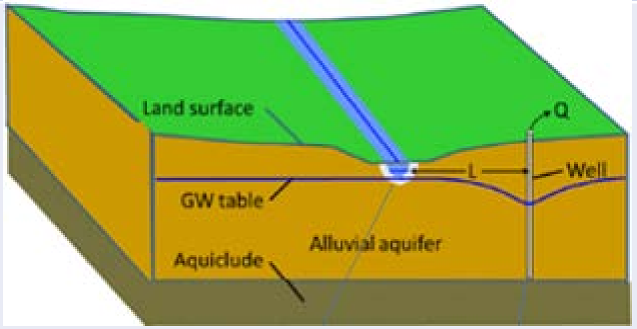
$$\frac{\Delta Q_s}{Q_w} = erfc\left(\sqrt{\frac{Sd^2}{4Tt}}\right) - erfc\left(\sqrt{\frac{Sd^2}{4T(t-t)}}\right)$$

8 Conceptual analytical models with existing calculators

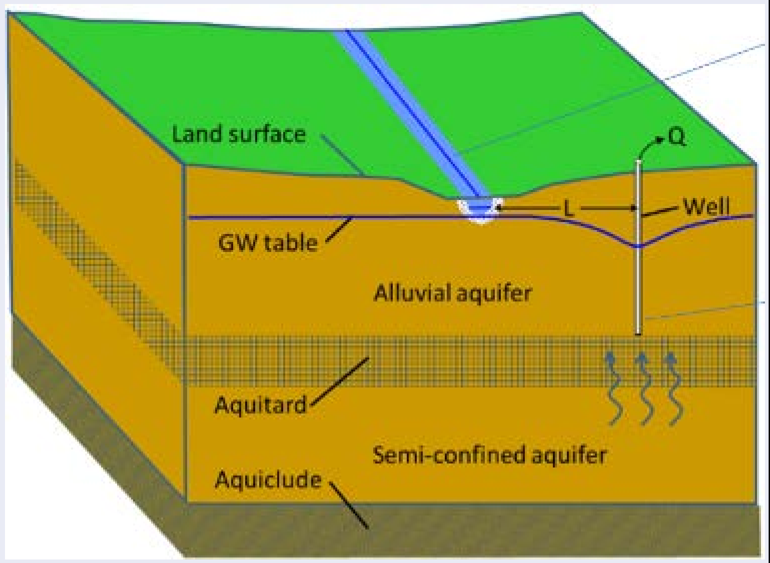
Jenkins 1968 (Variables = 5)



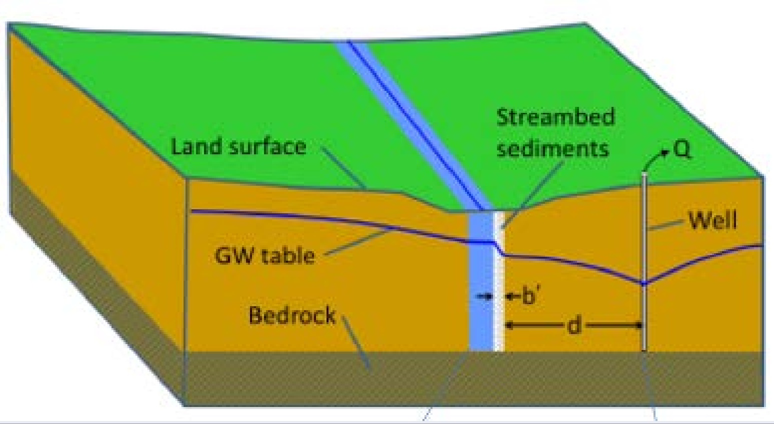
Hunt 1999 (Variables = 6)



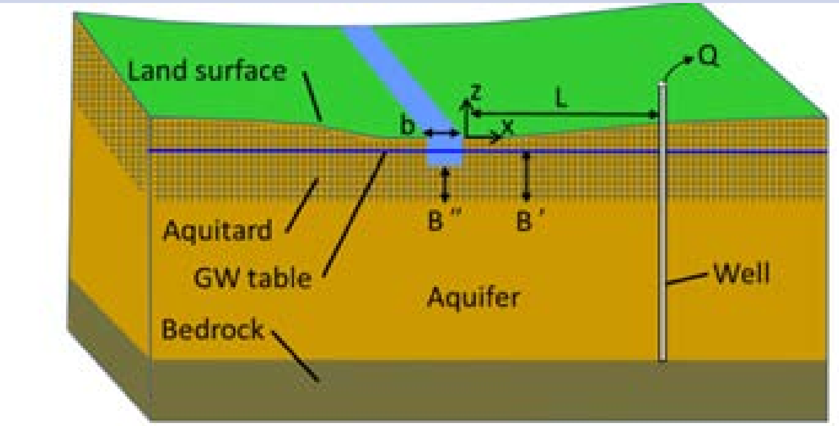
Hunt 2009 (Variables = 10)



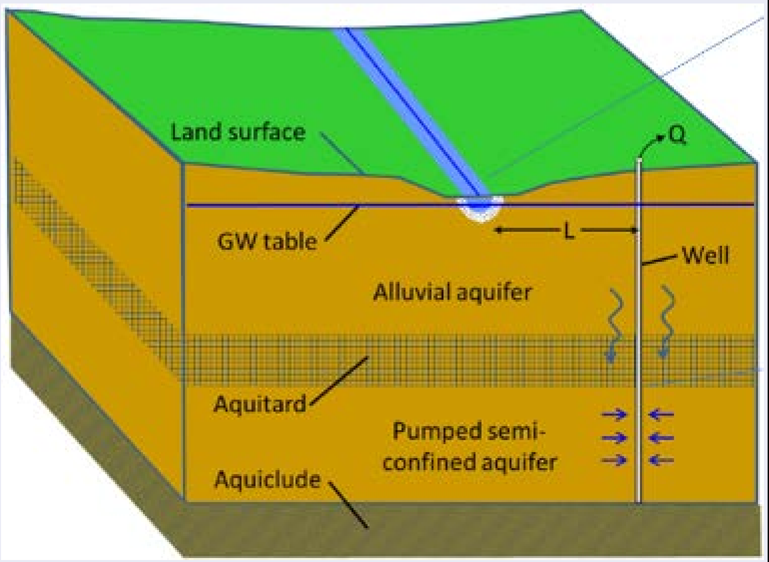
Hantush 1965 (Variables = 6)



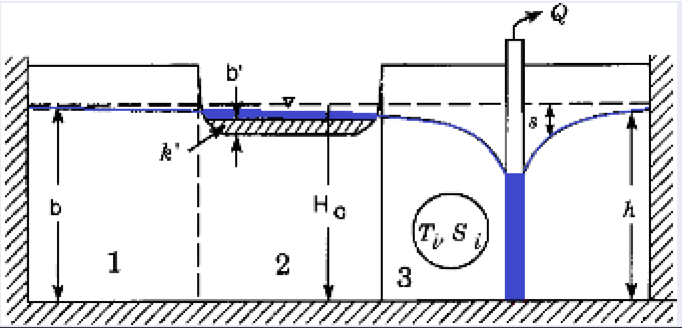
Hunt 2003 (Variables = 10)



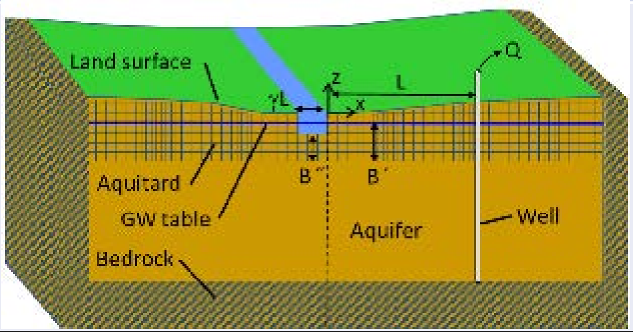
Ward & Lough 2011 (Variables = 9)



Butler 2001 (Variables = 7)



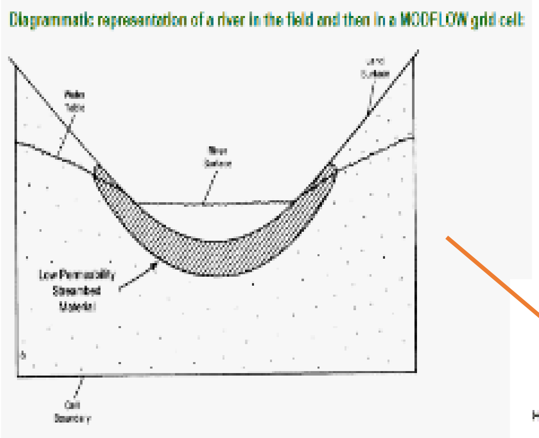
Hunt 2008 (Variables = 14)



MODFLOW

Built 8 conceptual models in MODFLOW, multiple scenarios for some:

- Varied number of layers (aquitards and aquifers)
- Varied boundary conditions (no flow to unlimited)
- Varied valley widths
- Varied well setbacks



The River Package (RIV) considers the streambed conductance and river head:

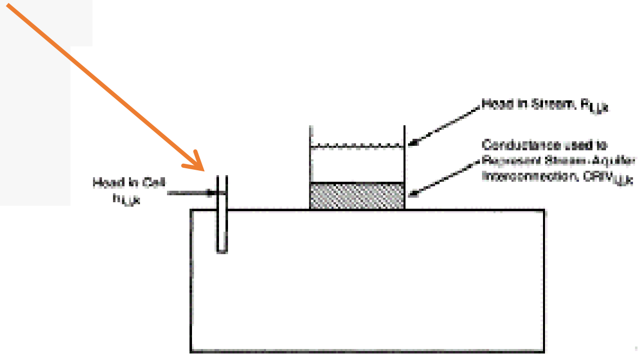
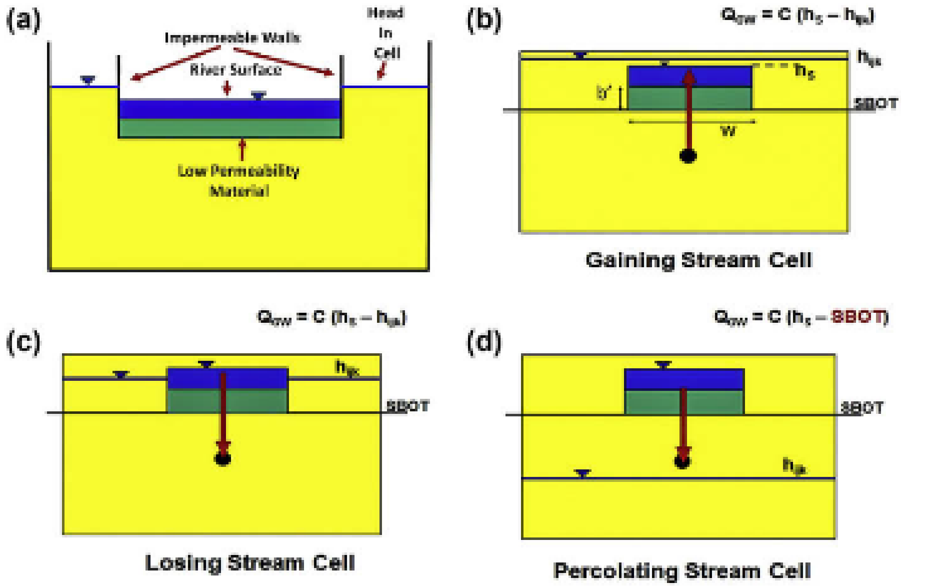


Figure 5.—Conceptual representation of leakage through a riverbed into a cell.

We used MODFLOW 2005 and Model Muse GUI with the following Packages (DRN and STR were used alternatively instead of RIV is few scenarios) :

Functionality	Package or process Name
LPF	Layer-property flow package, With Flat bed-rock, top of layer, water table, all sides as no-flow boundaries, with symmetric cell sizes.
RIV	**River Package, straight-line, river stage same as aquifer head, partially penetrating, with river bed below water table**
WEL	Well package, constant pumping rate, fully penetrating
PCG	Preconditioned – Conjugate Gradient Package solver
DRN	Drain Package
STR	Stream Package

How RIV package considers different stream types:



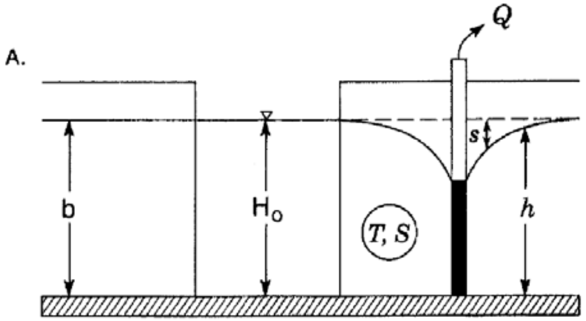
Analytical Models

Input | Output

Fully penetrating stream with no streambed resistance (Jenkins, 1968)

Distance (ft):
Transmissivity (ft2/day):
Storage Coefficient:
Pumping Rate (gpm):
Days of Pumping:

Reset | Submit

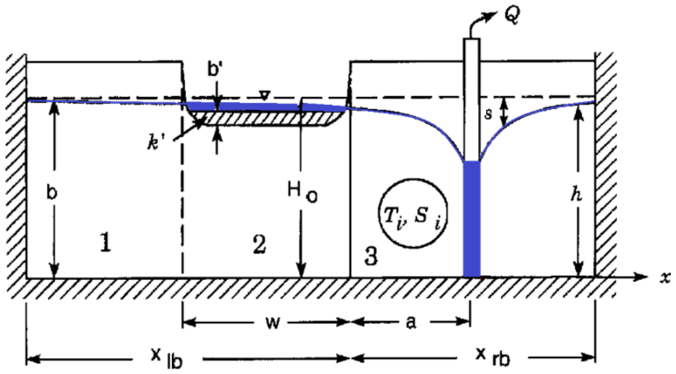


Jenkins/Glover

https://mi.water.usgs.gov/software/groundwater/CalculateWell/index.html

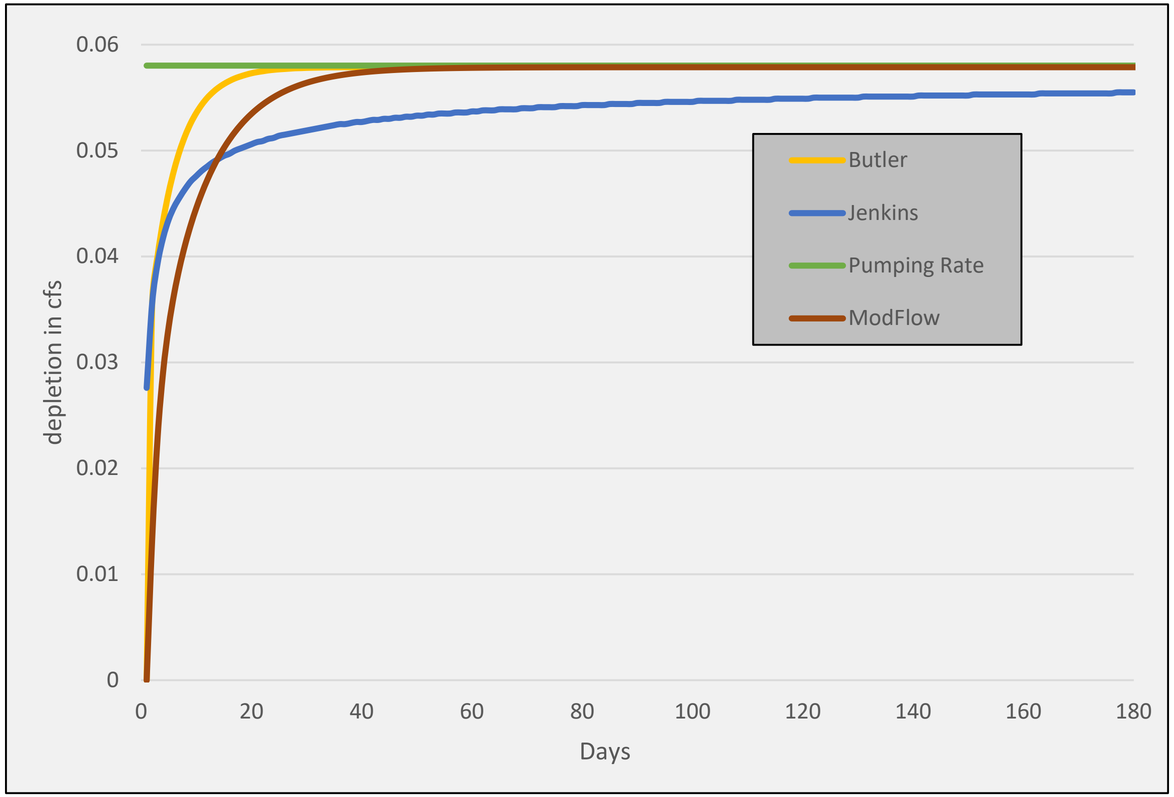
```
1                    /IOBS(no. of obs. wells)
10.0, 0.00           / XOBS1, YOBS1
82.5, 0.00           /XPUMP, YPUMP
0.5                  /RADIUS OF PUMPING WELL
625  0.15            / T AND S ZONE 1
625  0.15            / T AND S ZONE 2
625  0.15            / T AND S ZONE 3
-218.0, 182.0        /LEFT BOUNDARY, RIGHT BOUNDARY
20                   /WIDTH OF CENTER STRIP
25 0.01              /K AND THICKNESS OF STREAM BED
5000. 0 1 1 1        / Q, STOPT, TAU, TAUSTEP, TAUINC
180 1                / NTAU, IPRINT
10                   /N (NO. OF STEHFEST TERMS)
1.E-9                /TLIMIT1 (REL. ERROR)
```

Variables shown in red



Butler 2001(Valley Walls)

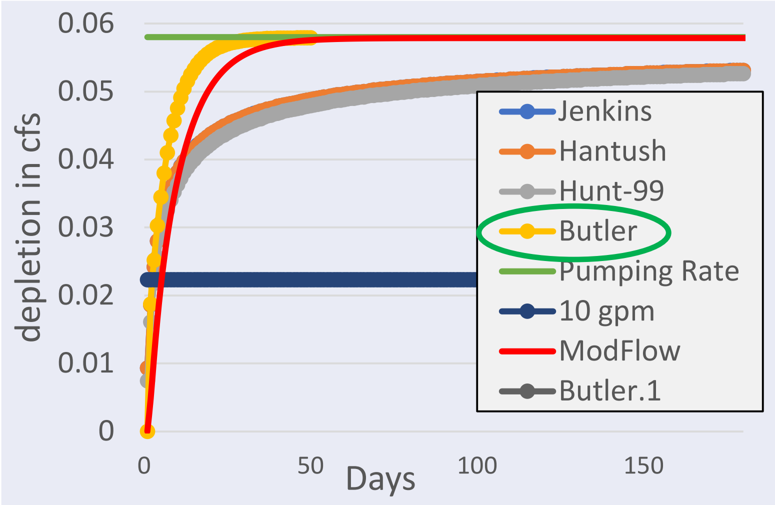
http://www.kgs.ku.edu/StreamAq/Software/strp.html



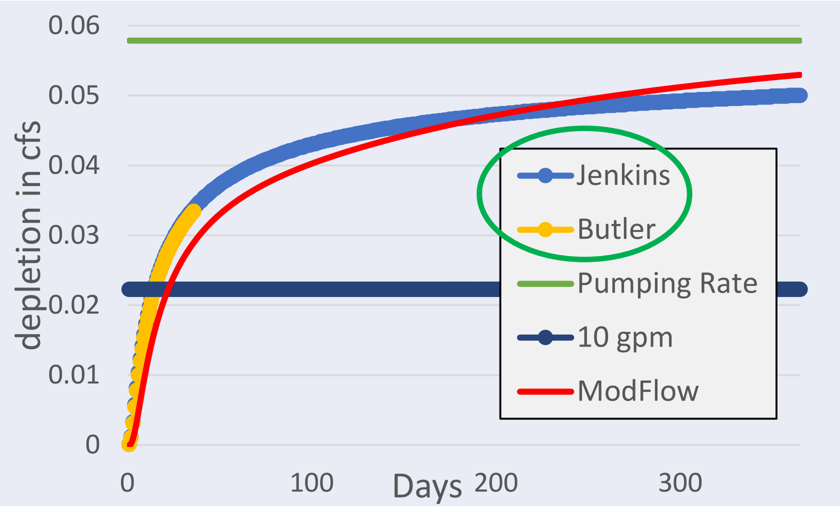
Analytical Model	Online	DOS .exe	R Studio	Intermittent or Continuous Pumping	Recovery
Jenkins (Glover)	X	X+online	X	X	X
Hantush	X	X+online	X	X	X
Hunt-'99	X	X+online	X	X	X
Hunt-'03	X	X+online		X	X
Butler		X			

Analytical models validation vs numerical (which looks best)?

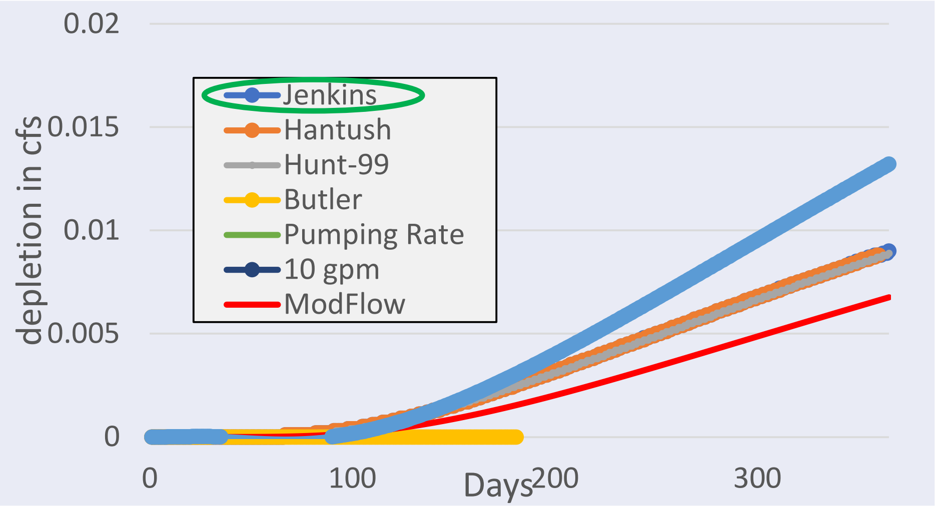
LW500’-1W-180d- 128‘ Setback



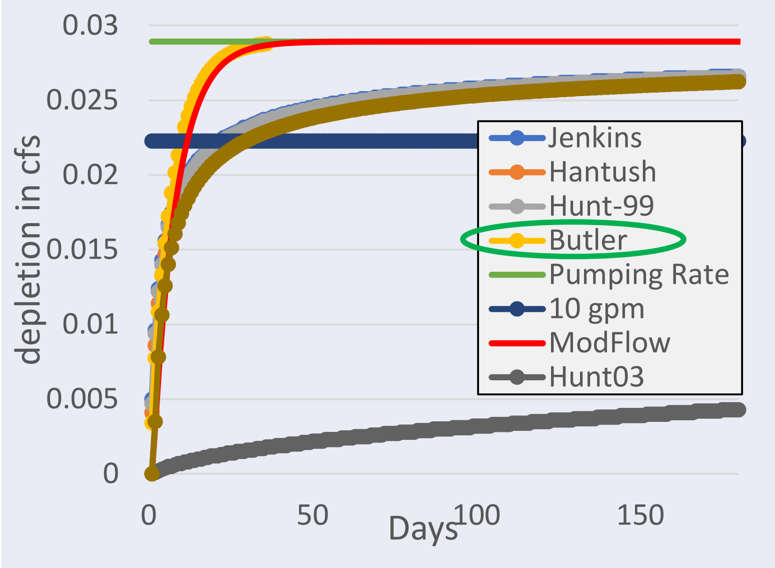
LW2640’-1W-365d- 300‘ Setback



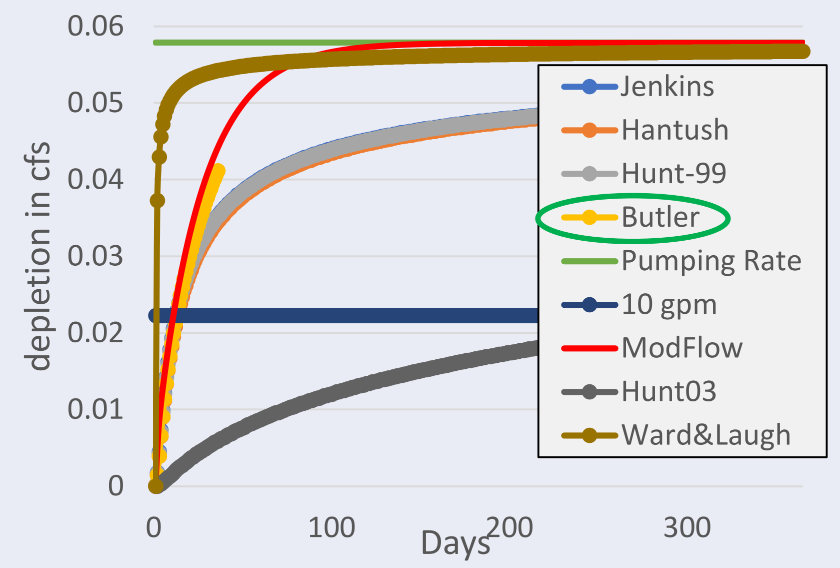
LW10,000’-1W-180d- 2480’ Setback



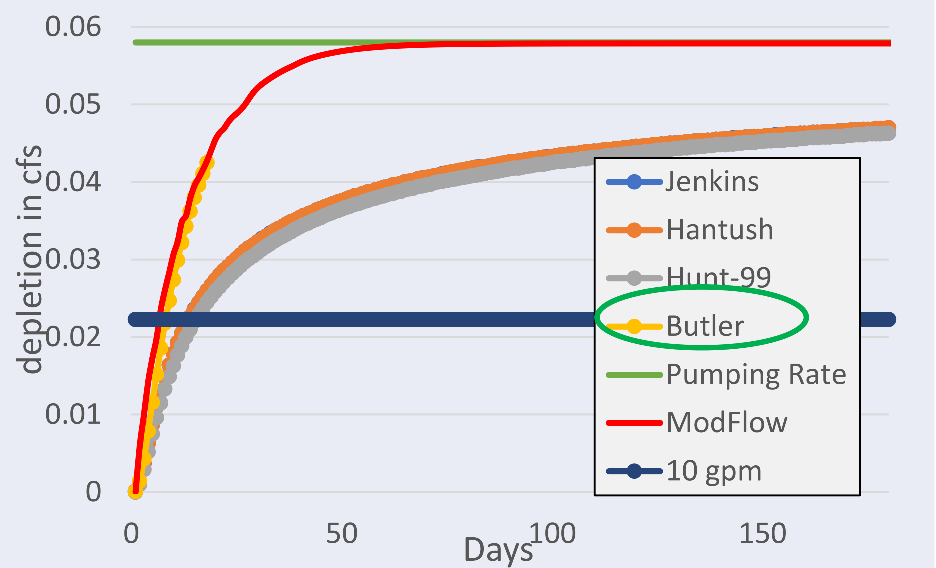
LW500-1W-365d-3L- Hunt’09



LW1000-1W-365-3L Ward & Laugh



LW1000-1W-180d-2L



Recommended Analytical Models[1]

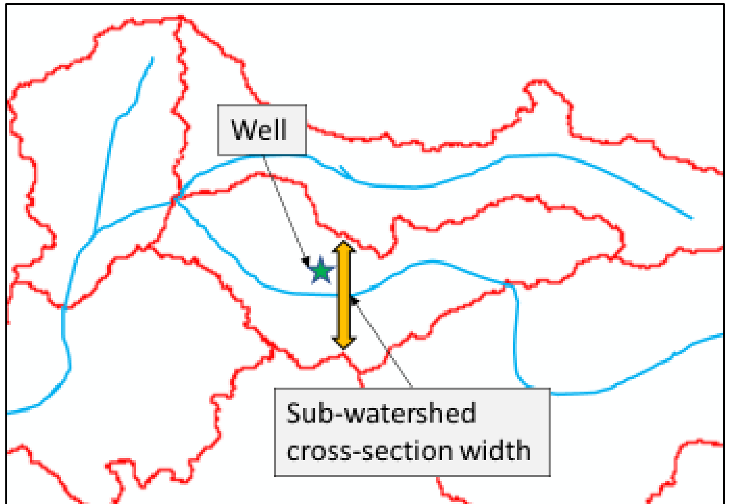
High Risk Zone			Medium or Low Risk Zone	
Valley Bottom Width >1,000 ft wide[2]	Valley Bottom Width < 1,000 ft wide			
Alluvial or Non-Alluvial (deep) well	Alluvial Well	Non-Alluvial (deep) Well	Sub-Watershed Width[4] <1,000 ft wide	Sub-Watershed Width >1,000 ft wide
Jenkins Model	**Butler** Model	**Butler** Model[3]	**Butler** Model	**Jenkins** model
Models use parameters from aquifer screened by well				

[1]- Subject to change based on additional modeling results or new calculators, and will likely vary geographically

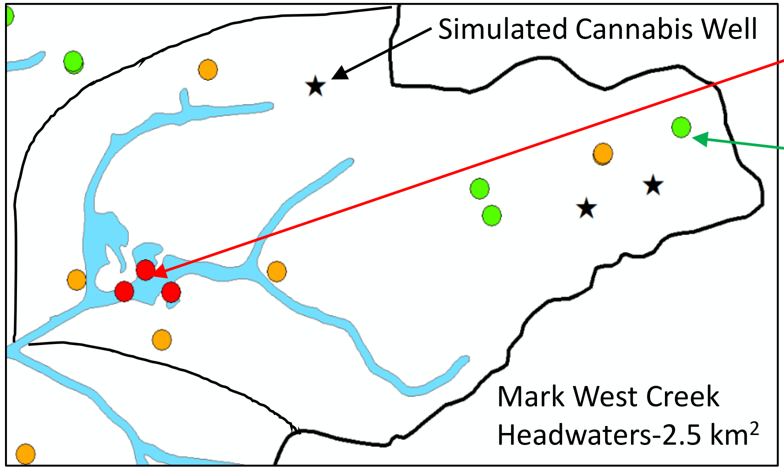
[2]- additional scenarios with varying aquifer parameters may modify transition distance threshold

[3]- Modeling ignored alluvium and aquitards

[4]- Sub-watershed cross section width

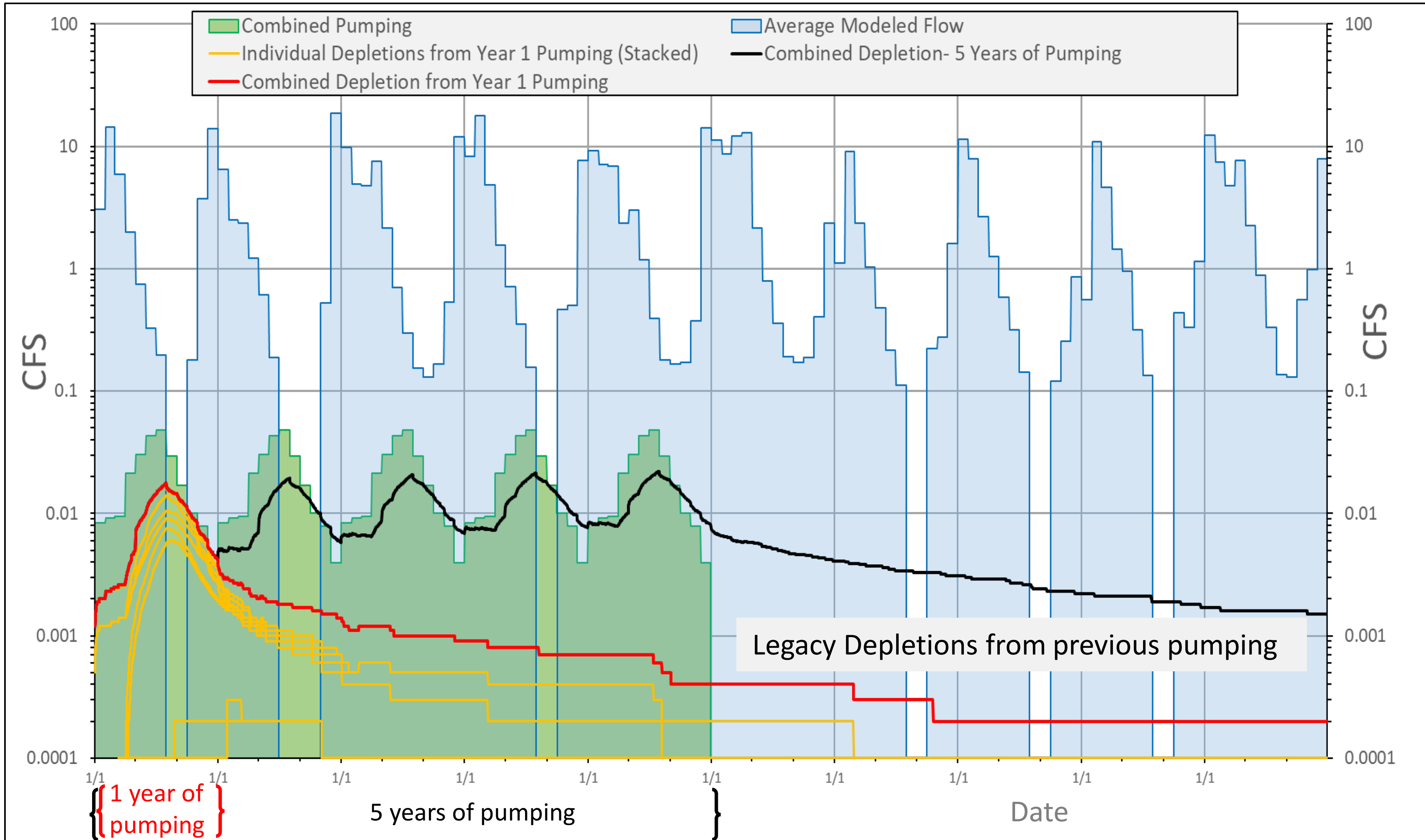


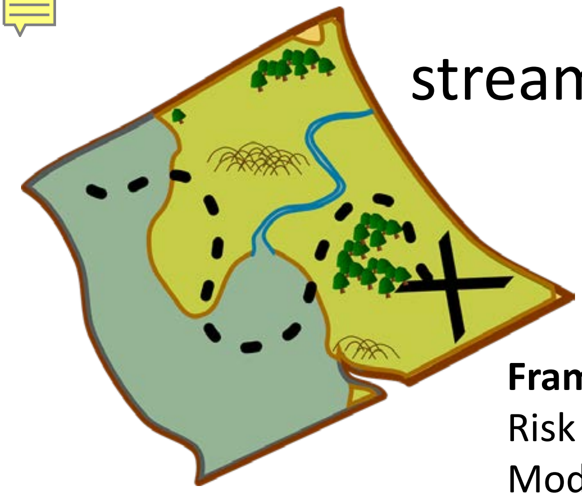
Example application in Mark West Creek using modified Emergency Regulation Data



Total Pumped= 72.03 acre-feet
Total Stream Depletion= 60.59 acre-feet
Stream Depletion Duration= ~45 years
Loss of Aquifer Storage= 11.45 acre-feet

1. Run V-BET tool to ID High Risk Zone
2. Identify Well Locations and details
3. Estimate Aquifer Parameters
4. Determine Analytical Model Use (chart)
5. Run Model for each well
6. Estimate streamflow
7. Plot results (individual or cumulative)





streamflow Depletion Risk Assessment Framework & Tools

Framework:
Risk Zones
Modeling Decision Chart

Tools:
Valley Bottom Extraction Tool
Analytical Model Calculators

Next Steps…

- Solicit feedback
- Develop additional examples to demonstrate Decision Support
- Complete documentation of sDRAFT
- Develop general guidance on this topic:
  - Assemble statewide (coarse) datasets (identify procedures to enrich locally)
  - Pre-stage some data or products to make usable

Questions?

Jeffrey.Sanchez@waterboards.ca.gov Behrooz.Etebari@waterboards.ca.gov