Reservoir Yield R&D Unit

Water Supply Workshop
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Outline

- Determination of Yield, Sizing Reservoirs
  - Storage / Yield Relationship
  - Simple Yield Computation Methods
  - Alternatives to Critical Period Analysis
  - Reliability
- Water Supply Contracts – different question
  - Firm Yield R&D
  - Methods in the Field
  - Yield in ResSim

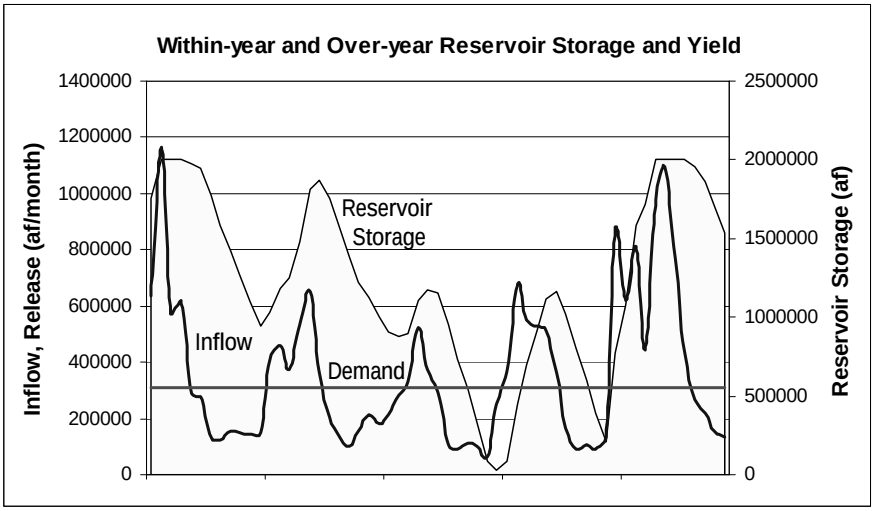
Redistribution of Water

The function of a reservoir system is to redistribute the natural occurrence of water in time and place.

- Formerly, people settled near rivers and used water as it arrived.
- Then we built reservoirs to accumulate and release water to improve the distribution in time...
  - store it when it comes, release as needed (supply) or at non-damaging rate (after flood)
- ...and conveyance to improve the distribution in space

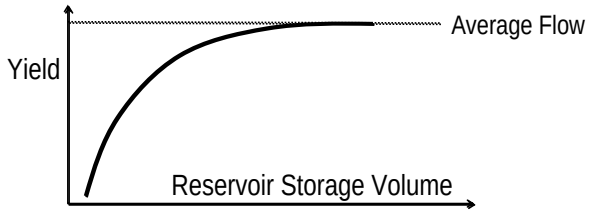
Distribution of Water in Time

- Within-year Reservoir Storage
  - Reservoir stores wet season water for use in the dry season
- Over-year Reservoir Storage
  - Reservoir stores wet year water for use in dry years or extended drought
- Evaluation of current and future demand and local hydrology will determine if within- or over-year is needed, and the required size of reservoir.



Storage / Yield of a Reservoir

- YIELD = amount of water that can be provided on a regular basis (yield $\leq$ average flow)
- The most basic evaluation is the at-site Storage / Yield relationship.



Storage / Yield Relationship

- In a study, there are 2 ways build the relationship:
  - Planning: For a given demand, how large must the reservoir at that location be?
  - Reassessment/Operations: For a given reservoir, what is the annual yield?

  Fix one variable, vary the other

  - *Supply Contract – what volume needed in existing reservoir to supply needed yield? (...share of inflow)*

Storage / Yield Relationship

- There are various methods for determining the relationship between reservoir storage and yield
  - Simplified Methods (Planning)
    - Rippl Mass Diagram (cum. inflow vs cum. demand)
    - Sequent Peak Algorithm (cum. net inflow)
  - Sequential Reservoir Routing (Operations)
    - simulation of realistic reservoir operation over a multiple year period
    - more complex demand patterns and sources can be evaluated, as well as losses

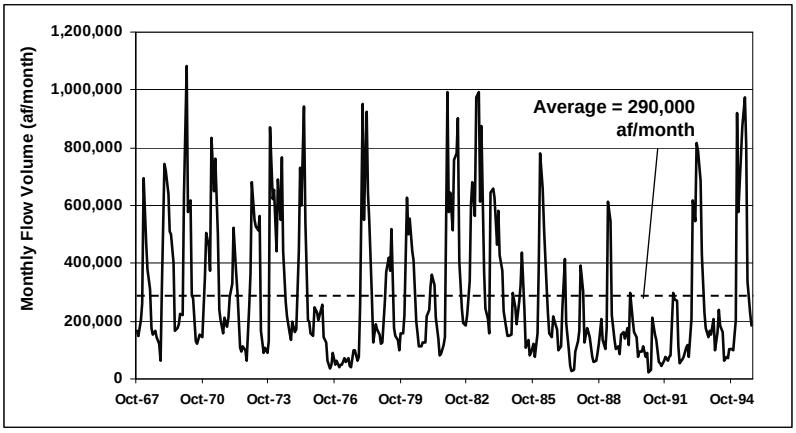
Input Data Needed...

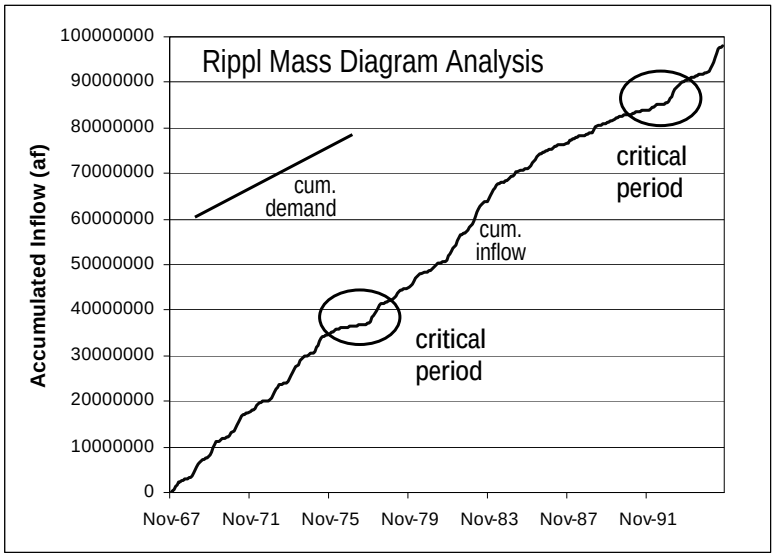
- The **supply** data used can be either
  - the historical record, or a critical dry period within the record – *be careful defining single critical period*
  - a synthetic drought event or data series
- The **demand** requirements can be either
  - 100% of actual or forecasted demand *constant or varied, depending on the method*
  - Partial demand, or demand met with some frequency or reliability

Set demand, compute needed storage

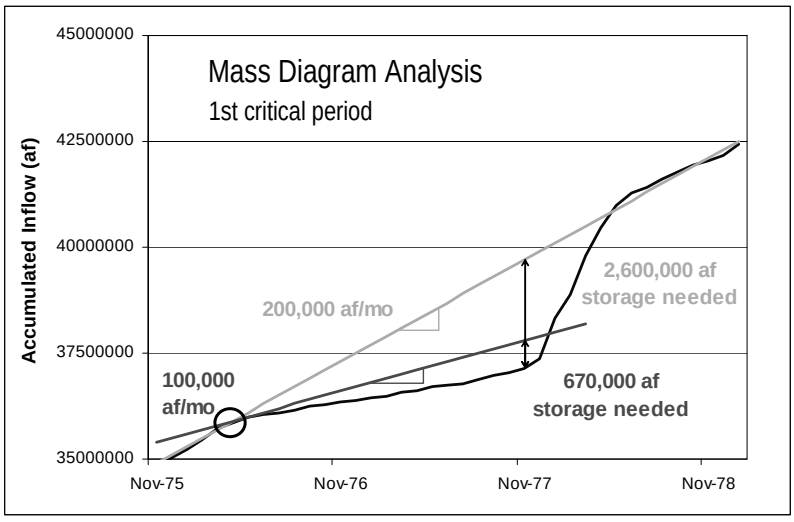
"Planning" Storage/Yield Analysis

Monthly Flow Volume, modified Feather River, Oroville, CA





demand must be constant...



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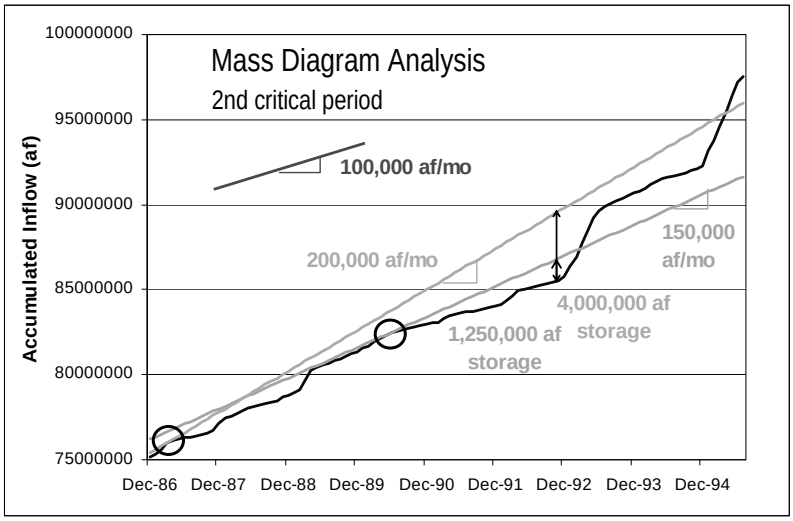

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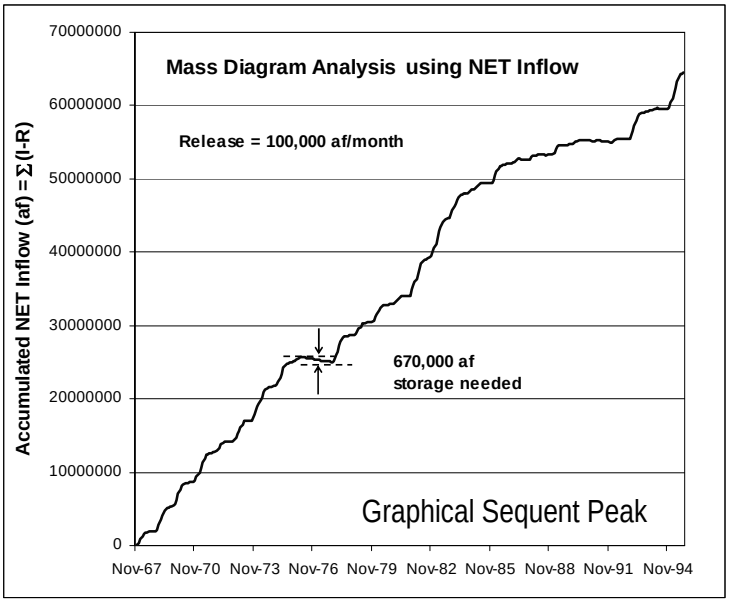
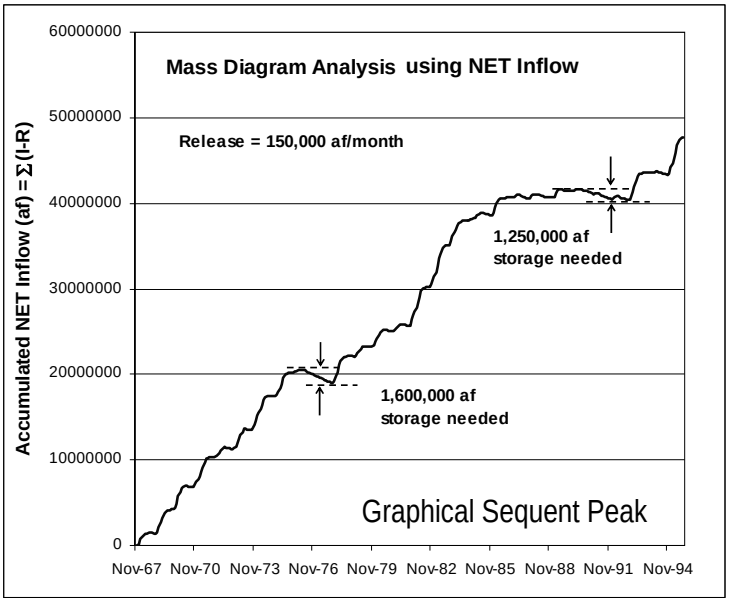


demand need <u>not</u> be constant...



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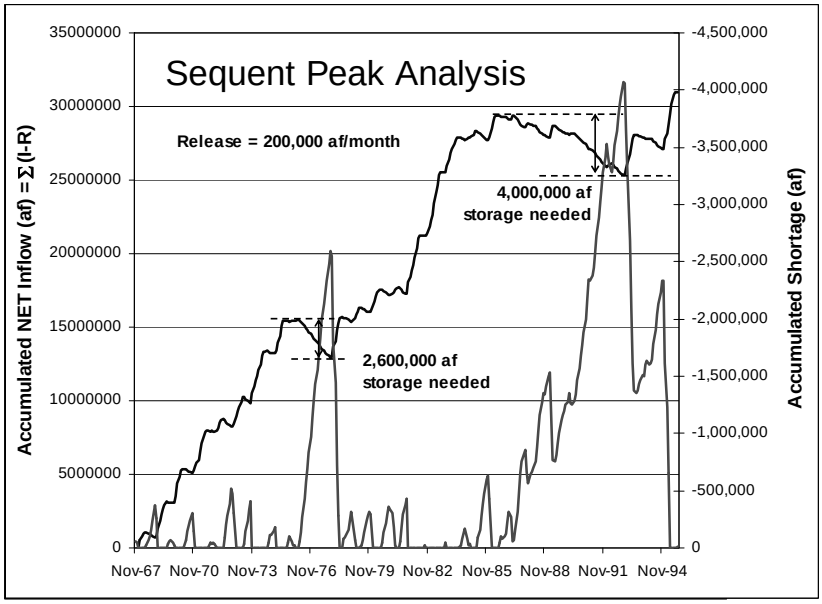
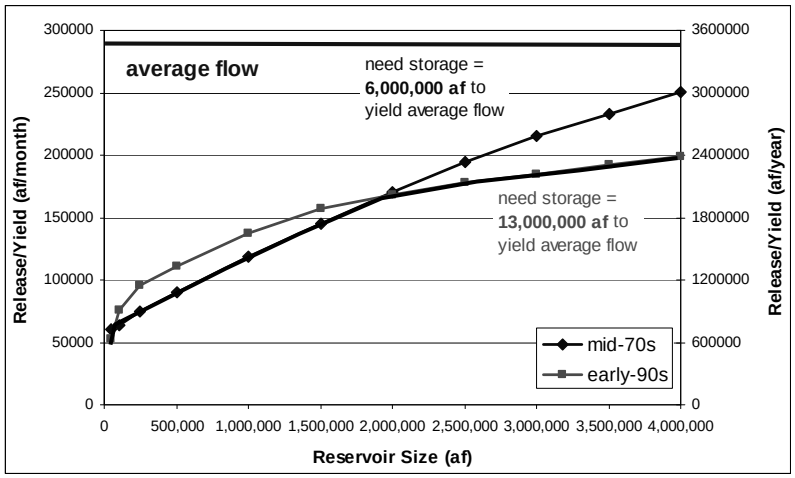


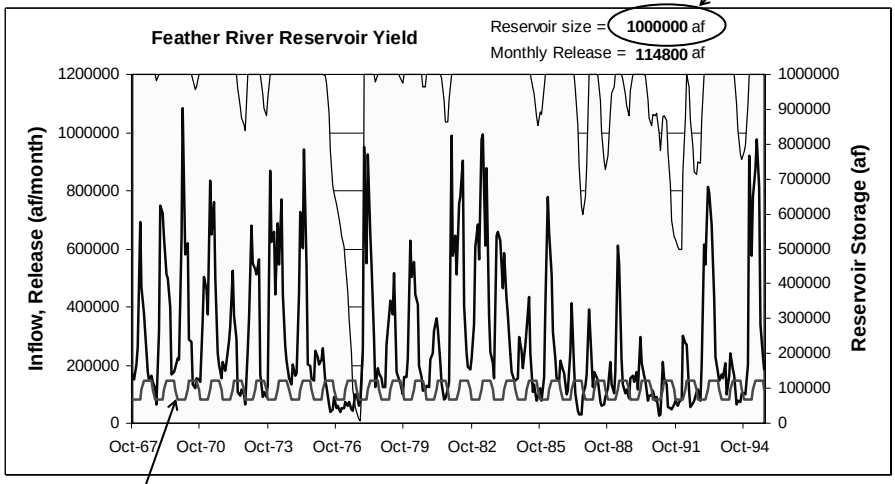
demand need <u>not</u> be constant...

Storage / Yield Relationship for Each Critical Period



Sequential Reservoir Routing

specify reservoir size

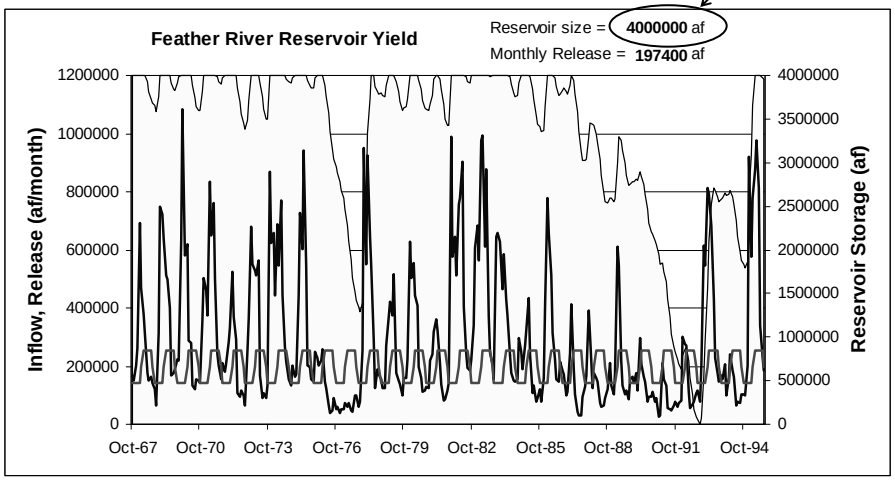


not release, doesn't include spill...

demand need <u>not</u> be constant...

Sequential Reservoir Routing

specify reservoir size



demand need not be constant...

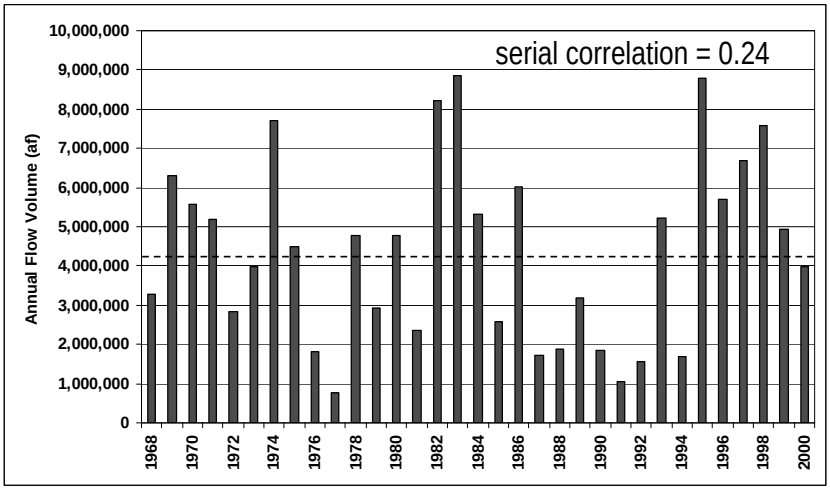
Critical Period Analysis

- These methods looked at historical critical periods of low streamflow and determined demand that could be met without failure ("worst case" analysis)
  - only one particular duration and magnitude -- many other drought options are possible
  - can be subject to sampling error with a short data set
  - also leads to false confidence about reliability
- Alternatives to critical period are probabilistic descriptions and synthetic data sets...

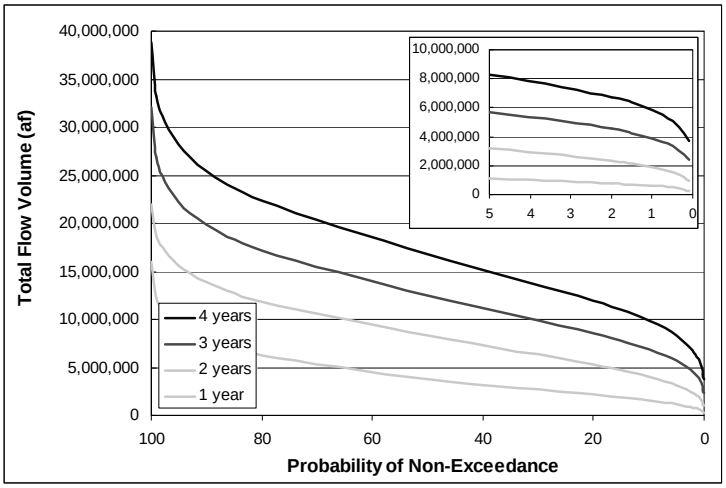
Alternatives to Critical Period

- Probabilistic description of drought
  - define a drought with a particular exceedance probability and duration
  - for this method, need to assume that annual volumes are independent...
- Specification of system reliability

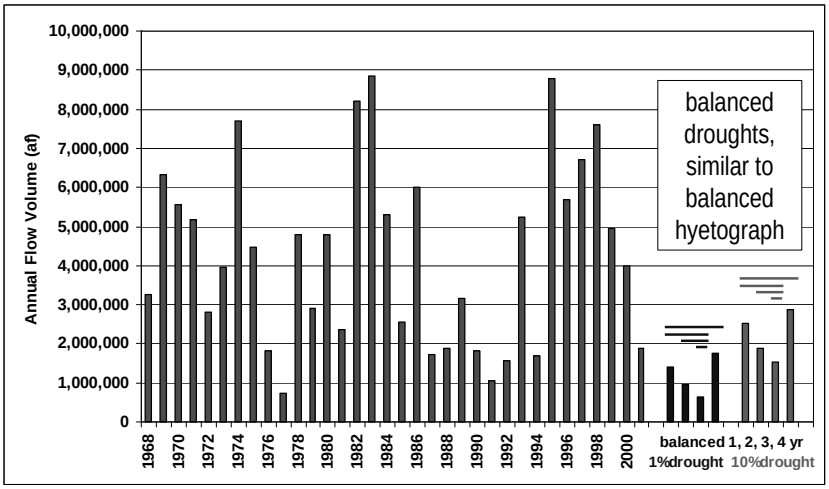
Annual Flow Volume, Feather River, Oroville, CA



Frequency of Drought Volume for Various Durations



Annual Flow Volume, Feather River, Oroville, CA



Statistics Issues...

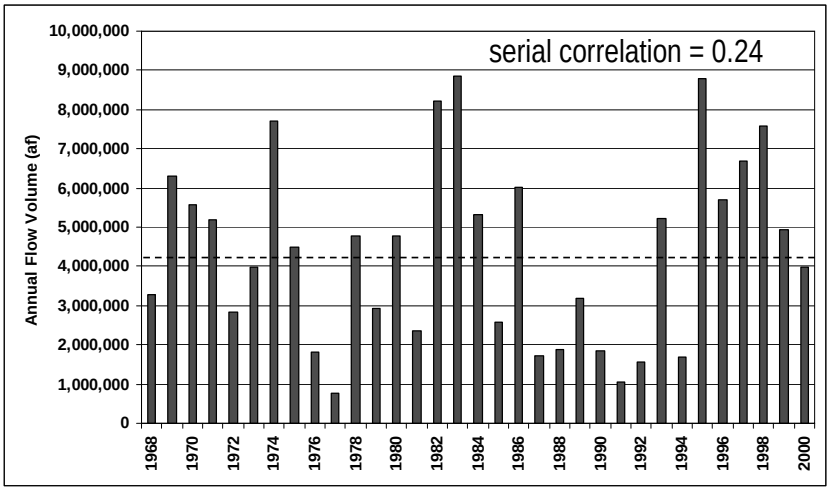
- For the creation of probabilistic balanced droughts, we assumed that annual volumes are independent, which in many cases is not accurate
- This assumption allowed frequency analysis on annual flow volume to determine volumes with 1% exceedence prob, or 5%, etc
- The same assumption can not be made on reservoir levels in an over-year system
  - ie, annual minimum elevations are NOT independent

Alternatives to Critical Period

- Probabilistic description of drought
- Specification of system reliability
  - use stochastic streamflow model to generate many years of synthetic flow
  - simulate reservoir operation with current demand, determine frequency of failure
  - determine a demand (yield) that provides certain probability of failure, ie 0.1%, 1%, 5%...

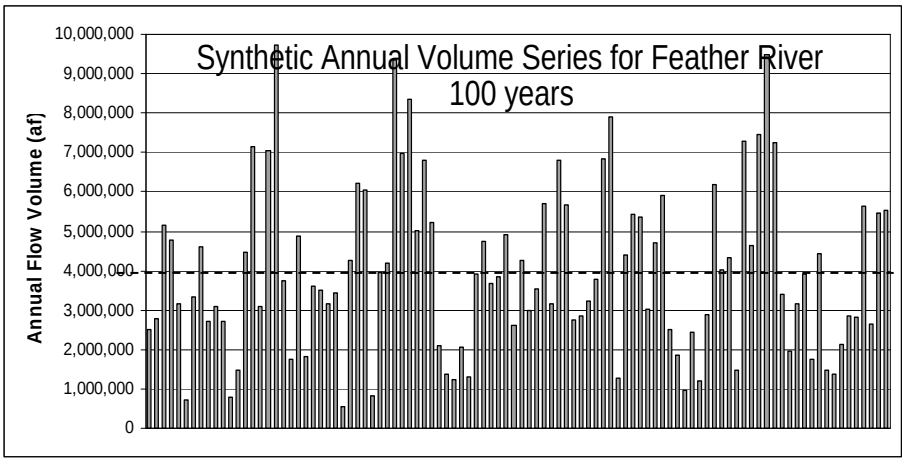
question: do we need 100% reliability?

aggregate monthly data into annual volume...

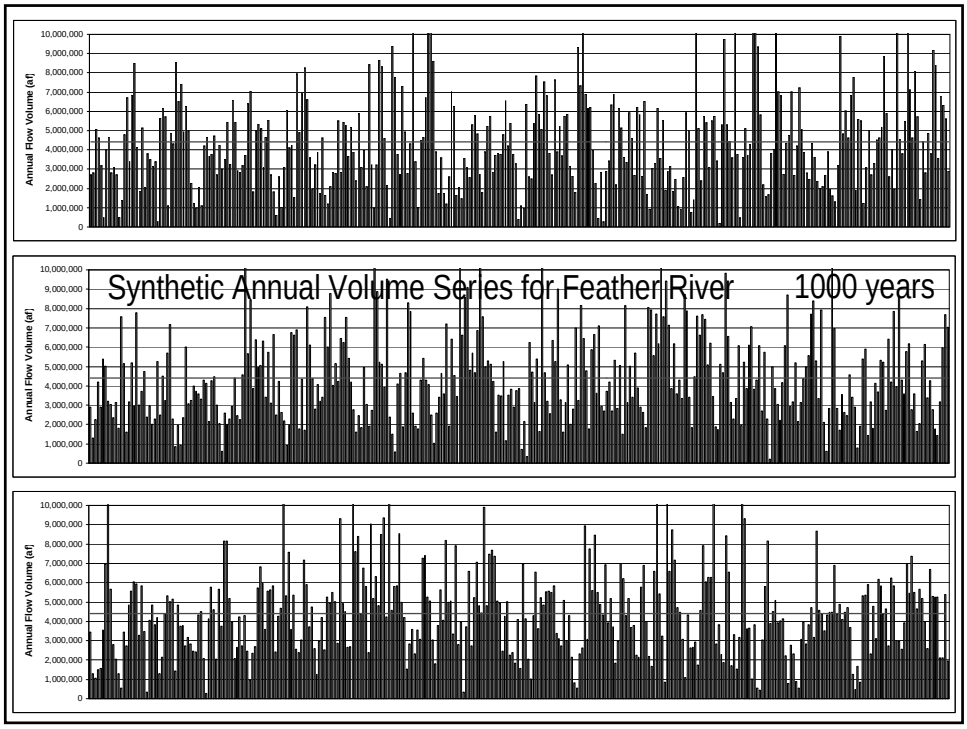


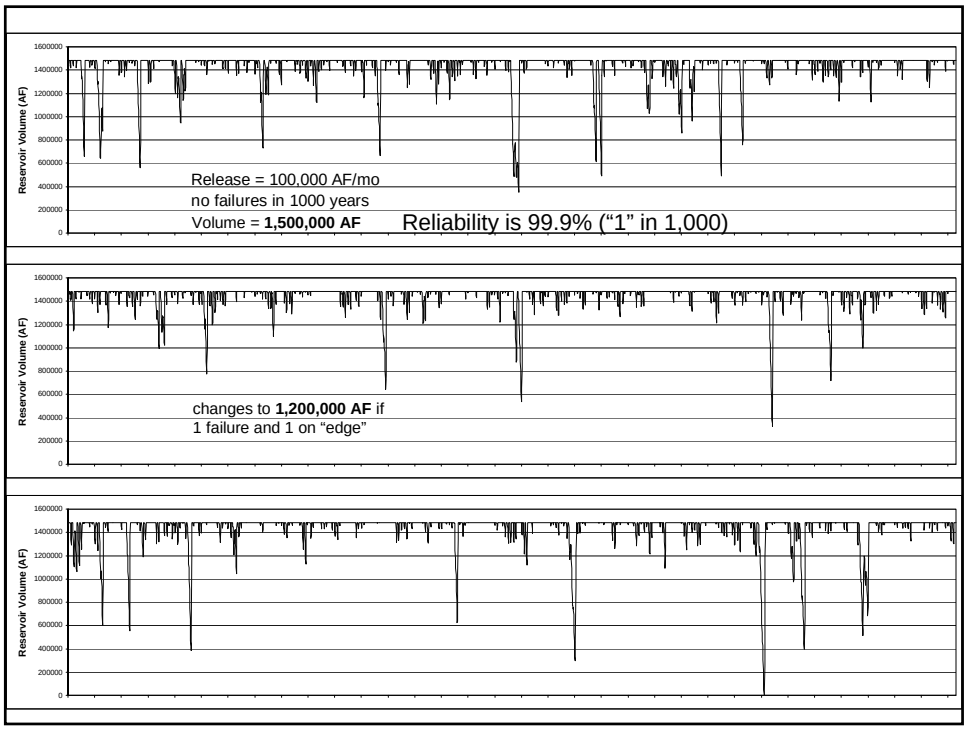
find mean, variance, correlation statistics...

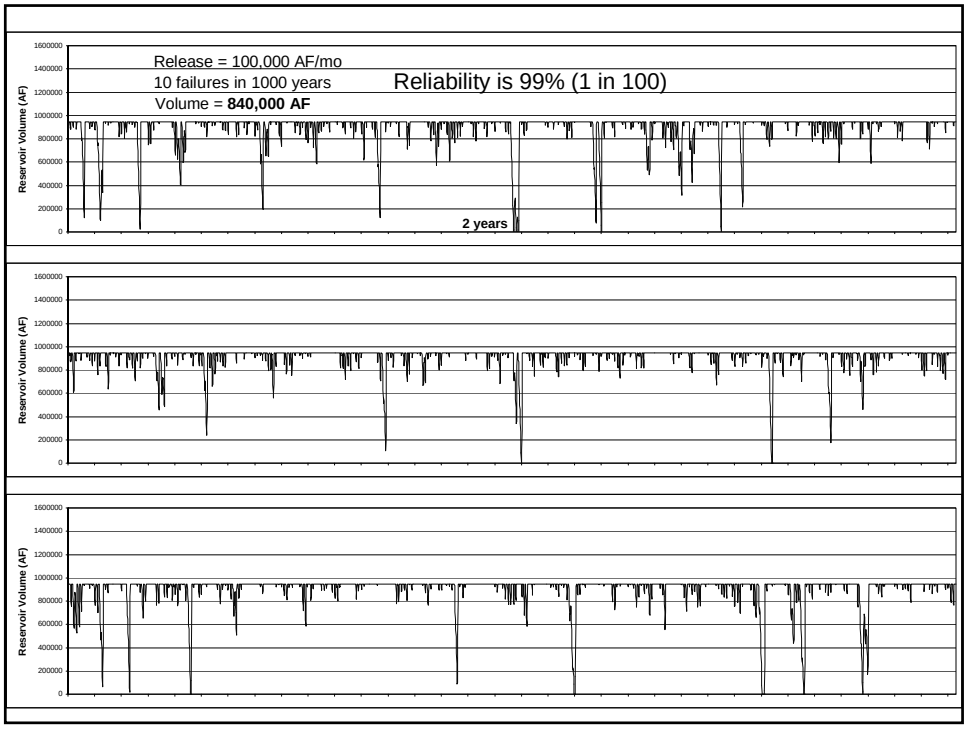
generate annual data with appropriate statistics using stochastic streamflow model AR(1)



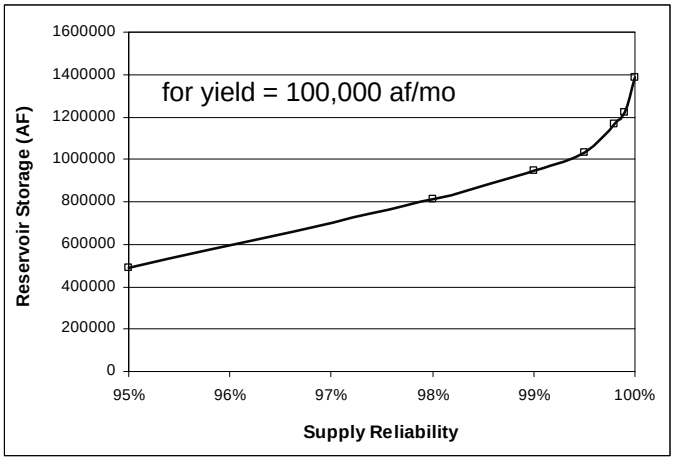
disaggregate annual volume into monthly...


Annual Flow Volume (af)
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Synthetic Annual Volume Series for Feather River 1000 years

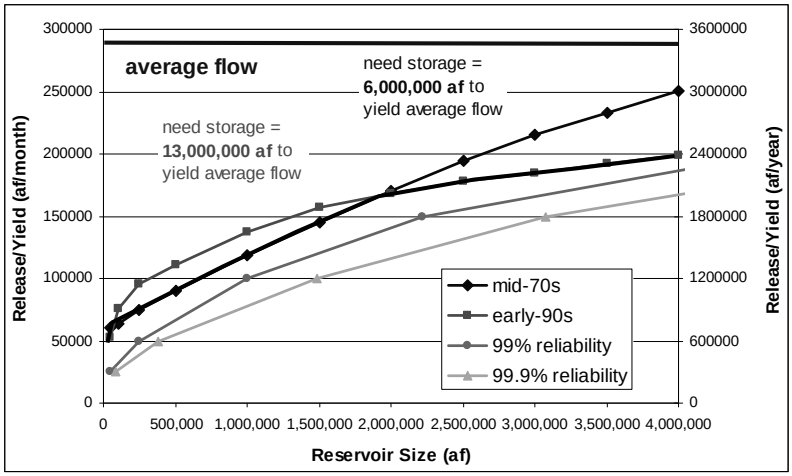

Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Release = 100,000 AF/mo
no failures in 1000 years
Volume = **1,500,000 AF**
Reliability is 99.9% (“1” in 1,000)
changes to **1,200,000 AF** if
1 failure and 1 on “edge”



Required Storage vs Reliability



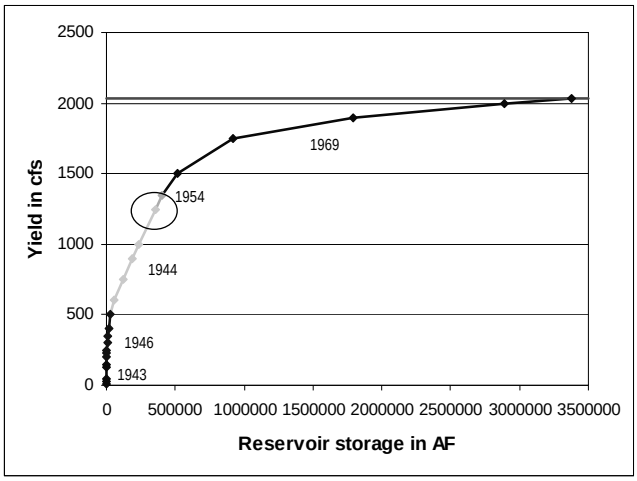
Storage / Yield Relationship for 1000 year series

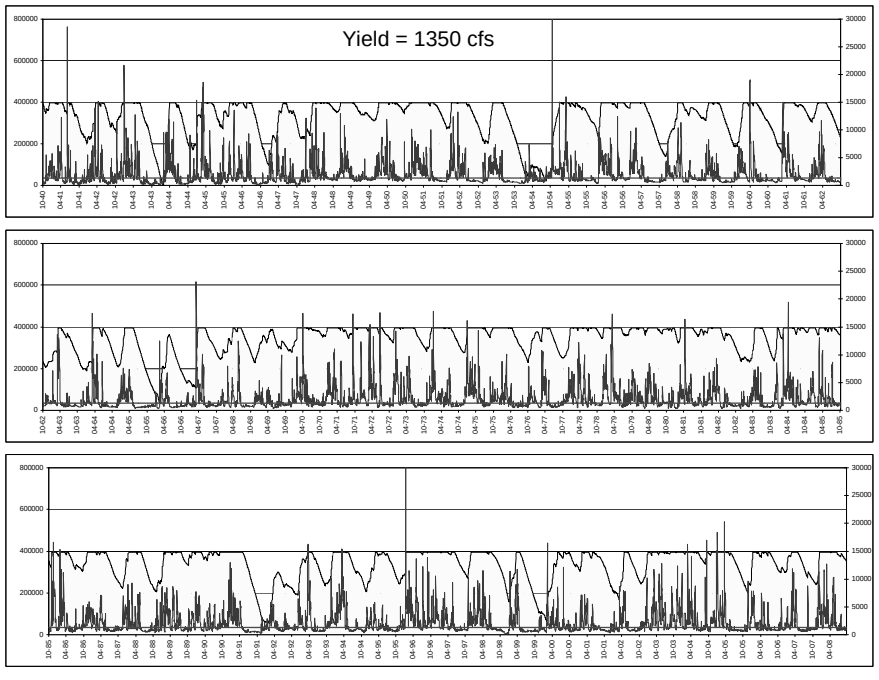


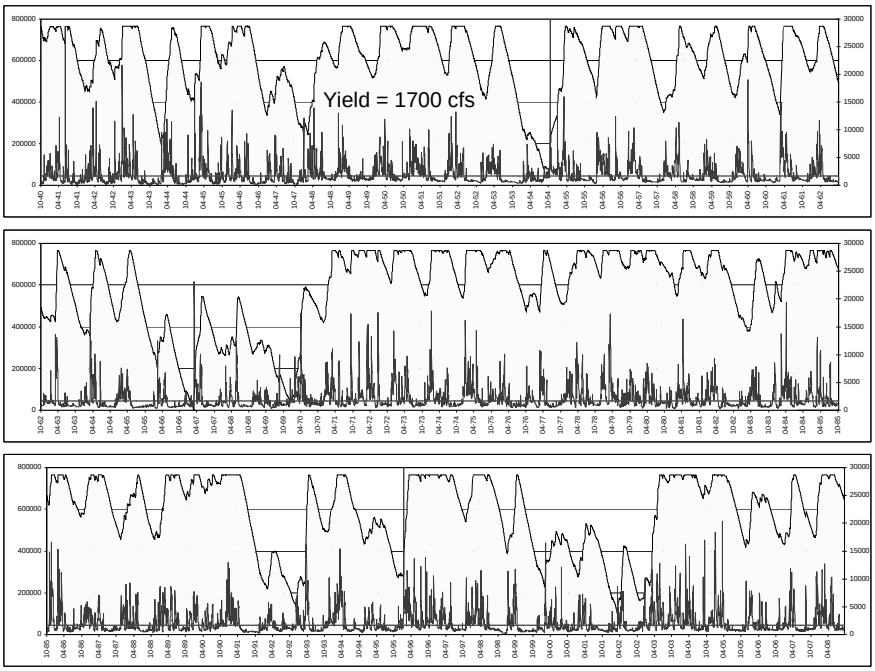
Water Supply contract volumes

- Question: In an existing reservoir, what volume is needed for user with demand of X mgd?
  - users seeking water supply will contract for a certain volume in the reservoir for their use
  - the important aspect is that the user is one of several users of the conservation pool
  - Some important questions are
    - "what access does the new user have to inflow...?"
    - "what accounting is made for water returned to the reservoir?"

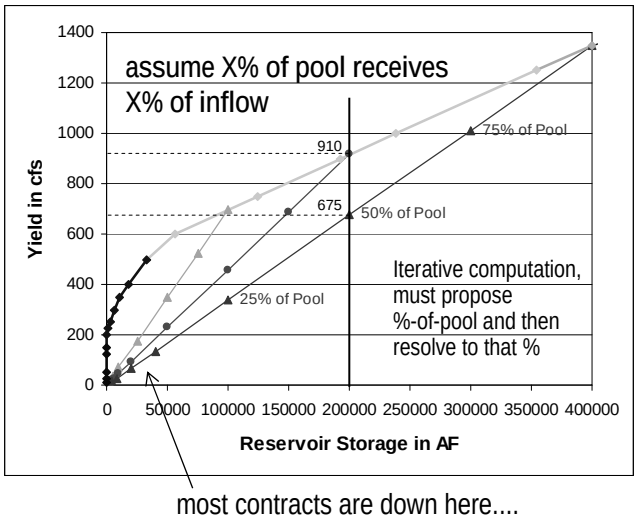
First develop storage/yield relationship







Evaluate user storage "account" = % of Pool



most contracts are down here....

More complex than this under Prior Appropriation Doctrine

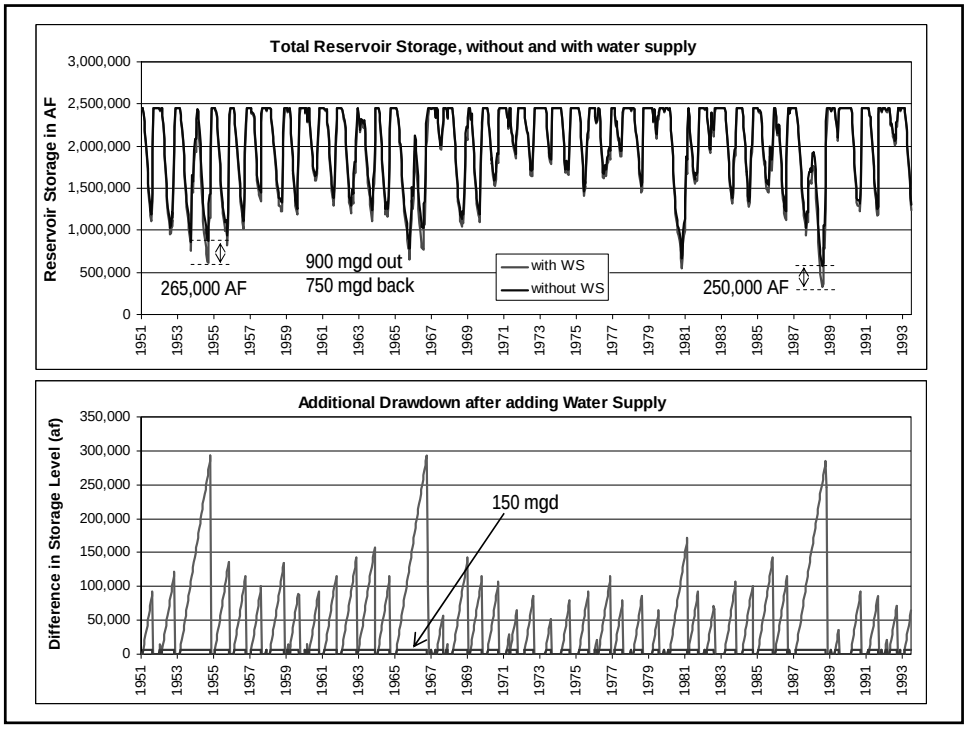
Notice, having half of a 400,000 AF conservation pool is not the same as having all of a 200,000 AF conservation pool. The difference is that only get half of the inflow.

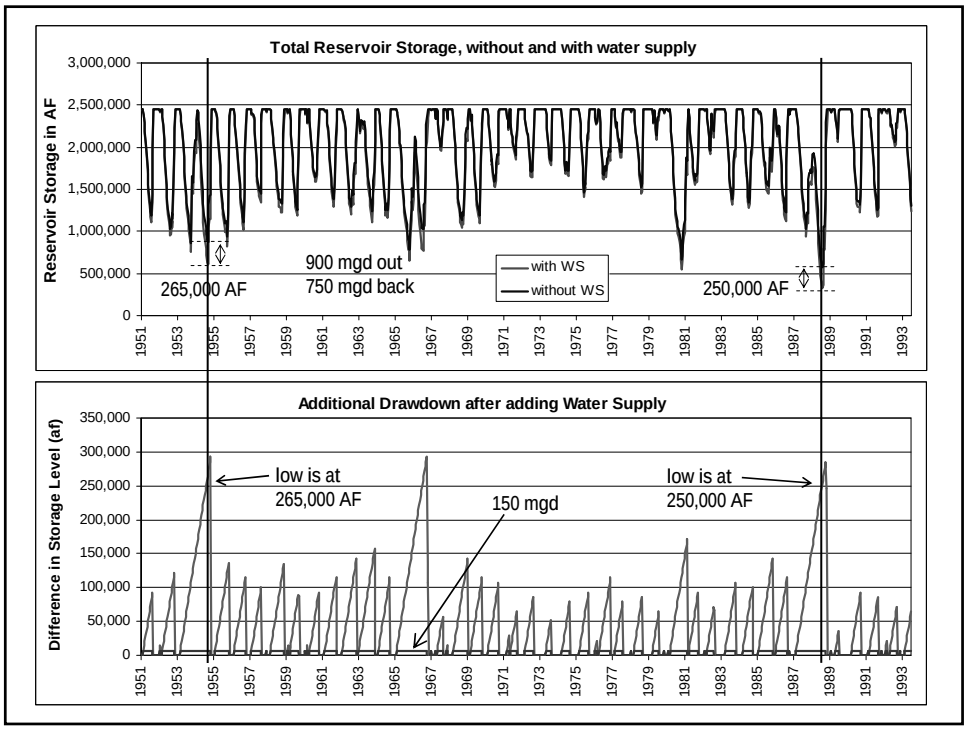
Water Supply / Firm Yield R&D Unit

- Survey the methods in use to compute firm yield for water supply contracts
- Evaluate methods
- Investigate “consistent” method that could apply in all or most cases, and build tools to implement
- So far, feedback from:
- NWW, LPR, LRN, LRL, LRH, POD, SPL, SWL, SWT

Methods in the Field

- There’s another method in use to answer the question “how much volume does X mgd need?”
- The method simulates the reservoir without the new use, notes the lowest storage in the POR or critical period, then adds the new use, find new lowest storage.
- Difference between lowest storages = volume needed
- This method seems correct, but makes implicit assumptions that are not obvious or correct...


Total Reservoir Storage, without and with water supply
Reservoir Storage in AF
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
265,000 AF
900 mgd out
750 mgd back
with WS
without WS
250,000 AF
1951 1953 1955 1957 1959 1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993
Additional Drawdown after adding Water Supply
Difference in Storage Level (af)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
150 mgd
1951 1953 1955 1957 1959 1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993


Total Reservoir Storage, without and with water supply
Reservoir Storage in AF
3,000,000
2,500,000
2,000,000
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500,000
0
265,000 AF
900 mgd out
750 mgd back
with WS
without WS
250,000 AF
1951 1953 1955 1957 1959 1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993
Additional Drawdown after adding Water Supply
Difference in Storage Level (af)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
low is at
265,000 AF
150 mgd
low is at
250,000 AF
1951 1953 1955 1957 1959 1961 1963 1965 1967 1969 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993

Methods in the Field

- The outcome of this computation is the new use draws directly from storage for the entire withdrawal, and only refills its "account" when the reservoir completely fills
- Implicit assumptions:
  - The added use's account has no access to inflow other than surplus (when reservoir is full)
  - The added use is given 100% credit for its return flow
- Is this correct? *...not in riparian water law states*
  - In Riparian states, more appropriate to allocate inflow in proportion with % of pool.

Methods in the Field

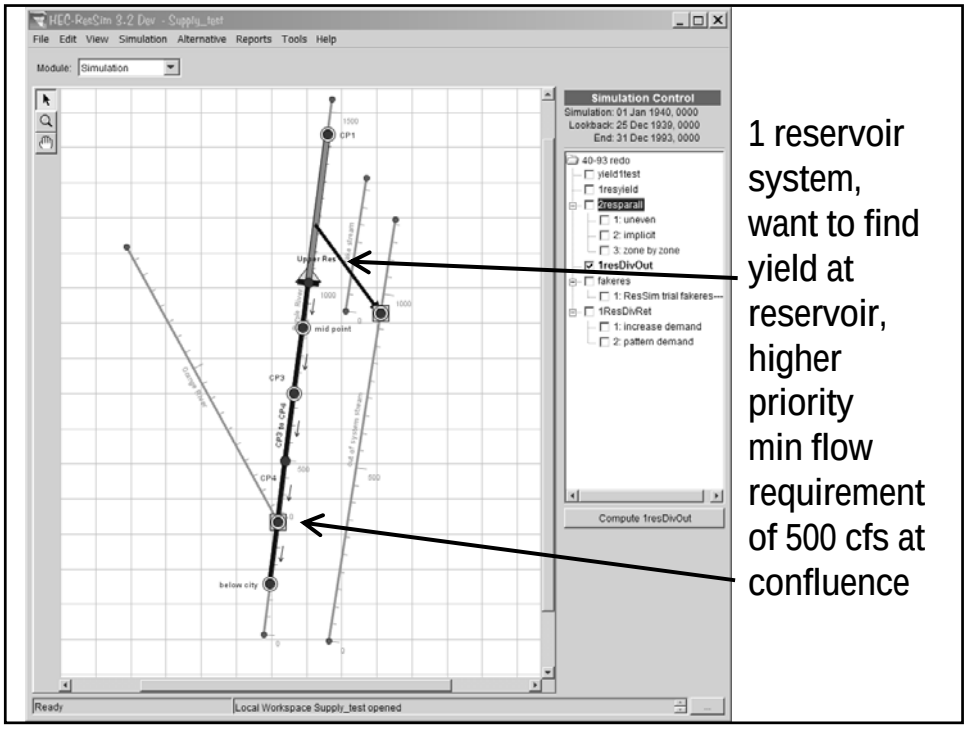
- Is this correct? *...not in riparian water law states*
  - In Riparian states, more appropriate to allocate inflow in proportion with % of pool.
  - in Prior Appropriation states, closer to correct, but should account for water rights
- To model this situation better, must track a storage account within the reservoir and explicitly model user's inflow and removal.
- Maximum deficit determines how large the volume must be (iterative if inflow = %-of-pool)

What about competing uses?

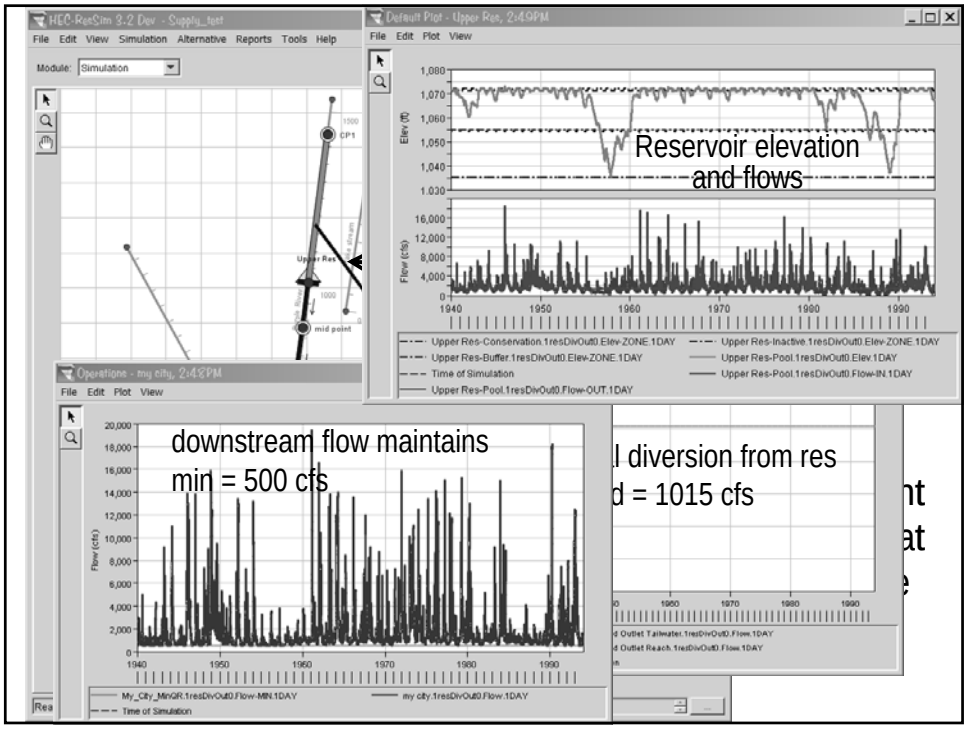
- Most of the methods demonstrated show water supply as the only use, and don't capture the conflict or priority between uses
- Only last method really captures other uses, but it has other problems...
- We need to simulate the reservoir realistically
  - add new use to existing reservoir system with other priorities and operations
  - track each users storage account

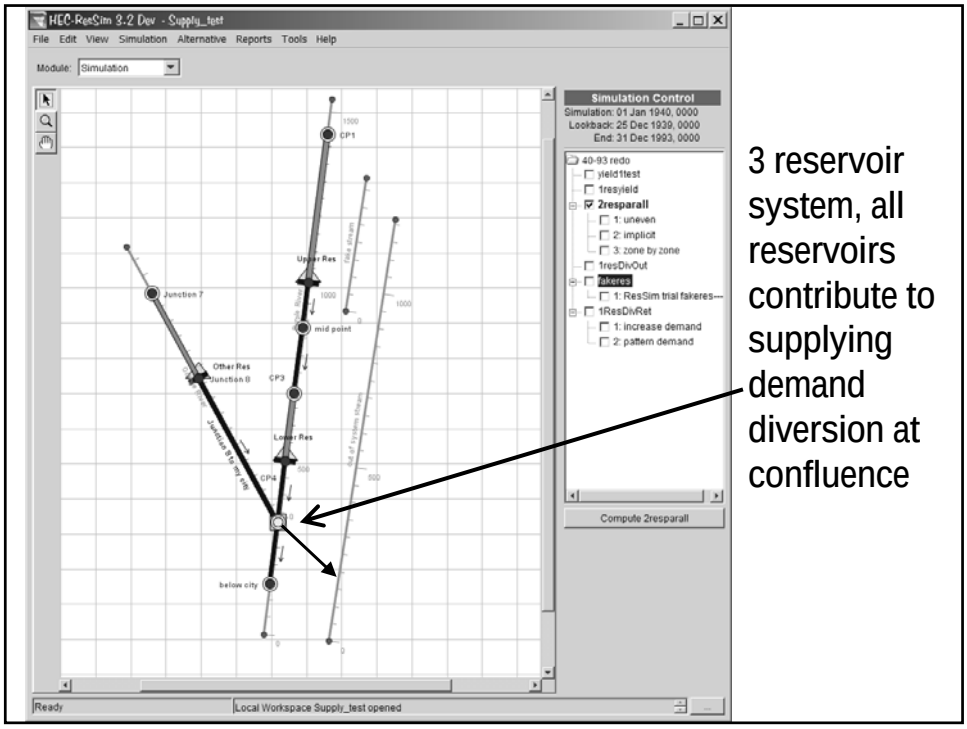
What about multi-reservoir systems?

- In the methods shown, multiple reservoirs serving the same demand are only captured by combining volumes
- It would be better to model the complete reservoir system... as well as the other uses and accounts
- As a start, HEC-ResSim now has ability to do "Reassessment/Operations" yield analysis
  - model existing reservoir or multi-reservoir system, increase yield iteratively until max the system
  - next step, tracking water accounts for adding users

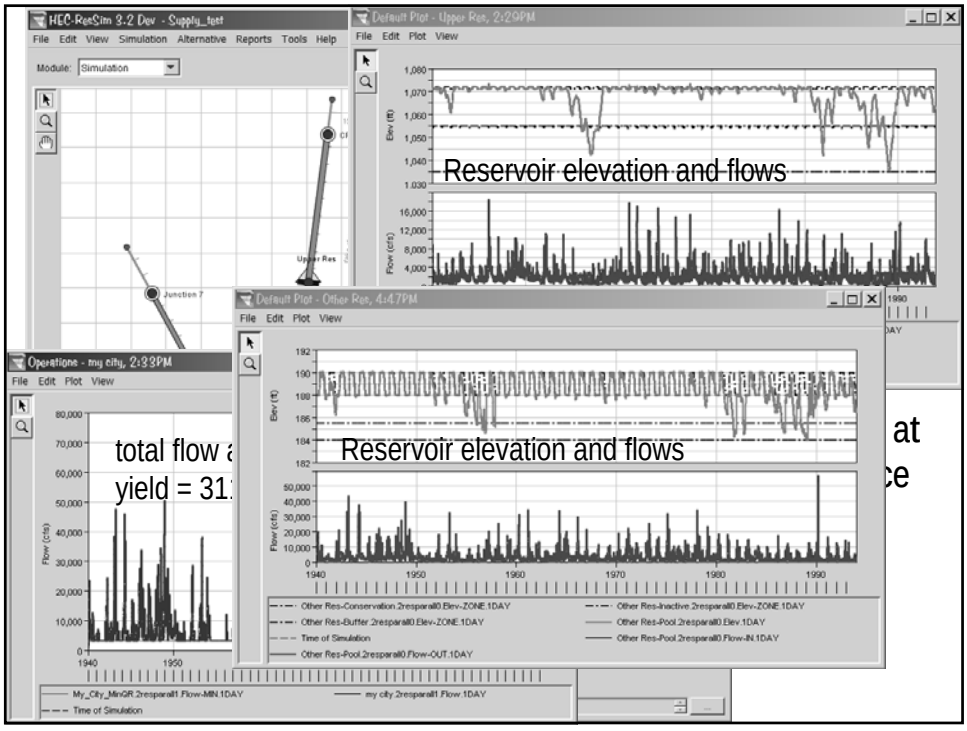


1 reservoir system, want to find yield at reservoir, higher priority min flow requirement of 500 cfs at confluence





3 reservoir system, all reservoirs contribute to supplying demand diversion at confluence



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Not yet, but soon...

- This module doesn't account for individual user storage accounts yet
- The computation is just full system yield, with the current reservoir and conservation pool sizes
- Next step is the add storage accounting, so can show various fractions of the conservation pool
  - Would also need a tool for defining inflow belonging to user, either % of total and user-defined.