Reservoir Yield R&D Unit

Water Supply Workshop
June 2, 2009

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USACE

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

Outline

- Understanding Yield
  - Simple Yield Computation Methods
- The problem with Critical Period
  - Alternatives to Critical Period Analysis
  - Reliability
- Water Supply Contracts – different question
  - Methods – pay attention to implicit assumptions
- Yield in ResSim

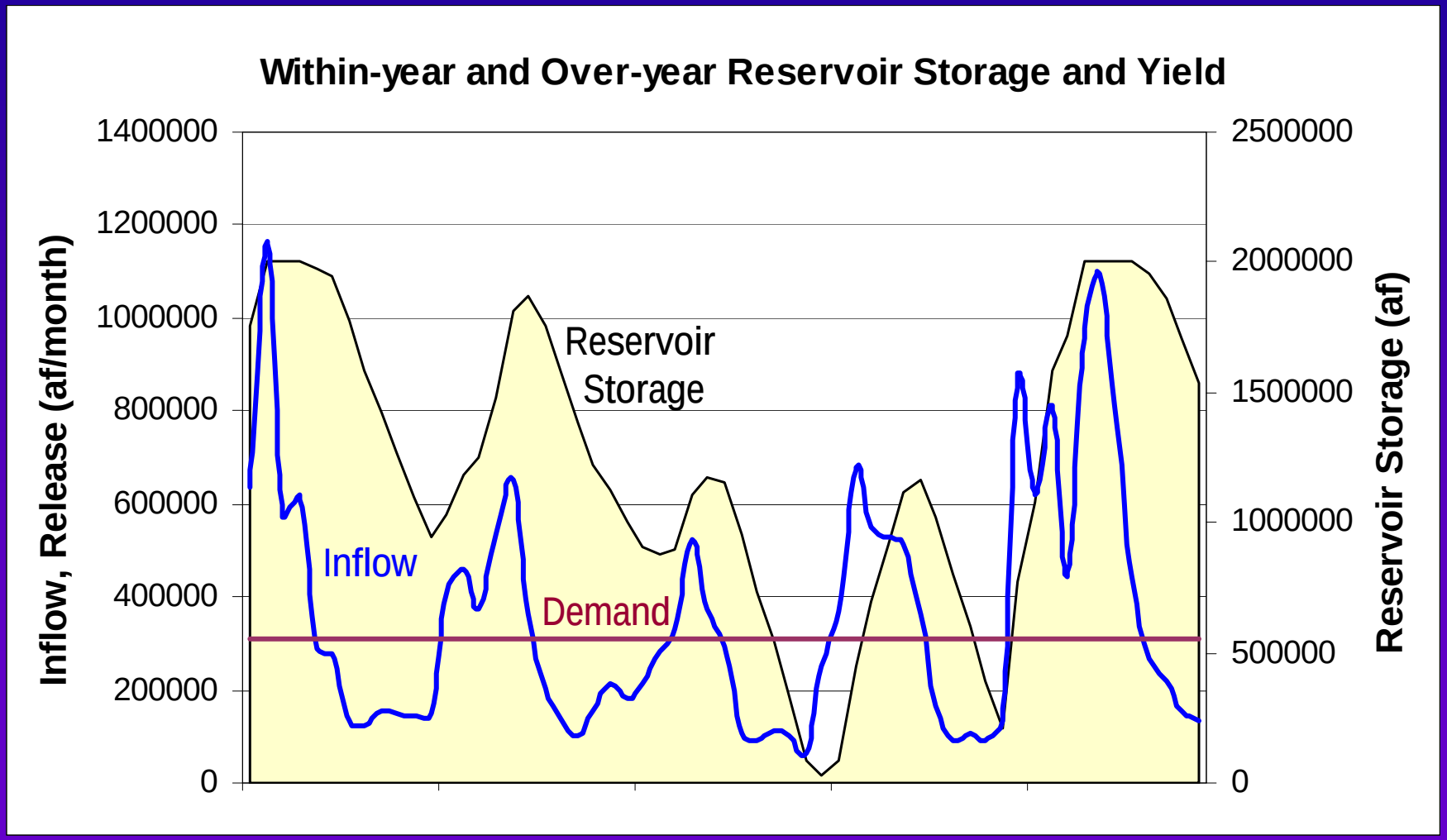
Redistribution of Water

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.


Within-year and Over-year Reservoir Storage and Yield
Inflow, Release (af/month)
Reservoir Storage (af)
1400000
1200000
1000000
800000
600000
400000
200000
0
2500000
2000000
1500000
1000000
500000
0
Reservoir Storage
Inflow
Demand

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 to ask the question:
  - Planning: For a given demand, how large must the reservoir at that location be?
  - Reassessment: For a given reservoir, what is the annual yield?

to generate the storage/yield relationship, fix one variable, compute 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

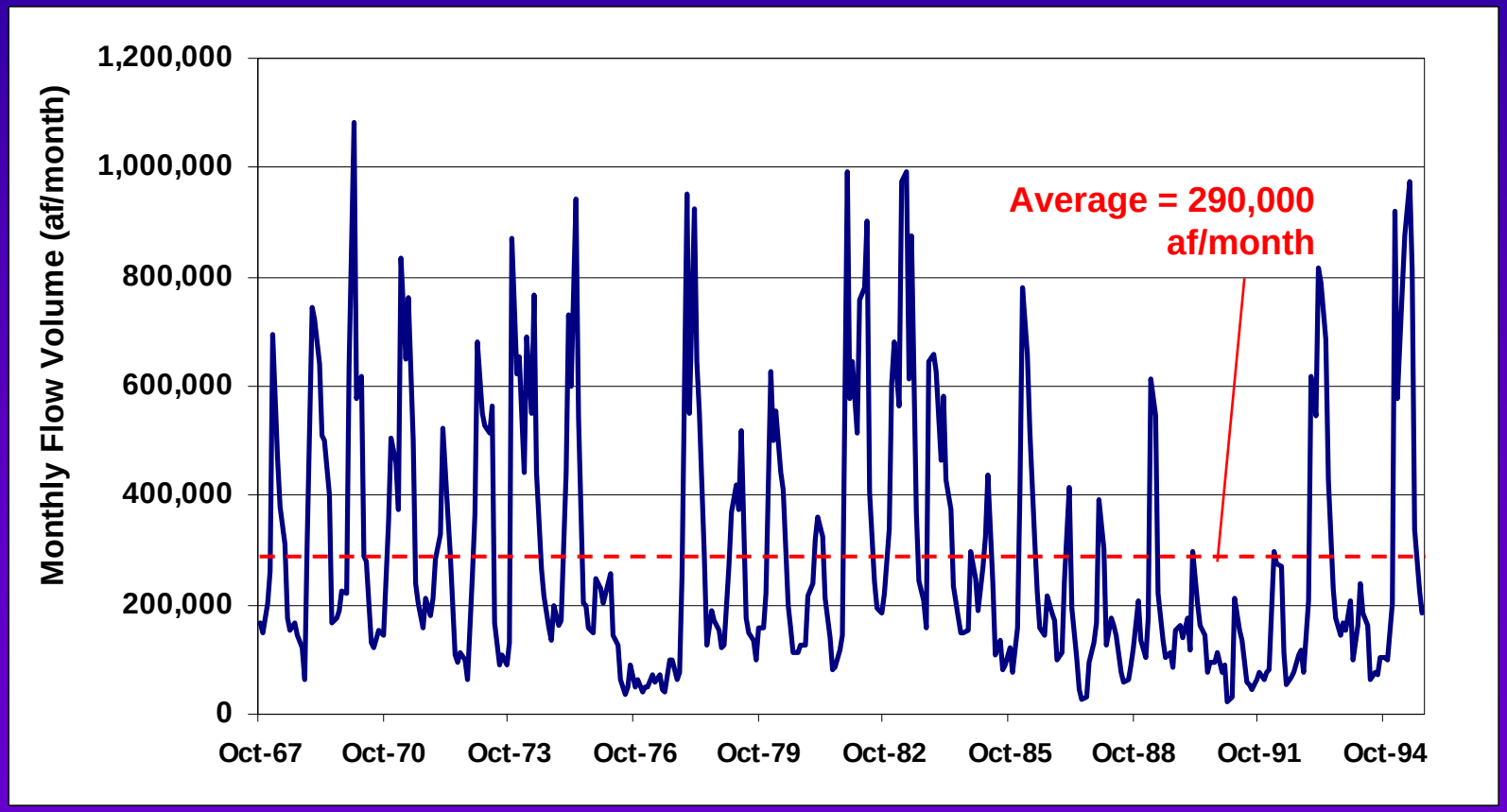
Input Data Needed...

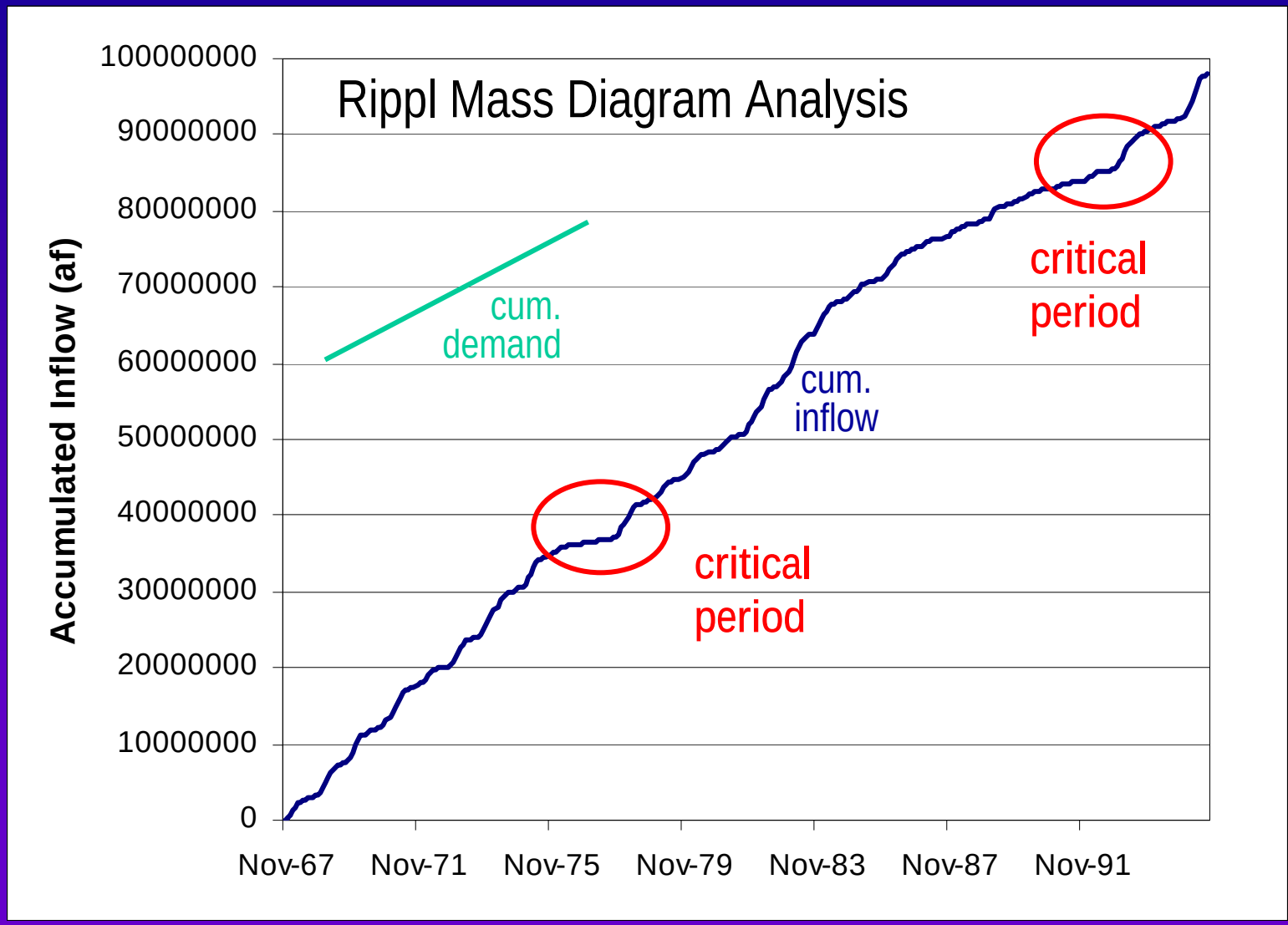
- The supply data used can be either
  - the historical record, or a critical dry period within the record – be careful defining single critical period
  - a synthetic drought event or data series
  - either full inflow, or inflow belonging to user
- The demand requirements can be either
  - 100% of 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

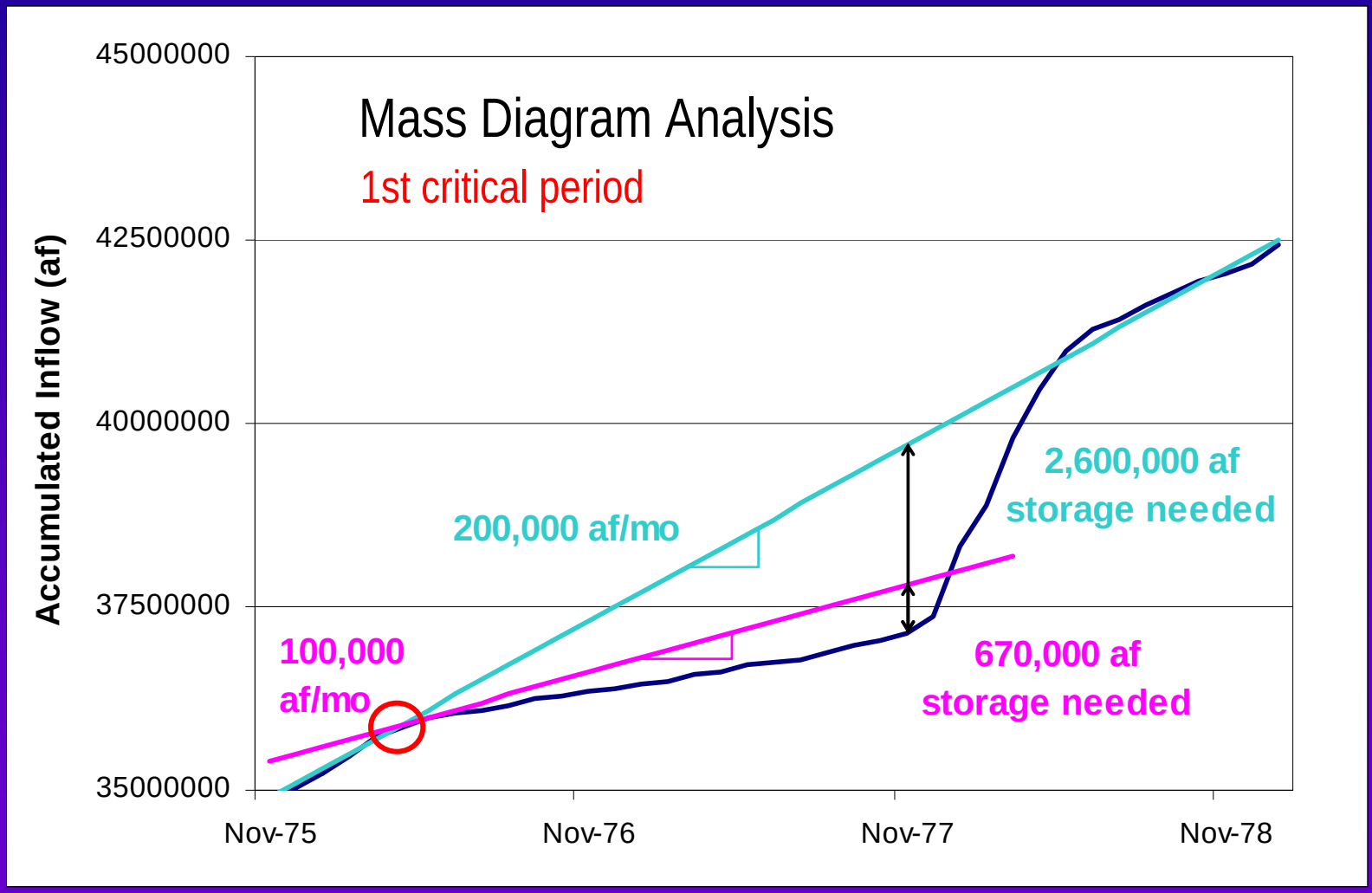
"Planning" Storage/Yield Analysis

Monthly Flow Volume, modified Feather River, Oroville, CA





demand must be constant...



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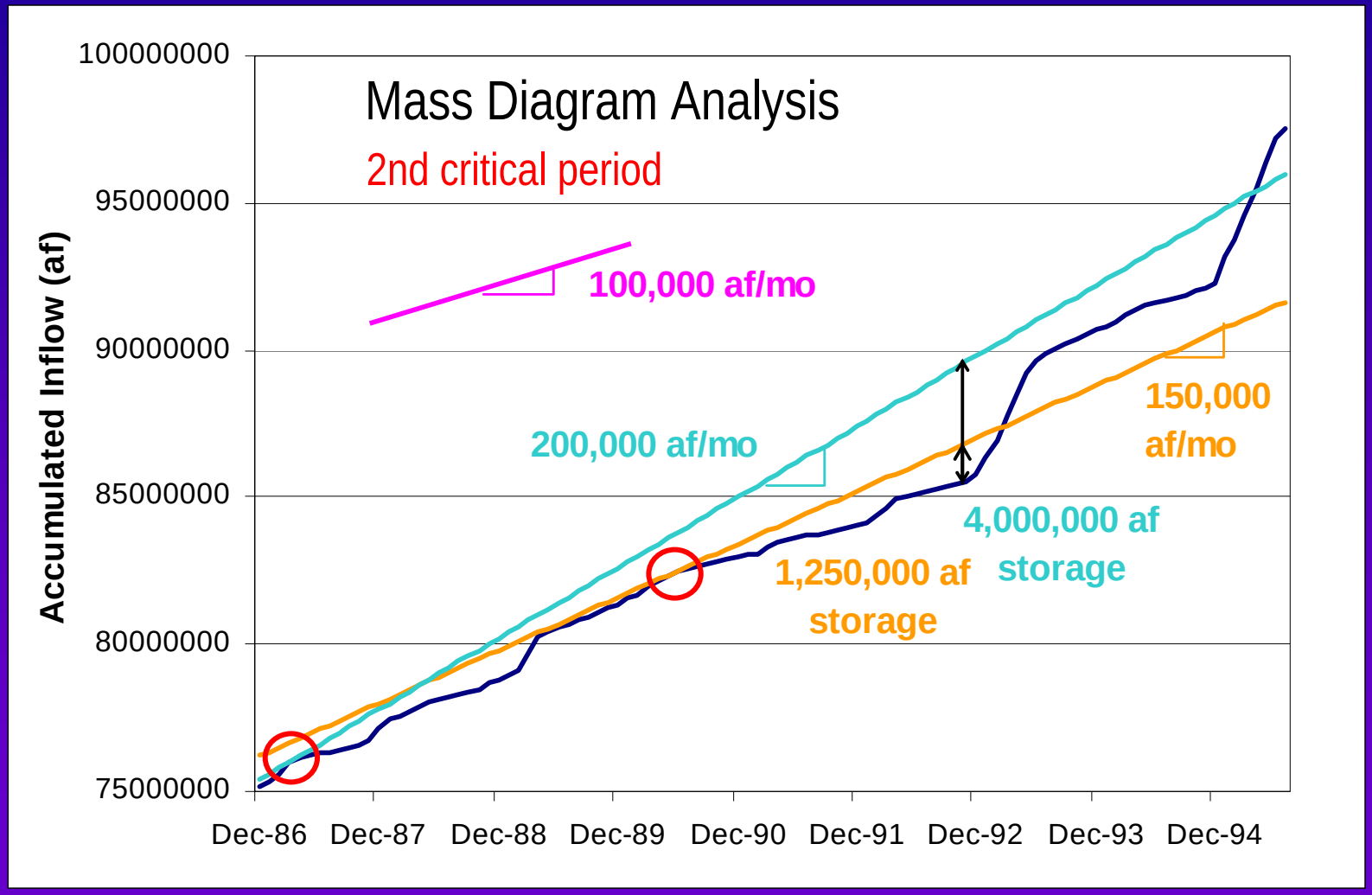
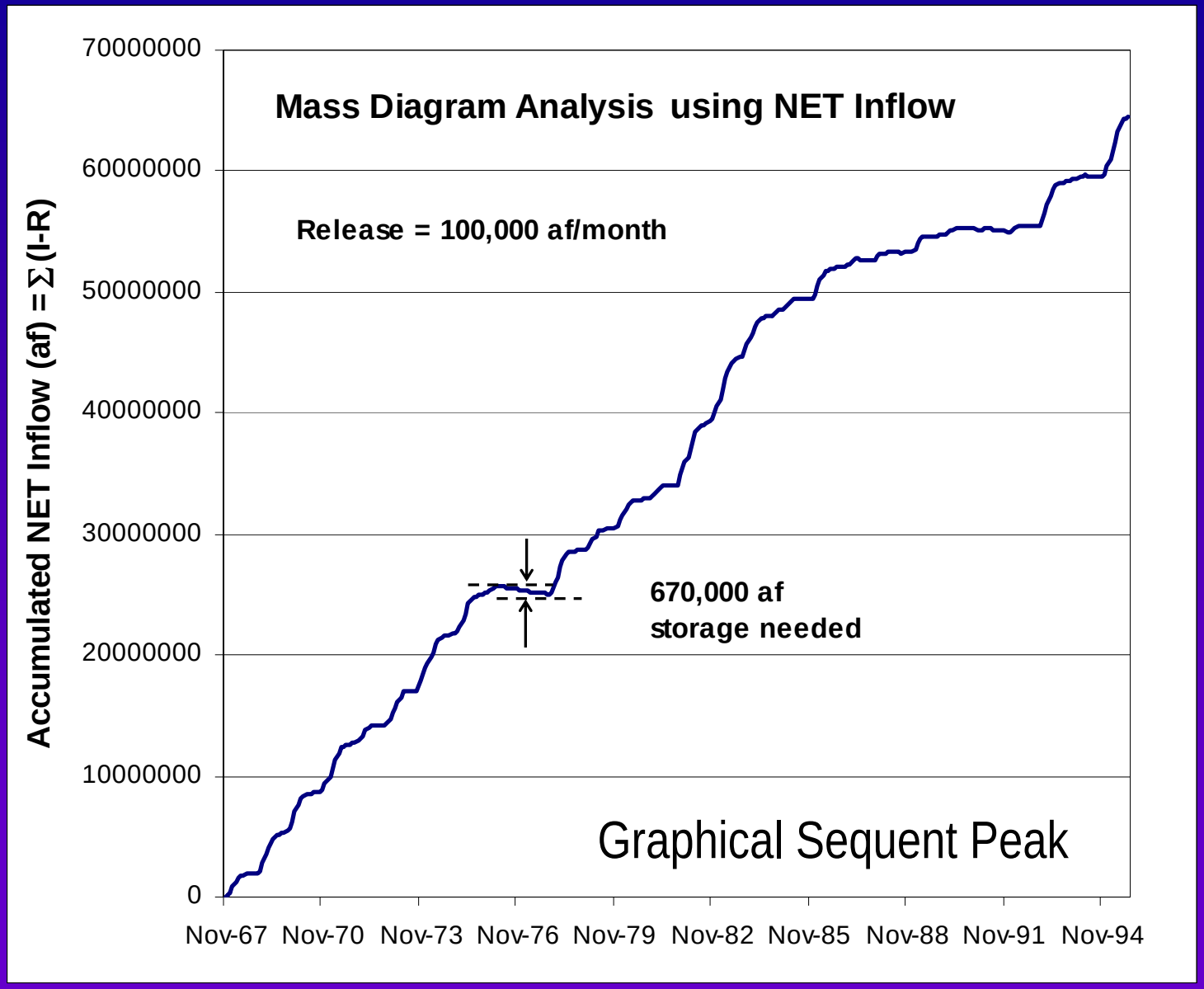
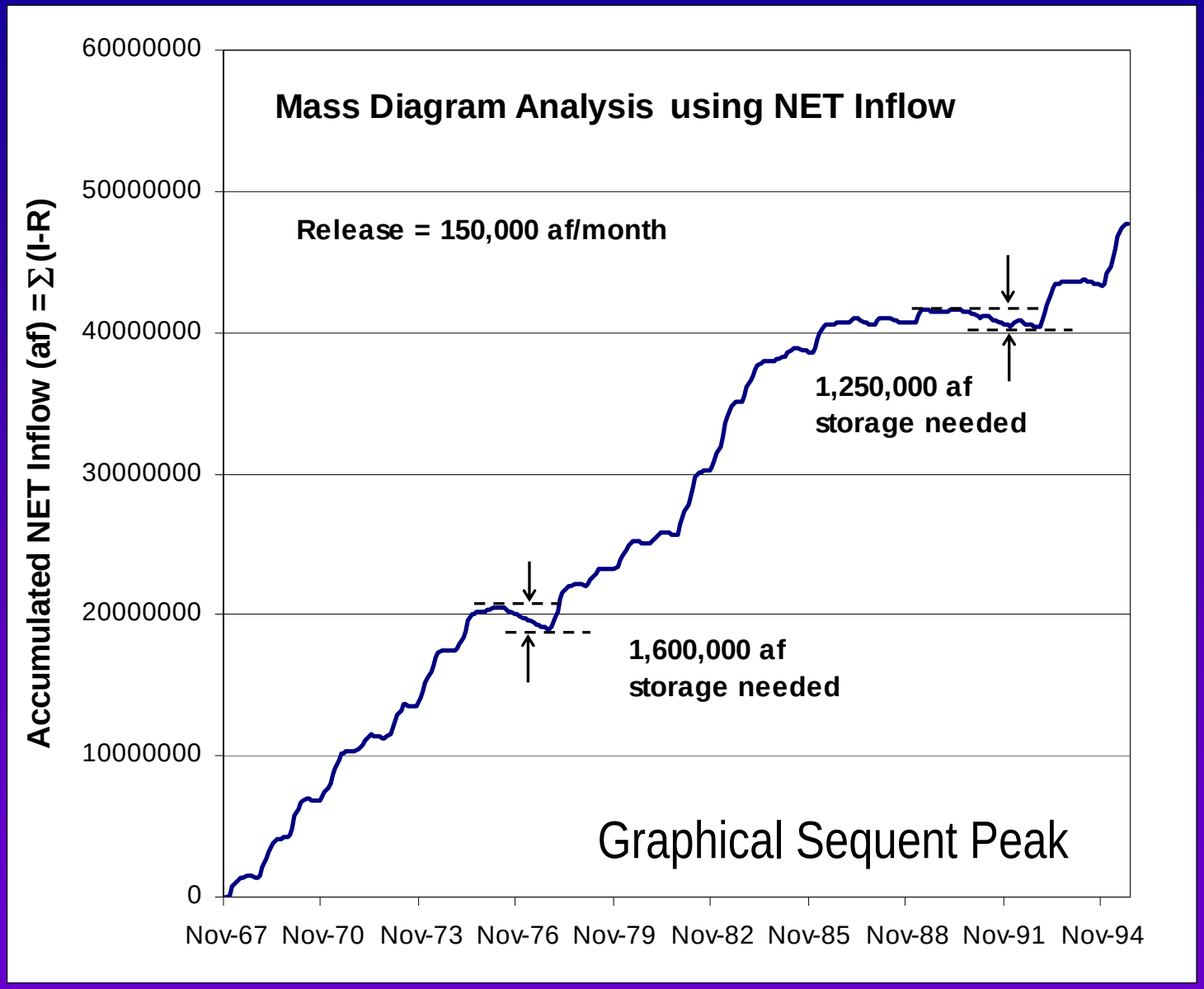


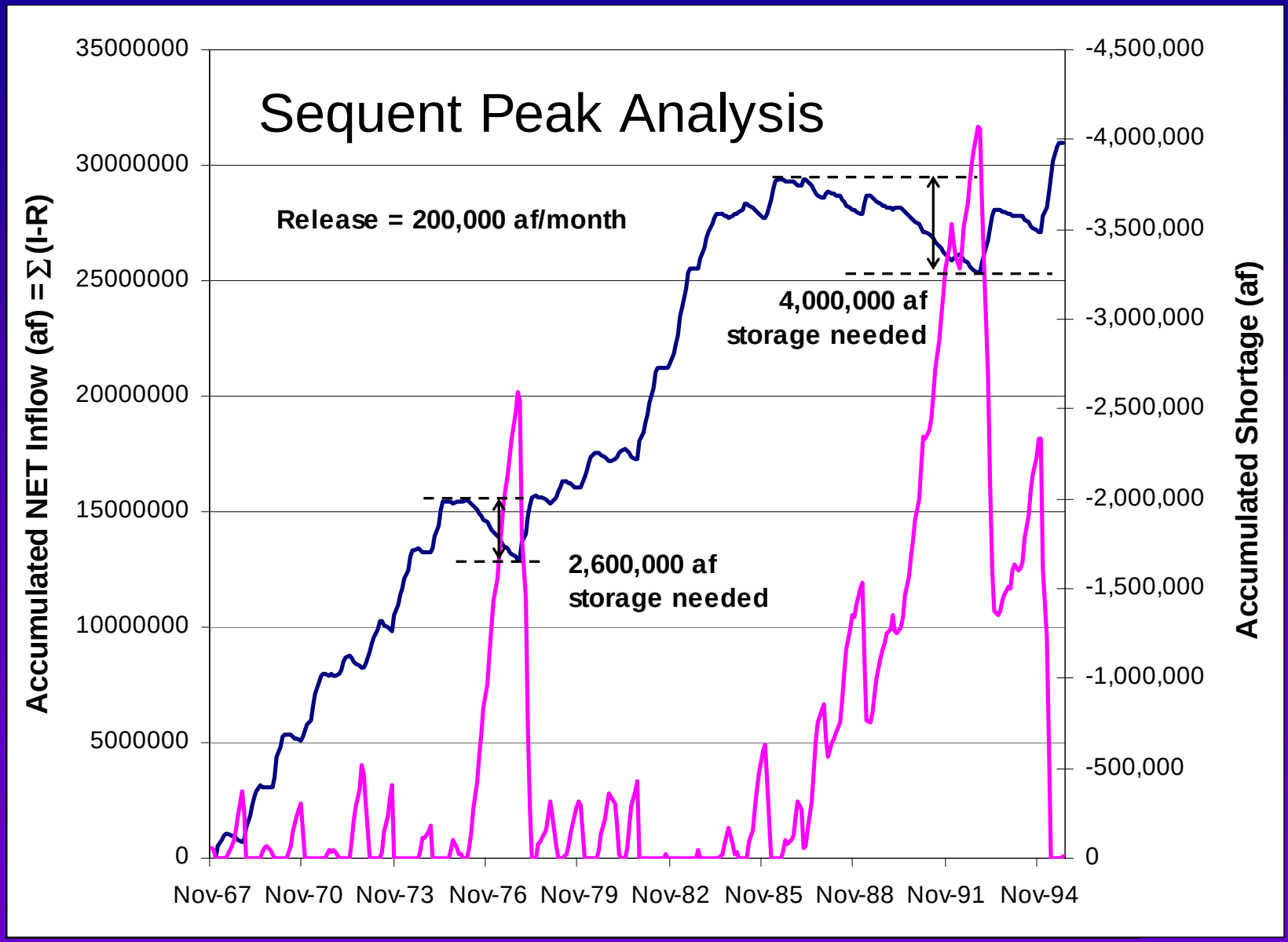
demand must be constant...



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

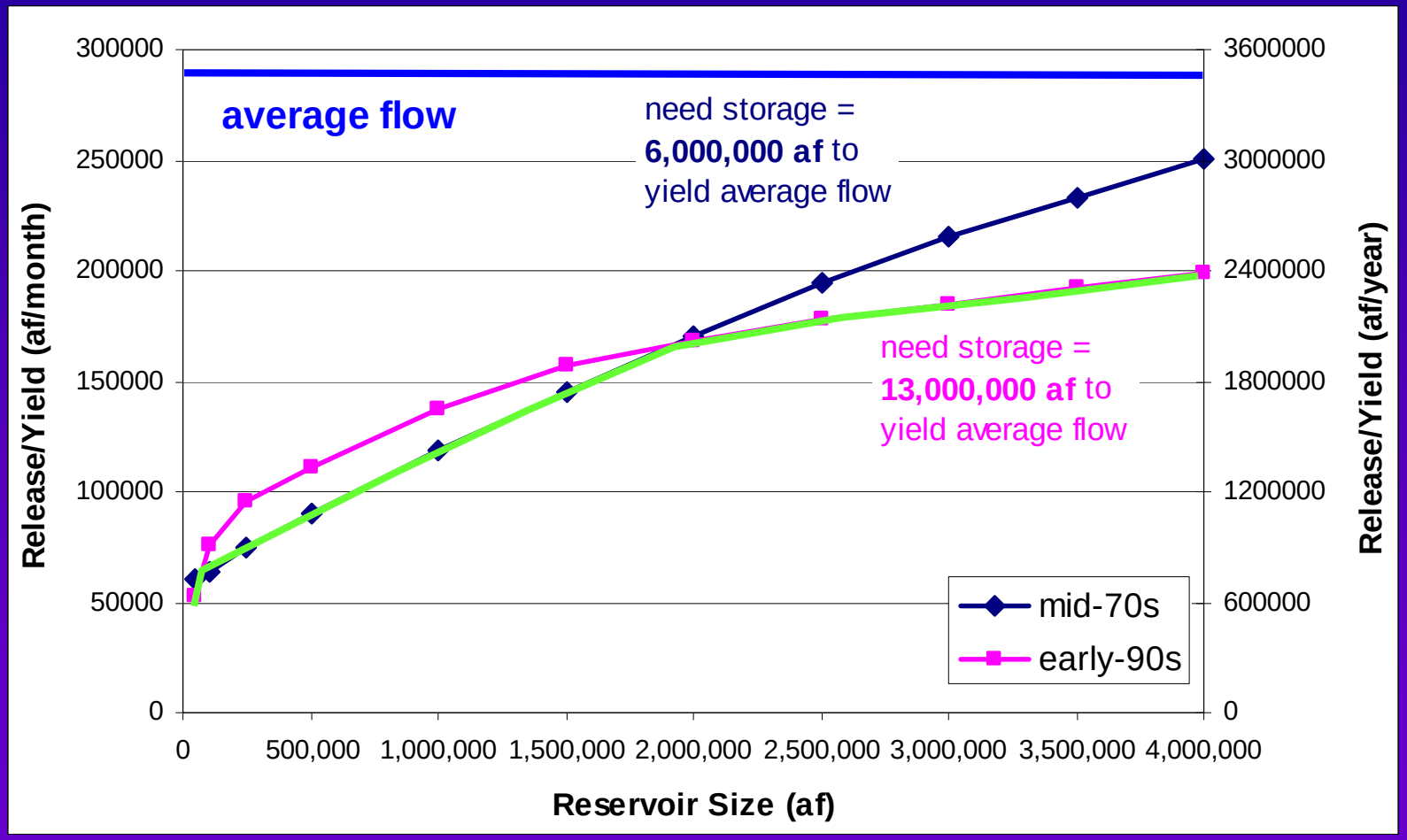


demand need <u>not</u> be constant...



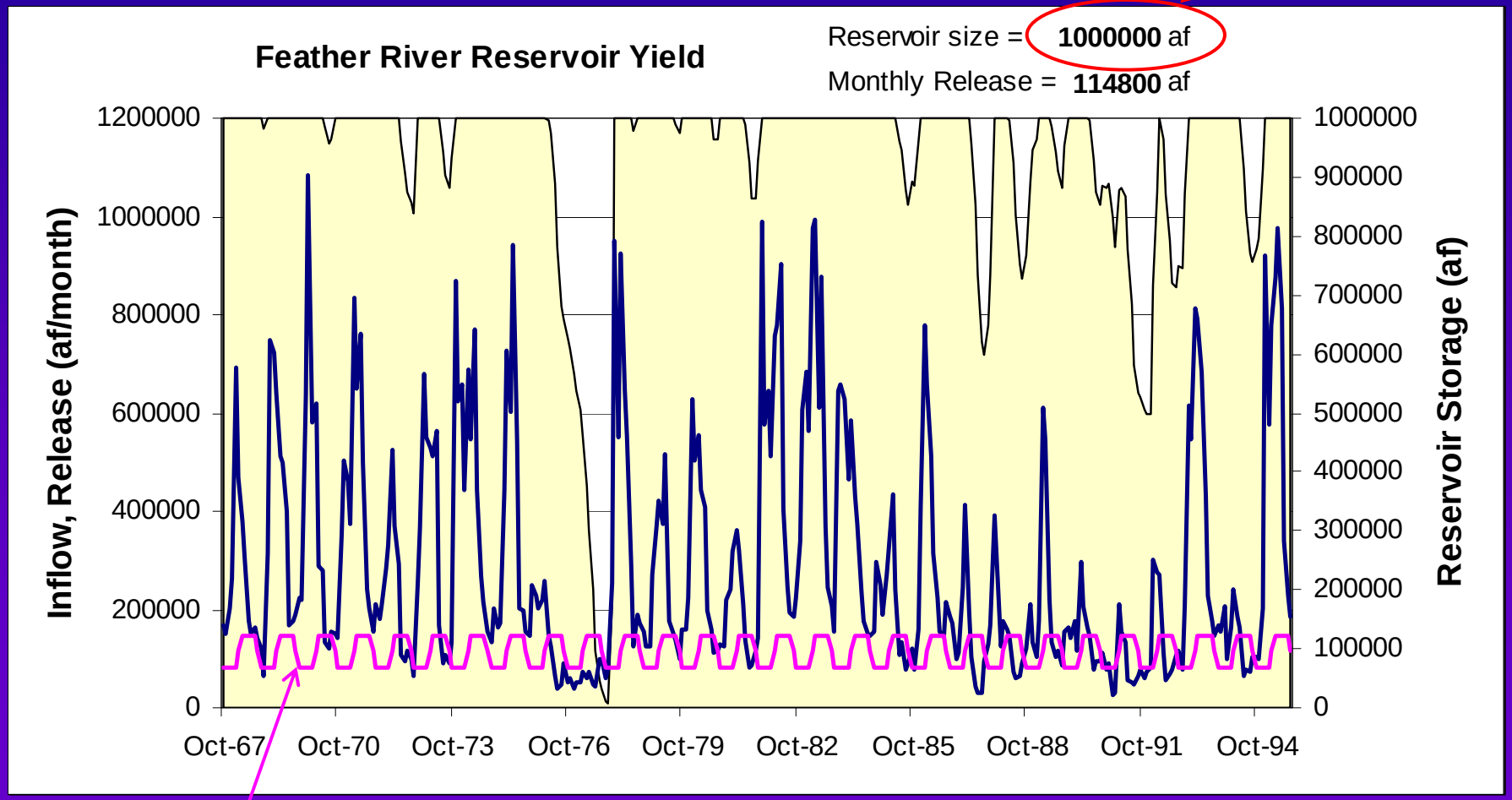
demand need <u>not</u> be constant...

Storage / Yield Relationship for Each Critical Period



Sequential Reservoir Routing

specify reservoir size

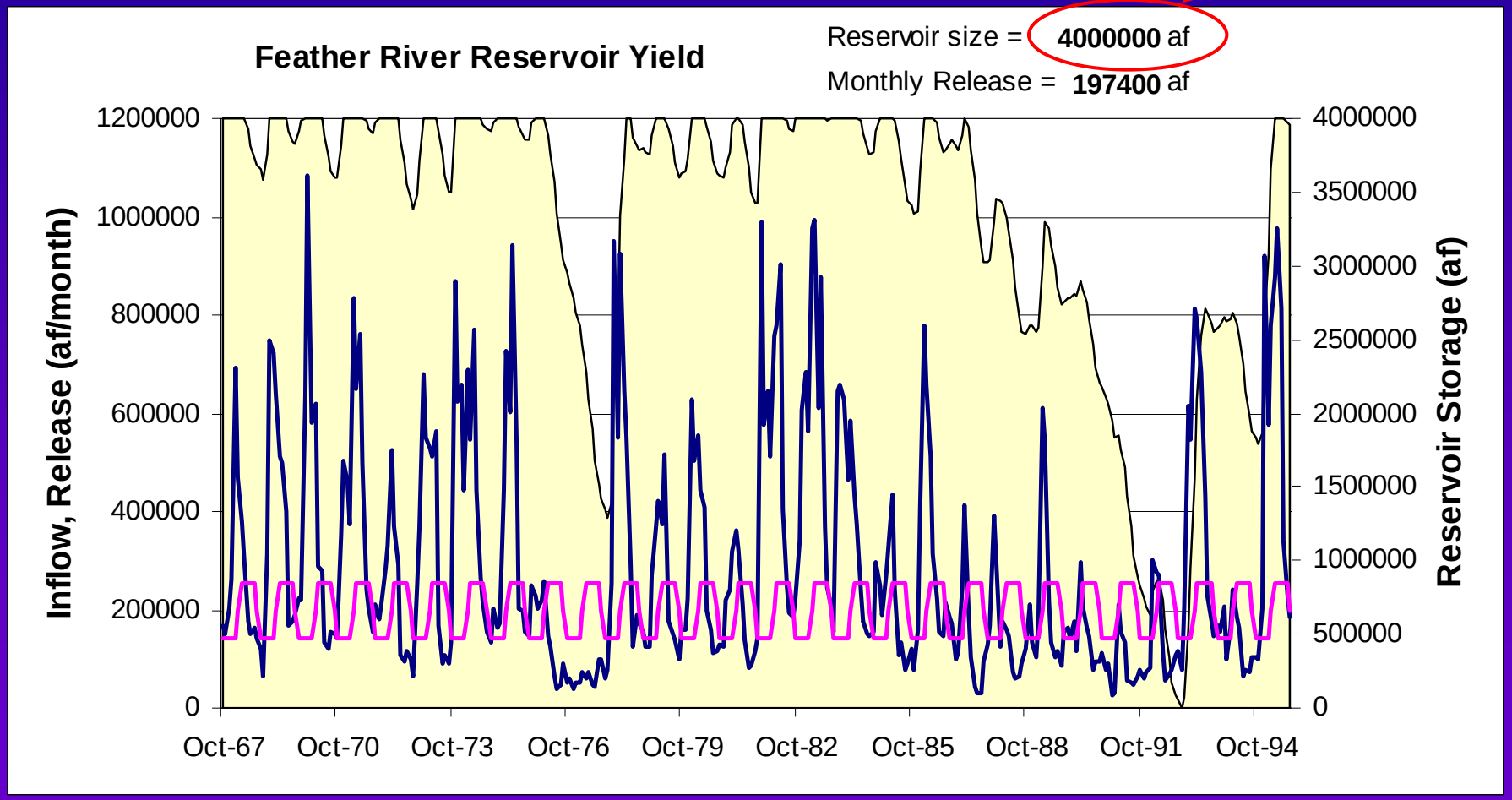


not release, doesn't include spill...

demand need not be constant...

Sequential Reservoir Routing

specify reservoir size



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

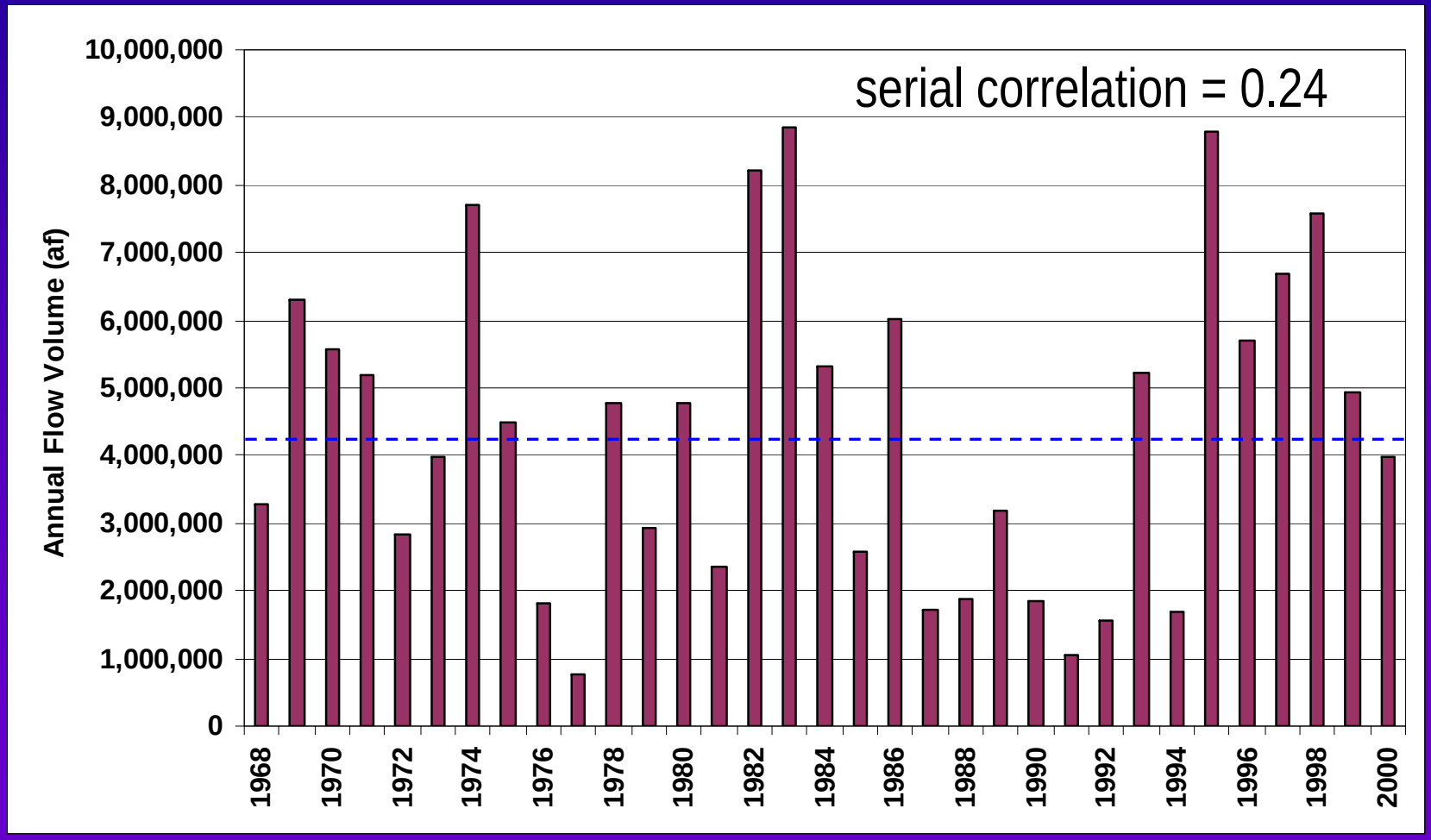
Critical Period Analysis

- 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...

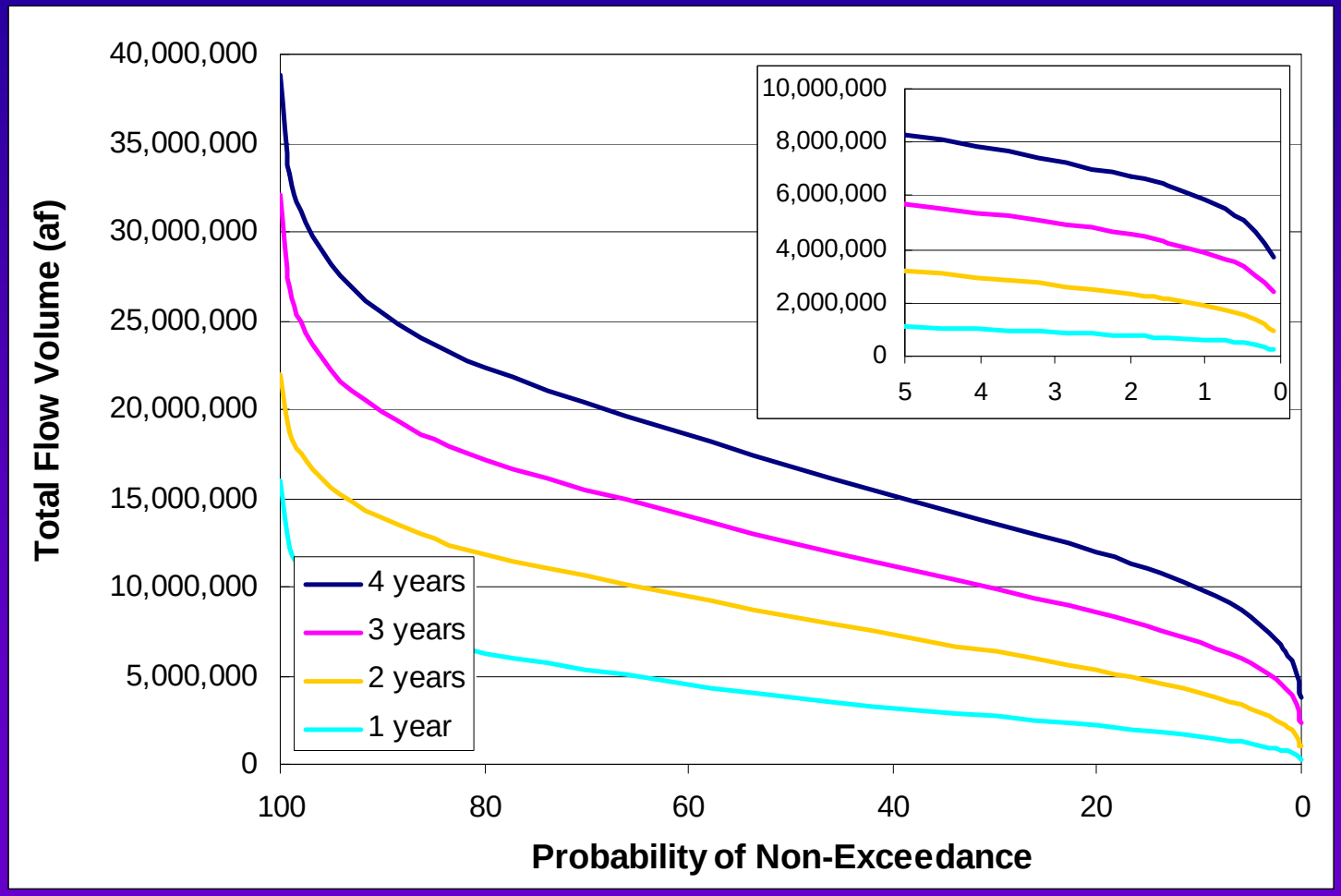
Alternatives to Critical Period

- 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

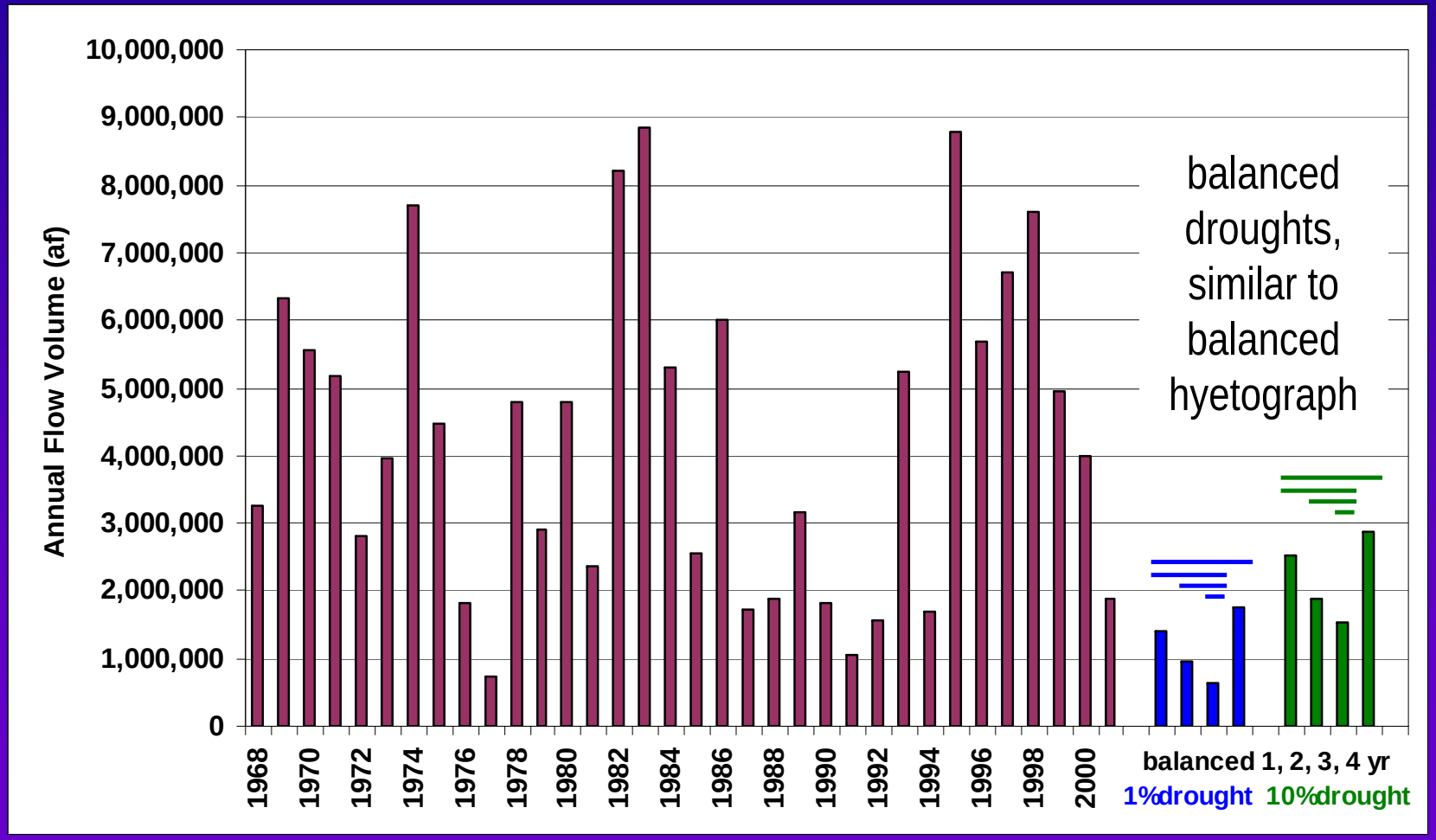
Annual Flow Volume, Feather River, Oroville, CA



Frequency of Drought Volume for Various Durations



Annual Flow Volume, Feather River, Oroville, CA



Statistics Issues...

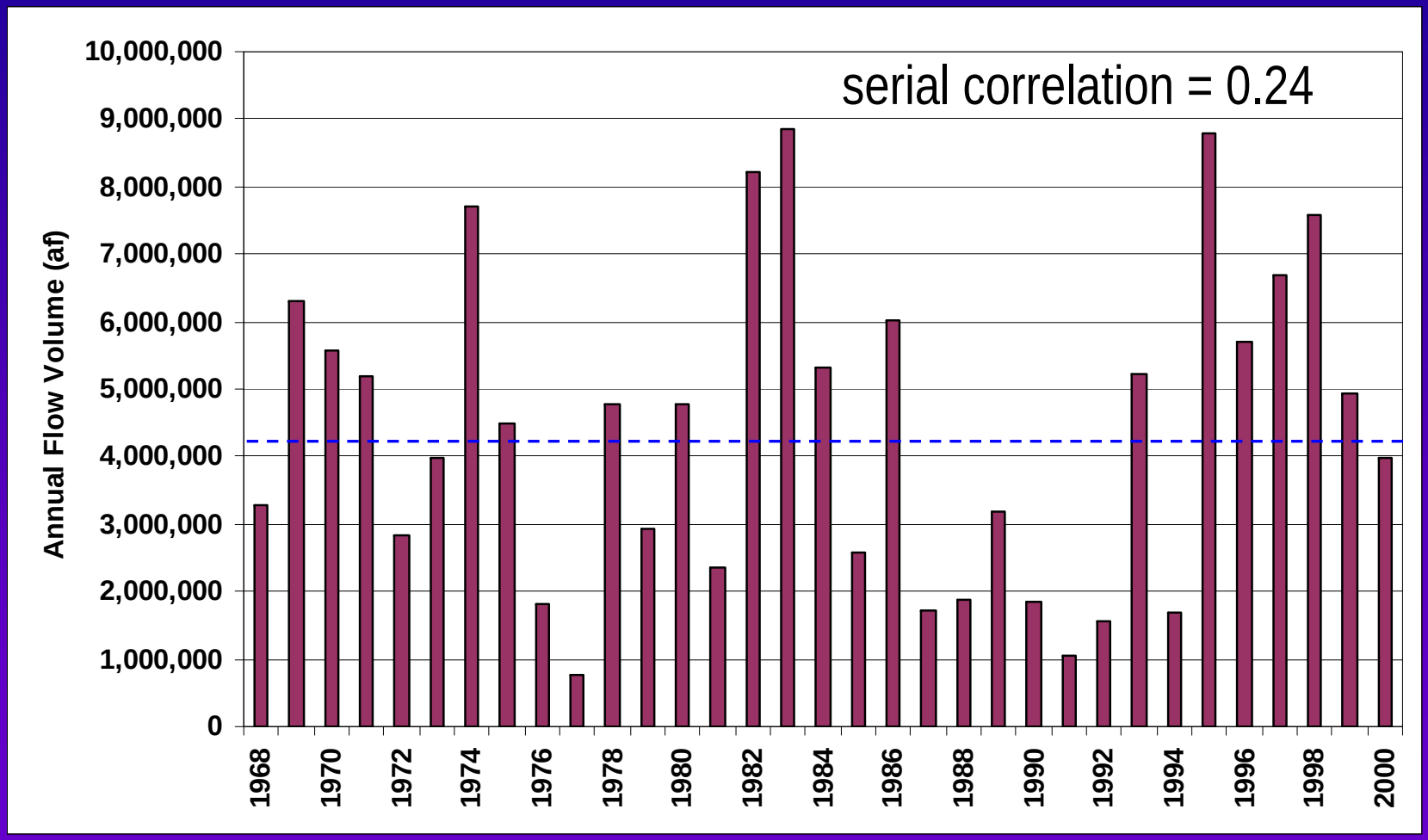
- For the creation of probabilistic balanced droughts, we assumed that annual volumes are independent, which in many cases is not accurate
- This assumption allowed frequency analysis on annual flow volume to determine volumes with 1% exceedence prob, or 5%, etc
- The same assumption can not be made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

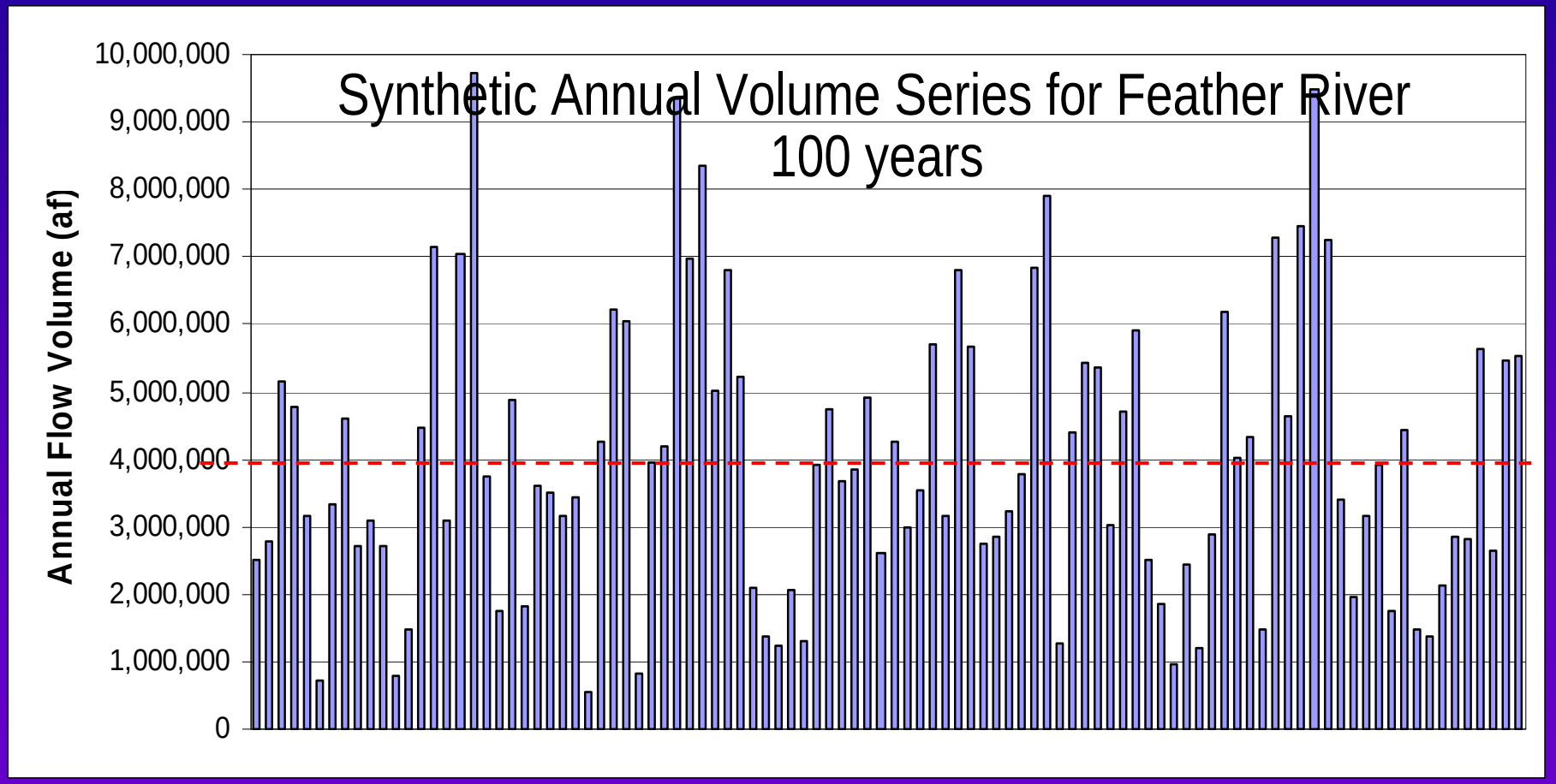
question: do we need 100% reliability?

aggregate monthly data into annual volume...

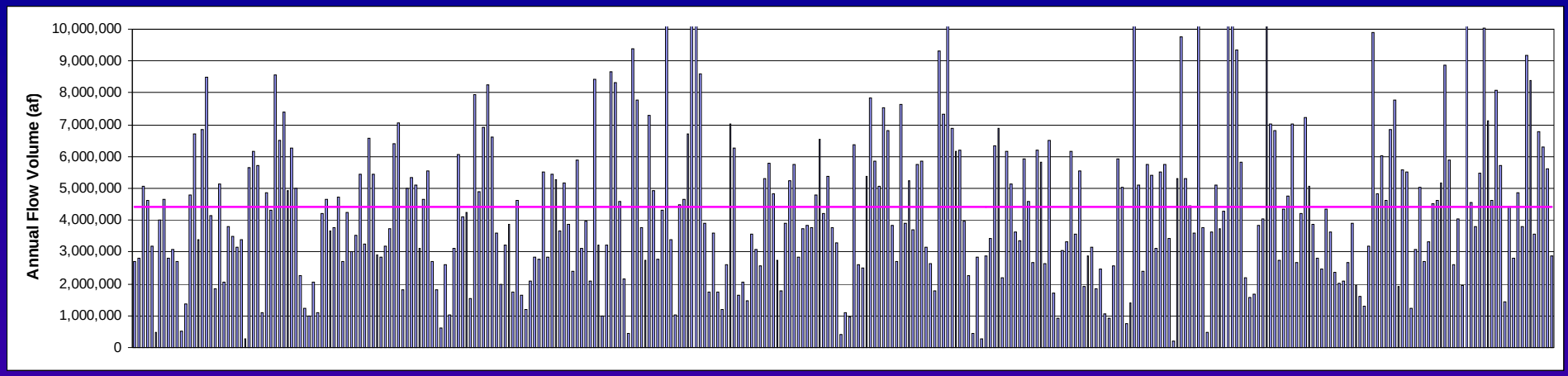


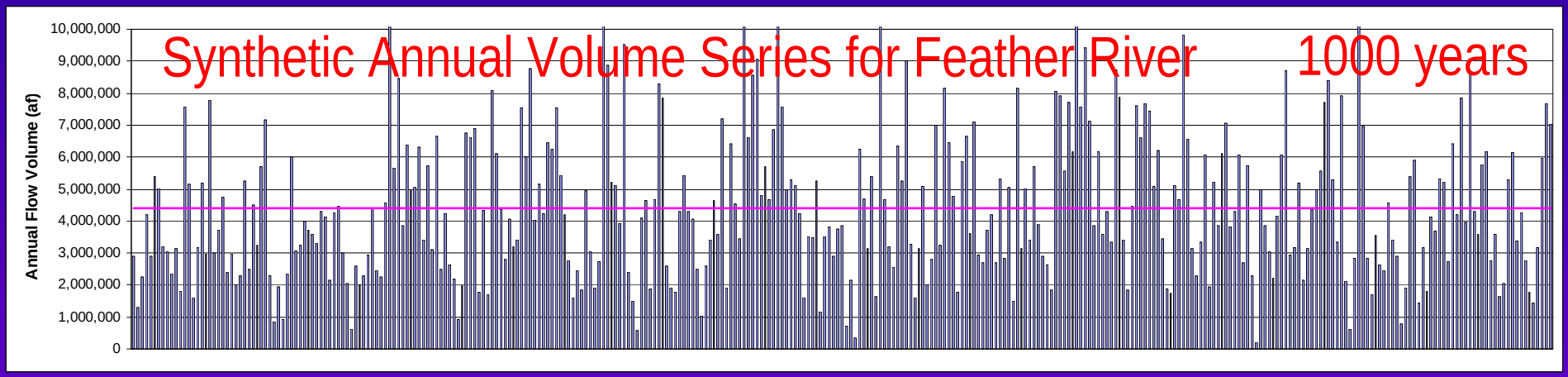
find mean, variance, correlation statistics...

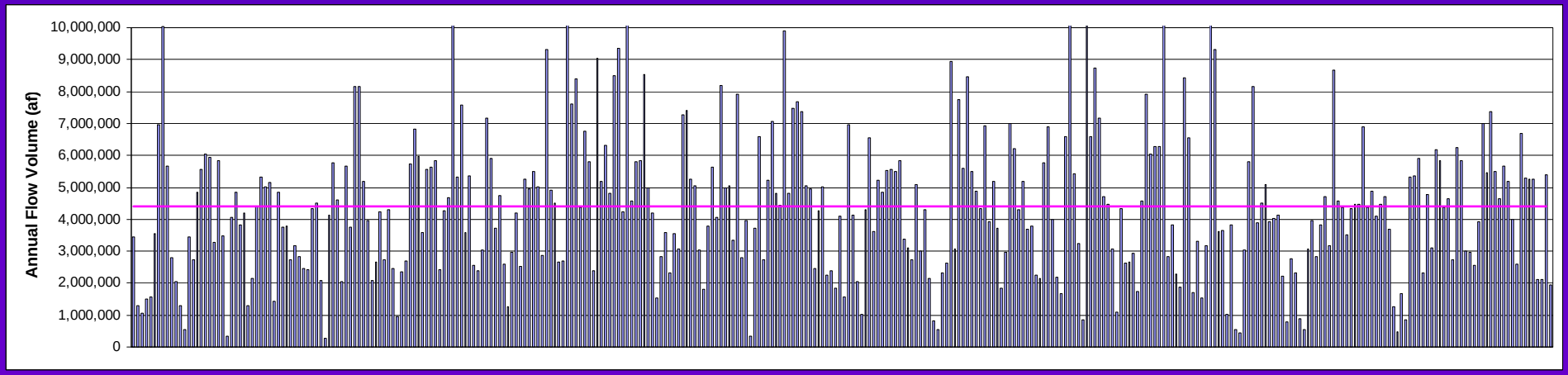
generate annual data with appropriate statistics using stochastic streamflow model AR(1)

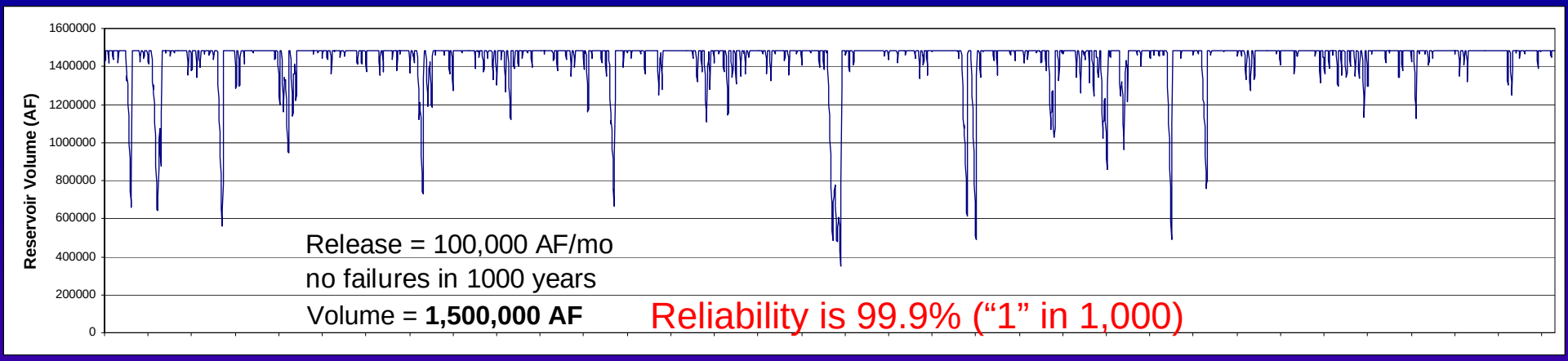


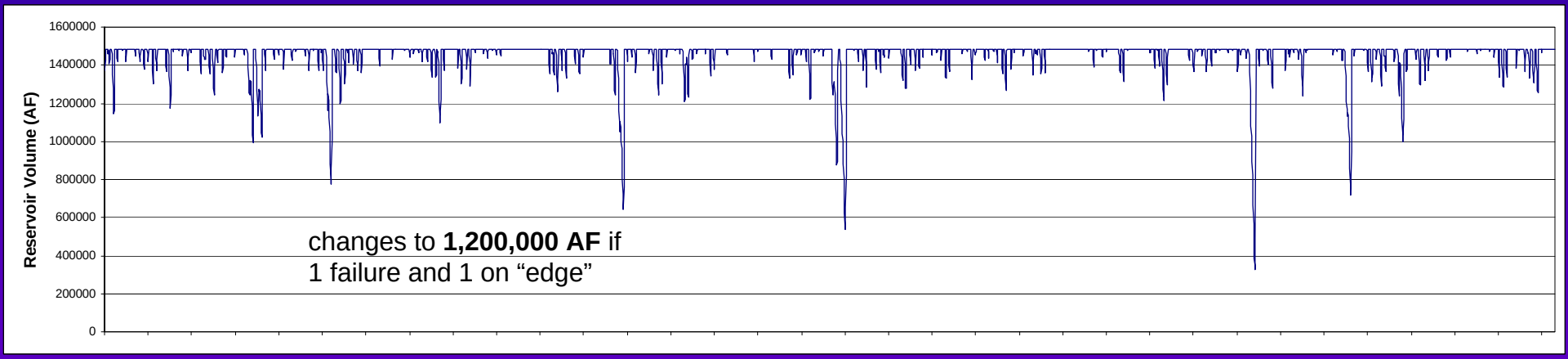
disaggregate annual volume into monthly...

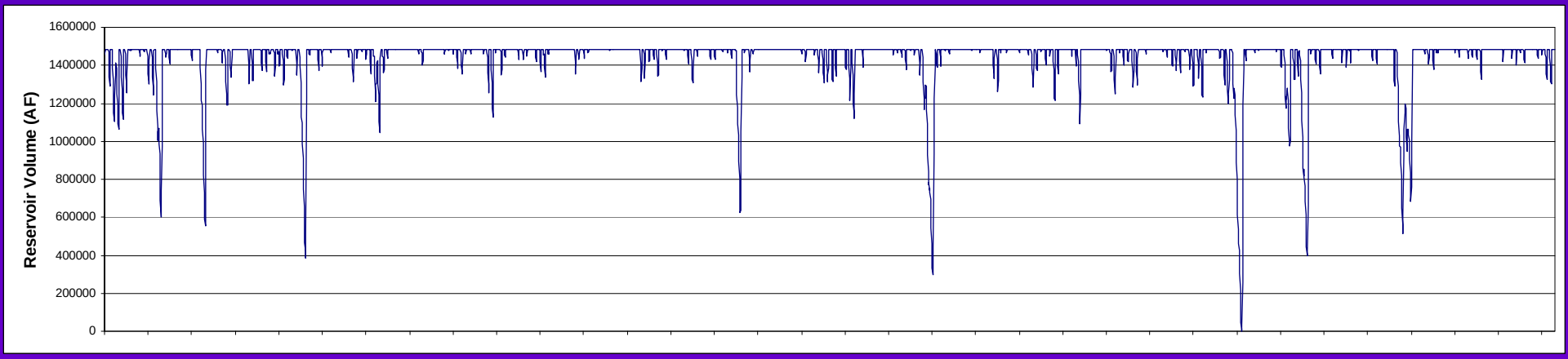

Annual Flow Volume (af)
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0

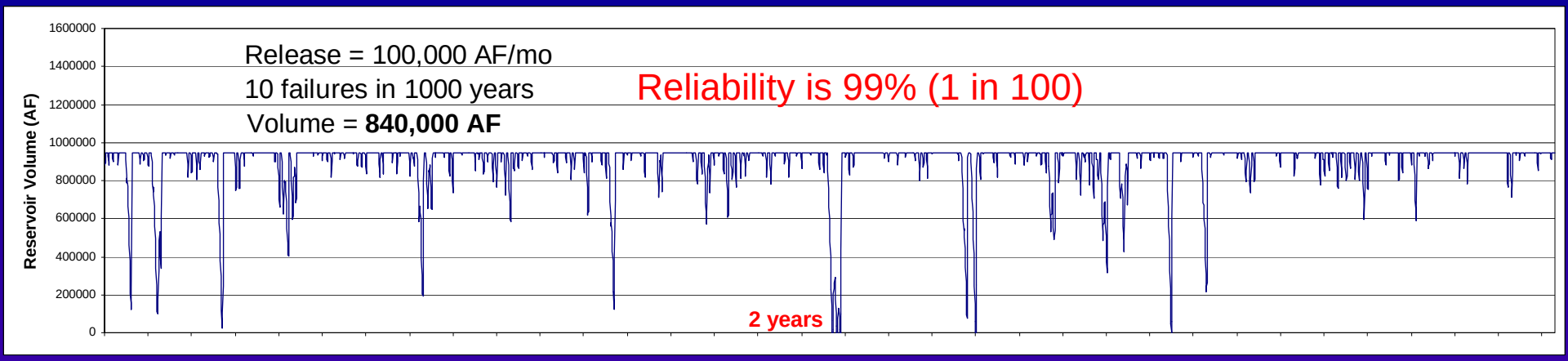

Synthetic Annual Volume Series for Feather River
1000 years
Annual Flow Volume (af)
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0

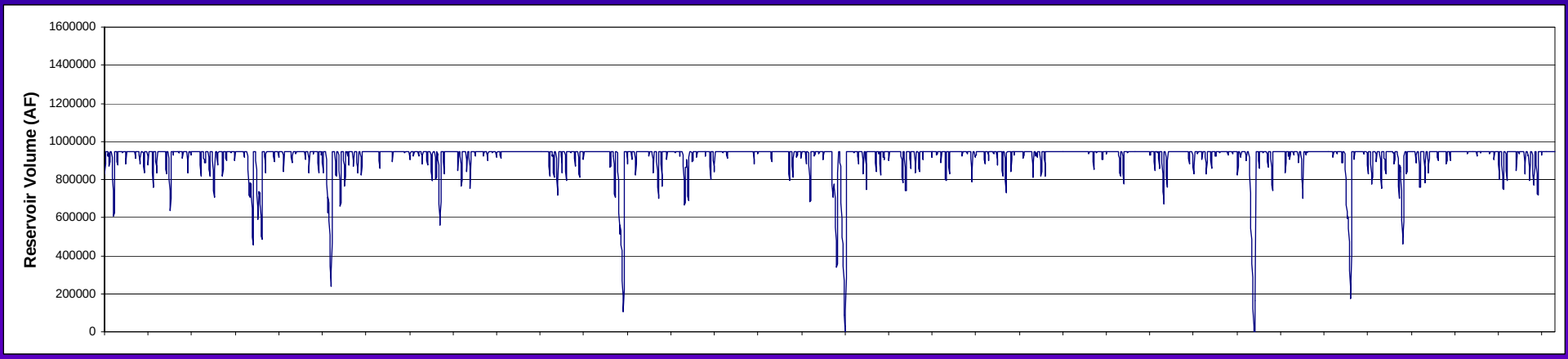

Annual Flow Volume (af)
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0

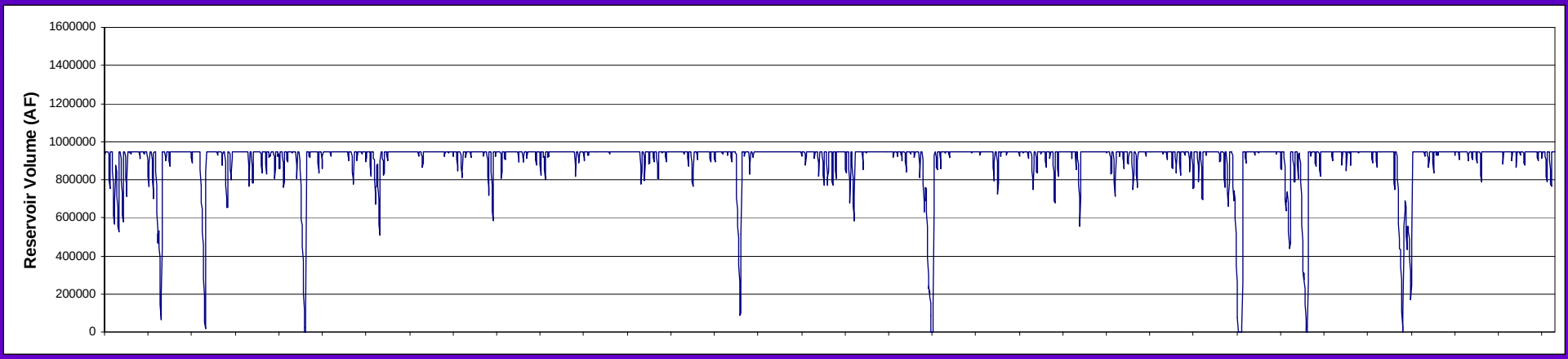

Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Release = 100,000 AF/mo
no failures in 1000 years
Volume = **1,500,000 AF**
Reliability is 99.9% (“1” in 1,000)


Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
changes to **1,200,000 AF** if
1 failure and 1 on “edge”

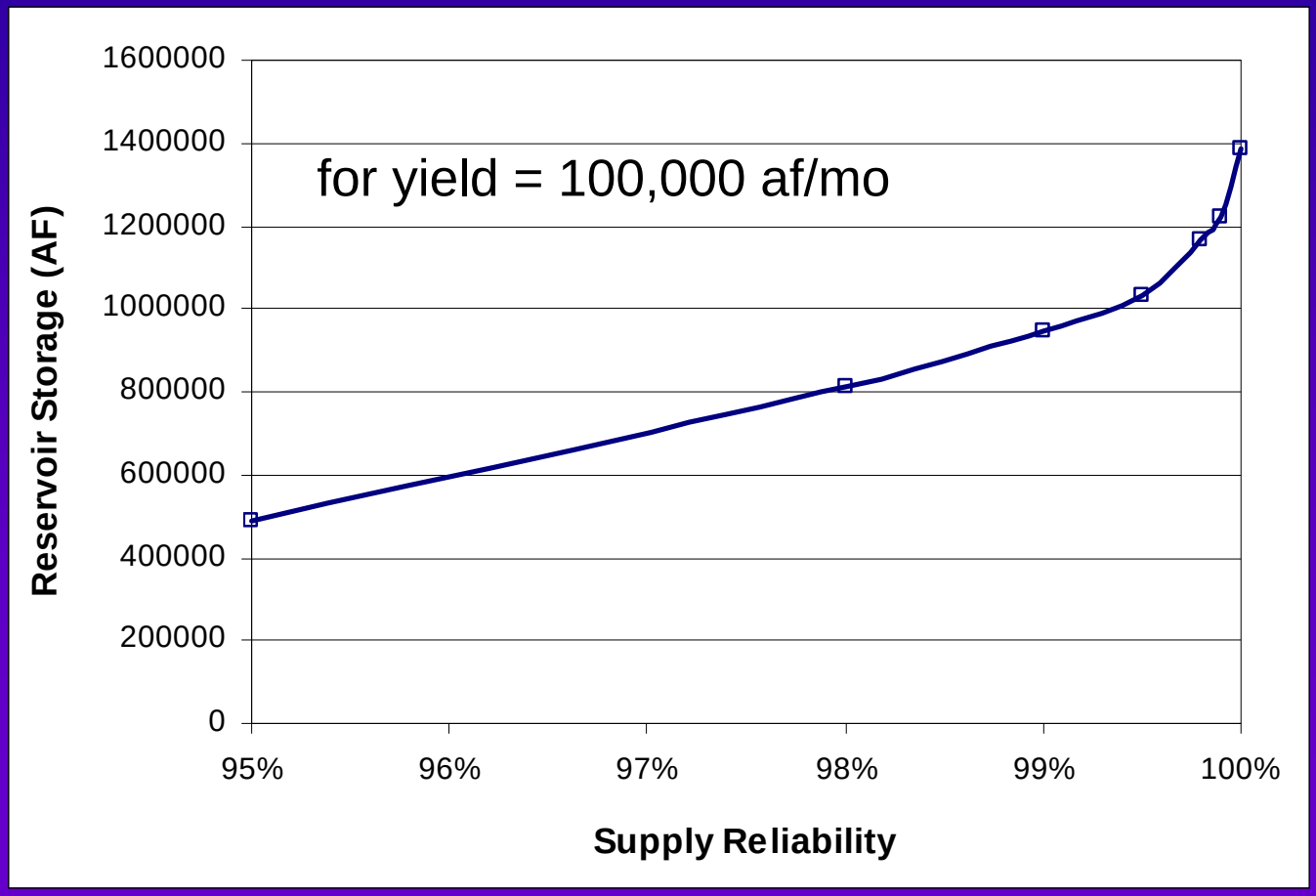

Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0


Release = 100,000 AF/mo
10 failures in 1000 years
Volume = **840,000 AF**
Reliability is 99% (1 in 100)
2 years
Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0

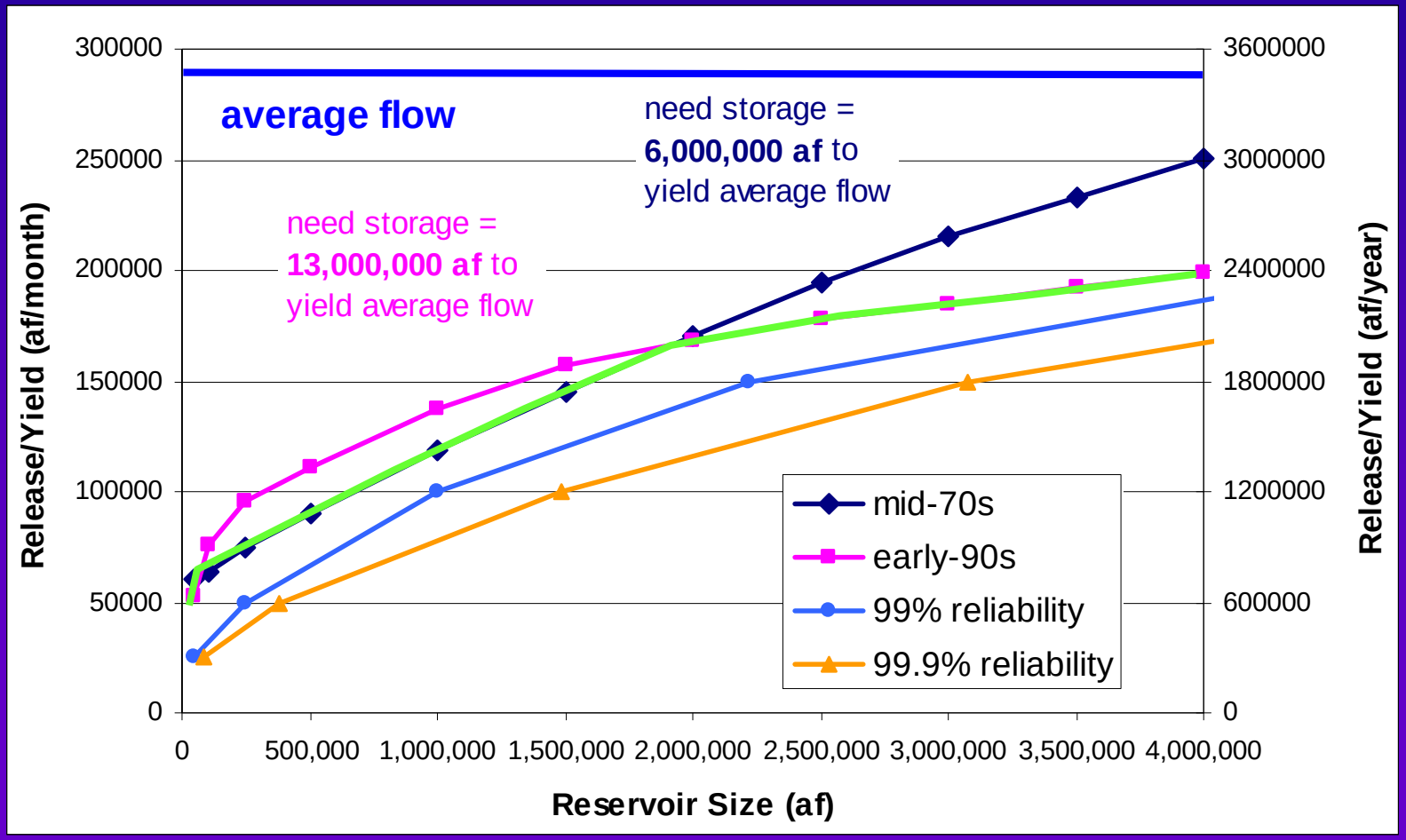

Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0


Reservoir Volume (AF)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0

Required Storage vs Reliability



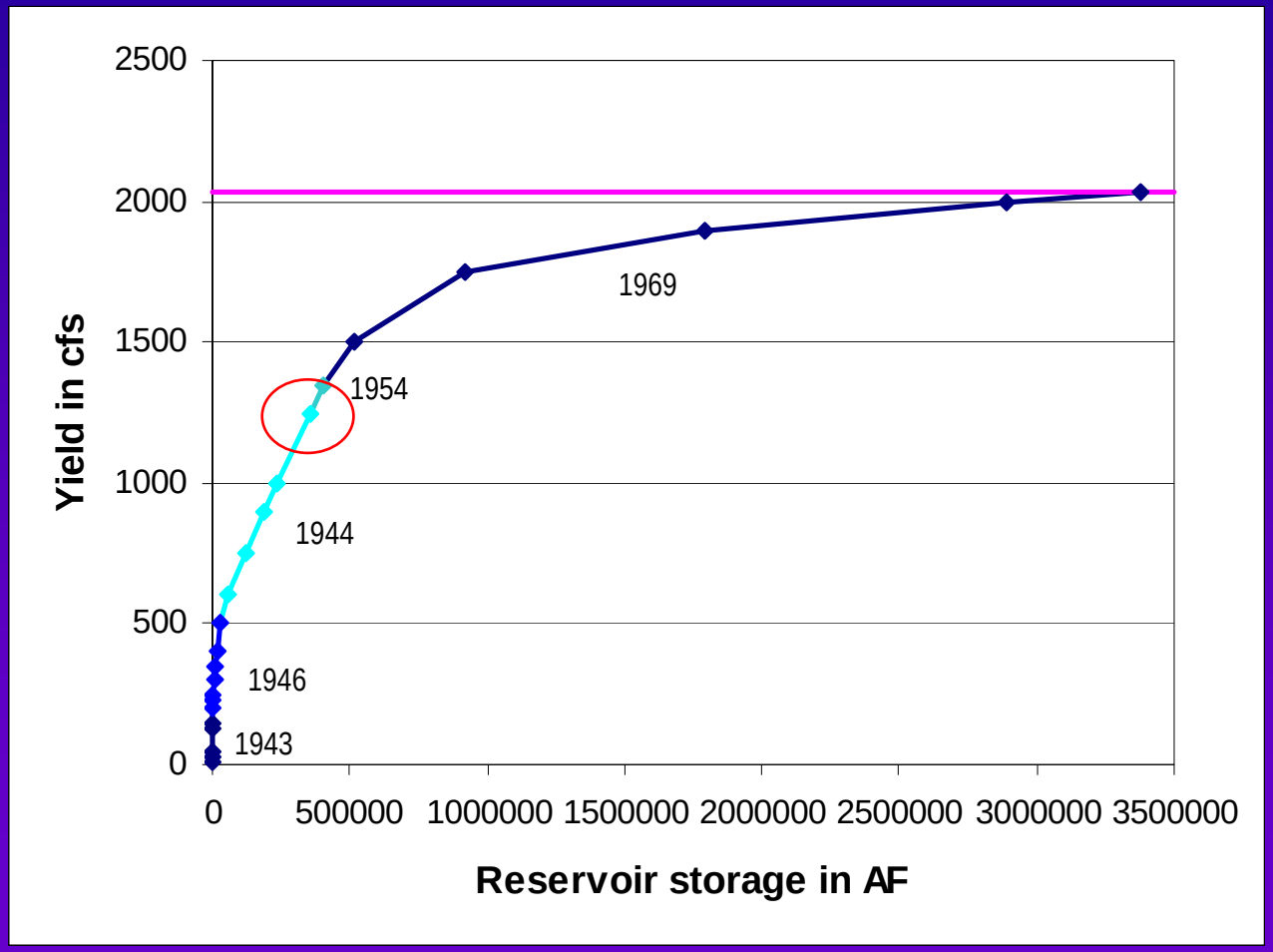
Storage / Yield Relationship for 1000 year series

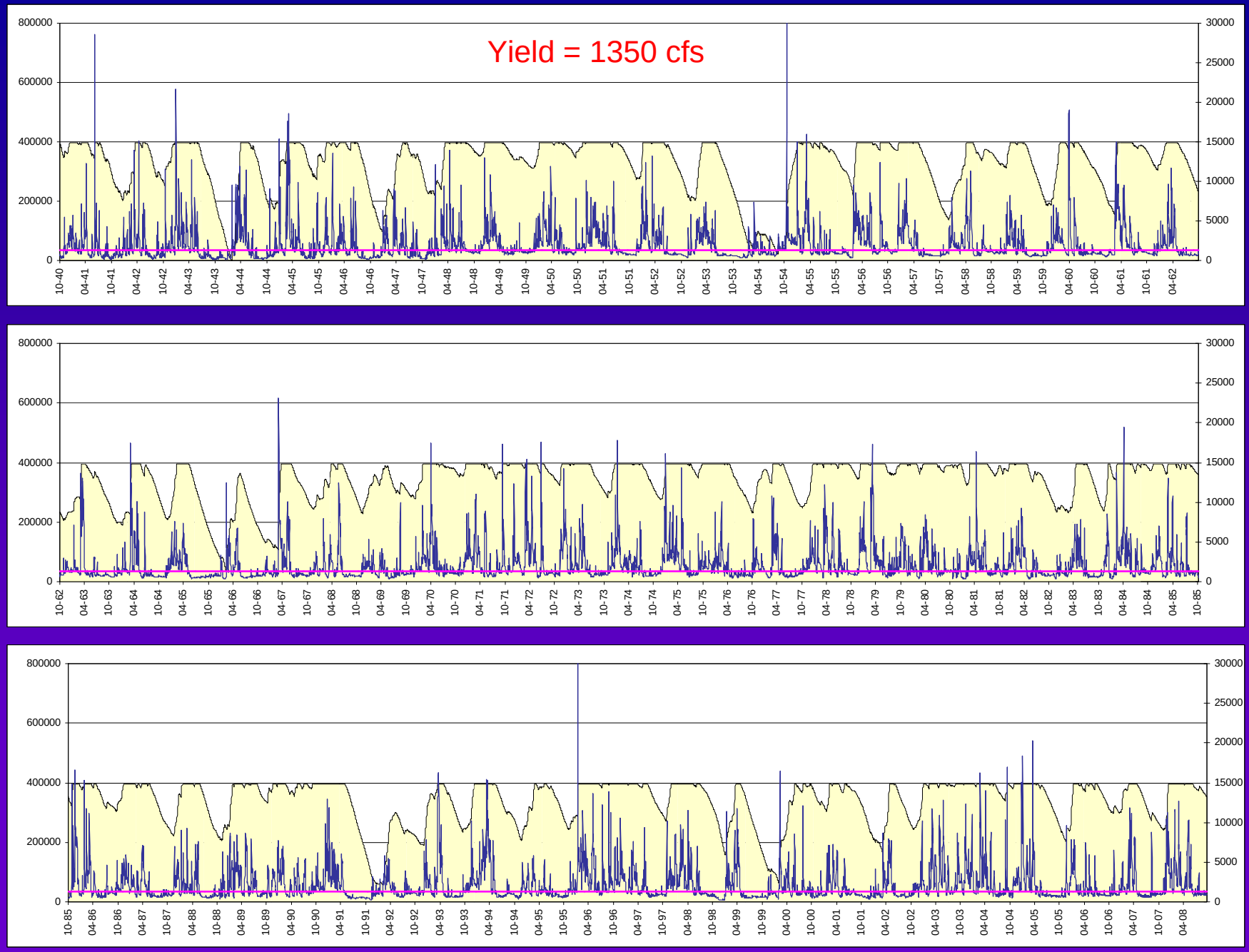


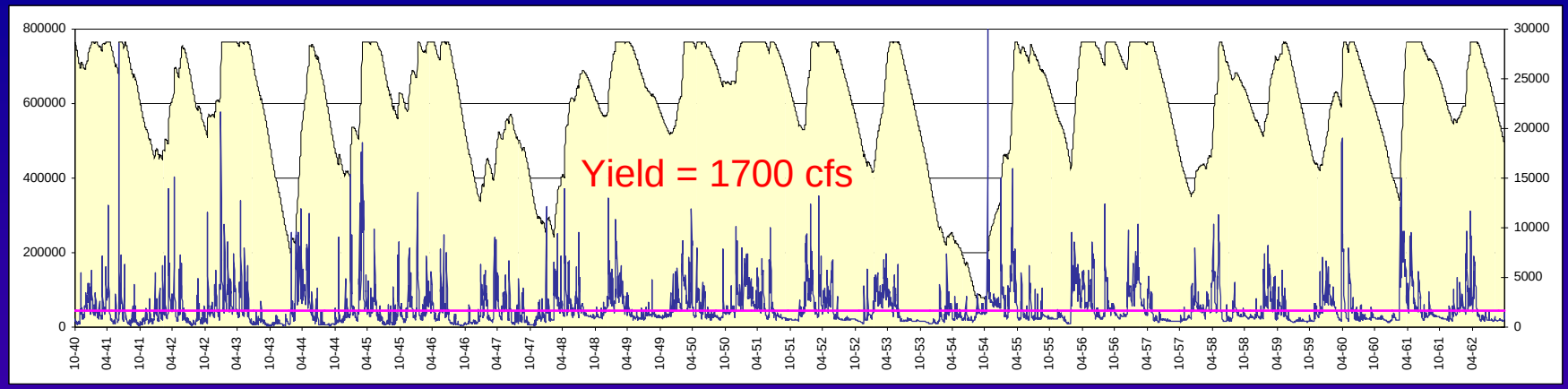
Water Supply contract volumes

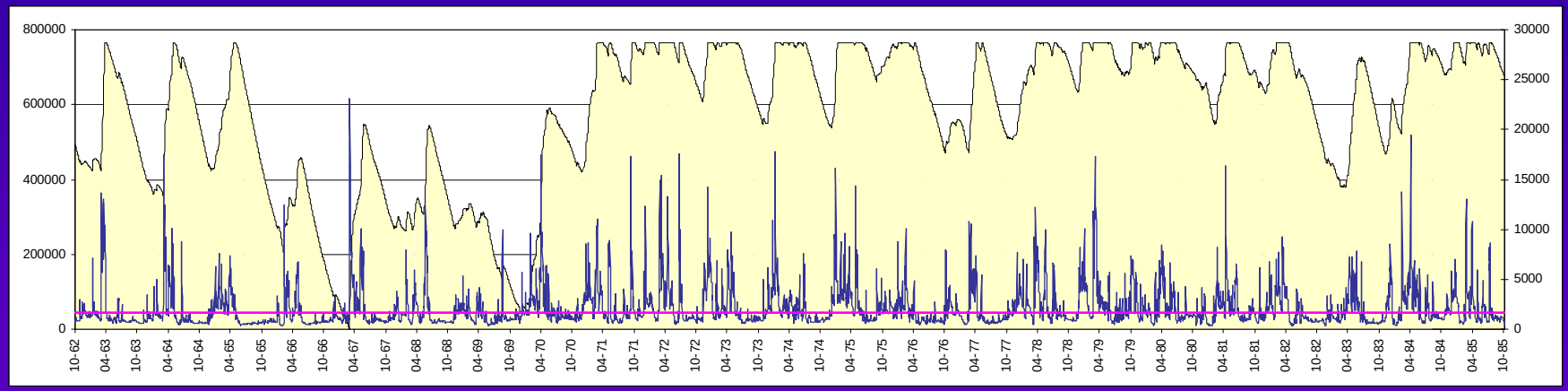
- Question: In an existing reservoir, what volume is needed for user with demand of X mgd?
  - users seeking water supply will contract for a certain volume in the reservoir for their use
  - the important aspect is that the user is one of several users of the conservation pool
  - Some important questions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

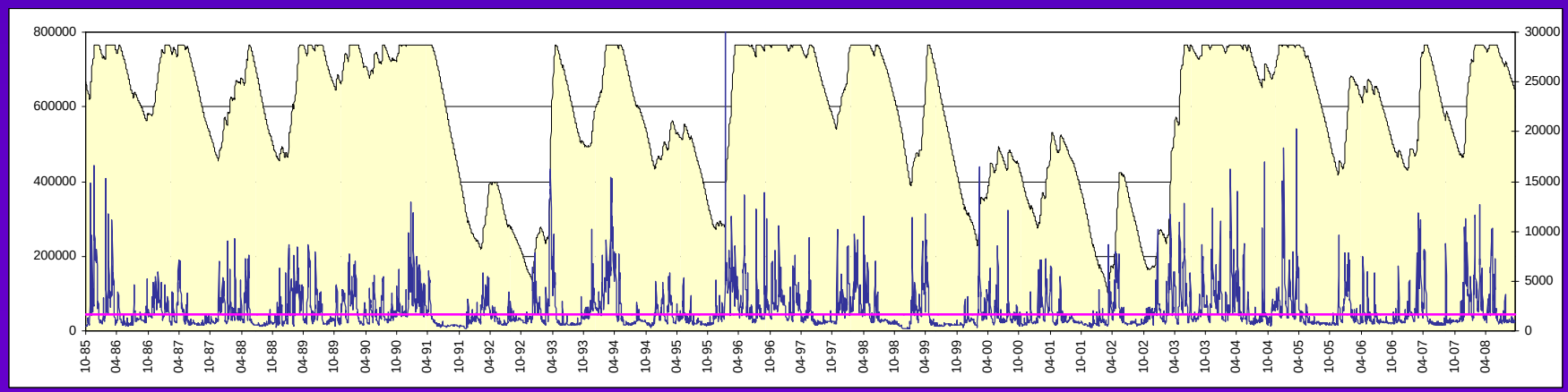
First develop storage/yield relationship



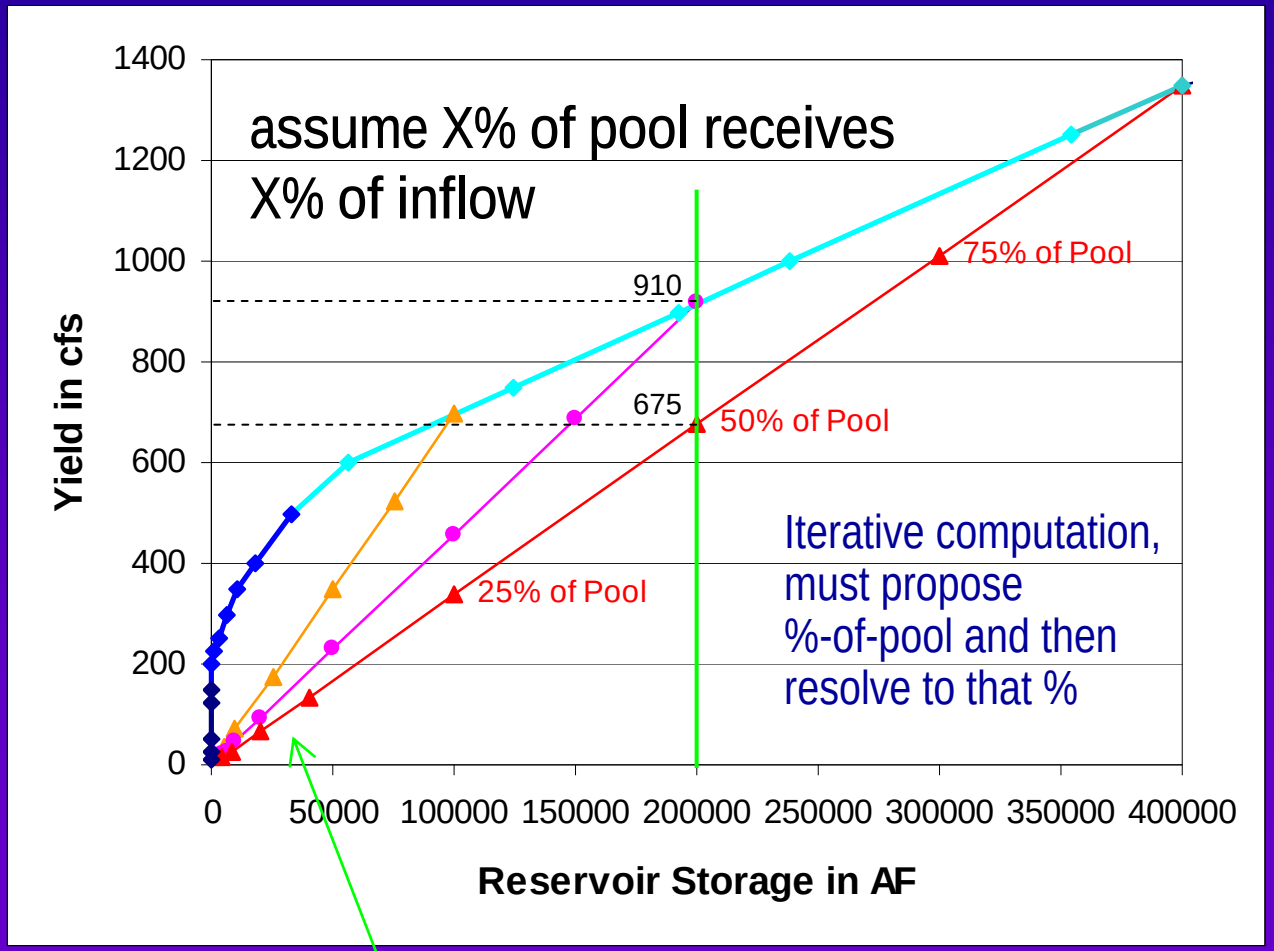

Yield = 1350 cfs
800000
600000
400000
200000
0
30000
25000
20000
15000
10000
5000
0
10-40 04-41 10-41 04-42 10-42 04-43 10-43 04-44 10-44 04-45 10-45 04-46 10-46 04-47 10-47 04-48 10-48 04-49 10-49 04-50 10-50 04-51 10-51 04-52 10-52 04-53 10-53 04-54 10-54 04-55 10-55 04-56 10-56 04-57 10-57 04-58 10-58 04-59 10-59 04-60 10-60 04-61 10-61 04-62
10-62 04-63 10-63 04-64 10-64 04-65 10-65 04-66 10-66 04-67 10-67 04-68 10-68 04-69 10-69 04-70 10-70 04-71 10-71 04-72 10-72 04-73 10-73 04-74 10-74 04-75 10-75 04-76 10-76 04-77 10-77 04-78 10-78 04-79 10-79 04-80 10-80 04-81 10-81 04-82 10-82 04-83 10-83 04-84 10-84 04-85 10-85
10-85 04-86 10-86 04-87 10-87 04-88 10-88 04-89 10-89 04-90 10-90 04-91 10-91 04-92 10-92 04-93 10-93 04-94 10-94 04-95 10-95 04-96 10-96 04-97 10-97 04-98 10-98 04-99 10-99 04-00 10-00 04-01 10-01 04-02 10-02 04-03 10-03 04-04 10-04 04-05 10-05 04-06 10-06 04-07 10-07 04-08


Yield = 1700 cfs
800000
600000
400000
200000
0
30000
25000
20000
15000
10000
5000
0
10-40 04-41 10-41 04-42 10-42 04-43 10-43 04-44 10-44 04-45 10-45 04-46 10-46 04-47 10-47 04-48 10-48 04-49 10-49 04-50 10-50 04-51 10-51 04-52 10-52 04-53 10-53 04-54 10-54 04-55 10-55 04-56 10-56 04-57 10-57 04-58 10-58 04-59 10-59 04-60 10-60 04-61 10-61 04-62


800000
600000
400000
200000
0
30000
25000
20000
15000
10000
5000
0
10-62 04-63 10-63 04-64 10-64 04-65 10-65 04-66 10-66 04-67 10-67 04-68 10-68 04-69 10-69 04-70 10-70 04-71 10-71 04-72 10-72 04-73 10-73 04-74 10-74 04-75 10-75 04-76 10-76 04-77 10-77 04-78 10-78 04-79 10-79 04-80 10-80 04-81 10-81 04-82 10-82 04-83 10-83 04-84 10-84 04-85 10-85


800000
600000
400000
200000
0
30000
25000
20000
15000
10000
5000
0
10-85 04-86 10-86 04-87 10-87 04-88 10-88 04-89 10-89 04-90 10-90 04-91 10-91 04-92 10-92 04-93 10-93 04-94 10-94 04-95 10-95 04-96 10-96 04-97 10-97 04-98 10-98 04-99 10-99 04-00 10-00 04-01 10-01 04-02 10-02 04-03 10-03 04-04 10-04 04-05 10-05 04-06 10-06 04-07 10-07 04-08

Evaluate user storage "account" = % of Pool



most contracts are down here....

More complex than this under Prior Appropriation Doctrine

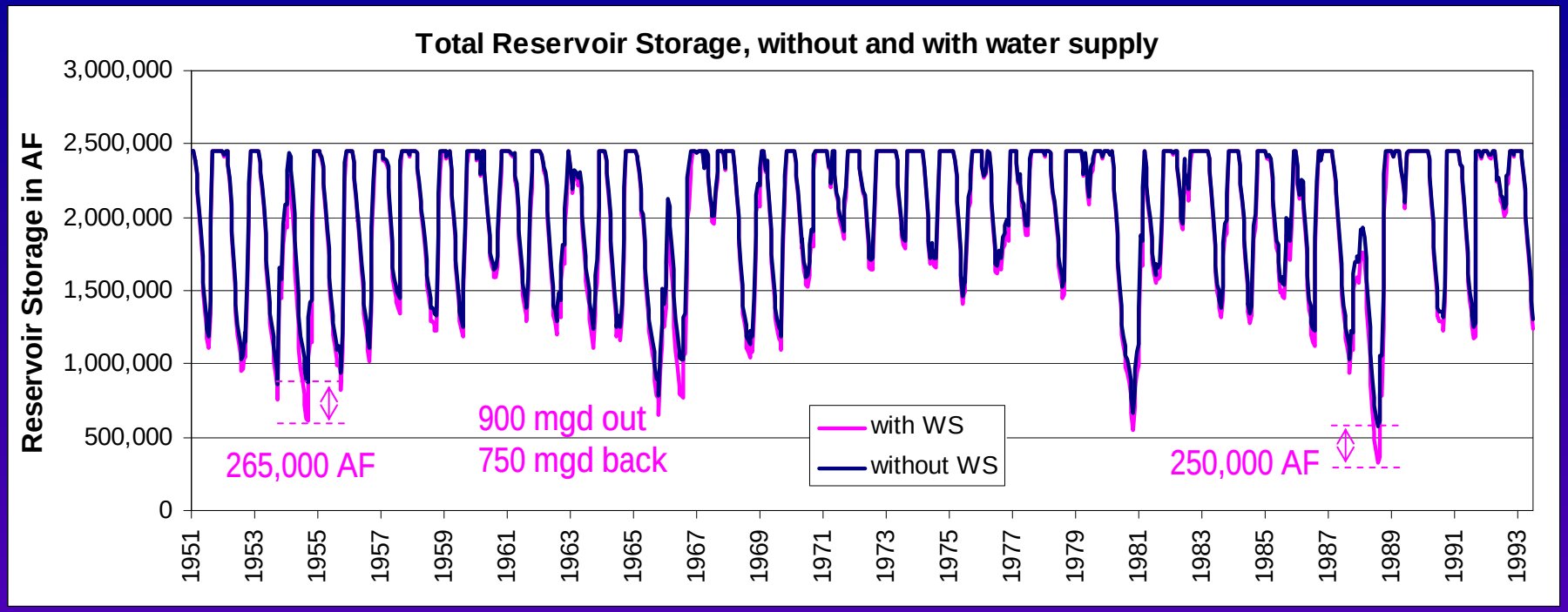
Notice, having half of a 400,000 AF conservation pool is not the same as having all of a 200,000 AF conservation pool. The difference is that only get half of the inflow.

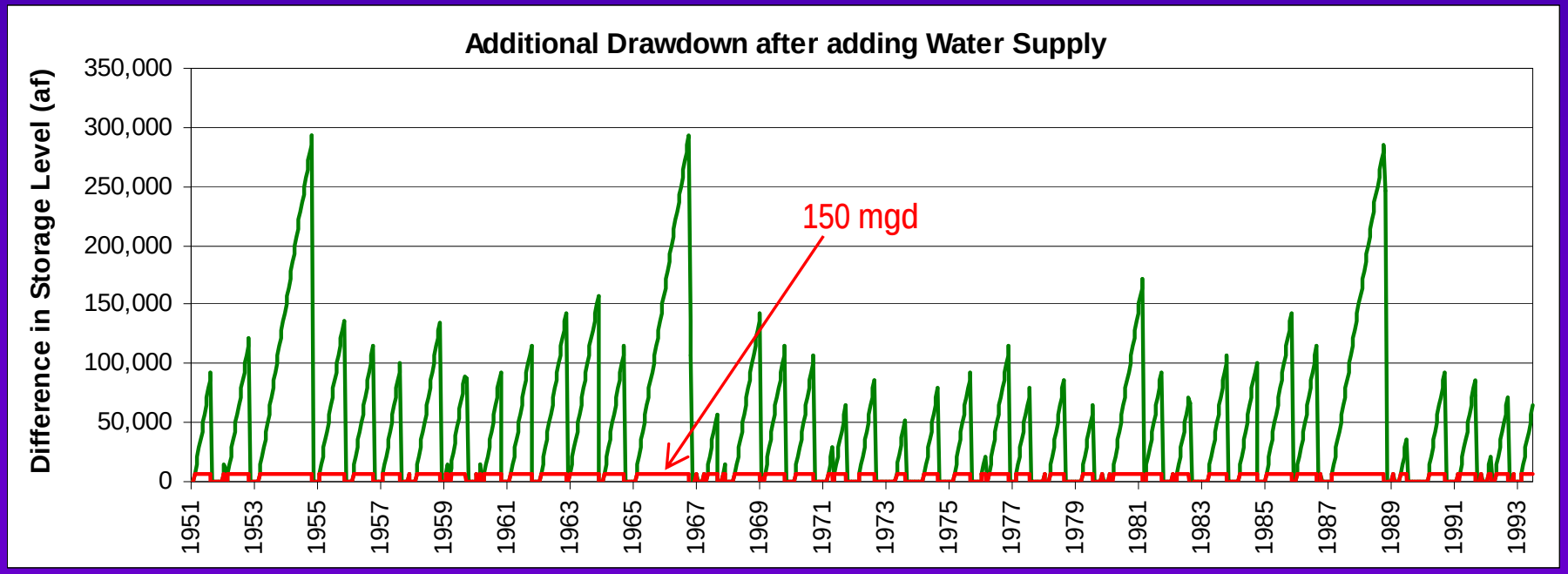
Water Supply / Firm Yield R&D Unit

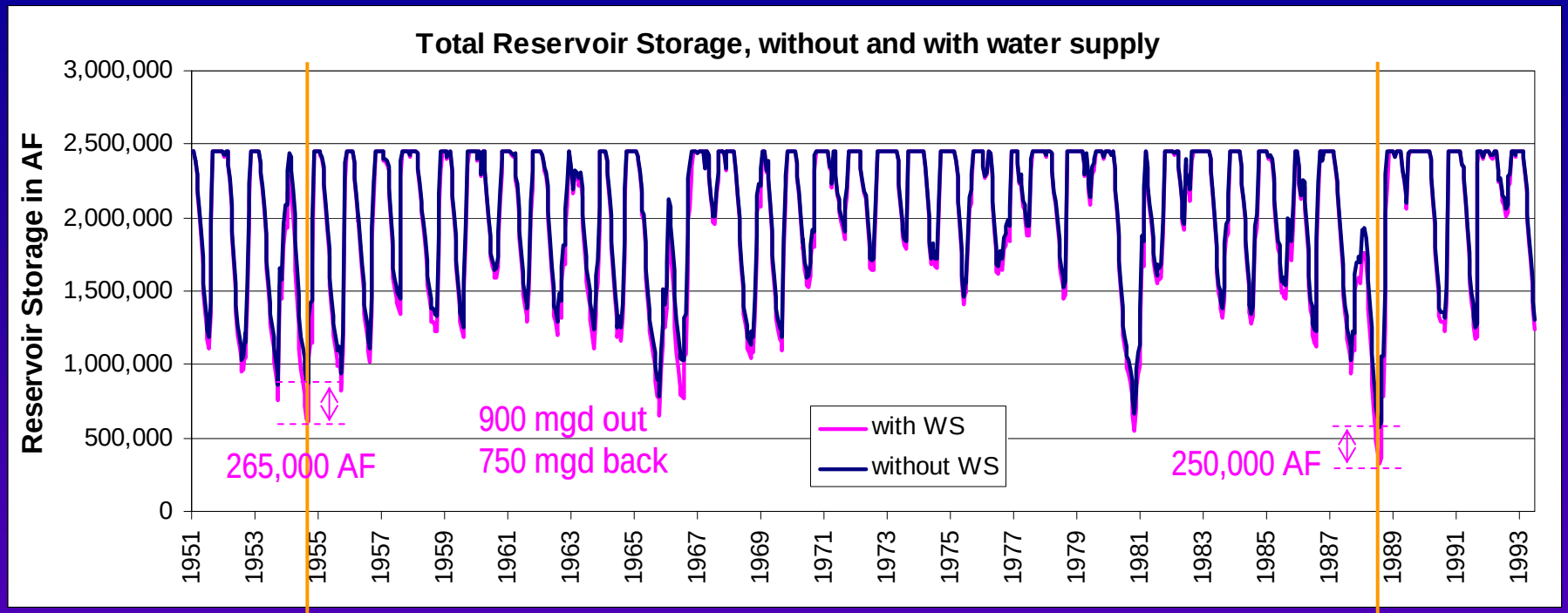
- Survey the methods in use to compute firm yield for water supply contracts
- Evaluate methods
- Investigate “consistent” method that could apply in all or most cases, and build tools to implement
- So far, feedback from:
- NWW, LPR, LRN, LRL, LRH, POD, SPL, SWL, SWT

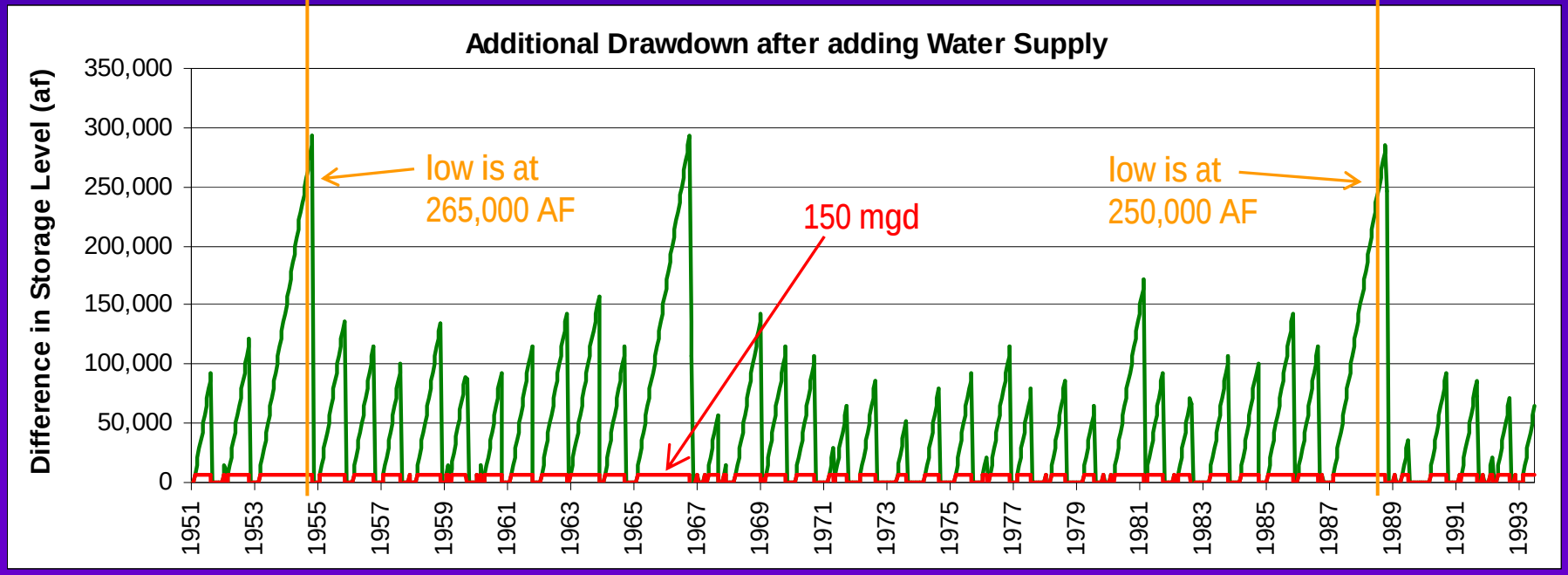
Methods in the Field

- 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
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
265,000 AF
900 mgd out
750 mgd back
with WS
without WS
250,000 AF


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
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
150 mgd


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
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
265,000 AF
900 mgd out
750 mgd back
with WS
without WS
250,000 AF


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
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
low is at
265,000 AF
150 mgd
low is at
250,000 AF

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

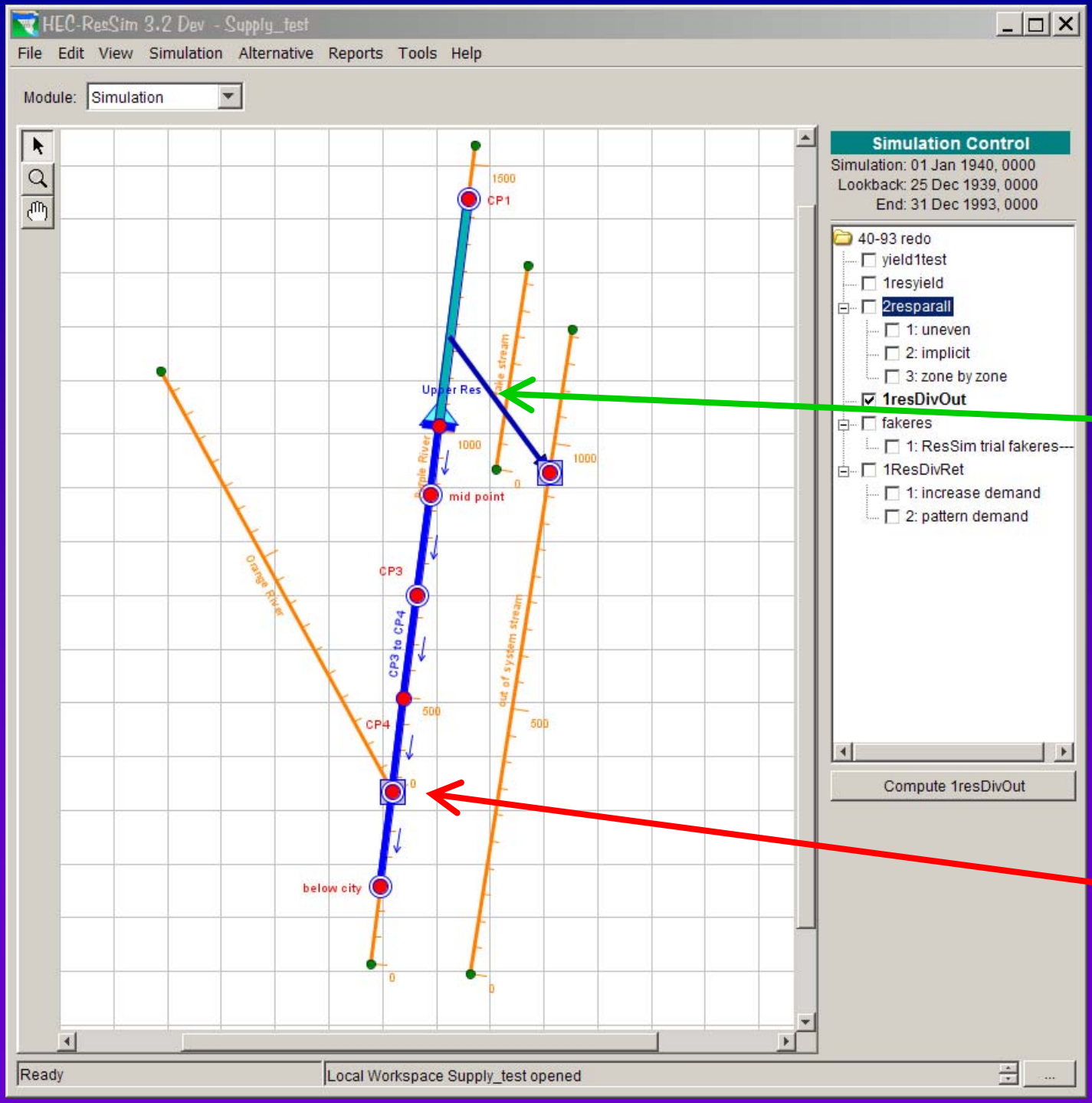
- Is this correct? *...not in riparian water law states*
  - In Riparian states, more appropriate to allocate inflow in proportion with % of pool.
  - in Prior Appropriation states, closer to correct, but should account for water rights
- To model this situation better, must track a storage account within 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?

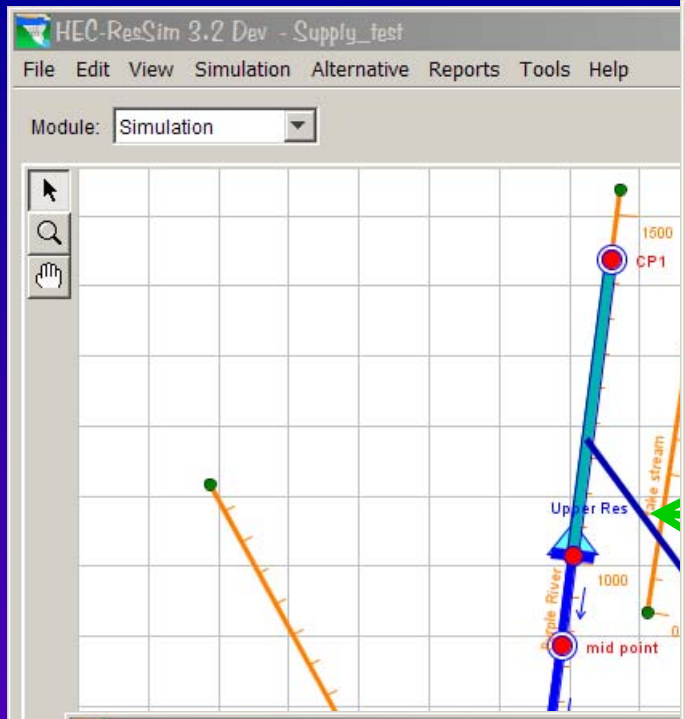
- Most of the methods demonstrated show water supply as the only use, and don't capture the conflict or priority between uses
- Only last method really captures other uses, but it has other problems...
- We need to simulate the reservoir realistically
  - add new use to existing reservoir system with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

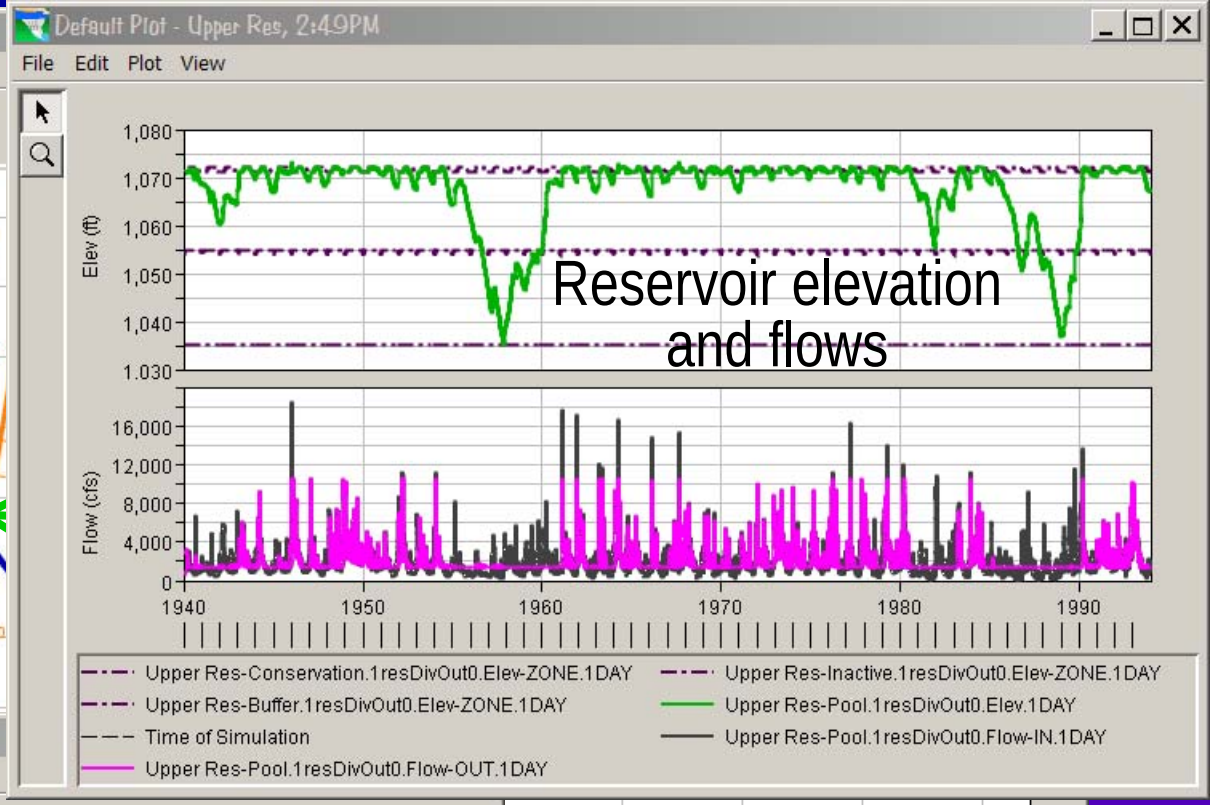
What about multi-reservoir systems?

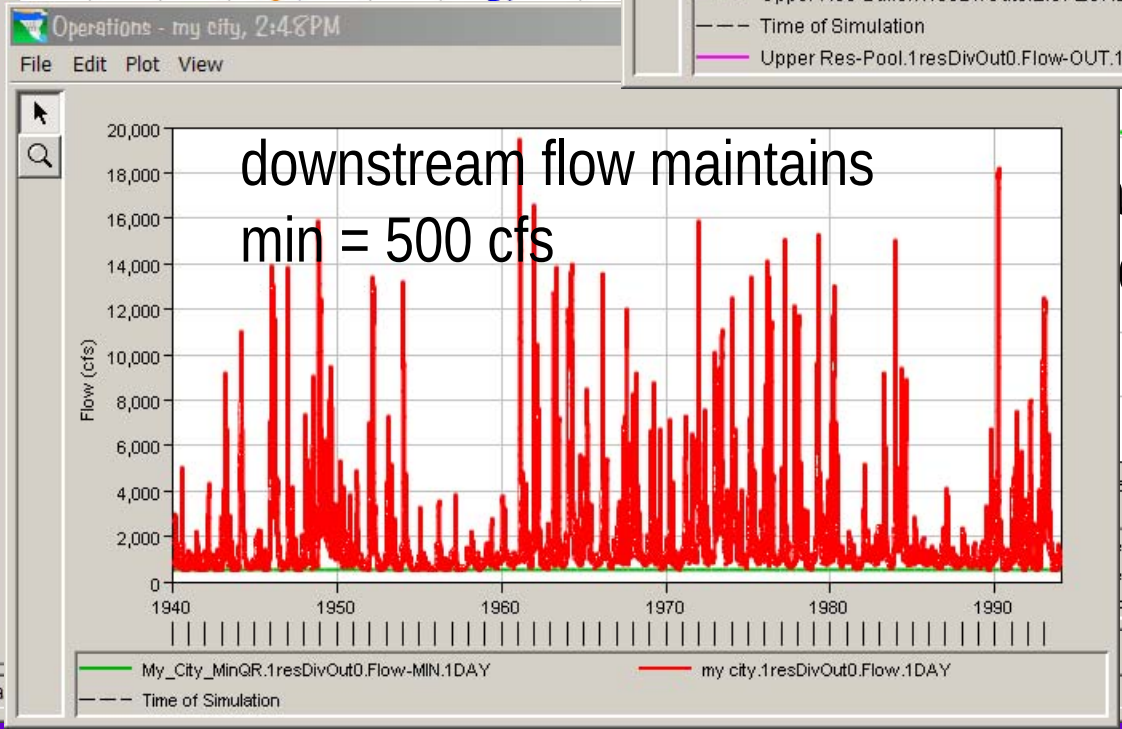
- In the methods shown, multiple reservoirs serving the same demand are only captured by combining volumes
- It would be better to model the complete reservoir system... as well as the other uses and accounts
- As a start, HEC-ResSim now has ability to do "Reassessment/Operations" yield analysis
  -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

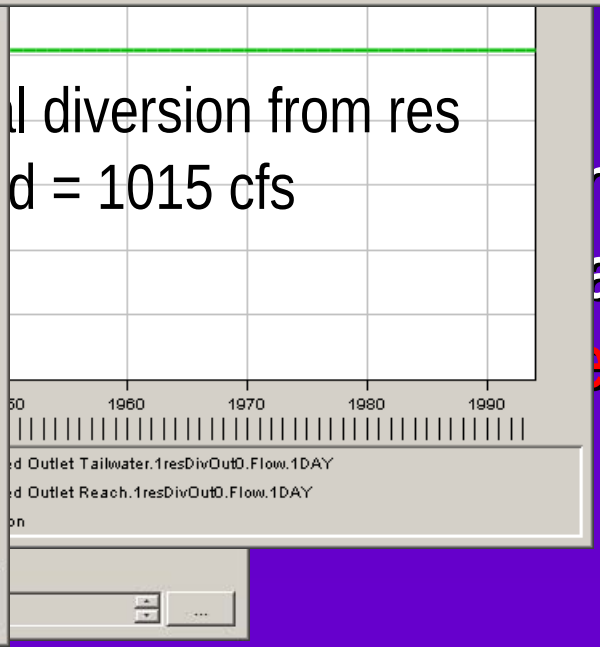


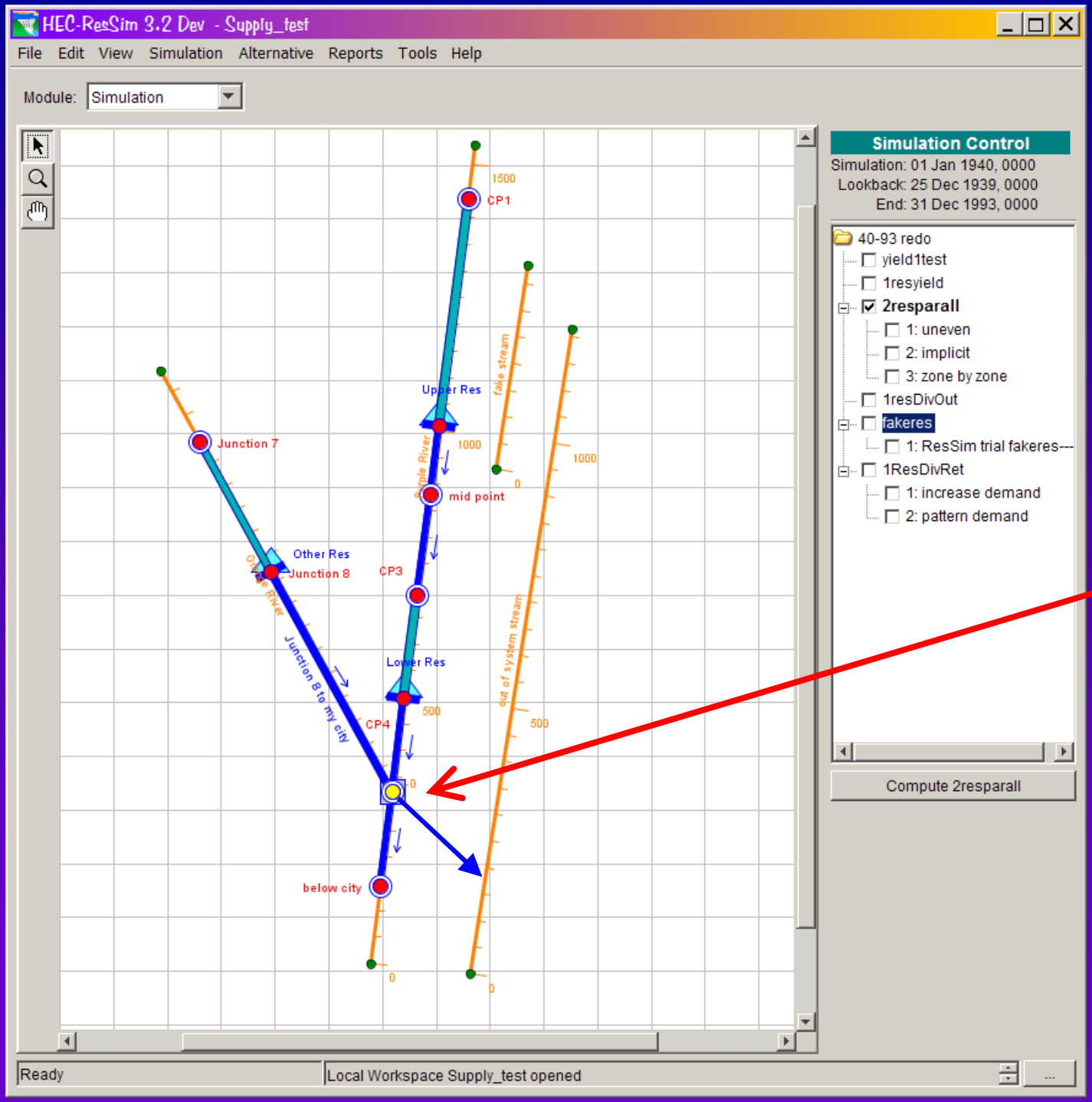
1 reservoir system, want to find yield at reservoir, higher priority min flow requirement of 500 cfs at confluence


HEC-ResSim 3.2 Dev - Supply_test
File Edit View Simulation Alternative Reports Tools Help
Module: Simulation
1500
CP1
Upper Res
1000
mid point

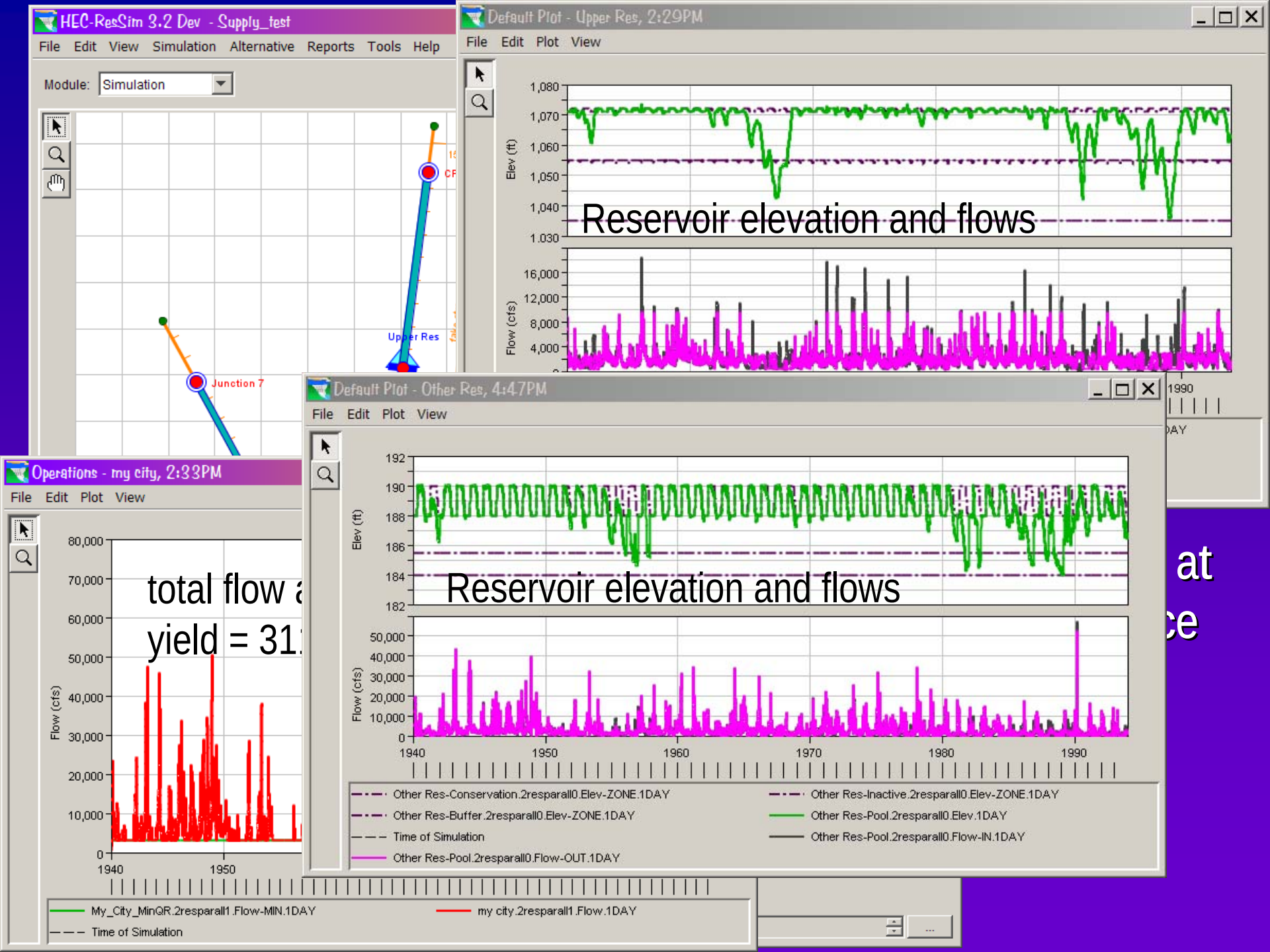

Default Plot - Upper Res, 2:49PM
File Edit Plot View
Elev (ft)
1,080
1,070
1,060
1,050
1,040
1,030
Reservoir elevation and flows
Flow (cfs)
16,000
12,000
8,000
4,000
0
1940
1950
1960
1970
1980
1990
Upper Res-Conservation.1resDivOut0.Elev-ZONE.1DAY
Upper Res-Inactive.1resDivOut0.Elev-ZONE.1DAY
Upper Res-Buffer.1resDivOut0.Elev-ZONE.1DAY
Upper Res-Pool.1resDivOut0.Elev.1DAY
Time of Simulation
Upper Res-Pool.1resDivOut0.Flow-IN.1DAY
Upper Res-Pool.1resDivOut0.Flow-OUT.1DAY


Operations - my city, 2:48PM
File Edit Plot View
downstream flow maintains
min = 500 cfs
Flow (cfs)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1940
1950
1960
1970
1980
1990
My_City_MinQR.1resDivOut0.Flow-MIN.1DAY
my city.1resDivOut0.Flow.1DAY
Time of Simulation


l diversion from res
d = 1015 cfs
1960
1970
1980
1990
d Outlet Tailwater.1resDivOut0.Flow.1DAY
d Outlet Reach.1resDivOut0.Flow.1DAY



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


HEC-ResSim 3.2 Dev - Supply_test
File Edit View Simulation Alternative Reports Tools Help
Module: Simulation
Junction 7
Upper Res
Default Plot - Upper Res, 2:29PM
File Edit Plot View
Elev (ft)
Flow (cfs)
Reservoir elevation and flows
Default Plot - Other Res, 4:47PM
File Edit Plot View
Elev (ft)
Flow (cfs)
Reservoir elevation and flows
Other Res-Conservation.2resparall0.Elev-ZONE.1DAY
Other Res-Buffer.2resparall0.Elev-ZONE.1DAY
Time of Simulation
Other Res-Pool.2resparall0.Flow-OUT.1DAY
Other Res-Inactive.2resparall0.Elev-ZONE.1DAY
Other Res-Pool.2resparall0.Elev.1DAY
Other Res-Pool.2resparall0.Flow-IN.1DAY
Operations - my city, 2:33PM
File Edit Plot View
Flow (cfs)
total flow a
yield = 31
My_City_MinQR.2resparall1.Flow-MIN.1DAY
Time of Simulation
my city.2resparall1.Flow.1DAY

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.