SPECIAL PUBLICATION SJ2009-SP1

EVALUATION OF THE FEASIBILITY OF WATER SUPPLY WITHDRAWALS FROM THE UPPER OCKLAWAHA RIVER BASIN – PHASE 2: INVESTIGATION OF POTENTIAL WATER SUPPLY YIELD AT MOSS BLUFF

Water Supply
Solutions, Inc.

Technical Memorandum

To: James T. Gross, P.G.

Copy: Elizabeth Thomas, P.E., DEE

From: Ronald L Wycoff, P.E., D.WRE

Date: October 21, 2008

Re: Evaluation of the Feasibility of Water Supply Withdrawals from the Upper Ocklawaha River Basin – Phase 2: Investigation of Potential Water Supply Yield at Moss Bluff

---

Purpose and Scope

This technical memorandum (TM) is the second of two prepared for St. Johns River Water Management District (SJRWMD) to address the potential availability of surface water supply within the Upper Ocklawaha River Basin (UORB). The first TM (Phase 1 dated July 24, 2008) provided a screening of available annual streamflow records, within the UORB, and identified the historic record at the Moss Bluff USGS gage for water years 1970 through 2007 as the most applicable for this water supply investigation. The analysis presented herein is based on daily streamflow records for Moss Bluff (USGS Station No. 2238500), for the 38-year period of analysis (POA) from October 1, 1969 through September 30, 2007.

The ultimate goal of this investigation is to explore and define, to the extent practical, interrelations between potential available water supply or “water supply yield” and important variables including:

- Trial diversion rules, defining possible water supply withdrawal constraints
- Maximum diversion capacity
- Off-line storage volume
- Overall water supply system reliability

To meet this objective, the daily discharge characteristics at Moss Bluff, for the POA, are quantified and presented.

Three trial diversions rules are then defined. These diversion rules are intended to represent a range of potential withdrawal constraints, which may be applicable in the future.

A water supply yield analysis is then conducted for each trial diversion rule. The first part of the yield analysis considers diversion only. That is, the potential divertible flow and water supply system reliability is investigated, as a function of installed diversion capacity.

The second part of the yield analysis considers off-line storage and selected levels of system reliability. Storage requirements are defined for each trial diversion rule, as a function of water supply yield and system reliability.

Moss Bluff Daily Discharge Characteristics

The Moss Bluff water control structure is located on the main stem of the Ocklawaha River and provides water level control for Lake Griffin. All water discharged from the UORB is measured at Moss Bluff.

The main objective of the water control structure is to meet the existing water level control schedule for Lake Griffin, which strives to maintain water levels in a rather narrow range and to prevent flooding. Discharge at Moss Bluff is controlled to meet this objective. The daily discharge statistics, for the 38-year POA, are reported in Table 1.

Table 1. Moss Bluff POA Daily Discharge Characteristics (discharge units are cubic feet per second – cfs)

Discharge Characteristic	POA Sample Value
Mean	198
Median	36
Maximum	2,340
Minimum	0
Std. Dev.	364
Coeff. of Variation	1.84

The mean discharge, of 198 cfs, is relatively small when compared to the 879 square mile tributary drainage area. The unit yield of the UORB, for the POA, is only 0.225 cfs per square mile. By comparison the unit yield of the main stem of the St. Johns River is approximately 1 cfs per square mile.

The median flow of 36 cfs is of some importance from a water supply development perspective. This small median flow, only 18% of mean flow, indicates a skewed flow distribution with long periods of low to moderate flow, and relatively short periods of high flow. In fact, the 198 cfs mean discharge rate is equaled or exceeded only about 22.4% of the time. This pattern is illustrated in the POA flow duration curve (Figure 1).

Cumulative mass discharge at Moss Bluff versus time is shown in Figure 2. The slope of the mass curve, for any time period, is equal to the average discharge rate for that time period. Relatively long flat portions of the curve indicate droughts. A long multi-year drought is indicated from mid 1998 through early 2003. Other shorter, but still significant, multi-year droughts are also apparent.

Trial Diversion Rules

Environmental limits and other constraints on water supply withdrawal at Moss Bluff have not been established. Such constraints will be defined when water needs for environmental restoration projects and minimum flows and levels (MFLs) are established. In order to proceed with this analysis, the 3 trial diversion rules were selected, in consultation with SJRWMD staff.

The trial diversion rules were defined to represent a range of potential water supply withdrawal restrictions, which may be applicable in the future once restoration needs and MFLs are established. The trial diversion rules are only examples of what may ultimately be applicable and because future withdrawal restrictions have not been established, it is unlikely that any of the 3 trial diversion rules will exactly match future withdrawal constraints.

The trial diversion rules include two parameters:

- A minimum flow rate, below which withdrawal will not be allowed.
- The fraction of streamflow above the minimum that may be withdrawn.

Maximum withdrawal rate and total volume diverted will also be limited by the installed diversion pumping capacity (Qp). For the purpose of this investigation, total water supply yield was limited to approximately 10% of the POA average discharge or about 20 cfs. That is, total water supply yields greater than about 20 cfs (13 mgd) are not considered.

The 3 trial diversion rules are defined, from least restrictive to most restrictive, as follows:

- **The 10, 1 rule** – The minimum flow rate, at the Moss Bluff water control structure, is 10 cfs and all discharge beyond this minimum limit, up to the installed diversion pumping capacity (Qp), may be diverted for water supply. For example, if the daily discharge is 30 cfs, then 20 cfs may be diverted for water supply.

- **The 10, 0.5 rule** – The minimum flow rate, at the Moss Bluff water control structure, is 10 cfs and 50% of the discharge above this minimum limit, up to the installed diversion pumping capacity (Qp), may be diverted for water supply. For example, if the daily discharge is 30 cfs, then 10 cfs may be diverted for water supply.

- **The 20, 0.5 rule** – The minimum flow rate, at the Moss Bluff water control structure, is 20 cfs and 50% of the discharge above this minimum limit, up to the installed diversion pumping capacity (Qp), may be diverted for water supply. For example, if the daily discharge is 30 cfs, then only 5 cfs may be diverted for water supply.

The 3 trial diversion rules are illustrated on Figure 3, which shows allowable water supply diversion rate as a function of daily Moss Bluff discharge. In the remainder of the TM, including figures, the 3 trial diversion rules will be referred to by their respective numeric parameters (10, 1), (10, 0.5) and (20, 0.5).

Yield Analysis Approach – The Moss Bluff Flow Diversion and Storage Routing Model

As previously discussed, water supply yield can be a function of many variables including, withdrawal constraints, diversion capacity, storage volume and desired water supply system reliability. The approach taken herein is to simulate the water supply system operation on a continuous basis. The Moss Bluff flow diversion and storage routing model is an EXCEL spreadsheet based simulation developed to represent important system components. It is applied to numerous scenarios to develop an overall understanding of the interrelationships among the several system variables.

Model Component and Structure

The model structure and system logic is illustrated on the model schematic diagram (Figure 4). The simulation begins with the historic daily discharge record for Moss Bluff for the 38-year POA (October 1, 1969 to September 30, 2007). The diversion rule is then applied to convert the historic record to a divertible daily flow sequence. The daily values in this sequence are then compared to the maximum installed diversion pumping capacity (Qp) and values greater than Qp are set equal to Qp.

The resulting daily flow array represents the total divertible flow, which is that portion of the total Moss Bluff discharge available to meet water supply needs.

For each day in the simulation, the daily divertible flow value is compared to the desired water supply demand (Qd). If the daily divertible flow rate is greater than or equal to the demand, the daily demand is met by the same day divertible flow. Any excess daily divertible flow becomes storage inflow.

If the daily demand cannot be fully met by the same day divertible flow then the demand is met by storage outflow (if available). Storage volume is updated each day to account for inflow and outflow and is checked to be sure that the end of day storage value is in the range from zero (empty) to the maximum storage volume (Vs) provided (full).

Success is defined as meeting the entire water supply demand on any given day and conversely failure is defined as not meeting the entire daily demand on any given day. Reliability is then the success rate. Ninety percent reliability is defined as meeting the entire daily water supply demand 9 days out of 10 over the long term. A 100% reliable system would meet the desired demand for each day in the 38-year POA. System reliability is tracked and reported in the simulation.

Input Variables and Output

User supplied simulation model input variables are defined as follows:

- Diversion rule variables:
    - Qmin = minimum flow rate below which water supply withdrawal will not be allowed, in cfs
    - Qfraction = fraction of discharge, above Qmin, which may be diverted
- Withdrawal facility
    - Qp = maximum installed diversion pumping capacity, in cfs
- Water supply demand
    - Qd = target water supply demand, or desired yield, to be met, in cfs
- Storage parameters
    - Vs = maximum storage volume provided. This value in input in days of storage applied to the desired demand. It is then converted to cfs-days (Vs*Qd), which is the volumetric unit used in the computations. The storage volume provided is also reported in units of cubic-feet, acre-feet and million gallons.

- Initial storage volume at the beginning of the simulation is input as a fraction of Vs. In all simulations for this analysis an input value of 0.5 was used. That is, it was assumed that the storage unit was half full at the beginning of each simulation period.

Results reported include the estimated water supply yield (average demand actually met) and full demand system reliability, for the POA.

In this analysis, water supply demand (Qd) is an input variable and is equal to the quantity of water desired from the water supply system. Demand may be thought of as the desired yield.

Actual water supply yield, on the other hand, is the average quantity of water actually delivered. It is an output of the water supply system. Reliability is then the percentage of time that the desired demand is actually met.

Yield will equal demand only when the water supply system is 100% reliable. In most cases, a water supply system will be less than 100% reliable and therefore, actual yield will be less than desired demand.

Limitations

This approach has several limitations. First, all computations are based on the selected 38-year POA, which reflects past and present water management practices. Future water management practices may change, which may impact the Moss Bluff flow regime and thus the underling basis of this analysis.

Secondly, only Moss Bluff discharge is considered. In certain storage applications other sources and sinks may become important. These include rain falling directly on the storage reservoir pool and evaporation from the pool, as well as seepage losses from the storage facility. In general, direct rainfall and pool evaporation are approximately equal over the long term and are often ignored in a preliminary analysis, such as this. However, in certain site specific applications, seepage losses from storage may be significant. The water supply yield estimates presented herein should be considered total yield and should be reduce by expected seepage losses if such losses are relevant to a given potential application.

Potential Water Supply Yield with Diversion Pumping Only

The first set of simulation runs addressed potential water supply yield considering diversion pumping only. In this case, storage volume is equal to zero.

For these simulations, diversion pumping capacity (Qp) and target demand (Qd) are the same. For each trial diversion rule, the diversion pumping capacity was incrementally increased and the corresponding total average yield and full demand reliability were determined. Tabular results for the diversion only simulation runs are reported in Appendix A.

Figure 5 presents the total yield results for each of the 3 trial diversion rules. As can be seen from the figure, the diversion rule has a significant impact on water supply yield. Consider, for example, a 20 cfs diversion capacity. For the 10, 1 rule an average of 17 cfs can be diverted for water supply, whereas; for the 20, 0.5 rule, the average yield falls to 10 cfs. This pattern holds for all diversion capacities considered.

Figure 6 presents the reliability results for each combination of diversion rule and diversion capacity considered. A reliability of approximately 90% can be achieved for a target demand of 10 cfs, for the 10, 1 diversion rule. For the 10, 0.5 diversion rule, the 90% reliability yield is only 5 cfs. Reliability diminished rapidly with increased target yield thereafter. For example, a 20 cfs target yield can be achieved only about 30 to 35% of the time for the 10, 0.5 or the 20, 0.5 diversion rule.

Potential Water Supply Yield with Diversion Pumping and Storage

The second set of simulation runs includes both varying diversion capacities and storage volumes. In order to fill a storage unit, the installed diversion pumping capacity (Qp) must be greater than the target water supply demand (Qd). The tradeoff between diversion capacity and storage volume, for any given application, is largely an economic issue. That is, there is an optimum (i.e. least cost) combination of diversion capacity and storage volume for any desired water supply yield and system reliability. Such issues can only be addressed in a project specific application, which is beyond the scope of this preliminary investigation.

For this analysis, a relatively large installed diversion pumping capacity (Qp), equal to 5 times the target water supply demand (Qd), was assumed for all simulation runs. This ratio is considered to be large enough to effectively minimize the required storage volume, which is often the most costly component of a diversion/storage system. For any subsequent project specific application, a relationship between diversion capacity and storage volume for the desired yield and reliability should be developed and the least cost combination should be identified.

However, for this preliminary feasibility analysis all simulations are based on an installed diversion pumping capacity equal to 5 times the target water supply demand (Qp = 5*Qd). For example, a 10 cfs target demand would be served by a 50 cfs diversion facility.

All diversion and storage system simulation results are presented in tabular format in Appendix B. The results are also presented graphically in two ways. Figures 7, 8 and 9 present required storage volume, in acre-feet, as a function of water supply yield for each of 5 alternative levels of system reliability. Each of the 3 figures presents results for a given diversion rule. Figure 7 is based on the 10, 1 rule and Figures 8 and 9 are based on the 10, 0.5 and 20, 0.5 diversion rules respectively.

The five levels of reliability were chosen to represent a range of possible water supply project objectives. The 90% and 95% reliabilities are associated with projects where reliability is relatively less important. An example might be a groundwater recharge project or perhaps a supplemental irrigation project.

The two highest levels of reliability 99.73% and 100% would represent standalone public water supply systems where reliability is quite important. The 99.73% reliability represents an average failure rate of one day per year and the 100% reliability is zero failures for the POA.

The 98% reliability is an intermediate level of reliability and could represent an application where reliability is important but not as critical as in public supply. A primary irrigation source may be such an application.

The results indicate that storage requirements can vary by orders of magnitude depending on both the diversion rule and on desired reliability. Consider for example a 20 cfs (13 mgd) demand and the 10, 1 diversion rule (Figure 7). To achieve a 90% reliability, a storage volume of only about 464 acre-feet (11.7 days) would be required. However, for a 100% reliability about 6,150 acre-feet (155 days) of storage would be needed. If we now consider the more restrictive 20, 0.5 diversion rule (Figure 9) the storage requirement increases to about 10,600 acre-feet (268 days) for 90% reliability, and to about 27,500 acre-feet (692 days) for 100% reliability.

The simulation results illustrated in Figures 7, 8 and 9 are also shown in Figures 10 through 14 in a different format. In this case, required storage volume as a function of water supply yield, is illustrated for each of the 5 levels of reliability. Individual curves on these figures represent the 3 trial diversion rules. These figures clearly illustrate the influence of the trial diversion rules on water supply storage requirements.

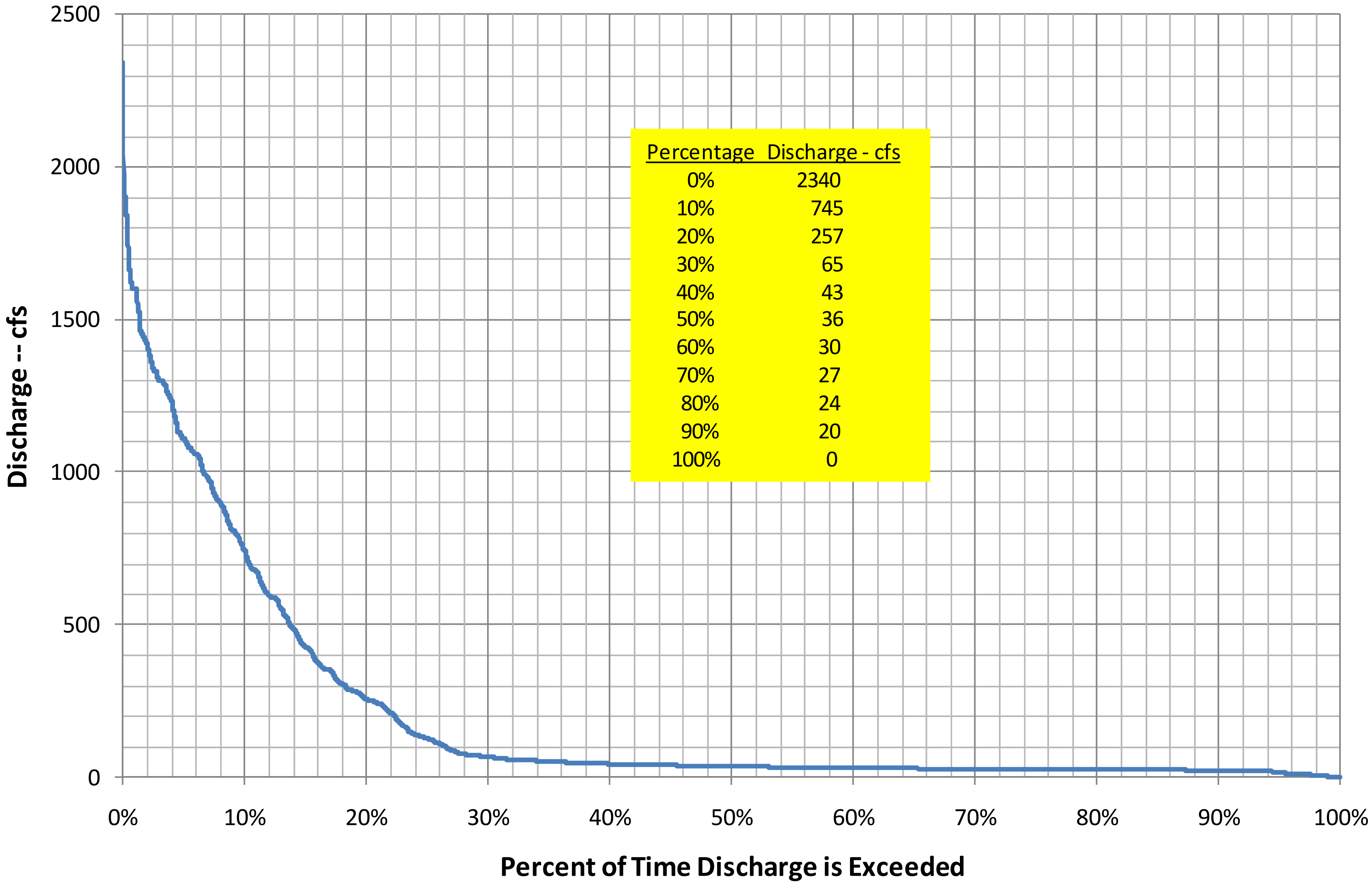
Discussion

The results of this evaluation of the feasibility of water supply withdrawal from the UORB indicate that total surface water yield from the watershed is relatively small, and highly variable. Development of a significant and dependable water supply would likely be difficult. However, small withdrawals with limited reliability may be less difficult and, therefore, more feasible.

The analysis is limited by the uncertainty associated with future withdrawal restrictions. However, sensitivity to 3 trial diversion rules is illustrated. It is apparent from the results that the diversion rule can greatly influence water supply facilities requirements.

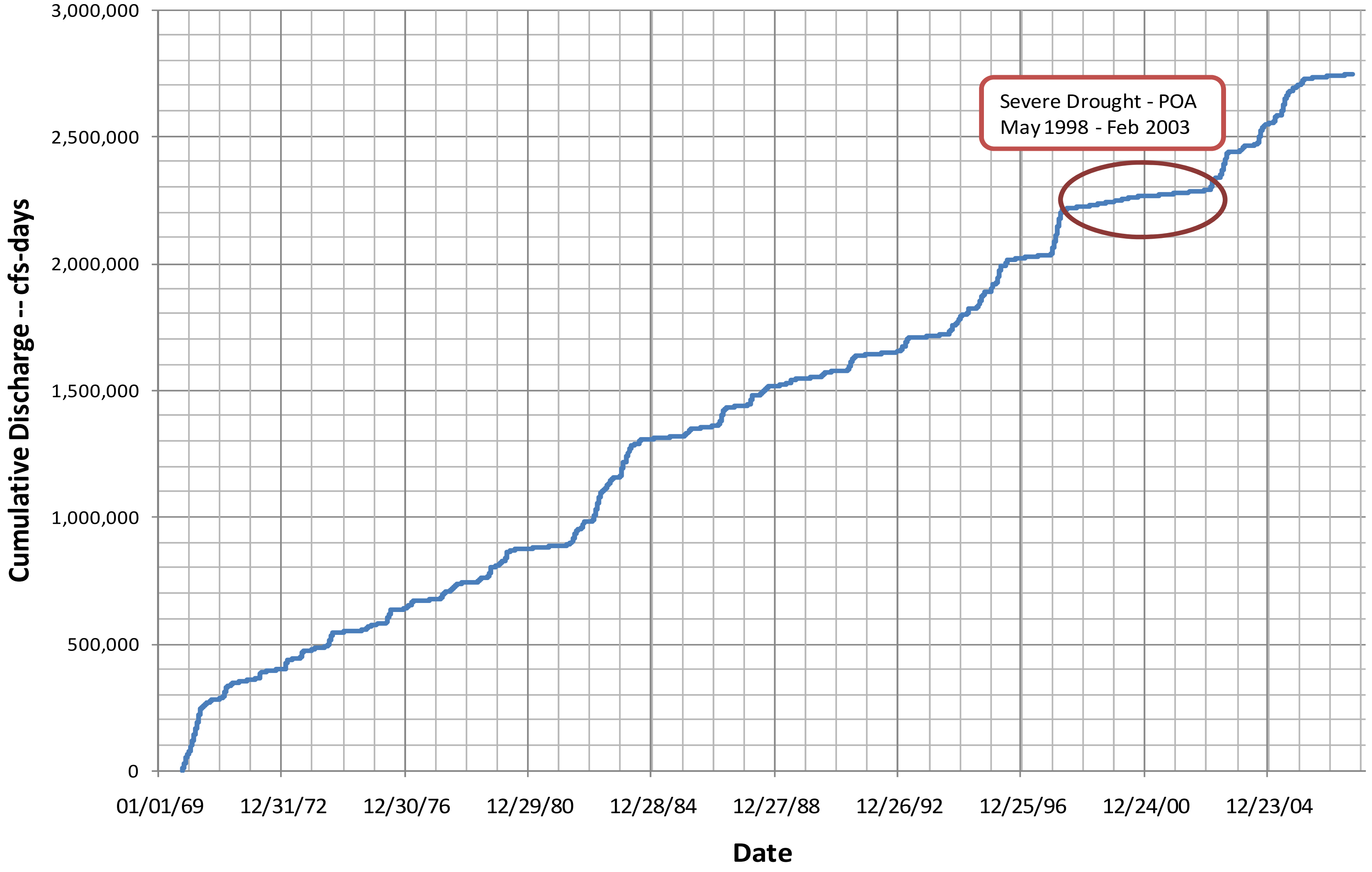
The water supply systems simulation analysis resulted in the development of a significant array of water supply yield performance curves and provides preliminary relationships between desired yield and the diversion and storage facilities required to develop the desired yield for various levels of system reliability. These data may prove useful in screening and directing potential UORB water supply projects.

Figure 1 -- Flow Duration Curve - Ocklawaha River at Moss Bluff
Period of Analysis (POA): Oct-1-1969 to Sep-30-2007



Percentage	Discharge - cfs
0%	2340
10%	745
20%	257
30%	65
40%	43
50%	36
60%	30
70%	27
80%	24
90%	20
100%	0

Figure 2 -- Cumulative Discharge Curve - Ocklawaha River at Moss Bluff
Period of Analysis (POA): Oct-1-1969 to Sep-30-2007



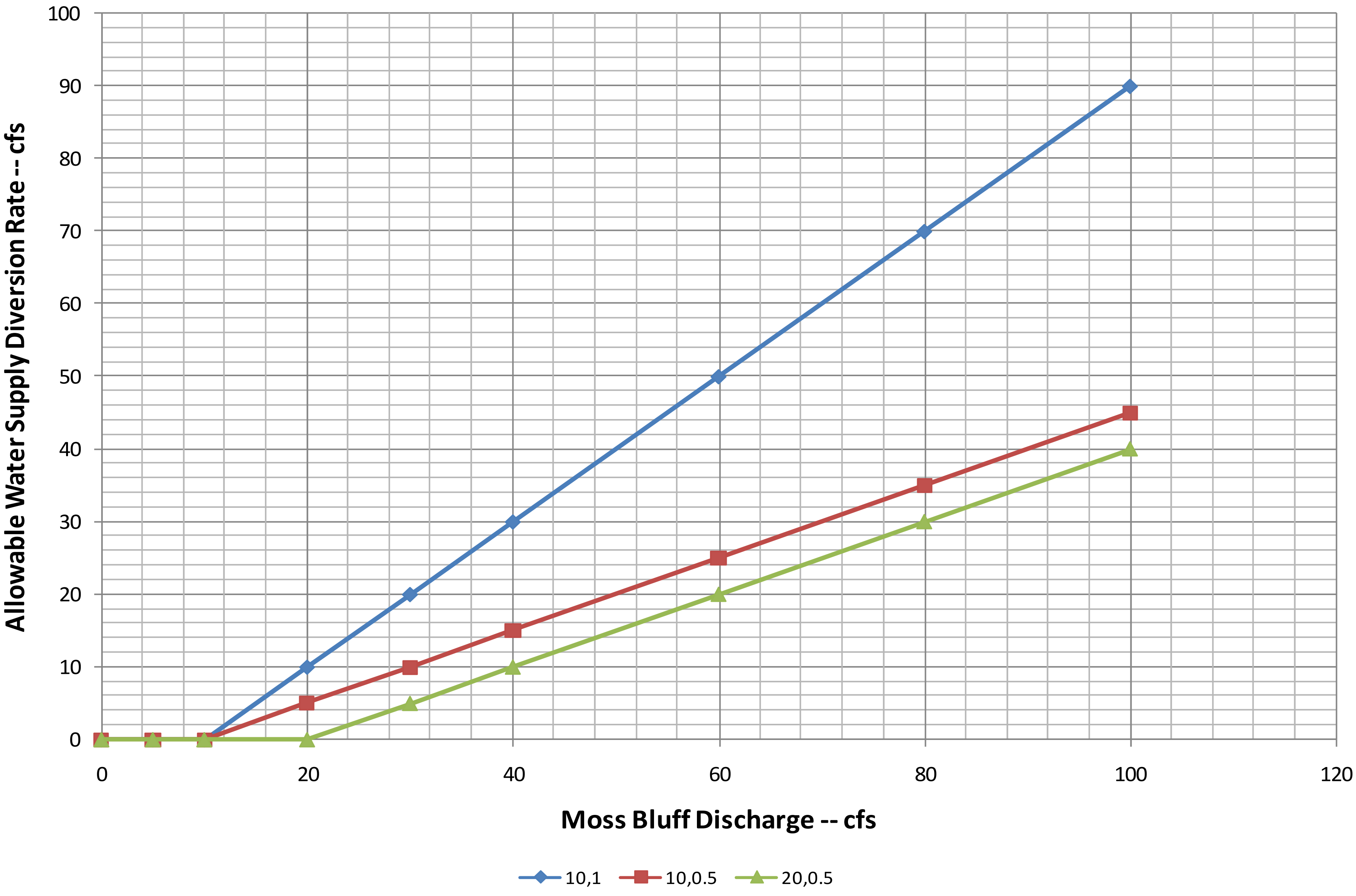


Figure 3 -- Trial Diversion Rules Selected for Analysis

Figure 4 -- Moss Bluff Diversion and Storage Routing Model Schematic Diagram

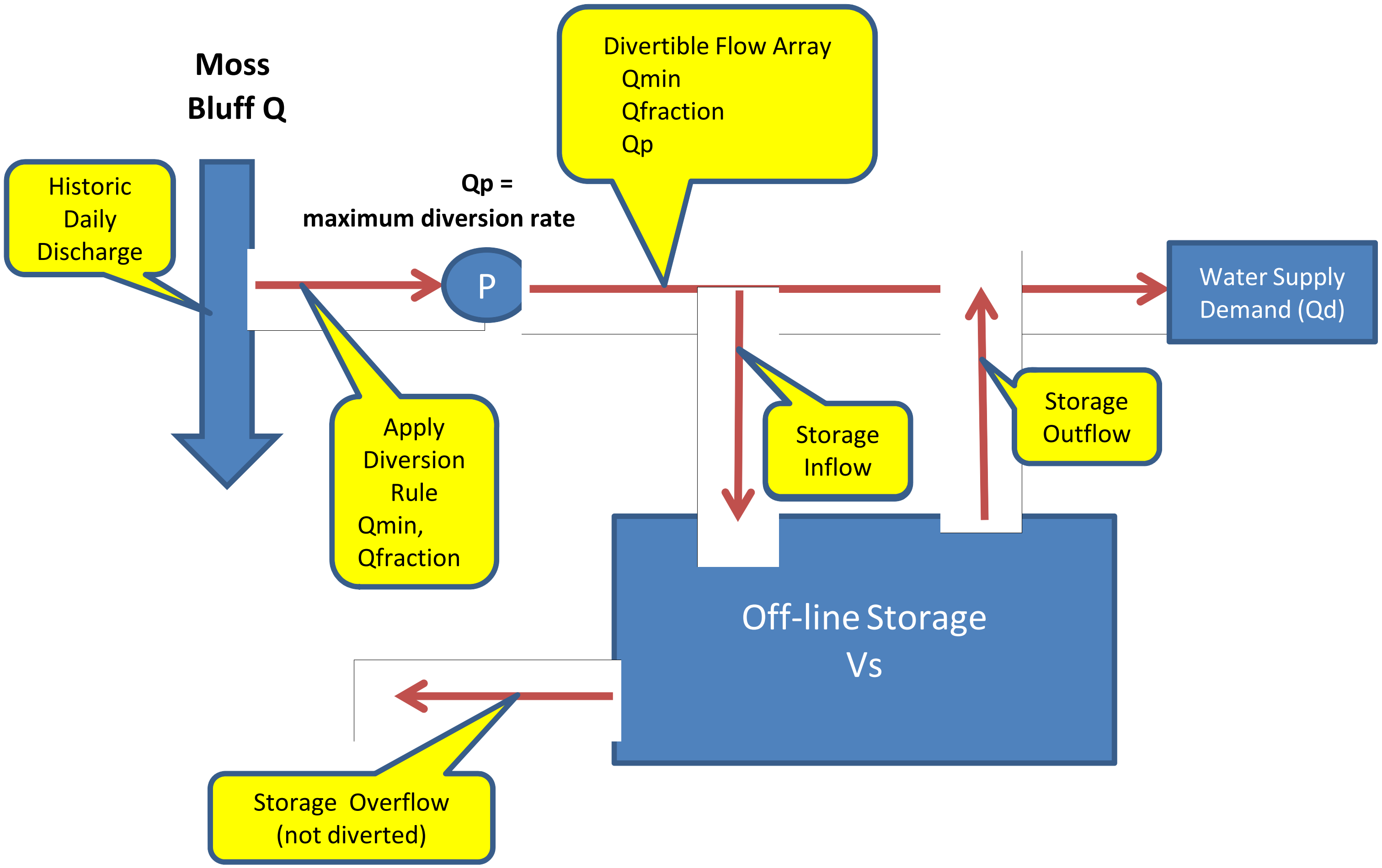


Figure 5 -- Average Water Supply Yield for 3 Diversion Rules Without Storage

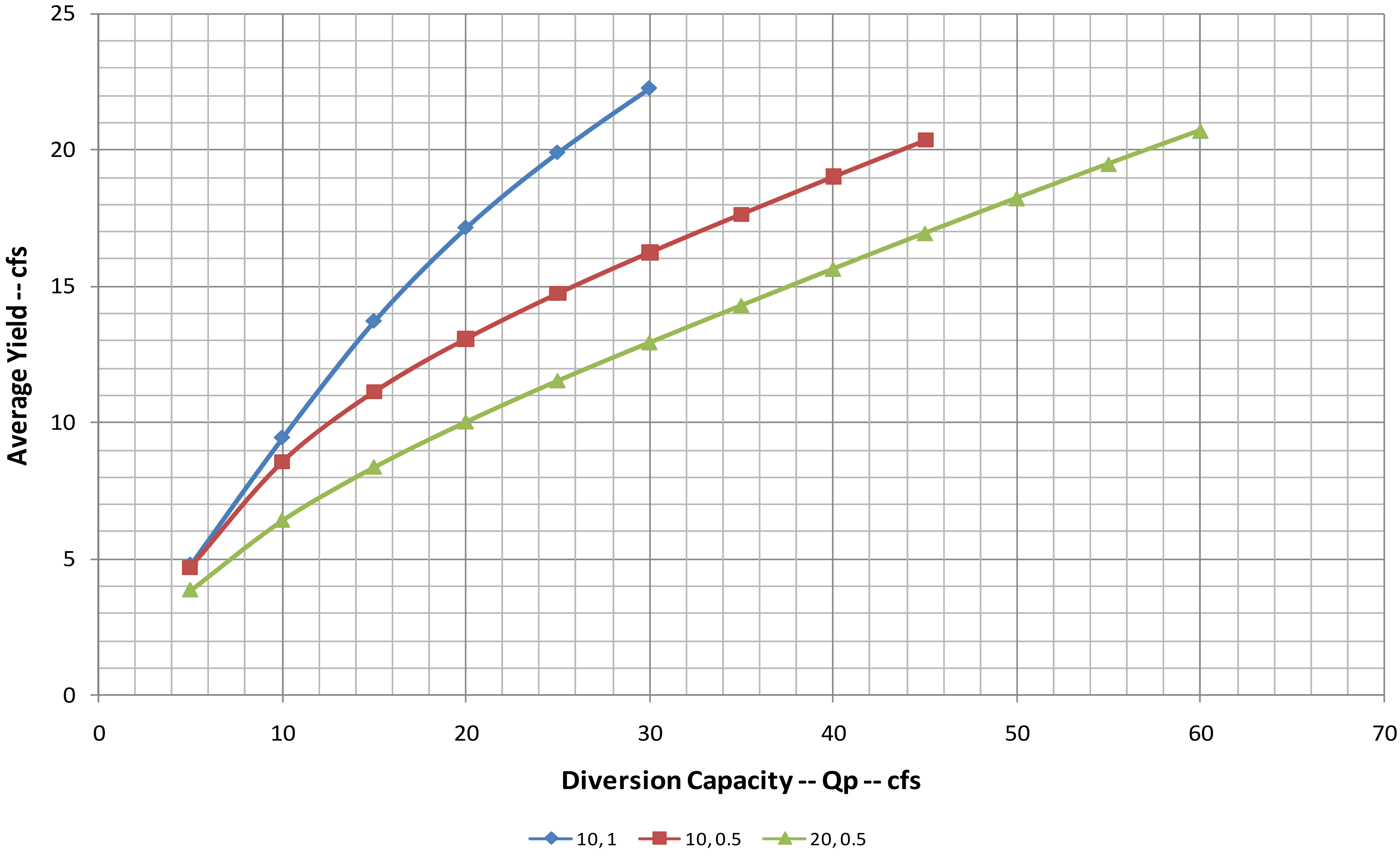
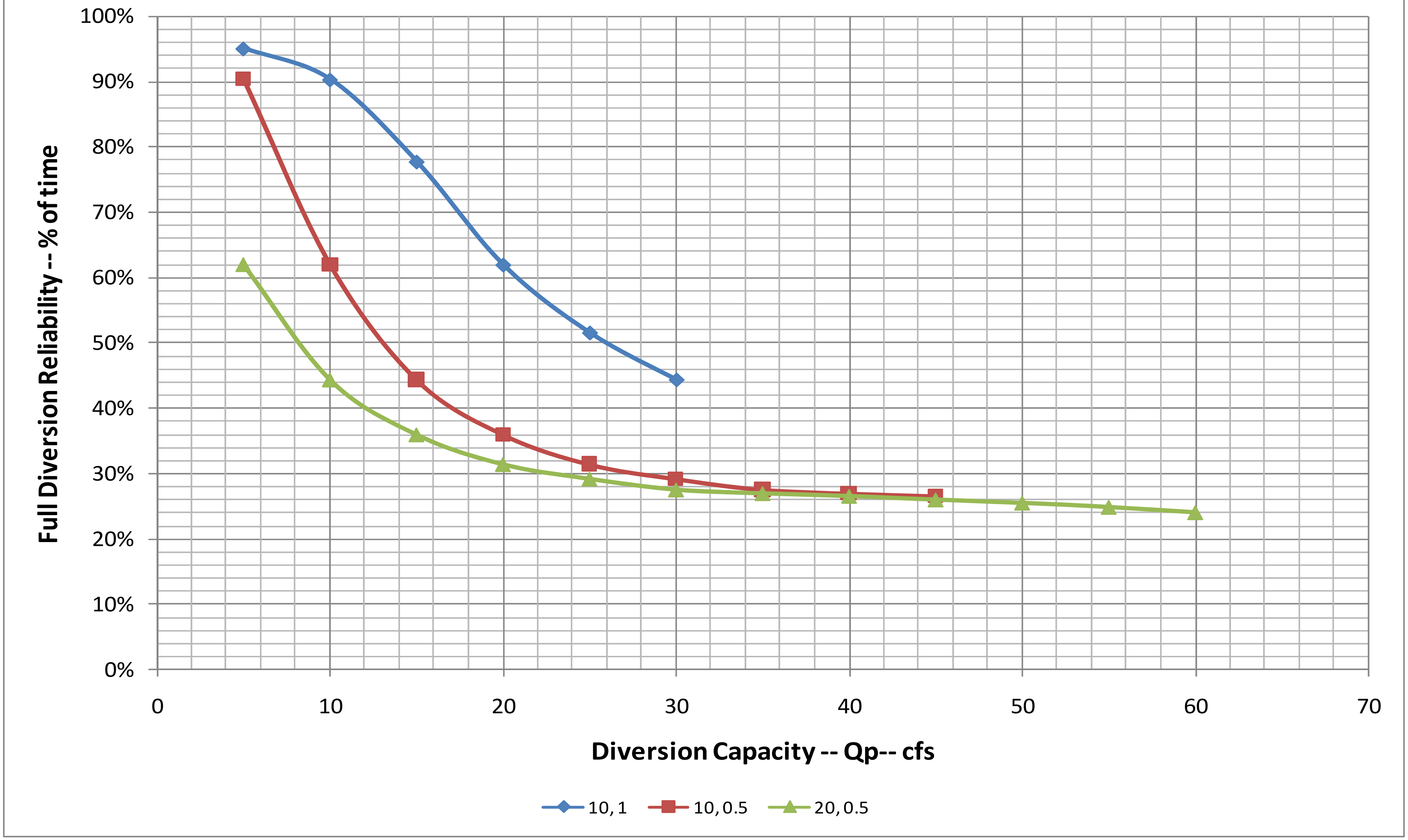


Figure 6 -- Full Diversion Reliability for 3 Diversion Rules Without Storage



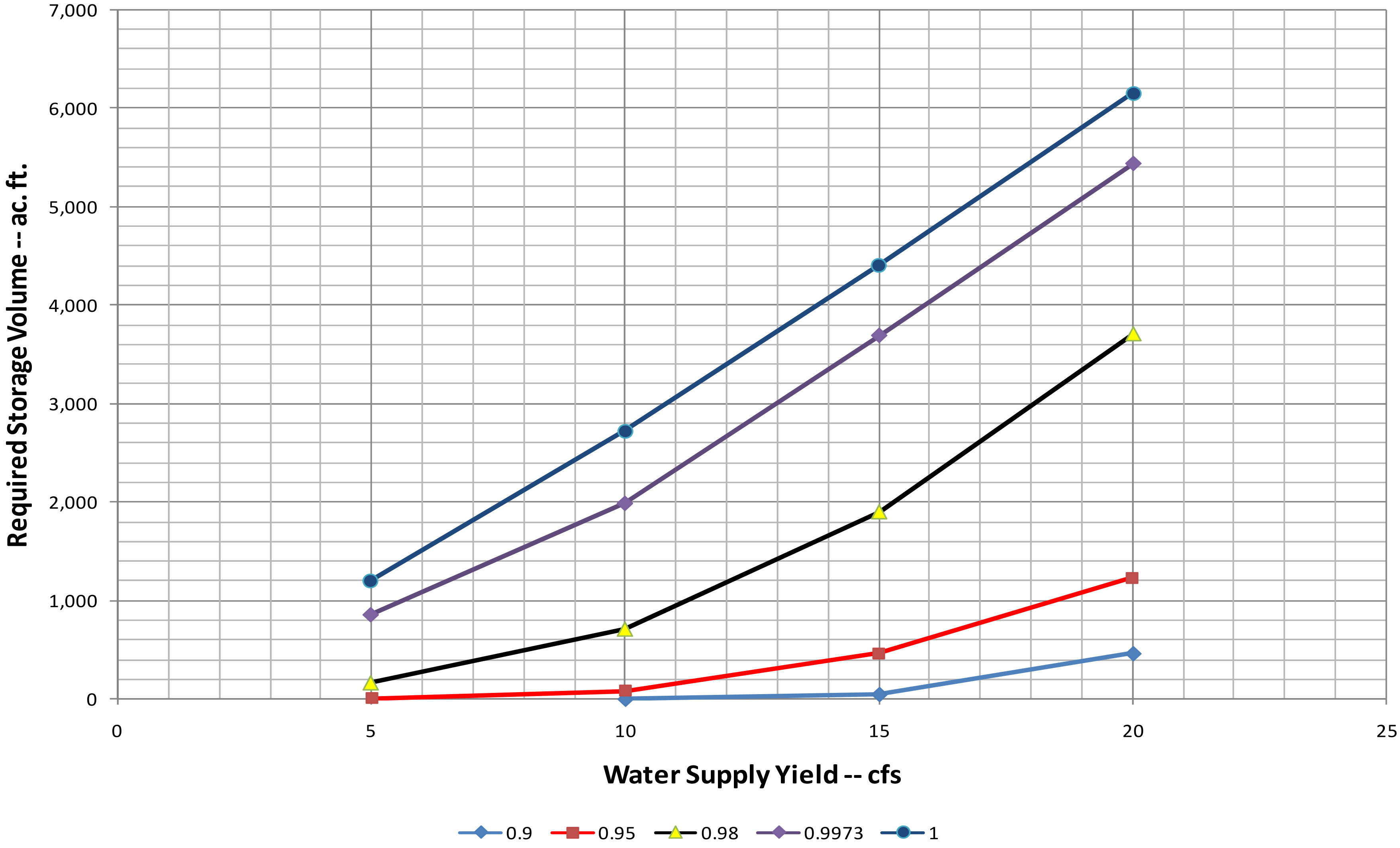


Figure 7 -- Storage Volume as a Function of Water Supply Yield and System Reliability for 10,1 Diversion Rule

Figure 8 -- Storage Volume as a Function of Water Supply Yield and System Reliability for 10, 0.5 Diversion Rule

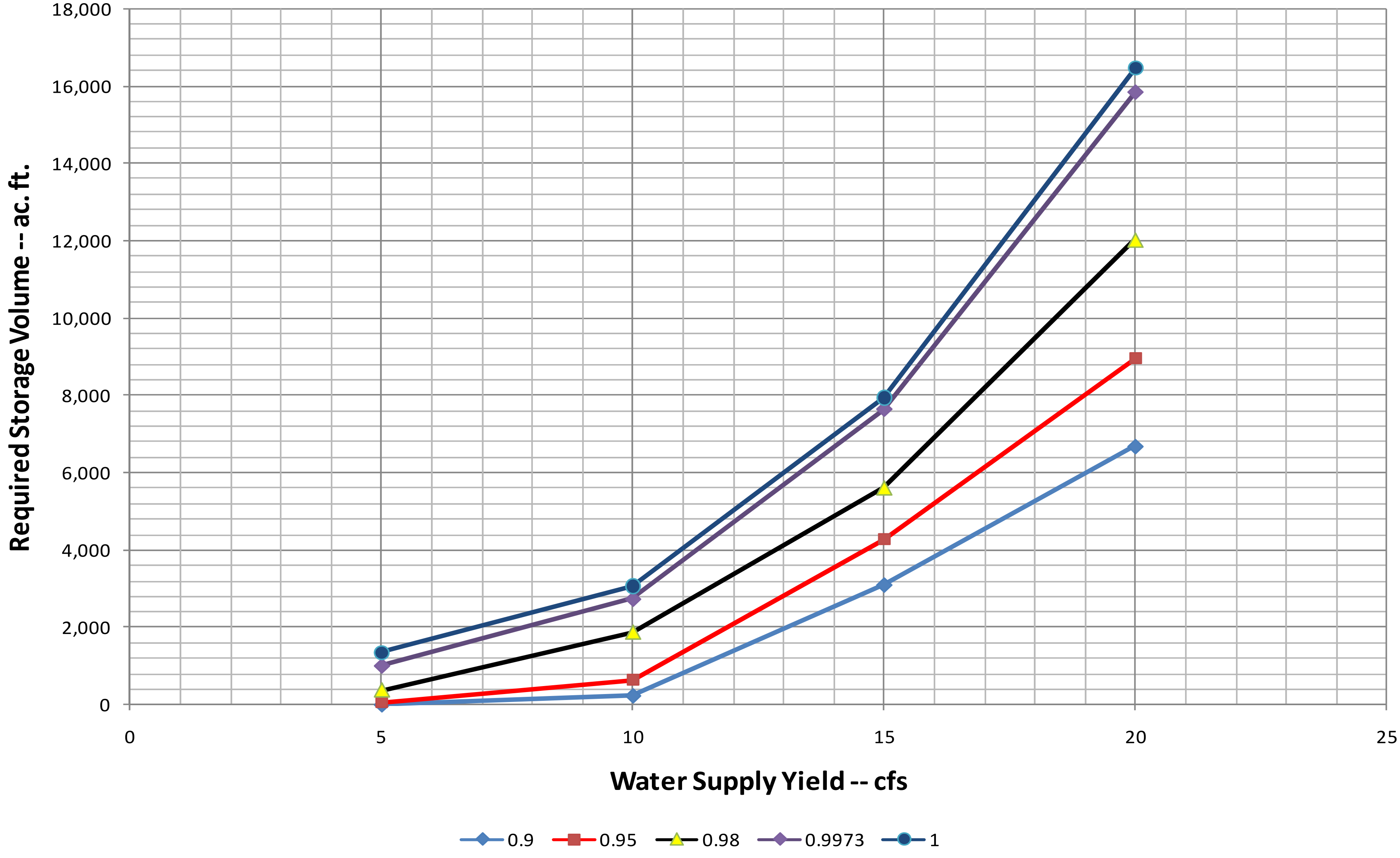


Figure 9 -- Storage Volume as a Function of Water Supply Yield and System Reliability for 20, 0.5 Diversion Rule

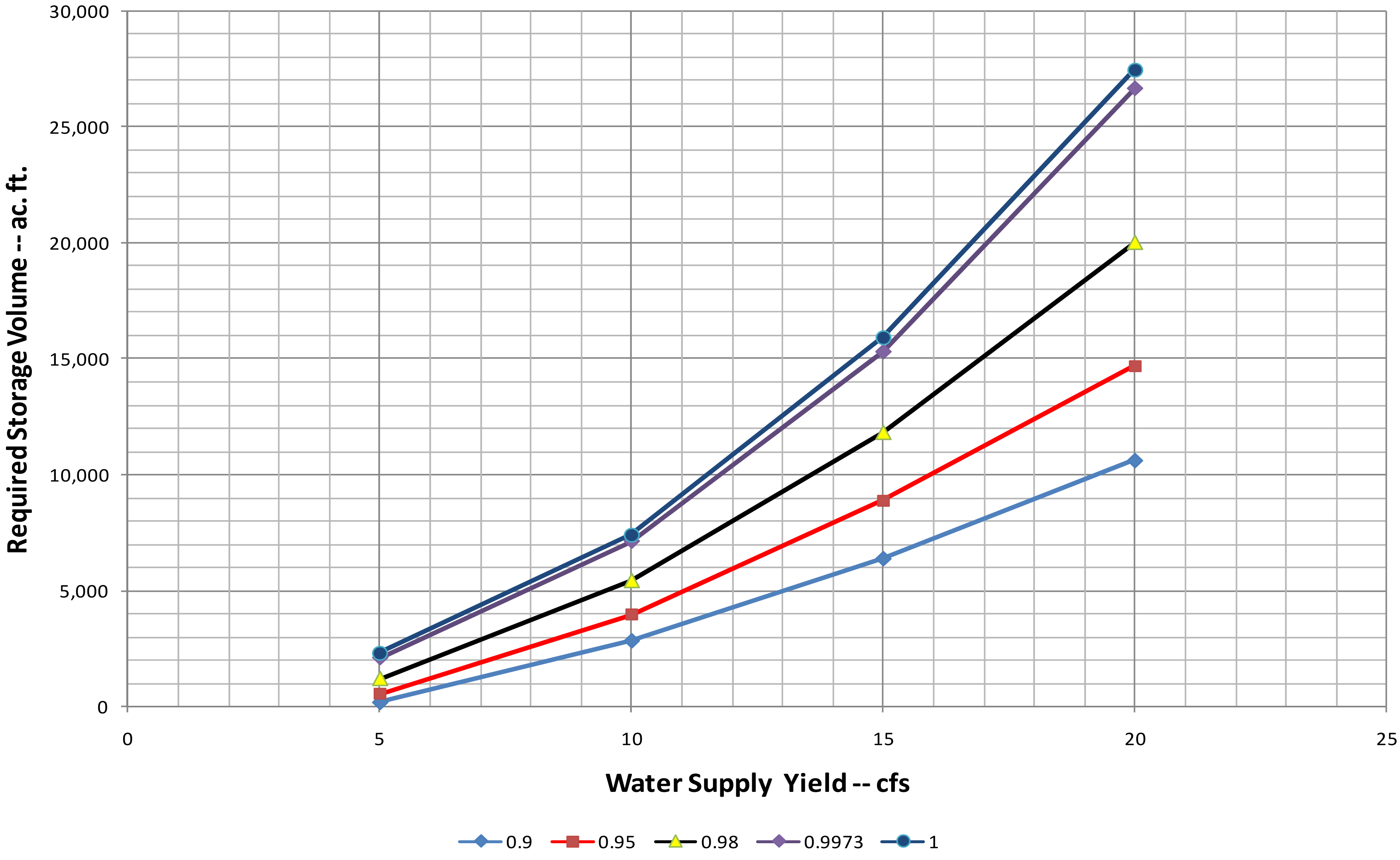
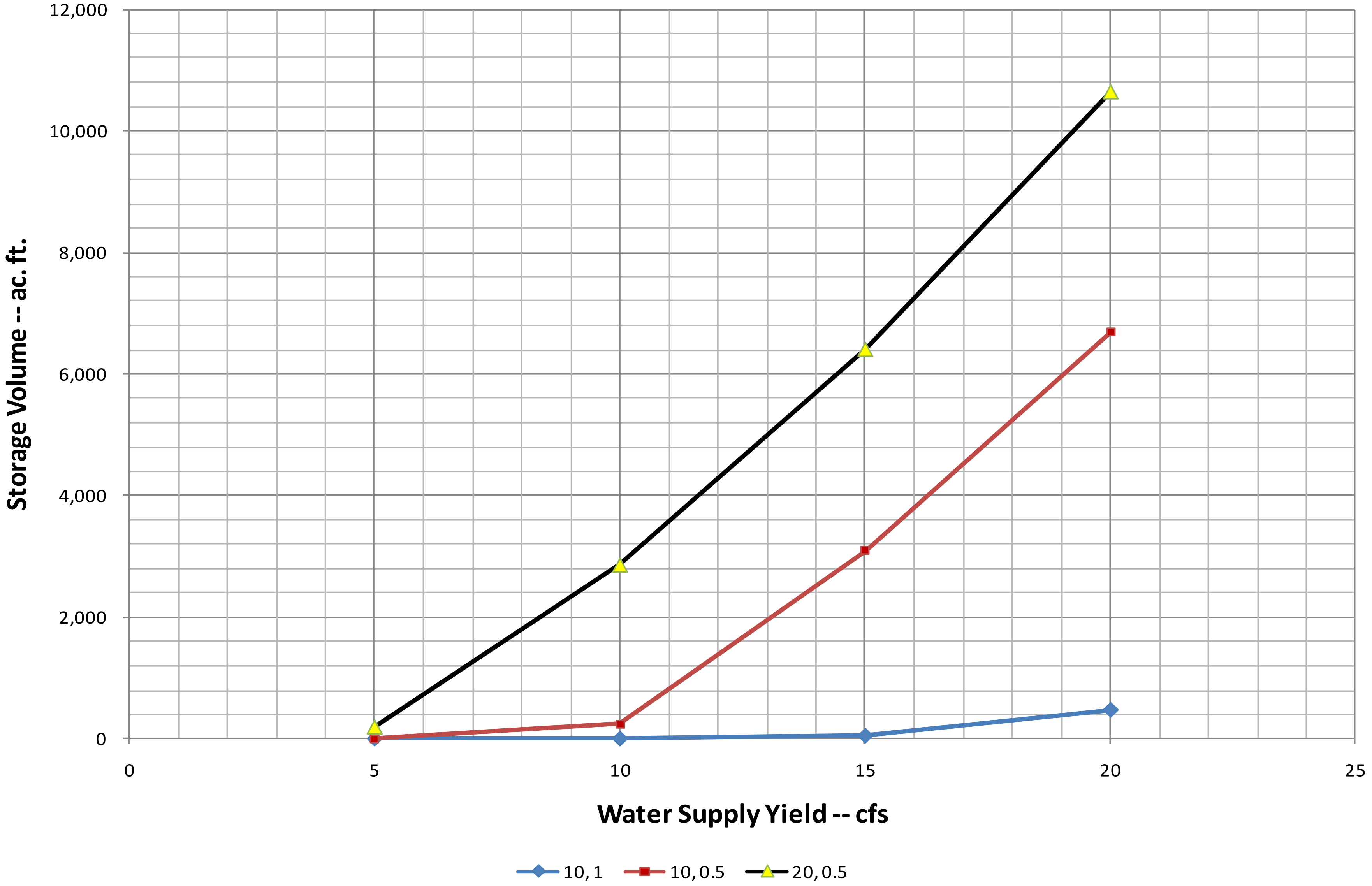


Figure 10 -- Storage Requirements for 90% Reliability by Diversion Rule



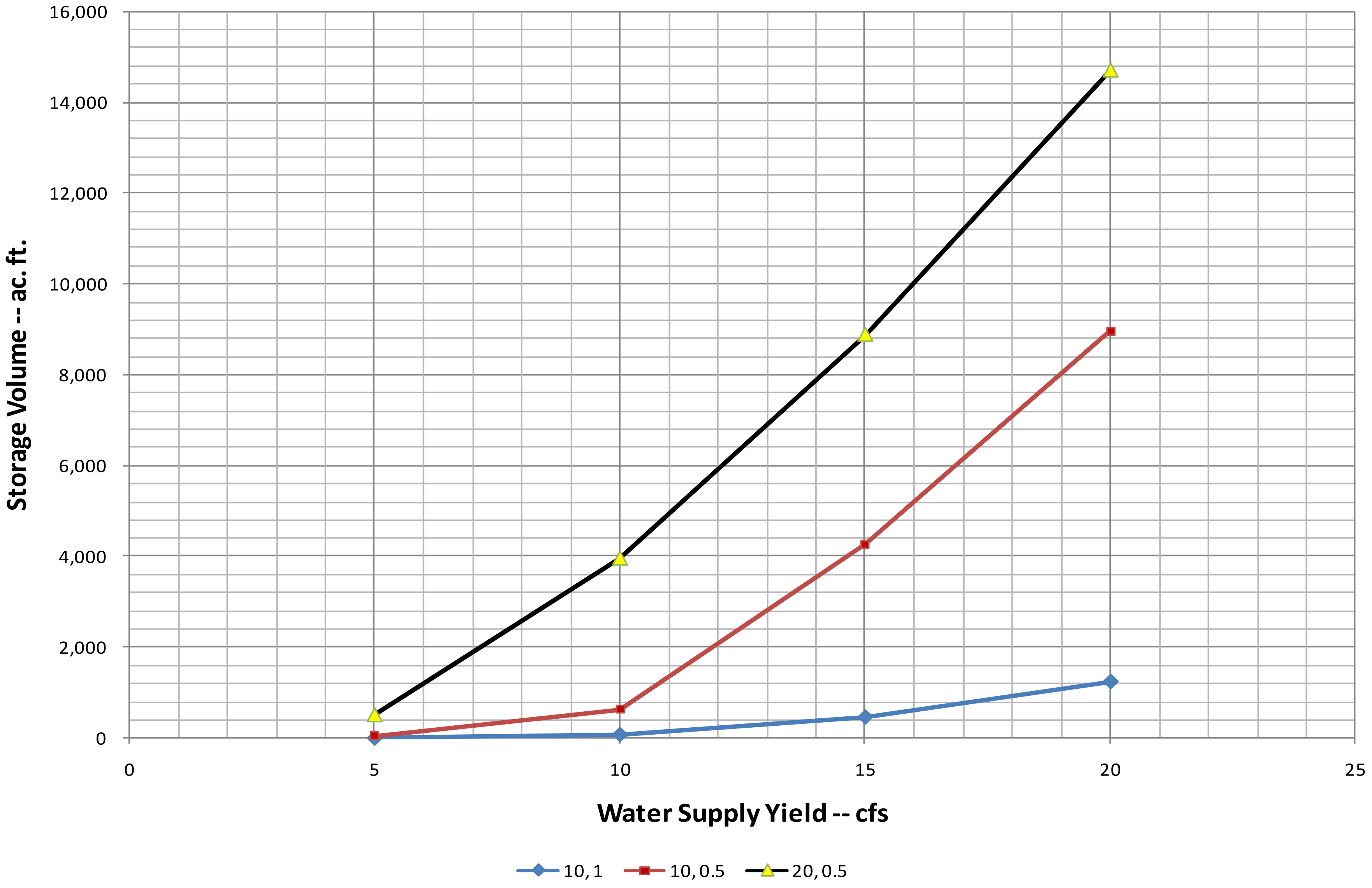


Figure 11 -- Storage Requirements for 95% Reliability by Diversion Rule

Figure 12 -- Storage Requirements for 98% Reliability by Diversion Rule

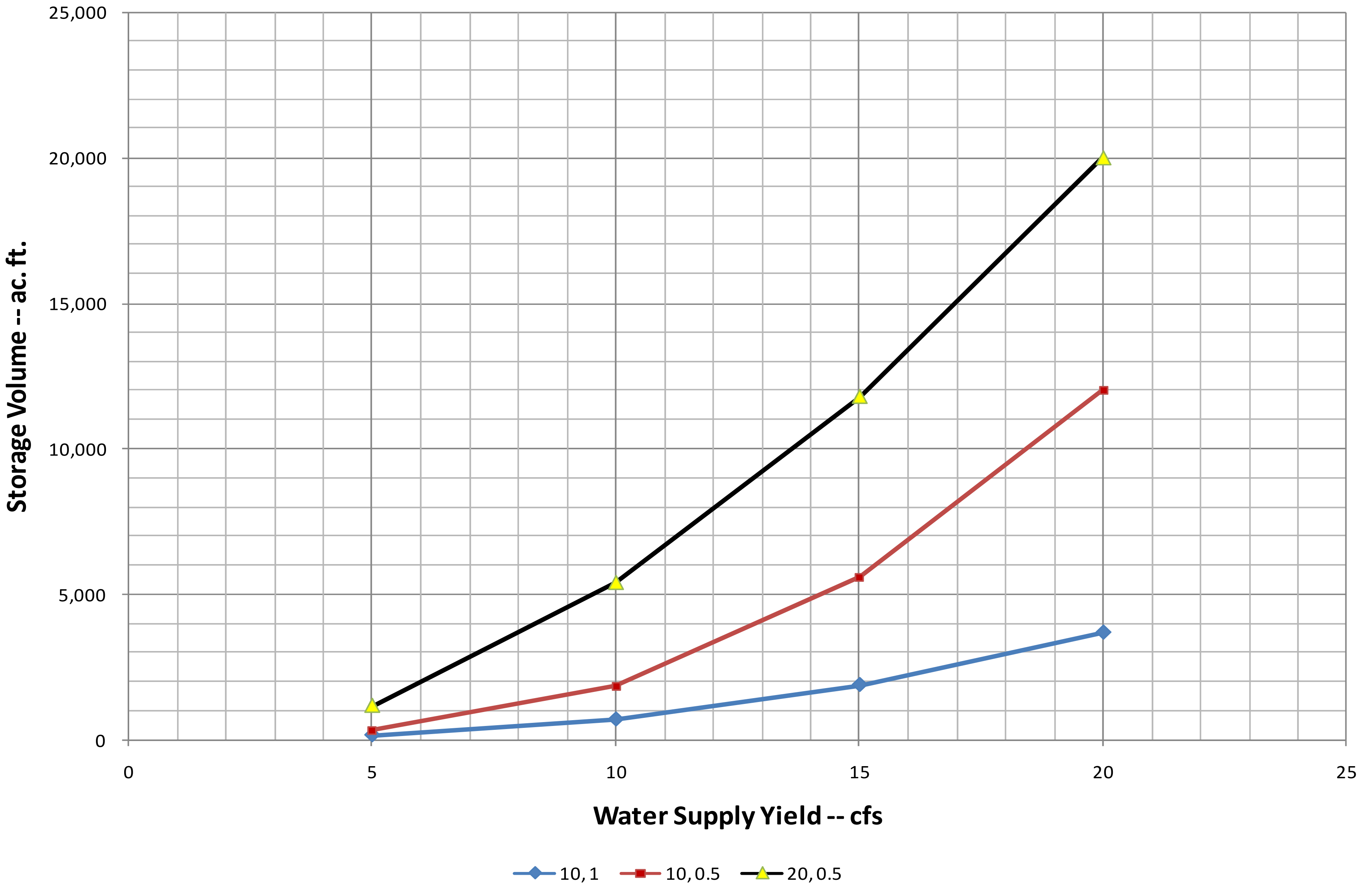
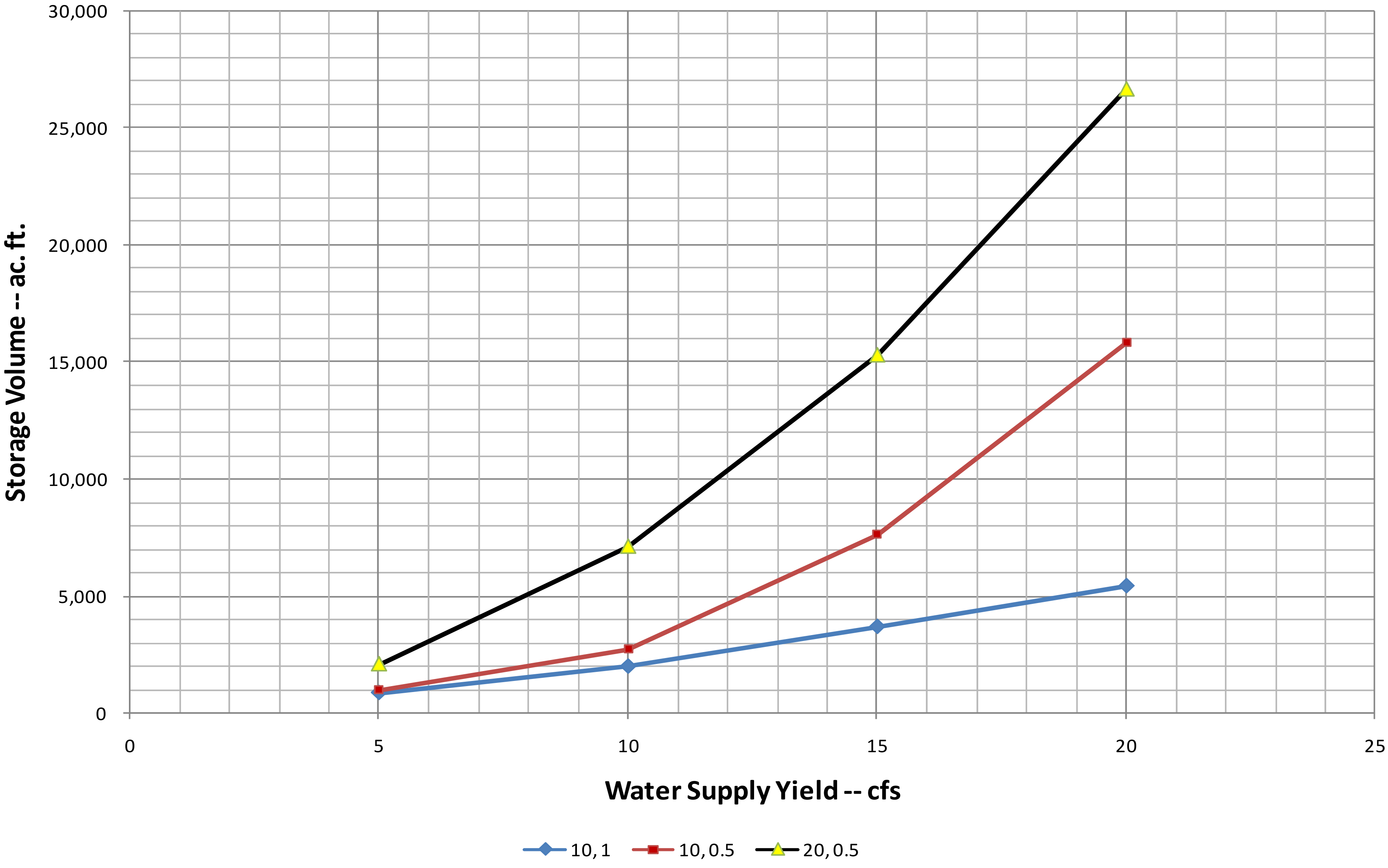


Figure 13 -- Storage Requirements for 99.73% Reliability by Diversion Rule



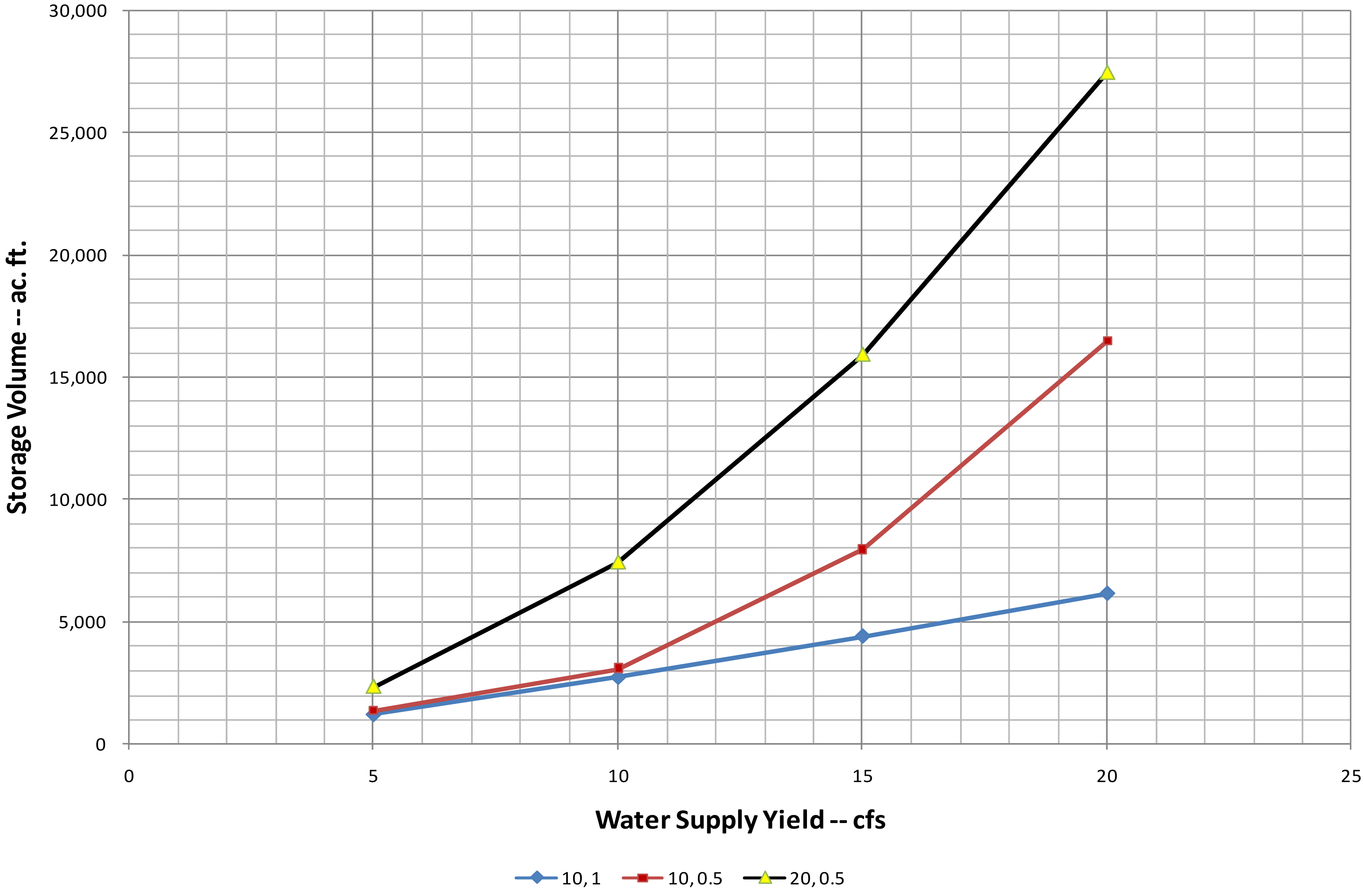


Figure 14 -- Storage Requirements for 100% Reliability by Diversion Rule

Appendix A
Moss Bluff Water Supply Yield without Off-line Storage.
Diversion pumping capacity (Qp) = Target demand (Qd)

a) 10,1 Diversion Rule

Diversion Capacity (Qp) cfs	Reliability		Average Yield -- cfs
	Yield = Qd	Yield>0	
5	95.1%	96.3%	4.78
10	90.3%		9.44
15	77.7%		13.72
20	61.9%		17.15
25	51.5%		19.91
30	44.3%		22.27

b) 10, 0.5 Diversion Rule

Diversion Capacity (Qp) cfs	Reliability		Average Yield -- cfs
	Yield = Qd	Yield>0	
5	90.3%	96.3%	4.72
10	61.9%		8.57
15	44.3%		11.14
20	35.9%		13.08
25	31.4%		14.74
30	29.2%		16.25
35	27.5%		17.65
40	27.0%		19.02
45	26.5%		20.35

c) 20, 0.5 Diversion Rule

Diversion Capacity (Qp) cfs	Reliability		Average Yield -- cfs
	Yield = Qd	Yield>0	
5	61.9%	88.7%	3.85
10	44.3%		6.41
15	35.9%		8.36
20	31.4%		10.02
25	29.2%		11.53
30	27.5%		12.93
35	27.0%		14.29
40	26.5%		15.63
45	26.0%		16.94
50	25.5%		18.22
55	24.9%		19.48
60	24.1%		20.70

These data are illustrated in TM Figures 5 and 6.

Appendix B
Moss Bluff Water Supply Yield with Off-line Storage.

Table B-1. Results for 10,1 Diversion Rule and Qp = 5*Qd

Target Demand (Qd) -- cfs	Diversion Capacity (Qp) -- cfs	Storage -- days	Storage ac. ft.	Full Demand Reliability	Expected Long Term Failure Rate -- days/year
5	25	0	0	95.05%	18.1
5	25	17	169	98.00%	7.3
5	25	86	853	99.73%	1.0
5	25	121	1200	100.00%	0.0
10	50	0	0	90.29%	35.4
10	50	4	79	95.00%	18.3
10	50	36	714	98.00%	7.3
10	50	91	1805	99.35%	2.4
10	50	100	1983	99.73%	1.0
10	50	137	2717	100.00%	0.0
15	75	0	0	77.71%	81.4
15	75	1.6	48	90.00%	36.5
15	75	15.5	461	95.00%	18.3
15	75	64	1904	98.00%	7.3
15	75	91	2707	98.86%	4.2
15	75	124	3689	99.74%	0.9
15	75	148	4403	100.00%	0.0
20	100	0	0	61.91%	139.0
20	100	11.7	464	90.00%	36.5
20	100	31.1	1234	95.00%	18.3
20	100	91	3610	97.89%	7.7
20	100	93.5	3709	98.00%	7.3
20	100	137	5435	99.73%	1.0
20	100	155	6149	100.00%	0.0

These data, for reliabilities of 90%, 95%, 98%, 99.73% and 100%, are illustrated in TM Figure 7.

Table B-2. Results for 10,0.5 Diversion Rule and Qp = 5*Qd

Target Demand (Qd) -- cfs	Diversion Capacity (Qp) -- cfs	Storage -- days	Storage ac. ft.	Full Demand Reliability	Expected Long Term Failure Rate -- days/year
5	25	0	0	90.29%	35.4
5	25	4	40	95.06%	18.0
5	25	36	357	98.00%	7.3
5	25	100	992	99.73%	1.0
5	25	137	1359	100.00%	0.0
10	50	0	0	61.91%	139.0
10	50	11.7	232	90.03%	36.4
10	50	31.1	617	95.00%	18.3
10	50	93.5	1855	98.00%	7.3
10	50	137	2717	99.73%	1.0
10	50	155	3074	100.00%	0.0
15	75	0	0	44.31%	203.3
15	75	104.1	3097	90.01%	36.5
15	75	143	4255	95.00%	18.3
15	75	188	5593	98.00%	7.3
15	75	256.5	7631	99.73%	1.0
15	75	267	7944	100.00%	0.0
20	100	0	0	35.93%	233.9
20	100	168.4	6680	90.00%	36.5
20	100	225.7	8953	95.00%	18.3
20	100	303	12020	98.00%	7.3
20	100	399	15828	99.73%	1.0
20	100	415	16463	100.00%	0.0

These data, for reliabilities of 90%, 95%, 98%, 99.73% and 100%, are illustrated in TM Figure 8.

Table B-3. Results for 20,0.5 Diversion Rule and Qp = 5*Qd

Target Demand (Qd) -- cfs	Diversion Capacity (Qp) -- cfs	Storage -- days	Storage ac. ft.	Full Demand Reliability	Expected Long Term Failure Rate -- days/year
5	25	0	0	61.91%	139.0
5	25	19.7	195	90.00%	36.5
5	25	51.5	511	95.00%	18.3
5	25	120	1190	98.00%	7.3
5	25	210	2083	99.73%	1.0
5	25	235	2331	100.00%	0.0
10	50	0	0	44.31%	203.3
10	50	143.8	2852	90.00%	36.5
10	50	199.5	3957	95.00%	18.3
10	50	273	5415	98.00%	7.3
10	50	358.5	7111	99.73%	1.0
10	50	374	7418	100.00%	0.0
15	75	0	0	35.93%	233.9
15	75	215	6397	90.00%	36.5
15	75	298.5	8881	95.00%	18.3
15	75	397	11812	98.00%	7.3
15	75	514	15293	99.73%	1.0
15	75	535	15917	100.00%	0.0
20	100	0	0	31.39%	250.4
20	100	267.9	10627	90.00%	36.5
20	100	370.4	14694	95.00%	18.3
20	100	504.5	20013	98.00%	7.3
20	100	672.2	26666	99.73%	1.0
20	100	692	27451	100.00%	0.0

These data, for reliabilities of 90%, 95%, 98%, 99.73% and 100%, are illustrated in TM Figure 9.