Assuring Water Supply for the Washington Metropolitan Area: Twenty-Five Years of Progress

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I would like to dedicate this paper to the late Melvin E. Scheidt, a long time member of this American Water Resources Association Chapter. It presents a historical perspective of the technical aspects of managing the water resources in the Potomac basin. First is a technician's history, more or less a listing of major events. Second is a description of the existing system, its operating objectives, and the problems of operating to meet those objectives. Finally, the paper covers the techniques and the tools which are available to solve those problems.

From 1950 to 1955 the Congress passed several resolutions asking the U.S. Army Corps of Engineers (COE) to review a document prepared during World War II, concerning hydropower and flood control development in the Potomac basin. It is interesting that the COE, at that time, found that there were no feasible hydropower sites on the Potomac. The only floodworks recommended by the COE were for the protection of the National Capital. In 1956, following a drought, Congress passed a resolution asking for a study of just about everything on the Potomac. The resulting study has been the basis for most of the work since that time.

In 1956 the plan of work for the study was prepared by a consulting firm, called Day and Zimmerman. The plan of work is particularly interesting. It contains a simple mass analysis diagram of the Potomac River at Washington (Figure 1). The diagram was used to estimate storage needed to augment the flows of the river at Little Falls and to thus provide water for Washington. It is simple and straight forward. The report concluded that a substantial but not exorbitant amount of storage would be required.

In the intervening years, this insight was lost in the attempt to formulate plans which were all things to all people. It was 21 years before the concept was rediscovered.

Another important thing happened in the late 1950s. Synthetic hydrology was developed by Prof. Harold Thomas at Harvard. Most of the techniques I will discuss later are based on the concept of streamflow synthesis. Twenty years is about the time it usually takes for something to go from theory to practice. We are just about on schedule.

In 1962 the first portion of the Potomac comprehensive planning study, the North Branch Report, was released. This, as well as the complete 1963 report of the COE District Engineer, was produced in large part by Harry Schwarz, one of the unsung heros of the Potomac. The work he did was extraordinarily comprehensive. The study recommended Bloomington Reservoir to fulfill the projected demands on the North Branch (Figure 2). Note that in 1963, 93 cfs was the dependable supply. Figure 2 notwithstanding, demands have not increased. It is very difficult to predict water demands into the future, a lesson we should all know by now.

In 1963 the COE Baltimore District Engineer's report came out. It was a full development plan. It recommended 16 major reservoirs on the Potomac (Figure 3), and over 400 "minor" reservoirs, all the size of the recently proposed Little Seneca Reservoir in nearby Montgomery County, or thereabouts. Not surprisingly, that plan ran into intense local opposition. There were so many projects, and so many people were against at least one of them, that it was nearly impossible to move toward implementation. The 1963 plan was never submitted to Congress.

In 1965, in response to the severe drought (that was the worst year of the 1960's drought in the Delaware basin) a new study, the Northeast Water Supply Study (NEWS) was authorized. In 1965, while the 1963 plan was still under review, President Johnson pledged to swim in the Potomac and to have the Potomac serve as a model for the Nation. He kicked the 1963 report back to a Federal Interagency Task Force. The Task Force interim report in 1966 recommended not 16 reservoirs but three for immediate construction in addition to Bloomington Reservoir. These were Little Capapon, Town Creek and Sideling Hill, all in the vicinity of Paw Paw Bends.

What had happened in the interim is that there was more faith being placed in waste treatment. The 1963 COE's report (Figure 4) recommended 360 mgd for waste dilution in the Washington Metropolitan Area. By 1966 there was additional progress in the development of advanced waste treatment. Water for waste dilution was no longer required.

In 1966 there was a drought. The one day low flow of 388 mgd on September 10 was by far the worst on record. The maximum daily withdrawal rate began to approach that record low flow and exceeded it for the first time (402 mgd) on July 17, 1971. That was used as a barometer for years to describe the severity of the Washington water supply crisis. In 1967 the Washington Suburban Sanitary Commission (WSSC) proposed a weir to backup water for their intakes in times of drought. The COE said no, not until there is a dependable supply for Washington, D.C. A perfectly reasonable argument. The weir was not completed until last year.

In 1968 the COE recommended in testimony before Congressional subcommittes the "Six-Pack" of resevoirs. They were the three recommended in 1966 by the Federal Intergency Task Force plus North Mountain, Verona and Sixes Bridge, with the latter two given top priority.

In the late 1960's another unsung hero, Herb Sachs, went to work. He almost single handedly put together the Maryland Potomac Water Authority, the agency which guaranteed the nonfederal share of the cost for initial water supply storage in the Bloomington Reservoir. This allowed Bloomington to proceed. If it weren't for Herb, Bloomington would still be a dream. In fact, during 1969, there was considerable speculation that he would never succeed.

In 1970 determination of water quality benefits from federal projects was left to the U.S. EPA Administrator. Credit for water quality benefits from low flow augmentation was effectively discontinued. The Secretary of the Army reevaluated the Chief of Engineers' report which contained the recommendation for six reservoirs in light of the new interest rate on federal investments, at that time 4-1/8 percent. He recommended only Sixes Bridge and Verona for construction at that time. That report was the first to mention limited use of the Potomac estuary for emergency supply. The Potomac River Low Flow Allocation Agreement negotiations formally started in 1970.

In 1971 the NEWS report recommended construction of a pilot treatment plant on the estuary. In 1972 it was authorized. In 1973 the consulting firm, Hydroscience, did a report quantifying the amount of water available from the estuary during extreme drought. Also in 1973 a Congressional conference committee asked for a reformulation of Sixes Bridge and Verona in light of new policies with regard to cost allocations. An interim NEWS report came out. In the interim NEWS report the COE responded that Verona and Sixes

Bridge were still the best alternatives for National Capital water supply. In 1973 the first money was appropriated for Bloomington and construction started.

The 1974 Water Resources Development Act authorized Phase One design on Verona and Sixes Bridge. Local opposition to Sixes Bridge caused further authorization to be conditioned upon completion of the pilot estuary treatment plant, the results of yet another Washington Metropolitan Area (WMA) water supply study, and finally a review of both by the National Academies of Science and Engineering. Also in 1974, an interesting report was completed for the WMA utilities. Black and Veatch, consulting Engineers, studied the feasibility of interconnections between the utilities for finished water distribution system reliability. That report analyzed six major interconnections. In 1974 the Metropolitan Washington Council of Governments (COG) and the COE completed the first draft of the Potomac River Low Flow Allocation Agreement. Note that by 1974 some eight reservoirs would have been completed under the 1963 COE plan, and by 1980 nine were scheduled for completion.

In 1974, a little known student at The Johns Hopkins University by the name of Dan Sheer put out a thesis called Economic Sequencing of Public Works Facilities. This thesis looked at the scheduling of the COE proposal of 16 reservoirs. The thesis concluded that by any economic measure Bloomington is by far the least desirable of the 16. I remember very distinctly arguing with Dr. Abel Wolman about this. Dr. Wolman said essentially that reservoir sites don't last, if a reservoir will be needed at an available site, it should be developed. Funny thing about Dr. Wolman, every time I've argued with him I've been wrong.

In 1976 the Interstate Commission on the Potomac River Basin (ICPRB) put together a funding package (Office of Water Research and Technology, Virginia, Maryland and ICPRB) for a reservoir operations study to be carried out by The Johns Hopkins University. The WSSC sponsored Bi-County Water Supply Study was also starting. In 1976 Congress asked the COE for a reformulation report on Sixes Bridge and Verona for WMA water supply. The new study evaluated an interconnection scheme, pumping raw water from the Potomac to the local reservoirs. It concluded that this could supply demands through the year 2000. This is a little bit different from some work I will show you a little later, in that it is quite a bit more complicated. By 1976 everyone was getting pretty frustrated with the failure to get anything done for the Washington Metropolitan Area water supply.

In 1977, work started on the Johns Hopkins study. It actually started at the U.S. Geological Survey, which although not a formal participant in the study, hired the two students who were going to use the project for their dissertations. The two were Jim Smith, who now works with the ICPRB, and Rick Palmer who formerly to worked for the ICPRB. Those two summer students put together all the raw data. By the time the project started analysis could begin.

In 1977 I was working for COG on 208 water quality management planning, when I came to some surprising conclusions about WMA water supply. It was quite by accident. This is how it happened. The question of how much water there would be coming over Little Falls, into the estuary had to be resolved. This was needed for modeling runs for waste load allocations. Since demands on the river equalled the 7-day 10-year low flow, the answer was nothing. Thinking about it, the water coming over Little Falls has some pollutants. If these are routed though the wastewater treatment plants, at least some pollutants will be removed. If that is true, then maybe the utilities should operate to maximize Potomac withdrawals all the time. That meant taking as much water from the Potomac as possible and reducing withdrawals from local reservoirs. Such operation would save a lot of water in the local reservoirs. How much?

The easiest way to answer that question is to compare demands, flows, and storage as per Tables 1-4. Those tables tell a clear story. The water in local storage is more than enough to meet demands through the turn of the century. This was, at the time, a startling conclusion.

In 1977 the final NEWS report came out and dropped the concept of interconnections introduced in 1974. The way in which those interconnections would be operated was too expensive. The NEWS report <u>was</u> the first report to examine variable operating rules. The report concluded that while the upper basin reservoirs were too far upstream to manage on a daily basis, they could be managed on a monthly basis. NEWS recommended a sliding monthly schedule. This was the first step towards the daily release schedules which are now being proposed.

There was a drought in the Occoquan in 1977. This drought was the catalyst for the development of risk analysis techniques. In August, the Occoquan reservoir was dropping like a stone. The people who knew the reservoir were saying that there was an emergency. This conflicted with a consultant's report on the safe yield of the Occoquan. At the end of August, data had been prepared by the two summer students working for the USGS. This data, when analyzed indicated the safe yield was a much lower yield than the consultant claimed. There was indeed a serious problem.

I discussed the situation over the phone with Bob Hirsch of the USGS. We developed a means for quantitatively assessing the situation. Simply, the technique uses multiple simulations, each starting with the current reservoir contents, and each using a different year streamflow. At that point, about 20 percent of the years would have run the reservoir dry. An independent technique using historical meteorological data and the National Weather Service River Forecast System (NWSRFS) instead of streamflow data was also developed. Both techniques gave similar estimates of the probability of running out of water. Table 5 gives these as of the end of October in 1977. At the then current production of 40 mgd, the probability of getting down to just about the panic level was 13 percent.

This was put to local elected officials. They agreed that the risk was too high. They asked, "How much do we have to reduce demand?" A reduction to 32 mgd from 40 mgd would reduce the risk to about five percent (Table 6). The local governments proceeded with a campaign to reduce use by 8 mgd. This was the first use of risk analysis.

The Potomac River Low Flow Allocation Agreement was finally signed in 1977 after over seven years of negotiation. The emergency estuary pumping station received its first appropriation. The Bi-County Water Supply Study Task Force adopted a plan calling for occasional restrictions. As far as I know this was the first time that use of demand management had been included in water supply planning. The Federal, Interstate, State, Regional Advisory Committee (FISRAC) to the Washington Metropolitan Area Water Supply Study (WMAWSS) advised the COE to look at raw and finished water interconnections.

In 1978 the final plan of study for the WMAWSS came out. Congress asked for a reformulation study for Bloomington Lake. The COE let contracts on raw and finished water interconnections studies for the WMA. The ICPRB did the finished water interconnections study. Quite frankly this was about the most interesting study I ever was involved in. The original concept was that if somehow all the fingers of the distribution systems could be connected, it would be possible to shove water from the reservoirs into the system when needed. Also, water from the Potomac could supplant reservoir water in the system when Potomac water was plentiful. After about three months work, that idea was abandoned. Finally an attempt was made to simulate the operations of the systems as they were currently planned, including the Fairfax County Potomac treatment plant, under construction at the time. Much to our surprise, the required distribution system flexibility already existed. This increased estimates of system yield by 100 mgd.

In 1978 the Hopkins study began producing results. They were a revelation. Figure 5 shows a potential yield at Washington in excess of a billion gallons a day given efficient operation. Because it assumes perfect foresight that number is too high. The challenge then, was to design practical rules which would produce yields nearly that large. An interactive simulation was developed to this end. The simulation, called PRISM was eventually adopted by the COE and used to develop their recommendations. Most important, a group of people from the utilities sat down and operated the systems using PRISM. An awful lot was learned by all, concerning what it meant to operate Bloomington a week in advance. The kinds of decisions to be made and the factors to be included would have to be in a reasonable operating rule for the whole system, became apparent.

In 1979 the Bi-County Water Supply Task Force recommended construction of Little Seneca Lake in Montgomery County for water supply as well as recreation. A Water Shortage Emergency Plan, prepared by COG, was adopted by the local jurisdictions. The ICPRB formed the Section for Cooperative Water Supply Operations on the Potomac (CO-OP). CO-OP's function is to set up an operations center for coordinated management of all water supplies during drought. WMA Water Supply Study Progress Report came out. That progress report recommended entirely local solutions to the WMA water supply study. This was based largely on the results of the PRISM model. At a meeting of FISRAC in December of 1979 the WMA utilities decided to form a WMA Water Supply Task Force to implement that recommendation. The paper by Mr. Robert McGarry will discuss the activities of the task force.

So much for history. I'll next describe the methods being developed to manage WMA water supply. The benefits of coordinated management are quite large. If you independently operate all of the facilities for WMA water supply the sum of the yield is less than 620 mgd. Joint operations can achieve yields of better than 825 mgd from the same system (Table 7). This is more than a 25 percent increase yield, and about equivalent to the combined yields of the proposed Sixes Bridge and Verona projects.

Construction costs for these two reservoirs would be close to a quarter of a billion dollars.

The WMA water supply system is not very complicated. There are two reservoirs upstream, Bloomington and Savage, which, for water supply operational purposes, can be considered as one. It takes four to five days for the effects of upstream releases to be felt in the WMA. There are two reservoirs on the Patuxent, one just upstream of the other. These can also be considered as one. Together they have about 10 billion gallons of storage, and safe yield of about 35 mgd for water supply. A 65 mgd (peak) treatment plant is located on the lower reservoir. That feeds the WSSC distribution system which is also fed by a treatment plant on the Potomac with 240 mgd of capacity. The WSSC system can feed almost the entire system from the Potomac, except during periods of peak demand. That creates the opportunity to save water in the Patuxent Reservoirs and thus make use of the entire capacity of the Patuxent Treatment Plant when the Potomac is low. Thirty-five mgd is the safe yield of the reservoirs for water supply. Coordinated operation increases the effective yield of the reservoirs from 35 to 65 mgd.

The Occoquan treatment plant has a capacity of 112 mgd. The reservoir holds 10 billion gallons, with a safe yield of 55 mgd. The Occoquan can be operated in conjunction with the nearly complete Fairfax County Water Authority intake and treatment plant on the Potomac. The water thus saved can assure 112 mgd of effective yield from that system, about double the safe yield.

Also there is the proposed reservoir on Little Seneca Creek. If built, it would be extraordinarily useful. Simply, it allows flexibility to correct for errors in upstream releases. These errors will be made because the releases must be based on 4-5 day flow forecasts; the reservoirs are that far upstream.

Short run operating objectives for the system are:

1. Balance the daily flow and daily demand including the flow-by; and

2. Balance the storage in the reservoirs.

The second objective is important because loss of any reservoir means a loss in flexibility for the system. In addition, the Occoquan is the only possible source for some portions of the FCWA service area.

The long range operating objective is to maintain storage sufficient to assure supply through the worst drought to be reasonably expected.

Operating tools available to meet short range objectives are:

1) upstream releases, made four to five days ahead of time;

2) flexibility in the local systems to take more or less water from the local resevoirs; and

3) demand restrictions to reduce the uncertainity in demand.

If peak demand is not met, there will be insufficient pressure somewhere in the system, with attendant health and fire hazards.

The only tool available to meet long range objectives is demand restrictions which reduce the average demand.

Operating problems are as follows:

1. Four to five day travel time from the upstream reservoirs requires basing releases on imprecise flow forecasts;

2. Great uncertainity exists in forecasting the demand, which can fluctuate 20 percent to 25 percent in any given day, and this makes it even more difficult to schedule the releases four to five days upstream.

3. Water quality releases in the North Branch.

The water behind Bloomington Dam is quite acid. In order to maintain good quality in the North Branch below Westernport, care is required in manipulating not only the amount but also the acidity of the water released on any given day.

Several analytical tools have been developed to deal with these problems. The USGS has developed a travel time model. It indicates that an effect equal to 40 percent of the water is seen at Washington on the fourth day and 60 percent on the fifth day. CO-OP has developed a crude demand model. We analyzed the variance in 10 years of daily water use and soil moisture deficit data. The average demand varys by as much as 10 percent per inch of soil moisture deficit in

July. There are strong correlations between demand and soil moisture deficit in July and August, weak correlations in June and September, and essentially no correlation in any other month of the year. This means that in July demand can be 30 percent more in a dry year than in a wet year. The demand models allow estimates in demand to be made for scheduling. These models are in need of more work.

Finally the National Weather Service and CO-OP have developed a flow forecasting model. Development of the predictor has been a major effort of CO-OP. Our first cut at a predictor was simply that the flow would remain unchanged. By running a simulation and operating the reservoirs through a drought using that predictor, the system yields presented earlier were developed. The NWS predictor, called the River Forecast System will certainly do better.

It will also provide long-range predictions. These are much more important than the short-range predictions . The long-range predictions allow us to determine when there is an unreasonable risk of not meeting long-range demand, so that modest demand reductions can still solve the problem. It is these new analytical tools which allow making releases from upstram reservoirs on a daily basis for use downstream. This means using those reservoirs in a way the 1974 NEWS study indicated they couldn't be used. NEWS used monthly release schedules. It makes a large difference, especially when you are looking at really short dips in the flow in the river.

The National Weather Service River Forecast System is basically a soil moisture accounting model (Figure 6). It takes historical rainfall records and traces water movement through several different storage compartments representing soils in the upper zone and lower zone. It keeps track of how much is in each one of those little reservoirs and how much drains into streams. It does not measure actual ground water levels to do this. The model is calibrated using historical meterological data. The parameters are adjusted until the model reproduces measured streamflow at USGS gauges. CO-OP has calibrated the model for the entire Potomac.

To make long-range forecasts, the model is run from the date on which the forecast is to be made, using the then current soil moisture conditions. This gives conditional streamflow traces. Meteorological records for each of 26 years are used to estimate streamflows which would occur if the weather were to repeat itself. The assumption is that a repeat of any year's rainfall is equally likely.

The amount of water in the ground at the beginning of the summer makes a big difference in the amount of streamflow that we can expect from the river. In May of 1981, the groundwater conditions, except in the North Branch, were as dry as they had ever been before. In the Shenandoah, which provides some 40 percent of low flows in the basin, the flow for May was a record low, only half of the previous record low. We used the procedure outlined above (called Extended Streamflow Prediction, ESP for short) and ran the resulting streamflows through a simulation model. We then counted the number of days of restrictions, shortages, and the maximum daily shortages that would have occurred if we had repeats of historical rainfall. There was a substantial probability of restrictions, and some probability that we would in fact have shortages (Table 8).

Forecasts were also made concerning the probability of impounding water in Bloomington Lake if the dam were closed. At the time, the North Branch was the only part of the basin that wasn't very dry. Figure 7 is a plot of probability versus storage for closing the dam on May 21 or June 1. On May 21 there was a 89 percent chance of getting a billion gallons in storage. On June 1, a week and a half later, there was only a 71 percent probability of achieving the same storage level.

The easiest way to illustrate how coordinated operations work is by example. The utilities and the COE agreed that it might be a good idea if they sat down and tried to operate through a simulated drought. Several tables show the kind of information used to determine daily operations. Long-range forecast information were produced every two weeks. The forecast was in Table 9 for September 15. On the evening before each simulated day the utilities were given a proposed operating sheet (Table 10) which contained a recommended additional upstream release, a predicted river flow, five day river flow prediction, predicted demands and recommended withdrawals. On the basis of this sheet the utilities began the next day with certain target withdrawals from the Potomac and from the reservoirs. On the sheet you can track the downstream progress of releases that were made previously from Bloomington and Savage. Notice that previous releases will not reach Washington for another two days. In the middle of the next day a revised operating sheet was produced (Table 11). In this case this revised operating sheet showed a small shortage of water, about 12 million gallons. The shortage occurred because of overpredicted flow and underpredicted demand.

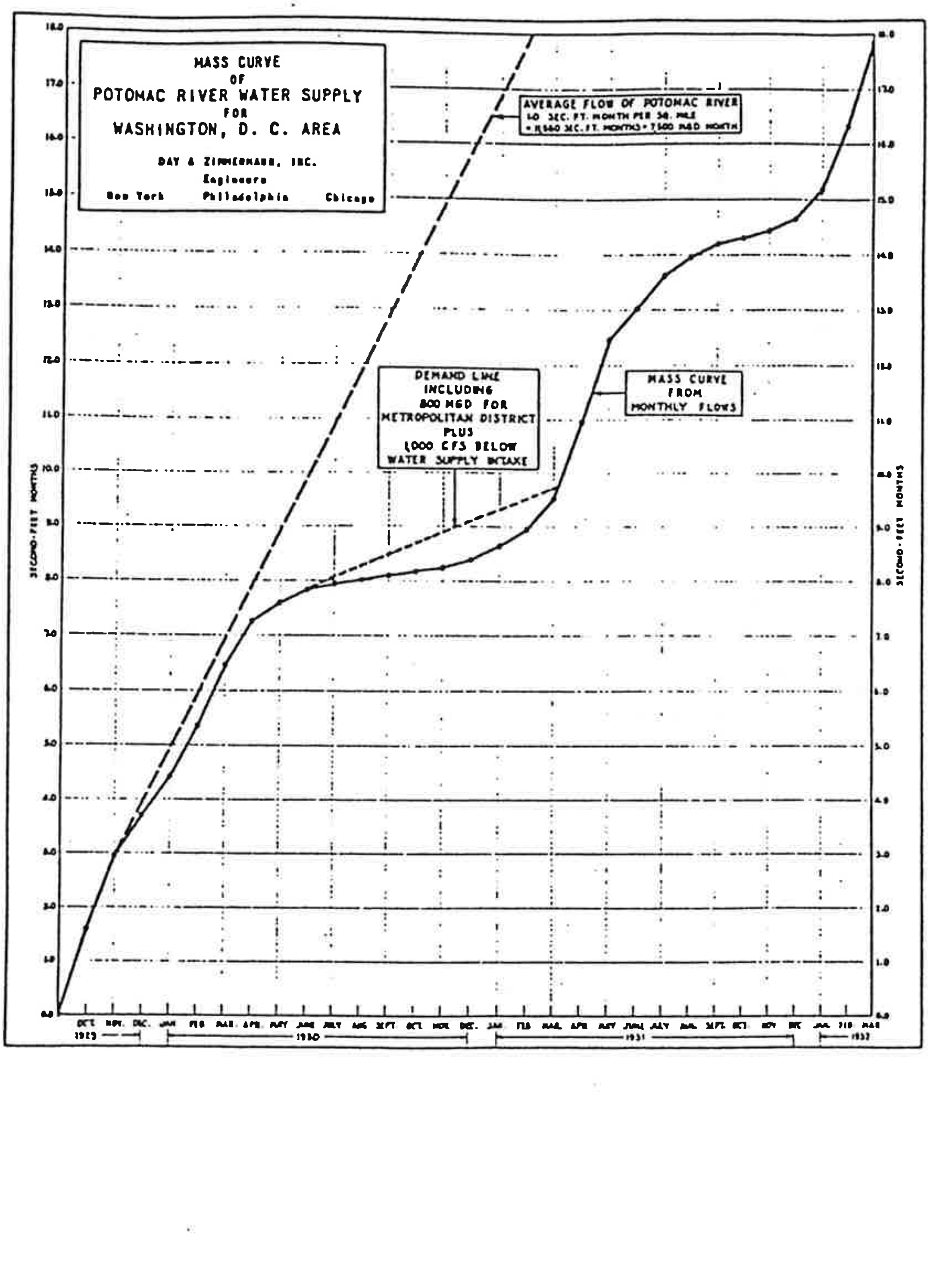
The drought rehearsal was quite successful. It showed rather conclusively that daily operation of the upstream reservoirs was possible and that the local utilities could effectively coordinate their operations. Moreover it pointed out some flaws in our proposed operations and forced corrections before an actual drought occurred. It showed dramatically which of our tools (e.g. demand prediction model) were most in need of improvement.

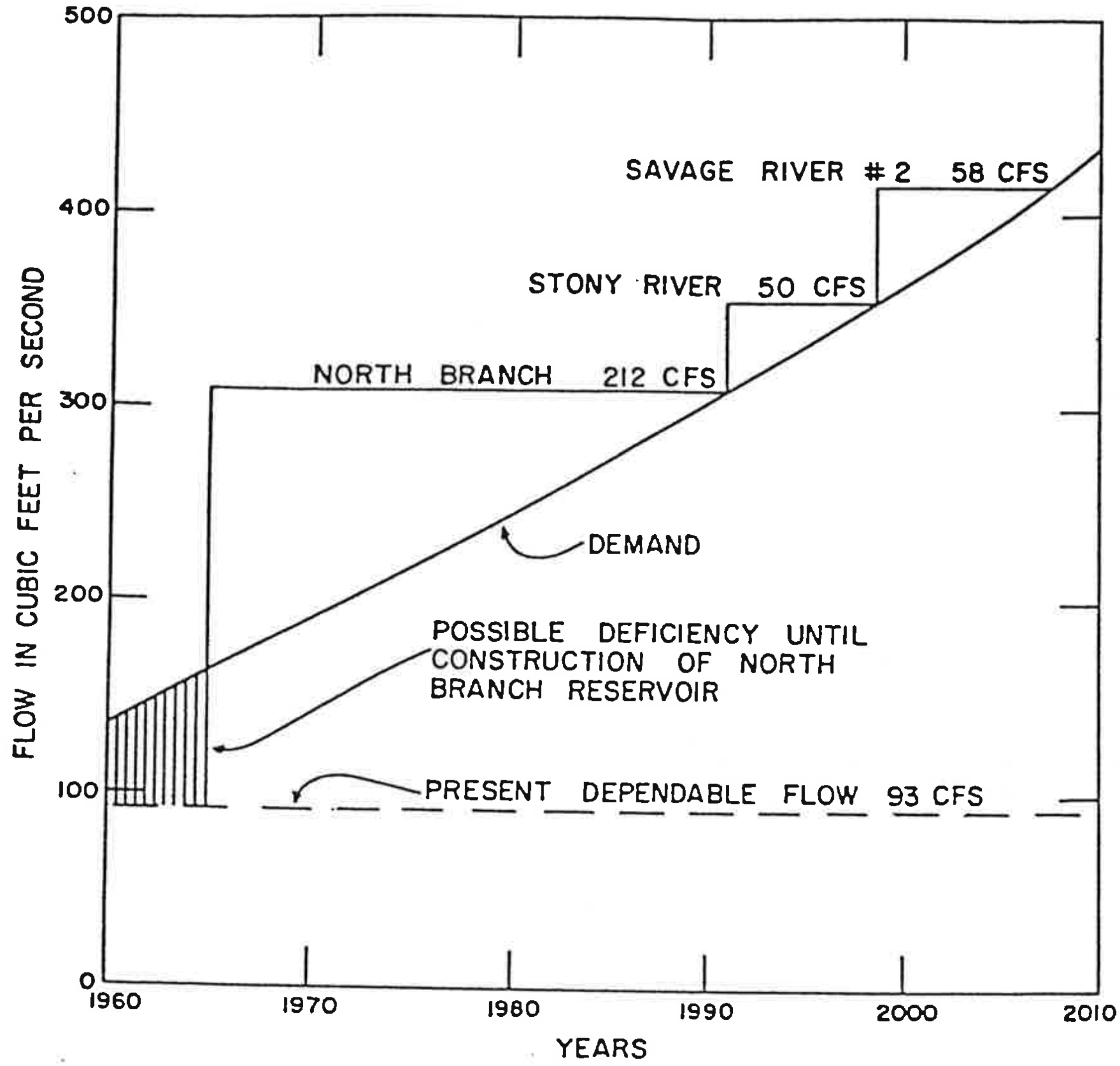
The "operations center" CO-OP was created to develop will be fully functional in April 1982. Contracts necessary to implement the results of CO-OP's technical work are under development by the WMA Water Supply Task Force.

CO-OP will continue to refine and improve its operational tools. Besides demand forecasting, CO-OP is working on such ideas as joint operation of the flood control and water supply storage in Bloomington Lake. Such operation can take full advantage of information produced by NWSRFS about the watershed behind the reservoir. If the soil is dry and will absorb up to an inch and one half of water, less empty storage for flood control is needed, and thus additional storage can be made available for water supply. If the soil is wet and long-term runoff is thus assured, more flood storage can be made available without risk of water supply shortage.

This paper has chronicled the history of the search for solutions to the WMA water supply problem since the early 1950's. A tremendous amount of effort, particularly by the COE, has produced an excellent base for decisions. Because of recent advances in hydrology and streamflow forecasting, long term solutions involving minimal additional construction are now at hand. I firmly believe that the WMA has one less problem to worry about.

FIGURE 1


MASS CURVE
OF
POTOMAC RIVER WATER SUPPLY
FOR
WASHINGTON, D. C. AREA
AVERAGE FLOW OF POTOMAC RIVER
DEMAND LINE
INCLUDING
800 MGD FOR
METROPOLITAN DISTRICT
PLUS
1,000 CFS BELOW
WATER SUPPLY INTAKE
MASS CURVE
FROM
MONTHLY FLOWS
SECOND-FEET MONTHS



POTOMAC RIVER REVIEW REPORT

NORTH BRANCH POTOMAC RIVER

PROJECT SEQUENCING IN RELATION TO WATER DEMANDS

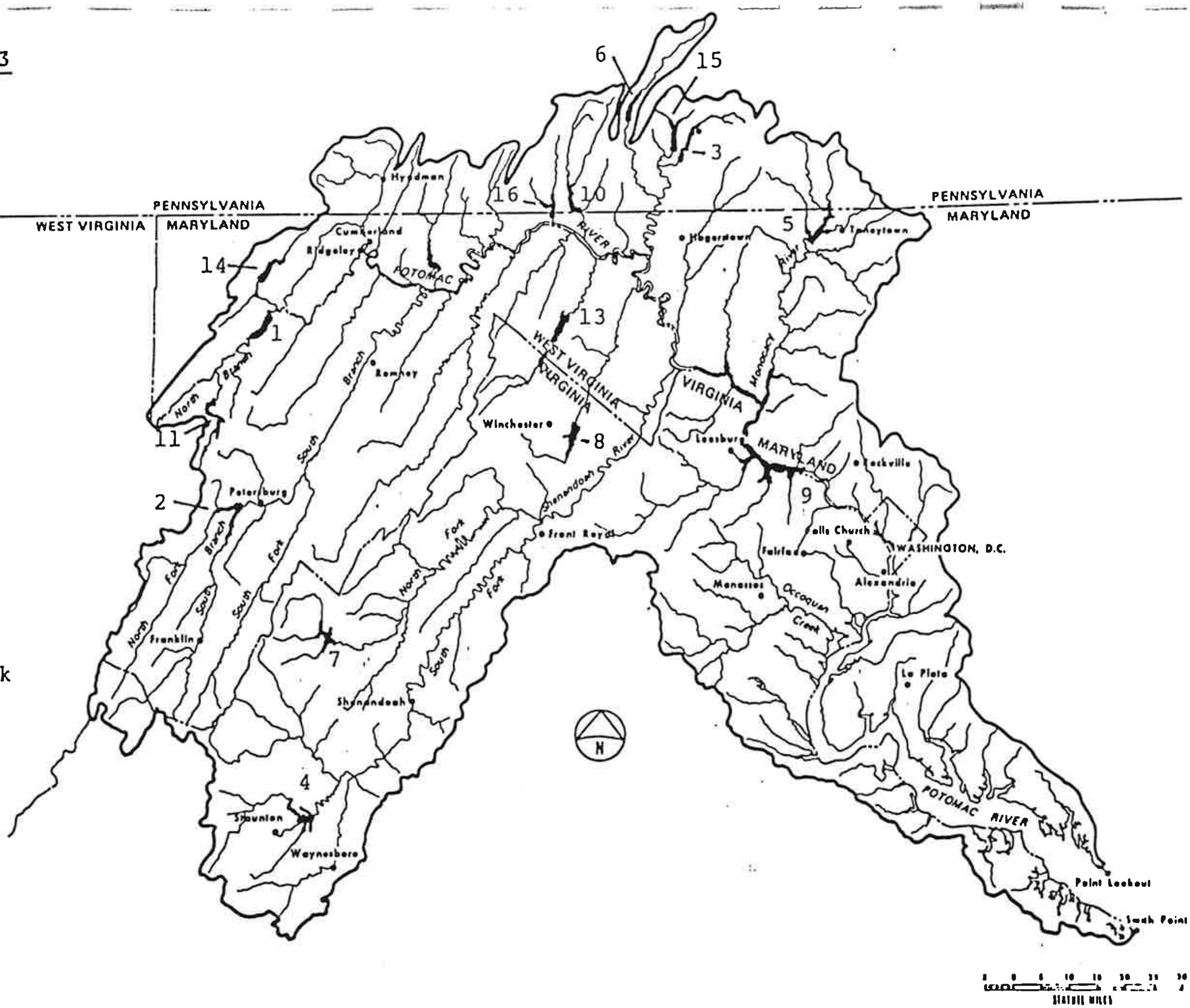
U.S. ARMY ENGINEER DISTRICT WASHINGTON

FEB. 1961 B410-205.1

FIGURE 2

FIGURE 3

1. Bloomington
2. Royal Glen
3. Chambersburg
4. Staunton
5. Six Bridge
6. West Branch
7. Brocks Gap
8. Winchester
9. Seneca
10. Licking Creek
11. Mount Storm
12. Town Creek
13. North Mountain
14. Savage II
15. Back Creek
16. Tonoloway Creek



Major Reservoirs in Recommended Plan

FIGURE 4

Water Supply Needs-2010

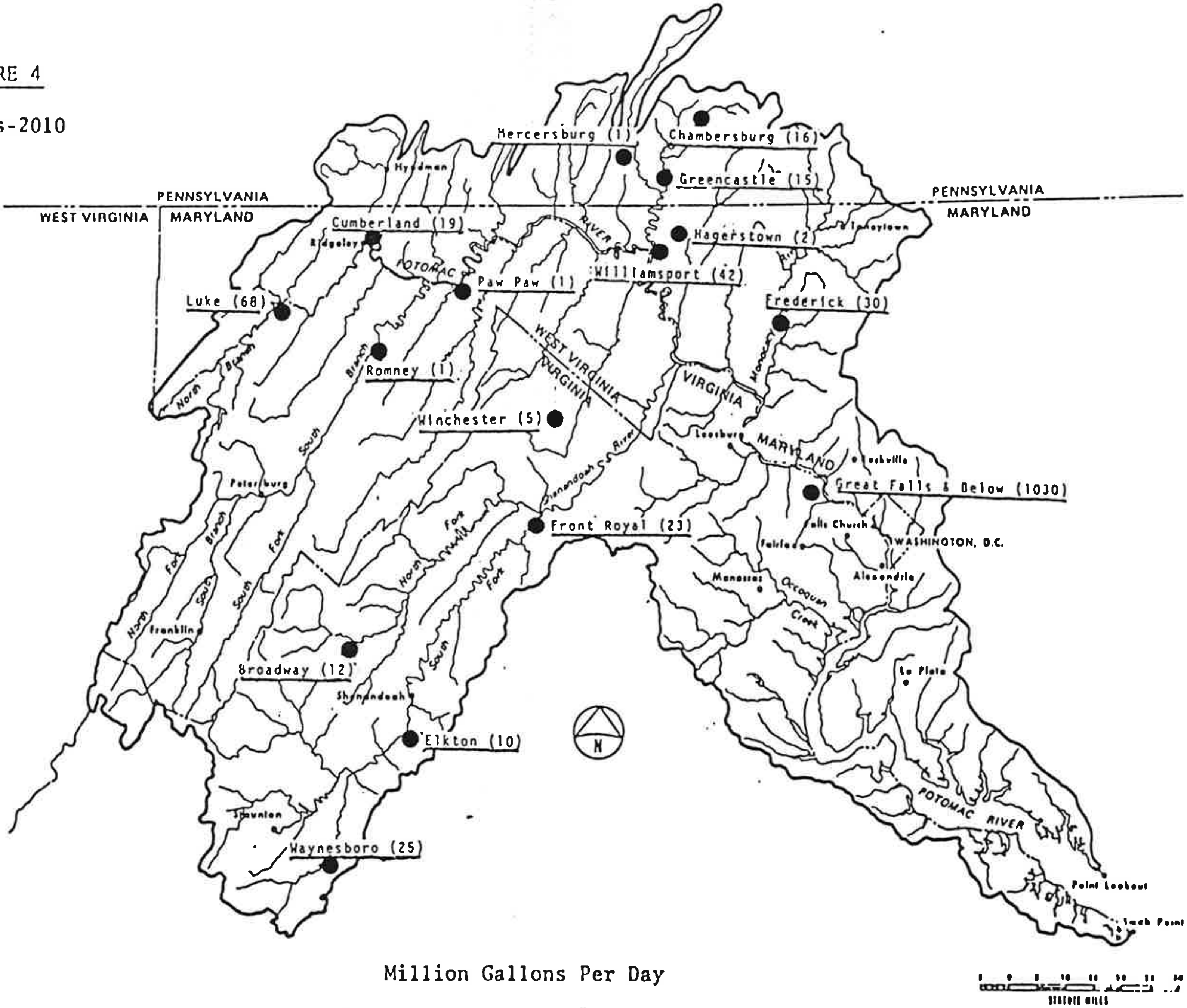
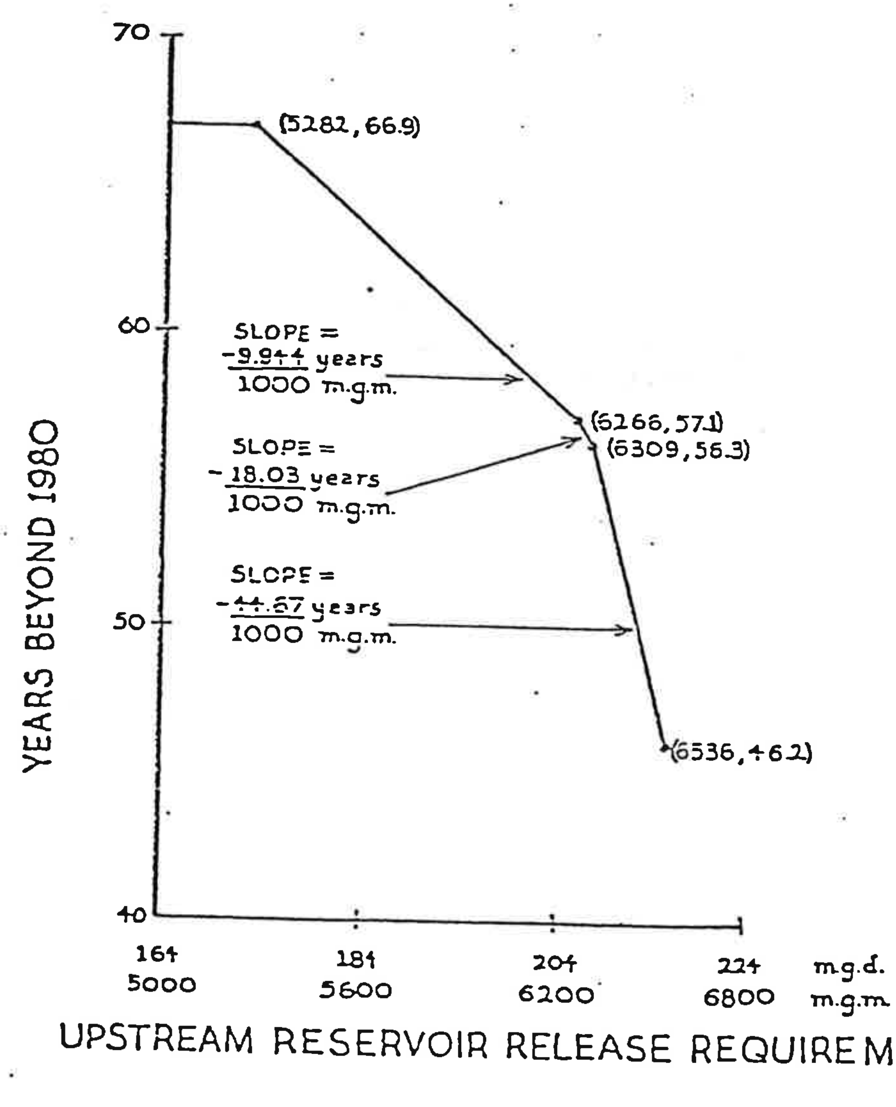
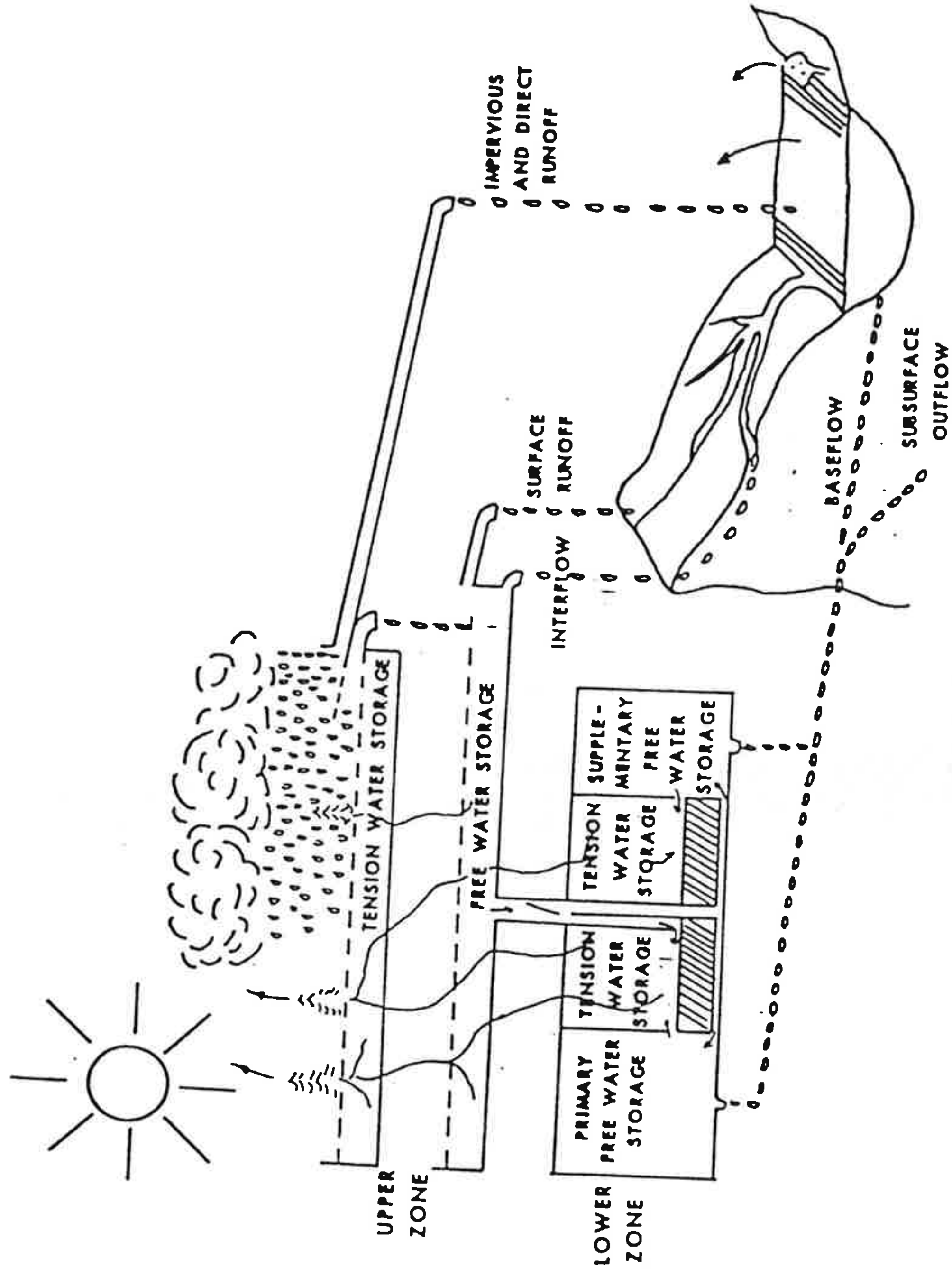


FIGURE 5

TRADE-OFF CURVE FOR UPSTREAM RESERVOIR RELEASE REQUIREMENT AND SYSTEM YIELD



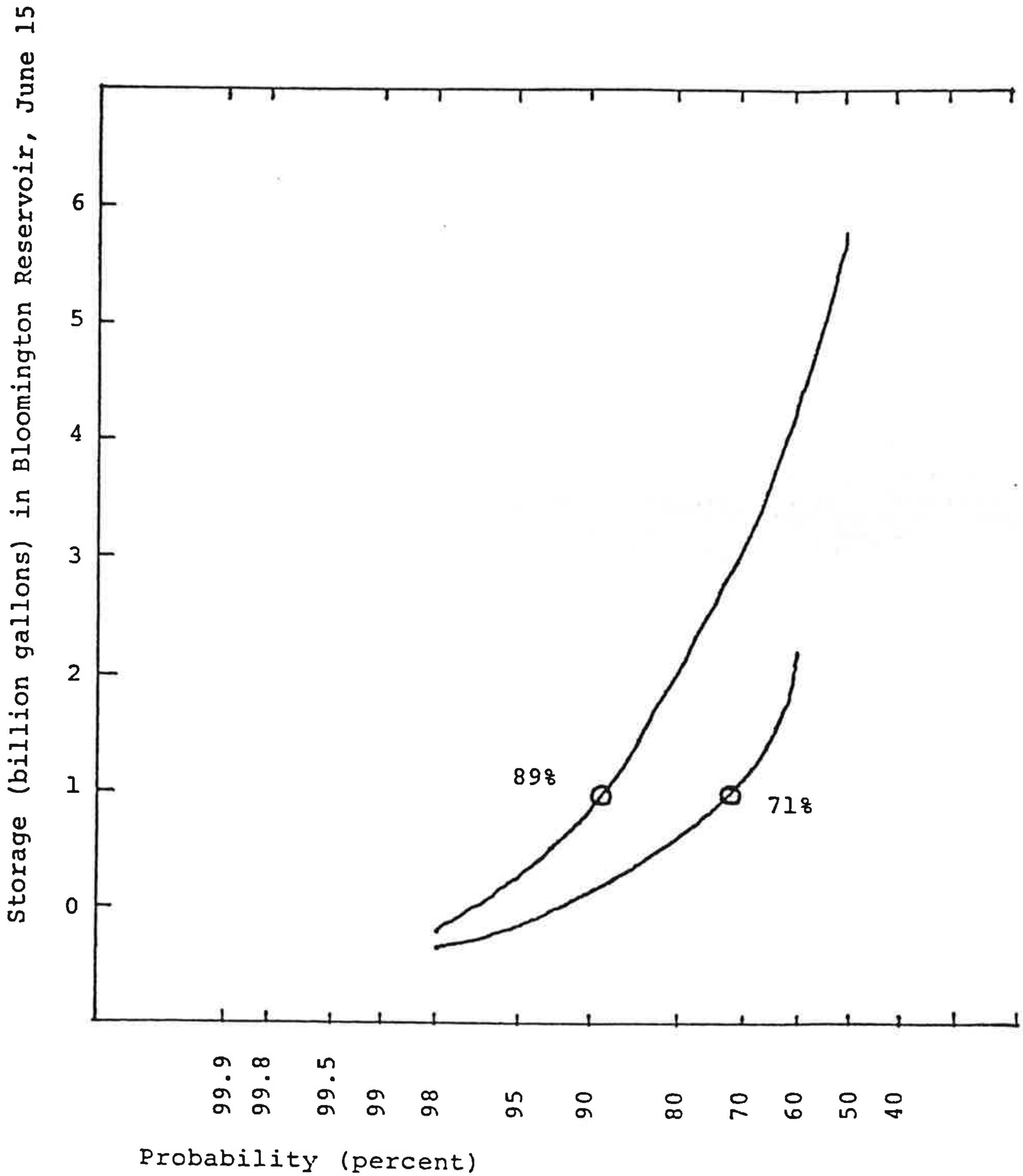


IMPERVIOUS AND DIRECT RUNOFF
SURFACE RUNOFF
INTERFLOW
BASEFLOW
SUBSURFACE OUTFLOW
TENSION WATER STORAGE
FREE WATER STORAGE
UPPER ZONE
LOWER ZONE
PRIMARY FREE WATER STORAGE
TENSION WATER STORAGE
TENSION WATER STORAGE
SUPPLE-MENTARY FREE WATER STORAGE

June 15, 1979

FIGURE 7

Probability Plot for Storage in Bloomington *



*Assuming Savage Reservoir is full at both close date and June 15

TABLE 1

Water Demand Projection
Year 2000

NEWS Study Monthly Demands*

July	August	September	Average Summer
771	755	723	750 mgd

MWCOG Demand Projections**

Annual Average	Max Day
564	798

* From NEWS Study Report, U.S. Army COE NAD, 11/75 p. 31. Figures for Potomac Demand Corrected by adding back 130 mgd assumed from Patuxent and Occoquan Reservoirs and assuming additional 10 mgd (total of 14 mgd) from Goose Creek and Beaverdam Reservoirs.

** From Linear extrapolation of figures in Impact Assessment: 1980, 1990, 1995 Water Resources Implications of Growth Forecasts, MWCOG, 1976.

TABLE 2

Drought Flows, Durations and Recurrence Frequencies*

Drought Duration	Frequency of Recurrence 10 yr.	20 yr.	50 yr.
7 - Day	541	478	419
14 - Day	575	506	438
30 - Day	641	568	503
60 - Day	729	632	541
90 - Day	813	697	580
120 - Day	929	794	658

* Flows in mgd at Point of Rocks, Maryland.

Source: Walker, Patrick N., Flow Characteristics of Maryland Streams, Maryland Geological Survey, 1971, p. 113.

TABLE 3

Total Water Deficits (billions of gallons, assuming no flow augmentation from Bloomington)

Drought Duration	Frequency of Recurrence 10 yr.	20 yr.	50 yr.
7 - Day	1.4	1.9	2.3
14 - Day	2.5	3.4	4.4
30 - Day	3.3	5.5	7.4
60 - Day	1.2	7.1	12.5
90 - Day	0	4.8	15.3
120 - Day	0	0	11.0

TABLE 4

Storage Capacities of Metropolitan Area Reservoirs

Reservoir	Storage*
Occoquan	9
Tridelphia	5
Duckett	5
Beaverdam (off Goose Creek)	1
Total	20

* Storage given in billion gallons, rounded down from working storage, and excluding flood control storage in Tridelphia and Duckett.

TABLE 5

PROBABILITIES OF FALLING BELOW STORAGE LEVELS AT 40 MGD (CURRENT PRODUCTION RATE) AT OCCOQUAN*

Storage Level	93 feet	88 feet	83 feet
Volume of Storage Remaining	1.7 B.G.	1.1 B.G.	0.7 B.G.
Probability	13%	10%	8%

* Purchase of 1.5 B.G. from Lake Manassas is assumed.

TABLE 6

PROBABILITY OF FALLING BELOW STORAGE LEVELS
AT 32 MGD PRODUCTION AT OCCOQUAN*

Storage Level	93 feet	88 feet	83 feet
Volume of Storage Remaining	1.7 B.G.	1.1 B.G.	0.7 B.G.
Probability	5%	3%	2%

* Purchase of 1.5 B.G. from Lake Manassas is assumed.

TABLE 7

Independent Yield of WMA Water Supply Sources

Source	Yield (mgd)
Potomac River (1 day low flow, 966)	388
Occoquan Reservoir	55
Patuxent Reservoirs	35
Bloomington Lake	135
	613

May 14, 1981

TABLE 8

Potential Consequences of
Historical Droughts for 1981
Washington Metropolitan Area

	100 mgd Flowby Over Little Falls			
	'66	'65	'64	'53
#Days of Restrictions	51	9	30	42
#Days of Shortages	6	0	0*	0
Max. Daily Shortage/mg	50	0	0*	0
Required Storage/mg**	1000	0	1000	0

	200 mgd Flowby Over Little Falls			
	'66	'65	'64	'53
#Days of Restrictions	56	40	35	59
#Days of Shortages	12	0*	14	0*
Max. Daily Shortage/mg	142	0*	95	0*
Required Storage/mg	3000	500	2000	1000

*Although no shortages would have occurred, the Emergency Stage of the LFAA would likely have been required.

**Storage necessary to avoid Emergency Stage under the LFAA.

TABLE 9

WATER SUPPLY FORECAST FOR SEPTEMBER 15, 1981

POTOMAC RIVER AT LITTLE FALLS:

CURRENT FLOW: 620 (MGD)

MINIMUM FLOW FOR THE PERIOD SEPTEMBER 15 THROUGH NOVEMBER 1

YEAR	CONDITIONAL MINIMUM FLOW (MGD)	OBSERVED MINIMUM FLOW (MGD)
1960	974	512
1961	873	496
1962	760	489
1963	582	390
1964	483	464
1965	838	424
1966	1711	489
1967	1164	426
1968	725	375
1969	1143	514

OCCOQUAN RESERVOIR:

CURRENT STORAGE: ________ (BILLION GALLONS)

YEAR	TOTAL VOLUME FOR THE PERIOD SEPTEMBER 15 THROUGH NOVEMBER 1: CONDITIONAL TOTAL VOLUME (Bill. Gals.)	OBSERVED TOTAL VOLUME (Bill. Gals.)	TOTAL VOLUME FOR THE PERIOD SEPTEMBER 15 THROUGH JANUARY 1: CONDITIONAL TOTAL VOLUME (Bill. Gals.)	OBSERVED TOTAL VOLUME (Bill. Gals.)
1960	0.8	7.8	13.4	10.7
1961	1.8	3.0	11.8	16.1
1962	0.9	0.8	13.0	11.3
1963	0.7	0.7	11.6	14.7
1964	2.9	2.6	9.0	12.5
1965	1.0	1.5	1.5	2.4
1966	4.7	25.4	46.5	37.0
1967	1.2	2.1	16.2	29.3
1968	0.5	0.7	9.6	10.5
1969	1.4	4.6	17.5	24.9

PATUXENT RESERVOIRS:

CURRENT STORAGE: ________ (BILLION GALLONS)

YEAR	TOTAL VOLUME FOR THE PERIOD SEPTEMBER 15 THROUGH NOVEMBER 1: CONDITIONAL TOTAL VOLUME (Bill. Gals.)	OBSERVED TOTAL VOLUME (Bill. Gals.)	TOTAL VOLUME FOR THE PERIOD SEPTEMBER 15 THROUGH JANUARY 1: CONDITIONAL TOTAL VOLUME (Bill. Gals.)	OBSERVED TOTAL VOLUME (Bill. Gals.)
1960	0.7	2.4	3.2	4.7
1961	1.1	1.3	2.8	3.6
1962	0.8	0.9	4.5	3.3
1963	0.7	0.8	2.9	4.2
1964	0.8	1.0	4.1	3.7
1965	1.2	1.2	2.3	2.5
1966	1.8	4.6	10.8	7.8
1967	2.1	2.5	4.4	7.7
1968	1.3	2.2	4.9	6.5
1969	0.6	2.3	2.8	5.8

TABLE 10

PROPOSED OPERATING SHEET FOR TOMORROW = 9/23

DAY #: 23
WEEK #: 4

428. =PRED. NATURAL FLOW + SAVAGE WQ RELEASE
0. = EFFECT OF ADDITIONAL SAVAGE RELEASES
----
428. = PREDICTED RIVER FLOW TOMORROW

511. = 5 DAY RIVER FLOW PREDICTION (INCLUDES REC. SUPPL. REL.)

1.252 = PRED. DEMAND/FLOW RATIO
1.000 = PRED. 5 DAY DEM./FLOW RATIO

3474. = SAVAGE STORAGE
44. = SAVAGE WQ RELEASE

99. = ******* RECOMMENDED ADDITIONAL SAV. REL.

	PRED.DEMAND	MAX.RES.WITHD.	LF ALLOCATION ALLOC	SP/SHT.	RECOM.WITHD. POT.	RES.	SHORTAGE	STORAGES
WSSC	148.	45.	124.	21.	122.	26.	0.	8740.0
WAD/COE	191.	0.	204.	13.	191.		0.	
FCWA	72.	112.	0.	40.	15.	57.	0.	5641.9
TOTAL	411.	157.	328.	74.	328.	83.	0.	

PREDICTED FLOWBY : 100.
PREDICTED DEMAND REDUCTION FACTORS (WSSC,WAD,FCWA): .15 .15 .05
PREVIOUS SUPPLEMENTAL RELEASES
0. 0. 0. 0. 25. 25.
6 DAYS PREV ---------------------- YESTERDAY

** MANDATORY RESTRICTIONS WILL BE IN EFFECT ***

PLEASE MAKE ANY PRESS RELEASES AND COMMUNICATE
CHANGES IN EXPECTED % DEMAND REUCTION TO WAD AND ICPRB
ALSO INDICATE HOW LARGE (OR 0.) ADDITIONAL SAVAGE RELEASE
IS DESIRED.
THIS SHEET CAN BE REVISED TO REFLECT THESE CHANGES IF YOU WISH

TABLE 11

REVISED OPERATING SHEET FOR TODAY = 9/23

DAY #: 23
WEEK #: 4

424. = NATURAL FLOW + SAVAGE WQ RELEASE
0. = EFFECT OF ADDITIONAL SAVAGE RELEASES
----
424. = TOTAL RIVER FLOW

	ACT. DEMAND	MAX.RES.WITHD.	LF ALLOCATION ALLOC	LF ALLOCATION SP/SHT.	RECOM.WITHD. POT.	RECOM.WITHD. RES.	SHORTAGE	STORAGES
WSSC	149.	45.	122.	18.	104.	45.	1.	8740.0
WAD/COE	221.	0.	202.	-19.	220.		1.	
FCWA	71.	112.	0.	41.	0.	71.	0.	5641.9
TOTAL	442.	157.	324.	39.	326.	116.	2.	

TODAYS SUPPLEMENTAL SAVAGE RELEASE IS : 0.

WITH RECOMENDED ALLOCATION, FLOWBY WILL BE : 100.

REVISE PATUXENT, OCCOQUAN AND POTOMAC WITHDRAWALS AS REQUIRED
PLEASE COMMUNICATE CHANGES TO WAD AND ICPRB

REFERENCES FOR FIGURES AND TABLES

Figures

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7. Probability Plot, ICPRB Water Supply Outlook, May 1981.

Tables

1-4. Water Demand Projection-Year 2000, Drought Flows, Durations and Recurrence Frequencies, Total Water Deficits, Storage Capacities of Metropolitan Area Reservoirs, Sheer, Daniel P., A Prespective of the Washington Metropolitan Area Water Supply Problem, ICPRB, June 1977.

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9. Water Supply Forecast for September 15, 1981, ICPRB CO-OP Drought Rehearsal, July 1981.

10. Proposed Operating Sheet for Tomorrow = 9/23, ICPRB CO-OP Drought Rehearsal, July 1981.

11. Revised Operating Sheet for Today = 9/23, ICPRB CO-OP Drought Rehearsal, July 1981.