Buffer Zone Reservoir Operation

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ABSTRACT

Texas' water demand is steadily increasing. In the past, ground water was used to meet the majority of demand. However, this continuing withdrawal is causing many problems. Because of this situation, the state is now turning to a greater reliance on surface water to meet its water needs. This shift is the beginning of the "management era" where the emphasis is on effective use of existing surface water facilities. Texas has studied and implemented various techniques which increase the efficiency of the reservoir. However, buffer zone operation has been overlooked as a strategy to increase the yield of reservoirs. This report analyzes the state's water problems and presently used strategies, yet focuses on the use, benefits and effectiveness of a buffer zone operation.

WATER NEEDS AND PROBLEMS IN TEXAS

The state of Texas is growing rapidly in population as well as in economic terms. Municipal, industrial, and agricultural water needs are steadily increasing with the state's continuing growth (See Table 1 on page 4). Thus, an increasing demand is being placed on the state's limited water supply. The goal of the state is to "supply in a cost-effective manner sufficient quantities of suitable quality water in each area of the state." {1}

At the present, ground water and surface water are combined to supply the necessary quantity of water. Ground water, however, supplies the majority of the demand. In 1980, ground water supplied 10.9 million acre-feet or 61% of the total water demand while surface water, essentially all from reservoirs, supplied 7.0 million acre-feet or 39% of the total water demand. Texas is underlain by 7 major aquifers and 16 minor aquifiers with 89% of the recoverable water lying in the Ogallala aquifer located in the high plains. With the present demand, water is withdrawn from most of the aquifers at a greater rate than is naturally recharged. Thus, ground water is being mined, at approximately 8 million acre-feet annually even though the reservoirs are full of evaporating water. The dependable water supply from the major reservoirs is about 11 million acre-feet annually, yet the state now only uses about 7 million acre-feet of this dependable yield. It should be noted that much of the ground water mining does occur where no surface water source is present. Even still, "ground water mining is causing water-level declines, decreased well yields, land subsidence, and saline water encroachment." {2} "By the year 2000, if current water use trends continue, the state's aquifers are projected to be capable of supplying about 6.8 million acre-feet, or about 63% of the present level." {3} Overall, considerable potential exists for greater coordination between the user of ground and surface water. The depletion of the ground water reserves is resulting in a shift to a greater reliance on surface water. Figure 1 on page 5 shows that Texas will be moving from a dependence on ground water to a dependence on surface water. As also can be seen from the projections, "Effective management of its surface water resources is essential to the continued growth and prosperity of the state of Texas." {4}

1980 Reported Water Use in Texas in acre-feet/year	
municipal and domestic	2,813,000
manufacturing	1,520,000
mining	239,000
steam-electric	330,000
agricultural	12,851,000
total	17,853,000

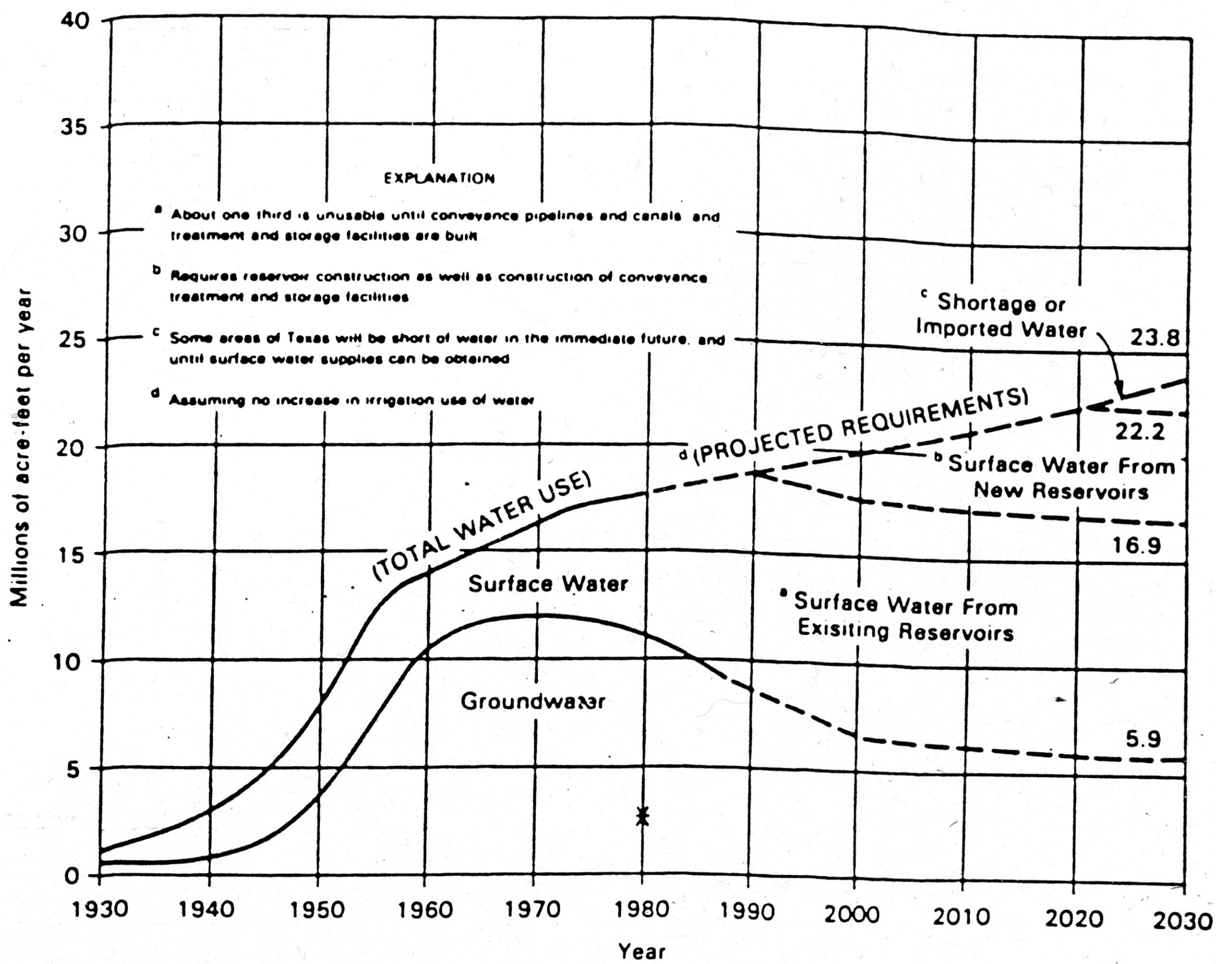
Projected Water Use in acre-feet/year

Year 2000	Low	High
municipal and domestic	3,512,000	5,081,000
manufacturing	2,407,000	2,718,000
mining	268,000	268,000
steam-electric	717,000	817,000
agricultural	10,427,000	16,543,000
total	17,331,000	25,425,000
Year 2030	**Low**	**High**
municipal and domestic	5,059,000	8,178,000
manufacturing	4,231,000	5,014,000
mining	387,000	387,000
steam-electric	1,119,000	1,417,000
agriculture	11,385,000	15,351,000
total	22,181,000	30,347,000

Note: In addition, estimated freshwater inflow requirements for Texas bays and estuaries range from a low (survival limit) of 4.7 million acre-feet annually to a high (enhancement) of 13.6 million acre-feet annually.

Source: Texas Department of Water Resources (1984).

Table 1. Texas Water Use Projections



Source: Texas Department of Water Resources (1984)

Figure 1. Water Use and Source of Supply Projections

SURFACE WATER RESOURCES

Essentially all surface water in Texas is contained in reservoirs. Reservoirs provide an area where water can be trapped and stored for future use. The world actually has adequate amounts of precipitation to meet all water needs but the temporal and spatial distribution of the rainfall presents problems. Texas' climate varies considerably from east to west and is characterized mainly by floods and droughts. The purpose of a reservoir, then, is to alter this temporal and spatial distribution of the runoff and to control and utilize the highly variable streamflow. "Each local and regional water supplier must have the capability to assure its water users of an adequate supply during drought conditions in its own area regardless of the statewide situation." {5} Thus, reservoirs are required in Texas for both dependable water supplies and for flood protection.

Presently, Texas has 182 reservoirs with a storage capacity equaling or exceeding 5000 acre-feet with 5 under construction. Reservoirs can be classified as a flood control, conservation, or multi-purpose. A flood control pool is used to temporarily store storm water to prevent or reduce down-stream flood damages. "The pool is kept empty except for during and immediately following a flood event. Outlet works and spillway gates are opened as necessary to keep the flood control space empty" {6} without, if possible, causing downstream flooding. A conservation pool is used to store water for future use. A multi-purpose reservoir serves both of these functions by providing a conservation pool and a flood control pool.

In a multi-purpose reservoir, the flood control capacity and conservation capacity are separated at a set elevation by what is termed the top of the conservation pool (See Figure 2 on page 9). The conservation capacity of a reservoir may provide some incidental flood protection whenever a flood occurs with a partially drawn-down pool. "Likewise, temporary storage of flood waters in a flood control pool may provide some incidental contribution to conservation purposes." {7} However, the flood control and conservation capacities are usually treated as distinctly separate pools serving different functions. "Planning, design, and operational problems associated with flood control are handled separately from those associated with conservation." {8} In fact, "reservoir operation of a multi-purpose reservoir is based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing flood waters to reduce downstream damages." {9}

Conservation storage capacity includes all controlled storage capacity which is not specifically allocated to flood control. "Conservation capacity is further divided into active and inactive capacity." {10} An inactive pool includes dead storage and sediment reserve. Dead storage is the water below the lowest outlet level which can not be released by gravity flow. It is useful, however, in providing head for hydropower and additional water surface for recreation. "Sediment reserve is often allocated to allow for anticipated loss of capacity during the life of the project due to sediment deposition." {11} Loss of reservoir capacity due to sedimentation is significant in Texas. Active conservation storage, or usable storage, is simply the capacity allocated to store water for withdrawl or release for beneficial purposes.

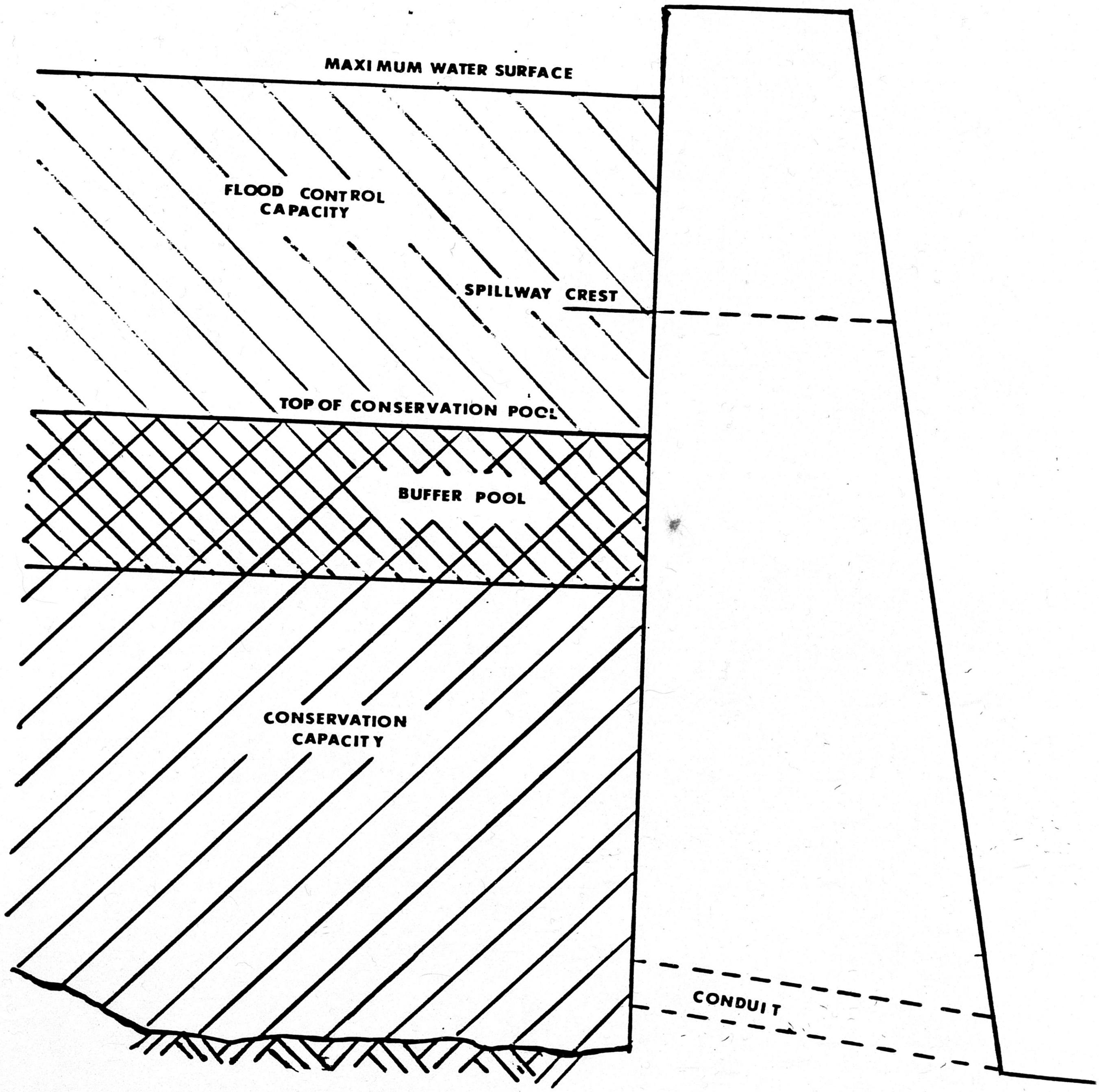


Figure 2. Reservoir Water Zones

USE OF WATER STORED IN RESERVOIRS

Water stored in the conservation pool is used for a variety of purposes. For offstream needs, it stores water for municipal, industrial, agricultural, steam-electric power, hydro-electric power, and mining demands in addition to brine control, and recreation. Conservation uses in a reservoir operation involve "both complementary and confliction or competitive interactions between these purposes." {12} "Instream flow needs include maintenance of sufficient streamflow for water quality, fish and wildlife habitat, livestock water, river recreation, and aesthetics." {13} Traditionally, practices favor offstream needs over instream needs. Yet, releases made for downstream users significantly help instream environmental needs and some reservoirs release water to provide a minimum instream flow level.

Instream flow needs are becoming a growing concern especially fresh water inflows to bays and estuaries. Located along the 400 miles of the Texas Gulf coastline are seven major and several minor estuaries. Coastal bays and estuaries are

> areas where seawater from the Gulf of Mexico mixes with fresh water inflows from rivers to create highly productive and diverse natural environments. The inflow of fresh water is widely recognized as an essential factor in maintaining the biological productivity of Texas bays and estuaries. Fresh water inflows provide nutrients, sediments, and a viable salinity gradient necessary for the survival and vitality of the estuarine biological. {14}

Virtually all of the coastal fisheries species are considered to be estuarine-dependent during at least some portion of their life cycles.

"The role of reservoirs in contributing toward the maintenance of desirable levels of fresh water inflows to the state's bays and estuaries has recently received considerable attention and will likely continue to be scrutinized in the future." {15} Overall, "The reservoir operating procedures for water supply purposes are based essentially on meeting the water demands subject to institutional constraints related to water rights, project ownership, and contractual agreements." {16}

YIELD OF RESERVOIRS

"Generally, water rights permits are limited so that the total amount of water allocated to all users does not exceed the firm (dependable) yield from a particular reservoir or portion of a river basin." {17} The planning and operation of reservoirs for water supply purposes is usually based upon the concept of dependable yield. Dependable yield represents the maximum amount of water which can be supplied continuously from a reservoir if historical inflows are repeated in the future. Future inflows may or may not closely resemble the flow sequence reflected by the past record. This maximum quantity of water which the conservation pool can supply depends upon inflows; evaporation and other losses which are highly stochastic; and storage capacity. Reservoir evaporation is quite significant in Texas. With dependence on these factors and others such as watershed development and construction of other reservoirs on the river, the dependable yield of a reservoir changes over time with these changing conditions.

Under natural conditions, the quantity of water necessary to meet Texas' large and growing needs is not available from aquifers and existing developed surface water resources; " . . . the scarcity of water supply in relation to water demand necessitates the development of additional dependable supplies and implementation of new and more effective water conservation programs throughout Texas." {18} In general, however, the thrust is towards a greater reliance on non-structural measures such as flood plain management and demand management since the building of new reservoirs is limited due to the availability of federal funds, prior development of the most avantageous reservoir sites, project economics, and environmental considerations as well as the fact that construction of new reservoirs decreases the yield of existing reservoirs since each river basin has a limited amount of stream flow. In summary, this transition to a "management era" provides for a more effective utilization of existing facilities.

NON-STRUCTURAL MEASURES FOR INCREASED EFFECTIVENESS OF EXISTING FACILITIES

With the steadily increasing water demands, the limited prospect of constructing new dams and reservoirs, and the continuing depletion of ground water reserves, Texas is placing an emphasis on the effective use of existing surface water facilities. Basically, the state wishes to maximize the dependable yield and use of existing reservoirs while decreasing the growth of the water demand and the need for flood control pools. Presently, to achieve these goals, several strategies have been studied in Texas with success. These methods include demand management, flood plain management, operation of reservoirs as a system, and the use of a seasonal rule curve in operating reservoirs. These strategies illustrate tremendous potential in reducing the state's water problems.

Demand management entails reducing water demands by imposing conservation strategies and analyzing the consequences of failing to meet the water supply demands. Municipal, industrial, and agricultural users especially have demand management potential. Residential and commercial conservation strategies include reducing leakage in distribution lines, "installation and use of efficient water using equipment, some changes in life styles, modification of the behavior and habits affecting water use, changes in plumbing codes and subdivision platting, and a regulation of water user." {19} Implemention of many of these measures depends "upon the costs of water saving technologies and incentives to purchase and use such equipment." {20} Conservation measures for industry include substituting lower quality water for fresh water for cooling and manufacturing purposes and increasing energy conservation. Industrial water use has been reduced due to the "rising energy costs and the high costs of treating wastewater to conform to effluent and water quality standards." {21} Conservation measures for agricultural users include improving "conveyance systems, the use of more effluent irrigation application systems, soil moisture monitoring, the development and use of drought-tolerant strains and varieties of crops, use of growth regulators and evaporation supressants . . ." {22}, brush control and increased use of treated municipal wastewater. By implementing a variety of these techniques, the water demand can be reduced considerably as is illustrated in Figure 3 on page 18 . This graph shows the water demand for the city of Waco with and without the use of demand management strategies. However, severe long-term cutbacks in water use are not warranted when reservoirs are full of water a majority of the time. A contingency plan is needed though for drought conditions to "help alleviate the adverse consequences of a reservoir failing to meet certain demand levels." {23} "A drought contingency program provides procedures for voluntary or mandatory actions, or both, to be put into effect to temporarily reduce the demand placed upon a water supply system during an emergency." {24} However, surface water should be used when it is available. Perhaps, as a solution, combining demand management with reservoir operation as integral components of a comprehensive water management process will prove effective in meeting the state's water demand.

Flood plain management involves the zoning and regulation of the 100-year flood plain. Many counties and cities "have adopted local flood plain management programs in compliance with federal requirements" {25} set up by the National Flood Insurance program. These requirements encourage land use which would minimize the property's exposure to flood damage. State and local entities are now assuming a greater responsibility for flood protection programs, both structural and non-structural. With these programs and the zoning and regulation of the 100-year flood plain, "susceptibility to flooding could actually decrease over time as existing activities choose to leave the flood plain and regulation prevents other activities from coming into the flood plain." {27} The system operation may also include increased coordination between purposes and users. Increasing the interaction between reservoirs usually results in a higher dependable yield than the sum of the dependable yields of individually operated reservoirs. Thus, system operation of reservoirs can yield a greater quantity of water for use.

Next, a seasonal rule curve operation increases the yield of a reservoir by providing additional conservation storage for certain months of the year. "Consideration of the interactions and tradeoffs between conservation storage control operations is becoming increasingly more important." {28} Recall that a reservoir operation involves the conflicting objectives of maximizing flood control capacity and maximizing conservation capacity. "A seasonal rule curve specifies the top of conservation pool elevation as a function of time." {29} Thus, the seasonal conditions of the reservoir can be reflected. It reallocates flood control capacity to conservation space simply by raising or lowering the top of the conservation pool. The reallocation can result in only a small reduction in flood protection, but, before implementing such an operation, the risks and consequences of failing to meet demands is weighed against the decreased flood protection. "In the past, public agencies and water users have not seriously pursued storage reallocation of existing projects as an alternative to developing new projects." {30} However, present and future circumstances have made use of a seasonal rule curve a workable solution to Texas' water problems.

These methods have been given considerable attention in the last decade in Texas. However, one technique has been overlooked and that is the operation of a buffer zone in a reservoir. At present, no reservoir in Texas has used this type of operation to increase its yield. Operation of a buffer zone involves the zoning of the conservation pool and results in a release of a secondary yield a percentage of the time, hence, improving the yield of the reservoir. The research herein studies and discusses the operation, use, and benefits of a buffer zone operation.

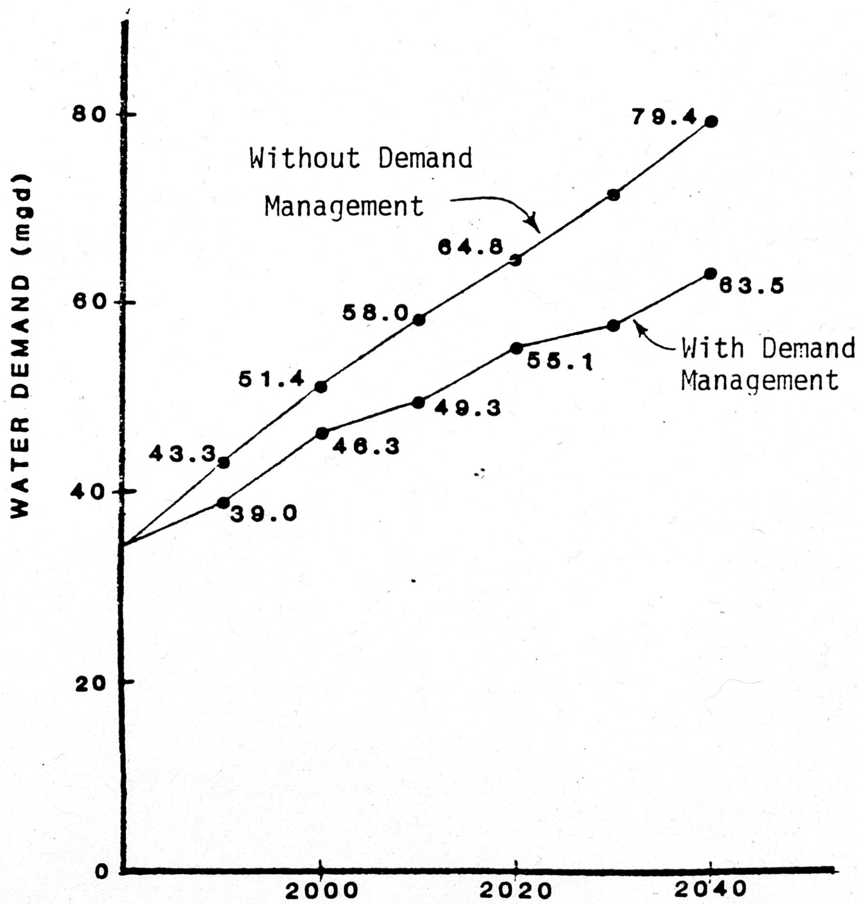


Figure 3. Water Demands

OPERATION OF A BUFFER ZONE

A buffer zone is set at any elevation between the bottom of the reservoir and the top of the conservation pool. A firm yield has been set for the reservoir and is designated as the required water demand. By definition, the firm yield has a 100% percent reliability. Reliability throughout this report is defined as the number of months the demand can be met divided by the total number of months in a period-of-record simulation. An additional demand, referred to as the secondary yield, is also set. The secondary yield is released in addition to the firm yield as long as the reservoir's water level is above the buffer zone level. If the reservoir's water level falls below the buffer zone level, the secondary yield is not released, only the firm yield is released. Thus, the secondary yield can only be released a percentage of the time and, therefore, has an associated reliability.

A limit is placed on the quantity of secondary yield since the firm yield, as defined, is guaranteed a 100% of the time. For that reason, a maximum secondary yield exists for each buffer zone level. The maximum secondary yield is the secondary yield which, when operated with a given firm yield, will draw the reservoir empty during the most severe drought period on historical record. It must be remembered that associated with a secondary yield anywhere from zero to the maximum secondary yield is a reliability. If the prescribed secondary yield is below the maximum secondary yield, the reservoir will not go dry. The water remaining in the reservoir can be seen as a safety factor. This safety factor might be of interest depending on the reservoir and demands place on the reservoir. However, it should by again noted that evaporation in Texas accounts for a large surface water loss; therefore, the water stored in the reservoir should be used when available.

CASE STUDY

To illustrate the effects, use, and benefits of a buffer zone operation, a case study was conducted. The reservoir analyzed was Lake Waco, and the computer modelling program used in the simulation of the buffer zone operation was HEC5 (Simulation of Flood Control and Conservation Systems). HEC5 was developed by the Hydrologic Engineering Center of the U. S. Army Corps of Engineers. The input date for HEC5 was secured from the Lake Waco manual issued by the U. S. Army Engineer District Fort Worth in 1971. The evaporation rate of the reservoir, an important aspect of the input data, was assumed to be the highest rate given in the Lake Waco manual. The precipitation which falls directly on the reservoir was neglected. Water losses in the distribution of the demand were neglected also. Historical monthly streamflow was used dating from 1907 to 1982; no synthetic streamflow data was generated.

DESCRIPTION OF WACO DAM AND RESERVOIR

The Waco dam and reservoir project was authorized by the Flood Control Act of 1954. Construction was initiated in 1956, and deliberate impoundment began in February 1965. The dam and reservoir are located entirely within the corporate limits of the city of Waco in central Texas. The dam is on the Bosque River 4.6 miles above its confluence with the Brazos River. At the top of conservation pool, the reservoir inundates the confluences of the four major tributaries of the Bosque River: North Bosque, Hog Creek, Middle Bosque, and South Bosque. The reservoir has a drainage area of 1,670 square miles. the water surface area at the top of conservation pool is 7,270 acres.

Waco Dam is 24,620 feet long with a maximum height of 140 feet. The dam is an earthen embankment except for a 1,043 foot concrete gravity spillway section. The spillway is controlled by fourteen 40-feet by 35-feet tainter gates. The outlet works consists of a 20-foot diameter conduit controlled with broome-type tractor sluice gates. Pertinent elevations in feet above mean sea level are as follows: streambed, 370 feet; top of conservation pool, 455 feet; spillway crest, 465 feet; top of tainter gates, 500 feet; maximum design water surface, 505 feet; and top of dam, 510 feet.

Project purposes include flood control, municipal and industrial water supply, and recreation. Flood control, conservation, and sediment reserve capacities are 553,000 acre-feet, 104,100 acre-feet, and 69,000 acre-feet respectively. The 69,000 acre-feet of sediment reserve was available at the time of initial impoundment to provide for 50 years of sedimentation. The Fort Worth district of the U. S. Army Corps of Engineers constructed, owns, and operates the project. Releases from the conservation pool are made at the discretion of local project sponsors. The city of Waco and the Brazos River Authority (BRA) have contracted with the Corps of Engineers for 12.6 percent and 87.4 percent, respectively, of the conservation storage. The BRA has contracted with the city of Waco to supply the city water from BRA's 87.4 percent share of the conservation pool. Thus, all of the conservation storage in Waco Lake is committed to providing municipal and industrial water for the city of Waco and its suburbs. (Wurbs, Nov. 1985)

PROCEDURE TO ANALYZE BUFFER ZONE OPERATION IN WACO LAKE

Water stored in Lake Waco is used solely to supply water for the city of Waco and its suburbs. The projection of this water demand is shown in Table 2 on page 26. The projected water demands for 1990 and 2000 were used. These demands are the firm yield and, as previously stated, are guaranteed 100% of the time. The monthly variation in demands, shown in Table 3 on page 26 was taken into account in calculations. The question is -- How much additional water can Lake Waco supply? The operation of a buffer zone answers this question.

Presently, the top of the conservation pool for Lake Waco is set at 455 feet. At this level, the dependable yield of the reservoir is an average of 81 cubic feet per second (CFS). However, a proposal has been approved by the Office of the Chief of Engineers in Washington, DC to reallocate 47,500 acre-feet of flood control capacity to conservation capacity. This reallocation will result in the raising of the top of the conservation pool to 462 feet. This additional storage increases the dependable yield of Lake Waco to an average of 102 CFS . Both of these levels and a seasonal rule curve were used in conjunction with a buffer zone.

For several combinations of firm yield and conservation pool, a buffer zone operation was simulated. The simulation entailed selecting a buffer zone elevation, prescribing a secondary yield and a firm yield, designating the top of the conservation pool, and finally, executing the

HEC-5 program. The secondary yield needs to be set at a value that allows the firm yield to be guaranteed 100% of the time. In most cases, the maximum secondary yield is the desired additional demand. From the output of the computer simulation, the reliability associated with the secondary yield and buffer zone level is computed. Repetition of this procedure will result in a set of curves which will prove useful in the evaluation of the buffer zone operation.

	Water Demand in MGD		
Year	Municipal	Industrial	Total
1980	28.1	6.0	34.1
1990	34.6	8.7	43.3
2000	39.1	12.3	51.4
2010	42.0	16.0	58.0
2020	45.0	19.8	64.8
2030	47.0	24.6	71.6
2040	49.2	30.2	79.4

Table 2. Water Demands

Month	Monthly Water Use as a Percentage of Annual Water Use
January	6.58
February	6.16
March	6.41
April	6.96
May	7.93
June	9.55
July	11.51
August	11.68
September	10.29
October	8.53
November	7.27
December	7.13

Table 3. Monthly Demands

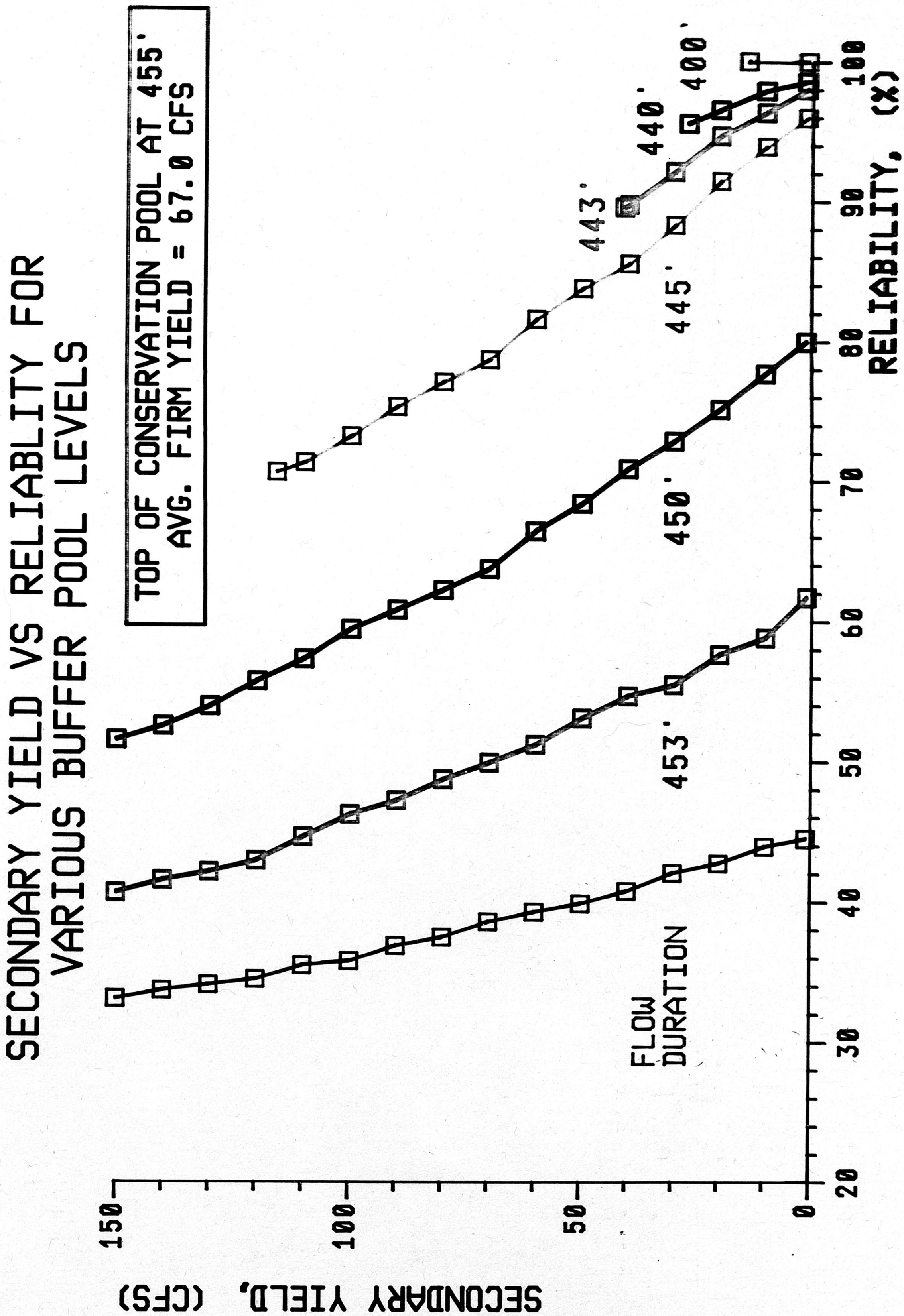

SECONDARY YIELD VS RELIABLITY FOR
VARIOUS BUFFER POOL LEVELS
TOP OF CONSERVATION POOL AT 455'
AVG. FIRM YIELD = 67.0 CFS
443'
440'
400'
445'
450'
453'
FLOW
DURATION
SECONDARY YIELD, (CFS)
RELIABILITY, (%)
150
100
50
0
20
30
40
50
60
70
80
90
100

Figure 4

RESULTS OF SIMULATION

The procedure just mentioned was repeated for various combinations of firm yield and top of conservation pool. The results of these simulations are presented in four(4) graphs. The tabular form of these curves is given in Appendix A. Figure 4 on page 30 illustrates the general pattern resulting from various buffer zone elevations for a constant firm yield. The flow-duration curve corresponds to no buffer zone operation. The secondary yield is simply the undemanded water released to insure that the flood control pool is kept empty. Study of the other curves indicate that as the buffer zone elevation is decreased, the reliability increases and the maximum secondary yield decreases. The buffer zone level of 400 feet corresponds to the bottom to the reservoir; therefore, all yields below the maximum secondary yield and including itself will have a reliability of 100% since the water level can never go below the bottom of the reservoir. For a buffer zone level of 400 feet, the summation of this maximum secondary yield and the firm yield will result in 81 CFS or the dependable yield of the reservoir for top of conservation pool at 455 feet. All set secondary yields below the maximum secondary yield will not draw the reservoir dry. Some amount of water will be remaining in the reservoir. This remaining water, as discussed previously, can be thought of as a safety factor. Since maximum use of the surface water is desired, the maximum secondary yield and associated reliabilities are the points of interest in the research.

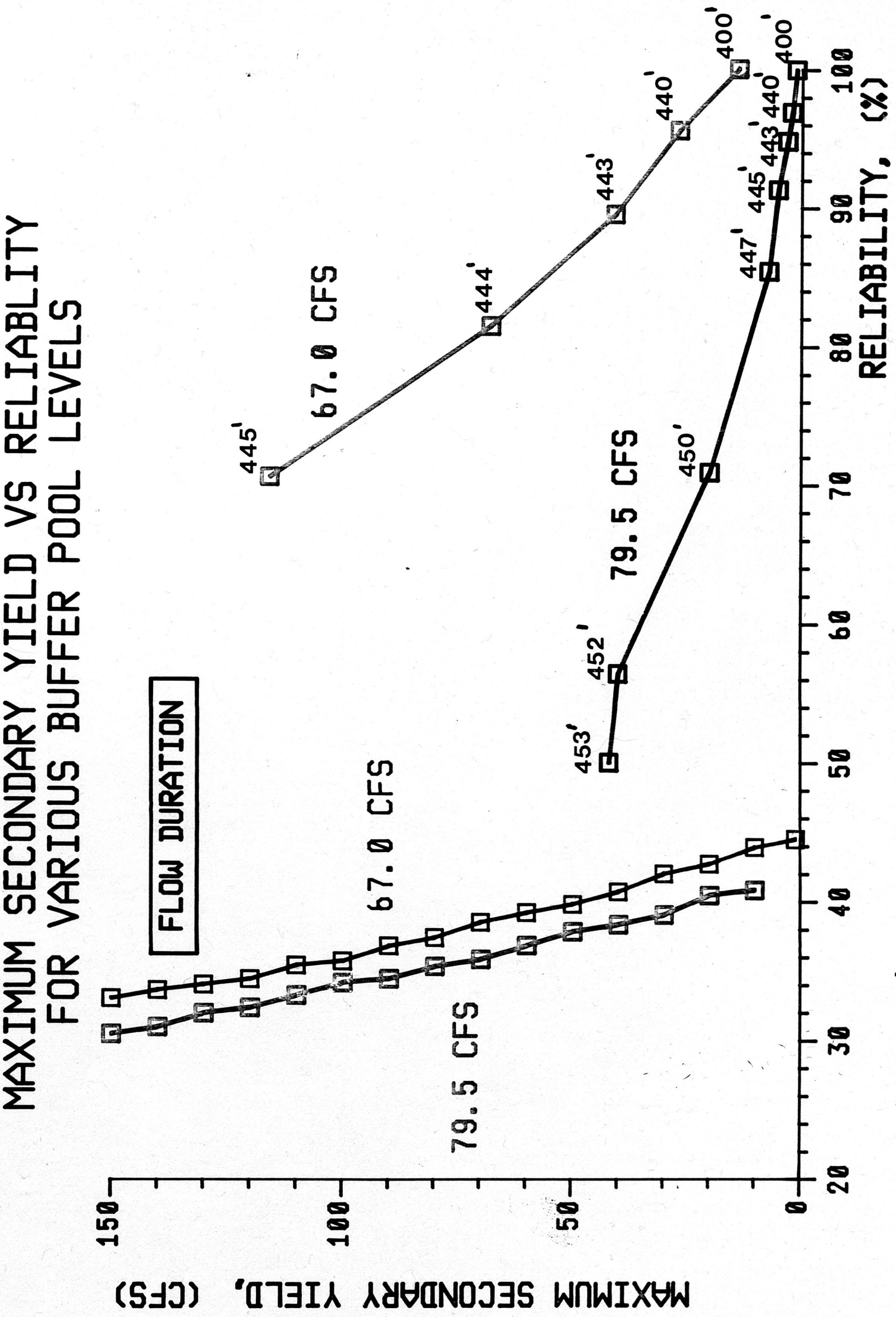

MAXIMUM SECONDARY YIELD VS RELIABLITY
FOR VARIOUS BUFFER POOL LEVELS
FLOW DURATION
67.0 CFS
79.5 CFS
445'
444'
443'
440'
400'
453'
452'
450'
447'
445'
443'
440'
400'
RELIABILITY, (%)
MAXIMUM SECONDARY YIELD, (CFS)
150
100
50
0
20
30
40
50
60
70
80
90
100

Figure 5

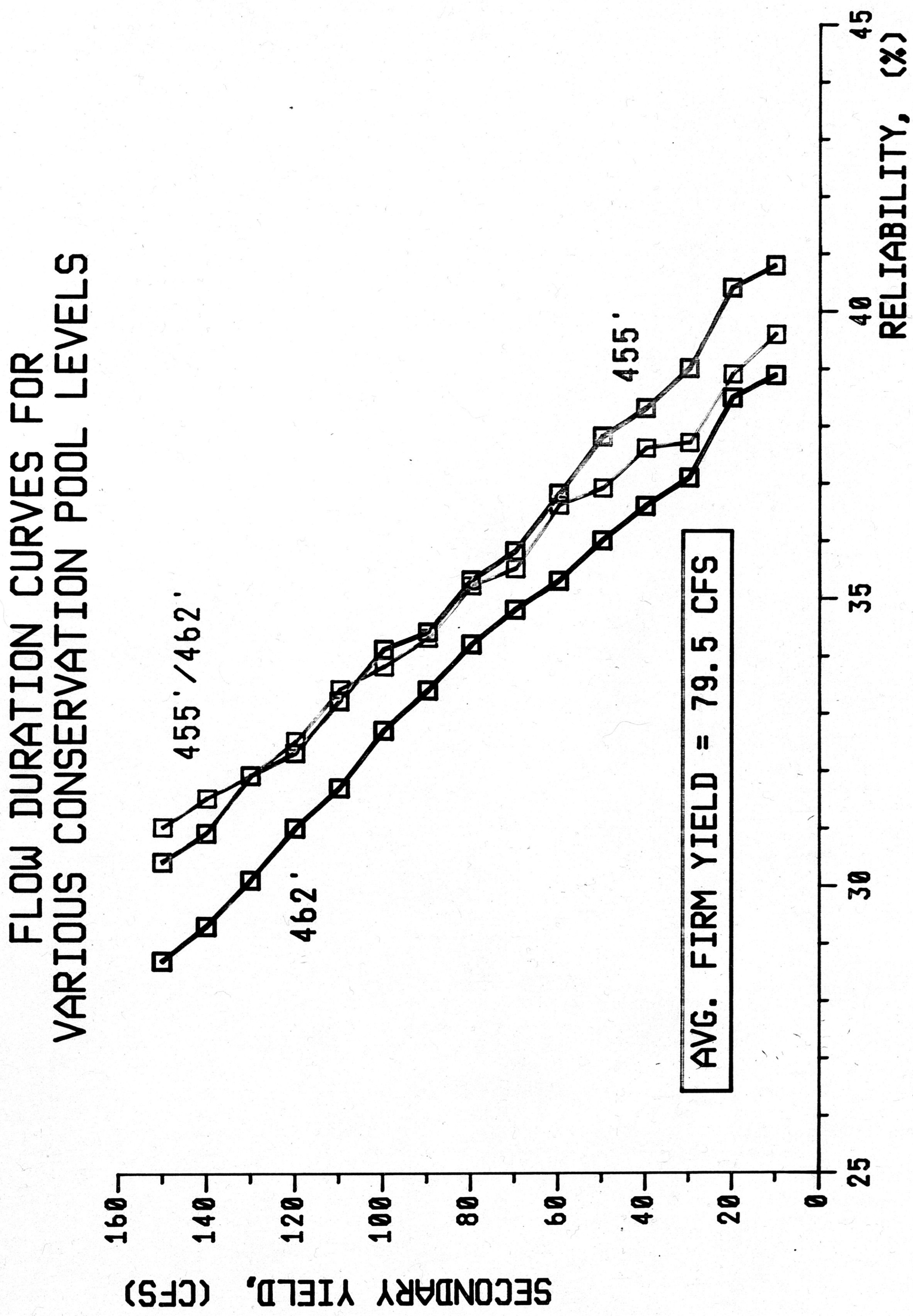

FLOW DURATION CURVES FOR
VARIOUS CONSERVATION POOL LEVELS
455'/462'
462'
455'
AVG. FIRM YIELD = 79.5 CFS
SECONDARY YIELD, (CFS)
RELIABILITY, (%)
0
20
40
60
80
100
120
140
160
25
30
35
40
45

Figure 6

The buffer zone operation of Lake Waco was studied for a firm yield of 67 CFS, the 1990 demand, and for a firm yield of 79.5 CFS, the year 2000 demand. A firm yield of 79.5 CFS is of particular interest since the dependable yield of the reservoir for a top of conservation pool at 455 feet is only 81 CFS. The result of these simulations are graphically illustrated in Figure 5 on page 31. This graph shows that the flow-duration curves for the two yields are very similar. For the majority of the time, no undemanded flow is released downstream. The maximum secondary yield versus reliability curves illustrate that an additional amount of water can be withdrawn from the reservoir while supplying the city of Waco its demand. The buffer zone level to use would be dependent upon the quantity of flows needed and the reliability required.

Figure 6 on page 32 and Figure 7 on page 33 compare the operation of a buffer zone for the top of the conservation pool at 455 feet and 462 feet as well as seasonally varied pool which is at 455 feet from November to March, and 462 feet from April to October. The flow-duration curve for each of these pools is shown in Figure 6. Once again, the flow-duration curves are quite similar and show that the majority of the time no undemanded water is released from the reservoir. The maximum secondary yield versus reliability for various buffer zones is shown in Figure 7 with the three curves corresponding to the three conservation capacities. The curves for the top of conservation pool at 462 feet and 455/462 feet are very similar. For each buffer zone level simulated, the maximum secondary yield remains the same; yet, the seasonally varied pool results in a lesser reliability. A tremendous difference in secondary yields exists between the 455 feet pool and the two other pool levels. The reason for this difference can be attributed to the fact that when the top of the conservation pool is raised, the dependable yield of the reservoir increases. In this case, the dependable yield increases from 81 CFS to 102 CFS .

Overall, from the tabulation of the results, the operation of a buffer zone can provide an additional amount of water with an associated reliability. The necessary quantity of secondary yield and required reliability will be dependent on the proposed use of the released water. The operation of a buffer zone alone does appear to have limited potential; however, using this technique in conjunction with other non-structural measures for improving the effectiveness of the existing facilities can be beneficial.

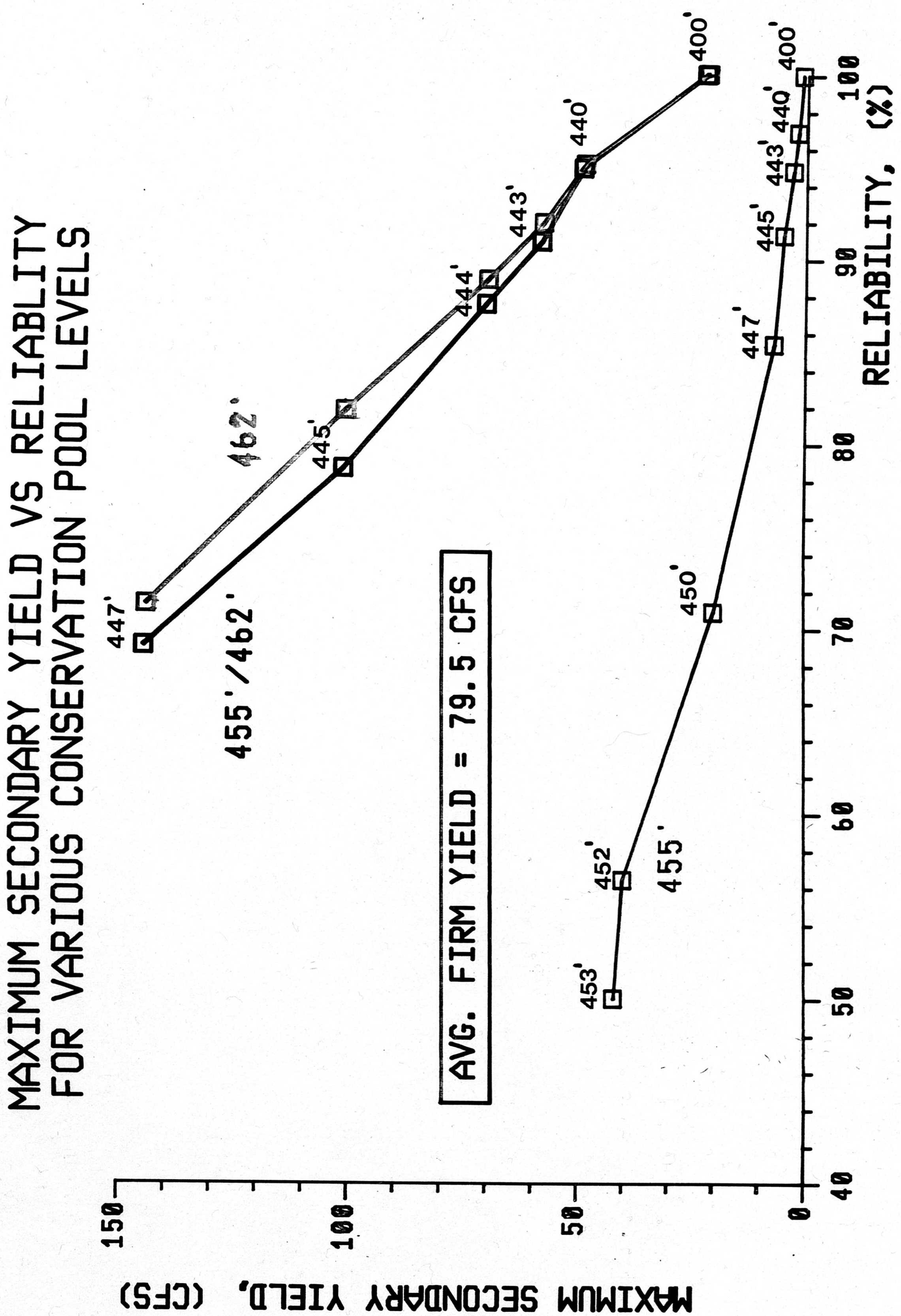

MAXIMUM SECONDARY YIELD VS RELIABLITY
FOR VARIOUS CONSERVATION POOL LEVELS
AVG. FIRM YIELD = 79.5 CFS
447'
455'/462'
462'
445'
444'
443'
440'
400'
453'
452'
455'
450'
447'
445'
443'
440'
400'
MAXIMUM SECONDARY YIELD, (CFS)
150
100
50
0
40
50
60
70
80
90
100
RELIABILITY, (%)

Figure 7

CONCLUSION

As demands increase, "secondary yields and zoning of conservation pools may become important to improve the effective use of a reservoir" {31} The focus of this report is to show the potential effectiveness, usefulness, and benefits from the incorporation of a buffer zone into a reservoir's operation policy. As has been illustrated by the case study, an additional amount of water can be released from the reservoir while providing a set demand to the city of Waco. Therefore, operation of a buffer zone can increase the yield of a reservoir. The secondary yield can only be provided a percentage of the time; however, this technique can be used in addition to other techniques to insure water demands. The operation of a buffer zone allows for the maximum use of surface water when it is available.

The secondary yield made available by operation of a buffer zone could be released to provide instream flow needs. Instream flow needs have traditionally been neglected. As shown in Figure 7 on page 33 by comparing the flow-duration curve to the various curves resulting from the operation of a buffer zone, water released simply for instream flow needs can be substantially improved. The flows levels would decrease, yet the flow can be maintained for a longer period of time. Another possible use of the additional flow is for the purpose of freshwater inflows to bays and estuaries. This topic, as mentioned before, is receiving considerable attention at the present. The operation of a buffer zone may provide sufficient quantities of water at an acceptable reliability. Instream flow needs and freshwater inflows to bays and estuaries are simply two examples of the potential usefulness of a buffer zone operation.

The buffer zone operation has its greatest potential when used as a portion of a comprehensive water management plan. Since operation of the buffer zone will provide a maximum use of surface water available in a reservoir, it should be used with various other non-structural measures to create a useful and effective water plan. The use of a buffer zone with a seasonal rule curve has also been shown. The seasonal rule curve can be implemented instead of permanently reallocating the flood control space with approximately the same dependable yield for the reservoir. The use of the buffer zone with a seasonal rule curve provides the same secondary yields only with a slightly smaller reliability. Operation of the buffer zone with regard to demand management strategies and ground water pumpage would be a benifical combination. The quantity of water released could be relatively high as long as the water level was above the buffer zone elevation. Ground water pumpage could be cut back and demand management measures relaxed. When the water level falls below the buffer zone elevation, demand management measures could be enforced and/or ground water pumpage increased. These combinations are only a few which can be constructed and developed to provide an effective water plan with the aid of buffer zone operation. Used by itself, the technique has limited potential; yet when included in a comprehensive plan, the method can be tremendously helpful in effectively using existing reservoir facilities.

The simulation conducted for this research was simplified. A reservoir can be divided into several zones with a secondary yield associated with each zone. Further studies should be conducted on various reservoirs to illustrate this method's full potential.

FOOTNOTES

Texas Department of Water Resources, "Water for Texas, a Comprehensive Plan for the Future", 2 Volumes, June 1984, p. 19.

Ralph A. Wurbs, "Reservoir Operation in Texas", Texas Water Resources Institute, Technical Report No. 135, June 1985, p. 20.

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Ibid, p. 1.

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Ibid, p. 31.

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Ibid, p. 77.

Ibid, p. 87.

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Texas Department of Water Resources, "Water Planning in Texas, Past-Present-Future", 1984, p. 1.

Texas Department of Water Resources, "Water for Texas", p. 32.

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Wurbs, "Reservoir Operation in Texas", p. 103.

Texas Department of Water Resources, "Water for Texas", p. 29.

Ibid, p. 17.

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Ibid, p. 79.

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Ralph A. Wurbs, *et al.*, "Optimum Reservoir Operation for Flood Control and Conservation Purposes", Texas Water Resource Institute, Technical Report No. 137, November 1985, p. 103.

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Wurbs, "Reservoir Operation in Texas", p. 103.

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APPENDIX

FLOW-DURATION CURVE

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)
0	100.0
10	43.9
20	42.7
30	42.0
40	40.7
50	39.8
60	39.2
70	38.5
80	37.4
90	36.8
100	35.7
110	35.4
120	34.4
130	34.0
140	33.6
150	33.0

SECONDARY YIELD VS. RELIABILITY

Buffer Zone Level at 453 feet

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)	Safety Factor (acre-feet)
1	61.7	15380
10	58.8	14990
20	57.6	14560
30	55.4	14120
40	54.6	13690
50	53.0	13250
60	51.1	12960
70	49.8	12960
80	48.6	12960
90	47.1	12960
100	46.1	12960
110	44.5	12960
120	42.8	12960
130	42.0	12960
140	41.4	12960
150	40.5	12960
200	35.8	12960
300	29.8	12960
400	24.2	12960
500	20.9	12960
600	18.5	12960
700	16.7	12960
800	14.4	12960
900	12.6	12960

SECONDARY YIELD VS. RELIABILITY

Buffer Zone Level at 450 feet

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)	Safety Factor (acre-feet)
1	80.0	15290
10	77.7	14060
20	75.1	13000
30	72.8	12750
40	70.8	11870
50	68.3	10980
60	66.3	10100
70	63.6	9210
80	62.1	8330
90	60.7	7460
100	59.3	6590
110	57.2	5940
120	55.6	5940
130	53.8	5940
140	52.4	5940
150	51.4	5940
200	45.2	5940
400	29.6	1390
600	22.1	1390
800	16.3	1390
1100	12.2	1390
1300	8.6	1390
1500	7.5	1390
1700	5.8	1390
1785	5.2	0

SECONDARY YIELD VS. RELIABILITY

Buffer Zone Level at 443 feet

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)	Safety Factor (acre-feet)
1	96.0	14900
10	93.9	11150
20	91.4	7890
30	88.2	6840
40	85.4	4450
50	83.6	4060
60	81.4	1880
70	78.5	1100
80	76.9	1100
90	75.1	140
100	73.0	140
110	71.1	140
116	70.4	0

SECONDARY YIELD VS. RELIABILITY

Buffer Zone Level at 443 feet

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)	Safety Factor (acre-feet)
1	98.0	14750
10	96.3	9700
20	94.6	5020
30	92.0	2760
40	89.6	580
41	89.4	0

SECONDARY YIELD VS. RELIABILITY

Buffer Zone Level at 440 feet

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Secondary Yield (cfs)	Reliability (%)	Safety Factor (acre-feet)
1	98.6	14690
10	97.9	8670
20	96.5	3200
27	95.5	0

MAXIMUM SECONDARY YIELD VS. RELIABILITY

Top of Conservation Pool at 455 feet

Firm Yield = 67 cfs

Buffer Zone Level (feet)	Maximum Secondary Yield (cfs)	Reliability (%)
400	14	100.0
440	27	95.5
443	41	89.4
444	68	81.3
445	116	70.4

FLOW-DURATION CURVE

Top of Conservation Pool at 455 feet

Firm Yield = 79.5 cfs

Secondary Yield (cfs)	Reliability (%)
0	100.0
1	41.5
10	40.8
20	40.4
30	39.0
40	38.3
50	37.8
60	36.8
70	35.8
80	35.3
90	34.4
100	34.1
110	33.2
120	32.3
130	31.9
140	30.9
150	30.4

MAXIMUM SECONDARY YIELD VS. RELIABILITY

Top of Conservation Pool at 455 feet

Firm Yield = 79.5 cfs

Buffer Zone Level (feet)	Maximum Secondary Yield (cfs)	Reliability (%)
400	1	100.0
440	2	96.9
443	3	94.8
445	5	91.3
447	7	85.4
450	20	70.9
452	40	56.4
453	42	50.0

FLOW-DURATION CURVE

Top of Conservation Pool at 455/462 feet

Firm Yield = 79.5 cfs

Secondary Yield (cfs)	Reliability (%)
0	100.0
1	40.5
10	39.6
20	38.9
30	37.7
40	37.6
50	36.9
60	36.6
70	35.5
80	35.2
90	34.3
100	33.8
110	33.4
120	32.5
130	31.9
140	31.5
150	31.0

MAXIMUM SECONDARY YIELD VS. RELIABILITY

Top of Conservation Pool at 455/462 feet

Firm Yield = 79.5 cfs

Buffer Zone Level (feet)	Maximum Secondary Yield (cfs)	Reliability (%)
400	22	100.0
440	49	94.8
443	58	90.8
444	70	87.4
445	101	78.5
447	144	68.9

FLOW-DURATION CURVE

Top of Conservation Pool at 462 feet

Firm Yield = 79.5 cfs

Secondary Yield (cfs)	Reliability (%)
0	100.0
1	39.8
10	38.9
20	38.5
30	37.1
40	36.6
50	36.0
60	35.3
70	34.8
80	34.2
90	33.4
100	32.7
110	31.7
120	31.0
130	30.1
140	29.3
150	28,7

MAXIMUM SECONDARY YIELD VS. RELIABILITY

Top of Conservation Pool at 462 feet

Firm Yield = 79.5 cfs

Buffer Zone Level (feet)	Maximum Secondary Yield (cfs)	Reliability (%)
400	22	100.0
440	49	95.0
443	58	91.8
444	70	88.7
445	101	81.6
447	144	71.1