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Optimizing Reservoir Management

New Strategies Including Systems Operation and Reallocation May Boost Reservoir Yields

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Many experts believe Texas can increase its surface water supplies without building new dams and reservoirs.

The answer isn't magic. The solution is better management and coordination of existing reservoirs.

New strategies/hat make every drop of water count include operating a group of reservoirs as a coordinated system; converting some reservoir storage space from hydropower production, flood control, and navigation to water supplies; and timing water levels in reservoirs to correspond to seasonal differences in streamflows and water demands. Scientists are learning more about the quality of water in lakes and how man's activities affect the chemical makeup of reservoirs.

A number of important developments are already taking place. Both the City of Dallas and the Brazos River Authority manage their reservoir systems so that releases of water are tied to climate conditions water demands. The Lower Colorado River Authority (LCRA) has recently submitted a management plan to the Texas Water Commission (TWC) that could allow LCRA to sell "interruptible water supplies" during wet years. Opportunities to reallocate storage space in Texas reservoirs have been summarized in recent report by the U.S. Army Corps of Engineers (COE). Otherstudies have described how systems operation could increase water supplies in reservoirs in the Sabine, Trinity, and Trinity-San Jacinto River basins.

Optimizing reservoir management has been the focus of many university research projects. Scientists at Texas A&M University have been studying the Brazos River basin. Studies have focused on developing mathematical models that simulate the amount of water the river can deliver under different operating scenarios, examiningthe impacts of converting storage from flood controltowatersupplypurposes, and evaluating the tradeoffs of utilizing reservoirs for different purposes. Researchers at the University of Texas at Austin have been studying the Highland Lakes of the Colorado River. Studies at UT have developed a flood management system that uses realtime data, estimated yields of the Highland Lakes system, and investigated how urbanization affects water quality. Researchers at Rice University are studying the water quality of Lake Houston and scientists at Southern Methodist University are examining how non-point source pollutants influence water quality at Lake Ray Hubbard.

Improving reservoir management, both for water supplies and water quality, will be increasingly important to Texas in the future because of the high costs of reservoir planning and construction and because many of the best sites for reservoirs have already been utilized.

Basic Reservoir Facts

To understand reservoirs and how they best can be managed a few basic terms need to be described. "Conservation storage" describes all of the storage capacity that is allocated for use in beneficial purposes, and is usually divided into active and inactive areas or pools. "Active storage" refers to the space that can actually be used to store water for municipal or irrigation use, hydropower or other beneficial purposes. "Inactive storage" refers to space to increase the efficiency of hydropower production, low-lying areas beneath the lowest outlet structures where water can't be released by gravity, and areas expected to fill up with sediments. Sedimentation is a serious problem in many Texas reservoirs: upper reaches of Lake Buchanan have accumulated as much as 40 feet of silt.

Figure 1 shows areas within reservoirs that are designated for specific purposes. The uppermost pool of a reservoir may be designated to hold surcharge or emergency storage during floods. Immediately below the surcharge pool is space that may be reserved to control floodwaters, followed by active and inactive storage. A way to increase the amount of water that can be stored in a reservoir is to increase the area designated to hold water supplies. This may reduce the volume of floodwaters that can be stored, increasing the risk of downstream flooding.

The ability of a reservoir to meet demands for water supplies is usually referred to as firm yield. Firm yield is the maximum amount of water a reservoir can supply annually during a repeat of the worst drought that particular area has experienced. To compute firm yields, scientists simulate reservoir operations using historic streamflow data and other factors such as water demands. In Texas, ratios of firm yield to storage capacity increase from the western to the eastern reaches of the state. Increased rainfall and lower rates of evaporation give many east Texas reservoirs annual firm yields that are greater than the amount of water the reservoir can store at any one time. In some west Texas reservoirs, firm yields are as little as 3% of the conservation storage capacity. The Texas Water Development Board has estimated the total firm yield provided by Texas reservoirs et about 11 MAF(million acre-feet)per year. An acre foot is the amount of water needed to cover an acre with a foot of water or roughly 326,000 gallons.

Texas has been the site of extensive reservoir development. There are 187 major reservoir with more than 5,000 acre feet (AF) of storage capacity. The reservoirs contain a total of more than 59 MAF - roughly 40 MAF of water supplies and more than 18 MAF to hold floodwaters. Almost 80% of the storage capacity is contained in 28 huge reservoirs, each of which can hold more than 500,000 acres. A review of reservoir operation in Texas (Wurbs, 1985) was published by the Texas Water Resources Institute (TWRI).

The federal government has constructed 43 of the 187 major reservoirs in Texas. These projects contain 39 MAF of storage capacity including almost all the flood control storage and more than half of the water supply storage in the state. The COE is the major federal dam-building agency in Texas and is authorized to build reservoirs for flood protection and navigation (it can also include storage for water supplies and recreation at multi-purpose reservoirs). Nearly all the reservoirs in Texas that store floodwaters were built by the federal government. Water supply reservoirs have been constructed by the COE, cities, river authorities and water districts.

Strategies to manage water supply or flood control reservoirs differ dramatically. Water supply reservoirs are usually operated by local or regional sponsors. Operations center around the use of long-term tools such as streamflow records and demand forecasting. Because many of the reservoirs are independently operated, each facility must be able to meet the demands of its customers during a drought. Consequently, negating the impact of potential droughts is a high priority.

Flood control operations are primarily the responsibility of the COB. COE district offices in Fort Worth, Galveston, and Tulsa provide overall management and coordination of Corps' flood control reservoirs for all of Texas and determine when and to what extent flood control releases should be made. Unlike water supply operations, decisions to release waters to make room for incoming floods must be made in a matter of hours. Considerations have to be given to the amount of water a dam can safely store before its structural integrity is threatened and the amount of water that can be released without flooding downstream areas. In many areas, extensive development has limited the rate at which floodwaters can be released. This could limit the amount of floodwaters a reservoir could safely store.

Increasing Yields with System Operation

Managing reservoirs as a system has many advantages over operating them individually: more water can be supplied, damages from drought and flooding can be reduced, and recreational interests can be better protected.

LCRA has operated its reservoirs as a system since 1984. LCRA recently submitted a management plan to the TWC that would allow the agency to sell the surplus water as "interruptible water rights" on a one-year only basis. LCRA determined that the combined firm yields of Lake Travis and Lake Buchanan near Austin were about 537,000 AF per year. Existing firm water rights commitments total roughly 489,000 AF per year. Each year, LCRA will project the amount of water it expects will be in the river basin the following year. Sales of interruptible water could be allowed If there is more water in the system than LCRA has committed to current uses, instream flows, and freshwater flows to bays and estuaries. The total amount available to LCRA would not exceed 1.5 MAF in any year. This would be the first time in Texas that interruptible water rights would be sold at prices less than the price of firm yields.

David Maidment of the Department of Civil Engineering at the University of Texas at Austin helped LCRA project how much water the reservoir system could supply and if different operating policies could increase yields (Vaugh and Maidment, 1985). The research also evaluated if water should be supplied for such uses as late season rice production and hydropower generation.

The LCRA plan would change the way the rice irrigation industry near the Texas coast is supplied with water. Rice irrigation uses more than 70% of the water supplies in the lower Colorado River basin. Because the rice growing region is below the most downstream dam on the Colorado River (see Figure 2), LCRA is asking that rainfall and natural flows in the river be used as the primary water supply for rice irrigation. Water would only be released from dams for rice production if natural flows were insufficient. LCRA officials say that rice producers will get as much water as they have historically used up to a maximum of 5.25 AF per year for each acre that was historically irrigated. The price of that water is expected to increase. LCRA previously charged only the price to deliver the water to the farmers, but is now seeking to set prices based on the amount of water actually released from the reservoirs (LCRA, 1989).

To monitor how much water is in the river system and to improve flood forecasting capabilities, LCRA is using "real time" data. LCRA receives data on river flows and weather conditions through a series of sensors along the Colorado River that are linked to a mainframe computer in a control center. The system warns LCRA of impending flooding in upstream areas by defining how much water is in the river and if flows are increasing. Downstream, it measures the amount of water in the river to help calculate if releases need to be made from upstream reservoirs for rice irrigation. Larry Mays and others in UT's Center for Research in Water Resources developed a system that merges real time data with alternative reservoir operating scenarios (Mays et al.1987). The system lets reservoir operators anticipate the impact of critical decisions before they are made.

LCRA's proposal also seeks to maintain minimum lake levels in the Highland Lakes to protect the recreation and tourism industry. When new requests for interruptible supplies of water are considered in the future, impacts on lake levels would have to be considered. The policy also recommends that water will only be released solely for hydropower production in emergencies (water released for other purposes could still produce some hydroelectricity), sets aside 25,000 AF for future instream flow needs, and includes provisions to determine instream flow needs of Texas warm water fish species.

Systems operation is being practiced in the Brazos River Basin. The Brazos River Authority (BRA) utilizes rainfall and natural river flows that enter the Brazos River below the confluence of the Brazos and Navasota rivers to supply water for downstream cities, water utilities and rice irrigation. BRA also keys reservoir releases from different parts of its watershed to match reservoir levels and demands. Some areas of BRA's watershed may be suffering a drought while others may have ample or surplus water supplies. In-basin water transfers help balance variations in rainfall and evaporation.

Ralph Wurbs of the Civil Engineering Department at Texas A&M University has conducted a number of studies on reservoir operation in the Brazos River basin. Much of the work has been funded by TWRI. One project developed a mathematical model which simulated hydrologic conditions, water rights, and operating strategies to see if joint operations could increase the amount of water produced by 10 selected reservoirs on the Brazos River system (Wurbs et al., 1988). Wurbs' results suggest that the estimated system firm yield was 155% of the sum of the individual reservoir firm yields including unregulated flows entering the river below the dams. When unregulated flows entering the river below the dams were not considered, system yields, were 119% of the individual yields.

Systems operation is being practiced in Dallas and is being proposed for the Houston area. The City of Dallas Water Utilities (McCarthy, 1989) has developed a computer model to determine annual reservoir operating policies. Dallas obtains water from six different reservoirs. Depending on which reservoir the water is taken from, pumping and water treatment costs vary considerably. For example, it costs less to pump water from reservoirs that are northwest of Dallas. However, since water from those reservoirs is conveyed to Dallas treatment plants via the Trinity River the water picks up suspended solids and urban runoff from the river and requires more treatment than water pumped from eastern reservoirs. The model balances water availability in the reservoirs and cost considerations and recommends the best alternative.

Studies have shown that operating three Houston-area reservoirs as a system could also boost yields (Sheer, 1986). The research simulated the amount of water that could be produced if Lake Houston, Conroe, and Livingston were operated as a system.

Conjunctive use of surface and ground water was also investigated. Results suggest that system management would increase yields by 127,000 AF as compared to independent management. Much of the increased yield could be obtained by first releasing water from Lake Houston (it's the smallest of the reservoirs and would fill and spill quickest).

System management has also been proposed in the Sabine River basin. The Sabine River Authority has proposed constructing Waters Bluff Reservoir and operating it as a system in coordination with Lake Tawakoni and Lake Fork. During early stages of droughts, water would first be released from Waters Bluff. Because Waters Bluff would be the largest reservoir in the system, it would be less likely to fill and spill. System operation could increase the combined yield of the system by nearly 50,000 AF (Sabine River Authority, 1988).

Two other cases are worth noting. The Trinity River Authority has been trying to construct Wallisville Reservoir near the Texas coast to keep saline water from the GuH of Mexico from contaminating fresh water supplies upstream when river levels are low. Proponents of the project say it could increase yields from Lake Livingston by 202,000 AF and could create an additional 157,000 AF in "new yield" by making inflows below Lake Livingston usable. However, the project has been the subject of environmental lawsuits for many years because of fears it may lessen freshwater inflows into Galveston Bay. Reservoir yields could also be increased by augmenting supplies with treated wastewater. For example, Mountain Creek Lake near Dallas is fed in part by potable-quality water from Joe Pool Lake and supplies cooling water for power plants. If Mountain Creek Lake were supplied with treated effluent, it could free up some supplies in Joe Pool Lake.

Reallocating Storage: Tradeoffs Between Flood Control and Water Supplies

Another way to increase the amount of water reservoirs can deliver is to reallocate water supplies within individual reservoirs. Each reservoir is designated to contain a set amount of space for holding floodwaters; storing water for such beneficial purposes as water supplies, navigation, irrigation, and recreation, and accumulating sediment. Many of the reallocations being discussed involve exchanging flood control storage for water supply storage. Reallocations of the lesser of 15% of the total capacity or 50,000 AF in COE reservoirs can be approved internally by the Corps, but reallocation of larger amounts of storage must be approved by Congress.

Reallocations of reservoir storage have already taken place or been authorized in many Texas reservoirs. At Grapevine and Benbrook reservoirs, contracts have been approved to convert navigation storage to water supplies. At Lake Waco, an agreement to convert flood control storage to water supplies has been approved but the reallocation has not taken place. Reallocation of hydropower storage to water supplies have taken place at Lake Texoma and been approved at Sam Rayburn Reservoir.

Studies have examined opportunities for reallocation in many Texas reservoirs. Investigations of potential reallocations at Bardwell Lake, Lake Texoma, Granger Lake, Lake O" The Pines, Sam Rayburn Reservoir, and Lake Waco (see Table 1) are reviewed in a recent COE report (COE, 1988). The report also discussed national issues such as use of water storage not undercontract, temporary use of storage allocated to future sediment build-up, reduced need for sediment storage, seasonal reallocations, reallocation of flood control and navigation storage, and systems operation. Studies have also investigated reallocations at Lewisville Reservoir, Grapevine Reservoir, Belton Reservoir, and Wright Patman Reservoir.

Reallocation of reservoir storage, particularly in the Brazos River Basin, has been a focus of Ralph Wurbs' research at Texas A&M University. Typically, reservoir storage capacities and operating policies are set prior to construction and remain constant through the life of a project. Wurbs suggests that reservoir operations should be reevaluated as demands and risks of flooding (from new reservoir construction and imposition of floodplain management regulations) change.

A Ph.D. dissertation by one of Wurbs' graduate students (Cabezas, 1985) developed a methodology that assesses reallocation scenarios based on the economic risks posed by increasing the vulnerability to flooding and water supply shortages. Results of a case study of Lake Waco suggest that potential economic losses from water supply shortages often outweigh losses from floods. The study also recommended optimal reallocations between flood control and water supplies based on varying levels of demand.

Another study (Wurbs and Carierre, 1988) assessed if elevations of the flood control and water supply portions within reservoirs could be varied to match seasonal streamflow conditions.

In some areas, space for flood control storage is commonly increased in the spring to anticipate large amounts of floodwaters that result from heavy seasonal rainfall. Once the risk of flooding decreases in the summer, extra space is created to hold additional water supplies. Only two Texas reservoirs, Lake O' The Pines and Wright Patman Reservoir, use seasonal operation.

Wurbs analyzed climate records including monthly rainfall, severe flooding and evaporation and utilized computer simulations to determine what seasonal reallocation strategy might work best. Wurbs research suggests that seasonal operation may be effective in Texas, even though flooding seasons in the state are not as distinct as they are in states where seasonal operation is widely practiced. Wurbs analyzed an array of seasonal operating strategies and permanent storage reallocations in a case study focusing on the Brazos River basin. For relatively small reallocations, seasonal operation increases firm yields almost as much as a permanent reallocation. Conceivably, water supply and flood control capabilities can be increased simultaneously.

Water Quality Studies

The ability to make maximum use of waters with limited quality and the impacts of manmade pollution on reservoir ecosystems are also being studied.

BRA has also conducted a number of water quality studies at Belton and Stillhouse Hollow reservoirs. Water quality in the lakes was sampled to measure the amount of nonpoint source pollutants that entered the lakes during heavy storms and to determine if eutrophication was occurring. To detect if land use changes near the lakes were adding to nonpoint source pollution loads, satellite images were analyzed. Results of the studies were used to compare different locations for future wastewater treatment plants and to recommend the site that would least impact water quality in the lakes. The COE has also investigated if naturally saline portions of the Brazos and Red rivers could be made more usable through salt control dams.

Scientists at the University of Texas at Austin have been studying how man's activities affect water quality in the Highland Lakes. The focus of one project was an evaluation of the effects of point and nonpoint source phosphorous loads on water quality (Miertschin and Armstrong, 1986). The study developed a mathematical model to simulate phosphorous concentrations within the reservoir system based on historical loads and population and land use projections. Another study focused on the effects of urbanization on the concentrations of toxic and organic chemicals found in the lakes (Wallace and Armstrong, 1986). The project involved collecting and analyzing sediment and water samples from along the length of Lake Austin and Town Lake to determine if a toxic problem existed and to see if there was a correlation between urbanization and the amount of pollution in the lakes. Results showed that sediments from Town Lake exhibited higher concentrations of organic chemicals, lead, and zinc than did Lake Austin. Stormwater runoff from streets was assumed to be a primary means for transporting pollutants into the lake.

Scientists at Rice University are studying how sediments are transported to and resuspended in Lake Houston. One investigation (Matty et al., 1987) placed sediment traps along the lake to estimate the influence of sedimentation on water quality. Results suggest that the amount of sediment entering the lake depends on the intensity of rainfall in the watershed and that intense storms that occur when lake levels are low may seriously lessen water quality.

Estimating the magnitude of nonpoint source pollution loads to Lake Ray Hubbard near Dallas is a focus of research at Southern Methodist University. Michael Collins has collected detailed field data from 30 storms to measure levels of total suspended solids, turbidity, nutrient concentrations, and other factors in the runoff. This data will be used in a stochastic model that will simulate water quality in runoff events. The information may provide a clearer picture of how and when pollutant loads enter the lake, and could help assess how the lake is affected by urban and agricultural runoff.

Summary

At first view, Texas appears to be on the verge of a water supply dilemma. Reservoirs are increasingly difficult to construct, both from a political and economic viewpoint. However, recent state water demand projections clearly show that new water supplies need to be developed to meet demands, even if conservation is implemented. The answer would appear to be to build more reservoirs, regardless of the cost or political will.

Nonetheless, strategies that optimize the management of existing reservoirs (particularly systems operation and reallocation of reservoir storage) may be a way to supply increasing amounts of water without immediately building new reservoirs. By taking advantage of the latest technology and by having university researchers work together with state and local agencies huge strides have been taken to make reservoir management more efficient.

Stewardship of land and water resources benefits everyone. If implemented, the strategies described in this report could be used to make the state's water resources benefit all Texans.

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