Density Currents In Activated Sludge Clarifiers

It's Better To Be Baffled!

Earle Schaller

There are 22,000 waste treatment plants in the United States, each processing over 1 MGD. Two-thirds—approximately 15,000—are municipal plants, while the remainder are industrial. It has been estimated that some 40 percent of these plants are operating at or beyond permit levels. There are numerous reasons for this, including design problems, operating problems, and increased loading.

Density Currents

In activated sludge plants, we can attribute some of the problem to the presence of density currents in the clarifiers. We know that density currents form in all activated sludge clarifiers, regardless of configuration. We also know that these currents have a significant negative impact on clarifier performance. Density currents create short circuits, increase effluent solids and reduce hydraulic capacity. Figure 1 depicts a typical centerfeed well and external launders. Density currents form in this tank when the denser input from the feedwell plunges to the bottom of the tank and then moves across the bottom just above the blanket until it reaches the outer wall. It then travels up the tank wall toward the effluent launder. As it courses along the bottom of the tank, the density currents pick up lighter solids which have been deposited and carry them up the wall to the effluent, in effect short-circuiting the main clarification volume of the tank. The net effect is an increase in TSS and a decrease in the apparent hydraulic capacity of the tank.

Density currents do not move in waves. Rather, their action is jet-like and random. They have been known to bounce off the bottom of the tank, and ricochet off the sides. Potential solutions to the density current problem include modifications to the feedwell where the problem appears to begin, placement of the weirs as far from these currents as possible, and the use of in-tank baffles as a physical barrier to these currents.

Virtually every form of feedwell modification has been attempted over the years. While several have been successful in specific configurations, no one modification has proven transportable for general use in clarifier design.

Numerous design standards recognize the effect of density currents and suggest that weirs be placed as far from them as possible. Here again, numerous configurations have been examined, including the use of duel inboard weirs located several feet from the tank wall. No single design has proven effective in and of itself in eliminating the effect of density currents, and some have even exacerbated the problem.

In-Tank Baffles

In-tank baffles have proven to be the most effective defense against density currents. Baffles have reduced TSS by as much as 50 percent, restored hydraulic capacity, provided a significant reduction in BOD, and reduced the downstream costs of treatment in terms of chlorine and other chemicals. Three types of baffles have been employed and each has been successful to almost the same degree in managing the impact of these currents on clarifier performance.

The ring baffle is a cylinder that sits within the clarifier and has a diameter approximately half that of the tank itself. If the tank has a 100-foot diameter, the ring baffle has a 50-foot diameter. The baffle cylinder reaches from just above the blanket to just below the surface of liquid in the tank. The baffle is suspended from the clarifier mechanism and rotates with it. While ring baffles have proven effective in dissipating density currents, they are more complex and more expensive to implement than the other baffle types. Moreover, the ring baffle places additional load on the clarifier mechanism and imposes added maintenance complications. Since it is no more effective than the other baffles, it is not generally found in use. It should also be noted that the use of the ring baffle causes some problems with sludge removal balance where riser pipes are used.

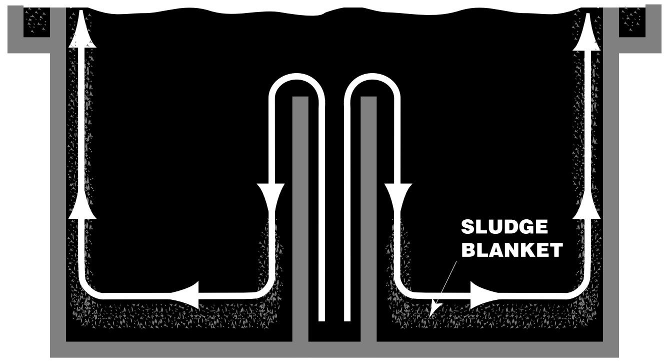

Figure 1. Density Currents in an Activated Sludge Clarifier

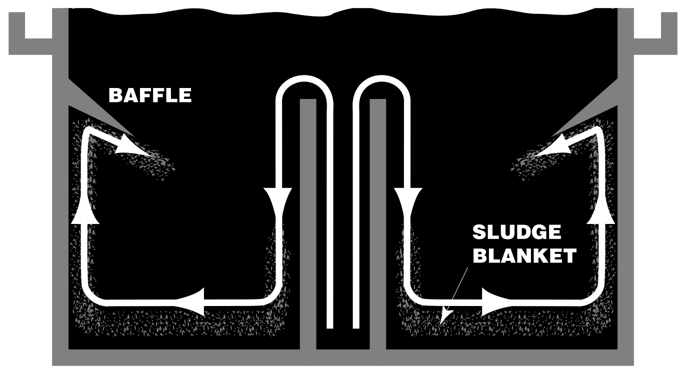

Figure 2. Clarifier with Inclined "Stamford" Baffle

The horizontal baffle, sometimes known as the McKinney or Lincoln baffle, is formed by extending the bottom of the inboard launder eighteen to twenty-four inches into the tank. This baffle has proven effective in stopping the solids carried by the density currents from reaching the weir. It is generally poured in place during the initial construction of the tank and is not easily retrofitted. The negative aspect of the horizontal baffle is the fact that sludge collects on the upper horizontal surface and requires considerable maintenance. Note that the baffle extends inboard of the weir and does not stop at the inboard edge of the launder trough. This is important in ensuring that the solids carried by the density currents are redirected towards the central clarification volume of the tank and are not allowed to simply drift upward toward the weir.

The inclined, or Stamford, baffle is simply the horizontal baffle inclined at an angle sufficient to allow built-up sludge to fall away. The Stamford baffle has proven extremely effective and is the most popular baffle in use today. The baffle can be fabricated from numerous materials and is ideally suited to both new and retrofit installations. In Figure 2, the inclined baffle is mounted directly to the tank wall and inclined at an angle of 30 to 60 degrees. The baffle is normally located approximately three feet below the level of the scum baffle. In tanks with internal launders, the baffle is cantilevered from the lower inboard corner of the launder trough.

The Connecticut Experience

The Stamford baffle was first implemented at the Stamford, CT WWTP. The Stamford plant supports a large urban population and is located on the shores of the Long Island Sound. Stamford had two 130-foot secondary clarifiers. The plant had never operated within permit levels and had a significant odor problem. Dye tests and other studies indicated that density currents were a significant contributing factor to the plant's problems. A prototype baffle was fabricated of plywood and was installed in one of the two tanks. This resulted in a 38 percent improvement in TSS. Within 60 days the plant was operating within permit levels. NEFCO, Inc. later replaced the wooden prototype with the first full scale fiberglass density current baffles which were installed in each of the two 130-foot clarifiers. Another baffle was installed in the new third clarifier, which was constructed in 1991. All the work carried out at the Stamford plant was done in conjunction with the Connecticut DEP, which called the baffle "the most cost-effective improvement in clarifier performance today."

Connecticut DEP lobbied the state legislature to institute a municipal grant program enabling municipalities to improve clarifier performance by installing baffles and other devices. Connecticut now requires that a baffle be installed as part of all new and upgrade projects. Other states are expected to follow this lead and mandate the installation of baffles. Connecticut now has more than fifteen plants equipped with density current baffles. According to the State DEP the baffles improve plant performance by 35 to 40 percent under average flow conditions and as much as 50 percent during peak flow.

The Greater Lawrence plant in Lawrence, Massachusetts, installed density current baffles in all four of its 165-foot diameter secondary clarifiers in 1993 and experienced even greater improvements than those at Stamford. In mid-1994, the city of Phoenix, Arizona, installed baffles in four of ten 140-foot diameter primary clarifiers. This underscores the fact that density currents form in primary as well as secondary clarifiers and that the baffle is equally effective in dealing with these currents at the primary treatment level. Baffles are currently being installed in four of the 80-foot square tanks at the Calumet WWTP, which serves much of Chicago. Here in Florida, density current baffles are currently being installed at the Northside WWTP in Lakeland and are planned for several other locations.

Design Considerations

There is a relationship between tank diameter and the optimum width, D, of the baffle, where D is measured as the horizontal distance from the wall to the outer edge of the baffle. D generally ranges from 18 to 48 inches. The actual length of the baffle, of course, depends upon the inclination angle. In the case of an inboard launder configuration, the bottom of the launder trough contributes to the baffle action. Here, a smaller baffle can be used. Note, however, that this baffle extends out beyond the weir to ensure that solids are not simply allowed to drift upward. In the case of dual weirs, solids are often deposited in the space between the outer weir and the wall and then flow over the outer weir. Here the baffle is fastened directly to the tank wall as though in an external launder configuration.

The baffle is typically described as a series of brackets attached to the wall at two-foot intervals and then covered with panels of aluminum, pvc, stainless steel, or fiberglass. The brackets themselves may be made of any of these materials. While this is a typical baffle configuration, it is expensive to fabricate and labor intensive to install. It involves considerable material handling, and alignment can be tedious and time-consuming. Proper fastening of the baffle is critical, however. The force of gasses trapped beneath the baffle, and the hydraulic pressure on the baffle when the tank is being filled can be sufficient to tear the baffle from the tank if it is not adequately secured.

The Stamford Baffle is comprised of eight foot baffle "modules." Each module is a one-piece unit which incorporates the baffle panel, bracket, and mounting and stiffening flanges. The module is molded of corrosion-resistant, uv protected fiberglass. The modules interlock to form a rigid structure, once installed.

There are a number of criteria to consider when developing specifications for the baffle.

- It must fit the curvature of the tank with no large gaps between the baffle and the tank wall.
- The width of the baffle should be scaled to the tank diameter and range from 18 to 48 inches. Too small a baffle would be ineffective. Too large a baffle would interfere with the clarification action of the tank.
- The baffle should always extend beyond the weir.
  The baffle should be inclined at an angle of 30 to 60 degrees to facilitate self-cleaning of sludge.
- The baffle should be supported adequately to ensure that it is held rigidly in place and has a professional, well-engineered appearance.

Provision should be made for venting gases and air that can become trapped beneath the baffle. To accomplish this, NEFCO molds vents directly into the mounting flanges.

There are three materials generally considered appropriate for baffle construction: stainless steel, aluminum and fiberglass. Stainless steel is an expensive material for use in this application. Aluminum is subject to corrosion in many waste environments. Fiberglass is the ideal material: it can be molded to shape; it can withstand years of being submerged; and finally, it can be formulated to withstand the most corrosive environments, a factor which is often encountered in industrial waste.

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Water Resource Management Planning for Collier County

Frederick Bloetscher, Charles W. Walker, W. Kirk Martin and Vicki C. Vaughn

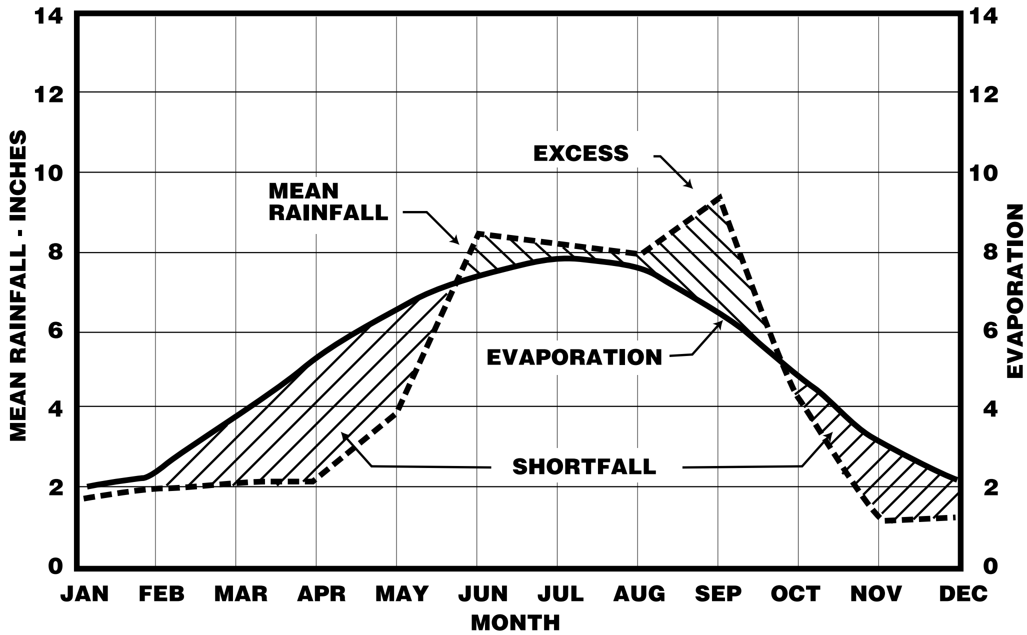

Figure 1. Rainfall versus Water Demand

The ecosystem of south Florida is dependent upon the cyclical climatic patterns; distinctive wet and dry seasons, corresponding to summer and winter respectively. Historically, the rain that fell during the summer months that did not evaporate during hot, summer days, would sheetflow across the flat terrain to the Ten Thousand Islands, replenishing the ecosystem and the aquifers as it went. Today, much of the rainfall is drained by an extensive system of canals without replenishing the environment or percolating into the underground aquifers now used for drinking water supplies. The result is a reduction in available fresh water during the dry season, which coincides with the increased winter population and the peak irrigation season for lawns and agriculture.

Water Use Planning

To address critical water supply areas, those areas where demands currently, or will shortly outstrip supplies, the South Florida Water Management District requires that utility systems within their jurisdiction create a water conservation plan as a part of their consumptive use permit. To this end, Collier County has developed a water resource management plan that not only meet the water conservation requirement of the district, but reviews initiatives to conserve current supplies and allow for future needs. The plan includes the common measures such as low-flow plumbing fixtures, lawn watering restrictions and xeric landscaping requirements. The water system currently has 100-percent of its customers metered for volumetric billing, utilize water system pressure adjustments during critical supply periods and has adopted an inverted rate structure to penalize high volume users, all of which contribute to reducing demands. However, the county has gone much further through 100-percent reuse of wastewater effluent, conversion to treatment technologies to allow for both the use of both fresh and saline raw water sources and investigations of aquifer storage and recovery (ASR) of potable water in a saline aquifer.

Reclaimed Water Systems

The use of reclaimed wastewater effluent (reuse) is designed to conserve water by using treated wastewater effluent for irrigation in place of potable or well water. This reduces the amount of potable water used for irrigation, as well as provides a solution to wastewater disposal. Significant amounts of potable water are saved by supplying effluent to major irrigators (typically golf courses). Potable water thus conserved is available for potable use by new customers, to improve service or for drought periods. However, the use of reclaimed water often requires retrofitting existing neighborhoods, which is expensive and in some cases impractical. A more practical application is use on large areas (like golf courses). The market for this measure depends on the capacity of the system to deliver the treated wastewater. This is determined by the quantity of wastewater and the system of distribution.

Collier County currently supplies irrigation-quality water to golf courses, which reduces aquifer draw-downs along the coast, helping to curb saltwater intrusion. Because the county is primarily comprised of upper scale, resort communities (over 50 of which have golf courses), there is a number of potential reclaimed water customers. The amount of effluent currently available for the reuse system lags significantly behind the demand, especially in the north end of the service area, but growth will make the demand and supply more comparable. Any deficits will need to be made up of stored water, wells or potable water, the latter of two of which are not attractive alternatives. The addition of residential dual water systems adds to the deficit of effluent available for large users.

Membrane Treatment

The technology of membrane treatment processes holds significant promise for meeting potable water delivery and quality goals. While not capable of saving water, membrane processes increase the number of potential sources of water and allow for conservation of surficial sources which are the most threatened in south Florida. Membrane processes allow

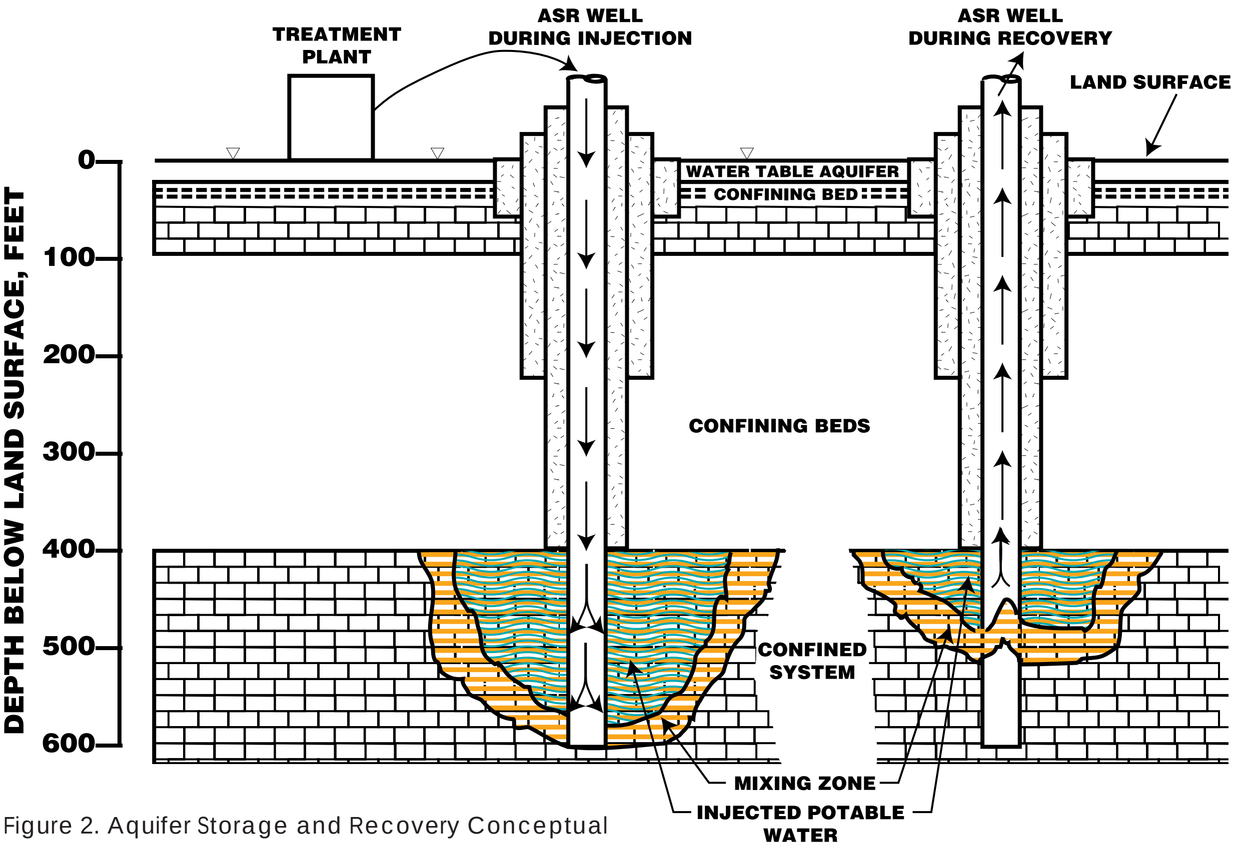

Figure 2. Aquifer Storage and Recovery Conceptual Diagram for Brackish Water Aquifers (After Missimer, 1994)

the treatment of more mineralized waters and provide better quality treatment, which allows utilities to meet the Safe Drinking Water Act requirements for both existing and future sources of water. Membranes are generally made from organic polymers and offer significantly flexibility in treatment options because the polymers can be designed to have varying porosities to remove contaminants. This membrane adaptability can be utilized to meet specific treatment requirements, including removal of salt, hardness, minerals, trihalomethane precursors, synthetic organic chemicals, and micro-organisms. Various types of membrane processes include: microfiltration, capable of removing micron-sized material; ultrafiltration; nanofiltration; and reverse osmosis which removes ion-sized molecular matter. Generally, the quality of the water coming from the membranes far exceed the requirements of the Safe Drinking Water Act.

Membrane processes operate in a pressure-driven system, whereby raw water (also called feedwater) is pressurized and pumped through polymer membranes. Only a certain percentage of the water actually is able to move through the membranes. The water that remains on the raw water side of the membrane is highly concentrated and mineralized. This mineralized water is decanted and is termed “reject water” or “concentrate.” This water generally is disposed of by deep well injection. Deep well injection is an expensive solution, especially in light of the fact that in many cases, the water coming off reverse osmosis has a lower mineral concentration than the seawater found in the general vicinity. The smaller the size of the membrane pores, the higher must the pumping pressure be, thus creating a higher cost to the customer. Reverse osmosis, used to remove ion-sized particles, is the most expensive of the membrane alternatives.

Collier County has recently completed construction and start-up of its new 12 MGD North County Regional Water Treatment plant, which utilizes softening membranes, requiring pumping pressures of 150 psi to remove hardness. However, the plant can be converted to reverse osmosis by simply upgrading pumps and changing the membranes to accommodate a 2200 chloride, 5000 TDS, saline source located 400 to 500 feet below the surface. A proposed South County Regional Water Treatment Plant will be reverse osmosis to treat more mineralized saline water after the year 2000.

Aquifer Storage and Recovery

While not a conservation tool per se, aquifer storage and recovery (ASR) is a relatively new concept in the management of water supplies in both potable and nonpotable water systems. Employing ASR technology can increase the efficiency of system operation. During the wet, low-demand portion of the year between June and October, some of all of the unused water treatment plant capacity can be used to treat water and inject it into a brackish water aquifer lying below the ground surface for future recovery. The injected, treated freshwater displaces the brackish, native water occurring in the aquifer. When the full treatment plant capacity is required by system demands, injection is discontinued. As demand increases beyond plant treatment capacity, freshwater is withdrawn from the aquifer (recovery), disinfected, and blended with the newly-treated water. Excess water can be left in storage as an emergency supply to be used during a severe drought or during an equipment breakdown. Figure 2 illustrates the process.

By effective use of ASR technology, smaller increments of water treatment facility expansions can be constructed and the

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Integrated Water Supply System Planning for Cocoa

Leila R. Goodwin, Herb Raybourn, Bob Bailey, and William Stephenson

Florida's water resources are becoming increasingly stressed, and, as a result, use of these resources for drinking water supply is limited by both physical and regulatory constraints. The city of Cocoa is expanding its existing groundwater supply system to include use of surface water from Taylor Creek Reservoir and an aquifer storage recovery system (ASR). The new system will meet maximal day demands up to 60 MGD in 2004 while maintaining current levels of groundwater use, management of the reservoir for flood control and recreation, and high reliability.

The integration of the two sources, groundwater and surface water, along with use of both the surface reservoir and ASR system for storage, results in an unusually complex water supply system. When the seasonal variability in reservoir inflows and demands are considered, it is clear that design of a reliable system will require more than simply "making the intake pipe big enough."

A computer program was developed to simulate the operation of the system on a daily basis. The results of the modeling include insights on how the two sources must be managed to meet demands with the desired reliability, recommendations for facility sizes, and which constraints are the most limiting on the city's ability to meet increasing demands.

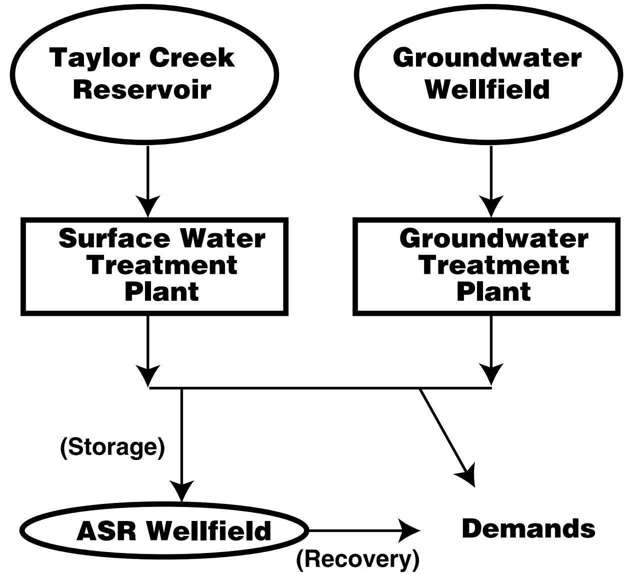

Figure 1. Cocoa Water Supply System Schematic

How Does the System Work?

By itself, Taylor Creek Reservoir (TCR) would be an unreliable system for meeting potable water demands. The average inflow to the reservoir is only 36 MGD, and reservoir levels are kept low in the summer months for flood control and recreation. It is likely that no water will be available from TCR for some period during the summer months. In order to meet projected demands for the city of Cocoa through 2004, an average day demand of 9 MGD must be met from the reservoir, supplementing the average groundwater wellfield use of 31 MGD.

While the reservoir itself helps to store water for later use, ASR is used to make the system reliable for water supply. When water from TCR is available, it is used to supplement groundwater use and treated water is stored in the ASR system for later use when TCR water is unavailable. Figure 1 shows a schematic of the water supply system.

In order to evaluate facility needs and to investigate the impact of different factors on the system, a computer program was developed to simulate the operation of the system on a daily basis. The program considers the following components:

- Reservoir inflows (synthetically generated based on 30 years of record)
- Demands (annually increasing with seasonal variations)
- Facility sizes
- Permitted withdrawals (groundwater and TCR)
- Reservoir operating schedule for flood control

In developing the program, rules for use of the two water sources and two types of storage were needed. The perception was that water from TCR would be stored in the ASR system when it was available, for use when reservoir levels are low. On a general level this is true, but initial results from the modeling showed that reliability of the system depends more on management of the wellfield.

Since TCR is essentially an intermittent source, the goal is to harvest the available water whenever possible. The question then becomes, on any given day, how much water to pump from the wellfield. Considerations include the demand, the amount available from TCR, the permitted maximum and average day withdrawals from the wellfield, and the amount of treated water already stored in the ASR system. Any treated water over and above the daily demands is stored in ASR for later recovery.

When there is no water available from TCR, the wellfield will have to be used at some rate higher than the average day permitted amount. Therefore, if the wellfield is pumped up to the average permitted amount when TCR water is available, the permitted average will invariably be exceeded for the year. In a dry year, when little water is available from TCR, ASR will be needed to supplement the wellfield in meeting demands. Again, the question is how much to pump from the wellfield before supplementing that source with water stored in ASR.

The risk of pumping the wellfield at a rate higher than the permitted rate will be minimized by using the wellfield at a "target" level, which varies during the year and is calculated as follows:

Target wellfield use = (Annual permitted volume – Annual volume used to date)/Number of days remaining in year

If the beginning of the year is relatively wet, then groundwater use will be lower than average and the target will increase, allowing more storage in ASR. In a year which begins with little water available from TCR, however, groundwater use will be higher than average and the target will decrease, calling for supplemental use of ASR to prevent overpumping of the wellfield.

Use of the simulation model showed that management of the wellfield so as not to exceed the permitted average day amount is critical to operation of Cocoa's water supply system. In fact, that is the measure of reliability for the system. Since the combination of the wellfield and ASR capacities will always be sized to meet maximum day demands, there is no risk "running out of water". Rather, the risk is of exceeding the allowed annual volume of groundwater use, which is 31 MGD. Figure 2 illustrates how the simulation results are summarized to portray reliability.

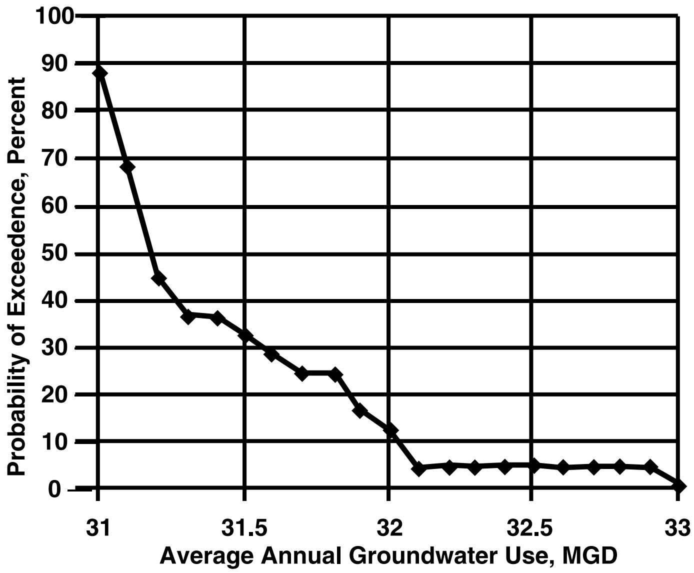

Figure 2. Example Results from Water Supply Simulation

What Facility Sizes Are Needed?

One of the primary reasons for developing the simulation model was to determine the facility capacities needed to meet projected demands for the city of Cocoa. In particular, the surface water treatment plant, reservoir intake structure, and ASR system needed to be sized. The groundwater wellfield and treatment plant will not be expanded.

The ASR system serves two purposes—to supplement the wellfield in meeting maximum day demands, and to provide storage so that TCR can be reliably used to meet average day demands. Initially, the ASR system is sized to meet the difference in maximum day demands. The simulation program is then used to verify that this capacity allows sufficient storage capability to obtain the water necessary from TCR to meet average day demands.

In a typical surface water supply system, the intake structure and treatment plant would simply be sized for maximum day demands. However, the combination of using two sources along with ASR makes sizing for the city of Cocoa more complicated. The system is very dependent on the timing of TCR water availability and demands. Therefore, the simulation program is used to determine the reliability associated with different facility sizes.

First phase facilities were sized to meet demands through 2004, when demands are projected to reach an average of 40 MGD and maximum of 60 MGD. As demands increase, the reliability decreases. Therefore, the worst case reliability, in the year 2004, was used to evaluate alternatives. Figure 3 shows the reliability of the system for different treatment plant/intake structure sizes, assuming the ASR system has a capacity of 12 MGD (maximum day demand of 60 MGD minus wellfield maximum of 48 MGD). Based on these results, the recommended treatment plant and intake structure sizes are 12 MGD.

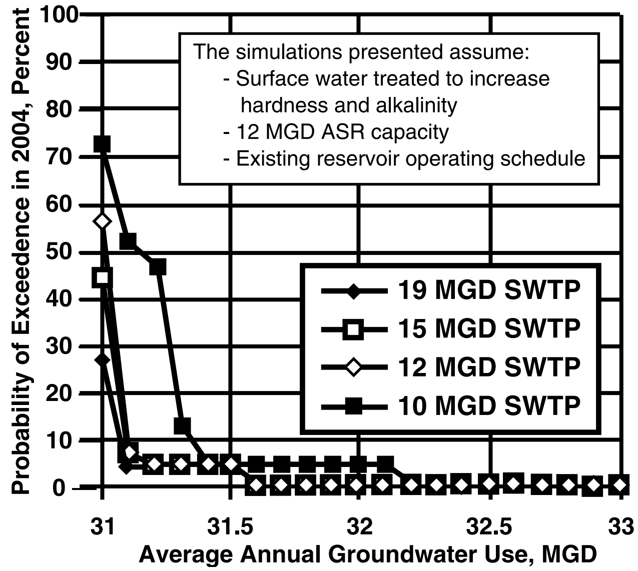

Figure 3. Water Supply Options—
Surface Water Treatment Plant Size

What Factors Influence the System?

In addition to sizing the first phase facilities, the simulation program was used to evaluate the effect of different factors on the reliability of the system. Figure 4 shows the reliability of several different options for meeting demands through 2004.

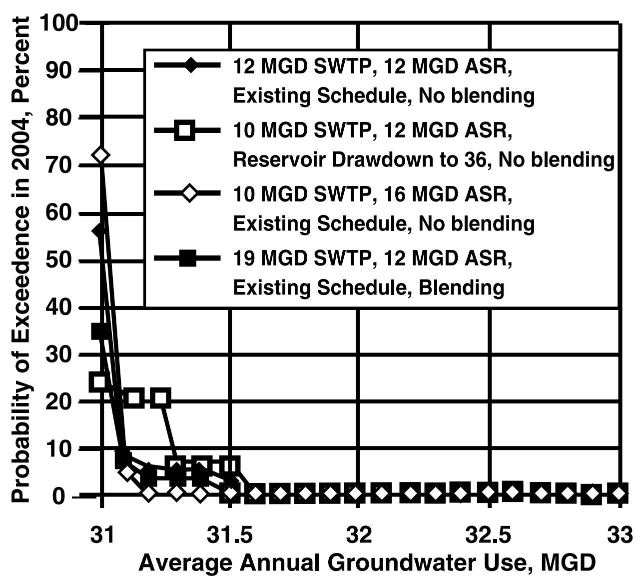

Figure 4. Water Supply Options for
Meeting Demands Through 2004

Blending

The groundwater is currently treated to reduce alkalinity and hardness, and the raw surface water has very low alkalinity and hardness. If the alkalinity and hardness of the surface water is not increased with treatment, then the amount of surface water that can be used is limited by the blended quality of the two sources. The simulation results show that this limitation is such that a much larger treatment plant (greater than 19 MGD) would be needed if the system relies on blending to increase the surface water hardness and alkalinity.

ASR Capacity

Increasing the ASR capacity to 16 MGD allows the treatment plant to be downsized to 10 MGD. Or, the expansion of the 12 MGD treatment plant could be delayed somewhat by adding ASR capacity before 2004.

Reservoir Operating Schedule

The existing reservoir operating schedule allows storage up to 43 feet National Geodetic Vertical Datum (NGVD) in the early spring, with drawdown to 39 feet NGVD in summer. In addition, Cocoa can not withdraw any water when the reservoir level drops below 39 feet NGVD. Allowing drawdown to 36 feet NGVD, or increasing storage up to 41 or 43 feet NGVD during the summer, would increase the reliability enough to downsize the treatment plant to 10 MGD, or delay the expansion of the 12 MGD plant.

Conclusion

During development of the city of Cocoa's water supply system simulation program, the perception that successful operation of the system depended on how TCR water is used was disproved. Instead, it was discovered that the system reliability, which is measured by how well the permitted withdrawals are met, depends on strict management of the wellfield use. The simulation program also quantified the effect of many different factors on the system's reliability, thus providing the information needed to size facilities and to compare other alternatives to facility expansion. The first phase expansion was sized to include a 12 MGD surface water intake and treatment plant, and a 12 MGD ASR system.

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system operated closer to average day demand. Considerable expense can be saved by the more efficient overall operation of the treatment facility (especially membrane facilities which are designed to run 24 hours a day). No added personnel costs are involved. System pressure will generally be sufficient for injection. Recovery costs are minimal, requiring only minor pumping costs and chlorination.

ASR may be a viable method (subject to proper geologic conditions) of increasing water treatment efficiency and promoting energy conservation. This procedure permits conservation of water during critical times, while utilizing excess resources in plentiful periods. Collier County has tested the concept by injecting potable water into the Floridan Aquifer zone and withdrawing water up to 200 chlorides. Six cycles have been completed indicating that the concept is viable at the site and that the retrieved water will only require disinfection prior to mixing with potable water in the on-site tank and pumping into the distribution system. Conversion of the construction permit to an operation permit is ongoing.

A major initiative discussed in Collier County was a proposed cooperative agreement with the South Florida Water Management District for an ASR project involving the removal of excess water from the Golden Gate main drainage canal during the rainy season. During the dry season, when irrigation demands exceed regular supplies, the injection freshwater can be recovered for use as an irrigation/effluent supplement. The idea is viable but county funding is lacking at this time.

Conclusion

The measure identified in Collier County's water resource management plan directly address the water availability problems, while meeting environmental concerns associated with traditional water shortages, aquifer declines and saltwater intrusion, and reductions in potable water use for landscape irrigation. Reuse supplies replenish coastal aquifer zones while providing an alternative to coastal wells. The North County Regional Water Treatment Plant allows for treatment of freshwater by membrane softening, saline water by reverse osmosis, or both, to meet current and future resources needs, which conventional lime softening plants do not. The ASR well will store excess water treated during summer months to offset peak usage. Preservation of the water resource remains vital for the quality of life and the development of Collier County, not just for current residents, but for generations to come.

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