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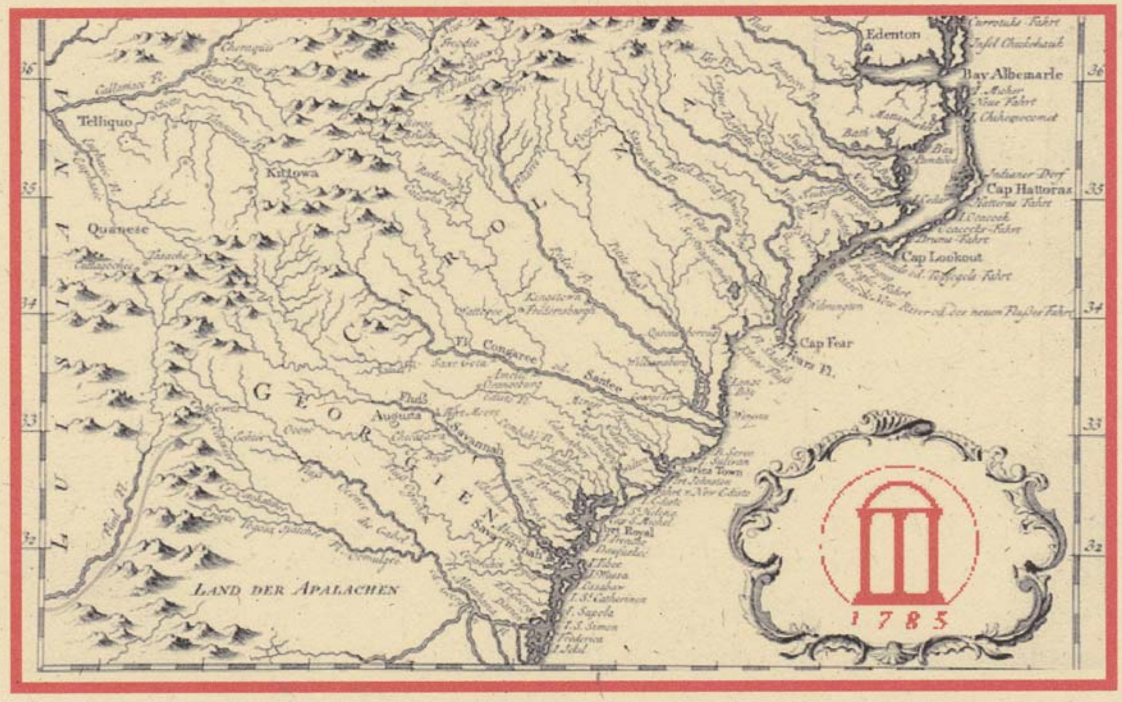

Reservoirs in Georgia: Meeting Water Supply Needs While Minimizing Impacts

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Meeting Water Supply Needs While Minimizing Impacts

May 2002

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Acknowledgements: The River Basin Science and Policy Center would like to thank Merryl Alber, Andy Keeler, Jim Kundell and Todd Rasmussen for their helpful comments on an earlier draft of this paper; Jan Coyne for graphic and cartographic assistance; Tyson Young and Erin Josey for administrative support; and Joycelyn Trigg for editorial assistance. Funding for production and printing was provided by The University of Georgia's College of the Environment and Design and that assistance is also gratefully acknowledged.

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EXECUTIVE SUMMARY

With a growing population and increasing demand for water supply exacerbated by a multiyear drought, Georgia residents are being challenged to meet water needs for now and for the future. To date, meeting water demands in North Georgia has often meant construction of reservoirs. The state's free-flowing rivers and streams, however, provide an array of services, and construction of reservoirs has consequences that extend throughout river ecosystems. The process by which water supply decisions are made must address increasing and often conflicting demands for water while maintaining the health and integrity of the state's rivers and streams.

This paper is directed at Georgia's water supply decision makers and the stakeholders in that process. Part I provides an overview of the number of reservoirs in Georgia and their impacts. Dams and reservoirs differ markedly in size, purpose, and operations, and their effects vary accordingly. Part I presents a generalized outline of impacts; for details on how these impacts vary with different types of reservoirs, beyond the scope of this discussion, readers are referred to the references listed in the notes. Part II describes water supply planning that considers a variety of water supply options in order to meet Georgia's future water needs while minimizing impacts on the services that free-flowing streams and rivers provide.

Part I : Quantity and Impacts of Georgia's Water Reservoirs

Reservoirs provide a variety of benefits to Georgians. Municipal and industrial water supply, navigation, and flood control are among the primary purposes for construction of larger dams in Georgia. Recreation, amenity uses, and agricultural water supply are the most common primary purposes of smaller reservoirs. Recreation benefits can include creation of popular sports fisheries. And, because reservoirs trap sediment, they can also have ancillary benefits. These benefits, however, come at the expense of the services that free-flowing streams provide.

Georgia's landscape is defined, in large measure, by its rivers and streams, which have shaped the state's development while supporting a rich biological heritage. In addition to providing water for drinking, irrigation, and other human uses, the state's free-flowing streams and rivers provide an array of services, including channel maintenance and sediment transport, waste assimilation and maintenance of water quality, habitat for a diversity of aquatic animals, and maintenance of riparian zone function. These services are often diminished or eliminated by reservoirs. Dams alter natural flow regimes, a fundamental characteristic of streams and rivers. Equally important, they fragment the riverine system, altering physical and chemical processes, disrupting biological communities, and interrupting longitudinal and lateral connections in the river-floodplain system. These changes, in turn, affect multiple services provided by free-flowing streams. For example, because of factors such as habitat alteration by reservoirs, 34 fish species and 16 species of freshwater mussels are imperiled in Georgia.

Almost all lakes in Georgia are reservoirs. The U.S. Environmental Protection Agency inventory of dams identifies 4,435 dams over six feet in Georgia, the highest density in the southeast. An earlier assessment and recent research in the Upper Oconee watershed, however, indicates that the USEPA inventory accounts for less than 7 percent of the actual number of reservoirs. Many of these are small and lie on smaller tributaries, and the extent of their environmental impact can be easily underestimated. In the Upper Oconee watershed, for example, only 8 percent of the total stream length in the basin is inundated by reservoirs, but a much larger percentage of the stream length no longer functions as a linked river system.

Detrimental impacts of reservoirs include the following:

- Reservoirs increase water loss through evaporation, resulting in a net loss of water from the river system.
- Reservoirs disrupt downstream transport of sediment. This effect can have localized benefits but can also result in degradation of aquatic habitat for fish, downstream erosion, and loss of property.
- Reservoirs can decrease a river system's capacity to assimilate waste and thereby cause downstream water quality problems.
- Dams block flows and create conditions that most native fish cannot tolerate within reservoirs and downstream of them.
- Reservoirs impede movement of migratory species and prevent natural recolonization of streams by other fish and organisms after droughts or other disturbances.
- Reservoirs alter highly productive floodplain forests and reduce their contribution to the food base, water quality, and habitat of adjacent rivers and streams.

While a few reservoirs may cause only localized impacts, the cumulative effects of many reservoirs is a matter of significant concern. How many dams result in streams and rivers that are no longer functional and cannot be restored? What are the cumulative effects of flow alterations between seasons and years, or the ecosystem effects of increasing fragmentation? Can existing reservoirs be managed to mitigate impacts that extend throughout the riverine system? The methods needed to further determine cumulative impacts and management alternatives are under development, but many questions remain unanswered.

While important questions remain, on balance current evidence indicates that many of the services provided by free-flowing rivers have been impaired by existing reservoirs in Georgia. With construction of additional reservoirs and further fragmentation of river systems, we risk losing more of these critical environmental services as well as the ability to restore impacted segments. The number of reservoirs that already exists in Georgia and the potential development of multiple new reservoirs highlight the need for a thorough accounting of cumulative impacts on the benefits that Georgia residents derive from free-flowing streams. And, they highlight the value of water supply planning to meet water needs while minimizing impacts on the services that free-flowing streams provide.

Part II: Water Supply Planning for the 21st Century

Water supply planning in Georgia, as elsewhere, is a complex challenge. It must balance conflicting demands for water, including protection of the water required to sustain functional stream-river systems. Meeting water supply needs will require efficient use of current supply and management of demand for future supply. Rather than relying on new reservoirs as the primary water supply solution, Georgia can benefit from water supply planning that considers a wider array of options and evaluates alternatives to identify those that are the most economical and least environmentally damaging way to meet future water demands.

Three elements are key to such an approach. The first is to define the goals of a water supply planning initiative broadly. If decision makers begin planning with an end result in mind (e.g., building a reservoir), the opportunity to identify other – and better – alternatives may be lost.

Second, as demands for water increase, it becomes not just helpful but critical to identify a full array of water supply options. This approach focuses first on managing and reducing water demand and then considers supply management options. Per capita water use in Georgia has been estimated as 8 to 10 percent greater than the national average. In 1995, per capita use in neighboring states was as much as 17 percent lower than that in Georgia. These figures underscore the potential significance of water conservation in water supply planning. Improved efficiency, demand management, water conservation planning, and use of additional supplies can all contribute to meeting Georgia's future water needs with minimum environmental impact, and programs from communities in Georgia and other parts of the country provide successful models on which to draw.

Finally, water supply alternatives analysis can be used to identify alternatives that cost-effectively meet water needs and minimize environmental impacts, including those associated with reservoir storage and altered stream flows. In this procedure, all demand management and supply options are identified and tabulated with their relevant information including total yield, start date, unit cost, and relative environmental impact. An alternative is formulated by selecting several of these options from the table so that the cumulative supply from the selected options always meets the water demand over the planning period. This alternative can then be modified to identify alternatives that would be the most economical and least environmentally damaging.

Benefits of this approach include consideration of environmental as well as economic costs. More specifically, implementation of water supply options is phased over time as needed to meet increasing demands, reducing up-front financing costs and matching cost increases with increases in ratepayers over time. Alternatives can include options other than new reservoir storage to provide back-up supply during low flow conditions, and the approach is consistent with the requirements of Section 404 of the Clean Water Act.

Several factors call for shifting water supply planning in Georgia toward a more comprehensive approach at this time. Most importantly, there is the growing challenge of meeting multiple demands for water, including water to sustain healthy streams and rivers and the services they provide. In addition, there are multiple benefits to be gained from such an approach. Finally, this is a period of adaptation in state water policy in general (e.g., the pending development of a comprehensive state water management plan). New information on the number of reservoirs and the potential significance of cumulative impacts suggest that adaptation in the water planning and reservoir policies formulated during the 1980s is needed to meet the complementary goals of providing for future water needs while minimizing impacts on the services provided by free-flowing streams.

PART I: QUANTITY AND IMPACTS OF GEORGIA'S WATER RESERVOIRS

Georgia's landscape is defined, in large measure, by its rivers and streams. From the turbulent headwaters of north Georgia rivers to the larger rivers of the Fall Line, the slow-moving stretches of Coastal Plain rivers, and extensive estuaries along the coast, Georgia's streams and rivers have shaped the state's development while supporting a rich biological heritage.

The vast network of streams embedded in our landscape sustains one of the most diverse freshwater biological communities in the world. Georgia's native fauna includes at least 269 different kinds of freshwater fishes, a variety exceeded only by the states of Tennessee and Alabama. Free-flowing streams and rivers provide an array of aquatic habitats, including small headwater seeps and springs; shallow pools and riffles of creeks; river shoals and deep, flowing pools; and the interface where rivers empty into coastal estuaries. Because Georgia has very few natural lakes, the majority of Georgia's fishes, as well as many kinds of macroinvertebrates (most mayflies, caddisflies, stoneflies, crayfishes, snails, and freshwater mussels), thrive only in stream habitats. Stream plants and animals form complex communities that process and assimilate carbon and nutrients and support productive fisheries. Floodplain forests and other riparian habitats are closely tied to and support these rich biological communities.

What is a water reservoir?

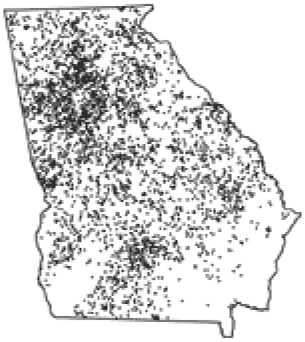
Reservoirs are artificial lakes in which water is collected and stored. Reservoirs are usually created when a dam blocks flowing water across a stream or river channel. They are constructed for a variety of purposes, ranging from public water supply or hydroelectricity production to irrigation or amenity/recreational use, and can vary greatly in size. The size and depth of a reservoir depend on such factors as its purpose, the amount of flow blocked by the dam, shape of the land surface, and height of the dam. Alternatively, reservoirs can be dug in upland areas that do not include stream or river channels. Water in these reservoirs comes from rainfall, runoff, groundwater seepage, and pumping from groundwater or surface sources.

When reservoirs are built, whether they are local, regional, on-stream or off-stream, the health and integrity of Georgia's valuable riverine resources are affected. Altered flow patterns and fragmented habitats negatively impact diverse aquatic populations. Other services provided by free-flowing streams and rivers are diminished or lost as well. For example, altered flow regimes change sediment transport and channel conditions and can impair or eliminate the river's capacity to assimilate nutrients and waste. Furthermore, these effects occur not only in the area inundated but extend upstream and downstream, throughout the riverine system, as well as laterally to the riparian land adjacent to the stream.

QUANTITY OF RESERVOIRS IN GEORGIA

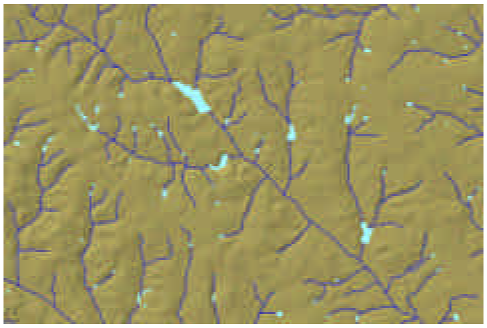
Almost all lakes in Georgia are constructed water reservoirs, with natural lakes found mainly along the coast and the Florida border (e.g., Carolina bays, limesinks). It is not known for certain how many reservoirs currently exist in the state. The National Dam Inventory, which lists dams larger than six feet in height, shows 4,435 reservoirs in Georgia (Figure 1). A recent study in the Upper Oconee River watershed, however, has demonstrated that the actual number of reservoirs in Georgia far exceeds this account.[1] The National Dam Inventory shows, for example, 276 dams in the Upper Oconee River watershed, while analysis of fine scale data found more than 5,400 existing impoundments (Figure 2). That is, the national inventory does

Figure 1. Reservoirs listed in the National Inventory of Dams[3]



Note: Georgia has the highest density of dams in the Southeast.

Figure 2. Impoundments in a portion of the Upper Oconee River watershed[2]



Note: Of the 83 impoundments in this view, only 4 are large enough to be listed on the U.S. Environmental Protection Agency National Dam Inventory.

not account for 95 percent of the reservoirs in this watershed. Many of these are small, occurring on smaller tributaries, and the extent of their environmental impacts can be easily underestimated.

The environmental impacts of reservoirs extend throughout a watershed (i.e., the land area that drains into a given water body). For example, reservoirs in the Upper Oconee River watershed range in size from 0.25 acre (0.1 ha) to 17,300 acres (7000 ha) and have flooded 520 miles (834 km) of stream habitat, which equals 8 percent of the total stream length. While a relatively small amount of river habitat is actually converted to lake habitat, 73 percent of the stream segments in the basin lie downstream of at least one impoundment and 100 percent of the stream segments lie upstream of at least one impoundment, resulting in extensive fragmentation of the aquatic ecosystem.

In the Upper Oconee, small reservoirs account for 40 percent of the stream length that is currently inundated. Many of these are located in the headwaters of stream networks, affecting the water source and quality for multiple downstream segments and contributing considerably to habitat loss and system fragmentation.

On-stream versus off-stream storage: A note on terminology

As it has become more difficult to gain approval for dams on larger rivers, it has been increasingly common for water supply reservoirs to be built on smaller streams with water pumped into the reservoir from a larger river. Impoundments on larger rivers are called **on-stream** while those on smaller streams are referred to by water supply authorities as **off-stream**. This use of the term "off-stream" does *not* refer to reservoirs that are located entirely away from streams or rivers of any size.

The value of an "off-stream" reservoir is that it does not create a major impoundment or block fish passage on the larger river, thus minimizing impacts on that segment. But it is important to note that, although called "off-stream," reservoirs built on smaller streams with water pumped from larger rivers do actually impound free-flowing streams. Small streams, despite their size, make significant contributions to the services provided by a river system. Cumulative impacts of many "off-stream" reservoirs can reduce the assimilative capacity of rivers and sustainability of aquatic populations.

Results of the Upper Oconee study are consistent with a 1993 assessment that concluded that there were approximately 63,000 small lakes and ponds in Georgia.[4] Based on this assessment, national inventory records, and the Upper Oconee study, we estimate that there are at least 68,000 reservoirs in the state today. These range in size and impact from farm and amenity ponds that are truly off-stream to reservoirs that impound small and medium-sized streams to large dams on the state's 14 major rivers, only four of which do not have mainstem dams. While providing a number of services, the thousands of on-stream reservoirs have interrupted the continuity of river systems in all of the state's major river basins.

SERVICES PROVIDED BY RESERVOIRS

Reservoirs, large and small, provide many benefits for Georgians. Municipal and industrial water supply, navigation, and flood control are among the primary purposes for construction of larger dams in Georgia. Lake Lanier, one of the state's largest reservoirs, was developed for the principal purposes of flood control, navigation, power generation, recreation, and drinking water. It produces hydropower for 20,000 to 25,000 homes per year, primarily to augment conventional sources during times of peak demand.[5] Millions of people visit Lake Lanier each year to fish, boat, and swim. While the full economic impact of the reservoir has not been quantified, recreation is the biggest revenue producer, generating $2 billion per year according to a 1995 estimate.[6]

Recreation, amenity uses, and agricultural water supply are the most common primary purposes for smaller reservoirs. Farmers rely on farm ponds to supply irrigation water and provide drinking water for livestock. Small recreation or amenity lakes, such as those found in housing developments, account for 65 percent of the reservoirs in Georgia listed on the National Inventory of Dams.[7] These impoundments can be designed to prevent erosion due to stormwater and promote the removal of pollutants from urban runoff.[8] Property values may be higher for homes adjacent to and in the same neighborhood as small reservoirs.[9]

Recreation benefits include creation of flatwater sport fisheries, and fishery impacts may also extend below the dam. Discharge of water from deep in Lake Lanier, for example, produces colder water temperatures below the dam. While release of cold water has eliminated the warmwater fish community native to this stretch of the Chattahoochee, it supports a popular introduced trout fishery between Buford Dam and Atlanta (despite periodic problems with low dissolved oxygen and high metal concentrations).[10]

Reservoirs can have ancillary benefits due to their ability to trap sediment. Even relatively small reservoirs are able to trap sand and silt, but the efficiency of trapping depends on the length of time that water stays in the reservoir. Clay particles, for example, are not generally trapped by reservoirs because of their small size and long settling time. The sediment trapping function may appear to mitigate poor land use practices and can cause downstream bed coarsening, a relative shift of the sediment particle size distribution from finer to larger materials. These effects, however, are often evident for only a short distance downstream depending on gradient, tributary sediment input, bank erosion, and other factors. Further, accumulating sediment decreases water storage capacity, limiting the functional life of the reservoir or requiring investment in dredging and sediment removal. Contaminants associated with accumulated sediment can further increase the cost of removal and disposal.

Much of the stream nutrient load, such as that from urban runoff or livestock waste, is attached to fine sediment particles. When these particles settle out in reservoirs, nutrients can be removed from the downstream system. Reservoirs can also act as biological reactors that promote growth of algae, further removing nutrients from the river and estuary system. Finally, biological processes in a reservoir can remove fecal coliform bacteria and pathogens from the water column, and concentrations of fecal coliforms and pathogens are usually lower downstream of reservoirs.[11]

In terms of water supply specifically, reservoirs help ensure that municipal, industrial, and agricultural water demands can be met during typical late summer low flow periods and during droughts. Larger reservoirs are sized to meet water demand and provide minimum downstream flows under specific low flow conditions. While not a guarantee, greater storage volumes decrease the chances of supply shortfalls or violation of minimum flow requirements during low flow periods. Overall, reservoir sizing depends on projected water demand, the degree of drought risk seen as acceptable, downstream flow requirements, and the economics of the reservoir-water supply system.

IMPACTS OF RESERVOIRS ON SERVICES PROVIDED BY FREE-FLOWING STREAMS

The benefits provided by reservoirs come at the expense of the services that free-flowing streams provide. Reservoirs alter natural flow regimes, a fundamental characteristic that underlies other features of streams and rivers. Equally important, they fragment the riverine system, altering physical and chemical processes, disrupting biological communities, and interrupting longitudinal and lateral connections in the river-floodplain system. Fragmentation and changes in flow patterns in turn combine to negatively impact four major services provided by free-flowing streams:

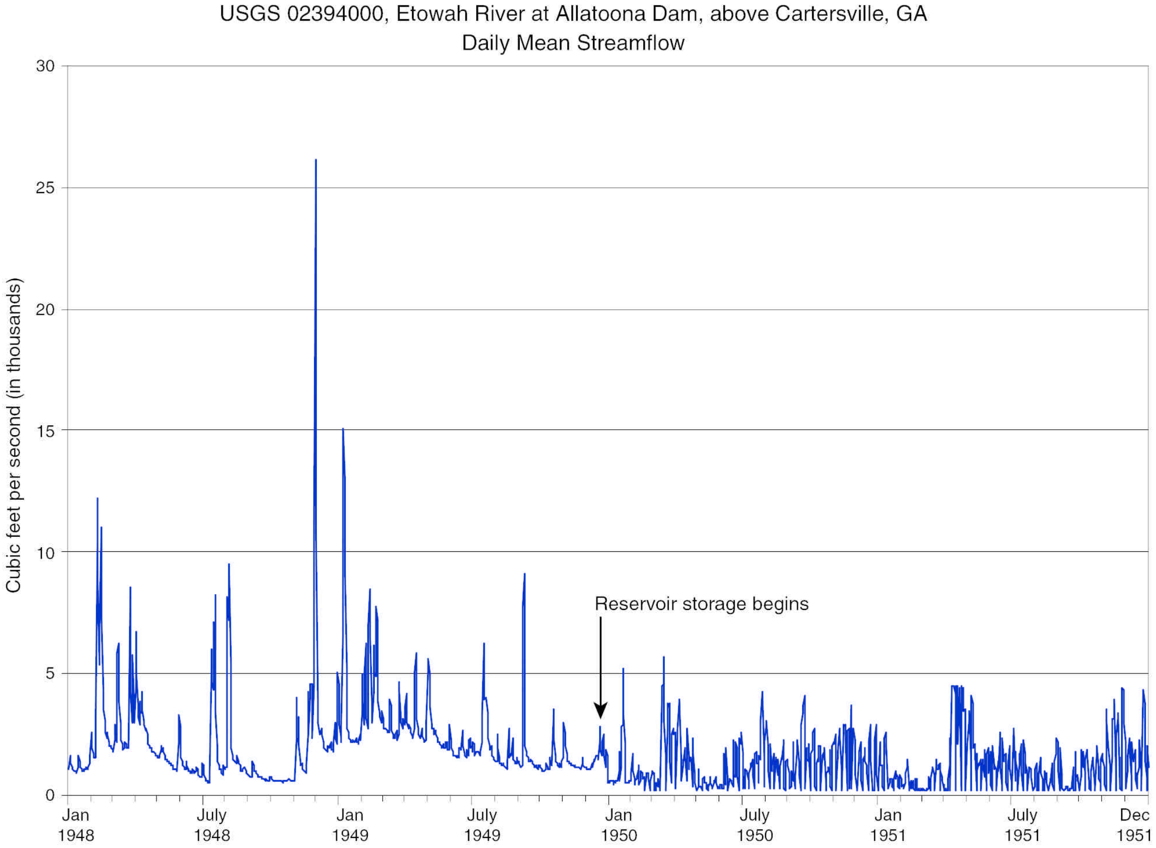
- Channel maintenance and sediment transport
- Waste assimilation and maintenance of water quality
- Habitat for a diversity of aquatic animals
- Maintenance of riparian zone function.

Altered Flow Regime

A stream's flow regime functions as a critical "master variable" that controls many services, including biological diversity and species distribution.[12] Seasonal and annual differences in water levels, water volume, and continuity of flow from the headwaters to the sea all contribute to these services. Variation in water levels provides energy inputs, a range of habitats, and connections between habitats. At high water, for example, floodplains are connected to the river channel. Fish can feed and escape prey in the floodplains, while organic debris is washed into the stream to provide food downstream. Flooding also provides connections between the river and wetlands and ponds that allow exchange of organisms and materials.[13] At lower flow, riffles provide important feeding and breeding habitat for many fish species. A river's physical, chemical, and biological cycles are tied to natural flows. The amount of water carried in streams and rivers, for example, is linked to the capacity to assimilate nutrients and waste. Salinities of coastal areas, in turn, are driven in large part by inflow of fresh water from rivers.

When natural flow regimes are altered, the basic function of riverine ecosystems is diminished. The environmental impact of reservoirs on streams and rivers is dramatic because reservoirs are the only structures that can simultaneously and thoroughly alter water level fluctuations, continuity of flow, and the amount of water in the system.

Figure 3. Water level fluctuations before and after construction of Allatoona Dam on the Etowah River



Note: The dam reduced high water levels and eliminated seasonal patterns of flow. Native fish populations have suffered as a result. Above Lake Allatoona, the river supports such fish as the Etowah darter, the frecklebelly madtom, the amber darter, and other species that rely on river shoal habitat. Below Allatoona dam, fish abundances are diminished in shoal habitats, and many fish species have been extirpated (driven locally extinct) due in large part to the unnatural flow patterns below the dam.[14]

Reduced water level variability. By its nature, a river is a dynamic ecosystem, with water levels rising and falling with the rains. In Georgia, free-flowing streams generally experience high flows in winter and spring and low flows in summer and fall. This pattern changes from year to year and in different parts of the state, and each river has its own pattern. While effects of reservoirs on flow patterns depend on the purpose for which the reservoir was constructed, differences in flow patterns after dam construction are often dramatic (Figure 3).

While the effects of reservoirs are most dramatic in the case of large dams on large rivers, small dams on small streams have significant local effects that, in aggregate, are very large. Small reservoirs typically

"Minimum" flows are not the only issue

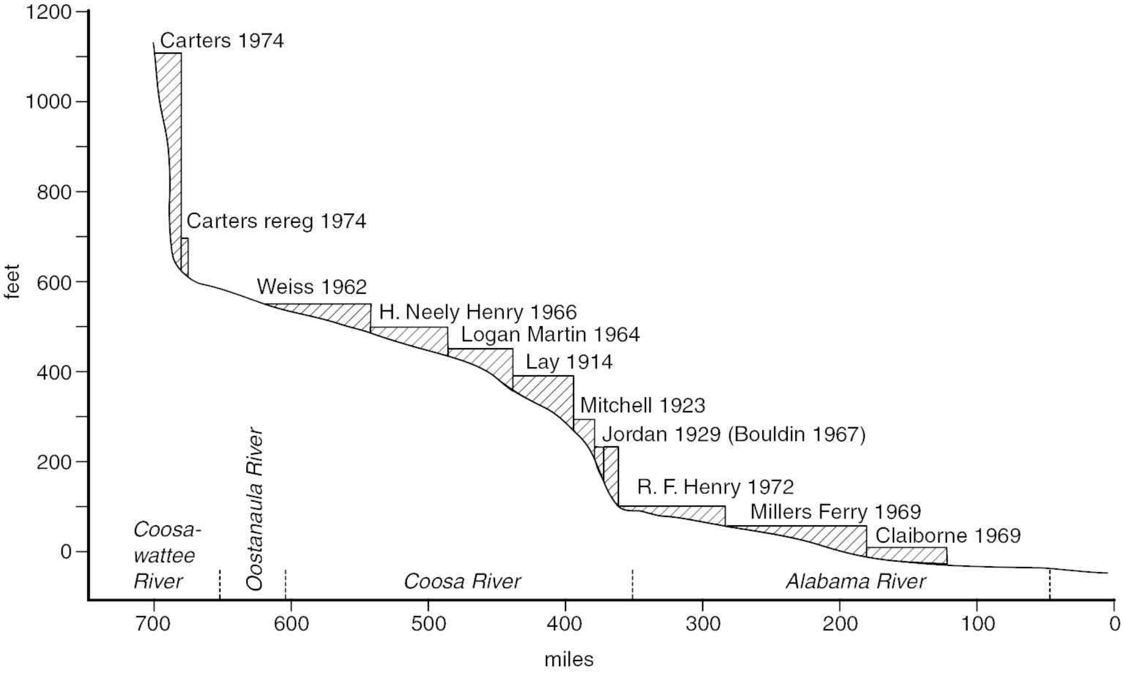
Conventional approaches to protecting rivers downstream from dams focus on maintaining a minimum flow level, without recognizing the importance of maintaining a *dynamic* flow regime. Such approaches have lead to declines in natural riverine biodiversity and ecosystem integrity. Alternative approaches, such as the Range of Variability Approach (RVA), emphasize management for flow regimes that more closely resemble the pattern of natural flows (e.g., high and low flows in the appropriate seasons). The RVA has been implemented along the lower Roanoke, and striped bass recruitment rates in this river have subsequently recovered to their highest postdam levels.[15]

damp flow peaks by catching high flow, releasing water only when the reservoir tops the dam and overflows. If water consumption and evaporative losses from the system are large, reductions in flows downstream of small reservoirs can also result in longer periods of low or no flow.

Loss of continuity. The very nature of free-flowing streams and rivers is determined by a continuous connection of water and the associated energy, sediments, nutrients, and biota, from headwaters to the sea. The food web of rivers, for example, is based on inputs from tributary streams, and downstream areas are sustained by the flow of water and transported materials. Dams placed across channels, whether large or small, block these connections, isolating upstream segments from the rest of the system.

Multiple reservoirs can result in highly fragmented systems. Along the Chattahoochee-Apalachicola rivers, for example, 13 dams of varying size divide the system into disjunct reservoir pools. The lower Chattahoochee River has been converted to a stair-step series of reservoirs, and in the 500 river miles from Lake Lanier to the mouth of the Apalachicola, mainstem riverine habitat totals less than 250 river miles, most of which lies in two segments.[17] A similar pattern is seen in the Alabama River basin (Figure 4). Considerable fragmentation may also be evident in smaller river basins. In the Upper Oconee basin, 8 percent of the stream length is inundated by dams. For 51 percent of the stream length, however, fewer than 25 percent of stream segments remain fully connected to upstream or downstream segments.[18]

Figure 4. The series of reservoirs in the Alabama River basin [16]



Note: The dams fragment the river into a series of lakes; disconnect segments of riverine habitat; and block flow of water, energy, sediments, nutrients, and animals.

While much attention has been given to the significance of low flows below reservoirs, fragmentation has equally damaging effects. The impact of fragmentation on the services provided by free-flowing streams and rivers has not, however, been a management concern. Georgia and many other states have provisions protecting "minimum flows" for environmental purposes, but there is no such protection from fragmentation. Encouragingly, the return of shad to Northeastern coastal rivers following dam removal provides evidence that at least some impacts of fragmentation can be reversed.

Water loss. Reservoirs result in a net loss of water from the river system, in part by increasing the rate of evaporation. Evaporation rates from a reservoir's open water surface are greater than the rates of water loss from the river and surrounding land prior to inundation. Average evaporation from Lake Lanier, for example, is estimated to be 40 inches per year.[19] This is 10 inches greater than the water lost from that land area prior to flooding. In short, water loss from the system following construction of the reservoir increased by roughly 33 percent, which represents 28.3 million gallons per day or water supply for approximately 170,000 Atlantans.[20]

Water consumption, which occurs when water withdrawn for a particular purpose is not returned to the source (e.g., evaporative loss from outdoor water use), also contributes to loss of water from the system. Along with increased evaporation, consumptive water uses decrease the amount of water available for downstream uses, with losses from multiple reservoirs accumulating. Unfortunately, both consumption and evaporation rates are particularly high during summer low water periods. That is, water loss is most significant during the time of year when the effects on stream systems are most pronounced.

Channel Maintenance and Sediment Transport Downstream

In their natural state, streams form channels that balance sediment supply and water runoff. Flowing water entrains sediments from the channel bed and banks until it has all it can carry at a given flow. Higher flows can carry more sediment and thus shape the channel by scouring pools and transporting previously deposited sediments downstream. When high flows eventually recede, they deposit sediments, adding coarser particles to riffles and gravel bars, and finer sediments to more slowly flowing habitats. If high flows spill over a stream's banks, the floodwaters may create natural levees as coarse sediments drop out of suspension, and then deposit finer (often organically rich) sediments onto floodplain habitats.

Reservoirs interrupt the downstream transport of sediment and floodwaters, resulting in a stream channel that is no longer in balance with its sediment and flow regime. The effects of this imbalance change with increasing

Classic cases of channel degradation and aggradation

A recent primer on the effects of dams summarizes two classic cases of downstream channel change.[21] The Snake River in Oregon is subject to channel erosion and degradation due to trapping of sediments by the Hells Canyon dam complex. Downstream, the reduced sediment load has caused a significant decrease in sandbar areas in 150 miles of river between the dam complex and the next major downstream tributary. In 1964, prior to closure of the complex's final dam, sandbar area at multiple points along the river routinely exceeded 50,000 square feet. In observations from the 1980s and 1990s, however, sandbar area was less than 35,000 square feet at all sampling points.

The Rio Grande River along the Texas-Mexico border has seen substantial channel aggradation due to impoundment and alterations in flow and sediment transport. Decreased flow in the Rio Grande, combined with sediment input from the tributaries, has caused the river's bed elevation to rise and the channel width to narrow. By 1974, bed elevation at Presidio, Texas, had increased 6 to 13 feet while channel width had decreased to roughly half that observed in 1933. The smaller channel holds less water, contributing to past flood damage and increased concerns about flood risk for communities that have grown along the floodplain.

distance from the dam. In the stream near the dam, channel degradation through scouring of sediments is most common. Because reservoirs trap sediment, water flowing from the reservoir carries a reduced sediment load.[22] During moderate to high flows from the reservoir, the "sediment-starved" water leaving the reservoir erodes the channel bed and banks until a balanced sediment load is achieved, with several consequences. One is bed coarsening, a relative shift of the sediment particle size distribution from finer materials to larger materials. The quality of habitat for fishes and invertebrates declines where the bed becomes "armored" or hardened by loss of moveable sediments.[23] Another consequence is incised, unstable stream channels and accelerated rates of bank erosion below reservoirs, which can cause loss of property.

Sedimentation and increased elevation of the stream channel, known as channel aggradation, most commonly occurs farther downstream. Sediment delivered from degrading upstream areas and by tributary streams accumulates in the channel and cannot be naturally removed because the reservoir restricts the frequency and size of flood peaks.[24] This accumulation of sediment occurs in addition to sediment inputs to the system during reservoir-related land clearing and dam construction.[25] Sediment accumulation degrades habitat by filling pools and clogging riffles and reduces a stream's capacity to transport high flows, setting the stage for more severe flooding than would otherwise have occurred.[26]

Waste Assimilation and Maintenance of Water Quality

Rivers are self-purifying systems. An ecologically healthy river removes nutrients and other material through chemical and biological processes, and human society depends on removal of nutrients and decomposition of organic matter introduced by point and nonpoint sources of pollution. Bacteria, algæ, and a host of other organisms that live attached to the rocks and wood in rivers are responsible for much of a river's capacity for self-purification. If the biota below a dam is degraded by factors such as excess sediment input or rapidly changing flows, the ability of the river to remove nutrients and toxins is diminished. For example, the Chattahoochee River below Atlanta has lost much of its capacity for phosphorus removal, and as a consequence that phosphorus is transported downstream to West Point Lake, where it has led to eutrophication (i.e., nutrient enrichment).[27]

Recent research demonstrates that small streams play an especially important role in removal of nutrients from nonpoint sources.[28] Much of the nutrient removal in a river system occurs in small headwater tributaries,[29] including the streams that would be impounded by some of the water supply reservoirs currently proposed in Georgia.

Physical, chemical, and biological processes in reservoirs can also remove nutrients and toxins from the water column. Much of this material will be deposited in the reservoir's sediments. If the impoundment is very deep or poorly mixed, zones with no oxygen (anoxic) will develop in the deepest waters. Denitrification, the bacterial conversion of nitrate to gaseous nitrogen, can be an important pathway for nitrogen loss in these anoxic waters. Although this process can improve water quality below the dam, under anoxic conditions, metals and phosphorus bound to sediments can also be released. Phosphorus stored in reservoir sediments cannot be viewed as permanent storage: it is released to the overlying water by both chemical and biological processes.[30]

Release of phosphorus to the water column can lead to algal blooms, which can in turn cause taste and odor problems in water supply systems. Release of phosphorus or metals from sediments can also lead to excess nutrients and a deterioration of water quality downstream. If the water released from the dam comes from the deep waters of the reservoir (hypolimnetic release), downstream water quality problems can be particularly acute. For example, the water released from Buford Dam sometimes carries high concentrations of metals released from Lake Lanier sediments, and these metals precipitate out downstream, causing problems in the fish hatchery below the dam.

Finally, reservoirs are more sensitive to nutrient loading than are rivers. For example, a reservoir is considered nutrient enriched if total phosphorus concentrations in its waters are above 50 µg/l, whereas a river is considered nutrient enriched if its total phosphorus concentration exceeds 100 µg/l.[31] Therefore, an amount of nutrient loading that has little noticeable impact in a river is more likely to result in nuisance algal blooms in a reservoir.

Habitat for a Diversity of Aquatic Animals

Two features enable Georgia's natural stream systems to support an unparalleled abundance and variety of fishes and other freshwater organisms: the nearly continuous flow of water and the interconnected nature of diverse habitats in stream systems. Flowing water supplies oxygen to stream habitats and transports carbon and nutrients downstream. Many stream animals feed on particles and prey carried to them by flowing water (a principle employed by the stream angler who floats a nymph past a waiting trout).

The connectivity of stream systems makes it possible for organisms to move between habitats and locations.[32] Some fishes move long distances to take advantage of the resources supplied by different habitats. For example, some fishes are anadromous, spending parts of their life cycles in saltwater and part in freshwater. Like salmon in the northwest, anadromous fishes such as American shad and striped bass historically ascended Georgia's rivers in great abundance in the springtime to spawn in flowing river habitats. The young of these fishes remain in river habitats for some time but eventually migrate back to the estuary and open ocean to grow, mature, and then repeat the reproductive migration upstream. Small, non-anadromous fishes also migrate among habitat types to complete their life cycles.[33] The trispot darter, a native of the Coosa River system in North Georgia, moves from larger streams (where adults typically live) into small headwater seeps to spawn in early spring.[34] The number of different fishes that move in this manner among stream habitats is not known, although research indicates that many fishes may move considerable distances.[35] Stream system connectivity also allows fishes and other aquatic life to repopulate areas following catastrophic losses, a part of the process by which streams naturally recover from periodic, extreme events such as floods and droughts.[36]

Reservoir construction directly impairs stream communities by eliminating stream habitat and altering stream habitat downstream from the reservoir.[37] An impoundment replaces flowing water habitat with lake-like habitat that is deeper and has virtually no flow. The bottoms of reservoirs typically accumulate silt, as discussed earlier, and may seasonally become oxygen depleted. A few of Georgia's native fishes such as certain basses, sunfishes, and catfishes can live in these conditions, and reservoirs may create popular sports fisheries. However, most of the animals that naturally inhabit Georgia's streams and rivers are adapted to flowing water habitats and will not persist in impoundments. Game fishes that do not thrive in reservoirs include the shoal bass and redeye bass; the deeper, still waters of ponds do not provide the appropriate prey (mostly invertebrates adapted to flowing water and coarse substrates) or habitats for these and most of our other native stream fishes.

Downstream from reservoirs, altered flow and temperature regimes reduce the stream's ability to support native communities.[38] Flow depletion can restrict the volume of stream habitats, leaving shallow water and channel margin habitats exposed and decreasing the availability of swiftly flowing habitats. Water temperatures in downstream segments can be lowered (by water released from deep within the reservoir) or elevated (by water released from near the reservoir surface) to levels that exceed the tolerances of native stream organisms. Dissolved oxygen may also be lowered below tolerances of stream organisms in downstream segments as a result of reduced flows or low dissolved oxygen levels in the reservoir.

By fragmenting naturally continuous stream systems into isolated upstream and downstream portions, reservoirs impede fish movements and animals dependent on movements between different parts of the system can be eliminated.[40] Even if animals can pass over the dam or through structures associated with the dam (such as standpipes, spillways, or turbines), many stream-adapted organisms are incapable of moving great distances through reservoirs, where they encounter unsuitable habitat and are exposed to predators. As a result of hydropower dam construction, migratory fishes such as striped bass and American eels can no longer reach many of the rivers historically populated by these species.[41] In addition to eliminating migratory species, fragmentation can prevent natural stream recolonization by fishes and other organisms following a catastrophic disturbance (e.g., an extreme high or low flow or chemical spill). Fragmentation also may prevent normal levels of genetic exchange among populations of organisms inhabiting different portions of stream systems.

Habitat fragmentation impacts in Georgia[39]

- American shad no longer ascend the Savannah River system past Augusta. Prior to construction of reservoirs on the Savannah, shad spawning runs extended at least to the Broad River in northeast Georgia. Similarly, because dams block upstream migration, Alabama shad have been extirpated from the Coosa River system in northwest Georgia.
- The Gulf sturgeon once inhabited the Chattahoochee and Flint rivers but is now blocked from moving into these drainages by Woodruff Dam at the Georgia-Florida border. The Atlantic sturgeon, in turn, is restricted by dams to the lower portion of the Savannah River, and reservoirs on the Coosa and Etowah rivers impede movements by the lake sturgeon, which is now very rare or extirpated in that system.
- American eels are no longer found upstream from large dams on the Oconee, Chattahoochee, Conasauga, Oostanaula, Coosawattee, and Etowah rivers.
- Freshwater mussels have essentially been eliminated from the upper Etowah River, perhaps due to mercury and sediment loading during 19th century gold mining. Whatever the reason for their decline, these animals cannot naturally recolonize because Allatoona Dam impedes upstream passage of fish carrying larval mussels from populations in the remainder of the upper Coosa basin.

Finally, reservoirs facilitate the introduction of non-native aquatic species. Reservoirs are often stocked with game fishes and, perhaps unintentionally, species used as bait (including minnows and crayfishes), typically without regard to the native status of those animals in the impounded stream system.[42] As a result, reservoirs can facilitate the spread of non-native aquatic organisms. Non-native aquatic plants introduced as ornamentals in ponds have spread through reservoirs and become nuisance species with substantial economic consequences. Further, non-native aquatic animals often spread from reservoirs into streams and may out-compete or prey upon native species, resulting in loss of species and fisheries.[43]

Maintenance of Riparian Zone Function

Streams and rivers form a network that, unlike any other natural landscape feature, connects areas throughout the watershed. The 44,056 miles of perennial streams and rivers, 23,906 miles of intermittent streams, and untold miles of ephemeral streams in Georgia's 14 major river basins[44] carry water, sediment, nutrients, animals, and energy literally from the mountains to the sea. These longitudinal connections form a continuum that dominates river systems,[45] but the connections that occur laterally between the surrounding landscape and the rivers determine many characteristics of the river and adjacent habitats.[46]

The riparian zone, which is the land adjacent to rivers and streams, provides an essential landscape for many critical interactions.[47] Riparian zones are integrally linked with and maintained by the dynamic highs and lows of natural river levels. These zones are often the most diverse habitat in the watershed due to the energy of the water that creates all of the floodplain features, such as oxbow lakes, internal drainages, terraces, swales, and levees.[48] One of the most important functions of riparian zones is providing habitat for wildlife from throughout the watershed.[49] The diversity of naturally occurring floodplain trees produces a reliable source of abundant food for wildlife. During high water, fish move into the floodplains from the rivers to feed and prepare to reproduce. Natural riparian zones provide protected access to water for wildlife, and migratory animals use riparian corridors to move through the landscape.

Vegetated riparian areas function as buffers that filter stormwater and help protect the water quality of Georgia's rivers and streams. As stormwater passes through a vegetated riparian zone, several physical, chemical, and biological processes remove nutrients and other pollutants from the water before it enters the stream or river.[50] Wetlands are particularly effective at removing nutrients and degrading pollutants.[51] Riparian vegetation also modifies stream temperature and morphology.[52] The overhanging vegetation shades and cools aquatic habitats. The branches and trunks that fall into streams and rivers add structure to the stream profile, creating pools and riffles that provide habitat and control stream gradients and changes in channel form.

When reservoirs are constructed, lateral and longitudinal connections are interrupted and riparian function degraded. In the area of the impoundment itself, riparian habitats are flooded and converted to less productive open water.[54] Wetland forests, like the extensive wetlands along Georgia's Piedmont and Coastal Plain rivers, produce as much plant material as do tropical rainforests (Table 1). Similarly, wetlands in floodplains can yield greater fish biomass than can reservoirs of an equivalent size.[55]

Table 1. Average productivity of different land covers (grams of dry plant per square meter per year)[53]

Tropical rainforests	2000
Forested riparian wetlands	2000
Cultivated land	650
Lakes and streams	250

Converting floodplain forests to open water also alters wildlife value in other ways. For example, plant species diversity is as much as 30 percent lower in riparian communities that occur along 50-year-old reservoir shorelines than in those along free-flowing rivers.[56] Animals migrating along the riparian corridor can be forced out of a forest's protection when confronted with dams and reservoirs, and moving into more exposed or developed areas can impede wildlife dispersion and survival. In addition, the abrupt, steep shoreline along reservoirs erodes and supports little vegetation, limiting access to water and the shoreline's utility as a wildlife niche.[57] The volume of water held in impoundments has a high heat capacity, which leads to unnaturally warm microclimates near the water body during the winter.[58] Dormancy of small animals that use these areas, such as salamanders, may be delayed and the animals endangered as winter progresses.

The quality of fish and wildlife habitat is also diminished downstream of reservoirs.[59] Dams block the passage of food produced in forests above the impoundment from downstream consumers,[60] thus decreasing the productivity of that stream segment. Wetland portions of the downstream riparian zone may become drier, with upland plant species able to invade as a result. Ponds and streams in floodplains are flooded less often, leaving fewer refuges for fish and affecting the time that fish feed in the floodplain, which in turn hampers reproduction and contributes to decreases in fish population densities and species diversity.[61] In addition, for smaller streams, loss of riparian cover leads to increases in water temperature. If temperatures increase past a critical threshold, these streams are unlikely to support self-sustaining populations of temperature-sensitive native species such as trout.[62]

Finally, reservoirs contribute to land uses that have negative impacts on natural ecosystem function. Reduced flooding below reservoirs, for example, allows easier access to floodplains, facilitating removal of floodplain forests and conversion to managed pine or agricultural use. The benefits of a diverse floodplain forest are thus lost, and nutrients, pesticides, and sediments in runoff from dirt roads, crops, and animal operations can overwhelm the riparian buffer's capacity to remove pollutants. Similarly, reservoirs can facilitate development, which in turn brings increases in impervious surfaces, runoff, and pollutant loading, all of which affect the quantity and quality of water in streams and rivers and may contribute to water quality deterioration in the reservoir itself.[63]

Cumulative Impacts of Reservoirs

The cumulative effects of multiple reservoirs pose significant concerns for the function of Georgia's river ecosystems. As described above, the impacts of individual reservoirs on flow regime, water quality, and wildlife habitat can be determined. What is not clear is when the combined impacts of multiple reservoirs exceed what a river ecosystem can tolerate, thereby diminishing or losing, perhaps irretrievably, valuable ecosystem functions. How many dams are too many from the perspective of ecosystem function?

Cumulative impact assessments become more important as rivers approach thresholds in system function, thresholds beyond which equilibrium conditions may be markedly different.[64] What are the impacts, for example, on salinity in a river's estuary if there are more than 5,000 dams in the subwatersheds that contribute flow to that river? How much is this impact exacerbated during the summer, when higher levels of water use and evaporative losses combine with low river flows? What are the potential effects on coastal fisheries and economies if salinity exceeds the tolerance levels of the animals that require estuaries for reproduction and feeding? Similarly, as discussed earlier, impoundments and flow alteration may be one of the greatest sources of riparian wetland loss.[65] The economic impact of the loss of these productive areas and their associated functions has not been determined.

Federal regulations define cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency…or person undertakes such other actions."[66] The U.S. Army Corps of Engineers, under Section 404 of the Clean Water Act, requires assessment of the cumulative impacts of reservoirs as part of the permitting process for dam construction and inundation of wetlands and stream channels. In addition, if the Corps finds that significant environmental degradation will occur as a result of issuance of a permit, a cumulative impact assessment is required for an Environmental Impact Statement under the National Environmental Protection Act.

To date, analysis of cumulative impacts under these regulations has been limited in scope in Georgia as well as nationally, and the Corps of Engineers now recognizes a need for more thorough review of cumulative impacts. In the past, impacts to riverine ecosystems were relatively small or isolated. There was adequate natural area to "absorb" the impact and restore the damage. For example, waste discharges into rivers were sufficiently small and spaced at intervals that enabled the stream's assimilative capacity to restore the system to equilibrium before the next event.[67] Assimilative capacity, however, is governed to a large extent by flow and can be compromised by upstream reservoirs, as described above. While localized water quality effects are known, the uncertainty of systemwide effects of multiple reservoirs raises questions about economic impacts and health effects associated with degraded water quality.

While many questions remain, we do know that extensive impoundment of Georgia's rivers and streams has already profoundly altered the critical habitat that directly sustains one of the most diverse freshwater biological communities in the world.[68] Thirty-four of Georgia's native fish species and 16 species of freshwater mussels have been listed by the state as threatened or endangered due in part to alterations in the riverine system resulting from impoundments. In the Alabama River basin (Figure 4; page 6), for example, dams have destroyed the habitat required by native mollusks (mussels and snails), virtually eliminating this fauna from the Coosa River.[69] In short, we have already lost fauna due to reservoirs on the main channel of rivers, and multiple "off-stream" reservoirs have as great a potential to harm aquatic fauna as do mainstem reservoirs.

We are just beginning to recognize and assess the cumulative impacts of the thousands of dams that exist in Georgia. It is clear that reservoirs have numerous impacts on the services provided by free-flowing rivers: some of these are beneficial under certain conditions, while others are clearly detrimental. Further, all potentially accumulate as the number of impoundments in a given watershed increases. The methods needed to further determine cumulative impacts are under development, but many questions still require more research.

MITIGATING RESERVOIR IMPACTS

Because more than 50 percent of the nation's wetlands have already been lost, Section 404 of the Clean Water Act requires that impacts to wetlands and streams from activities such as reservoir construction be mitigated. Such mitigation follows a sequence – first, to avoid any impacts; second, if impacts are unavoidable, to minimize them; and, third, to compensate for any impacts that occur. As part of the application for a Corps of Engineers permit to impact wetlands and streams, the applicant must show that the project is necessary and cannot be built in uplands. If project impacts cannot be avoided, an alternatives analysis is required to show that the least environmentally damaging and practicable site and design have been selected. Any impacts on streams and rivers must be compensated with restoration, creation, or preservation. The goal of compensation is to provide adequate in-kind replacement for unavoidable loss of stream and wetland services.

It has recently become clear, however, that mitigation programs are not working as intended.[70] Complete sets of water supply alternatives are not being considered before reservoirs are planned. While locating reservoirs off a mainstem river does minimize some environmental impacts, other site, design, and management factors that could further minimize impacts are not being incorporated. The degree of stream or wetland alteration and success of compensatory mitigation is not precisely known for Georgia, but it is known that nationally:[71]

- functions lost from free-flowing rivers are not replaced;
- some required mitigation projects are never undertaken or are not completed;
- enforcement of mitigation requirements is inadequate;
- completed mitigation projects are often not properly evaluated; and
- evaluated projects typically have a low success rate for performing the functions they are intended to replace.

While few "best management practices" exist for reservoirs, consideration of their individual and cumulative effects could help minimize negative impacts. While the area of impacted wetlands and streams is currently a significant factor in reservoir siting, consideration could also be given to the location of existing reservoirs in a drainage and an effort made to identify site(s) that minimize or offset flow alterations and fragmentation of the stream-river system. Removal of obsolete or unsafe dams would also help replace lost functions of free-flowing streams and rivers.

Improved operation of existing reservoirs may provide opportunities to offset or mitigate impacts as well. A number of changes in dam operations, including seasonally variable flows, low fluctuating releases, periodic high flows, multi-level intake structures, and aeration of release waters, could decrease downstream effects on sediment transport, water quality, and habitat.[72] Implementing such strategies for mitigation purposes, however, poses several significant challenges: the accurate assessment of site-specific impacts; developing a clear understanding of the objectives for reservoir operations; balancing multiple uses of the reservoir and downstream segments; and balancing human uses and environmental services.

To date, such changes in dam operations have seen limited implementation in Georgia. At Sinclair Dam on the Oconee River, for example, Georgia Power has adjusted release schedules to improve habitat for an imperiled fish, the robust redhorse, and a similar agreement was recently executed for Lake Jackson on the Ocmulgee River.[73] In 2001, the state adopted an interim instream policy that incorporates variable minimum flow provisions, with a recommendation that site-specific studies be conducted over a four-year period to establish a permanent minimum flow policy.[74] The effect of the variable flow requirements is unclear at this point, however, and the policy applies only to new or expanded withdrawal permits, grandfathering or excepting a number of proposed as well as existing reservoirs. The mitigation potential of periodic high flows, variable releases, and other operational strategies remains to be explored for these facilities.

CONCLUSIONS: RESERVOIR IMPACTS

We now recognize that the effects of reservoirs extend far beyond the area flooded by a dam, with downstream ecosystem health dependent on much more than the maintenance of minimum flows. Alteration of flow patterns, water loss, and fragmentation of the river system affect the services provided by free-flowing streams in a number of ways, with effects extending upstream, downstream, and laterally into valuable riparian land. To date, efforts to mitigate these impacts have been flawed at best, and many states are working to remove dams because of their detrimental effects.[75]

We also now recognize that the number of existing reservoirs in the state is likely to be much greater than commonly understood. And, while it is not likely that new reservoirs as large as Lake Lanier or other federal projects will be constructed in the near future, there are considerable pressures for ongoing development of reservoirs across the size spectrum from farm ponds to large water supply impoundments. The number of reservoirs that already exist in Georgia and the potential development of multiple new reservoirs highlight the need for a thorough accounting of the cumulative reservoir impacts on the benefits that Georgians derive from free-flowing streams. Preliminary evidence indicates that the cumulative effects of both large and small dams can be surprising.[76] We do not, however, know how various combinations of different size reservoirs with varying purposes and operations affect aquatic ecosystems. This and other important questions remain for further study.

We do know that, on balance, current evidence indicates that many of the services provided by free-flowing rivers have been impaired by existing reservoirs in Georgia. Impacts include profound alteration of the critical habitat that directly sustains one of the most diverse freshwater biological communities in the world. With construction of additional reservoirs and further fragmentation of river systems, we risk losing more of these critical environmental services as well as the ability to restore degraded segments. Systemwide impacts should be better understood before making significant state and local investment in development of additional reservoir storage.

The number of reservoirs already in place in Georgia, along with the potential for additional impacts and loss of restoration options, leads to a broader question: How should we best manage our water resources to balance human and ecosystem needs? Part of the answer is to improve management of all parts of the system, including existing reservoirs, and to seek alternatives to reservoir storage when practicable. Water supply planning to identify alternatives that minimize environmental impacts while meeting future water needs are the best way to maintain the services provided by free-flowing streams. As described in Part II, such planning approaches are clearly feasible, build on positive trends already under way, and can yield multiple benefits for Georgians now and in the future.

PART II: WATER SUPPLY PLANNING FOR THE 21ST CENTURY

The challenges facing water supply planners in Georgia are many. We have moved from a period of having abundant water to one with growing demands for water for multiple uses and evidence of increasing environmental impacts from water impoundment and withdrawal. Water supply planning in Georgia must balance conflicting, varied demands while protecting the water required to sustain healthy, functioning streams and rivers.

Worldwide, as water supply expansion through reservoir construction has become more expensive and less environmentally feasible, increasing attention is being given to both demand management and non-reservoir sources of supply.[77] Rather than relying on reservoirs as the primary water supply solution, Georgia could benefit from planning that considers a wider array of options and evaluates alternatives to identify those that are the most economical and least environmentally damaging.

Meeting future water needs for Georgia's population, commerce, and environment will require, among other things, using current supply more efficiently and managing future demand. Water conservation is vital to optimizing use of our water resources, and Georgia state law requires water conservation plans as part of the application for new or expanded water withdrawal permits (except for farm use).[78] A requirement that permittees report program results became effective in 2001. The current reporting form, however, is simply a checklist of program elements, and to date, the implementation and effectiveness of these water conservation plans has not been systematically evaluated statewide.[79]

Water conservation planning provides a starting point for optimizing use of water resources, but it alone is not sufficient. Three elements are key to more effective water planning:

- defining the purpose of water supply planning broadly,
- identifying a wide range of water supply options that can provide part of the projected demand, and
- selecting the package of options that best meets the full projected demand with minimum environmental damage and practicable cost.

PURPOSE OF WATER SUPPLY PLANNING

A critical first step in developing an effective water supply plan is to clearly define the purpose of the planning process at the outset. If decision makers begin water supply planning with a preconceived result in mind, such as building a reservoir, the public will miss the benefit of having other water supply alternatives adequately examined, alternatives that might better meet demand, be more cost-effective, and cause less environmental damage. Thus, in writing the purpose statement, it is essential that decision makers not limit the alternatives by defining the goal too narrowly (e.g., choose a site for a reservoir).

Instead, the goal should be defined broadly. For example, the purpose may be stated as to provide sustainable water supplies for a specific region for a certain period of time. Every part of this statement of purpose should be examined carefully. Geographic borders, for instance, are one consideration: in some areas, it may be more cost-effective and environmentally beneficial to work with other counties, municipalities, authorities, or industries in the region. In other regions, the water supply needs of some localities may have been incorporated in other water supply plans or proposals; double counting or duplicating those needs in the planning process contributes to misleading or inaccurate projections of water demand.

WATER SUPPLY OPTIONS

Considering a range of water supply options is critical to meeting water demands while minimizing environmental impacts. This approach to water supply planning focuses first on managing and reducing water demand and then on supply management. According to research in Georgia and other parts of the country, nonstructural options, in particular, can decrease the need for additional withdrawals.[80] Through comprehensive water conservation that uses some or all of the options described below, water use can be reduced as a cost-effective alternative to new infrastructure[81] (Figure 6). The following sections outline demand management options and then address supply management, including use of existing sources of water and potential sources of additional water.

Demand Management, Water Conservation, and Use Efficiency

In general, demand management strives to meet water demand by reducing the amount of water used, rather than by traditional methods of increasing water supply.[82] Demand management is accomplished through nonstructural options such as management of leaks and unaccounted losses, increased efficiency of indoor and outdoor water use, provision of water audits, and use of conservation rate structures. Such options are designed to offset growing demand by making water use more efficient in all sectors.

It is worth noting that, in the most recent year for which national data are available (1995), per capita water use in Georgia was estimated at 195 gallons per day (domestic, commercial, industrial, and thermoelectric power uses).[84] Average per capita use in the South Atlantic-Gulf region that year was 182 gallons per day, and the national average was 179 gallons per day. Further, per capita use in Georgia's neighboring states was as much as 17 percent lower than Georgia's (Figure 5). While a number of factors can contribute to variation in per capita water use, these figures highlight potential contributions of nonstructural options to meeting Georgia's future water needs.

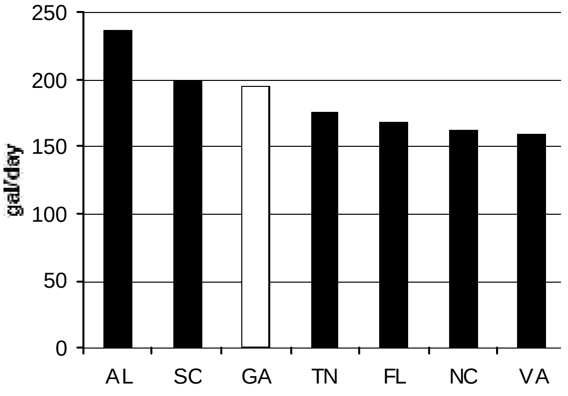


Figure 5. Per capita water use in Southeastern states (1995; gallons per day)[83]

One element of more efficient use is better management of leaks and unaccounted losses, which can involve significant volumes of water. Localities across the United States are estimated to lose almost 10 percent of the water they withdraw to leaky infrastructure.[85] Upgrading leaky pipes and improving existing infrastructure in the metro Atlanta region alone could potentially save 6 to 22 billion gallons of water a year.[86]

Reservoir costs versus conservation savings: Hard Labor Creek, Walton County[87]

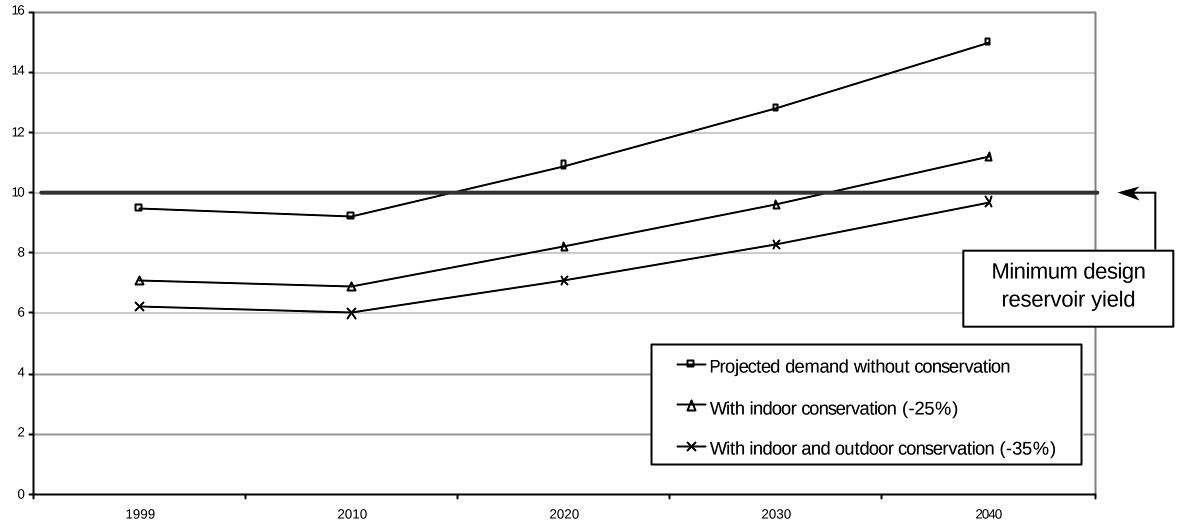
Hard Labor Creek Reservoir, under development by Walton County Water and Sewer Authority, will cover approximately 1,300 acres with a storage capacity of 13 billion gallons. The reservoir is expected to supply 10 to 13 million gallons per day (mgd) and may be supplemented by withdrawals from the Apalachee River for a total of 41 mgd.

Hard Labor Creek Reservoir is expected to cost about $45 million. Direct costs can be broken down into three categories: land procurement (50 percent of total costs), construction (35 percent of total costs), and environmental mitigation (15 percent of total costs).

The cost of the reservoir itself must be coupled with the cost of treatment facilities to pump and process the water drawn from the reservoir. Because water treatment plants can be built and upgraded as demand increases, these costs are more incremental than the one-time cost of constructing the reservoir. A general rule for pricing the construction of water treatment facilities is $1 million per 1 million gallons of production capacity.[88]

By contrast, substantial reductions in water use are possible with comprehensive water conservation programs. Programs might include adopting conservation rate structures, surcharges for excessive use, educational programs, and incentives for the use of ultra-low flow devices and outdoor watering restrictions. The figure below shows the base design yield for the Hard Labor Creek Reservoir, projections for peak daily water use without additional conservation measures, and projections for peak daily use after conservation measures are applied. The figure shows that, assuming growth rates follow projections, indoor and outdoor water conservation can eliminate the need for new reservoir capacity until the year 2030 or later.

Figure 6. Projected peak daily water use with and without conservation (million gallons per day)



Improving efficiency of indoor water use can also offset increases in demand. More efficient indoor technologies have consistently resulted in significant reductions in water consumption (Figure 7). Chatham County, for example, saw consumption drop 1 million gallons a year following residential retrofitting with only 600 ultra-low-flush toilets.[89] The city of Los Angeles provides funding to promote retrofitting with water-efficient appliances. Estimates indicate that the ultra-low flush toilet component of the program by itself saves 9 billion gallons of water a year (approximately 25 million gallons per day).[90]

Figure 7. Alternative water supply options: How much water might be saved?

Managing leaks and unaccounted losses

- The metro Atlanta region loses nearly 14 percent of its water to unbilled/unaccounted loss.[91]

Improving indoor water use efficiency

- In New York City, installation of efficient plumbing fixtures helped decrease average daily water consumption by 250 million gallons from 1988 to 1997.[92]
- In Los Angeles, retrofitting with ultra-low flush toilets in Los Angeles has saved 9 billion gallons of water a year (approximately 25 million gallons per day).[93]
- In Atlanta's Brown Village, water consumption dropped by more than 20 million gallons a year following distribution of ultra-low-flush toilets, low-flow showerheads, and energy conservation information to 340 residents. Savings are expected to approach $200,000 over the next five years.[94]

Improving outdoor water use efficiency

- In California, detailed guidelines for outdoor water saving practices in a variety of circumstances coupled with wide-ranging incentives for water savers have resulted in 19 to 35 percent savings for large landscaping projects.[95]

Water audits

- In New York City, the Department of Environmental Protection surveyed nearly 175,000 residential units over three years, identifying and measuring leaks. In units with extreme leak problems, water use rates were double the average use rate. It was estimated that residents could save a mean of $100-$200 per leak per year, simply fixing a leak in the shower, toilet and/or faucets.[96]

Conservation rate structures

- In Spalding County, daily water use per connection declined from 243 to 231 gallons in the two years following implementation of conservation pricing as a stand-alone conservation practive. During this period, the number of customers increased by 21 percent while total water demand increased by only 15 percent.[97]

Reclaimed and reused wastewater

- A filtration system in a Cobb County laundry facility will process nearly 42 million gallons of wastewater for reuse each year, decreasing their water use by 85 percent and wastewater discharge by 95 percent. Annual cost savings may be as high as $355,000.[98]
- Clayton County's water/wastewater treatment facilities save nearly 226 million gallons of water a year by using reclaimed water within its facilities. The facilities reuse water for, among other things, the systems' chlorinators, for washing equipment, and for removing dust in their biosolid pelleting system.[99]
- Water reclamation at a semiconductor manufacturer in Austin has reduced water consumption by 30 percent (40 million gallons annually) and also has achieved a seven-month payback on the initial investment of $146,000.[100]

Outdoor water use offers substantial conservation opportunities as well. Household water use in Georgia increases dramatically during the summer due to outdoor watering, becoming in some households as high as 100 percent greater than in the winter.[101] A variety of guidelines on reduction of outdoor water use are available to Georgia residents,[102] but to date in Georgia, there has been limited use of water conservation incentives to reinforce guidelines that are voluntary except in times of drought.

Water audits can help accomplish more efficient water use. Audits provide a better understanding of how and where water is used and where potential savings can occur. Normally, audits are performed on residential dwellings or commercial buildings and involve evaluating landscaping and irrigation systems, checking for leaks, and teaching the customer how to read a water meter.[103] Audits are designed to help customers save both water and money by identifying ways to conserve water inside and outside their homes or businesses.

Another important component of demand management is implementing conservation pricing. The basic premise is that charging more for higher levels of consumption provides an incentive to not “waste” water. As of 2001, nearly 23 percent of U.S. water utilities had shifted to an ascending block rate structure, in which unit prices increase with the quantity of water used.[104] The Irvine Ranch Water District in California, for example, avoided having to raise rates after replacing its flat rate-per-unit charge with an ascending block rate structure. Since 1991, this rate structure has proven cost-effective and has successfully reduced water demand in multiple sectors.[105] Spalding County, Georgia, also initiated conservation pricing in 1991. By 1993, per customer water use had decreased by 5 percent while yearly revenue per connection went from $162.43 to an inflation-adjusted rate of $184.39.[106]

As an alternative to changing rate structures, simply increasing the price of water can cause a reduction in water demand. In the early 1990s, the City of LaGrange, Georgia, for example, increased water supply and wastewater capacity by 50 percent at a cost of $37.5 million. To pay off this debt, the city raised monthly water and wastewater rates. Their customers reacted to the rate increase by using less water so that, rather than seeing the projected demand increases, the city’s water demand actually decreased from 10-11 million gallons per day (mgd) to 9 mgd, and their wastewater demand decreased from 7.5 mgd to 5.5-6.0 mgd, leaving the city with reduced revenues.[107] The lesson here is that implementation of demand reduction options, such as pricing, before building more water supply capacity can prevent investments that prove to be an unnecessary local cost burden.

As indicated by LaGrange’s experience, plans that rely on conservation rate structures and other demand management options may be unfavorably received by water suppliers due to their concern about decreased revenue streams. Indeed, if the plans are not managed properly, incentive rate structuring can cause financial instability and little water savings. The design of successful conservation pricing, however, includes provisions for the return of all payments in excess of fixed operation and maintenance charges to the agency or water provider, thus creating a dual incentive program. Areas in California, Utah, and New Mexico have implemented conservation plans and conservation pricing programs with these elements and have achieved nearly 85 percent customer satisfaction.[108]

In Georgia, it is conservatively estimated that water conservation could accomplish 10 percent reduction in future water use.[109] Other states, however, have set and met much higher reduction goals. Reductions as high as 20 percent of indoor water use and 54 percent of outdoor water use have been demonstrated and sustained through the implementation of comprehensive water conservation plans.[110] The City of Los Angeles, for example, has implemented a water conservation program that includes public education, funding to promote use of water-efficient appliances, ordinances that require water-efficient appliances in new construction and retrofitting prior to sale of residential and nonresidential property, and water rates that increase with consumption. As a result of this program, water consumption has remained level while the city's population has increased by 1 million (32 percent population growth from 1970 to 2000).[111]

California has undertaken one of the most ambitious conservation planning efforts in the country, creating a model that was recently proposed for use in the Atlanta metro area.[112] The California Urban Water Conservation Coalition (CUWCC) was established to assist 158 local and regional water agencies with water conservation planning (Figure 8). Guidelines and best management practices are identified by the CUWCC board and passed on to government agencies to implement. Marin County provides an example of the impact of the CUWCC's programs. The county adopted a resource management plan that incorporates innovative water conservation and recycling programs. Phased implementation of this plan has stabilized water demand at 1980 levels, averting the need for construction of a major new water supply pipeline.[113]

Figure 8. California Urban Water Conservation Council Overview[114]

- Created as a consortium of water suppliers and public advocacy groups to identify and implement cost-effective best management practices.
- ***BMPs endorsed by the Council***
  - Residential water surveys
  - Residential plumbing retrofits
  - System audits, leak detection and repair
  - Metering with commodity rates
  - Large landscape conservation
  - Residential ultra-low toilet replacement
  - High efficiency washing machine rebates
  - Commercial, industrial, and institutional conservation
  - Wholesale agency assistance
  - Conservation pricing
  - Water waste prohibition
- ***Cost effectiveness of BMPs***
  - All BMPs cost $0.46 to $1.40 per 1, 000 gallons saved
  - Many utilities pay $1.40 per gallon or more for supply
  - BMPs are only required when the agency's avoided cost of water is higher than the cost per acre foot of the BMP program
- ***Progress of the CUWCC to date***
  - $70 million spent annually on conservation
  - More than 2 million high-efficiency toilets installed
  - Metro Water District service area in Southern California using same amount of water as 1984 with 3 million more people

Supply Management

Supply management options address existing supplies as well as identification of additional sources of water. A basic element is maintenance of current sources and reservoir storage capacity through recharge area protection and reduction of erosion and sedimentation. Other options include use of excess reservoir storage or well capacity, managing return flows to offset withdrawals, and treating water sources with marginal water quality (Table 2).

Recycled water and reclaimed/reused wastewater can also be a source of additional supply. These options offer advantages such as a high reliability of supply, a known quality, and often a centralized source near urban demand centers where the water can be used readily for domestic and commercial irrigation or other uses.[115] In Georgia's coastal counties, for example, application of reclaimed water for golf course and agricultural irrigation was recently recommended to enhance water supplies.[116] Currently, the President Street Water Quality Control Facility in Savannah supplies reclaimed/reuse water to a golf course on Hutchinson Island, a process that can easily be applied in other areas with large irrigated landscapes. Beyond the net water savings, water recycling and reclamation can also reduce annual sewer and energy costs.[117]

Table 2. Alternatives for water supply and demand management
(with relative environmental impacts in parentheses: A = lowest impact; F = greatest impact)

Demand Management (conservation and water use efficiency)	**Supply Management**
Indoor residential (A) - low flow faucets/showerheads - low flow toilets - front-load washing machines - full loads for dish and clothes washers	Maintenance of existing reservoir storage capacity (A)
Outdoor residential (A) - water efficient/low impact landscaping - sprinkler management - mulching	Commercial and industrial (A) - recycle - water reclamation and reuse
Leakage/unaccounted loss (A) - water supply upgrade/maintenance - wastewater distribution upgrade/maintenance	Purchase water from nearby utilities or large users during drought (A-B)
Water use audits (A)	Wastewater augmentation to streams to maintain instream flow with increased withdrawal (B)
Drought management strategy (A)	Contracted flow augmentation from upstream and downstream reservoirs (B)
Conservation rate structure (A)	Excess capacity of existing wells (B)
Agricultural (A) - irrigation system management - low water demand crops - no-till cropping system	New lagoon, completely off-stream, filled during high flow (B)
	Conversion to groundwater supply (B-C depending on region)
	Treatment of low quality water sources (e.g., desalinization) (B-C)
	Expanded reservoir capacity (C)
	Utilization of existing streams during drought with equal return flow, provided no net change of streamflow (C-D)
	New reservoir construction (D-F)

In Fulton County, the Cauley Creek Water Reclamation Facility treats county wastewater and provides it to customers for irrigation use.[118] The first of its kind in Georgia, the facility is a public-private partnership that currently sells 2.5 mgd to a variety of commercial and institutional customers. Water from the facility is not treated to the level required for drinking water but does exceed EPD's urban water reuse standards. Rather than using potable water for irrigation, reclaimed water is used on golf courses and other landscapes, saving energy as well as decreasing the demand on local water supplies. However, because irrigation is a consumptive use (i.e., water is returned to the atmosphere rather than the source), the treated wastewater is not directly returned to the river system, an important tradeoff in use of reclaimed water. Reclaimed water that substitutes for existing uses does reduce the need for water withdrawal, but to help protect the viability of stream systems, potential increases in consumptive water use should also be considered.

Demand management, improved efficiency of use, more effective use of existing supplies, and identification of alternative sources can all contribute to meeting Georgia's future water needs with minimum environmental impact. Accomplishing this goal will require an array of solutions, including use of existing and new technologies to tap the range of supply options available in a given area. Various programs from communities in Georgia and other parts of the country provide successful models on which to draw.

EVALUATION OF WATER SUPPLY ALTERNATIVES

When non-structural programs and additional supplies are included, the array of potential water supply options can be large (Table 2). Each option that can meet part of the projected demand has development costs, environmental costs, and risks in the reliability of supply in drought years. Water supply alternatives analysis provides the means by which sets of options that meet the full demand can be identified and systematically compared.

The goal of a full water supply alternatives analysis is to identify the alternatives that cost-effectively meet water needs while minimizing negative environmental impacts, including those associated with reservoirs and altered stream flows. This approach is consistent with federal Clean Water Act requirements that a permit can only be issued for the water supply alternative with minimum environmental damage and practicable cost (Section 404). Moreover, since conservation options have low impact and, per unit of water, are typically less than half the cost of new reservoir construction, taxpayers are given the opportunity to identify alternatives that may better meet their needs.

A procedure for a full alternatives analysis is outlined in Figure 9.[119] In this procedure, all demand management and supply options are first identified and tabulated with their relevant information including total yield, start date, unit cost ($/mgd), and relative environmental impact category (see Table 2 for representative options and their relative environmental impact). Then, an alternative is formulated by selecting several of these options from the table so that the cumulative supply from the selected options always meets the water demand over the planning period. If the options are selected from the table in order of least environmental impact (regardless of cost), then the resulting alternative is the minimum impact alternative. If the options are selected in order of least unit cost (regardless of impact), then the resulting alternative is the least cost alternative.

Figure 9. Identifying "practicable cost" alternatives with minimum environmental impact[120]

1. Project the future water supply needs by water use category.
   - Define a local water supply service area that does not overlap with others.
   - Project water supply needs for 30 years based on drought conditions and an approved drought management strategy.
   - Project water needs for individual categories of use, including indoor residential, indoor commercial, industrial, leakage and unaccounted loss, and outdoor use, following the drought management strategy.
   - Indicate whether rate structure promotes water conservation.
   - Show wastewater quantity produced during droughts as a potential water supply source for limited uses.
2. Identify the water supply options.
   - Identify the water conservation, demand management, or supply increase options with the amount of water saved or produced by each.
   - Estimate the full costs and relative environmental impact category (e.g., low, medium, high) of each option.
   - List the options in order of lowest unit cost.
3. Formulate the water supply alternatives.
   - Formulate the least-impact alternative by selecting the low-impact options identified in step 2, in order of lowest unit cost, phased in over time to match supply with demand. Continue adding options, going secondly to the medium-impact options, until supply meets demand.
   - Calculate total cost for the least-impact alternative. If too expensive, then formulate other alternatives by removing options with highest unit costs and then adding medium-impact options in order of lowest cost.
   - High-impact options, such as reservoirs, should be included in an alternative only if alternatives formulated using the low- and medium-impact options are not feasible. If high impact-options must be included, show the year when they will first be needed.
4. Repeat the analysis for a watershed or regional service area and then compare local and regional alternatives.

What is required to meet the conditions for a 404 permit, however, is something between these two: an alternative that reflects both environmental and cost objectives. This choice is called the least environmentally damaging practicable alternative (i.e., it must be workable considering cost). It is formulated by modifying the minimum impact alternative as necessary to reduce the total cost to a practicable level. The modification is made by removing the most expensive low-impact options from the selected set and replacing them with lower cost, but higher impact, options until the total cost becomes manageable. The issue of what is "practicable cost" has not been clearly addressed by the United States Environmental Protection Agency, but it would be at least equivalent to what has already been implemented in Georgia — at least $3.5 million for each million gallons of water per day.

The method outlined here provides for meeting water demands over every year of the planning period, including during drought events. It can also provide for maintenance of natural stream flow patterns during droughts. The need to meet demand and maintain instream flow during drought has frequently been used as justification for building reservoirs as the primary water supply solution. While reservoirs do help ensure that demand can be met under these conditions, they do not provide a guarantee. And, as indicated in Table 2, they are not the only option that can meet these needs.

The method presented here also allows phasing of water conservation and water supply options over time as needed to meet increasing demands, thereby reducing the up-front financing costs and better tailoring cost increases to the increases in the number of ratepayers over time. Finally, this method meets the requirements of the Clean Water Act Section 404, which specifies that only the least environmentally damaging practicable alternative should be permitted.

IMPLEMENTING COMPREHENSIVE WATER SUPPLY PLANNING IN GEORIGA

In summary, water supply planning that starts with a broad definition of purpose, identifies a wide range of demand management and supply options, and incorporates a full alternatives analysis can provide multiple benefits. Incorporating multiple options, rather than selecting a single structural option, allows phasing of increased supply with increased demand, which can minimize costs overall. And, with an incremental approach using conservation options, water savings can be achieved immediately. In the systematic comparison of alternatives, environmental costs are considered as well as economic costs. Finally, these elements follow sound planning practice and completion of a full alternatives analysis can help minimize regulatory issues and costly delays in achieving a secure water supply.

Several factors make this an opportune time to shift water supply planning in Georgia toward a more comprehensive approach. The first, of course, is the benefits that can be gained from this approach. More importantly, there is the growing challenge of meeting multiple demands and needs for water, including the water needed to sustain healthy streams and rivers and the services that they provide. As described in Part I, reservoirs impair many of the services that free-flowing streams and rivers provide. With increasing pressures on Georgia's water resources, it becomes more critical to avoid the consequences of inadequate planning and failure to identify less damaging alternatives.

Finally, this is a period of adaptation in state water policy in general.[121] New information on the number of reservoirs and the potential significance of cumulative impacts suggests that it is also time for adaptation in state policy regarding water supply planning, including reservoir policies that were formulated during the 1980s.[122] The focus of an updated regional reservoir program, for example, should be framed as areas where water supply alternatives are needed rather than casting the problem as areas where reservoirs are needed. Similarly, current review of the state's interim instream flow policy should include assessment of the effectiveness of variable flow requirements, implications for required back-up storage, and other ways to meet the goal of protecting adequate streamflows for aquatic needs. In addition, local governments would benefit from a water planning process that gives them the tools and methodologies for more comprehensive consideration of water supply options and comparison of alternatives. Such adaptation would help meet the complementary goals of providing for future water needs while minimizing negative impacts on the services provided by the state's streams and rivers.

Given our current knowledge, the best way to maintain the services provided by free-flowing streams is to seek alternatives to reservoir storage, where practicable. Doing so will require a shift from water supply planning practices typical in Georgia to date. Elements of such a shift have been demonstrated in several local or regional initiatives in Georgia, and programs here and in other parts of the country provide models on which to draw. Experience in Georgia and elsewhere indicates that, through water supply planning that looks to nonstructural sources first, Georgia can reduce or postpone extensive infrastructure expansion in order to meet increasing water demands.[123] In short, water supply planning to minimize environmental impacts and costs while meeting future water needs is clearly feasible, builds on positive trends already under way, and can yield multiple benefits for Georgians now and in the future.

Contributor Biographical Sketches

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Bud Freeman is a Senior Public Service Associate at The University of Georgia's Institute of Ecology and the Curator of Zoology Collections for the Georgia Museum of Natural History. Dr. Freeman is one of the foremost experts on fish species native to Georgia. Dr. Freeman's research focuses on the distribution and abundance of fishes endemic to southeastern systems, in the context of preserving species diversity, and function in streams and rivers increasingly affected by human population development; quantifying basin characteristics in southeastern watersheds harboring remnant endemic communities; and systematics and taxonomy of southeastern freshwater fishes.

Mary Freeman is a Research Ecologist with the USGS Patuxent Wildlife Research Center. Current projects include an investigation of the land use and geomorphic indicators of biotic integrity in Piedmont streams and an analyses of the effects of instream flow depletion on biological integrity of stream fish communities. Dr. Freeman is part of a multidisciplinary team that is examining the relationship of fish abundance and diversity to habitat availability and stability in a flow regulated southeastern U.S. river system.

Kathy Hatcher is a Public Service Assistant with The University of Georgia's Institute of Ecology. Her research and outreach projects include water resources planning and management; quantitative analysis of decision alternatives for decision making; computer models for predicting natural resources systems' responses; procedures for designing efficient data collection programs and environmental management studies; environmental ethics framework. Dr. Hatcher organizes Georgia's Water Resources Conference.

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Alice Miller Keyes has been an environmental policy analyst with The Georgia Conservancy since June 1999. She is responsible for keeping up with statewide water-related issues and for developing initiatives, focusing primarily on watershed based water resource protection and water use and conservation. Prior to joining The Georgia Conservancy, Alice worked as a research assistant on water policy and management issues while earning a Masters of Science from the University of Georgia, Institute of Ecology. Her masters research at the UGA was largely focused on watershed management and planning in Georgia and the Southeast. Alice has also worked in environmental consulting and served with the national service organization AmeriCorps, gaining valuable experience with geographic information systems, streambank restoration/rehabilitation, water quality monitoring and aquatic habitat assessments.

Michael Merrill graduated with a M.S. in Conservation Ecology and Sustainable Development from the Institute of Ecology at the University of Georgia, Athens. His M.S. thesis examined the local and watershed influences on stream fish biotic integrity in the Upper Oconee Watershed in the Georgia Piedmont. He is currently the River Restore Technical Coordinator for the Massachusetts Department of Fish and Wildlife Riverways Program. River Restore is dedicated to reconnecting natural and cultural river communities by selective removal of dams.

Judy L. Meyer is the Director for Science of the River Basin Science and Policy Center, and Distinguished Research Professor in the Institute of Ecology at UGA. A member of the faculty at UGA since 1977, she is an aquatic ecologist who has published over 125 scientific papers on her research on rivers and streams in Georgia and North Carolina. Her research has focused on ecological processes that maintain water quality, on river and stream food webs, and on the impact of watershed disturbance and riparian zone management on river and stream ecosystems. Dr. Meyer has served as Vice-president and as President of the Ecological Society of America, the national organization for professional ecologists. She was elected as a Fellow of the American Association for the Advancement of Science and is currently a member of EPA's Science Advisory Board.

Ellen Sutherland has been the Executive Director of the Georgia River Network for the last two years. She works with watershed groups across the state providing educational training opportunities, strategic planning facilitation, and in-depth water policy analyses. She received her M.S. in Conservation Ecology & Sustainable Development and her B.S. in Ecology from the University of Georgia.

Seth Wenger performs applied ecological research and environmental policy development for UGA's Office of Public Service and Outreach at the Institute of Ecology. His current projects include: researching the impacts of urban growth on imperiled fishes; assisting in the development of a greenspace protection plan for Gwinnett County; Georgia; serving on a state committee to evaluate environmental planning regulations; and working on the development of a Habitat Conservation Plan for the imperiled species of the Etowah River Basin. Past projects included development of scientifically-based guidelines for riparian buffer protection in Georgia and a study of the water quality impacts of various growth management policies.

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