The Second
D. R. F. Harleman Honorary Lecture in
Environmental Fluid Mechanics

The Role of Reservoirs in the Sustainable Water Resources Development In the United States

By

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Applied Research Auditorium

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University Park, PA 16802

DONALD R. F. HARLEMAN HONORARY

LECTURE IN ENVIRONMENTAL FLUD MECHANICS

The Harleman Lecture serves to honor Dr. Donald R. F. Harleman, who distinguished himself in the fields of hydraulics and environmental engineering as a student and a member of the faculty at the Massachusetts Institute of Technology (MIT) from 1945 though 1991, when he retired as processor emeritus. He currently holds the title of Senior Lecturer at MIT.

The Lecture was established by an initial grant in November of 2001 from Joseph R. Reed, Professor Emeritus of Civil Engineering at Penn State. It was formally approved in February 2002 by the University's Board of Trustees as the "Donald R. F. Harleman Endowment in Environmental Fluid Mechanics". The Endowment will be supplemented in the future though an estate plan bequest made by Dr. Harleman in July 2002.

The Harleman Lecture is intended not only to enrich the faculty and students in the hydrosystems division of Penn State's Civil and Environmental Engineering Department, but also the entire engineering community external to the Department as well, by providing contact with outstanding researchers and practitioners in the field from outside the University. The lecture will be a fall semester parallel to the very successful Kavanagh lecture in Structural Engineering established in 1994 and held annually in the spring.

PROGRAM

Opening Remarks .... Dr. Arthur C. Miller

Professor of Civil Engineering
The Pennsylvania State University

Welcome .... Dr. Andrew Scanlon

Professor and Head
Civil & Environmental Engineering

Introduction of Speaker .... Dr. Arthur C. Miller

Professor of Civil Engineering
The Pennsylvania State University

Harleman Honorary Lecture ....William B. Bingham, P.E.

Vice President
Gannett Fleming, Inc.

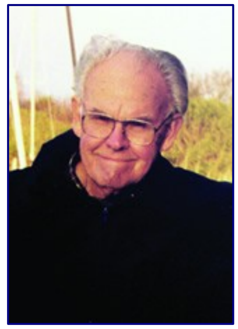
Questions and Answers..Dr. Miller and Mr. Bingham

Presentation...Dr. Miller

Closing Remarks..Dr. Miller

Reception

Donald R. F. Harleman



Donald R. F. Harleman, a native of Palmerton, PA, received his B.S.C.E. degree from Penn State in 1943 and his M.S. and Sc.D. degrees in Civil Engineering in 1947 and 1950 from the Massachusetts Institute of Technology (MIT). He worked as a design engineer for Curtis-Wright Corporation in Ohio during WWII. Through 1962 he held research and faculty positions in Hydraulics at MIT, and in 1963 he became Profession of Civil Engineering. He was appointed Ford Professor of Environmental Engineering in 1975, and achieved Emeritus status in 1991. He currently holds the title of Senior Lecturer at MIT.

Dr. Harleman has been an active member of the National Academy of Engineering and is an Honorary Member of the American Society of Civil Engineers (A.S.C.E.). He has won six (6) A.S.C.E. awards, including two (2) Hilgard Hydraulic Prizes in 1971 and 1973, and a Stevens Awards in 1973. The Boston Society of Civil Engineers has honored him with three (3) awards with the latest being in 1990, and he has received two (2) awards from the College of Engineering at Penn State as Outstanding Alumnus in 1979 and as a Alumni Fellow in 1987. He has served as a member of the Board of Editors of the international *Journal of Hydraulic Research,* and was a member and Chairman of the Executive Committee of the Hydraulics Division of A.S.C.E. in the 1960's. He has spent residence time overseas as a visiting engineer at the Delft Hydraulics Laboratory in the Netherlands and at the International Institute for Applied Systems Analysis in Austria, as well as being a Guggenheim Fellow in the Department of Applied Mathematics and theoretical Physics at the University of Cambridge, England. He gave the First Hunter Rouse Hydraulic Engineering Lecturer for A.S.C.E. in 1980.

For ten (10) years beginning in 1973, Don Harleman was the Director of the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics. During that same period, he was the head of the Water Resources and Environmental Engineering Division of MIT's Department of Civil Engineering. He has a very extensive record of research, publications and consulting on a national and international level. His current consulting takes him occasionally to Mexico, Hong Kong, Italy, and Brazil.

Don Harleman is a co-holder of two (2) U.S. patents in hydraulics and environmental engineering. He is the co-author of the 1968 textbook *Fluid Dynamics*, and also the author of "Stratified Flow" in Streeter's 1960 *Handbook of Fluid Dynamics.* The Donald and Martha Harleman Professorship at MIT was established in 2000 through an endowment raised by his friends and former students.

The Role of Reservoirs in
Sustainable Water Resources Development in the United States

Abstract

Dams and reservoirs have played a major role in the development of sustainable water resources for mankind for more than 5000 years. The first known man-made reservoir dates back to the drinking water reservoir of Jawa in Jordan (3200 BC). During more modern times in the United States, the development of the west would not have been possible without the multitude of dams and reservoirs constructed in the last century. Over the past two decades, in particular, planning activities for new dams and reservoirs have come under increasingly rigorous scrutiny and analysis of adverse impacts and have resulted in new and more comprehensive approaches to the development of dams and reservoirs.

This lecture will examine the role of dams and reservoirs as we seek to meet the ever increasing demands for more water for our growing population and at the same time preserve the environment for future generations. The lecture will discuss the historical development of dams and reservoirs to lay a foundation for understanding our nation's current water resources needs and some of the projects. We will examine the current state of our nation's water resources programs, how they compare with other parts of the world, and how we must find new approaches to meeting our needs.

Water resources development in the United States is definitely at a crossroads. Regulations that govern the construction of new dams and reservoirs have made projects on major river systems very difficult if not impossible to implement. Yet, our population continues to grow and water demands continue to escalate.

More and more water resource agencies are turning to "off river" alternatives such as pumped storage projects. While these pumped storage projects may be more costly to construct and operate, they often represent an opportunity that will have a significantly lower adverse impact on ecological, cultural and historical resources. Two of these projects will be discussed that demonstrate many of the issues that must be addressed. The projects are similar in that they are both successful, "off stream" reservoir projects for water supply, but there the similarities cease. Olivenhain Dam, a 320 feet high roller-compacted concrete gravity dam, is located in a dry canyon in San Diego County, California. Hunting Run Dam is a 90 feet high dam in Spotsylvania County, Virginia.

Olivenhain Dam is the key feature of what the San Diego County Water Authority (SDCWA) refers to as the Emergency Storage Project (ESP). SDCWA imports more that 90 percent of its water from the Metropolitan Water District in Los Angeles to the north, through two major aqueduct systems that cross many active faults, making the aqueducts and San Diego vulnerable in the event of a major earthquake. Should an earthquake damage the aqueducts, it is estimated that a severe water shortage could last for six months while repairs are made. The $827 million ESP was devised to meet the needs of the region for the six month period. Operational and hydraulic modeling studies of the region led to the selection of the components of the ESP including Olivenhain Dam, raising a second existing dam, various large pipelines, pump stations and water tunnels.

The Hunting Run Dam is a key feature of a $50 million water supply project for Spotsylvania County, Virginia, near Fredericksburg. The county is located just 40 miles south of Washington D.C. and continues to experience significant population growth and increased demands for more water. The Hunting Run Dam will create a water supply reservoir that will store water pumped from the Rappahannock River during times of high flow and is located "off stream" in a very small watershed.

The lecture will use these two case studies to present the engineering design issues that the water resources engineer must address today as well as the social environmental and cultural issues that are often more difficult than the intricacies of design.

The Role of Reservoirs in
Sustainable Water Resources Development in the United States

Introduction

Water, it's what we live for. In fact it is why we live. Our earth is often referred to as "the water planet", yet we seem to be in need of a safe supply of water in so many places in the world today. While we live on the "water planet", in fact we live in a world of salt. Nearly 97.5 percent of the earth's water is saltwater, another 1.7 percent is locked up in glaciers and permanent snow cover leaving less than 1 percent fresh water that is readily available for our use.

Water remains the most vital resource to sustain our civilization. Where water has been available and developed, civilizations have flourished. Yet rainfall and runoff are neither evenly distributed by location nor season, which creates a need to develop solutions to address the imbalance between demand and availability. Dams and reservoirs have been used successfully to collect, store and manage water in watersheds for centuries.

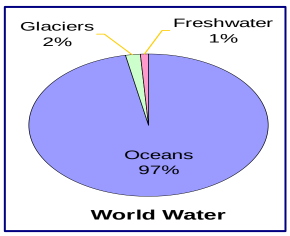


Figure 2

According to recent studies more than 1.1 billion people worldwide do not have access to safe drinking water, including 627 million in Asia and 381 million in Africa. In the 1990's the annual mortality rate for water borne diseases was more than 5.3 million persons. Today more than 3.5 million children die every year from waterborne diseases.

As the world's population grows these problems will only get worse. By 2050 the UN estimates that the world population is likely to be about 8.9 billion. Perhaps as important is the fact that water consumption per capita in the last 50 years has increased about two-fold. So the math is pretty simple. We must increase our supplies or there will be less to use per capita. Compounding the situation, is the fact that the parts of the world with the fastest growing populations are the areas with the most severe water problems. These include Asia, Africa, Mexico and the Middle East. The Middle East is the most volatile and water shortages alone there could lead to war. Even in the United States 8 of the 10 fastest growing cities are in the arid west, with leader Las Vegas growing at 83 percent in the decade of the 90's.

Availability of water has always been crucial to development and for almost 5,000 years, dams have served mankind to ensure adequate supplies of water to sustain the world's population. The Jawa Dams built in Jordan about 3000 BC, were the first well documented dams and were part of an elaborate water supply system for 2000 people. One of the first known large dam and reservoir projects was built in Egypt near Helwan, about 20 miles south of Cairo.[1] There still exist remains of this dam known as the "Sadd el-Kafara", an Arabic name meaning: "Dam of the Pagans". This rubble masonry dam was not a small structure, but was nearly 350 feet long and 37 feet high. Although most ancient dams were for irrigation, it is believed that the "Sadd el-Kafara" was for water supply for a nearby alabaster quarry. The remains of the dam suggest that it may have been poorly constructed and may or may not have had a spillway to safely discharge floodwaters.[2] There appeared to be no watertight upstream face and no foundation cutoff. It is reported that the dam was washed away by floodwaters during construction.[3] So you see, even 5000 years ago the first dam engineer had to be concerned with hydrology and hydraulics, construction materials and methods and the dam's foundation. The earliest dams in the Americas date back to the pre Columbian period in Central and South America by the Aztecs, Mayas and Incas. Dam building in the United States actually began in what is now Arizona and New Mexico as an extension of irrigation works that were built in central Mexico. These dams were small simple structures built by the Native Americans. In the early 1600's timber crib dams were built to power early mills in New England. By 1869 the City of New York had a population in excess of 1 million and had built the Croton Aqueduct System.

Dams have become an integral part of our infrastructure and worldwide have enhanced the quality of life. Today there are more than 76,000 dams in the National Inventory of Dams, compiled by the U S Army, Corps of Engineers. Dams in the United States provide many benefits: irrigation, water supply, flood control, hydropower, navigation and recreation. Only 2% of dams in the U.S. are over 100 feet high, and more than 38,000 are under 25 feet. About 55% of dams in the U.S. are privately owned and the most common primary purpose of dams is recreation.

[1] Smith, Norman, "A History of Dams", The Citadel Press, 1972
[2] Smith, Norman, "A History of Dams", The Citadel Press, 1972
[3] Jackson, D. C., "Dams, Studies in the History of Civil Engineering", Ashgate Publishing Company, 1997

U.S. Water Resources 1930 to 1970

The objectives for the nation's infrastructure of dams, levees, navigation systems and diversions for water were developed between 1930 and 1970, with an emphasis on water for agriculture, electric power, navigation, flood prevention, water for cities and industry and dilution of wastes. These objectives are still valid, but the values and laws under which these systems operate today have a number of added objectives: enhancement of aquatic and streamside or riparian habitat, recreational opportunities and a general desire for preservation of natural environments for future generations. These challenges will require scientists to collaborate with water managers to predict how changes in the management of our water infrastructure will affect its traditional goals and serve the newer environmental goals.

In the past groundwater provided much of our domestic and industrial water supply, but today many of our aquifers are overused with the rate of recharge less than withdrawals. These groundwater supplies must be supplemented with reservoirs that store water when plentiful to be used when rainfall is low. This is particularly true in the arid west of the United States. Most of the US west of the 105th meridian is arid and receives less than 15 inches of precipitation per year yet much of our agriculture and food production lies there. In fact the story of the American West is the quest for water, which led to the large water resources development programs that were developed by the Bureau of Reclamation and the Corps of Engineers in the period spanning 1920 to 1970. While Reclamation celebrated its 110^{th} anniversary in 2002, its heyday was marked by the construction of large water projects during the Depression and the thirty-five years after World War II. Reclamation operates about 180 projects in the 17 Western States, mostly for irrigation, but also for water supply and hydropower. About 5 percent of the land area of the West is irrigated, and Reclamation provides water to about one-fifth of that acreage, about 9,120,000 acres. The Corps owns and operates 283 civil works dams in the United States, mostly for flood control and navigation. Basically, in the west, the Corps constructed flood control dams while Reclamation built the irrigation dams.

The Crossroads

Water Resources development in the United States and in fact the world is at a crossroads. The stress on our water systems will continue to worsen and our ability to solve the water needs will be challenged like never before. We have all experienced or read about the droughts of the past several years, were not confined to our arid west, but experienced here in Pennsylvania. Remember the water restrictions of 2001 and 2002? Drought continues today in the west and so does the growth of the population.

In order to sustain our quality of life we will be called upon to think and act differently than in the past. We must develop a more comprehensive water resources policy in the United States that encompasses all water uses and needs including water supply, irrigation, navigation hydropower, recreation and the environment. The rules have changed. This brings to mind Spencer Johnson's best selling book: "Someone moved my cheese!" [4] Only in the context of our nation's water resources , the cheese is water and the maze is the new environmental awareness framework within which all new major infrastructure projects must be implemented. Sustainability is the key word and while there is no universally accepted definition of sustainable water resources development I do like the definition proposed in an A.S.C.E. publication which states; "Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity."[5]

I believe that dams and reservoirs have a prominent role to play in developing sustainable water resources project in the years ahead. But the rules have changed. Regulations that govern the construction of dams and reservoirs have made projects on major river systems very difficult if not impossible to build. We must find new approaches to meeting our needs.

One new approach is presented in a United States Society on Dams (USSD) White Paper on Panning for Dams and Reservoirs.[6] This approach contends that successful decision-making and creditable project planning need to be founded on the values of equity, efficiency, accountability, sustainability, and participatory decision-making. These values of sustainability had begun to become the foundation of planning processes for dams and reservoirs in the United States during the late 1980's and early 1990's. More formally, these values were specifically identified in the report issued in 2000 by the World Commission on Dams (WCD). Under this scenario, meeting the needs of a society and achieving the purpose of a project are more important than the actual implementation of a particular project. This process is one that was followed by the SDCWA for their current Emergency Storage Project (ESP) discussed below.

[4] Johnson, Spencer, M.D., "Who Moved My Cheese?", G.P. Putnam & Sons, 1998
[5] A.S.C.E., "Sustainability Criteria for Water Resource Systems", 1998
[6] United States Society on Dams, Planning Processes for the Development of Dams and Reservoirs, Alternatives Analysis: A Framework for Successful Decision Making, 2003

The USSD White Paper summarizes the process as: "Responsible planning for dams and reservoirs requires decision-making and planning processes that are founded on the values of equity, efficiency, accountability, sustainability, and participatory decision-making. Alternatives development and screening processes need to be based on a well-defined statement of project need and purpose. The public needs to be directly involved in the development and workings of both of these processes. The purpose of the planning phase decision-making process is to effectively identify project alternatives that successfully meet the identified societal need and project purpose with an efficient investment of pubic resources. Accountability and public participation in this process lead to a decision that can be implemented and sustained. The process supports our professional responsibilities for stewardship and the sustainability of public resources in the development of dams and reservoirs for promoting and sustaining a healthy and prosperous society."[7]

As a result of these more comprehensive planning processes, more and more water resource agencies are turning to "off-river" alternatives such as pumped storage projects. While these pumped storage projects may be more costly to construct and operate, they often represent an opportunity that will have a significantly lower adverse impact on ecological, cultural and historical resources. Two of these projects will be discussed that demonstrate many of the issues that must be addressed. One of these projects is in the arid west, Southern California, and one is closer to home in the Middle Atlantic States in Virginia. The projects are similar in that they are both successful, "off stream" reservoir projects for water supply, but there the similarities cease. Olivenhain Dam, a 318 feet high roller-compacted concrete gravity dam, is located in a dry canyon in San Diego County, California. Hunting Run Dam is a 90 feet high composite earthfill and roller-compacted concrete gravity dam in Spotsylvania County, Virginia.

Olivenhain Dam

Figure 3

The San Diego County Water Authority (SDCWA) supplies water to nearly 3 million residents around San Diego County and supports the region's $126 billion economy (see Figure 3). San Diego is located in an arid desert climate and therefore must import most of its watersupply. About 90 percent of its water is supplied by the Metropolitan Water District of Southern California (MWD) in Los Angeles and is from California's State Water Project and the Colorado River. It is delivered to the SDCWA through the California State Water Project and the Colorado River Aqueduct. This water is brought 500 miles away from Northern California and 200 miles away from the Colorado River through the Colorado River Aqueduct to Riverside County by means of aqueducts and pipelines owned and operated by the California Department of Water Resources and the Metropolitan Water District of Southern California (MWD) (see Figure 4). Along the way the delivery system is vulnerable to both man made and natural hazards including sabotage, accidents, washouts and most significantly, earthquakes. The aqueducts cross several major faults as shown on Figure 5.

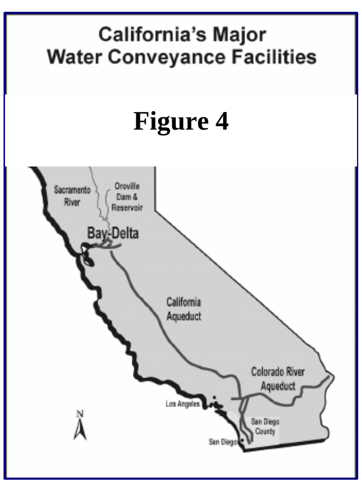


Figure 4

From Riverside County, treated and untreated water is delivered to the Authority's 23 member agencies through two major aqueduct systems consisting of five major pipelines owned and operated by the Authority that run north to south through San Diego County as shown in Figure 3. These member agencies include water districts and municipalities within the County, which provide retail water service for residential, agricultural, and business use.

Since a major earthquake could interrupt the County's imported water supply, the Authority is implementing an Emergency Storage Project (ESP) to ensure a prolonged interruption of normal imported water deliveries without lasting economic or environmental damage to its service area. Planning studies were performed during the 1990's that determined the need for a system of reservoirs, pump stations, and pipelines to provide water to the region if a water shortage emergency should occur. Plainly stated, the SDCWA determined that should a major earthquake occur the aqueducts could be out of service for a period of 6 months. To avoid the severe consequences, they determined a need for what they call the Emergency Storage

[7] United States Society on Dams, Planning Processes for the Development of Dams and Reservoirs, Alternatives Analysis: A Framework for Successful Decision Making, 2003

Project (ESP). Following detailed modeling studies, studies of construction costs and environmental impacts, the Authority selected a system identified as the ESP. The ESP final option was driven largely by environmental forces to avoid the development of a reservoir project on a major flowing river. The ESP includes

- the new Olivenhain Dam, which is a 318 feet high roller-compacted concrete dam that creates a 24,000 acre foot reservoir;
- a pipeline connecting the new reservoir to the Second Aqueduct;
- a pipeline connecting the new reservoir to the existing Lake Hodges;
- raising the existing San Vicente Dam by 54 feet for an additional 52,100 acre feet of water;
- a pipeline connecting San Vicente to the Second Aqueduct;
- five new pump stations and related facilities.

Figure 5

In all the ESP will be an $827 million investment over 10 years for water supply reliability. The conveyance portion of the ESP includes approximately 20 miles of new pipelines and pump stations initially sized from 10,000 to 30,000 horsepower. These facilities will be constructed to deliver water from these three reservoirs – Olivenhain, Hodges, and San Vicente to the Authority's aqueducts and member agencies during an emergency.

The Olivenhain Dam and Reservoir project is Phase 1 of a four phase project that should be complete by 2010. The reservoir began to fill on August 6, 2003, as the gates in the intake/outlet tower were opened to bring in water from the second aquaduct. The dam was dedicated on September 4, 2003.

Phase two of the ESP is an 11-mile long tunnel, pipeline and pump station connecting the San Vicente Reservoir to the Water Authority's second aqueduct. The San Vicente Pipeline will allow the Water Authority to move water anywhere in the region it is needed. Phase three is the completion of a pipeline and pump stations connecting Lake Hodges and the Olivenhain Reservoir. This will allow the Water Authority to pump water into Lake Hodges and maintain the lake at a constant water level. The Lake Hodges connection is scheduled for 2008 and will provide an additional 20,000 acre-feet of water storage. The final phase will raise the San Vicente Dam 54 feet to provide an additional 52,000 acre-feet of water storage.

Olivenhain Design

The dam was designed as a concrete gravity dam constructed using roller-compacted concrete (RCC) placing methods. RCC methods allowed a quicker and more economical dam construction (as compared to conventional concrete placing methods) using limited forming on the upstream and downstream faces, only. The zero-slump concrete is placed in one-foot "lifts" and compacted with a 10-ton vibratory roller, much like conventional earthfill embankment dam construction. RCC gets its economy from a fast placement schedule, as the zero-slump concrete will support heavy construction equipment immediately after placement. Each subsequent lift was placed as quickly as possible. RCC was placed 24-hours a day, seven days a week. The Olivenhain Dam is the first RCC gravity dam permitted by the state of California and, with a height of 318 feet (97 meters) and RCC volume of 1.44 million cubic yards (1.1 million cubic meters), is the tallest RCC dam in the North America. The project design was performed by the Parsons-Harza Design Team, a joint venture. Gannett Fleming was a major subconsultant to the design team and was responsible for RCC materials investigation, RCC mix design, RCC thermal stress modeling, dam facing system design, foundation gallery design, instrumentation system design and related construction phase services.

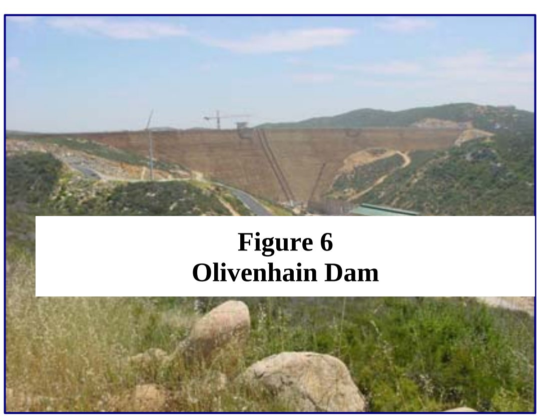


Figure 6
Olivenhain Dam

The Olivenhain Dam has the typical geometry for concrete gravity dams with a vertical upstream face and a 0.8:1 sloping downstream face with the point of intersection with the upstream face at the dam crest. The crest width is 20-feet (6.1 meters) with a crest length of about 2,570 feet (783 meters).

The dam is located in a closed watershed, creating a reservoir that will require filling from the Authority's raw water supply aqueducts. The 407-acre watershed that includes a 201-acre reservoir surface (at maximum normal maximum pool) has a Probable Maximum Flood (PMF) peak inflow of 7,891 cfs based on a 6-hour local storm

Probable Maximum Precipitation (PMP) of 11.4 inches. The total "Local Storm" PMF runoff volume is 386-acre-feet, which could be totally contained within the reservoir without spilling. A 25-foot wide uncontrolled overflow spillway is provided, however, in the unlikely event of failure of the reservoir filling pumps to shutoff. The spillway is sized for 350 cfs capacity, which is the same as the maximum capacity of the filling pumps. To accommodate its multi-use role, the project operates two separate inlet/outlet structures – one at the dam for flows to and from the Authority's aqueduct supply line and flows to the treatment plant; and a separate structure on the reservoir rim that makes a vital hydraulic connection to the nearby Lake Hodges. A portion of the existing Lake Hodges reservoir is being reallocated for the ESP. There is currently no hydraulic connection from the reservoir to the Authority's aqueduct system. The Hodges Headworks Structure was built as part of the dam construction though the full utilization of Lake Hodges storage for the ESP is scheduled for a later implementation phase, about 2007.

The primary design objective is for the dam to survive a large seismic event and remain fully operational. The seismic design event is a 7.25 magnitude event on the nearby Rose Canyon Fault, about 17.8 km distant. This event would create a peak acceleration of 0.244g horizontal and 0.193g vertical.

The dam and reservoir are primarily underlain by the Escondido Creek Granodiorite of early Cretaceous age. The rock is light gray and fine-grained and weathers to a light tan color, but exhibits a light gray color on freshly broken surfaces. Depths of excavation ranged from a minimum of 15 feet to somewhat less than 100 feet in the left abutment saddle area. The values of the foundation grade selected during site investigations were accurate generally within a few feet.

The structural design to optimize seismic performance of Olivenhain Dam began with conventional two-dimensional, static stability analyses to provide a solid foundation of analytical investigation to give the dam general shape and function. Optimization of the dam addressed several areas, including:

- A curvilinear "chimney section" to minimize stress concentrations at the downstream face;
- A foundation profile excavated to "line and grade" to minimize uneven foundation surface typical when excavating to a particular quality of rock; and
- Foundation "shaping blocks" to accommodate two topographic low reaches along the dam axis, allowing for a continuously diminishing cross-section towards each abutment.
- A flexible PVC geomembrane upstream facing system.

This optimization of the dam was accompanied by detailed analyses to predict peak stresses in the dam in order to develop RCC material properties and construction methods. The dam has a curved downstream face at the top, which allows the principal stresses to vary uniformly rather than abruptly.

Based on a detailed evaluation of dam facing systems, a geomembrane system was selected for the upstream face of the dam. There is little doubt that use of geomembrane liners in dam construction represents a significant change in the practice of concrete dam design and construction in the United States; a change that has been resisted by some practitioners. There are certainly numerous examples of concrete dams, including roller-compacted concrete, that are performing acceptably well without a geomembrane liner. However, RCC technology has significantly changed the design, construction, and performance of concrete dams. Several of the early RCC dams had significant cracking and/or leakage problems that resulted in significant concern and/or cost to the owner to either investigate or construct repairs to remediate the problems at each dam. Cracking and seepage in RCC dams has not been limited to only the early dams constructed in the 1980's. In fact, there are current examples worldwide of RCC dams with concrete facing systems that have experienced cracking significant enough to warrant investigation of potential repair methods. With few exceptions, geomembrane-lined dams worldwide exhibit a high level of performance, typified by low seepage quantities and large pore pressure reduction at the upstream face. Since the early 1990's, geomembrane liners have and are being used on a higher percentage of RCC dams due to these performance characteristics.

The downstream face of any dam is typically the most noticeable feature of the entire project. This is especially true for a large concrete gravity dam like Olivenhain. The issue of aesthetics has been very important to the public and residents near the Olivenhain Dam project site. The future reservoir is surrounded by a forest preserve with hiking, biking, and horseback trails leading to the reservoir perimeter and there is ongoing development of 500 private residences within the ridge tops surrounding the dam site. The environmental mitigation plan for the project stipulated the requirement that "Structures including the dam shall be colored and/or painted to blend with the surrounding environment".

The use of either pigmented pre-cast concrete blocks or staining of formed RCC was considered for the downstream face for this project. Both options were noted to have the benefit of being essentially maintenance free since concrete color additives or staining permanently alter the color of the concrete. For this project, either pigmentation option was comparable in cost. Since RCC against formwork was the preferred facing alternative, a stain was applied to the downstream face so that the dam's color blended into the natural surrounding landscape. The total cost for this alternative, including pigmentation, was $2.9 million.

Cracking is always a concern for RCC dams and we performed non-linear incremental stress-strain analyses to predict the potential for cracking in both the transverse and longitudinal directions. The results of the analyses were used to determine the appropriate contraction joint spacing and pre cooling temperature for the RCC. The information gained from these thermal stress analyses was used to specify minimum RCC mixing plant capacity, maximum RCC placement temperature, and RCC placement milestone dates. This information was also used in conjunction with an evaluation of the foundation rock profile to establish the number of and the stationing for the transverse contraction joints. The recommended transverse contraction joint spacing varied from 125 feet in the taller central portion of the dam to approximately 75 feet near the abutments where foundation restraint is relatively greater. To improve the factor of safety against cracking potential, a Type II cement with a heat of hydration limit of 80 calories per gram at 7 days was specified.

Since all of the design phase thermal analyses must rely on averaging of historic climatic data, estimated RCC heat generation and hypothetical estimates of RCC production rates and placement milestone dates, the thermal modeling was re-evaluated during the course of the construction phase to account for actual construction conditions and changes in the mix design.

Hydraulic design considerations for the dam and reservoir operational features include the following:

- Emergency water supply in case of a catastrophic regional earthquake or drought (primary purpose);
- Storage for daily use by the Olivenhain Municipal Water District water treatment plant located immediately downstream of the dam;
- Regional storage for excess seasonal flows in the nearby Lake Hodges reservoir;
- Make-up water source for the nearby Lake Hodges reservoir;
- Conveyance facility to move water from Lake Hodges reservoir to Authority's aqueduct system during an emergency;
- Potential upper reservoir for a pumped-storage electric energy generation system with Lake Hodges reservoir.

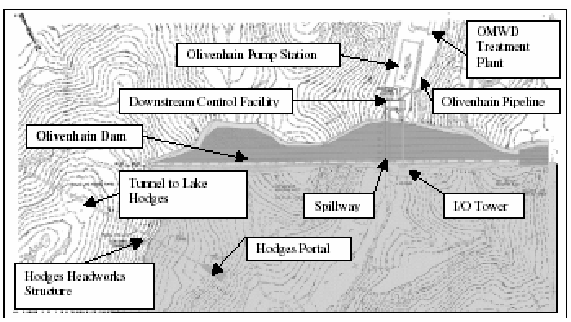


Figure 7

There are three primary water control structures associated with the Olivenhain Dam to address these design considerations: a spillway, the Dam I/O Works with associated downstream valving at the dam, and the Lake Hodges Headworks Structure for flow between the Olivenhain Reservoir and Lake Hodges.

The I/O facilities at the Olivenhain Dam and Reservoir control water into and out of the Olivenhain Reservoir. There are two locations that water can enter or exit the reservoir – at the dam or at the Hodges Headworks Structure. At the dam, an 84-inch diameter "I/O Pipe" connects the Olivenhain Dam to the Authority's new Olivenhain Pump Station located immediately downstream of the dam.

Inlet/Outlet Tower

At the upstream (reservoir) side of the dam, the Inlet/Outlet (I/O) Pipe exits into the "I/O Tower". The I/O Tower is a 303-foot high structure with three main walls. The walls are six-feet thick near the bottom and four feet thick at the top. The tower controls the specific level in the reservoir where water is inserted or drained. This is important because the reservoir will have different levels of water quality varying vertically within the water column. For example, cold water is heavier than warm water, so the reservoir will have colder water at the bottom and warmer water at the surface. When introducing water into the reservoir, the operator will have the flexibility to selectively fill and drain water at levels that meet water quality requirements. This minimizes the potential of taste and odor problems often associated with reservoirs in Southern California and helps manage the reservoir water quality.

Fish Screens: Each of the three main sides of the tower has a fish screen that can be lowered to cover a port opening when water is being drained from the reservoir and will preclude fish from becoming entrained into the I/O pipeline.

Crest Control Building: A control house was provided on the dam crest to protect sensitive mechanical and electrical equipment required for the Dam I/O Tower gates and fish screens. Although local control of the gates may be possible from this structure, primary gate control is from the dam Adit Building.

Environmental Concerns

As part of most modern construction projects, environmental and political factors were a major part of the Olivenhain Dam project. In order to achieve local community acceptance, many concessions were necessary. These concessions included the following:

- No work was allowed on the project site outside of a 7:00 a.m. to 7:00 p.m. work window Monday Through Friday excluding holidays except RCC placement operations,
- No deliveries were allowed on Harmony Grove Road outside of a 7:00 a.m. to 4:00 p.m. work window Monday Through Friday excluding contract holidays,
- All blasting had to be performed between 7:00 a.m. and 4:00 p.m. Monday through Friday excluding contract holidays, and
- Noise emissions from the project site were required to be below 55 dba at specific monitoring locations throughout the valley.
- The construction site was a designated “No Smoking Site” with large fines for violations due to the critical fire hazard in that area.

Construction

The construction facilities needed to be laid out within the 200 acre reservoir foot print which include approximately 100 acres of steep terrain. Special considerations were necessary when determining the layout of facilities on this constricted site. The Contractor determined the location of the concrete batch plant and aggregate processing plant by factoring in stockpile needs, access requirements for deliveries from outside vendors, access requirements for maintenance crews, accessibility for the various types of haul units from the plants to different areas of the project site, location of waste areas, site drainage characteristics, availability of utilities needed for the different plants, relationship to the designated borrow sources and proximity of adjacent residences, as well as other outside influences that were affected by certain operations.

Due to the nature of the job, there were two concrete batch plants. The first batch plant was to produce conventional concrete (CC) and the second batch plant was for RCC. The conventional concrete plant was an Irie Strayer plant with a 10 cubic yard mixer with a central mix capacity of approximately 150 cubic yards per hour. The RCC plant was a state of the art CON-E-CO central mix plant that has two double drum plants married together with a total of four 8 cubic yard Schwing paddle type mixers. The plant sustained total capacity of 1,200 cubic yards per hour during RCC production. The plant also has the capacity to store 1,560 tons of cement and 2,650 tons of fly ash.

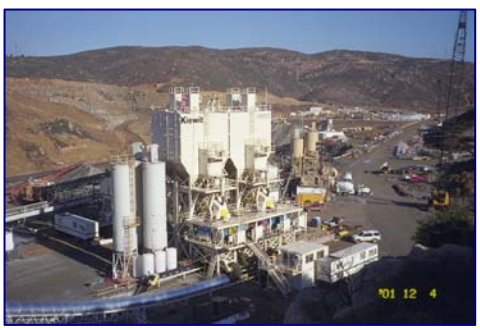


Figure 8

RCC Placement Operations

Figure 10
Olivenhain Dam, Upstream Face

The RCC placement began in February 2002 with the placement of the Left Abutment shaping Block, a placement of 225,000 cubic yards of RCC. This placement was the first real RCC production placement and tested all of the plant and equipment.

Upon completion of the left abutment shaping block the main delivery conveyor was moved to the main valley section and RCC production began in late April. The RCC was placed at world record rates through the spring and summer, reaching rates as high as 16,000 cubic yards per day. The normal work pattern was two ten-hour shifts per day and six day weeks. This high rate of production facilitated the completion of the RCC section of the dam by October 31, 2002, 2.5 months ahead of schedule. Once RCC was completed, the Contractor began installing the upstream membrane system. This process was accomplished by utilizing swing stages set up on top of the dam to place and fasten the membrane to the dam face. This installation process was completed in August 2003.

Testing and Fill Program: Testing of all operational control systems began in June 2003 and was completed in July 2003. A permit to allow filling the reservoir was issued by DSOD in July 2003. Filling began in August 2003 and continues at a slow rate to ensure that all mechanical and electrical facilities are fully operational and that the dam structure meets design requirements. The fill process has been successful to date and will be ongoing this fall. The reservoir is currently being held at elevation 805, which creates a 122 feet deep pool.

Hunting Run Dam

Figure 11

The Hunting Run Water Supply Project is a comprehensive project initiated by Spotsylvania County in response to rapid economic development of the area. In cooperation with the City of Fredericksburg, Spotsylvania County is assuming the role as the primary regional water supplier. The new water system is comprised of the new 12 mgd Motts Run Water Treatment Plant using a river water source augmented by flow from two dams (existing Motts Run Dam and the new Hunting Run Dam), two raw water pump stations located near each dam, and various pipeline interconnections between the existing County system and the City's system. Gannett Fleming was retained by the County to provide professional engineering services in both the design/bid and construction phases. The entire project was performed on an accelerated schedule to meet rapidly increasing system demands.

The Hunting Run Dam is located as an "off stream pumped storage reservoir", which greatly facilitated planning and environmental permitting for the project. Water discharged from the Hunting Run facility into the Rapidan River will be withdrawn approximately nine miles downstream from the Rappahannock River at the Motts Run Water Treatment Plant, from which finished water will be distributed in urban areas of the County and to the City of Fredericksburg.

The Rappahannock River Intake serves as the primary source of supply to the water treatment plant and also as water supply to the Motts Run Reservoir pump storage. Total intake capacity is 34 mgd. Water is captured through four 48-inch diameter wedgewire screens each sized for 9 mgd. The screens are equipped with automatic airburst backwash. Each screen is designed to be retracted to the stream bank work platform for inspection and cleaning. The intake also has a water flushing system to remove accumulated sediment from the screen area. The screens are designed to protect migratory fish, eggs and fingerlings in accordance with the requirements of the Corps of Engineers permit and the state Department of Game and Inland Fisheries.

The Rappahannock Raw Water Pump Station contains six vertical turbine pumps. Four are designed to pump form the river directly to the water treatment plant. The other two are designed to pump water from the river to refill Motts Run Reservoir or to pump water from Motts Run Reservoir to the water treatment plant. The pumps are fully automated and can be controlled by direct command of the operators at the water treatment plant. Alternately, the operators can select a desired pumping mode and the pumps are sequenced and controlled based on clearwell level, plant flow and river level.

The intake and pump station are located in a scenic stretch of the river. The architectural treatment of the intake and pump station was carefully developed, with the assistance of a local architect, to mimic the riverfront of nearby historic Fredericksburg. The architectural concept has been given several awards, including by the Friends of the Rappahannock, the local river recreational community.

The Rapidan River Intake and Raw Water Pump Station incorporates similar design features. The capacity is 24 mgd with three 8 mgd pumps. The Rapidan facilities are designed to supply pump storage flows to Hunting Run Reservoir and to meter and control releases of water back to the river.

Due to the variable foundation conditions and the geotechnical properties of the in-situ residual soils, the new dam was designed as a composite structure consisting of an approximately 1,300-foot-long roller-compacted concrete (RCC) gravity section that transitions into an approximately 1,200-foot-long shallow zoned earth embankment dam. The earthfill portion of the dam continues along a natural ridge where the existing topography rises to meet the crest elevation of the dam.

The dam's permanent outlet works and a portion of the raw water pipeline were built early in the project and designed to serve as the temporary diversion works for the natural stream during foundation excavation and dam construction. By combining the capacity of the 36-inch-diameter raw water main with that of the principal spillway conduit, the size of the diversion conduit needed during construction could be reduced.

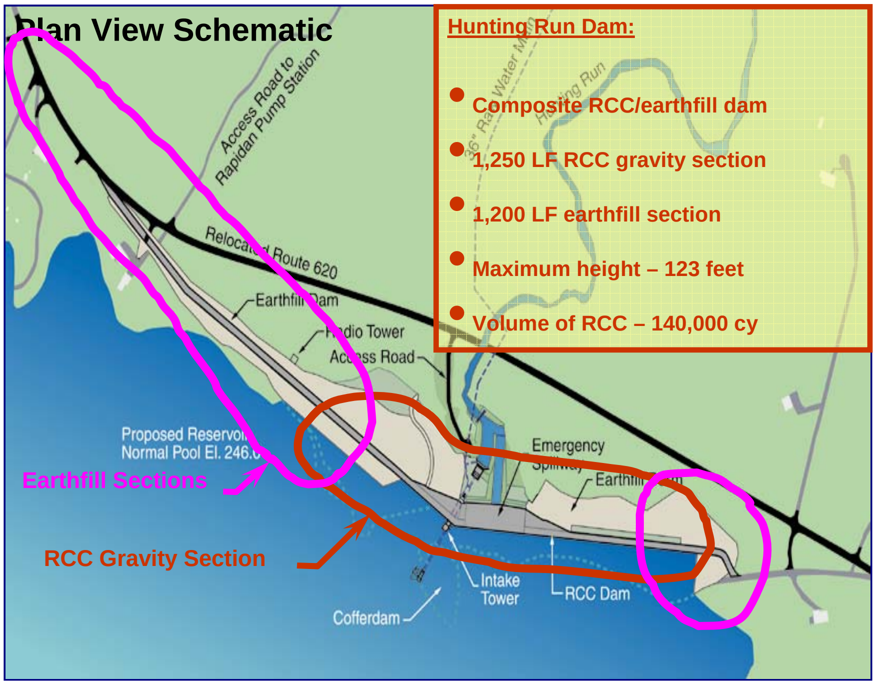


Figure 12
Hunting Run Dam

Over 400,000 cubic yards of earth and rock had to be excavated to reach a suitable foundation for the gravity dam. Prior to design, a geotechnical investigation including borings and rock testing was conducted to characterize the foundation conditions at the site. Like many projects of this magnitude, however, the geotechnical investigation provided an indispensable but limited view of the actual nature of the potential foundation. Variable foundation conditions and irregular bedrock weathering, which is typical of this region of Virginia, suggested that the foundation excavation should be planned and performed in phases. This approach allowed inspection of the exposed foundation condition and a field determination of whether to extend the excavation in certain areas. Based on the foundation inspection at interim construction stages and the extent of loose material that was discovered during foundation cleanup, much of the dam's foundation was extended below the initial foundation grade.

A grout curtain approximately 1,300-feet-long with depths ranging between 10 and 80 feet will help to minimize seepage under the dam. The drilling and grouting program consisted of an estimated 30,000 lineal feet of drilling to construct a single-line grout curtain, an optional second and third line of grout holes in selected areas, and a final program of shallow contact grouting drilled from the heel of the RCC gravity dam. Approximately 380,000 cubic yards of earth and rock fill around the RCC gravity dam and within the earth embankment portion completed the structure.

The dam's gravity section required approximately 150,000 cubic yards of RCC. Concrete aggregates from local quarries were stockpiled on-site, and the RCC was produced at an on-site concrete plant and delivered by conveyor to the working area. Part of the downstream face of the RCC gravity section was unformed at an easy to construct slope of 0.85 horizontal to 1.0 vertical. As a cost-saving measure, approximately 550 feet of the gravity structure was constructed with a downstream slope of 0.5 horizontal to 1.0 vertical with an earth embankment downstream that will buttress the slender gravity section. The vertical face of the gravity dam was formed using precast concrete panels that were fabricated on-site. Panels on the upstream face are lined with PVC membrane bonded directly to the precast panels,

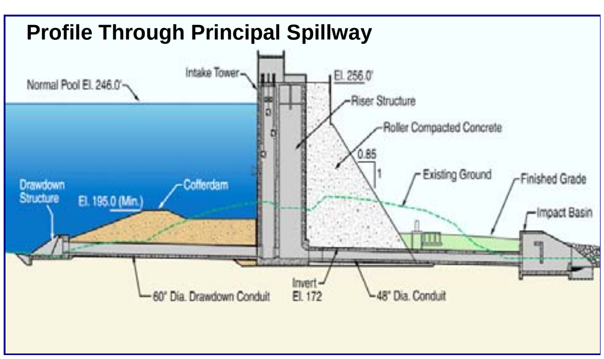


Figure 13
Dam and Intake Tower

providing a virtually impervious water barrier adjacent to the reservoir pool.

A new supervisory control and data acquisition (SCADA) system provides control and monitoring of the remote pump station as well as valves, gates, and instrumentation at the dam. The SCADA system is incorporated into the control and monitoring system that was recently installed at the new Motts Run Water Treatment Plant so that the facilities can be operated entirely by radio telemetry from the treatment plant.

ASI RCC, Inc., of Buena Vista, Colorado was awarded the contract for Hunting Run Dam and Related Facilities in April 1999, and construction began in earnest in May, and the project was completed in April 2003. The project cost of the Hunting Run Dam was $28 million and the total Hunting Run Water Supply Project was $60 million.

Conclusions

Major water resources projects in the United States will be more and more difficult and complex to shepard through the planning and environmental permitting process. Success will be dependent on responsible planning processes that define the need and purpose, identifies the alternatives, performs decision-making that involves all stakeholders and promote sustainable projects.

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