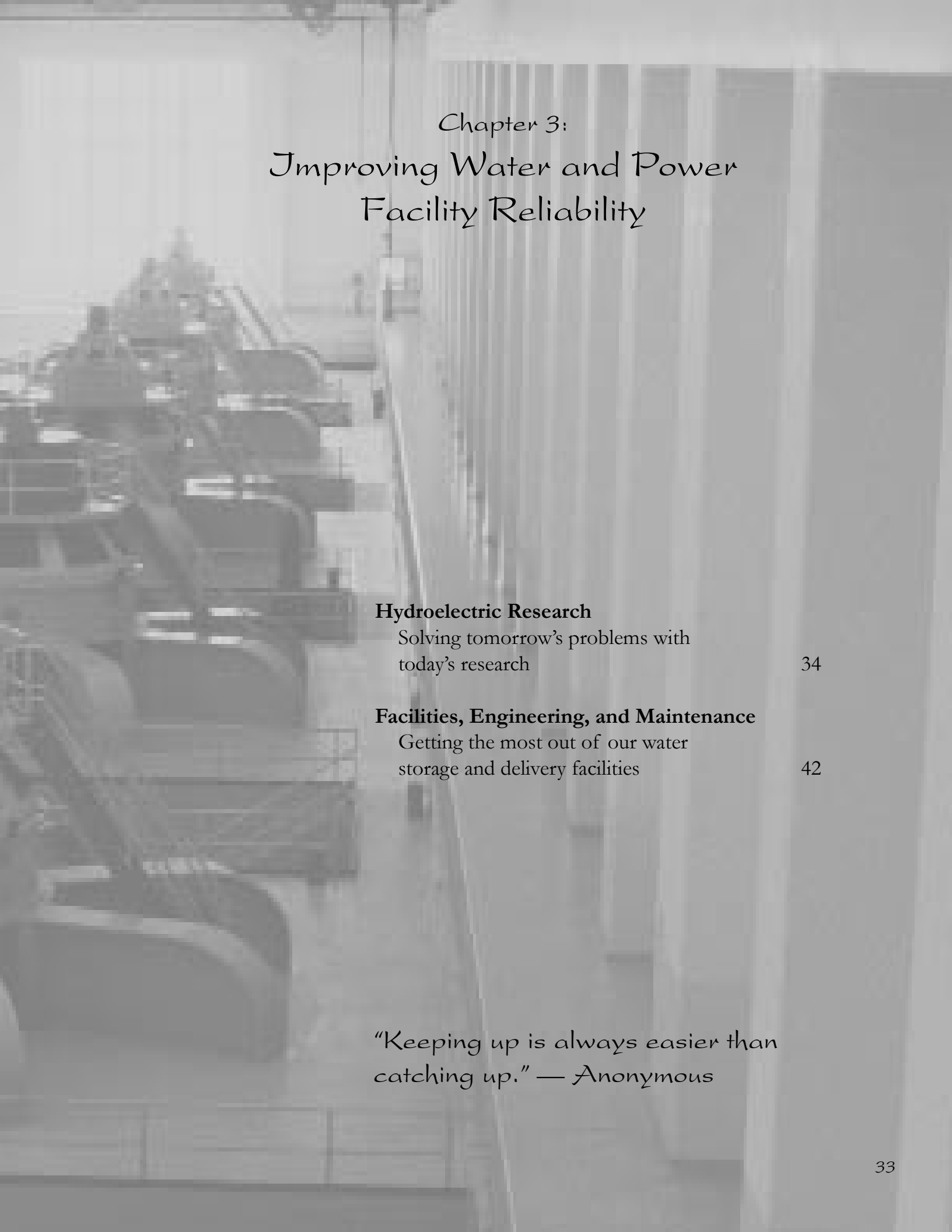
Reclamation has a strategic plan to accomplish its mission in accordance with the Government Performance and Results Act. Within the strategic plan, science and research is one of six principles that guide how Reclamation will achieve our strategic, long-term, and annual goals. The goals and strategies below are excerpted from the 2001 Performance Plan and 2000-2005 Strategic Plan. We have quoted them here to tie these to our specific research focus areas.

Reclamation's Goals	*Reclamation's Strategies*
Meet water and power contracts **Achieve cost-effective power production**	**"Through the Hydroelectric Infrastructure Protection and Enhancement Program, we are testing ways to maximize hydropower generation while maintaining system reliability. Through this program, researchers investigate power system diagnostics, modular Supervisory Control and Data Acquisition (SCADA) systems, power system stability, and machine condition monitoring."**
Reduce risk to public safety.	**"Reclamation researches innovative, cost-effective, and reliable dam safety solutions. For example, researcher's work will continue development in risk analysis, flood hydrology, seismotectonics, and structural behavior."**



Chapter 3:
Improving Water and Power Facility Reliability

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Solving tomorrow's problems with today's research 34

Facilities, Engineering, and Maintenance
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"Keeping up is always easier than catching up." — Anonymous

Solving tomorrow's problems with today's research

In a generator so large that the wrenches to fix it are bigger than a man, something as small as a ball bearing or transistor could give way and cause a major and very expensive failure. Many Reclamation facilities have served the American public faithfully for a long time–powerplants range from 40 years old to almost a century old. Now, more than ever before, we must find problems before they start. How can we determine the challenges ahead for our aging power facilities in the midst of security concerns, deregulation, power shortages, and competing demands?

The Science and Technology Program's hydroelectric infrastructure protection and enhancement research finds ways to ensure that the power equipment is fully functioning. This keeps the power system in balance to guard against blackouts. In the power industry, small changes in operating, maintaining, or doing business can, and frequently do, result in huge cost savings. Portions of some of these activities are funded by the Power Resources Office through Power Program Services. The research pays for itself many times over and concentrates on:

- Protecting the safety and health of the public and Reclamation employees
- Improving operation and maintenance efficiency while supporting competing water uses
- Providing increased power system reliability (e.g., help prevent regional blackouts)

The program develops, researches, and adapts state-of-the-art methods, diagnostic tools, and processes to Reclamation's facilities to address complex questions:

- How do we work in a deregulated marketplace? Programs such as Open Access Hydro develop economic and capability models to examine ways our powerplants can be used to meet market needs and optimize value.
- How can we extend the lives of our aging powerplants? Decisionmaking efforts involving the life extension, risk assessment, root cause analysis, etc., help determine the best strategy for updating, maintaining, or replacing our systems. Developing effective decisionmaking tools helps to preserve Reclamation's infrastructure and to reduce costs.
- How can we maintain our equipment effectively? Processes such as Reliability Centered Maintenance establish a maintenance schedule based on how the equipment should be maintained to achieve the desired reliability and dependability at the lowest cost.

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Hydroelectric Research

Solving today's problems is not enough–we must find ways to identify and address tomorrow's challenges. "We keep our fingers on the pulse of the hydropower industry and do today what will need to be done to best meet Reclamation needs tomorrow," says Bert Milano, Group Manager, Hydroelectric Research and Technical Services Group, Technical Service Center. Researchers anticipate needs by working closely with Reclamation facility managers and staff, other utilities such as Electric Power Research Institute and Western Systems Coordinating Council, and technical/professional organizations.

Examples of visionary products include power system stabilizers, electronic voltage regulators, digital controllers, insulation testing techniques, economic optimization, excitation limiters, stability alignment techniques, modular Supervisory Control and Data Acquisition, reliability centered maintenance, root cause analysis, machine condition monitoring, variable-speed drives, harmonic analysis, safe grounding practices, and doubly fed machines. While these are all part of everyday life in Reclamation today, initially, not many outside of the Science and Technology Program saw the need for these technologies.

Reclamation's innovations

Reclamation is the Nation's second largest hydroelectric power producer with 58 hydroelectric powerplants. Altogether, the plants have an installed capacity of over 14 million kilowatts and annual hydropower revenues of nearly $1 billion. These powerplants meet the needs of 14 million people. The massive scope of Reclamation's water and power efforts; the size of our facilities, plants, and equipment; the technologies involved; the environmental issues; and recent concerns with deregulation and preventing regional blackouts pose unique challenges. The Science and Technology Program has developed and applied many innovative solutions to keep the lights on, water flowing, and humans and fish happy.

Reclamation's Technical Service Center provides a cadre of 22 specialized engineers, who make over 250 technical assistance trips to the field each year to anticipate, diagnose, troubleshoot, and research power system maintenance, efficiency, and reliability.

Hydroelectric Research

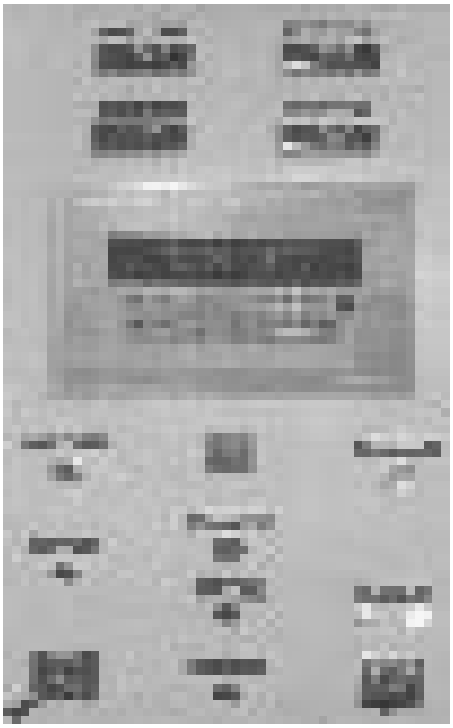
Hydroelectric research carefully considers the best ways to apply new technologies and research areas that will be most fruitful for all of Reclamation and the hydropower industry. Considerations include competing benefit-to-cost possibilities, technology limitations, chances for success, activities from other research organizations, and budget constraints. The most important deciding factor is to provide broad overarching technology support to Reclamation's facility managers so they will be ready to help Reclamation meet tomorrow's facility, water, and energy demands.

Exciting new developments

Researchers anticipate needs by working closely with Reclamation facility managers and staff, other utilities such as Electric Power Research Institute and Western Systems Coordinating Council, and technical and professional organizations. Some examples of solving tomorrow's problems with current research:

- Advancing modular SCADA systems. This research finds ways to upgrade, add, or replace individual modules rather than an entire system. The modular approach helps Reclamation meet rapidly changing needs quickly and cost effectively. Hoover Dam Powerplant was the first to implement this SCADA technology. This approach, combined with economic optimization and project-led modernization, resulted in an additional $30 million of energy being made available each year. Other Reclamation facilities, including the Central Valley Project, are using modular SCADA. Now, 90 percent of the market is modular based.

- Developing digital governors. The research program developed software algorithms for digital governors to control generator speed. These governors are cheaper, more reliable, and provide higher performance. They are now in powerplants at Mt. Elbert, Colorado; Headgate Rock, Arizona-Colorado; and Folsom, California. Woodward Governor, the largest governor manufacturer in the world, announced that they will only manufacture the digital governor that Reclamation developed.

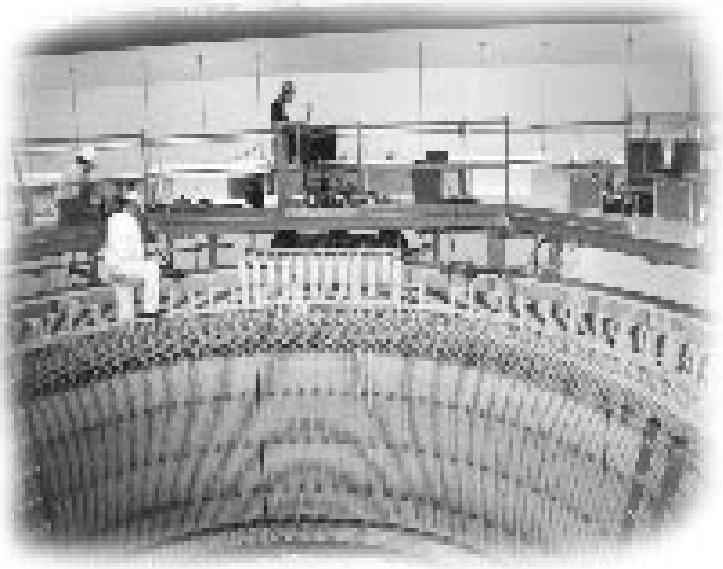


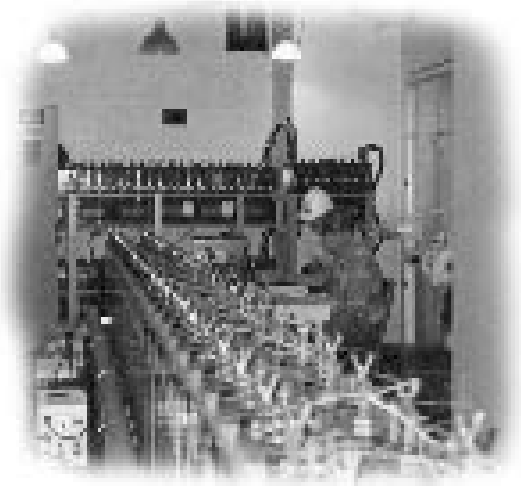
Digital governor

Hydroelectric Research

The Science and Technology Program made wireless voice communication in Reclamation water conveyance tunnels during maintenance work practical. This giant brush "scrubber" is cleaning the concrete liner of the 17.5-foot-diameter Clear Creek Tunnel, Central Valley Project, California. Mounted atop the tow truck is a 2-foot-diameter, 10-gigahertz dish antenna providing safety-required voice communication to the surface crew that is 8.5 miles away from the tunnel entrance.

An investigation of Glen Canyon Unit 8 determined the cause of premature stator winding failure. Researchers found widespread insulation delamination and determined that this resulted from manufacturing deficiencies. The Science and Technology Program research developed new test and inspection methods for field diagnostics of high-voltage machine insulation systems.





Reliable station batteries are critical for operating a powerplant and must be available in emergencies. This state-of-the-art, computer-controlled test equipment has saved many thousands of dollars by ensuring batteries were available when needed. This equipment and testing is an outgrowth of the Science and Technology Program.

a retrospective

Through constant innovation and anticipation, the Science and Technology Program's hydroelectric research has helped to keep lights on and affordable over the years. In the past decade alone, the program saved millions of dollars, avaoided accidents, reduced possible blackouts, and ensured power stability.

Saved costs

The Science and Technology Program saved costs in many programs, including:

- **$8 million a year savings from improved plant performance with an optimized Master Supervisory Control System at Hoover and Grand Coulee powerplants**
- **$2 million a year savings from increased power transfer capabilities by installing a transient excitation boosting at Grand Coulee to improve stability**
- **$1 million a year savings from less downtime for generators from the unwatered governor test methods and hardware at Reclamation's powerplants**
- **Reduced costs for aligning generators from $75,000 (private sector) to below $15,000 (Reclamation)**

Avoided costs

The Science and Technology Program's innovations helped avoid significant costs such as:

- **$30 million in replacement costs for a hydrophone monitoring system on the Central Arizona Project siphons**
- **$1.6 million to replace failed cables at Flatiron Power and Pumping Plant, Colorado; Grand Coulee, Washington; Yellowtail Powerplant, Montana; and Mt. Elbert, Colorado**
- **$1.5 million to replace a damaged core and winding at Grand Coulee Powerplant, Washington**
- **$1 million to rewind Grand Coulee pump unit**

Hydroelectric Research

Electric power systems stability

- **Six new digital governor algorithms.—These algorithms are better able to meet water release constraints and provide excellent speed control to enhance the stability and security of the interconnected power system. These new 505HBR digital governors, installed and commissioned at Headgate Rock powerplant, are now the industry standard.**
- **New methods in field testing of excitation systems.—These methods enhance the stability of the Western power grid and reduce the possibility of regional blackouts.**

Power operations research

- **New management tools.—A scoping study provided new management tools and a heads-up briefing on how new trends and developments could quickly be introduced into Reclamation business.**
- **Hydroturbine optimization techniques.—These techniques, incorporated into the SCADA system at Hoover powerplant, improved powerplant efficiency between 4 and 7 percent (depending on time of year and plant conditions). Wholesale revenues could increase by $1 million per percent of increase in efficiency.**
- **Monitoring and evaluating ancillary services.—Determining the value of ancillary services provided by our facilities in the Lower Colorado and Mid-Pacific Regions shows that these services have valuable monetary benefits that would cost much more if they were replaced from another source. This information can also provide increased security to the power system.**

1990 a retrospective

Electric power diagnostics

- **Root cause analysis techniques.—This analysis quickly assesses causes of failures and applies the knowledge gained Reclamation-wide, thus preventing expensive recurrences.**

- **Personal protective grounding.—This research greatly improved the safety of the electric power system and helped to avoid electrocutions and serious accidents.**

- **Guidelines.—Operating guidelines for failure analysis, worksite cleanup, and disposal of toxic insulation failure byproducts ensure safe and effective working environments.**

- **A prototype rotor-turning gear device.—This device was installed at Glen Canyon Powerplant to safely rotate a generator rotor and then stop it quickly at any desired position. This safe rotor-turning gear improves plant safety and maintenance convenience.**

- **A specialized capacitance probe.—This probe performed safe, non-destructive electrical tests to determine the condition of the water-cooled stator winding insulation in the Grand Coulee Third Powerhouse. This diagnosis led to winding replacements, saving many millions of dollars in avoided costs in lost revenue and equipment damage from potentially catastrophic insulation failures. Technology transfer efforts to private industry resulted in similar savings to over 100 large generators throughout the world.**

- **Smart detection and pinpointing of hidden faults.—This laboratory prototype is faster at locating faults in large synchronous machine stator windings, thereby saving 4 to 5 days to repair. Lost revenues while the generator is being repaired can reach over $150,000 a day.**

- **A turbine rough zone tracking algorithm.—This software program is used at Yellowtail Powerplant and other locations to alert the remotely located control center operators when generators are running at levels that cause significant damage to the turbine.**

- **A harmonic overcurrent relay.—This relay senses dangerous currents on the power system at two user-selectable harmonics and initiates protective action. These actions can save millions of dollars in damage to generators and other power system equipment. Reclamation patented this invention.**

- **Air-core current transformer.—This transformer, coupled with a fiber-optic signal transmission line, can afford complete electrical safety to the connected instrumentation and operator. The transformer is suitable for a wide range of currents and is lightweight and easy to install. The technology is being transferred to the private sector as it is much cheaper than the current technology.**

- **Electromagnetic Transients Program.—A global $15-million partnering effort is developing a complex power system analysis computer program. The program is used for planning, design, diagnostics, and research involving almost all aspects of power system analysis. More than 1,200 utilities throughout the world currently use the program, including the National Aeronautics and Space Administration and the U.S. Navy. Reclamation's contributions of $250,000 to the program to date have saved Reclamation over $5 million.**

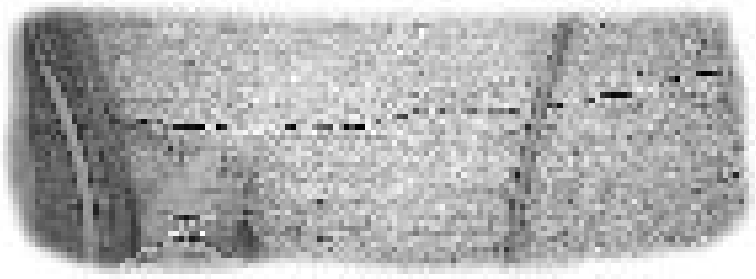
Getting the most out of our water storage and delivery facilities

When you get to be 100, the ravages of time take their toll. The elements have cracked and blemished your skin. You don't function as well as you did in your youth. Then, parts of you begin to fall off. But look on the bright side—you're a hydraulic structure made of concrete, steel, and earth–and state-of-the-art technology can rejuvenate you for another 100 years.

The Science and Technology Program can now apply technology that did not exist when we designed our projects to repair, rehabilitate, restore, and improve efficiency of hydraulic structures. Through laboratory and field experimentation, we are researching ways to improve:

- **Design, repair, and maintenance capability**.—We can use new technologies to replace old and inefficient or environmentally unacceptable technologies. This research focuses on understanding structural aging processes. We are also developing new concrete repair materials and methods, new-generation paint and coating systems, and alternative canal lining technologies. Linings can save about 30 to 50 percent of the water losses in old canals.

- **Capability to assess the condition of structures.**—New technologies provide less invasive and more effective ways to identify problems early:
  - The failure of a single steel structure could compromise an entire water project, leaving thousands of farms and cities without water. The Science and Technology Program has tested new instrumentation to monitor steel structures continuously and alert operators of maximum loads.
  - Mix cement, aggregate, and water together. Let this mixture harden and you get concrete—most of the time. Sometimes alkalis in the cement react with certain types of aggregate, and you get a gel that swells as it absorbs water. This gel, an alkali-silica reaction (ASR), can break down a large concrete structure. It rendered the original American Falls Dam in Idaho useless. We are developing tests to predict the degree and rate of deterioration of an ASR-infested structure. This will help us better plan repair and maintenance activities to prolong its service life before entire structures need to be replaced.



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- **Performance of hydraulic structures.**—New ways to measure performance can lead to better operating decisions:

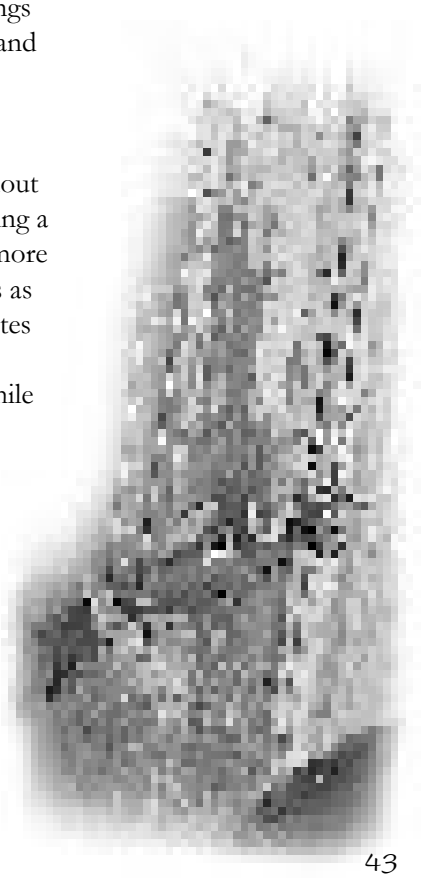
  - The less force we can subject stilling basins to, the smaller, more durable, and less expensive we can design them to be. We often use stepped roller-compacted concrete slopes along spillway chutes to minimize the force and turbulence of water flowing into the basins. One of our research projects seeks to better quantify this force and turbulence more accurately. At the same time, this project will improve our ability to measure the amount of dissolved gases in the water, a critical factor for fish.

  - Rock and debris entrained in stilling basin flows continually damage concrete stilling basins at 38 Reclamation facilities and many other non-Reclamation facilities. Repairing this damage can cost several hundred thousand dollars, cause costly facility downtime and require frequent underwater inspections to monitor damage. We are developing a new device to tame surging waterflows and will test it on Mason Dam.

  - The costly repair of hydraulic turbines, grates, and other stuctures also causes large losses of power revenue and water deliveries. Reclamation is researching new ways to measure cavitation, one of the causes of hydraulic structure damage. Acoustic sensors can easily detect cavitation implosions inside an operating turbine or other hydraulic component. We can analyze these readings to determine the damage implosions cause and modify operations to reduce and repair cavitation before the damage becomes excessive.

- **Our understanding of the magnitude of possible floods at our dams.**—Throughout the early 20th century, engineers designed and operated dams without the luxury of present-day hydrologic science and information. We are developing a Stochastic Event-Based Flood Model (SEFM) which can more accurately and more economically predict probable flood conditions. Reclamation uses these results as input to dam safety risk assessment. These more modern, reliable flood estimates may also eliminate or minimize the need to enlarge dams, as we may be able to reallocate reservoir space to provide water for environmental and other uses while still maintaining safe operations.

So now you should feel rejuvenated. Reclamation has replaced your aging concrete, steel, and earth with materials that make you feel young again. It monitors your vital systems with state-of-the-art technology, immediately detecting the slightest threat to your health. It has strengthened you structurally and systematically. No longer battered by the water you control, you can carry on with confidence.



1990 a retrospective

Reclamation operates and maintains hundreds of water resources projects, each with its hydraulic stuctures and equipment. We have been building these projects for almost 100 years. Despite their age, they must continue to perform to carry out our water resources management objectives. Facilities research helps to ensure our project's continued performance.

Preventing erosion

Erosion during floods can fill reservoirs and overtop dams. We developed a method to help protect dams by paving the downstream face of the dam with an articulated mat of individual blocks. The blocks dissipate the energy of the overtopping flows while the flowing water keeps the blocks in place. The erosion-protecting blocks provide a low-cost alternative for protecing low-head dams and other features from the forces of flowing water. These blocks have been patented and are now a commercial product, Armorwedge, sold through Armortec <http://www.armortec.com> under an exclusive licensing agreement with Reclamation. Armortec has added this product to their line of concrete products used to protect against erosion caused by spillway, canal, and other overland floodflows.

Addressing corrosion

Our corrosion research helped Reclamation successfully address issues associated with corrosion related deterioration of prestressed-concrete siphons on the Central Arizona Project. The Science and Technology's corrosion research lengthened the lives of our facilities by slowing or halting corrosion.

Extending the life of our structures and saving money

Concrete repair technologies developed under the Science and Technology Program and published in Reclamation's Guide for Concrete Repair are considered industry standards. These repair technologies are the foundation for all concrete repairs specified on Reclamation facilities and other federal agencies such as U.S. Forest Service, the Bureau of Land Management, and the U.S. Fish and Wildlife Service. Reclamation has saved millions of dollars by using these repair techniques rather than rebuilding. These techniques can easily double or triple how long a repair lasts over previous repair methods.

Facilities, Engineering , and Maintenance

Extending the life of canals, conserving water, and saving money

The Science and Technology Program worked with the Pacific Northwest Region, 20 geosynthetic manufacturers, and 10 irrigation districts to develop low-technology, low-cost canal lining systems that irrigation districts can install. Thirty-five test sections have been constructed using combinations of membranes, geotextiles, shotcrete, soil, coatings, and sprayed-in-place foam. Cost/benefit analysis has shown that every $1 spent on canal rehabilitation can return $3 to $5 in conserved water, and that every $1 spent on canal lining maintenance can return up to $10 in conserved water. These savings can really add up when we consider the over 16,000 miles of canals, many currently unlined, that serve Reclamation project lands.

Early detection of problems and saving money

The Science and Technology Program has developed non-destructive technologies to evaluate the internal condition of large concrete dams, spillway gates, spillway slabs, and to measure in-situ stresses in bridge decks. This research has also improved methods to investigate on-site soil conditions. Working with various area offices, we have developed new technologies and then taken these technologies to other Reclamation projects. Where these techologies are used, costs have been cut by 80 percent. The improved reliability of these assessments has reduced the cost of repairs by over 50 percent through advanced detection and more targeted repair locations.