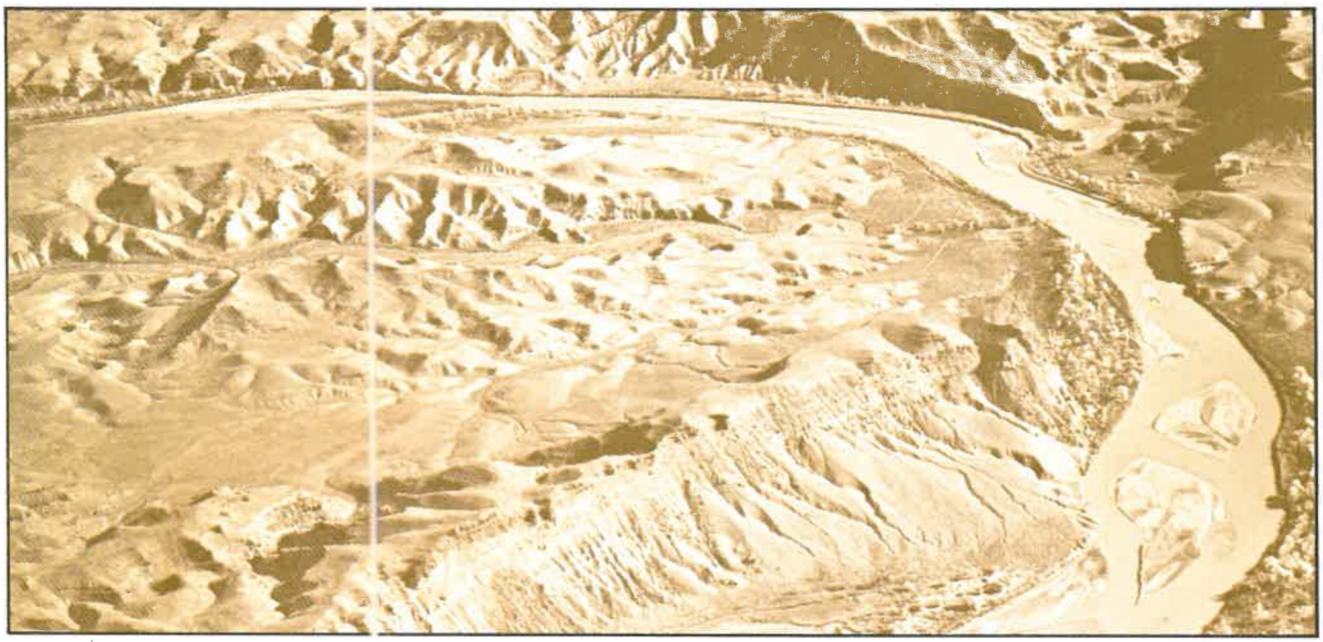
Colorado's Water

A 1978 report of the Colorado Water Resources Research Institute

Recreation and Irrigation—pages 16 & 24



Sediment and Salt Loads to the Colorado River System—pages 7 & 26

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INTRODUCTION

The Colorado Water Resources Research Institute was established by the U.S. Congress in 1964 to provide Colorado decision-makers and water resource managers with scientific and technical assistance through research. The Institute serves as a bridge between the state's academic community and its water users and officials.

Located on the campus at Colorado State University in Fort Collins, the Institute draws upon scientists of Colorado State University, the Colorado School of Mines, and the University of Colorado for research on water resources problems. A Technical Advisory Committee helps identify and establish the priority of each problem. Research projects thus are initiated on problems of the highest priority. The committee is composed of water officials representing state agencies, local governments, industries, agriculture, federal agencies and private consultants. The names of individuals serving on the committee are listed in the back of this report.

A secondary function of the Institute is the training of professionals for careers in water resources planning and management. Some 250 masters degree students and 165 doctoral students have received training and experience working on research projects sponsored through the Institute. This publication reports on 14 research projects in progress during the fiscal year 1977. These projects illustrate the problem-solving mission of the Institute. More than 100 projects have been completed to date, each on a water problem of priority concern to Colorado water users.

Norman A. Evans, Ph.D.
Director
May, 1978

Photo: the Colorado Rockies south of Kremmling

CHANGES NEEDED IN COLORADO'S WATER MANAGEMENT?

If water continues "to flow toward money," will Colorado's irrigated agriculture, fish and wildlife, and other recreational assets be injured?

"Many people believe the answer is *Yes,*" says Phillip O. Foss. "They are convinced of the validity of the old adage that water flows toward money. Furthermore, they believe that where Colorado is concerned, that direction of flow may be harmful." The CSU political scientist adds: "If you look at the history of western water development, it is hard to disagree with that conclusion."

Energy developments and growing urban areas are the new monetary lodestones which may be changing the "flow" of Colorado's water, according to Foss. As is well-known, the distribution of people, water, and topography in Colorado is not optimum. Most of the people are east of the Rockies, the mountains are in the middle, and a lot of the state's water flows westward. Foss believes this maldistribution will continue. "The projections are for continued population growth east of the Front Range."

The Colorado State University faculty member has been conducting a three-year study on the effectiveness of present institutional arrangements in Colorado for managing water. Sponsors of his study have been the Colorado Water Resources Research Institute at CSU and the U.S. Office of Water Research and Technology.

"Since trans-basin diversions or transfers between uses ... affect more than just the immediate parties...some review and regulation... would be advisable"

Professor Foss's review of the situation in Colorado has convinced him that many changes in the present system are not feasible, even though they might be theoretically attractive. "Major alterations in the present system would cause disruptions and conflicts too horrendous to contemplate. But adjustments in the system are possible and should be made," Foss states.

The university political scientist knows that any alterations in Colorado's water-related institutions will need to be both technically feasible and politically acceptable. He is also aware of the difficulties involved. "These 'adjustments' would have been made earlier if they had been easy." Foss's report on his three-year study points out the changes other states have made when faced with similar problems. He also is proposing some alternative solutions.

His apprehension that water in Colorado will indeed flow toward the bidder with the most money is the reason for Professor Foss's suggestions (nos. 9 & 10 at right) that diversions between river basins ana between different uses should require the approval of the Colorado Water Conservation Board. "Individuals and organizations now can buy water rights, assuming a willing seller. They can construct a diversion structure, and actually divert the water," Foss relates. Since such trans-basin diversions or transfers between uses—such as between agricultural and energy devlopment— affect more than just the immediate parties, Foss believes some review and regulation at the state level would be advisable.

Another desirable adjustment is legal determination of the present water rights in Colorado, according to Foss. "All water rights and decrees should be adjudicated. Many of the present water rights are only paper rights. Some of the water is either not being used, or is not being used beneficially, as the law requires." The CSU political scientist is aware that such adjudication processes would be expensive and time-consuming. "Nevertheless," he asserts, "We need to find out where Colorado is in terms of rights versus actual use."

If water continues to "flow toward money" more western slope rivers may resemble the watercourse pictured at the left

Some Proposed Changes in Colorado's Water-Management Institutions. The following are taken from a report by Professor Phillip O. Foss, Colorado State University Department of Political Science to the Institute.

1. The present water referee system and its functions should be transferred to the Office of the State Engineer, with appeals to the courts possible.
2. The present "water judges" should be assigned to a single state water court.
3. The legislature should adopt a state water policy plan. At present there is no state water policy except the accumulation of local and individual decisions.
4. A state body should be established to coordinate land use planning with water management. The two functions are obviously interrelated, but they now operate separately and independently of each other. "Planned Growth and Planned Development" are mainly slogans.
5. Outdoor recreation and fish and wildlife values should be legally recognized as beneficial uses of water in Colorado.
6. A separate governmental unit should be established to coordinate outdoor recreation and fish and wildlife with water management.
7. The water quality function should be transferred from Public Health to the State Engineer's Office or established as a separate unit in the Department of Natural Resources.
8. The Colorado Water Conservation Board (CWCB) should be authorized to construct impoundments and other needed structures and finance them through revenue bonds, direct appropriations, or other appropriate methods. Such authorization should be separate from the present $10 million revolving fund.
9. Trans-basin diversions should require the approval of the CWCB.
10. Transfer of use from one major category to another should require approval of the CWCB—e.g., transfer from irrigation to domestic use.

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THE GROUNDWATER BANK: A Time for Deposits and a Time for Withdrawals

"For some river basins in Colorado, the best thing may be not to line the irrigation canals and ditches. Let the canals lose the water through seepage. Let the water recharge the aquifer(s), especially in areas located far away from the river, near the aquifer boundary.

"If you line the canals, then water which would otherwise seep into the aquifer would be kept in the river and would go right on down the river—such as the South Platte. That might be good for Nebraska but not for Colorado.

"This is what I feel intuitively. Our studies may or may not quantitatively confirm this personal conclusion."

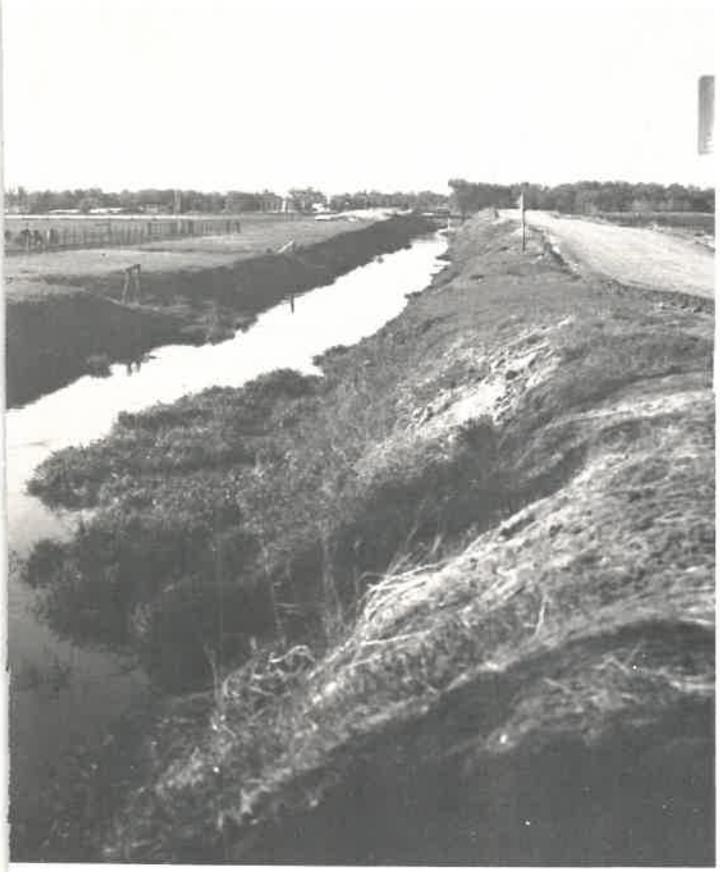
These comments were made by Hubert J. Morel-Seytoux, professor of civil engineering at Colorado State University. The Fort Collins investigator and educator has been conducting research on the conjunctive use of surface water and groundwater for several years. He and a number of visiting professors, research associates, and graduate students from CSU are now working on two projects supported by the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute.

Prof. Morel-Seytoux also is participating in an intensive investigation for the State of Colorado on the "hydrologic and economic impacts of applying efficiency criteria to the irrigation conveyance, distribution, and application system of the South Platte Basin." The objective of this latter project, Morel-Seytoux says, is to evaluate the impact of various water conservation practices—such as the lining of canals, improvement of water use efficiency on the farm, etc.—on the overall operation of the South Platte system.

He reports that some unexpected conclusions were reached as a result of their study of the South Platte. "We found that water just does not move downslope through an aquifer alone. Under certain conditions, the water may flow back from the aquifer into the stream, then move rapidly down the river until it reaches another area of the aquifer with a low water table. Then it will flow into that aquifer.

The CSU civil engineer points out that this phenomenon can act as a quite rapid transfer of water from upstream to downstream portion of an aquifer. "This can be an advantage or disadvantage, depending upon where you are along the river system and what your water requirements are." According to Morel-Seytoux, a river under some conditions may control the level of water in these alluvial aquifers. The opposite may also take place, for under different conditions, the aquifer may be "in control" of the river's level.

The university faculty member feels strongly that both the surface water and the aquifers must be managed together, or conjuctively. He also



At first glance, it would seem that the lining of canals such as the one above would be a water-saving measure

believes some revisions are needed in Colorado's water laws to make this conjunctive use efficient. "It is ironic, but the way the law stands now, an irrigator or pumper can withdraw water from an aquifer only when there is a plentiful supply of surface water. During such conditions, the pumper is assumed not to be damaging any senior surface rights.

Aquifers could be regarded as reservoirs

"But in times of scarce surface flows, the present law prohibits withdrawals from an aquifer if senior surface rights might be damaged."

The Fort Collins civil engineer is convinced that failure to look upon aquifers as viable and effective underground storage reservoirs is the reason for this inconsistency in Colorado water law. He points out that surface reservoirs are built so that they can be used in times of drought to supplement surface water supplies. "Shouldn't aquifers be looked at in the same way?"

Prof. Morel-Seytoux extols the virtues of aquifers: "They are excellent means of storing water, they are very natural, and little capital expenditures are needed to use them."

If this line of thinking were to be adopted, some changes would be needed in present pumping regulation to allow pumping to continue during low river flow, some of which could be discharged to the river to satisfy surface water rights. During times of large surface flows, arrangements would be made to recharge the aquifer as much as possible.

"Then when surface water supplies are low, the water could be withdrawn from the aquifer."

Recharging at aquifer boundaries best

The studies of the CSU engineers indicate that the recharging efforts should be directed along the aquifer's boundaries, as far from the river as possible. Otherwise the water may return too quickly to the stream and not be available for pumping when needed. "If the recharging is done as far away from the main channel as possible," Morel-Seytoux says, "the travel time of the water back to the stream may be greatly increased, as much as by several years."

The testing phase of the computer model developed by the CSU investigators is almost completed. According to Morel-Seytoux, use of this computer program will allow the appropriate regulatory agency in the state to assess the effect on streamflows of well pumping, upstream reservoir releases, and initial water table drawdowns.

A major objective of the CSU engineering studies was to make these computer analyses possible at reasonable cost. "We had to develop computer models that were cost-effective, as well as realistic, time-wise," Morel-Seytoux states. "The computer runs must not be lengthy, yet the answers must be refined enough to be useful. We are now modeling aquifer/surface water systems in one-week intervals."

PASS THE WATER BUT KEEP THE SALT!

As the water in a river descends from mountaintop to sea-level estuary, a number of things happen. Clear sparkle changes to dull turbidity. The oxygen content decreases. Microscopic forms of life become more common. And, particularly in the arid West, the amount of salts carried along in the liquid increases. These salts include not only the sodium chloride which graces our household tables, but also such elements as calcium, magnesium, potassium, and chlorine. Also likely to be present are such components as sulfates, nitrates, and carbonates. These changes in the water are not considered to be beneficial, particularly the increase in salts.

Some of this growth in salts comes from reuse of the stream's water. As water passes over farm fields, some minerals are picked up from the soil and from the fertilizer which has been applied. These compounds can be carried back to the stream. Still other chemicals may be included in discharges from industrial processing plants and from municipal waste treatment facilities. And then there are the contributions of Mother Earth. It has been estimated, for example, that more than one-half of the total salt load of the Colorado River comes from natural sources, such as saline springs and sediment loosened by erosion.

These increases in salt content can cause problems for downstream users of water—including farmers, municipalities, and industries. In some areas, the water can be described by the old saying—"Too thick to drink, but too thin to plow!" When the water is too "thick" with

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Sediment eroded from cliffs and gullies contribute to the chemical salts carried in western streams, such as the Green River, located in eastern Utah

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minerals, the growth of food crops can be adversely affected.

The salinity problem in the West took on international overtones in 1972, when the United States formally promised the Republic of Mexico that the salts in the Colorado River would be kept at a given level at Morelos Dam, located a few miles downstream from where the river flows into Mexico. Norman Evans, director of the Colorado Water Resources Research Institute, explains: "Minute 242 of the International Boundary and Water Commission of the United States and Mexico—which is in effect a treaty between the United States and Mexico—provides that the U.S. can deliver water at the Morelos Dam which has 115 parts per million salts (plus or minus 30) more than the Colorado contains when it passes Imperial Dam. But no more." The two dams are about 30 miles apart and are located to the east of California's Imperial Valley. Yuma, Arizona lies between the two structures.

Evans continues: "In effect, the treaty provides that the U.S. will not deliver any worse water—salt content-wise—to Mexico than is delivered to the farms in the Imperial Valley. One hundred and fifteen parts per million is the normal pick-up of salt content that would be expected in the 30-mile stretch between Imperial and Morelos."

According to Professor Evans, the U.S. government is spending $100 million dollars for a desalting plant at Yuma to meet this treaty obligation with Mexico.

". . . although irrigation return flow contributes significantly to this salinity increase, the salts of natural origin are the largest contributors"

Stanley A. Schumm, professor of earth resources at Colorado State University, describes the increase in the salt content of the Colorado River that takes place between the high country of Colorado and the Mexican border as "dramatic." He states: "As water is lost due to evaporation and various uses, the salt concentration keeps getting higher. In central Colorado, the salt concentration in the river may only be a few hundred parts per million. But by the time the water has reached southern Arizona, the concentration approaches 900 parts per million."

"At that level, the water's value for irrigation has been greatly reduced," Schumm adds.

In a bulletin recently prepared for the CSU Institute, Schumm and doctoral student Jonathan B. Laronne report that the average annual salinity concentration of the Colorado River has almost doubled during this century. The CSU geologists add that although irrigation return flow contributes significantly to this salinity increase, the salts from diffuse and point sources of natural origin are the largest contributors. Schumm and Laronne explain that "point sources" include saline seeps and springs as well as industrial and urban effluents. What they term the "diffuse sources" originate from the entire drainage basin of the Colorado.

Natural sources need controlling

These widespread natural sources were the focus of a three-year study by Schumm and Laronne. Support for their investigation was received from the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute. Schumm says: "Considerable funds are being spent on research to reduce the amount of salinity coming from agricultural areas. But a lot of the salts in the Colorado are coming from these natural, diffuse sources. We thought it was time to take a detailed look at what was happening and to propose some possible control measures at these natural sources."

Earlier investigations of the Colorado Basin saline runoff problems "fingered" extensive deposits of a certain kind of rock as the culprit. These deposits, called the Mancos Shale, originated from marine waters during the Upper Cretaceous Age, some 70 million years ago. Schumm and Laronne report that the Price and Dirty Devil River Basins, as well as the central reach of the Gunnison Valley, are extensively underlain by Mancos Shale. The same situation exists throughout the Grand Valley and in the San

Juan River drainage basin between Shiprock, New Mexico and Bluff, Utah.

Mancos Shale is described by Schumm and Laronne as being drab gray when weathered, and dark gray when freshly exposed to the air. It is laid down in thin beds and is often covered with patches of "white alkali" or salt efflorescence. According to the authors, weathering of the shale produces a "friable semi-powdery mass that is sticky and impervious when wet." Being of marine origin, it is understandable that the Mancos Shale would yield high sediment and salt loads to the Colorado River.

Among the specific objectives of the Schumm/Laronne study of the Mancos Shale was to determine the amount of salts stored in the bed materials of alluvial channels and terrace deposits, including the walls of gullies as well as in the bedrock of associated Mancos Shale deposits. Another goal was to uncover the relation between sediment yield and salt yield. Still another hypothesis that the geologists wished to test was that salts are stored in valley alluvium—materials deposited by running water—and are released after these materials are eroded.

During 1975, extensive samples of soil and surface sediments were taken from selected areas in the Price Basin in Utah, in the Grand Valley of Colorado, and in the San Juan River Basin near the Colorado-New Mexico border. Following the gathering of numerous samples, extensive laboratory analyses were made to determine their salt content.

Hillslopes higher in mineral content

Among the findings of the university scientists were that samples of Mancos Shale from hillslopes contained an appreciably higher content of soluble minerals than did the valley alluvium. The highest salt concentrations were found in efflorescent crusts on the bedrock (Mancos Shale) bed of North Miller Creek, a tributary of the Price River.

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Healing of gullies, such as the one at the left, would go a long way toward reducing the Colorado River salt load

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Although the Mancos Shale is widely recognized as the largest major source of salinity in the Upper Colorado River Basin, the Mesa Verde formation is also an important contributor, according to the CSU geologists. However, they concluded that areas underlain by Mancos Shale and its associated shallow alluvial deposits are presently the major diffuse sources of salts. "They contribute significant amounts of both sediment and solutes at any time, but especially when gullied."

Schumm points out that the Mancos Shale and associated alluvial materials are gullied throughout the entire Upper Colorado River Basin. The gullies may have been formed at the end of the 19th Century by climatic changes and/or by overgrazing.

One solution, Schumm says, would be to cause sediment deposition in these gullies. "Sure, the salt will still move through but it won't be coming out in such large quantities. If we could heal these gullies, and thus store the sediment, we would be cutting off the big salt supply from the cliffs and from the badlands," Schumm says.

Spring damage higher than fall

The CSU professor also believes control of sheep movements would help. "In the spring the shale tends to be puffed and loose due to frost action. But then following summer rains, it is a very tight, sealed surface. So, if sheep trail through the area in the spring, they kick material down into the channels. It will be flushed out of the channel during the next rain, thereby increasing the sediment and salt production. The same sheep moving through in the fall probably would have much less impact."

Another technique recommended by Laronne and Schumm would be to keep channels away from Mancos Shale outcrops by straightening reaches or deflecting them away from the valley sides so that the main channels would remain in the center of the valleys.

Information on additional research being carried out at Colorado State University on the salinity problem of the Colorado Basin begins on page 26.

URBAN FLOOD CONT

If a developer constructs homes or other buildings in a river valley which then alters the drainage pattern so that increased flooding takes place farther downstream, who should pay for preventing such damage? The developer? The eventual home buyers?

How should these preventive costs be determined? Should they be assessed before the first board is cut or after the development is complete?

"The question of who should bear the costs of rectifying these kinds of flood problems has been the subject of considerable controversy," says Robert L. Hiller, a specialist in natural resource law at Colorado State University. Hiller and civil engineer Neil S. Grigg* are the principal investigators on a project designed to measure the impact of urban/suburban growth on water runoff, along with Raymond A. Bullock, director of utilities for Lakewood, Colorado, and L. Scott Tucker, executive director of Denver's urban flood control and drainage district. Funds for the project were received from the U.S. Office of

Suburban growth can alter flood runoff patterns

ꞮOL: Who Should Pay?

Water Research and Technology through the Colorado Water Resources Research Institute.

There is little doubt that the building of housing tracts, shopping centers, roads, etc., does cause changes in storm drainage patterns. In their report to the Institute, Hiller and Grigg describe the problem as follows:

> *"The urbanization-induced reduction in pervious land area and increase in storm water removal efficiency (lined channels, concrete drains, etc.) are causing measured increases in peak runoff rate and total runoff volume."*

In other words, as more rooftops, streets, and paved parking lots are added, the faster and higher flood waters will rise—downstream.

Downstream is "out-of-mind"

The critical word here is "downstream." Since the construction-caused damage does not take place on the site of the tract or shopping center being built, the developer usually "sees" no need to pay for the drainage impact costs generated by his development, Hiller and Grigg point out.

An additional problem is where to find funds to pay for the cost of drainage structures or on-site retention ponds before a housing tract has been fully developed. Prof. Hiller asks: "Is it fair to require a developer to pay all the cost of drainage facilities?

"But on the other hand, if the tract is built without provision for preventing accelerated runoff, then it never will be accomplished."

"The opposite tack...is to promote growth by subsidizing the off-site drainage costs with general tax funds"

Hiller points out that some drainage control programs attempt to slow urban/suburban growth by requiring high initial development costs for off-site drainage. The opposite tack, he says, is to "promote growth by subsidizing the off-site drainage costs with general tax funds."

The two-year study by the CSU faculty members and graduate students is designed to help municipal officials, developers, and home owners. Part of the research included extensive reviews of drainage regulations and relevant case law, along with published material on public finance and urban drainage economics.

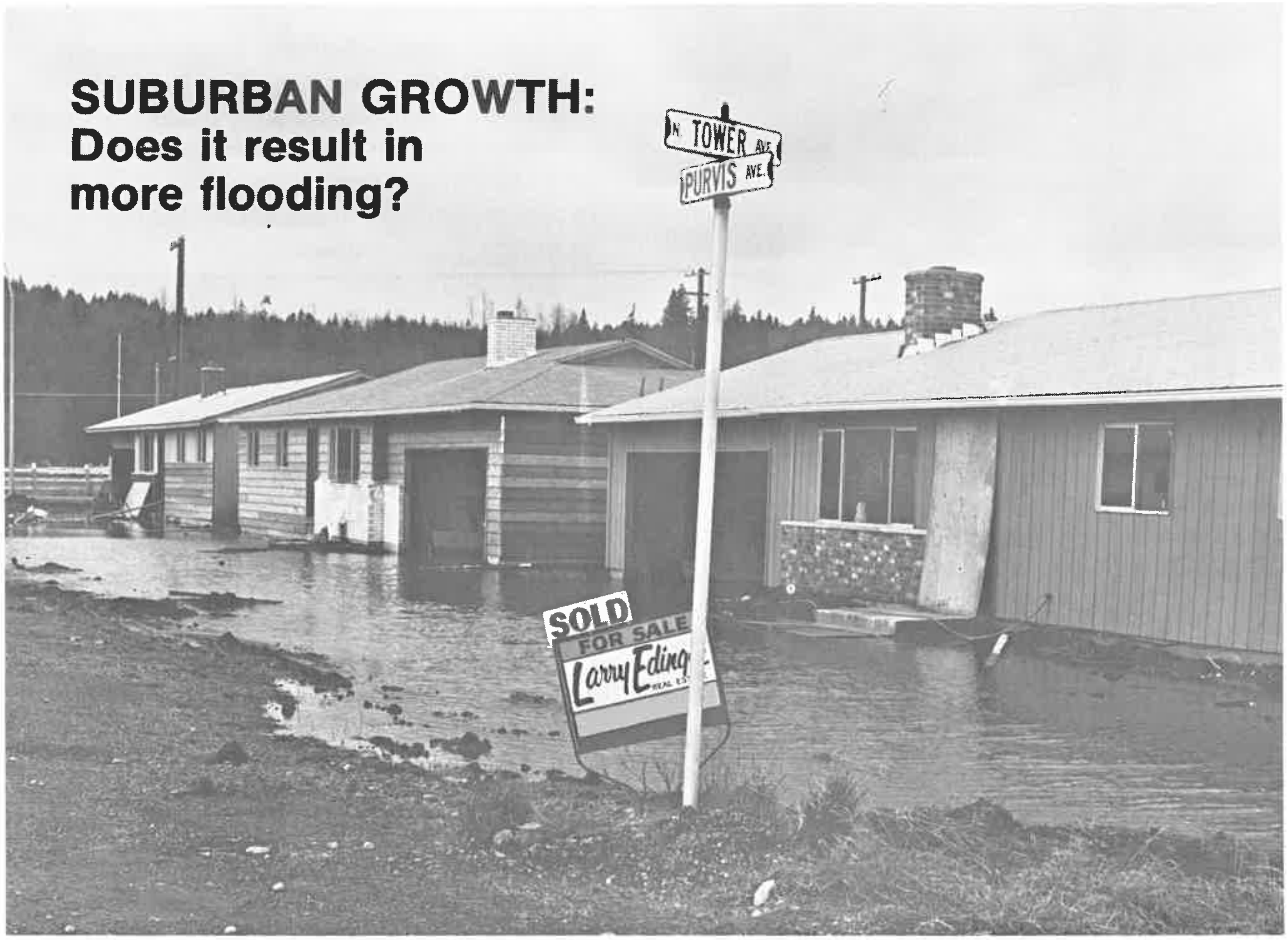
Scheduled for completion in June of 1978, the study report will include a handbook of technical, legal, and economic criteria of various alternative drainage programs.

Hiller and his fellow investigators also are working on the development of a "model drainage ordinance." It will be unique in that it will present options to city officials, according to Hiller. "We will set out the alternatives, the techniques for quantifying the possible runoff, and the legal options for arranging for payment of the costs," says the CSU legal specialist.

"The results of this project will provide local governments with various legally-based alternatives for handling these problems," says Hiller. "The specific approach can be selected by the decision-makers of the local government."

**Now with the University of North Carolina.*

SUBURBAN GROWTH: Does it result in more flooding?



Attractive homes on large lots...fresher air...greener countryside...less traffic...muddy brown flood waters..*MUDDY BROWN FLOOD WATERS???*

Most people move to the suburbs to improve their housing situation and to get away from the concrete and congestion of the core city. In some instances and some areas, what they may get are muddy brown flood waters lapping at their suburban dream houses, according to a CSU professor. Donald O. Doehring says: "Large increases in flood hazards are synchronous with urbanization. As an area is urbanized through the building of housing tracts, shopping centers, and streets, the overall surface permeability is reduced." The CSU environmental geologist points out that when suburban growth takes over farms and open fields, there is less exposed soil for the rain to soak into, and many of the natural storage areas of ponds and depressions are filled in. In some geographical locations, this change in land use can dramatically increase the chance of floods, something the prospective suburban home purchaser seldom thinks about before signing up for his multi-decade mortgage.

Amount of flood rise not established

Such a possibility has been known to hydrologists and other water behavior specialists for some time. However, the potential height of water rise under different levels of urbanization and varying amounts of rain has not been established, according to Doehring. He says: "The standard engineering and planning practice regarding flood hazard delineation in the United States is based on the assumption that one percent flood expectancy is static and that subsequent urbanization of the catchment will have no significant impact on that expectancy." The "one percent flood expectancy" referred to by Prof. Doehring is sometimes referred to as the one-hundred-year flood and has a one percent chance of being equalled or exceeded every year.

The CSU geologist recently completed a study of the build-up of flood hazards in a rapidly growing area around Boston, Massachusetts. The research was funded in part by the U.S. Office of Water Research and Technology. The completion report for the OWRT investigation was issued in February of 1978 under the auspices of the Colorado Water Resources Research Institute.

Although the physical location for the studies was eighteen river basins in Massachusetts, the techniques developed can be used in other areas, such as the rapidly growing area just east of the Front Range in Colorado.

Urban growth affects large floods

The research goal was to determine if increased numbers of tract homes, etc., had a significant effect on the one-hundred-year flood mentioned earlier. Doehring states: "Prior studies around the country and in New England indicated that when a watershed is urbanized there is an attendant increase in flood hazards up to the ten- or twenty-year flood. But the thinking was that for larger storms, the increased urbanization would not be a factor."

The university scientist explains that the rationalization was that in a large storm, ponds and other low-lying areas are quickly filled and the rain intensity is so high that the infiltration capacity of the soil, even if not capped with asphalt streets and parking lots, would be greatly exceeded.

But as a result of the extensive measurements and analyses made in the New England river basins, Doehring concluded that the "impact of urbanization can be a factor right on up to a one-hundred-year flood."

The Colorado State University professor justifies this different conclusion by saying: "We started by looking at the literature. The first thing we noticed was that with one exception, all the studies which concluded that there would be no effect beyond the ten- to twenty-year flood were done in areas of thick, clay-rich soils—such as around Washington, D.C."

"Urbanization might only raise a flood level 1.8 feet... but 1.8 feet could double the area inundated by a flood"

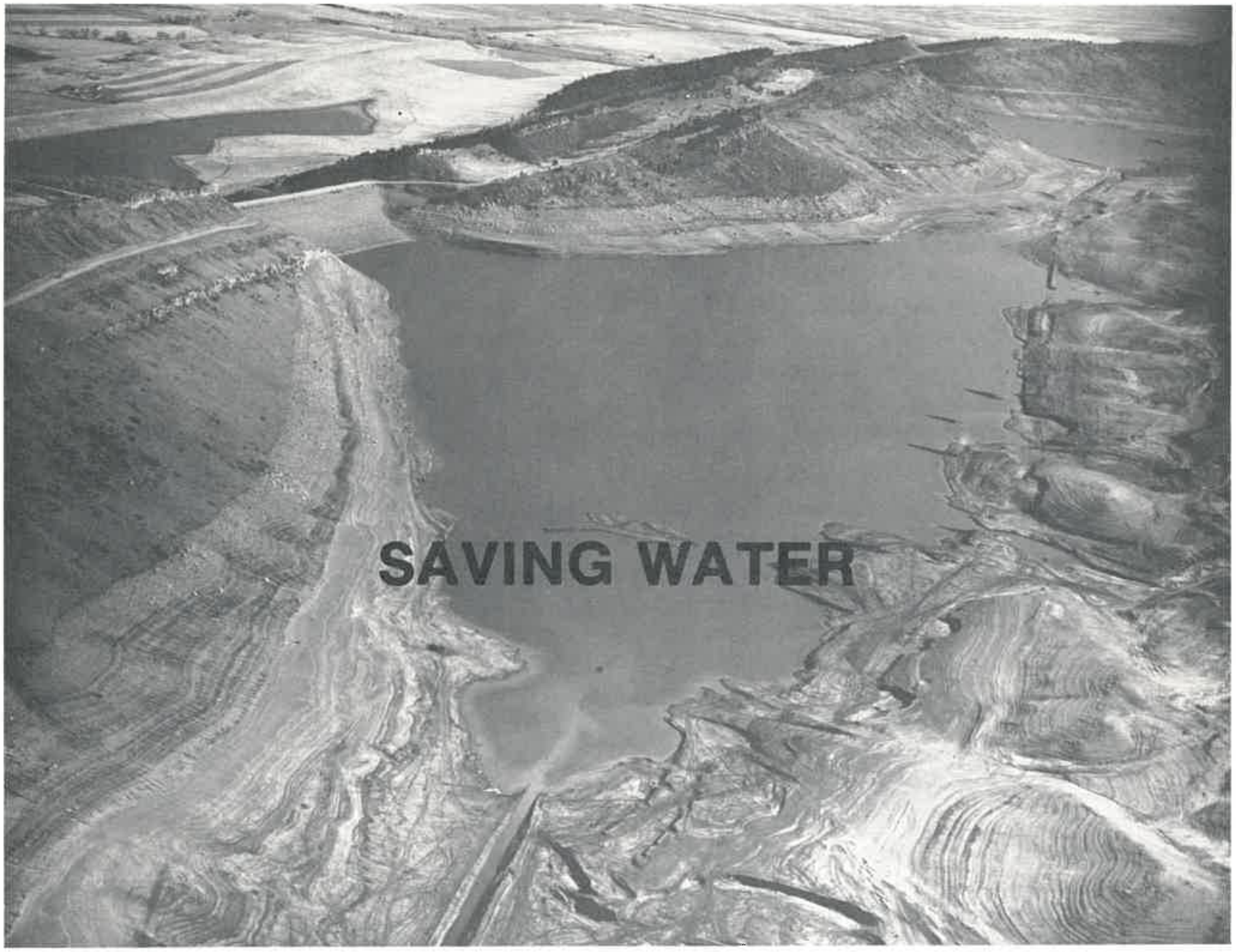
Doehring adds: "When you have 8 to 10 feet of clay, it doesn't make too much infiltration difference when you cover it with blacktop."

The CSU geologist is convinced that what may happen flood-wise after urbanization is strongly dependent on the type of soils and the topography of the land. "If a similar study were to be made of conditions along Colorado's Front Range, it might be that for floods larger than the twenty-year flood, the urbanization might have no significant effect. But what we developed was a set of techniques and mathematical formulae for making a good estimate of the probability of a significant change taking place after urbanization."

The increase in flood levels does not have to be large to cause considerable damage to homes and city business districts, according to the CSU faculty member. "Urbanization might only raise a flood level 1.8 feet, for example, but 1.8 feet could double the area inundated by a flood."

Doehring, who has presented papers on this research to international scientific meetings in Amsterdam and in Leningrad, warns of the danger of not considering the effects of suburban growth. "The consequences (of having a static conception of flood hazards) are potentially disastrous in that the actual hazards on which land use decisions should be based will not be estimated reliably."

Prof. Doehring also points out that during the next decade, implementation of the National Flood Insurance Act will prgressively shift the financial burden of flood damage from the general taxpayer to flood plain occupants. Since actuarial rates must be established for several zones of risk, accurate delineation of these zones is vital if the program is to function equitably.



Although the low flows of 1977 are becoming just memories, the need to conserve water still exists

"There are operational things a water utility district can do, such as fix leaks in the system and reduce the pressure if it is too high. The utility also can apply economic pressure by raising the price of the water, especially at peak demand times such as in the summer. There are public education programs by which the utility can try to educate the home owners to use less water.

"But the question then is—how acceptable are such changes and restrictions to the water users?"

Professor J. Ernest Flack believes a municipal water utility should have a good idea of how their customers will react before instituting any operational or economic changes. "Restrictions seem to work well over the short haul, but I am not sure they are effective over a long period," Flack says.

Between 1975 and 1977, the University of Colorado engineer was a co-investigator with Duane W. Hill on a research project designed to achieve urban water conservation. Hill was a professor of political sciences at Colorado State University during that period. Student project assistants included Wade P. Weakley, and Robert Snodgrass.

The project, sponsored by the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute, had two main objectives. The first was to assess the engineering and economic feasibility of various means of conserving city water. Among the means studied were water saving devices, pricing, water use restrictions, public education, horticultural changes (smaller lawns, hardier shrubs, etc.), system and household leakage reduction, and metering.

The second major objective of the research was to develop public survey "instruments" that could be used by utilities to determine the social and political acceptability of any proposed conservation program.

Flack and Hill have developed a handbook—published by the Institute—for use by utility managers to determine the most suitable set of alternatives for conserving water in their city or town. The handbook includes the procedure for conducting a survey to determine the social and political acceptability of the measures being considered.

The survey technique was tested in Louisville and Lafayette, two towns near Denver, by Prof. Hill's students. "What they came up with was a 'door-step' type of interview that can be done in twenty minutes. Interviews that are longer are not as effective and are difficult to administer," Flack states.

Raising the price of urban water does not always cut usage, the university civil engineer reports. "If the price of the water already is medium-to-high per gallon, then small price increases do not seem to have much effect."

The same results apply to charging more for water used in peak demand times, such as the watering of lawns during the summer. "The price jump will have to be considerable to achieve any significant reduction in water usage," Flack says.

One of the conservation measures studied during the two-year project was encouraging the planting of smaller home lawns. Prof. Flack points out that in the case of new housing developments, a city might refuse water hookups to homes with more than a maximum size lawn.

Colorado cities and their residents do need to continue water conservation measures regardless of whether their area is experiencing normal or water-short years, Flack believes. "Water supply systems are expensive, there is increasing competition for water, and there will be increasing conflict for the amount that is available."

WATER MOVEMENT IN THE FOREST

How does water get from the top of a mountain to a stream at the bottom? It is tempting to say the water simply moves downhill till it reaches the flowing stream.

But this would be a great oversimplification. There is a lot of complicated action that takes place after the raindrop falls or the snow crystal melts. Ooze changes to drip, drip accelerates into trickle, trickle swells into rivulet, rivulet meets more rivulets until a dashing mountain brook is formed. In some instances the end result may be a raging mountain torrent.

Although water behavior specialists and foresters are interested in the entire process, considerable attention has been directed toward learning more about what happens during the initial stages. Several Colorado State University scientists are particularly interested in how snow melt water moves through the litter layer and the soil of subalpine coniferous forests in Colorado. Professors Stanley L. Ponce and Arthur T. Corey, along with graduate students Owen R. Williams and Mark Spearnak, have been monitoring the flow of snow melt through selected areas of the Frazier Experimental Forest.

Ponce reports that during the time snow was melting at the Frazier site, the runoff was carried as surface and near-surface flow in the litter layer and in the upper four to five centimeters of the soil. There also was some flow through the soil two and a half to three meters below the surface.

The university investigators found that the amount of flow was highly variable and dependent upon conditions at the different test sites. They also concluded that under saturated conditions, the potential rate of percolation through the soil generally could be in excess of the normal rates of snow melt.

Ponce also reveals that under conditions where the soil, but not the litter, freezes there may be a flushing of nutrients and sediment from the litter into the mountain stream when the snow melts. Such an occurrence could have eutrophic implications for a lake or reservoir located down the watershed.

SINGLE OR MULTI-PURPOSE RESERVOIRS?

Can privately owned irrigation reservoirs in Colorado's Front Range be "opened up" for recreation without injuring existing water rights or without placing their owners in positions of liability? What are the physical and legal barriers to such an action? Could these reservoirs, located at high elevations, support a successful recreational fishery?

A number of faculty and graduate students at Colorado State University have been grappling with these and other related questions for several years. Robert Aukerman, Clarence A. Carlson, Robert Hiller, and John W. Labadie have been the principal investigators in the research with assistance from graduate students John M. Shafer, Mary E. McAfee, and Thomas M. Keith. Their investigation was supported by the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute.

Despite Colorado's reputation as a leading recreational area, there are not enough recreational resources for the people who live here or who visit. As phrased in a report by Aukerman, Carlson, Hiller, and Labadie: "Even the most fragile and inaccessible lakes...are constantly being assulted by increasing numbers of backpackers, jeepers, and horsepackers.

"The result has been the inevitable overcrowding and overuse of the existing water sites open to the public."

The university investigators do not see any forthcoming improvement: "Current management practices and projected plans call for restricting the number of recreation users...the situation can only become worse. Compounding the problem is the rapid population growth along the Front Range...one of the fastest in the country."

With this over-demand for water-related recreation, it was inevitable that attention would turn to the many irrigation reservoirs scattered among the peaks and canyons of the Front Range. Nearly all of these bodies of water are now used only for storage of irrigation water. This single-purpose usage drew the following comment from Aukerman and his co-investigators: "In a time when recreation demand for water already exceeds existing available resources...it seems inconceivable that reservoirs will continue to be managed for (a) single purpose, excluding recreation as a use of the water resources."

"...it seems inconceivable that reservoirs will continue to be managed for (a) single purpose, excluding recreation..."

Water right owners must be protected

The Colorado State University faculty members are aware of the water rights implications of such a proposal. They wrote: "Since water is a property right, the owner must be convinced there is a legitimate demand, that there are practical reasons for him to make his reservoir available for recreation, and that the management of water for recreation is not in direct conflict with his major use." Also recognized are the problems of liability for personal injury and the responsibility for public health.

Such convincing will not be an easy task. Some of the responses of the reservoir owners—private firms and individuals as well as professional water managers contacted—have run like this:

"Would you rather eat or recreate?"

"Water is too scarce to use for recreation."

"We have always drawn down reservoirs and distributed water this way. It works. Why change it?"

"What is in it for me? Why should I allow my water to be used by others?"

"This city cannot take the chance of polluting our water supply."

"Recreationists vandalize and destroy our dams by driving on them."

To develop answers to these concerns, the CSU investigators have formulated two major

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LIST OF PUBLICATIONS AVAILABLE

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CR 18	Experimental Investigation of Small Watershed Floods	6/70	5.00
CR 29	Identification of Urban Watershed Units Using Remote Multispectral Sensing	6/71	5.00
CR 40	Selection of Test Variable for Minimal Time Detection of Basin Response to Natural or Induced Changes	12/72	5.00
CR 42	Theory and Experiments in the Prediction of Small Watershed Response	12/72	5.00
CR 43	Experiments in Small Watershed Response	12/72	5.00
CR 56	Evaluation and Implementation of Urban Drainage and Flood Control Projects	6/74	8.00
CR 65	Urban Drainage and Flood Control Projects: Economic, Legal and Financial Aspects	7/75	10.00
IS 13	Flood Plain Management of the Cache La Poudre River Near Fort Collins	8/74	2.75
IS 17	Cache La Poudre River Near Fort Collins, Colorado - Flood Management Alternatives - Relocations and Levies	8/75	5.00
IS 22	Implementation of the National Flood Insurance Program in Larimer County, Colorado	9/76	4.00
IS 24	Factors Affecting Public Acceptance of Flood Insurance in Larimer and Weld Counties, Colorado	9/77	3.00
IS 27	Proceedings, Colorado Drought Workshops	11/77	Free

B. WATER SUPPLY AUGMENTATION AND CONSERVATION

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CR 8	Improving Efficiency in Agricultural Water Use	6/69	5.00
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CR 16	Experimental Investigation of Small Watershed Floods	6/68	5.00
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C. IDENTIFICATION AND CONTROL OF ENTERING POLLUTANTS

		Date	Price
CR 14	Hydrogeology and Water Quality Studies in the Cache La Poudre Basin, Colorado	6/69	$ 5.00
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CR 26	Water Temperature as a Quality Factor in the Use of Streams and Reservoirs	12/71	5.00
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D. EFFECTS OF POLLUTANTS

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CR 34	The Mechanism of Waste Treatment at Low Temperature, Part B: Sanitary Engineering	8/72	5.00
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IS 10	Proceedings of a Workshop on Revegetation of High-Altitude Disturbed Lands	7/74	3.00

F. ECONOMIC EFFECTS

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CR 13	Economics of Groundwater Development in the High Plains of Colorado	6/69	5.00
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CR 70	An Economic Analysis of Water Use in Colorado's Economy	12/75	5.00
CR 75	Physical and Economic Effects on the Local Agricultural Economy of Water Transfer to Cities	10/76	3.00
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G. ECOSYSTEM EFFECTS

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SR 4	Piceance Basin Inventory	12/71	10.00
IS 7	Wildlife and the Environment, Proc. of Governor's Conference, March 1973	3/73	3.00
IS 10	Proceedings of a Workshop on Revegetation of High-Altitude Disturbed Lands	7/74	3.00
IS 11	Surface Rehabilitation of Land Disturbances Resulting from Oil Shale Development	6/74	Free
IS 14	Bibliography Pertinent to Disturbance and Rehabilitation of Alpine and Subalpine Lands in the Southern Rocky Mountains	2/75	3.00
IS 21	Proceedings: High Altitude Revegetation Workshop No. 2	8/76	4.00
IS 25	Surveillance Data - Plains Segment of the Cache La Poudre River, Colorado 1970-1977	1/78	5.00
TR 1	Surface Rehabilitation of Land Disturbances Resulting From Oil Shale Development	6/74	10.00
TR 4	Vegetative Stabilization of Spent Oil Shales	12/74	3.00
TR 5	Revegetation of Disturbed Surface Soils in Various Vegetation Ecosystems of the Piceance Basin	12/74	4.25

H. PUBLIC WELFARE (SOCIAL GOALS) EFFECTS

CR 37	Searching the Social Science Literature on Water: A Guide to Selected Information Storage and Retrieval Systems - Preliminary Version	9/72	5.00
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I. INSTITUTIONAL PROBLEMS

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J. PLANNING AND ANALYSIS METHODOLOGY

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K. WATER CONVEYANCE AND CONTROL WORKS

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L. OTHER

		Date	Price
IS 1	Inventory of Environmental Resources Research in Progress - Colorado State University	1/71	Free
IS 3	Inventory of Environmental Resources Research in Progress - Colorado State University	7/72	Free
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TR 2	Estimated Average Annual Water Balance for Piceance and Yellow Creek Watersheds	8/74	Free

Questions have been raised as to the appropriateness of restricting some reservoirs to irrigation storage

approaches or objectives. The first was to identify the factors essential for selection, planning, and management of reservoirs for recreation. The second was to demonstrate the physical, biological, and legal feasibility and potential for enhancing water recreation opportunities on these bodies of water.

Norman Evans, director of the Colorado Water Resources Research Institute, describes the project as an examination of the possibilities: "We want to protect the owner's rights as well as keep him from liabilities. There cannot be any mandatory requirements that reservoir owners make available their water for recreation use. But surely there can be opportunities for negotiation."

Over the two years of the project, the investigators sought to identify, (1), those factors which had the greatest effect on the attitudes and behavior of recreationists; (2), those practices managers felt were important; (3), the fishery potential and water needs; and (4), the ways of meeting these needs by timed water delivery, water management, and legal arrangements.

Information was collected during the study from 131 Colorado reservoirs, all above the 6000 foot level. These high reservoirs are operated in conjunction with other reservoirs located on the plains below the Front Range.

Domino effects possible in water system

"It's a complex system," says Evans. "Water might be released from Reservoir A high up in the Front Range which is owned by an irrigation company near Sterling. But the water might be delivered to a canal near Fort Collins.

"Then water might be taken by the Sterling company from a plains reservoir owned by the Fort Collins company.

"So if you make changes in that system, there would be a domino effect that might unexpectedly affect water users in the far reaches of the basin."

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It is in this area of complexity that Prof. Labadie made his contribution. A specialist in systems engineering, Labadie utilized a computer modeling program to simulate the behavior of selected reservoirs in the Front Range and on the plains. "We tried to determine if it was hydrologically feasible to hold the water longer than usual in the high country reservoirs without injuring the water rights of the irrigation companies," Labadie says.

Plains reservoirs would fluctuate more

The CSU civil engineer believes the results of the computer analysis demonstrated that it would be physically feasible to utilize the high reservoirs for recreation. Of the five reservoirs simulated, acceptable storage levels for both fishery and irrigation uses could be maintained at four.

To achieve this goal, one device would be to fluctuate the water levels more severely in the plains reservoirs, says Labadie. "This theoretically allowed the water to be kept longer in the high reservoirs."

"...sufficient water would have been maintained in the high reservoirs for recreation while those irrigators would have been receiving all their due allotments"

Labadie explains this simulation was carried out under the firm condition that the historical water demand of irrigators receiving the reservoir releases had to be satisfied: "During the theoretical three-year period we simulated, sufficient water would have been maintained in the high reservoirs for recreation while those irrigators would have been receiving all of their due allotments." He adds: "Admittedly, there would be some impact on irrigators farther downstream since the river level would vary

Increased conjunctive use of plains reservoirs with those in the high country could expand the use of the latter for recreation

somewhat under this new management practice. A total basin-wide study is the next step."

Another major part of the investigation was concerned with the legal options, liabilities, and limitations on utilizing these storage reservoirs for recreation. Among the legal aspects reviewed by Prof. Hiller and discussed in the project report are the questions of diverting water to put it to beneficial use, water storage rights, minimum stream flows and lake levels, as well as existing transfer mechanisms.

Some notable findings emerged from the project team's study of the attitudes of persons now seeking recreation at Colorado lakes and reservoirs. These "recreationists" fall into three groups, according to the authors. The first group is Facilities-and-Access-Oriented, the second is Solitude-Oriented, while the third group is Hiking-and-Scenic Oriented.

Members of the first group—Facilities-and-Access-Oriented—apparently wish to drive to the reservoir of their choice over good roads (paved or maintained dirt), don't wish to travel too far (less than two hours), and desire to have well-developed facilities when they arrive (toilets, picnic tables, fire grills, trash cans, wood, water, boat ramps, along with parking and camping sites). Representatives from this first group will accept crowded conditions, provided they have a good chance to catch a fish.

The less people, the better

Those persons whom the investigators place in Group Two—Solitude-Oriented—seem to place little value on having easy access (road passable only to four-wheel drive vehicles OK); they prefer drives of less than three hours; want only moderate facilities at the reservoir (toilets, trash cans, tables, fire grills); do not want too many other people around; and will not be too unhappy if they fail to catch a fish.

The final "group of persons" does not wish to drive up to the reservoir. They desire foot access only, but are willing to drive for almost four hours to the place where they park their vehicle. Toilets and trash cans are the only facility wanted at the site, the quality of the fishing is unimportant, and other people are not too welcome.

TWEAKING THE RIVER?

A spider web and a large river system would seem to have little in common. The web, though cleverly constructed of gossamer threads, is fragile and ephemeral. Here today and gone tomorrow. But the river endures. It is constantly renewed at its source to flow downslope.

Yet the spider's web and a large river system—the mountain headwaters, the flood control dams, the irrigation diversion structures, the municipal water reservoirs, the underground aquifers—do have a point of similarity.

The entire river system may respond

Tweak or pull a spider's web at one point and watch. The entire web stretches, alters in shape, accommodates to the new stress. A river system reacts similarly. A change in precipitation at the stream's headwaters, perhaps induced by cloud seeding; construction of new dams; diversion of more or less water for urban and agricultural purposes; pumping of increased amounts of water from the aquifers fed by the stream—all of these can be a "tweak" or "pull" to which the entire river system downstream will respond.

The problem is that the response of the spider's web is immediate. You can see the change. Not so with a large river system. Changes may take place slowly and be difficult to detect and measure—at least until the impact becomes severe.

A number of Colorado State University faculty and graduate students have been working for several years to improve the visibility of "tweaks" and "pulls" on river systems, particularly those being applied to the Cache la Poudre and the South Platte. Leaders of the project are David W. Hendricks and Hubert J. Morel-Seytoux, civil engineering professors at the Fort Collins institution. The research is sponsored by the U.S. Office of Water Research and Technology and the U.S. Corps of Engineers.

"The water resources system of the South Platte River Basin is very complex and the water is intensively used," says Hendricks. He adds that

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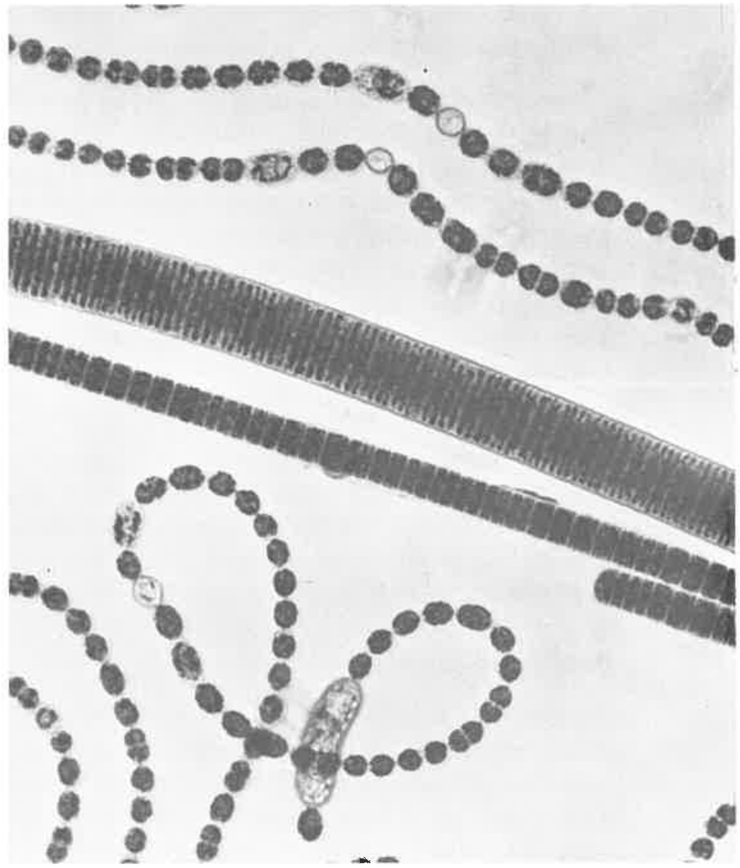
future water demands in this basin must be met by importing additional amounts of water from Colorado's west slope area or by transfers from present farm uses. A third alternative mentioned by the CSU faculty member is water reuse.

The question is—what effect would such changes or "tweaks" have on the rest of the South Platte system? Hendricks states: "You can't, for example, look at Denver in isolation from the rest of the system. If you do something to one part of the system, all the other parts will be affected to some degree."

To help out in this situation, the CSU civil engineers devised what they term an input-output water balance model. The model depicts the entire water resources system of the South Platte. The model parallels the Leontif economic input-output model except that instead of annual dollar amounts, water transfers in acre-feet per year are shown.

The model can be used to determine the best or optimal allocations of water from its various origins such as Cherry Creek, the Big Thompson, the Cache la Poudre River, etc.—by which the quality and quantity requirements of agriculture, cities, etc., can be satisfied at minimum cost, maximum net benefits, or both. According to Prof. Hendricks, the input-output water model is the same thing as a block diagram, but is in matrix form. "What the model displays in an organized way is the information already available. It takes a very complex system and pulls it together so it can be understood. Then if you want to do some planning, the data is available," he states. The results of the Hendricks-Seytoux research have been applied by the Omaha District of the U.S. Corps of Engineers in a study of the water resources of the South Platte Basin.

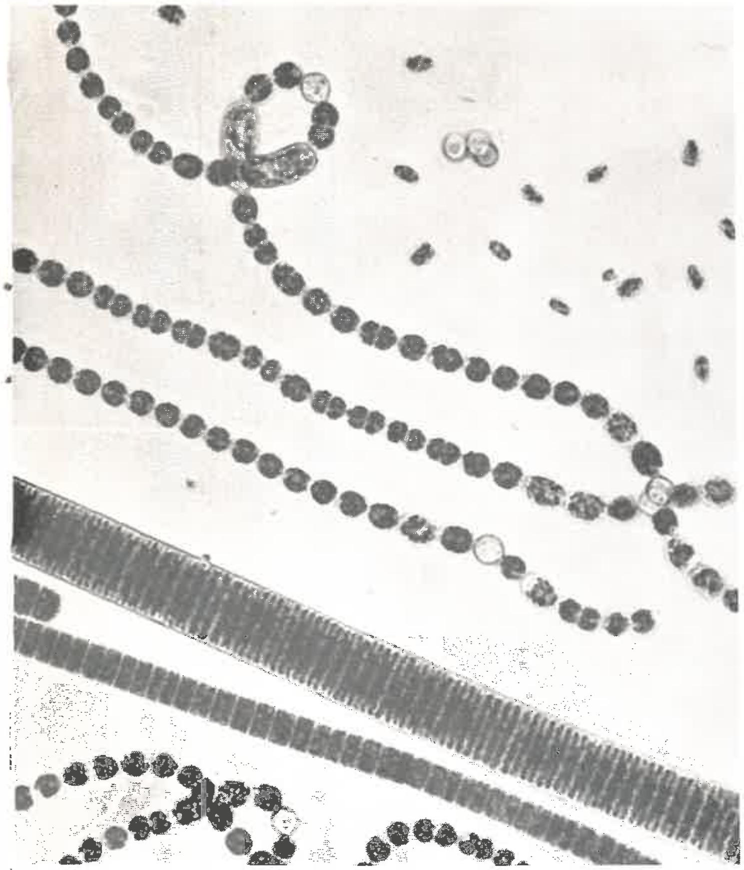
It is apparent from the Hendricks-Seytoux research that considerably more reuse of water is in store for residents of the South Platte area. Prof. Hendricks says: "In the study we defined the basin-wide water reuse factor as the ratio of total water use to the virgin water originating within the basin and imported. In 1970 this overall basin reuse factor was 2.03; the reuse factor in 2020 for a drought condition is estimated to be 3.52."



CROP GROWTH SLOWED BY ALGAE?

Algae—the aquatic plants* often seen in lakes, reservoirs, streams, and in roadside ditches—are already known to cause problems. In lakes and reservoirs, too many algae may lead to the depletion of oxygen and subsequent fish kills under certain conditions. Some species of algae also have been implicated in the fatal poisoning of animals when they drank algae-contaminated water. And when massive growths (called blooms) of algae take place in a lake or reservoir, their decaying masses and their accompanying odors are anything but aesthetically pleasing.

It also has been established that some algae produce material that inhibits the growth of algae



Microscopic photograph of algae

of the same species as well as those of a different kind. The inhibitor-producing algal species may decrease the population of another, allowing the inhibitor producer to become dominant in a particular lake or reservoir.

Some species of algae also may be producing material harmful to farm crops. This possibility has been uncovered by Professor Paul Kugrens of the Colorado State University Department of Botany and Plant Pathology during an investigation performed for the Colorado Water Resources Research Institute and the U.S. Office of Water Research and Technology.

Algal extracts harmful to test plants

In his research, Kugrens examined the effect of algal-produced inhibitors on "higher plant" tissues, such as radish cotyledons (the first leaf to emerge from a sprouting radish seed).

The first step in the investigation was to obtain samples of algae from farm ponds and reservoirs in eastern Colorado. The species he and his graduate students found were *Aphanizomenon, Microcystis, Nitzschia, Hyrodictyon, Scenedesmus, Lyngbya,* and *Anabaena.* All of these "are common 'bloom' algae in lakes, ponds, and reservoirs in Colorado," Kugrens says.

When extracts from these algae were added to the moist filter papers on which the radish cotyledons were growing, harmful effects were obvious. Some deaths occurred, and necrotic, or dead tissue, areas were observed by the CSU botanist. The growth of the exposed specimens also was less than non-exposed cotyledons.

In addition to these observations, Kugrens took a detailed look at the algae-extract treated radish cotyledons via the tremendous magnifying power of an electron microscope. He found "sub-cellular changes including retardation of protein body degradation, lack of starch formation, disruption of proper photosynthetic lamellar (thylakoid formation in chloroplasts), decrease in cell size, and retardation of vascular tissue development."

If farmers obtain their irrigation water from ponds, lakes, or other sources that support these algal blooms, enough inhibiting material could be present to affect the growth of seedlings or mature plants. Crop yields thus could be lessened, according to Kugrens. He also points out that crop plants may be stressed by algal inhibitors and thereby rendered susceptible to a variety of pathogens.

The university scientist believes that although a positive cause-effect relationship has not yet been definitely established between the algae and crop damage, farmers should avoid irrigating with water containing blooms of algae. "This would be especially true at the seedling stage, although in late growth (stages) the plant stress caused by algal inhibitors may allow pathogens to infect the plant," Kugrens warns.

**There are many forms and species of algae. Their chief characteristic is a lack of true plant stems, roots, and leaves. Some algae are extremely small, such as the planktonic or free-drifting types found in lakes and impoundments. Other forms such as the marine kelps, reach lengths of 100 feet and more.*

HARMFUL CONTENT OF MINE DRAINAGE WATER VARIES

What impact water draining from a mine may have upon the surrounding environment depends on several factors, a Colorado School of Mines professor reports. Thomas R. Wildeman of the Department of Chemistry and Geochemistry says much depends upon what is in the ore being mined as well as the topography and the location of the water table. Wildeman came to this conclusion after a three-year study of waters draining from abandoned mines in Colorado's Central City District. This area is some twenty miles west of Denver and is historically the most important of the several gold, silver, and base-metal districts that make up the Front Range mineral belt of Colorado.

"We came up with some curious discoveries. What was in the drainage water did not depend on the minerals in the mine as much as one would expect," say Wildeman.

"If you were collecting samples of drainage water in an adit or tunnel that was being mined primarily for lead and zinc, you would expect to find more lead and zinc in the water than if the adit was being explored for gold, for example. But that was not what we found," states the School of Mines geochemist.

The amount of such elements as lead, zinc, manganese, cadmium, and other so-called heavy metals in the drainage water bore a surprising relationship to the amount of pyrite in the ore. Pyrite is a fairly common mineral that consists of the iron disulfide FeS2. It is brassy yellow in color, and its brilliant metallic luster has earned it the sobriquet of "fool's gold."

"We first found that the amount of these elements in the water seemed to be a direct function of the amount of pyrite in the veins of ore," Wildeman says. "What we thought was going on was that when the pyrite is oxidized through weathering, ferric iron and hydrogen ions are released. These act as catalysts to promote the dissolution of additional sulfide minerals, thus raising the amount of minerals in the drainage water."

As it turned out, this was not the entire story. When the Golden, Colorado investigators checked the waters from still other adits in the Central City area, they found that an abundance of pyrite did not always mean high quantities of metals in the water. "Even if the adit contained considerable pyrite, the drainage water might not be too bad," Wildeman reports.

"What we determined next was the significance of the water table's location. If the adit was above the water table, the pyrite was open to oxidation through weathering. Then the amount of metals in the drainage water was higher.

"But if the adit was below the water table, the pyrite could not be oxidized, and the metal content of the water would go down," Wildeman says.

Contact with pyrite a major factor

They also found that the quality of water draining from active mines was not necessarily any worse than water coming from abandoned mines. Professor Wildeman says: "Active mines could be better than abandoned mines because in most active mines the drainage water would not be in contact with the pyrite."

Another finding of the School of Mines scientists was that the highest concentrations of iron, manganese, zinc, copper, cadmium, and lead in the drainage water come from adits located in the central zone of the ore body, with the lowest concentrations of the metals in the peripheral zone drainage water.

According to Wildeman, the ores in the Central City District are in a concentric zonal arrangement and are well defined by lateral changes in the mineralogy and textures of the ore and the gangue minerals as well as by metal ratios.

"...the quality of water draining from active mines was not necessarily any worse than water coming from abandoned mines"

Drainage from abandoned mines in the Central City district west of Denver is a significant quality factor in the district's streams

"The most important conclusion shown by this zonal variation of the drainage is that the highest concentrations of zinc, cadmium, and lead occur in the central zone drainage water even though sphalenite and galena, the ore minerals which concentrate these elements, occur in greatest abundances in the intermediate and peripheral zones," Wildeman asserts.

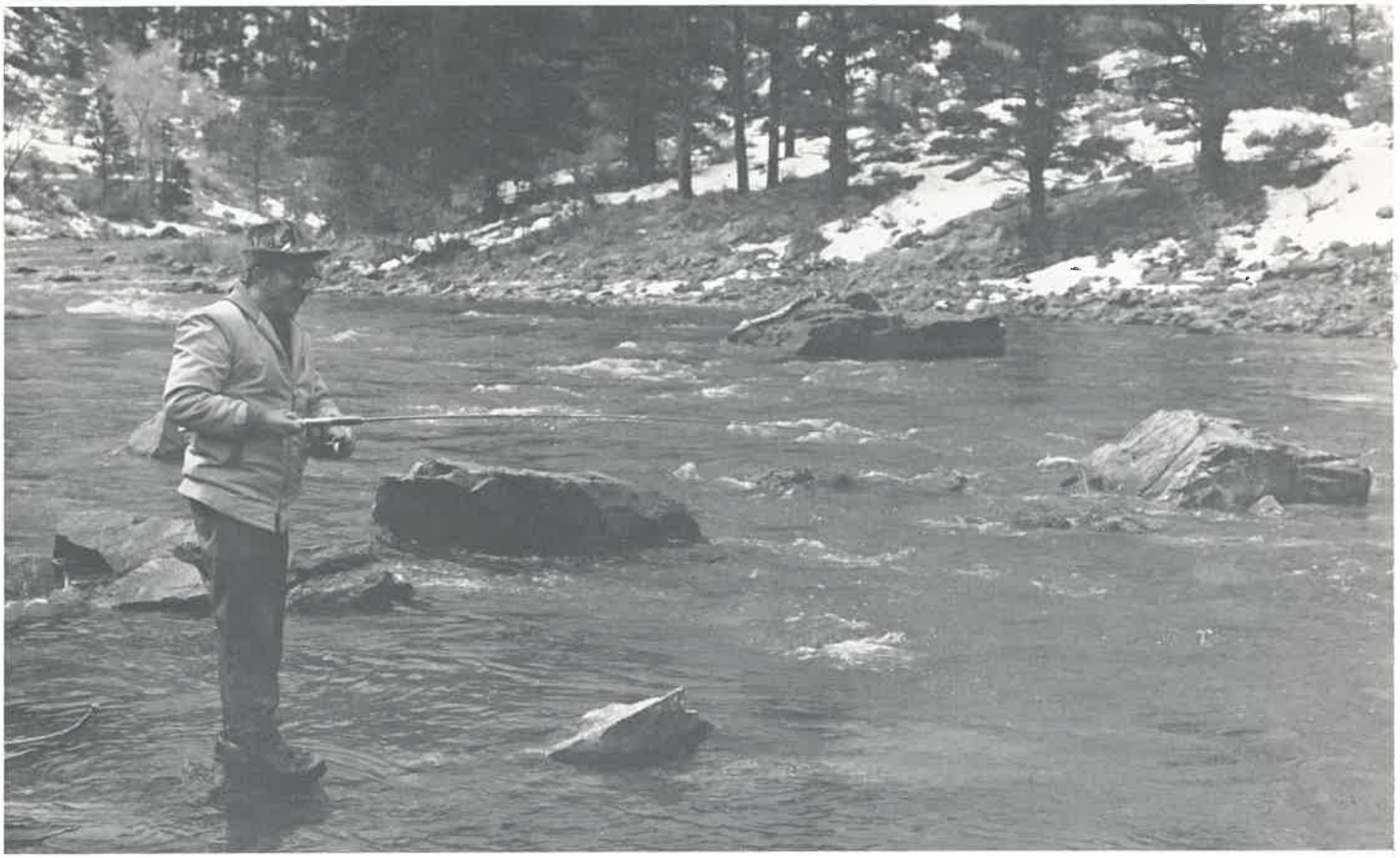
Mines of greatest economic importance occur on the intermediate zone or on the margin of the central zone. Thus there is not necessarily a correlation between the economic grade of an ore extracted from a mine and the harmfulness of the water draining from a mine, according to the School of Mines faculty member.

Most mine drainages are fed from a "diffuse flow aquifer system in which the water residence time is on the order of months," Wildeman reports. He reveals that the chemistry of the drainage water seems to be little affected by changes in precipitation or by seasonal variations.

Two suggestions for improving the quality of mine drainage are advanced by the School of Mines professor. One, keep the time as short as possible during which the water is in contact with the vein minerals. Two, seal the vein minerals away from contact with the air wherever possible.

Implementation of these suggestions may be difficult, Wildeman observes. "The two rules are somewhat at odds because lowering the contact time typically lowers the water table which may expose more of the ore to the air."

As long as the mine is operating, this may not be too bad a situation, Wildeman believes. "But," he says, "once shut down, the effluent from the abandoned operation may become quite harmful. Central City is an obvious example of how not to abandon a mining district."



The "price" fishermen might pay for this level of river flow is being determined

RECREATION/IRRIGATION: The Value of Water

"One dollar and fifty cents has been bid by the gentleman with the fishing rod...do I hear one dollar and sixty, one dollar and sixty for this nice, clear, cool acre-foot of water...

"The gentleman in the corner wearing bib overalls bids one dollar and sixty...do I hear one and seventy, one and seventy...going, going...gone to the man in bib overalls for one dollar and sixty..."

A fanciful scene? Certainly...but such a face-to-face bidding session between fishermen, other recreationists, farmers, city water managers, and industrial developers might be interesting in view of the current dispute over the allocation of limited water resources. The trouble is that in the real world the fishermen, the back-packers, the family campers, etc., do not put up any dollars directly for purchasing water for their recreational uses. They buy equipment and licenses, and pay game taxes, but they do not "buy" water by the acre-foot or by the gallon as do other groups of users.

Yet the recreational people claim their uses have an economic "value." The question is—what dollar figure can be assigned to these uses? For example, what amount would a fisherman pay for a certain quantity of water flowing down the upper reaches of Colorado's Poudre River?

Bidding "game" conducted

Economists at Colorado State University are using an interesting method to find answers to these questions. Professors Robert A. Young and S. L. Gray and graduate student John Daubert are conducting a "bidding game" to arrive at the amount of money recreational users of the Poudre River, located in Colorado's Larimer County, say they would pay for certain levels of flow in that stream.

"The bidding game process asks the respondent to visualize an environmental situation that would have value to him, but is unpriced at present," states Young. "Then you ask him or her if he would pay so much, say two dollars, for that recreational experience. If the answer is affirmative, you then ask if they would pay three dollars—and so on until they would pay, or bid, no higher."

The "environmental situation" in this CSU study is different levels of flow—from low to high—in the Poudre River. As part of the investigation, supported by the U.S. Office of Water Research and Technology through CSU's Water Resources Research Institute, Daubert took color photographs over a 12-month-period of five levels of flow at six different spots along the Poudre. Some of the photographs show deep pools of green water interspersed with stretches of white-capped rapids. Others show exposed mud bars and coated rocks.

As this is being written, Daubert is conducting personal interviews with a randomly selected number of residents of Fort Collins. He is showing the photographs of a site and asking residents what they would "bid" or pay for the various levels of flow shown in the pictures for a particular type of recreational experience. He then repeats the bidding game, using a different site and/or kind of recreation.

Later in the spring, Daubert will move the locale of his survey to the Poudre Canyon itself. There he will conduct the same "game" with actual visitors to the area. The university economists anticipate that some of these canyon recreationists will be from the Fort Collins area but that a significant number will be from elsewhere in Colorado as well as from out-of-state.

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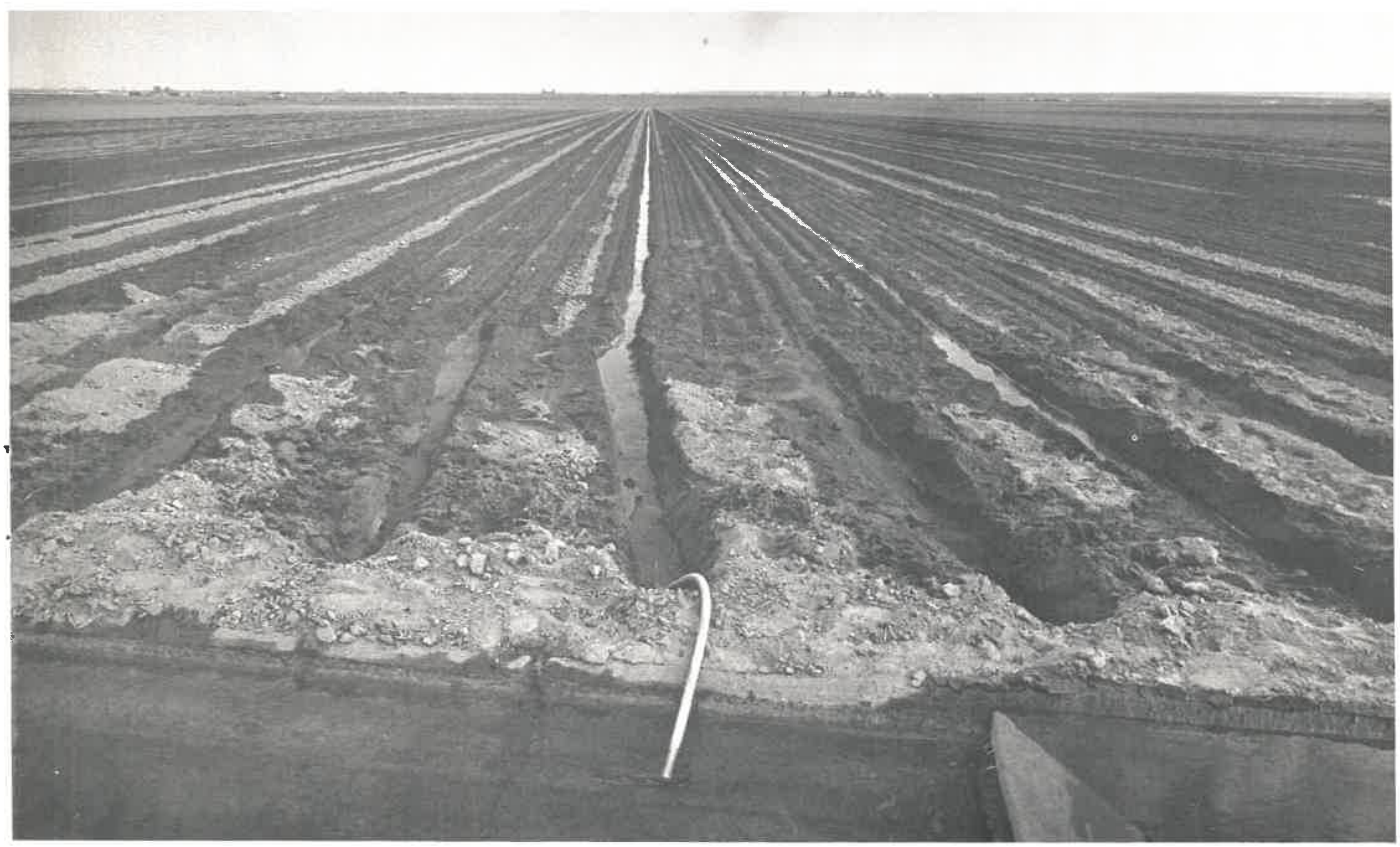
On the other hand, a definite price has been established for irrigation water



OVERLOADING THE COLORADO RIVER:

Sediment and Salts

Could the Colorado River become so loaded with calcium, magnesium, sodium, and other "salts" that it could not be used to grow lettuce, carrots, and other crops? A number of scientists and governmental agencies apparently think so. The U.S. Bureau of Reclamation says about the Colorado: "A large variety of crops, providing a needed diversity to the national diet, is irrigated by its waters...But the concentration of dissolved solids in the river, now among the highest of the great rivers of North America, is increasing." The Bureau concludes: "The increase will further impair the usefulness of the water."

More than farm crop damage would result. Increasing salinity of the Colorado means water of a poorer quality would be diverted to the Metropolitan Water District of Southern California and to the Las Vegas Water District. This would cause added economic costs in water treatment and corrosion damage to the large block of domestic water users in California and Nevada.

Impact will be widespread

Prof. H. Shen, a member of the Colorado State University civil engineering faculty, has been conducting a study on the roles of sediment movements on salt loading into the Upper Colorado Basin. He calls attention to the additional fact that upon completion of the Central Arizona Project, water users in the Phoenix and Tucson areas also may be affected.

Norman Evans, director of the Colorado Water Resources Research Institute, points up the magnitude of these economic costs: "A recent investigation established that each additional part per million of salt carried in the Colorado

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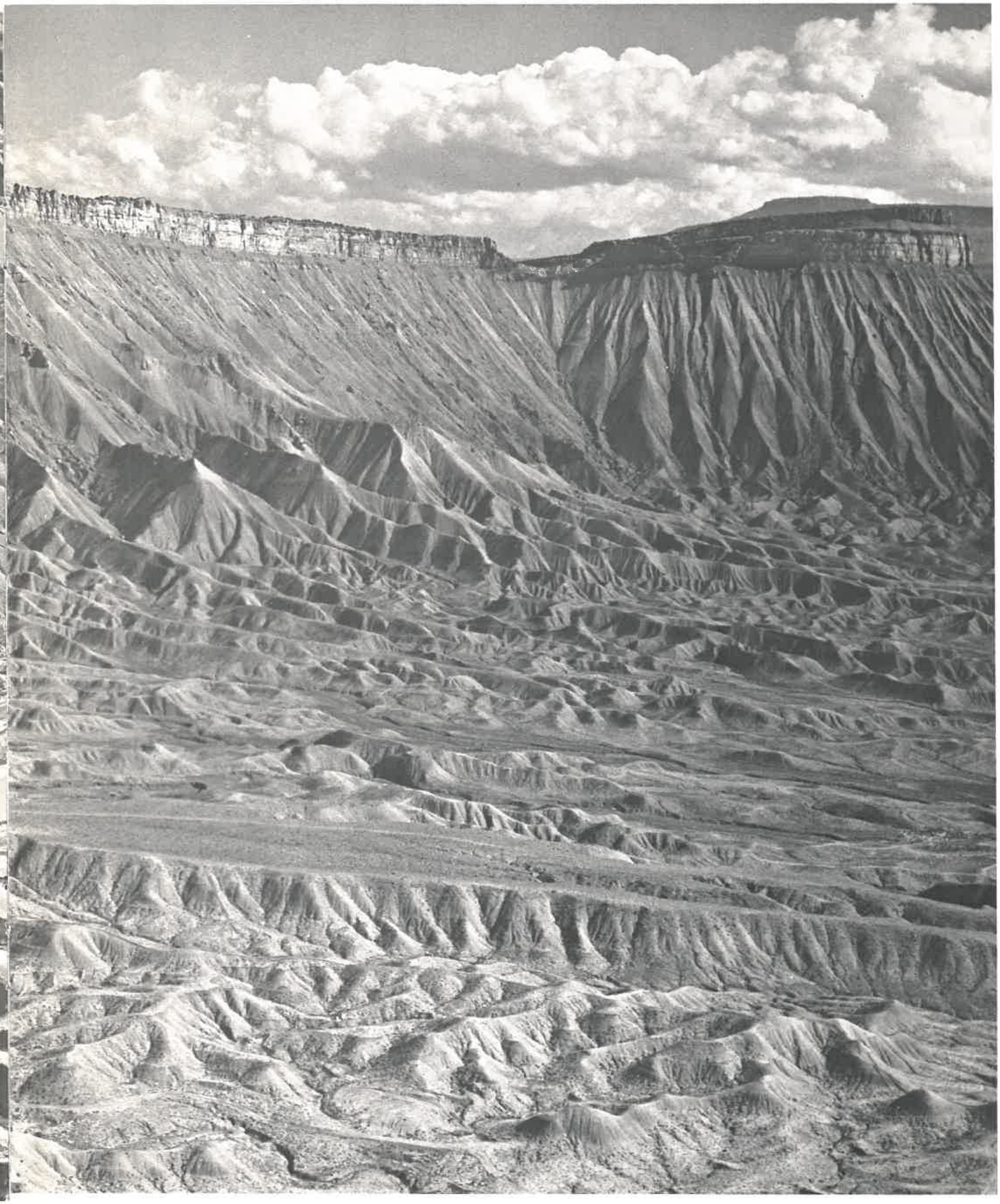
Salts in the sediment eroded from such strata as the Book Cliffs (near Grand Junction, Colorado) may eventually reach the waters of the Colorado River



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River can mean from 250 to 400 thousand dollars in added cost each year to downstream users of the Colorado." Crop yields may be reduced, domestic water systems may corrode more rapidly, and industrial water may need to receive additional treatment.

When the Colorado starts out—on the western slope of the Rockies—it is in good shape. Its total dissolved solids average less than 50 mg/l. But

". . .the United States has a formal treaty obligation . . . to keep the amount of salts in the Colorado at a specified level"

from the headwaters down to the Gulf of California, it is all "downhill" in slope and all "uphill" in number of milligrams of salts per liter of liquid. The U.S. Bureau of Reclamation describes the problem in almost poetic—if ironic—terms:

"Rising high in the Rocky Mountains, the Colorado River flows for most of its length through arid and semi-arid regions of the United States and Mexico. The great river and its tributaries have cut into mountains and plateaus, formed alluvial valleys, carved magnificent canyons, and produced a highly productive delta. In the process, its waters accumulate the solution products of erosion and weathering. From headwaters to mouth, a distance of nearly 1,400 miles, the salinity progressively increases..."

The Green River, below Desolation Canyon, in eastern Utah State

As pointed out in the article on page seven of this annual report, the United States has a formal treaty obligation to the government of Mexico to keep the amount of salts in the Colorado at a specified relationship with the amount of salts in the irrigation water delivered to California's Imperial Valley.

The salts in the Colorado come both from natural sources and from irrigation return flows. Considerable research is being directed toward reducing the contribution from irrigated lands, according to Shen. However, the natural processes of erosion and weathering are still a major source of the Colorado's salts. "It has been estimated by federal agencies," Shen says, "that forty-seven percent of the salts at Hoover Dam (on the Colorado near Las Vegas, Nevada) are derived from natural point and diffuse sources."

Professor Stanley A. Schumm, principal investigator for another project described on page seven, is working with Prof. Shen on this study. Additional investigators include Agricultural Research Service soil scientist S. R. Olsen, along with K. K. Tanji, J. D. Whittig and J. W. Biggar of the University of California at Davis. Support for the research is being received from the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute.

Sediment has role as salinity carrier

The major goal of the study conducted by Shen, Schumm, Olsen, and their co-investigators from the University of California is to find out how much, when, and how soluble salts enter the Colorado River system from various diffuse sources. Specifically, they want to determine the chemical and mineral characteristics of stream sediments and soils so as to identify their potential contribution to salts in the river. The engineers and scientists also want to know what happens, both physically and chemically, between the salts already in solution in the river and the sediment being carried along the stream. Shen states: "We want to understand more about the release and transport mechanisms of sediment as a salinity carrier. The adsorption of salts by soil in the region has long been known; however, the significance of this contribution to river salinity has not been thoroughly investigated."

The Colorado State University engineer points out that the sediment being carried along in river water that is already saline may contain significant amounts of minerals that may dissolve out farther down the stream: "Saline river waters are often saturated with respect to the least and the intermediate soluble minerals which, under more dilute conditions, will add dissolved matter to the river water."

Dissolving sediment will add more salts

As an example, data collected in May of 1976 at the confluence of the Green and Price Rivers (in eastern Utah) indicated the Price River was carrying as much as 2000 ppm total dissolved solids along with a load of sediment. When this Price River sediment reaches the higher quality Green River water, its salts will partially dissolve out, thus adding even more salt to the Green, according to Shen.

As part of the studies on the Colorado's salinity problem, many additional samples were taken from West Salt Creek, northwest of Grand Junction, Colorado, the Price, the San Rafael and the Dirty Devil Rivers of Utah. Approximately 1000 samples were analyzed and inventoried by soil scientists at CSU and at the Davis campus of the University of California.

A technical advisory committee has been providing suggestions on the study to the Colorado and California university scientists. Representatives from the U.S. Department of Interior, the Colorado Water Conservation Board, the New Mexico Interstate Stream Commission, and the Colorado River Board of California are on the committee.

The final report on the project's first phase is under preparation.

"The major goal . . . is to find out how much, when, and how soluble salts enter the Colorado River system from various sources"

STORM RUNOFF:
The Overlooked Pollutant

"There are two options. One is to decide that since storm water runoff can add significant pollution to streams, there is no point in requiring an extremely high degree of treatment for non-storm wastes at city sewage plants. The other option is to treat the storm water." These two choices are posed by Edwin R. Bennett, professor of environmental engineering at the University of Colorado. Bennett points out that in nearly all of Colorado's cities, the storm and sanitary sewers are separate. The former drains directly into rivers and creeks while the sanitary collection lines run to sewage treatment plants.

This arrangement was implemented in the 1940's and up to the present time to eliminate the cost of treating the large volumes of water that rainstorms and snow melting bring. During those decades, stream pollution from storm runoff was not considered to be a serious problem.

"Thirty years ago, it was said secondary treatment for sewage was too expensive... The same thing will happen with ...storm water"

This optimism has not been substantiated by time. A recent study conducted in Washington, D.C. indicted storm runoff as a major source of pollutants. The Metropolitan Washington Council of Governments found that the runoff from parking lots, rooftops, streets, and farm lands could be the source of two-thirds of certain water pollutants found in the area. According to the council, pollutants from brake linings, dead leaves, chemical fertilizers, settled air pollutants, and car tire particles accumulate on roads and roofs. These materials then are washed off during storms and carried into local streams which flow into lakes, reservoirs, and estuaries. The impact of these pollutants upon fish and other aquatic organisms is not regarded as beneficial.

The same scenario may be taking place in the urban areas of Colorado. Bennett, along with Prof. K. D. Linstedt and graduate students from the University of Colorado, found that in one area—Boulder—major amounts of pollutants were coming from storm waters. "We found that storm water runoff is a significant source of stream pollution," Bennett says. "We compared the pollutant load to a stream from the effluent of a sewage treatment plant to the pollutant loading coming from storm runoff."

They determined that most of the suspended solids (80%) and total dissolved minerals (56%), as well as a substantial amount of the organic pollutants (40%) and lead (40%), are due to the storm water discharges.

The University of Colorado engineers sampled the storm water runoff from three different areas at Boulder. One was a high-density multiple unit housing development. The second was an isolated residential sub-division, while the third was a mountain watershed with no roads or buildings. This investigation was supported by the U.S. Office of Water Research and Technology through the Colorado Water Resources Research Institute.

As might be suspected, considerable eroded material was found in the storm runoff from the mountain watershed but little of the oil, grease, and chemical compounds associted with human activities. "Many of the pollutants found in storm waters are generated by autos," Bennett states.

Supporting this conclusion were the findings of the storm water sampling conducted at the Boulder multi-family housing area. High levels of pollutants were found where there was a lot of car traffic.

Prof. Bennett does not expect immediate action on storm water pollutants. "Treatment of storm runoff will be expensive as these storms generate large volumes over short periods. It would be expensive to build treatment plants with enough capacity to handle these volumes.

"But the day will come when we will do it. Thirty years ago, it was said secondary treatment for sewage was too expensive. Nearly everyone fought against it. Then one day, they decided to do it. The same thing will happen with the treatment of storm water.

"If we want high quality streams in Colorado, some treatment of storm water must be accomplished," Bennett concludes.

Many pollutants are found in the storm-water runoff from urban areas such as Boulder, Colorado, shown above

CHANGES NEEDED IN COLORADO'S WATER MANAGEMENT?

continued from page 3

11. The State Engineer should be given enforcement authority, with appeal to the courts possible.
12. Water should be "zoned" in much the same way that land is zoned to maximize "beneficial use" for all purposes.
13. All "paper" water rights in the state should be adjudicated.
14. The appropriations doctrine should be modified in terms of a quantitative measure of right.
15. The "waste" of irrigation water should be defined and rewards or sanctions used to reduce such wastage.

RECREATION/IRRIGATION

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Young is cautiously confident the bidding game will yield results worth considering. "It is an experimental technique, but other investigators have found in related contexts that people 'bid' quite honestly. They try to give you a reasonable assessment."

The results of the CSU investigation could be used to assess the economic trade-offs between instream uses of water and diversionary uses such as farm irrigation, according to Professor Young. "We hope to be able to develop a technique to determine in which cases the aggregate willingness to pay for water-based recreation might be sufficient to justify reallocation of some of the flows in rivers from diversion to instream uses. We want to develop this measure so there can be a direct comparison—using the same common denominator—dollars."

Prepared by David C. Flaherty