Competing Interests in Water Resources — Searching for Consensus

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Preface

The papers included in these Proceedings were prepared for the 1996 **Water Management Conference** *Competing Interests in Water Resources — Searching for Consensus*. The Conference, sponsored by the U.S. Committee on Irrigation and Drainage, was held in Las Vegas, Nevada, December 5-7, 1996.

The purpose of the Conference was to address and improve understanding of an important problem facing all water users and water suppliers — the problem of competition for sufficient water supplies to meet all needs. The Conference addressed such issues as water rights; conjunctive uses of water; demand management; water marketing and water transfers; and the environmental, social and economic impacts of proposed solutions to water shortages.

The Conference included Technical Sessions and a Poster Session on four topics:

- Environmental Needs
- Demand Management
- Water Marketing and Water Transfers
- Social and Economic Impacts

The Proceedings includes 34 papers presented during the Conference. It also includes a Keynote Address by John R. Wodraska, General Manager, Metropolitan Water District of Southern California, and a dinner address by Kenneth R. Wright, President, Wright Water Engineers, and Ruth M. Wright, Board Member, Northern Colorado Water Conservancy District .

The U.S. Committee on Irrigation and Drainage and the 1996 Water Management Conference General Chairman extend their appreciation to the speakers, authors, participants and session moderators.

Herbert W. Greydanus
Conference General Chairman
Sacramento, California

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BUILDING CONSENSUS IN IDAHO TO BENEFIT WATER QUALITY, ENDANGERED SPECIES, THE ENVIRONMENT, AND IRRIGATION!

Mark A. Limbaugh[1]

ABSTRACT

Balancing the needs of the environment, endangered species, and a healthy agricultural economy within a river basin is challenging. On the Payette River in Idaho, consensus has been reached in an attempt to deal with current demands for water while protecting the reliability of irrigation water supplies.

The Payette River system includes 845,000 acre feet of storage in three reservoirs, which is used to irrigate 150,000 acres of farmland and provide minimum pools for local fisheries and recreation. A Biological Opinion issued last year by the National Marine Fisheries Service protecting the listed Snake River salmon under the Endangered Species Act calls for 427,000 acre feet of Idaho water to be released annually to augment flows on the lower Snake River to benefit migrating smolts. The past few years, 145,000 acre feet from the Payette basin has been leased annually to the local water rental pool by storage contract holders for the purpose of flow augmentation under this BiOp. Renting this water creates a problem with water quality in one of the reservoirs, which has been labeled "water quality limited" by the State of Idaho under the federal clean water act. A local water quality group on the reservoir has opposed drawdowns for flow augmentation during summer months in order to protect water quality and cold water fisheries in the reservoir. Conversely, additional flows during the summer would benefit water quality on the lower Payette River, also designated "water quality limited" by the state. Flows in the river have historically been low in the summer as a result of conserving storage water for irrigation. Low flows during the summer not only aggravate problems with water quality and local fisheries on the river, they also have the same affects downstream on Snake River reservoirs.

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[1] Watermaster, Water District No. 65, Payette River System, 102 N. Main, Payette, Idaho 83661.

In a series of meetings, representatives of all interests on the river discussed what could be done to improve overall river health. Consensus was achieved through compromise, cooperation, and communication. It was decided to split the release; about one half of the water would be released in the summer to benefit the lower river, and the balance would be released during the winter to benefit fisheries and water quality during summer months on the reservoir.

BACKGROUND

Water District No. 65 was formed in 1992 under Idaho Code as a vehicle for the State of Idaho to distribute water according to the prior appropriation doctrine to water right holders on the Payette River. A watermaster is elected annually by the water users, and is then appointed by the Director of the Idaho Department of Water Resources. The watermaster is responsible for delivery of Payette River water and overall Water District management. The Water District is funded through assessments paid by water users on the river and administrative fees charged by the rental pool. "Rental pool" refers to the statutory method by which entities may lease their storage water to other users for beneficial uses consistent with state law. Within the District, a total of 150,000 acres are irrigated by two irrigation districts, ten irrigation companies and many private diversions from the Payette River. The Payette River drains approximately 2 million acres and includes three storage reservoirs within the District (Figure 1).

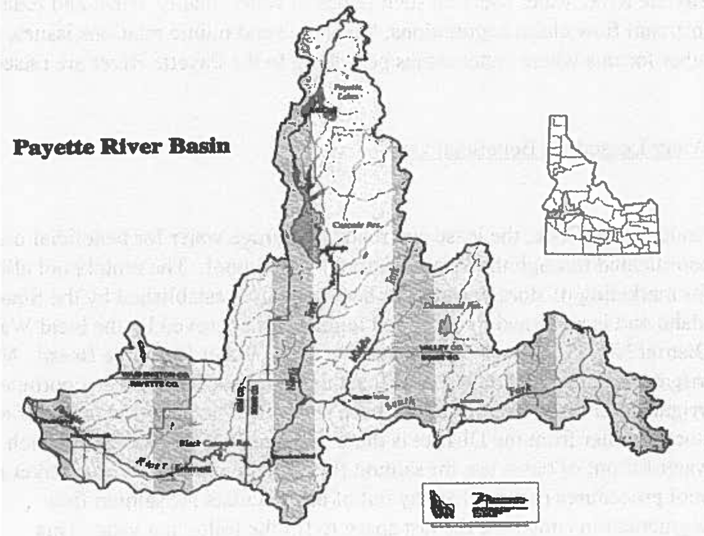

Figure 1: The Payette River Basin

Normally, the basin produces adequate natural flows to meet irrigation demands of the senior water rights on the river. Junior water rights have historically been shut off mid-summer of every year, thus creating the need for storage water. Two reservoirs, Cascade and Deadwood, were built by the U.S. Bureau of Reclamation during the 1930's and 40's and contain over 800,000 acre feet of active storage capacity, while the third reservoir, the Payette Lake system, was built in the early 1900's by a group of private water users and provides over 35,000 acre feet of storage.

A computer accounting program was developed in 1993, and is used to track river flows and calculate natural flow available for appropriation by water rights on the system. When natural flow drops below the amount being diverted from the river, storage water is released from reservoirs to maintain deliveries. During good water years, water users with storage space in the reservoirs may lease a portion of their storage water to the rental pool. Water users without storage space may rent water from the rental pool.

Beginning in 1995, the water users of Water District No. 65 have employed a full time watermaster to coordinate water deliveries, storage accounting, and overall Water District management. In addition, the watermaster represents Payette River water users on such issues as water quality, tribal and federal instream flow claim negotiations, legislative and public relations issues, and other forums where water issues pertaining to the Payette River are raised.

Water Leased for Beneficial Use

Under Idaho Code, the lease and rental of storage water for beneficial uses is coordinated through the Water District's rental pool. The rental pool allows for marketing of storage water for beneficial uses established by the State of Idaho and is governed by rules and regulations approved by the local Water District No. 65 Advisory Board and the Idaho Water Resource Board. Many irrigators on the Payette River utilize this rental pool in order to continue to irrigate after their water right has been shut off. The other major renter of storage water from the District is the U.S. Bureau of Reclamation which rents water for out of basin use for salmon flow augmentation. Payette River rental pool procedures require that any out of basin rentals for salmon flow augmentation constitute the last space to fill the following year. This provision protects irrigation interests with junior water rights, which rely heavily upon their storage space every year, by not subjecting their refill to compete with refill of out of basin uses.

Water Quality Issues

In 1993, a lawsuit was filed against the Environmental Protection Agency by several conservation and environmental groups, arguing that the EPA had not done enough to ensure that the State of Idaho meet the requirements of the federal Clean Water Act on many of its streams and lakes. In the decision, a federal judge in Seattle issued an order in the late spring of 1994 to the EPA and the state to address this problem, listing, among others, the lower Payette River and Cascade Reservoir as high priority, water quality limited stream segments. This listing means that a Total Maximum Daily Load (TMDL) must be approved by EPA before 1998. The Idaho Legislature, in response to the decision, enacted legislation in the spring of 1995 addressing water quality concerns on 962 stream segments in Idaho by requiring the establishment Basin Advisory Groups (BAG's) and Watershed Advisory Groups (WAG's) on individual watersheds. Members of the BAG's are appointed by the State of Idaho to oversee the formation of the WAG's, and eventually the setting of a TMDL, on each stream segment listed within a basin. The WAG's are comprised of individuals who represent the different interests on a stream segment listed as water quality limited or impaired. The WAG's, which must be authorized by their governing BAG, have the responsibility of proposing a TMDL on the stream segment they represent to the BAG and the State of Idaho for approval.

Payette River Stakeholders

Many individuals and organizations are dependent upon the Payette River system for their livelihood. Idaho Power Company is a public utility which provides electricity to irrigators, homes and businesses in Idaho, Eastern Oregon and Northern Nevada. Idaho Power Company generates most of its hydroelectric power at facilities on the Snake and Payette Rivers. All runoff from Southern Idaho eventually goes through Idaho Power's Hells Canyon complex, a series of three dams on the lower Snake River. Irrigation demands and reservoir operations impact Idaho Power Company's ability to produce and market power in the region.

Cascade Reservoir Coordinating Council represents various interests on Cascade Reservoir. Water quality, fisheries and the general health of the reservoir are concerns addressed by this council.

Many rafters, kayakers, and sportsmen use the Payette River throughout the year for recreation, fishing and hunting. Between 1983 and 1989, recreational use of the Payette River system grew by 400 percent[2]. The North and South Forks and the Main Payette River are world-class whitewater runs for kayakers and rafters. The Payette River supports four different rafting companies acting as outfitters and guides to paying customers. In addition to the many watersports on the river, many of the drainages in the agricultural areas of the basin form wetlands and habitat for waterfowl and upland game birds for hunting. The Payette River also supports both a cold water fishery to the north and a warm water fishery to the south.

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[2] The Idaho Statesman, *"Agencies hope survey will help shape future of Payette River"*, by Pete Zimowsky, August 31, 1996.

FLOW AUGMENTATION FOR ENDANGERED SALMON

In 1995, the National Marine Fisheries Service (NMFS) issued a new biological opinion on how to save the endangered salmon runs in the Snake River. The opinion called for 427,000 acre feet of storage water, to be rented or purchased from willing sellers from the upper Snake River basin. The water would be accounted for downstream to meet flow targets at the Lower Granite Dam on the lower Snake River near Lewiston, Idaho.[3] In theory, the water would be released from upper reservoirs during fish passage periods to augment the flows at Lower Granite in order to speed the salmon smolts on their journey to the Pacific Ocean. Of the total 427,000 acre feet of water from the upper Snake River basin, approximately 145,000 acre feet are to be rented from the Payette River basin. Idaho Power Company, in association with the Bonneville Power Administration, rented flows from the upper Snake for this effort from 1990 through 1994. This was accomplished by the passage of special legislation by the Idaho Legislature to allow the use of rented storage water for downstream out-of-basin endangered salmon flow augmentation. The original legislation expired on December 31, 1995. In order to meet the new biological opinion's flow targets, new legislation had to be drafted and passed by the Idaho Legislature. A consortium of water users, legislators, governmental representatives and attorneys representing various water interests developed a bill to allow for flow augmentation efforts to continue until the year 2000. Under this bill, which became law in 1996, the water must be rented from the local rental pools designated and approved by the State of Idaho and must be from willing sellers. The water is subject to the procedural rules each local rental pool has established, such as last to fill requirements for out of basin use. Finally, the special legislation must be renewed by the end of 1999, when the current biological opinion expires, in order for continued flow augmentation to occur.

FLOW AUGMENTATION TIMING

[3] National Marine Fisheries Service, *"1995 Biological Opinion for the Restoration of the Endangered Snake River Salmon"*, April, 1995.

Timing of the salmon flow augmentation water has been an issue of debate. The biological opinion NMFS issued on the endangered salmon species in the Snake River calls for a technical management team, which includes representatives from all the action agencies involved with the salmon recovery efforts, to "call" for the water when conditions warrant additional flows in the Snake River at Lower Granite Dam. The salmon water comes from various sources in the upper Snake River basin, including several reservoirs in Eastern Idaho, as well as reservoirs on the Boise and Payette Rivers. Coordinating the release of water from these reservoirs at the correct time has been problematic for water managers. To facilitate the release of the flow augmentation water, Idaho Power Company has utilized their Brownlee Reservoir on the Snake River, located below all irrigation facilities in the upper Snake basin, to release fish flows when called for. In order for Idaho Power Company to release water for fish flow augmentation without bearing the financial burden associated with lost powerhead and shifted seasonal generation pattern, Bonneville Power Administration and Idaho Power Company annually enter into an agreement, whereby BPA compensates Idaho Power for these lost revenues by replacing that lost power during winter months, a high demand period.

CASCADE RESERVOIR WATER QUALITY

Cascade Reservoir is a large, shallow reservoir in Central Idaho with a total capacity of 680,411 acre feet, and an active capacity of 636,004 acre feet[4]. Many summer homes have been built around the reservoir and fishing and other water sports are enjoyed by many on the reservoir. The reservoir was built to support irrigation in the lower Payette River valley and for power generation at both the Idaho Power Company facility on the dam itself and the U. S. Bureau of Reclamation facility downstream at Black Canyon Dam. The watershed above Cascade Reservoir produces an average annual runoff of 732,550 acre feet[5]. In the eighties and nineties, there were several dry years which compounded water quality problems in the reservoir. During 1994, one of the worst drought years on record for the Payette Basin, water quality in the reservoir declined significantly due to a large drop in the water levels and hot summer temperatures. This drop in water levels was caused by high

[4] Bureau of Reclamation, *Cascade Reservoir 1995 Sedimentation Survey*, by Ronald L. Ferrari, May, 1996.

[5] Ibid.

irrigation demand due to below average natural flows in the Payette River, and the release of flow augmentation water for salmon migration on the Lower Snake River. With high levels of phosphorus flowing into the reservoir from various sources, many fish and even some cattle grazing around the reservoir were killed by toxic algae blooms.

As a result, the Cascade Reservoir Coordinating Council was formed to address the water quality problems in the reservoir. The group is a grassroots effort by property owners and business leaders whose livelihood and investments depend upon tourism and recreation on the reservoir. The negative publicity resulting from the deteriorating water quality in the reservoir had affected the area tourist industry, causing lost revenues and declining property values to local residents. Many point and non-point sources of pollutants were identified. These sources are currently being dealt with, including the upstream city of McCall sewage treatment plant, a major contributor of phosphorus to the reservoir.[6] Best management practices (BMP's), practices which, when applied to normal operations, enhance the quality of runoff or excess waters from these operations, were instituted on several of the drainages to the reservoir, as well as cost-share programs for improvements to water delivery and return flow systems on these drainages. Funds for these improvements have been secured from federal and state programs under the Clean Water Act. A total of $2.8 million has been funded for FY95 and FY96 for restoration activities on the reservoir. Another $7.7 million has been planned for the modification of the McCall sewage treatment plant upstream of the reservoir.[7]

During 1995, as a result of water quality legislation passed by the Idaho Legislature, the Cascade Reservoir Coordinating Council was appointed the official WAG, and is responsible for setting the TMDL on the reservoir.

LOWER PAYETTE RIVER WATER QUALITY

The lower Payette River was also designated a "water quality limited" stream segment in 1995, and consequently was listed as a high priority stream segment within the State of Idaho under the federal Clean Water Act. A WAG was formed in order to begin setting a TMDL. The WAG is currently

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[6] *Cascade Reservoir Watershed Management Plan*, Idaho Division of Environmental Quality, October, 1995.
[7] Ibid.

monitoring the river, gathering additional information on water quality in order to establish this TMDL. Return flows from surrounding irrigated agricultural lands have historically been a source of sediment, nutrients and bacteria on the lower Payette. These water quality problems are intensified by low flows associated with the operation of the river to deliver water to irrigation diversions. Currently, the Idaho Department of Agriculture is coordinating an effort with several local, state and federal agencies to characterize the water quality of return flows in the agricultural drains. As a result, many irrigators and livestock producers have implemented best management practices to reduce the amount of pollutants entering these drains which flow back to the river. Cost-share programs were used to initiate many of these BMP's, but an increasing number of established BMP's are voluntary efforts by local farmers to help mitigate the water quality concerns on the river.

FLOW AUGMENTATION AND WATER QUALITY - THE PROBLEM

With the advent of flow augmentation rentals from the rental pool, several of the water quality problems on the river have been magnified. During the 1993 water year, the flow augmentation water was released in the summer months to meet downstream requirements at Lower Granite Dam on the lower Snake River. During this year, the reservoirs filled and the summer weather was cool and wet, lessening the need for any water quality improvements to the river or Cascade Reservoir. In 1994, flow augmentation water was again released during the summer months. This year was hot and dry, and the effect of the summertime release was devastating to the reservoir, though the effect on the river was positive. In 1994, Cascade Reservoir did not fill to capacity, and irrigation demand was high. Storage water, normally called for in mid-July, was called for on June 12. Coupled with the summertime fish release, reservoir levels were lowered quite rapidly. Hot summer temperatures at the reservoir and the low water levels resulted in large algae blooms throughout the entire reservoir. As a result, during 1995, the Bureau of Reclamation held the flow augmentation water in Cascade Reservoir for wintertime release, thus keeping reservoir levels high throughout most of the summer months. The 1995 water year was extremely good, with above average snowfall and runoff. Water quality during 1995 in the reservoir was improved, with the reservoir meeting temperature standards for cold water fisheries for the first time in many years.[8]

Water quality on the lower Payette River, however, was not as good. Flows were managed to conserve storage water for rental out of basin and to maximize storage water carryover. The Payette River is operated to maintain an operational flow of 135 cubic feet per second at Letha, Idaho, located about 7 miles downstream of Emmett, Idaho (Figure 1). This operational flow at Letha allows for deliveries of water above and below Letha. Return flows from agricultural drains discharge to the river below Letha, resulting in sufficient flows to fill all natural flow rights. At this minimum flow, however, return flows from agricultural drains also cause temperature and sediment problems in the lower reach. Under existing water quality laws, this degradation of water quality by irrigation practices placed the burden on agriculture to improve the quality of return flows to the river. As a result, many BMP's approved by the state's Department of Agriculture, which include the use of polyacrylimide compounds (PAM) and straw mulching of irrigation furrows which reduce the levels of sediment and nutrients in the tail waters of treated fields, have been adopted by area farmers in an effort to help meet water quality standards. The impact of the few BMP's put into place on area farmland is already felt at the river, with a definite improvement in water quality in the major agricultural drains. However, the widespread use of BMP's on irrigated acres within the lower Payette basin is many years away, at best.

FLOW AUGMENTATION AND WATER QUALITY - ONE APPROACH

With the listing of the lower Payette River as a water quality limited segment by the State of Idaho, the Cascade Reservoir Coordinating Council called for a meeting with the Water District and federal and state agencies involved with water quality and salmon recovery. The meeting included federal representatives from Bureau of Reclamation, U.S. Fish and Wildlife, Bonneville Power Administration, state representatives from the Division of Environmental Quality, Fish and Game, and representatives from Idaho Power Company. The meeting focused on the Coordinating Council's concern that improving water quality in Cascade Reservoir may be at the

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[8] Quote from Don Anderson, Idaho Fish and Game, *"Pact puts water back into Payette River"*, by Stephen Stuebner, Star News, August 8, 1996.

expense of water quality in the lower reach of the river, since holding water in Cascade Reservoir during the summer negatively impacted water quality in the lower Payette River. Also, the higher reservoir levels in 1995 resulted in some erosion of the reservoir banks when a series of storms hit the area. The group agreed to split the flow augmentation releases in 1996. Some of the water would be released in the summer to benefit the lower river and the remaining water would be released in the winter to allow for higher reservoir levels during summer months. Many other issues needed to be addressed including the agreement between Idaho Power Company and Bonneville Power Administration (BPA) to shape flows out of Idaho Power Company's Brownlee Reservoir. This agreement was crucial to a split release. If the shaping agreement was not in place, all salmon water released from Cascade Reservoir would be required in the late spring and summer months, when called for by the Technical Committee. Using Idaho Power reservoirs on the Snake for timing flows, and replacing those flows with water from upper reservoirs such as Cascade, provides the flexibility to address the concerns previously mentioned. The amount of water to be released in the summer and the winter for a split release needed to be determined. This required a review of snowpack and a review of existing water quality data from Cascade Reservoir to determine an acceptable split.

After analyzing the expected runoff of the snow pack, which was excellent for 1996, and reviewing the status of the shaping agreement, a final meeting was held three weeks before the release of storage flows was to begin. During this meeting Idaho Power representatives informed the group that an agreement was being drafted and all parties had agreed to sign. The efforts to improve water quality on both segments of the river were an incentive to negotiate the shaping agreement. The final task was to agree on the percentages of water to be released in the summer and winter, respectively. Idaho Power representatives requested a 70/30 summer/winter release; Idaho Fish and Game personnel at Cascade argued for a 30/70 release, indicating that the more water held in-reservoir during summer months the better for the reservoir fisheries. It was decided that a 50/50 release, with half released in the summer and half in the winter, was acceptable to all parties. The fish release began in early July and continued through August. Idaho Power indicated that, during September through November, they do not want any flow augmentation water released into their Snake River reservoirs, as any flows downstream of those reservoirs during this time period affected the nesting fall chinook. Excess water released during nesting periods must continue during the entire nesting period in order to avoid an "incidental take" of that endangered species. Failure to maintain the flow could subject Idaho Power to penalties under the ESA.

RESULTS OF THE SPLIT RELEASE

In the summer of 1996, a total of 75,168 acre feet of storage water was released for salmon flow augmentation through the local rental pool. The remaining 76,132 acre feet will be released during winter months to complete the flow augmentation water rented from the Water District's rental pool. The effect of this split release on water quality in the lower Payette River and Cascade Reservoir are not yet available but public reaction has been positive. According to Stephen Stuebner, a reporter for the Star News in McCall, Idaho, increased recreation on the lower Payette River was noted throughout the summertime salmon release. In an article published by the Star News, Stuebner wrote that the split release resulted in "...a river flow of 1,400 cubic feet per second at Letha, compared to less than 100 cfs a year ago" (see Figure 2). According to the article, the release allowed the Payette River to run "full and wide", with an increase in the number of people enjoying the river at Letha, a contrast to 1995, "...when the river was reduced to a tiny trickle."[9] The previous year, Stuebner had written an article complaining about the lack of water in the lower river in order to conserve storage water in Cascade Reservoir.[10]

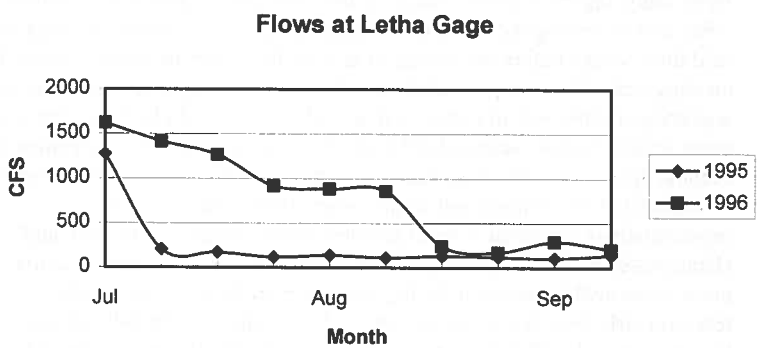

Figure 2: Flows at the Letha Gage, Lower Payette River[11]

Additional benefits include increased power production at the two hydroelectric generating facilities on the river: at Cascade Dam and at Black

[9] Star News, *"Pact puts water back into Payette River"*, by Stephen Stuebner, August 8, 1996

[10] Star News, *"Lower Payette River suffers from Cascade Reservoir hold-back"*, by Stephen Stuebner, October 5, 1995.

[11] U.S. Bureau of Reclamation data.

Canyon Dam. Power from Black Canyon Dam benefits the Black Canyon Irrigation District and the Emmett Irrigation District as they use power generated at the dam to operate pumps on their delivery systems. If power is not produced during summer months by this facility, these two irrigation districts have to purchased power "wheeled-in" from other sources, at a higher price than locally produced power.

Also, increased flows during July and August on the Payette River benefits a burgeoning whitewater industry. Both private and commercial outfitters were ecstatic about river operations during 1996. In an article written for The Idaho Statesman newspaper in Boise, Idaho, Pete Zimowsky, the Statesman's outdoor recreation editor, stated that "Rafters can be thankful for good flows…" on the Payette River this season, citing the agreement to split the salmon release from area reservoirs and mentioning the "'win-win' situation for rafting, fishing, water quality, and the endangered salmon."[12]

THE PAYETTE RIVER WATERSHED COUNCIL

In addition to water quality and recreational benefits, another significant achievement to come from the agreement to split the salmon flows is the formation of the Payette River Watershed Council. Membership on the Council consists of representatives from the Cascade Reservoir Coordinating Council, upper basin interest groups, hydropower utilities, the kayaking and rafting community, Idaho river advocacy groups, and irrigation interests on the river through Water District No. 65. An effort is underway to identify and include a number of other Payette River stakeholders on the council, such as recreational mining interests, cities and counties bordering the river, and livestock grazing interests. A draft mission statement reveals the purpose of such a council: "The Payette River Watershed Council is a forum for the open communication and sharing of information concerning the Payette River and its watershed. The purpose of the Council is to encourage and promote a healthy and viable watershed by striving to build understanding, respect for, and consensus among all of the interests in the watershed." The Payette River Watershed Council will negotiate any future agreements on flow augmentation releases, as well as inform and educate the public about the Payette River and its operations.

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[12] The Idaho Statesman, *"Conditions near perfect for whitewater players"*, by Pete Zimowsky, August 8, 1996.

Groups such as the Payette River Watershed Council will be in the forefront as more and more demands are placed on our limited water resources. It has been our experience throughout the year that all stakeholders on the river benefit from the added communication and spirit of cooperation associated with this approach to water management. In good water years, it is much easier to meet the wide variety of needs on a river system such as the Payette. And in preparing for drought years to come, it is imperative that all water interests establish credibility with each other to successfully survive difficult times. The future of water management in the West, and the destiny of irrigated agriculture in Idaho, will depend on our ability as water managers to build consensus among the stakeholders in the decision making process. When irrigated agriculture takes the lead in this process, it succeeds in maintaining its credibility and productivity through the difficult times of continually increasing demands on precious water resources.

ENDANGERED FISH RECOVERY AND WATER DEVELOPMENT IN THE UPPER COLORADO RIVER BASIN

John Hamill[1]

Today, I am going to talk about two competing interests, endangered fish recovery and water development in the Upper Colorado River Basin, and a recovery program that was developed to deal with both of these concerns. However, before I start, I would like to address one of the questions that I am frequently asked: *"Why should we recover the endangered fishes in the Colorado River?"* After all, the Colorado squawfish and the razorback sucker are not prized sportfish. Nor do they have the charisma of a bald eagle or a gray wolf. The simple answer, of course, is that the Endangered Species Act is the law of the land and it places a high priority on the protection and conservation of threatened and endangered species. The fact that the law has been re-authorized several different times lends support to the argument that endangered species protection is an important national priority. Public opinion polls seem to support this argument.

To get a more complete answer though, the rationale and purpose of the Endangered Species Act must be examined. The purpose of the Act is to prevent the extinction of native plants and animals and preserve the ecosystems upon which the threatened and endangered species depend. One of the more compelling reasons I find for this law is the belief that native plants and animals are, in fact, very good barometers of the overall health of the environment--health not just for the endangered fish but for people as well. The fact that

[1] U.S. Fish and Wildlife Service, P.O. Box 25486, DFC Denver CO 80225

native plants and animals are having a very difficult time surviving is an indicator that the environment has changed, and if these changes are allowed to go unchecked, ultimately the quality of human life will be adversely affected.

Let's examine the situation in the Colorado River basin. In the Upper Colorado River Basin, there are 14 native fish species (Table 1). Five of these are listed as endangered under the Endangered Species Act, and three are identified as species of concern by the Fish and Wildlife Service. In summary, over two-thirds of the native fish community is in some degree of jeopardy in the Upper Colorado River Basin.

I think it is reasonable to assume that if these fish go extinct then many of the values that humans depend on in this river basin for will be compromised. What kind of values am I talking about? I am talking about this river as a source of quality water for growing crops and for meeting municipal and domestic needs. I am talking about the river as source of water for recreation such as fishing, boating, and esthetics--a value which seems to be growing in importance. Finally, the riparian communities associated with these rivers support about 90 percent of the wildlife in the arid west. I think it is not unreasonable to assume that if native plants and animals go extinct many of the values that humans derive from the river also will be adversely affected. Conversely, if these fish can be save these values should also be preserved.

The Upper Colorado River Recovery Program grew out of the conflict over how to provide water to support recovery of these endangered fish, while also providing water to meet human needs in the basin. The geographic scope of this Program is the Upper Colorado River upstream of Lake Powell (Figure 1). The San Juan River Basin, which is technically part of the Upper Basin, was not included in the Upper Basin Program primarily because at that time, it was developed in the early 1980's, there was not a recognized issue related to the endangered fish in the San Juan River.

Table 1 List of Native Fish Species

Family and Genus	Species	Common Name	Endemic/Status
SALMONIDAE			
Salmo	clarki pleuriticus	Colorado River cutthroat trout	
Prosopium	williamsoni	Rocky Mountain whitefish	
CYPRINIDAE			
Ptychocheilus	lucius	Colorado squawfish	yes (E)
Gila	cypha	Humpback chub	yes (E)
Gila	elegans	Bonytail chub	yes (E)
Gila	robusta	Roundtail chub	yes
Rhinichthys	osculus yarrowi	Speckled dace	
Rhinichthys	osculus thermalis	Kendall Warm Springs dace	yes (E)
CATOSTOMIDAE			
Xyrauchen	texanus	Razorback sucker	yes (Cand.)
Catostomus	latipinnis	Flannelmouth sucker	yes
Catostomus	discobolus	Bluehead mountain sucker	
Catostomus	platyrhynchus	Mountain sucker	
COTTIDAE			
Cottus	bairdi	Mottled sculpin	
Cottus	beldingi	Paiute sculpin	

Note: Status refers to Federal status

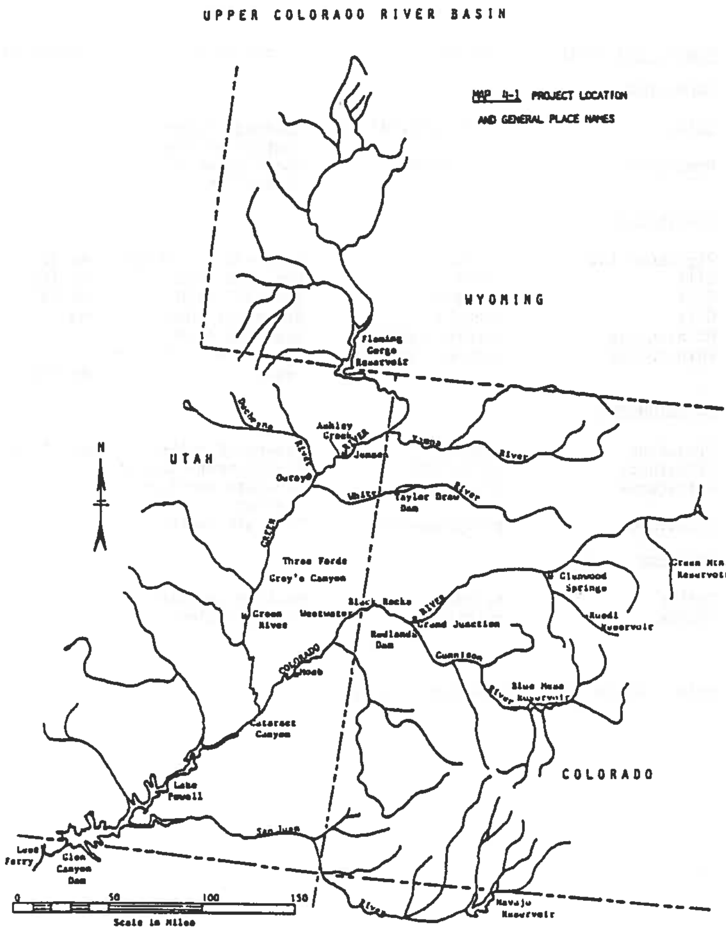
UPPER COLORADO RIVER BASIN
MAP 4-1 PROJECT LOCATION
AND GENERAL PLACE NAMES
WYOMING
Flaming Gorge Reservoir
UTAH
N
Duchesne River
Ashley Creek
GREEN RIVER
Jensen
Yampa River
Ouray
White River
Taylor Draw Dam
Three Fords
Grey's Canyon
Green Mtn. Reservoir
Glenwood Springs
Black Rocks
Green River
Westwater
RIVER
Grand Junction
Ruedi Reservoir
Redlands Dam
COLORADO
Moab
Gunnison
Blue Mesa Reservoir
River
Cataract Canyon
COLORADO
Lake Powell
San Juan
Lees Ferry
Glen Canyon Dam
0
50
100
150
Scale in Miles
River
Navajo Reservoir

Figure 1

The Program is made up of Federal, State, and private parties (Table 2). The Program was initiated by a cooperative agreement signed by the governors of Colorado, Utah, and Wyoming; the Secretary of the Interior; and the Administrator of the Western Area Power Administration. Subsequent to that agreement being signed, several major environmental and water user groups provided resolutions supporting the goals and objectives of the Program. By doing so, they became official members of the Program. The Program operates by consensus, meaning that we do not do anything unless all of these parties agree to a course of action.

The Recovery Program consists of five recovery elements:

1. Instream Flows -- Identification and Protection
2. Habitat Restoration
3. Nonnative Fish Control
4. Stocking of Endangered Fish
5. Research Monitoring and Data Management

First, I will briefly describe what they are doing in each of those elements, and then I will talk about some of the broader policy issues related to water development in the Upper Basin.

The first element deals with instream flows. A fundamental tenet of the Recovery Program is that the flows the fish need will be provided consistent with State law. Another fundamental tenet is that fish need water in specific quantities, in specific locations, and at specific times of the year in order to meet their biological requirements. There are several actions currently being undertaken to restore and protect the flows needed for recovery of the fish. The major activities involves re-regulating the operations of several Bureau of Reclamation facilities in the Upper Colorado River Basin: mainly Flaming Gorge Dam on the Green River; and the Aspinall Units on the Gunnison River. In addition, blocks of water have been set aside in several smaller reservoirs (i.e. Green

Table 2

MISSION

To recover four endangered fish in the Upper Colorado River Basin while providing for future water development to proceed in compliance with the Endangered Species Act.

Federal

U.S. Fish and Wildlife Service
U.S. Bureau of Reclamation
Western Area Power Administration

States

State of Colorado
State of Utah
State of Wyoming

Private

Colorado Water Congress
Utah Water Users Association
Wyoming Water Development Association
National Audubon Society
Environmental Defense Fund
Colorado Wildlife Federation
Wyoming Wildlife Federation
Colorado River Energy Distributors Association*

* Nonvoting Member

Mountain Reservoir, Ruedi Reservoir, and Steamboat Lake) to assist in providing flows for the fish. We also are looking at coordinating the operation of several Bureau of Reclamation and private facilities in the upper mainstem of the Colorado River, which currently provide a lot of the water supply for the Denver metro area. The goal is to coordinate the operations of these reservoirs to enhance peak spring flows for the endangered fish.

Under the Program, the States made a commitment to use their instream flow programs to legally protect instream flows for the fish. To meet this commitment, the State of Colorado has filed for instream water rights on both the Yampa and Colorado rivers. In addition, the State of Utah enacted a policy to subordinate new appropriations to the flows recommended by the Fish and Wildlife Service for endangered fish recovery in the Green River. Finally, the Program, through the Bureau of Reclamation, is looking at how irrigation canals in the Grand Valley area of the Colorado River can be more efficiently operated. The water that is saved will be used to enhance flows in the Colorado River.

The principal biological goal of these activities is to more closely mimic the natural or historic hydrograph in these rivers which is characterized by a high spring peak flow and low stable flows during the remainder of the year. There is a growing body of scientific evidence that suggests that the well-being of the endangered fish is tied to the presence of a relatively natural hydrograph.

In addition to providing and protecting instream flows, the Program is doing a lot of things to improve the habitat through physical habitat development. This is a recently taken photo of the Redlands Diversion Dam on the Gunnison River that was built around 1910. Off to the left is a fish-passage structure that was recently built around that diversion dam. It is designed to provide access to about 50 miles of historical habitat on the Gunnison River for the endangered fish. Over 8,000 native fish have used the facility since it went into operation in July. Recently, one Colorado squawfish use the ladder. In addition to this facility, which is the first of its kind in the upper basin, we have plans to build similar fish passage ways at a number of other locations in the Gunnison, Colorado, and Yampa Rivers.

Another important aspect needed for recovery of these fish is restoration of floodplain habitats. This is a photograph of the Gunnison River back in 1957 prior to construction of the Aspinall Units. This flooding is characteristic of what used to happen in many parts of the basin during spring runoff. The river would essentially get out of its bank and flood bottom lands areas.

The razorback sucker utilized those areas in the early spring to feed. Also, while the razorback spawns in the river, the larvae drift down the river ending up at these types of flooded bottomland habitats where the nutrient rich water provides food in order for them to grow. Today, because of reduced flows and construction of levees and dikes many of these areas are no longer accessible to fish.

We are working with willing landowners to acquire easements to allow levees to be removed. The main focus is on the Middle Green River and the Grand Valley area of the Colorado River, and the Gunnison River.

The third element of the Recovery Program deals with stocking the native fish. The first 4 to 5 years of the Program were spent studying the genetic composition of wild populations and raising fish with that same kind of genetic diversity in our hatcheries. The genetic surveys are complete and the results are, in fact, relatively definitive. We have built additional hatchery facilities to allow more capability to produce fish. About 2 years ago we started stocking razorback suckers into the Colorado and Green Rivers systems. This last fall, bonytail will be stocked on a limited basis, into the mainstem of the Colorado River near

Moab, Utah. Stocking is especially important to razorback and bonytail recovery because these fish are so rare and there is little or no evidence of successful recruitment of young fish into the adult population. Hopefully, the actions we have taken to improve habitat and improve instream flows will provide better conditions for them to survive.

Nonnative fishes are a big problem throughout this system. Since the turn of the century there have been about 45 nonnatives fishes introduced into the Upper Colorado River system. Many of these fish are sportfish like the pike, large-mouth bass, and small-mouth bass. Others are small forage fish like red shiners and fathead minnows were either intentionally or accidentally introduced into the system. In many locations, the total biomass of the river system is probably 90 percent nonnative fishes. There is little doubt that nonnatives fishes are creating major problems for the native fish.

Our goal is to minimize the impacts the fish are having on the natives. After 3 years of negotiations a set of Nonnative Fish Stocking Procedures were finalized. The Procedures provide guidelines that define the situations and locations where stocking nonnative fishes is acceptable or unacceptable. We also recently completed a strategy for how to approach control of nonnative fishes in mainstem rivers. Some strategies include mechanical removal of the nonnatives and removing harvest limits on nonnative fish. To date, the primary focus has been on northern pike removal in the Gunnison River and small-mouth bass in the Duchesne River, however, these efforts will be expanded over the next several years.

The final element of the Program deals with research, data management, and monitoring. While we still have an active research component in this Program, during the 4 to 5 years there has been a conscious effort to shift from research into more active on-the-ground kinds of recovery activities, such as restoring flooded bottom land, removing nonnatives, etc. Current research is directed at trying to better understand the flow requirements of the fish and looking at biological factors such as imprinting and homing. Since 1986, there has been a long-term monitoring program in place to track the status and trends of the fish populations. We are expanding this now to also include looking at the status and trends of some of the nonnative fish. Finally, a major activity going on this year involves refining the recovery goals for these fish and address the question *"When is enough going to be enough?"* General recovery goal have already been developed for each of the four fish. This project will identify some very specific parameters that define what a healthy self-sustaining population looks like on a river-reach-by-river-reach basis.

As I mentioned earlier, the Recovery Program has two goals: to recover the fish <u>and</u> allow water development to proceed in accordance with the Endangered Species Act. From a water project standpoint, the accomplishments of this Program are designed to serve as a "reasonable and prudent alternative" for water depletion projects which are subject to section 7 consultation. Since 1988, nearly 300 water projects with a potential to deplete about 200,000 acre-feet of water have received favorable biological opinions from the Fish and Wildlife Service. I believe that the Program has provided much greater regulatory certainty for water users than would have been realized without the Program.

Planning in the Recovery Program centers around the Recovery Implementation Program Recovery Action Plan (RIPRAP). The RIPRAP identifies specific actions that will be taken under the Program. The RIPRAP is also used by the Fish and Wildlife Service as the standard to determine whether or not this Program is achieving "sufficient progress" for water projects to receive favorable biological opinions when they are subject to review under section 7 of the Endangered Species Act.

Approximately $42 million has been expended since the inception of the Program in Fiscal Year 1989. A large part of the funding has come through the Bureau of Reclamation either in the form of power revenues derived from the operation of the Colorado River Storage Projects (CRSP), or more recently, from appropriated funds for capital projects. While the cost of this overall Program is shared by all Program participants, the largest percentage of cost has been born by the Federal Government. About one and a half years ago, Reclamation indicated they could not continue to fund the Program in the way that they had in the past and that alternative funding mechanisms and cost sharing arrangements were needed to keep this Program viable. As a result, the Program participants began discussing how to provide more stable funding source for both the San Juan and the Upper Colorado River Basin Recovery Program. We got to a point last winter where a Bill that authorized both of the Programs was drafted. It would provide an $82 million cost ceiling for the Upper Basin Program through the year 2003, which is when the Program expires. For the San Juan Program, the cost ceiling was $22 million until the year 2007 which is when the San Juan Program is set to expire. It specified a cost-sharing arrangement where the Federal Government would fund 50 percent of the costs, power revenues would be used to fund another 35 percent of cost of the Program, and the States would fund about 15 percent. However, this legislation was put on hold pending resolution of some issues that the water users have. Specifically, the water users wanted more firmer guarantees that water projects would receive favorable biological opinions before they agreed to back the legislation.

I would be remiss in saying that everyone is satisfied with the Recovery Program. In particular, there are recent indications that the water users are not happy with the way the Recovery Program is going. I understand they have two primary concerns. One is how the Fish and Wildlife Service is conducting section 7 consultations on water projects in the Upper Basin Program. The water users want greater certainty or guarantees that they will be allowed to develop their compact entitlement in exchange for support of the Program.

Their other issue related to priorities in the Program. They believe that protection and provision of instream flows are being over-emphasized and that greater emphasis should be directed at stocking razorbacks and bonytails, physical habitat restoration, and nonnative fish control.

My general reaction to that is I do not believe that additional assurances or guarantees can or should be provided. There are a lot of positive things going on in the Program, but there are also many uncertainties about what it is going to take to recover these fish within existing levels of development. Large amounts of new development will only add to the uncertainties. In light of those uncertainties, I believe that it would be irresponsible and a violation of the ESA for the Fish and Wildlife Service to give assurance that water development would be allowed to go forward under any circumstances. Greater certainty for the water development will be possible at the time fish populations improve.

In terms of Program priorities there is a process in place for annually evaluating the priorities of the Program. The water users have contributed to and supported the current Program priorities. As always, water users are welcome to submit their priorities for review and see how their ideas stack against other ideas.

I believe that the Recovery Program has worked for water users and the fish. In terms of water development, over 300 water projects have received favorable biological opinions. None of these projects have been litigated since the inception of this Program. That is a track record that few groups have enjoyed. In addition, the water users have paid less than five percent of the total cost of this Program including the costs for implementing the reasonable and prudent alternatives for water projects undergoing section 7 consultation.

In terms of the fish, many important recovery actions have been implemented as a result of the Recovery Program. I am convinced that the Fish and Wildlife Service can not recover these fish solely by using our section 7 authorities. We need a cooperative effort that has broad political support in order to restore this river system.

I think there are clear motivations for both parties to stay involved in the Program. We have kept this program healthy by cooperation, and respecting everyone's point of view and working on issues until consensus has been achieved. There's always a strong temptation to fight; a temptation that must be resisted. Ultimately, it comes down to every party assessing whether there is a better alternative to the Program. Right now, I believe the Recovery Program is the most effective forum for reconciling conflicts between endangered fish recovery and water development in the Upper Basin. Thank you.

THE CALFED OPS GROUP: A PROCESS FOR RESOLVING FISHERY AND WATER SUPPLY CONFLICTS IN WATER PROJECT OPERATIONS

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Robert G. Potter[3]

ABSTRACT

A unique group of representatives from State and federal water supply and environmental agencies and water user and environmental groups was established in 1994 to help guide the operation of the California State Water Project and the federal Central Valley Project. This group, the CALFED Ops Group, is charged with coordinating the operation of these projects with endangered species constraints, water quality, and requirements of the federal Central Valley Project Improvement Act.

The Ops Group develops short-term operation plans (less than a year) that incorporate improvements for fish with the intent of incurring no net loss of water supply. This is done by using real-time fish monitoring data, sharing facilities, and adjusting regulatory requirements. The Ops Group has defined a process for responding to operational situations quickly while incorporating representatives of all the agencies and stakeholders. The process is designed to have operational decisions made at the lowest level but an issue may be quickly elevated to the policy level if necessary. A description of the decision-making process and examples of the Ops Group efforts are included.

INTRODUCTION

California's topography is dominated by its Central Valley. The valley is formed by two river systems -- the Sacramento River and the San Joaquin River. Both rivers flow into the Sacramento-San Joaquin Delta which flows into the San Francisco Bay and eventually through the Golden Gate to the Pacific Ocean. The Sacramento River flows from the north, originating from the Cascade Range near the Oregon border. The San Joaquin

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River flows from the south, originating in the Sierra Nevada Mountains. (Fig. 1)

The Sacramento and San Joaquin rivers are extensively developed with reservoirs and canals to provide flood control and water supply. The Delta is an essential hub for two major water supply systems -- the California State Water Project and the federal Central Valley Project. Both projects have large export facilities in the Delta which pump water made available from unregulated flow and/or releases from the projects' reservoirs upstream of the Delta. During 1980-1991, the average annual inflow to the Delta was 27.8 million acre-feet (34.3 billion cubic meters)and the total SWP and CVP Delta exports averaged 5.0 million acre-feet (6.2 billion m^3)(DWR,1993). Water exported from the Delta is conveyed via large aqueducts to provide municipal, industrial, and agricultural supply to most of the area south of the Delta. (Fig. 2)

The Delta is also the state's most important fishery habitat. It consists of hundreds of miles of channels which provide habitat and passage for an estimated 25 percent of all warm-water and anadromous sport fishing species and 80 percent of the state's commercial fishery (WEF, 1995).

In 1989, fish dependent upon the Delta began being listed under the federal Endangered Species Act. The winter-run chinook salmon was listed in 1989, followed by the delta smelt in 1991. These listings had significant impact upon the operation of the SWP and CVP because Delta exports could be required to stop if it were concluded that they threatened the survival of a listed species. Decisions were based upon the number of fish recovered at the fish recovery facilities of the export facilities. Numeric criteria, called incidental take limits, were developed to indicate when adjustments in operations may be appropriate.

Sudden shutdown of the export facilities in 1992 due to the presence of winter-run chinook reduced water supply deliveries by 250,000 acre-feet (0.3 billion m^3) (CUWA, 1993). Incidental take limits undermined confidence in CVP and SWP water delivery forecasts. This uncertainty coupled with several years of drought alarmed California's agricultural and business communities and financial investment institutions.

Both the federal and State governments recognized the water management and environmental crisis in the Delta and each developed a process to resolve it. Governor Wilson's Water Policy (4/92) titled "Ending California Water Wars" declared "The Delta is broken. ... nowhere is there a greater need for a comprehensive program

Fig. 1. California's Central Valley

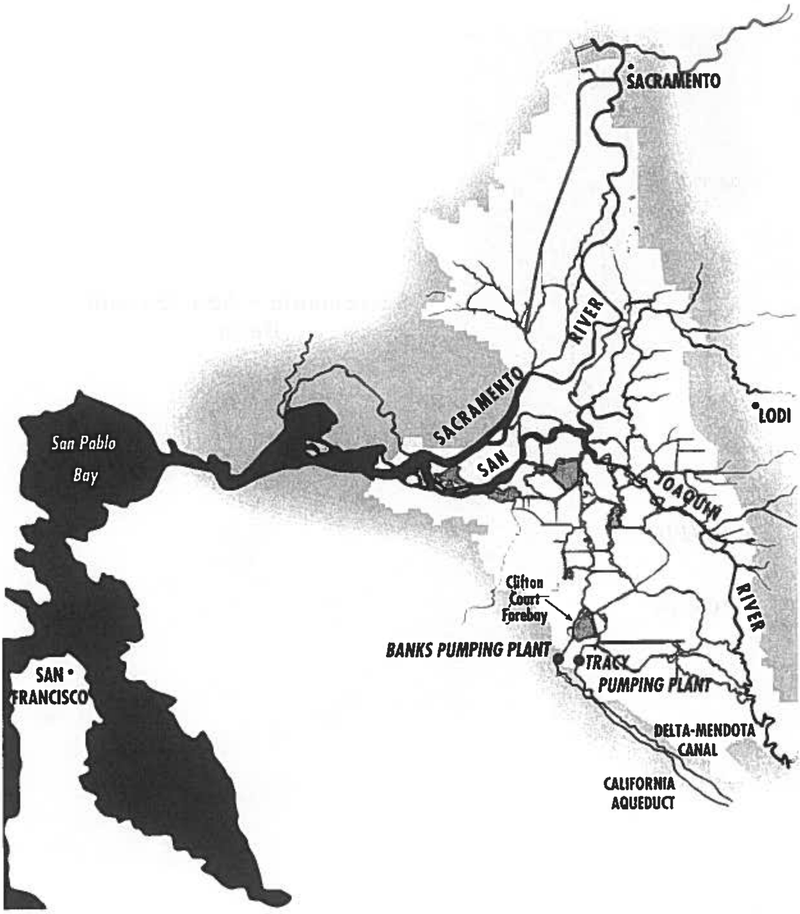

Fig. 2. The Sacramento - San Joaquin Delta

than in the Delta." It went on to describe his process for resolution. He established the California Water Policy Council consisting of representatives from eight State agencies to oversee the process. The federal government passed the Central Valley Project Improvement Act (CVPIA, 10/92) which dedicates up to 800,000 acre-feet (987 million m^3)of CVP water supply to fish and wildlife purposes. In 1993, the Federal Ecosystem Directorate (ClubFED) consisting of representatives from the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, and the National Marine Fisheries Service was established to coordinate federal resource protection and management decisions in the Delta and its watershed.

These two processes came together in June 1994 when the California Water Policy Council and ClubFED signed the Framework Agreement. To reflect their common intent, the two groups combined to become CALFED. The agreement committed the State and federal governments to processes for (1) setting water quality standards for the Bay-Delta estuary, (2) developing long-term solutions for the Bay-Delta, and (3) coordinating CVP and SWP operations with endangered species, water quality, and CVPIA requirements. The CALFED Ops Group is the mechanism for implementing the third task. The Ops Group was given additional emphasis with the signing of the Bay-Delta Principles for Agreement on December 15, 1994.

The Ops Group began meeting in August of 1994. The first public meeting was in January 1995. At that meeting, representatives of environmental and water user interests (referred to as "stakeholders") first began providing input to the Ops Group.

OPS GROUP FUNCTION

Ops Group meetings are held monthly and are open to the public. Deliberations are conducted in consultation with stakeholders. For the Ops Group process to be effective, representatives are to be present at Ops Group meetings and participate fully in all deliberations.

Decisions are made by unanimity of designated representatives of the CALFED agencies. The CALFED agencies are the USBR, USFWS, USEPA, NMFS, California Department of Water Resources, California Department of Fish and Game, and the State Water Resources Control Board staff. Participation of NMFS, USFWS, and DFG in the Ops Group does not limit or constrain their authority and responsibility regarding federal or State Endangered Species Acts.

Three areas of project operations are overseen by the Ops Group: (1) adjustment of export limits to minimize endangered species' take or to generally improve fishery conditions; (2) operation of channel gates which control conveyance of Sacramento River flow into the central Delta; and (3) export for the CVP by the SWP or export for the SWP by the CVP to improve fishery conditions or make up losses to water supply caused by previous operational changes to improve fishery conditions.

Decisions can involve changes in CVP and SWP export rates or reservoir releases that do not conflict with other operational constraints such as flood control requirements, water quality parameters, or regulatory permits and which are intended to have no net water supply costs.

OPS GROUP DECISION-MAKING PROCESS

Ops Group decisions must be made relatively quickly to be effective in CVP and SWP operations. In order to accomplish this, a hierarchy of groups is used to try to reach consensus at the lowest possible level yet assure that all Ops Group participants are informed. The hierarchy consists of Sub-groups, the No-Name Group, the Ops Group, and CALFED.

Sub-groups A sub-group is the working-level group which analyzes data and proposes an operation action. The group may or may not include the CVP and SWP operators. A sub-group can be a workgroup associated with endangered species (winter run and delta smelt) or real-time fish monitoring, or a temporary workgroup formed to address a particular operational issue.

No-Name Group This group is comprised of a representative of each of the CALFED agencies and interested parties who is responsible for being the contact person for their agency or interest group at any time when information regarding listed species or other factors are deemed to be potential urgent issues to be addressed by the Ops Group. Because the No-Name Group includes representatives from the CALFED agencies and interest groups, it is used by the USBR and DWR as a forum to assess and modify, if necessary, proposed changes to the CVP and SWP operations.

Figure 3 illustrates the Ops Group decision-making process. As shown, the sub-group proposes a change in operations to the CVP/SWP operators. The CVP/SWP operators review the proposal with their management, possibly revising it or consulting with the sub-group. The operators then act upon the proposal, choosing to either implement, modify, or not implement it. A

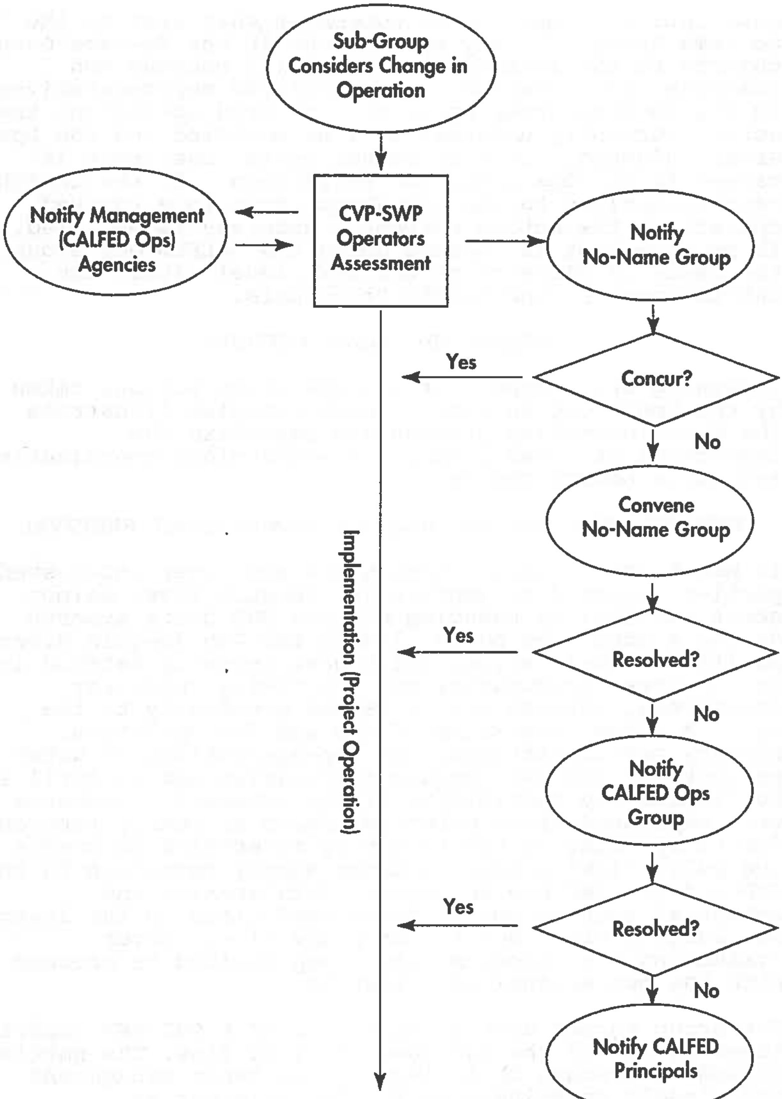

Fig. 3. The CALFED Ops Group Decision-Making Process

description of the chosen action is then sent to the No-Name Group. If any participant in the No-Name Group objects to the action, the group will convene and evaluate the operation. If the CALFED representatives to the No-Name Group agree to a revised operation, the action currently underway will be modified and the Ops Group informed. If they cannot agree, the issue is raised to the Ops Group for evaluation. If the CALFED representatives to the Ops Group agree to a revised operation, the action currently underway is modified. If no agreement is reached among the CALFED Ops Group, the issue is elevated to the next level within the CALFED process, the CALFED Principals.

RECENT OPS GROUP ACTIONS

Following are examples of the operation actions taken by the Ops Group in 1995. These examples illustrate the decision-making process and emphasize the importance of close agency and stakeholder coordination and quick communication.

IMPROVEMENTS FOR SAN JOAQUIN SALMON SMOLT SURVIVAL

In March 1995, fishery biologists and other interested parties proposed to improve San Joaquin River salmon smolt survival by reducing CVP and SWP Delta exports during a scheduled pulse flow in the San Joaquin River. Smolts are small salmon which have recently hatched in the upstream tributaries and are making their way downstream, through the Delta and eventually to the sea. A group consisting of CVP and SWP operators, fishery representatives, and representatives of water projects on the San Joaquin tributaries met on April 12 to discuss the feasibility of the proposal. Concerns were expressed about potential costs of energy foregone due to spilling at the tributary reservoirs to create the pulse flow; potential water supply reduction to the CVP and the SWP due to export curtailments; and potential aggravation of flood conditions in the lower San Joaquin River due to the pulse flow. After evaluating the concerns, the group decided to proceed with the operational modification.

The group agreed upon an objective of a CVP/SWP export level of 20% of the San Joaquin River flow. The parties agreed to discuss their issues with their management and closely coordinate to try to implement an operations plan by April 15.

SWP operators concluded export reductions would probably not effect the project's water supply if hydrologic conditions remained wet. However, if conditions turned dry and resulted in decreased flows and increased water demands, there could be an impact to SWP water supply that would have to be recovered later in the year. CVP operators were concerned about an unrecoverable impact to their project's water supply because the CVP export facility has substantially less pumping capacity and, therefore, very little capability to make up lost exports later in the year. The decision was made to proceed with the proposed operation and incorporate the strategy that SWP exports would be reduced the most with CVP exports being adjusted as necessary to reach the target percentage. The participants of the original group were notified of the decision and other members of the Ops Group were informed by their representatives. During the period of concern, April 15 through May 15, the total exports averaged 19% of the San Joaquin River flow.

To help the CVP make up any losses to its water supply resulting from the export reduction, the possibility of exporting for the CVP at the SWP pumping facilities was explored. The Ops Group discussed the issue and was in favor of proceeding. Confirmation regarding the legality of this action was requested and received from the State Water Resources Control Board. Since wet conditions continued through late spring, no reduction in CVP water supplies resulted and no export for the CVP at SWP pumping facilities was required.

PROTECTION FOR SACRAMENTO SPLITTAIL

Another export reduction was coordinated through the Ops Group in June 1995. The action was taken in an attempt to reduce the number of Sacramento splittail recovered at the CVP and SWP fish recovery facilities. This operation was guided by information from the Real-time Fish Monitoring Program. "Real-time" means that data obtained in the field are provided as information to the CALFED Ops Group within 48 hours. A test of the first Real-time Fish Monitoring Program was conducted in May and June of 1995 to assess the feasibility of protecting chinook salmon, delta smelt, splittail, and other species from the operation of Delta export facilities.

Sacramento splittail began being recovered at the fish facilities at the end of May. By June 4, the daily estimated salvage had exceeded 440,000 fish. The data-analysis group of the Real-time Fish Monitoring Program, met on June 6 to evaluate the available data and develop a recommendation for operational changes. The discussions continued through June 8 with members of the No-Name Group and other stakeholders. Although recovery of Sacramento splittail continued at record high levels, data from real-time monitoring suggested that a huge population existed. As a result, significant export curtailments were not pursued.

However, it was agreed that a short-term curtailment might yield valuable information on how changes in export levels affect salvage of Sacramento splittail. Exports were reduced by nearly 5,000 cfs (141 m^3 per second)for three days beginning on June 11. To avoid the possibility of increased salvage of Sacramento splittail due to higher export levels required to recover the export lost during this test, SWP operators agreed to delay export recovery until after June, when essentially all Sacramento splittail had left the southern Delta.

THE OPS GROUP AND CVPIA

In 1996, another spring export reduction was done. When the reduction was made, it was not clear as to how the exports would be increased in the fall to make up for the reduction. The main point of contention involved the application of the federal Central Valley Project Improvement Act. As mentioned previously, the CVPIA dedicates up to 800,000 acre-feet (987 million m^3)of CVP yield to fish and wildlife purposes. Strict implementation of this highly contentious requirement could have reduced deliveries to CVP water contractors south of the Delta beyond the delivery reductions they agreed to in the Delta Accord.

Of all the issues facing the Ops Group, the application of this portion of the CVPIA is the most volatile. The proposal for making up the CVP export reduction involved using the SWP export facility in the fall of 1996. It was necessary for the SWP to export for the CVP because the CVP export facility does not have sufficient pumping capacity. This type of operation requires approval by the State Water Resources Control Board. The Board, in turn, requires that the shift in exports not cause significant negative effects upon any legal user of water or to fish, wildlife, or water quality. The Ops Group is looked to as the forum for resolving any conflicts.

A very tenuous agreement was reached between water users and environmentalists on the make-up export for the fall of 1996. To reach agreement, the Ops Group held an emergency meeting to negotiate conditions that would allow all of the CVP reduction to be made up. Once the conditions were agreed to, a letter was sent from the Ops Group to the Board stating there was general consensus regarding the fall make-up exports, describing the process for adjusting exports in response to environmental concerns, and describing the environmental (aquatic) warning conditions that would trigger an operational response. The make-up export was approved and began October 13, 1996. A total of 130,000 acre-feet (160 million m^3)was exported by the

SWP for the CVP. The entire spring export reduction was recovered by December 1996.

CONCLUSION

The Ops Group is a vital forum for exploring ways of improving conditions for fish without additional decreases to water deliveries. The Ops Group has improved the understanding of all participants regarding the constraints and objectives of the water projects, the impact of hydrologic uncertainty upon the ability to commit to a proposed action, and the wide range of concerns environmentalists have regarding the Delta aquatic habitat.

Agencies and stakeholders continue to look to the Ops Group to develop operational plans that incorporate their needs and requirements. There is general acknowledgement that the issue of implementing CVPIA's dedication of CVP yield to fish and wildlife purposes has the potential of weakening the Ops Group because stakeholders will stop participating and begin to seek legal remedies. There is also a general hope that this will not happen because it would also set back progress in developing the long-term water management plan for the Delta by the CALFED Bay-Delta Program.

The strength of the Ops Group is its process for making operational decisions or addressing operational issues. When a new situation or issue is put before the group, discussion focuses on how the issue will be handled within the Ops Group. Often a special subgroup is established to address the issue and report to the Ops Group. A common understanding of the process helps alleviate fear that individual concerns will be brushed aside. It also leads to constructive discussions and improved decisions.

The Ops Group has faced several challenges in the past two years and is stronger because of them. It has improved understanding and credibility between agencies and stakeholders. The CALFED Bay-Delta Program is developing ways to assure all interested parties that any facility built as part of the long-term solution will be operated as intended. Assurances can include such things as legal requirements and allocating quantities of water to specific uses in the definition of the project. The development of operational plans and real-time operational decisions that include all of these assurances will require close coordination of all interested parties. Coordination which should also be identified as an assurance. It is very possible therefore, that the Ops Group will be incorporated into the assurances being developed for the long-term water management solution to the Delta.

REFERENCES

CUWA, 1993 -- California Urban Water Association. The Delta. May 1993.

DWR, 1993 -- California Department of Water Resources. The Sacramento-San Joaquin Delta Atlas. 1993.

WEF, 1995 -- Water Education Foundation. Layperson's Guide to the Delta. 1995.

WATER QUALITY IN TRANSBOUNDARY STREAMS

Alberto Ramírez[1] Sergio S. Solis[2]

ABSTRACT

Along the 2000 miles (3200 km) USA - Mexico border several perennial rivers flow, sometimes these streams constitute the international boundary, namely in the case of Colorado and Bravo/Grande rivers, others they just cross from country to the other, as the Tijuana, New and Nogales rivers.

Their importance for the border environment and life sustainability in this region have been the subject of many documents since the beginning of their history. The Colorado river could be considered as the circulatory system for an area comprising two Mexican states, Sonora and Baja California and two US border states, Arizona and California, as it constitutes, at least for the Mexican .population of the zone, the main and sometimes only source of water.

On moving eastbound along the border some others transboundary creeks and rivers appear, noticeably the Santa Cruz and San Pedro rivers as well the Nogales creek, flowing from Nogales, Sonora to Nogales, Arizona and subsequently discharging into the San Joaquin river basin.

As important as the Colorado river, stands the Rio Bravo/Rio Grande, stretching for 1240 miles (2000 kms)(borderline segment only) along the border between the two countries, providing drinking water, agricultural irrigation water and recreation areas for more than 3 millions people living in about 14 paired cities and towns.

Because of the above mentioned factors, the quality of the water comprising these international rivers is a crucial issue for the survival of the region. For this reason, water quality in most of these streams has been monitored by both countries for some years, either individually or trough joint studies.

This paper presents a summary of the main monitoring activities developed unilaterally by Mexico or jointly, trough CILA/IBWC, on the transboundary streams in recent years, as well as a brief review of the water quality situation in the international region of the Colorado river.

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INTRODUCTION

The Border

The length of the border between Mexico and the USA, is of approximately 2000 miles (3200 Km). Along this region, several rivers and creeks either flow from one country to the other which is the case of the Tijuana, New, Santa Cruz rivers and the Nogales creek, or constitute the actual international boundary among them as it happens with the lower Colorado river or the Rio Bravo/Grande, that forms more than half of the boundary 1243 miles(2000 Km) between the two countries.[1, 2]

The main pairs of border cities are located in Figure 1

The border region presents the following characteristics:

1.- Geographical:
The border region between Mexico and the USA was defined in the La Paz Convention in 1983, as the 62.15 MI(100 km) area located at both sides of the international boundary. It comprises the Mexican states of Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon and Tamaulipas, and from the US side the states of California, Arizona, New Mexico and Texas. Thirty five Mexican municipalities, 25 counties on the US side and fourteen pairs of sister cities lay along this border

2.- Climate
Dessert conditions prevail in most the border area. Some exceptions to this can be observed in the areas close to the mountain regions in the California Coastal range, the Colorado river low basin, the irrigated plains of Sonora and the riparian regions of the Rio Grande/Bravo and the coastal lands of the Gulf of Mexico. Most of the border region gets less than 10 in.(250 mm) of rain per year, only the mountain areas get enough rain to ensure agricultural crops without irrigation. The semiarid plains nearby the Gulf of Mexico get between 12 to 20 in (300 - 500 mm) of rain per year, the low coastal lands get more than 38 in (1000 mm) of rain per year.

Temperatures on the Pacific and Gulf coasts are more or less stable throughout the year, with ranges varying from 13 to 24 degrees Celsius along the Pacific coast and from 18 to 27 degrees Celsius in the Gulf of Mexico's coast. Temperatures in the central regions vary depending on the altitude. Below 2400 ft (800 m) above sea level (a.s.l.) average annual temperature is 24 degrees Celsius. From 2400 ft to 5700 ft (800 to 1900 m) a.s.l. average annual

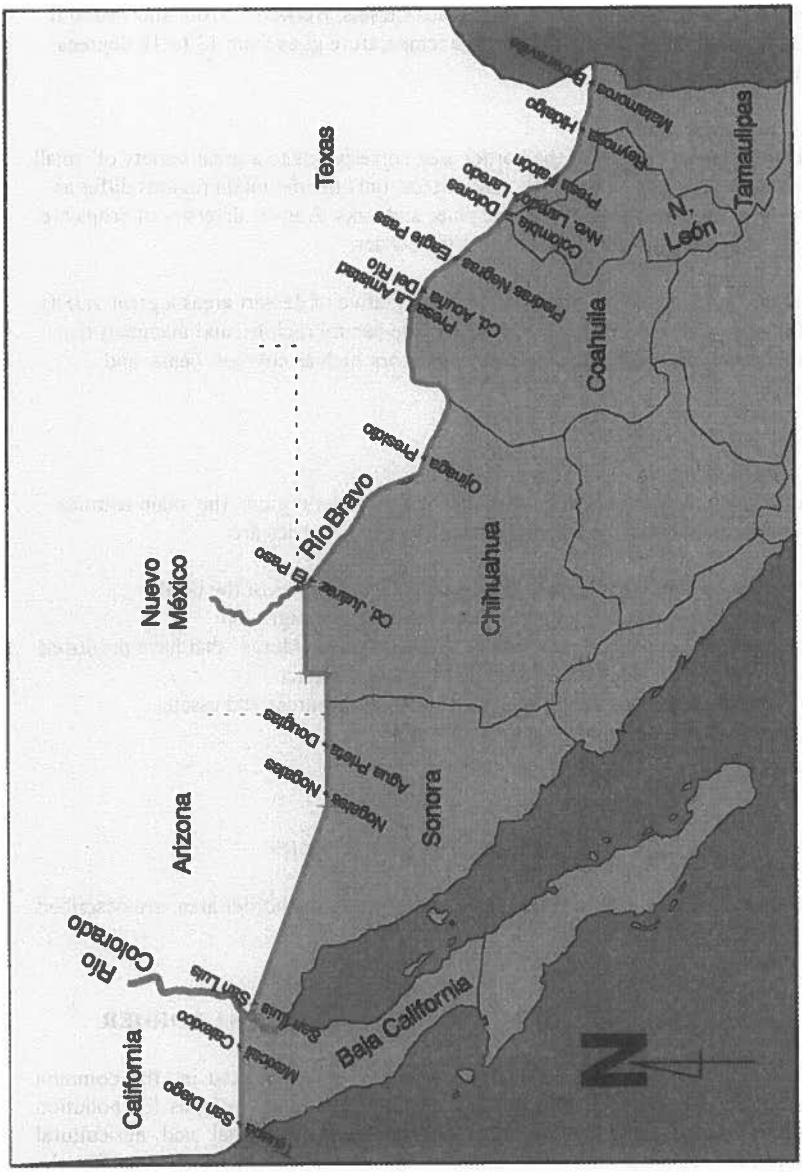

Figure 1.- The borderland between Mexico and the United States

temperature varies from 18 to 24 degrees Celsius. Between 5700 and 11000 ft (1900 to 3200 m)a.s.l. annual average temperature goes from 13 to 18 degrees Celsius.

3.- Biological aspects
The vegetation in most of the border area corresponds to a great variety of small size bushes, mostly xerophytes, and cactus, only the mountain regions differ as they present trees that may include pines and oaks. A great diversity of crops are cultivated in the irrigated lands along the border.

Animal populations are particularly representative of dessert areas a great variety of reptiles can thus be found, specially in the central regions, and mammals that include rodents, deer and even some predators such as coyotes, bears and cougars.

4.- Socioeconomic
Concerning the socioeconomic aspects of the border region, the main features that differentiate this area from the rest of both countries are:

a) An intense interaction among communities from sides of the border
b) Rapid population growth, originated mostly from migration
c) Presence of new economic factors such as "Maquiladoras" that have produced a strong social, economical and environmental impact
d) Constant transboundary exchange of people, resources and assets
e) Dependence on the same sources of water

TRANSBOUNDARY RIVERS

The main hydrologic areas that can be identified on the border area, are described in Figure 2 [3, 4]

WATER QUALITY ALONG THE MEXICO/USA BORDER

Amongst the water quality problems that have been detected in the common waters flowing between Mexico and the USA, the main reasons for pollution are, in general, due to raw sewage discharges, industrial and agricultural wastewater flowing untreated into the rivers, all of this originated by the continuos growing and immigration in this area.

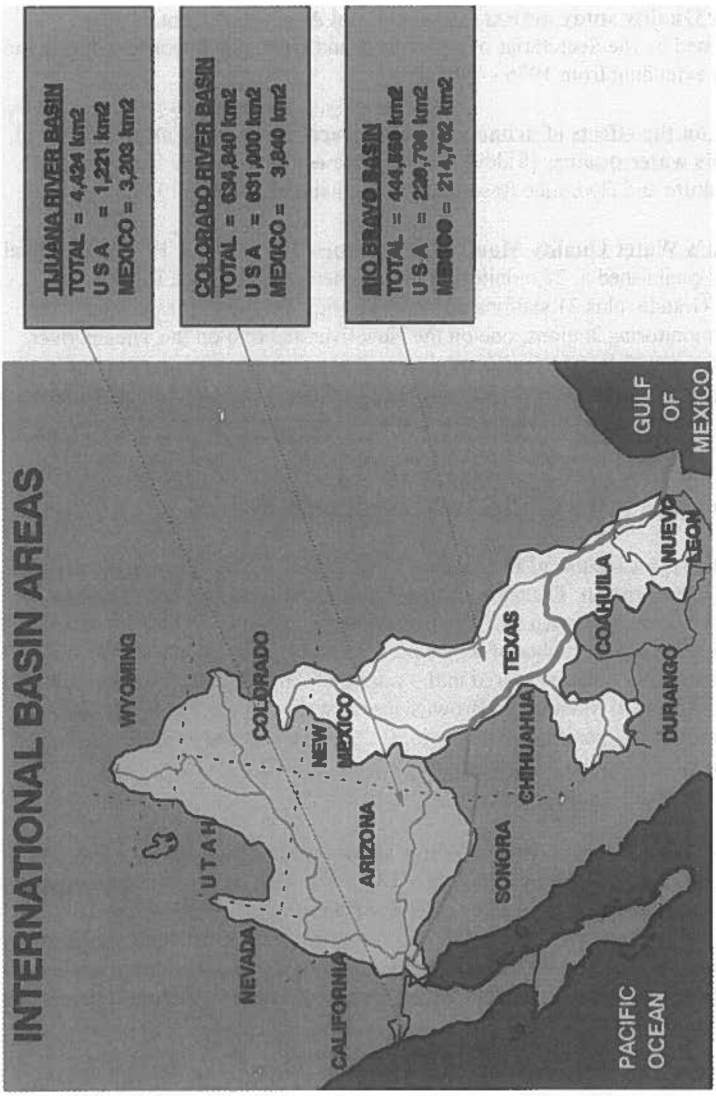

Figure 2.- The main River Basins along the Border

Water Monitoring Studies Performed by Mexico

Water Quality study between Amistad and Anzalduas Dam, it was performed by the Secretariat of Agriculture and Hydraulic Resources during the period extending from 1976 - 1987. [7]

Study on the effects of urban and agricultural wastewater on the Rio Bravo's water quality, [8]developed under a contract for the Secretariat of Agriculture and Hydraulic Resources during February - May, 1978.

C.N.A.'s Water Quality Monitoring Network, [9, 10] since 1976 this federal agency established a 24 monitoring stations network along the Rio Bravo/Grande, plus 21 stations on the tributaries. On the Colorado river CNA has 4 monitoring stations, one on the New river and two on the Tijuana river. The system gathers nmeteorological as well as water quality data in this basin. Among the parameters analyzed, physicochemical and bacteriological parameters are included

International Water Quality Monitoring Programs

"Joint Memorandum of the Engineers of IBWC/CILA Recommending an Initial Observation Program of the Water Quality in the International Waters between Mexico and the United States", signed in July 5th of 1977, this program sets a number of parameters, mainly physicochemical and bacteriological, to be measured in the waters of the Rio Bravo/Grande, from Cd. Juarez/El Paso to Matamoros/Brownsville, as well as in the Pacific Ocean coast in the area of Tijuana, B.C./San Diego, Cal., the New River in Mexicali, B.C./ Calexico, Cal. and the Ambos Nogales area.

Minute 289 - "Observation of Water Quality along the Mexico - United States Border ", signed in November 13, 1992. This IBWC Minute defines the general agreement terms to carry on joint monitoring programs on the transboundary streams between the two countries. It identifies the procedures for evaluation, publication, handling and releasing of data obtained during the joint monitoring programs. It includes the agreement to create a binational data base on water quality

Several joint programs have been developed based on this Minute, all of them, coordinated by IBWC/CILA, and following the same basic outlines agreed by the two countries:

Program Description: The field work of this type of studies, including sampling, is performed by a binational team formed by technicians from the concerned agencies in both countries. Location of the sampling sites as well as the type of environmental matrixes to be sampled are determined jointly, considering flow conditions, climatic factors and possibilities of contamination due to nearby human activities. Duplicate sampling of either water sediment, fish tissue or soil samples are taken and sent to laboratories in each country to be analyzed. Once the data from the analyses is obtained , it's exchanged and evaluated by both countries before the final joint report is released to the public. The data from these study cannot be used unilaterally by either country without the express consent of the other.

Parameters: Among the parameters that have been analyzed in the samples gathered in this kind of joint studies are included: Volatile Organic, Metals, Fecal Coliforms, Cations y Anions, Conductivity, pH, alkalinity, dissolved oxygen and other conventional parameters, as well as bioassays to determine toxicity in water and sediment and biological evaluations from fish and benthic organisms.

Figure 3.- Joint Water Quality Monitoring Programs coordinated by CILA/IBWC

"Joint Report of the Principal Engineers concerning the Determination of the Presence of Toxic Substances in the Rio Bravo/Rio Grande Waters ", [11]signed on November 11, 1992. The main objective of the study was to screen the system for the occurrence and impact of toxic chemicals. The goals were to clarify concerns about present conditions in the river, and to determine if existing water quality control are adequate. The study was conducted during 1992-93 and involved sampling at 19 mainstreams sites and 26 tributaries along the reach of the river which forms the international boundary between the US and Mexico

"Joint report of the Principal Engineers related to Joint Program for the determination of the presence of toxic substances in Colorado and New Rivers", signed in march 22nd, 1995. This study was designed following the same outlines than for the Rio Bravo/Grande Joint Study, aiming to detect presence of toxic substances on both the Colorado and New rivers.

The study proposes sampling of water, sediment and fish tissue in 8 stations, three of them on the New River, including the discharge to the Salton Sea. The remaining 5 stations were located on the Colorado River, including 3 on the border section of the river, one on the Yuma Drain and the other one on the Gila river.

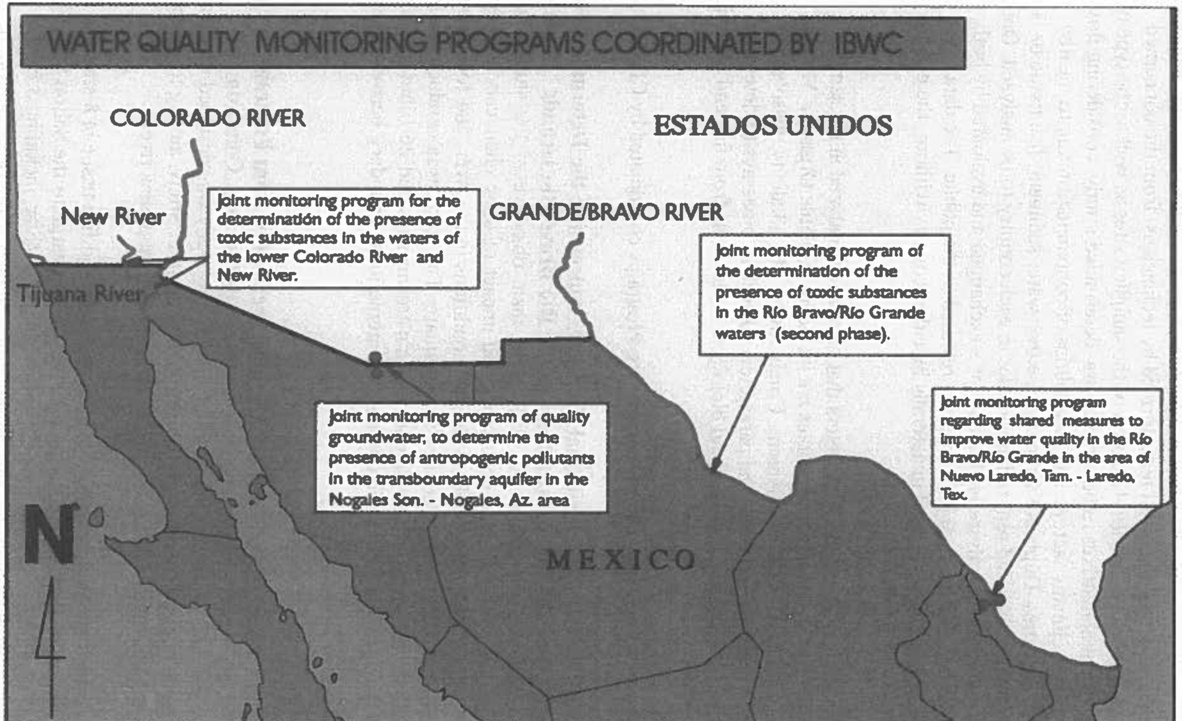

Figure 3.- Joint Water Quality Monitoring Programs coordinated by CILA/IBWC

Figure 4.- Sampling Stations on The Colorado and New rivers. Station location on the Colorado responds to particular aspects considered to impact water quality in the area

"Joint Report of the Principal Engineers concerning the Second Phase of the Determination of the Presence of Toxic Substances in the Rio Bravo/Rio Grande Waters " , signed in may 12 of 1995. The program searches to reevaluate conditions along the river, specially in the concern areas detected in the first part of the study, including stations not considered during the first phase in order to obtain a more accurate characterization of the actual conditions in this international stream.

"Joint Report of the Principal Engineers concerning the Joint Monitoring of the Groundwater quality, to determine the presence of antropogenic pollutants in the transboundary aquifer in the Nogales, Son - Nogales, AZ. area", signed in January 25th of 1996. Considering the topographic features of this area and taking into account the growing tendency observed in Nogales, Son., the lack of an adequate industrial pretreatment program and the insufficient sanitation services available, possibility of groundwater contamination was deemed possible and hence a joint monitoring program on the subject was agreed upon.

Minute 279 - "Joint Measures to Improve Water Quality in the Rio Bravo/Grande in the Area of Nuevo Laredo, Tam. - Laredo, Tex.", signed in august 28th, 1989. The purpose of this intensive water-quality sampling was to collect baseline data in the vicinity of the new Nuevo Laredo Wastewater Treatment Plant; to be able to compare the water quality before and after the Wastewater Treatment Plant entered in line. From the resulting information subsequent measures on water quality monitoring and standards will be recommended

INTERNATIONAL BOUNDARY AND WATER COMMISSION
JOINT MONITORING PROGRAM FOR THE DETERMINATION OF THE PRESENCE OF TOXIC SUBSTANCES IN THE LOWER COLORADO AND NEW RIVERS

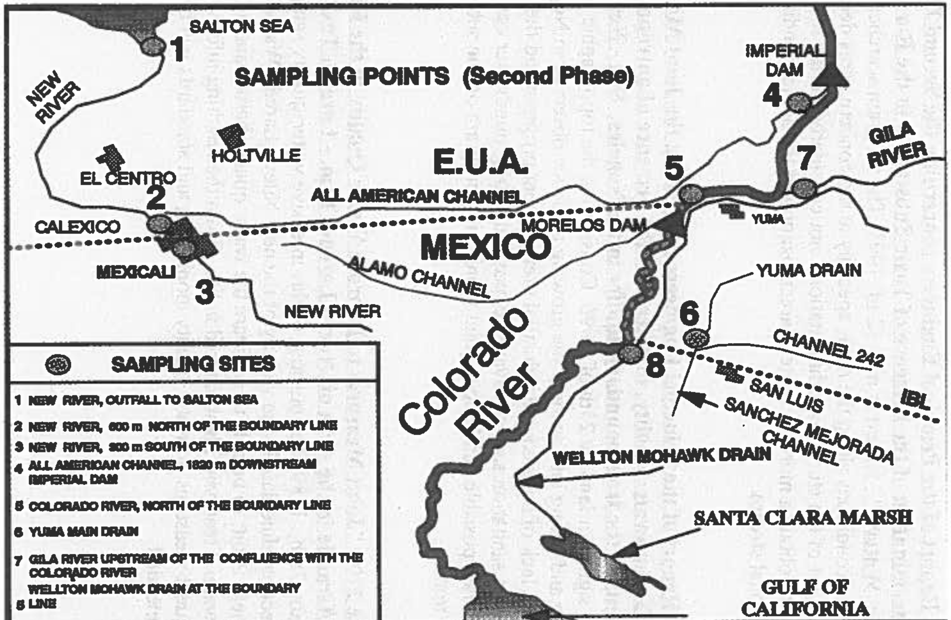

Figure 4.- Sampling Stations at the Colorado and New Rivers

CASE STUDY

In order to illustrate the importance of water quality aspects on the transboundary rivers that exists between Mexico and the USA, the Colorado river situation has been chosen as case study, given its importance and sensitivity for both nations.

Colorado river

The Colorado river is born in the USA, it has a total length of approximately 1696 miles (2730 kms), from which, 18 MI (29 km) constitute the international boundary, in the states of Baja California and Arizona, in Mexico and US respectively. The last 100 mi.(160 km), the river flows in Mexican territory and into the Gulf of California, trough the state of Sonora. Water quality in this river remains a crucial and controversial issue between the two countries, specially regarding the salinity level in the waters delivered to Mexico under the 1944 International Waters Treaty, and the silt accumulated in Mexican territory. Also, because of the socioeconomic impact it has had on the Mexican side of the border. [5, 6, 12]

Present conditions of the problems of the Colorado river in Mexican territory due to siltation and salinity.

Siltation problems, the sediment transport towards Mexican territory is a process that has been taking place for decades, usually during the flood periods, as it happened at the beginning of 1993, when intense rains in the Lower Basin of the Colorado River in United States territory, caused an increase of the storage levels of the dam system, generating discharges from Painted Rock Dam to the Gila River and then to the Colorado River. This situation, forced Mexico to take measures to protect the river banks because the conveyance capacity of the river in the Mexican reach was limited to 700 m3/s approximately. (figures 3,4 and 5)

Mexico carried out surveys to quantify the volume of sediment deposited in the Colorado River channel and in the canals' network of the Irrigation District 014, due to the Gila River flood during the first months of 1993. The sediment deposition in Morelos Dam risked the adequate diversion of Mexican waters.

The results of the survey estimated a sediment volume of up to 3.358 millions of cubic meters, thus requiring approximately $14'655,713 US dollars for removal works.

Salinity problems, during the first seventeen years of 1944 Treaty enforcement, Mexico received its water allotment from the Colorado River, with a water quality similar to the one of the water used by the farmers in Imperial Valley, California and the Yuma, Arizona, region. At that time the salinity difference between the waters in Imperial Dam and Morelos Dam was similar and did not exceed 900 PPM.

In 1966-67, there was a significant increase in the salinity of the water from the Southern Gila Region. Mexico then carried out a series of exertions during meetings in Mexico City as well as in Washington, DC. On August 30th, 1973, the Commissioners of both sections signed minute 242 which was called "Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River". Minute 242 stipulates that the salinity difference between the waters delivered to Mexico in Morelos Dam and the Colorado River waters in Imperial Dam, would not be over 121 PPM +/- 30 PPM, Mexican count. (figures 7 and 8).

However, salinity of the waters delivered to Mexico continues to be an issue of controversy and dispute, due to the fact that there exists a significant difference in the salt contents in the water that Mexico receives at the Morelos Dam and the one alloted to Mexico in the International Southerly Boundary, as shown in Figure 5.

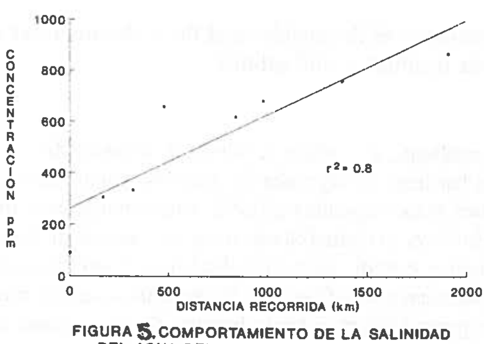

FIGURA 5. COMPORTAMIENTO DE LA SALINIDAD DEL AGUA DEL RIO COLORADO DURANTE SU RECORRIDO

Additionally, salt concentrations may vary drastically in very short periods, as shown in Figure 6, causing ill effects on crops, depending on their type and ripeness stages.

Finally, whereas salt concentration in the Colorado rivers changes gradually throughout most of its length due to natural causes and increased human use, when the water saltiness is compared between Morelos Dam and that in the Southerly Boundary Limit, there's a sudden increase (Figure 7) that, shows that agricultural irrigation drainage water is been added in that area before it flows down into Mexico.

Where as, when the water saltiness is compared between Morelos Dam and that in the Southerly Boundary Limit, there's a significant difference (Figure 6) that, shows a considerable increase in salinity in the water delivered to Mexico, that consequently affects the agricultural activities in this country.

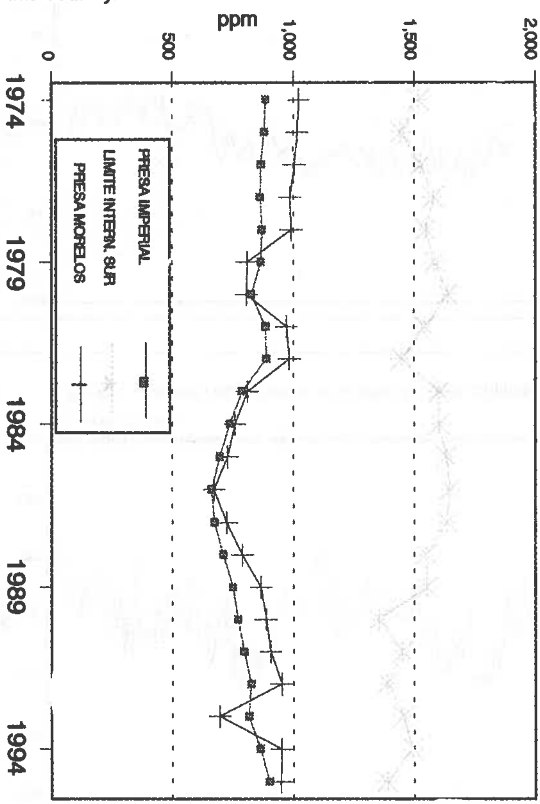

Figure 6.- Colorado water salinity at, Imperial Dam, Morelos Dam, and the South International Boundary Limit, from 1974 - 1994.

Aditionaly, salt concentrations may vary drastically in a very short period, as shown in Figures 7 and 8, causing ill efects on crops, depending on their type and ripeness stages.

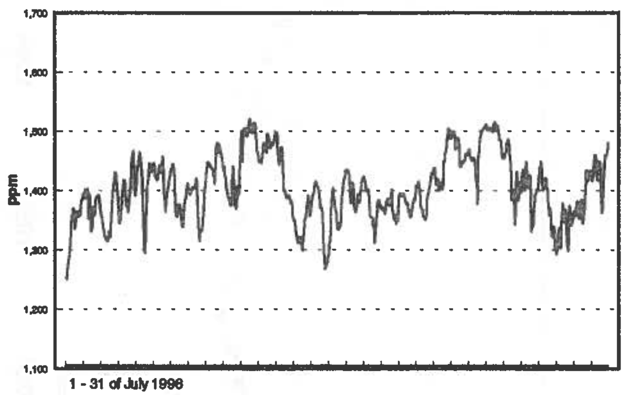

Figure 7.- Colorado River Salinity at Sánchez Mejorada channel

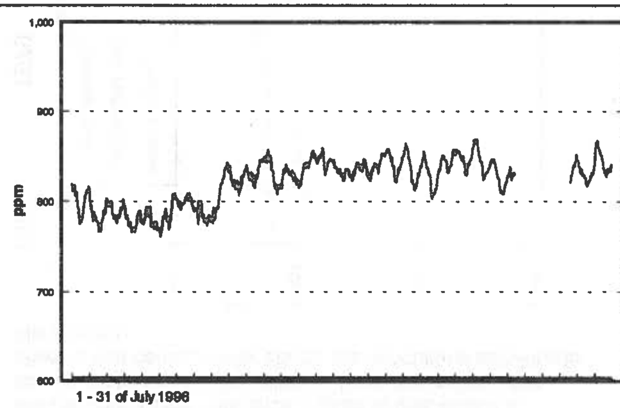

Figure 8.- Colorado River Salinity at Morelos Dam

CONCLUSIONS

Water distribution was the primary concern in the international Treaties signed between Mexico and the USA. However, water quality as become as important an issue as volume and distribution. Water pollution on transboundary rivers has produced increasing concern along the border and it's been the subject of a series of joint monitoring programs. Numerous efforts, both at the domestic and binational levels have been and are being instrumental to gather data on the existing water quality conditions along the transboundary streams between Mexico and the United States.Major water quality problems are observed in the Lower Colorado river basin eventhough a Treaty and several IBWC's Minutes have been signed concerning its water distribution and minimum quality standards, salinity and sediments continue to interfer in the beneficial use of these waters in Mexico.

Diferent kind of water quality problems may be observed in other rivers along the border, but the common denominator for them all seems to be the dynamics of this region and the human pressure, that rapidly overcomes the available capabilities to deal with the basic problems of sanitation, wastewater treatment and appropiate disposal of agricultural irrigation effluents.

Our level of knowledge with respect to the water quality on the common waters between Mexico and the USA has been improving gradually trough time, and at the present time it permits to establish adequate measures to improve not only the quality of the water that flows across our lands, but mainly the quality of life of their inhabitants and the to search the sustainability of our region as well.

REFERENCES

1.- Border Integrated Environmental Program, First Stage. 1992 - 1994. Secretaría de Desarrollo Urbano y Ecología (SEDUE) & US Environmental Protection Agency. 1992. Mexico, D.F.

2.- Border XXI. Draft document. May, 1996. Secretaría del Medio Ambiente Recursos Naturales y Pesca (SEMARNAP) & US Environmental Protection Agency. El Paso, TX.

3.- Boletín Hidrométrico del Río Colorado. Num.34. 1993. Comisión Internacional de Límites y Aguas entre México y Estados Unidos. Cd. Juárez, Chih.

4.- Boletín Hidrométrico del Río Bravo. Num.63. 1993. Comisión Internacional de Límites y Aguas entre México y Estados Unidos. Cd. Juárez, Chih.

5.- La Salinidad del Río Colorado. 1975. Secretaria de Relaciones Exteriores, México, D.F.

6 - Comportamiento de la Salinidad en el Agua del Río Colorado. M. Cervantes R. & Francisco A. Bernal R. 1991. in "Manejo Ambientalmente Adecuado del Agua". P. 128 - 135. El Colegio de la Frontera Norte. Tijuana, Baja California.

7.- "Estudio sobre la observación de la calidad del agua entre las presas internacionales Amistad y Falcón". 1987. Secretaría de Agricultura y Recursos Hidraúlicos (SARH), Mexico, D.F.

8.- Rio Bravo Basin Water Quality Study. !978. Felipe Ochoa &Asociados, under contract by Secretariat of Agriculture and Hydraulic Resources. S.A.R.H., México, D.F.

9.- Boletín de la Calidad del Agua 10. 1977-1986. CNA, México, D.F.

10.- Informe de la Calidad del Agua en las Cuencas fronterizas con E.U.A. 1987- 1995. CNA, México, D.F.

11.- Binational Study Regarding the Presence of Toxic Substances Along The Boundary Portion Between Mexico and the United States. September, 1994. International Boundary and Water Commission Mexico/USA. Cd. Juárez, Chih./El Paso, TX.

12.- International Waters Treaty. Between Mexico and the United States. February 3, 1944. Oficina de Límites y Aguas Internacionales, Secretaría de Relaciones Exteriores. 1947. Mexico, D.F.

FISH FRIENDLY WATER FOR AGRICULTURAL, URBAN AND ENVIRONMENTAL NEEDS: A CALIFORNIA CASE STUDY

Neil Schild, P.E.[1] Marilyn Cundiff-Gee[2]

ABSTRACT

A project was developed to provide "fish friendly" water for approximately 8,000 acres of wetlands, 8,000 acres of agricultural land, urban water users, and millions of migrating waterfowl. The confluence of Big Chico Creek, and the Sacramento River, is north of the San Francisco Bay/Sacramento-San Joaquin River Delta area. Big Chico Creek once supported healthy runs of chinook salmon and steelhead trout. In the early 1900s, five large pumps were installed on Big Chico Creek, with a combined capacity to divert, for irrigation purposes, about 135 cubic feet per second (CFS) of water. Later, these same pumps were also used to provide water for about 8,000 acres of refuge wetlands on State and Federal wildlife areas. When the pumps were in operation during low flow periods, the unscreened diversion caused stream flow reversals during out migration periods, resulting in a substantial loss of downstream migrants. Due to the loss of winter run salmon, the California Department of Fish and Game and the U.S. Fish and Wildlife Service elected not to exercise their legal right to use the pump station, thus limiting their ability to manage and maintain the critical wetlands. For many years, biologists have called for the removal of the pumps, however, the private landowners did not have $4.5 million necessary to move and screen the pumps. Identifying mutual areas of interest and the multiple benefits associated with this project led to the formation of a partnership consisting of stakeholders that more often than not, were polarized and against one another, i.e., environmental, agricultural and urban water interests. Because of the partnership, the following benefits were achieved: $4.5 million was raised to move the pumps; agricultural operations will continue, fisheries will not be affected, and wetlands will again provide critical habitat for other threatened and endangered species and millions of migrating waterfowl.

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INTRODUCTION

California agriculture is considered one of the most diversified industries in the world with an abundance of land resources, fertile soils and temperate climate zones. Coupled with sophisticated technology, California has been the top-ranking agricultural state in the United States. In 1995, cash farm receipts approached almost $20 billion and generated more than $70 billion in related economic activities (American Farmland Trust 1995).

Within California, the Central Valley is the nation's most important agricultural area, with eleven of its 21 counties producing 250 different commodities with a market value of $13.3 billion a year (American Farmland Trust 1995). From crops as diversified as nuts, stone fruits and cereal grains, this level of production occurs on approximately 6.7 million acres (2.7 million ha) of irrigated cropland.

While the abundance of land resources, fertile soils and temperate climate zones produce an environment that is conducive to high yields and high farm cash receipts, it also provides for some of the most diverse and abundant wildlife in the nation. The Central Valley wetlands and agricultural areas support the largest single concentration of wintering waterfowl (approximately 3-4 million birds) and are considered one of the most important wintering areas for waterfowl in North America (Bellrose 1980, Heitmeyer 1989a).

California's great Central Valley supports approximately 60 percent of the ducks and geese wintering in the Pacific Flyway. However, nearly 95 percent of the Central Valley's historic wetlands have been lost (Gilmer et al. 1982). Of the remaining 300,000 acres (121,410 ha) of wetlands, two-thirds are privately owned and managed for the purpose of providing wintering waterfowl habitat and duck hunting opportunities (Heitmeyer 1989a). The remaining one-third consists of State Wildlife Areas and National Fish and Wildlife Refuges (Central Valley Habitat Joint Venture 1990).

Located within the heart of the Central Valley is the Bay-Delta. The Bay-Delta is the largest estuary on the West Coast. The Bay-Delta is a beautiful, lush, and varied ecosystem including a maze of tributaries, sloughs, and islands encompassing 738,000 acres (298,668 ha). Lying at the confluence of California's two largest rivers, the Sacramento and San Joaquin, it is a haven for plants and wildlife, including 70,000 acres (28,329 ha) of wetlands and supporting 120 different fish and wildlife species. The Bay-Delta is also critical to California's economy, supplying drinking water for about 22 million Californians and nearly half of the entire state's irrigation water for

200 different crops, including 45 percent of the nation's produce (CALFED Bay-Delta).

The economical and ecological significance of the Bay-Delta cannot be understated and for centuries has been the focus of debate and competing interests ranging from economic and ecological to urban and agricultural. While the debate surrounding the use of these natural resources continued, the quality of the Bay-Delta ecosystem continued to suffer and decline. Wetland, riparian and associated upland habitat continued to suffer, and native species continued to decline. For the urban water user, the Bay-Delta no longer served as a reliable source of high quality water and agricultural interests were faced with an increased shortage of water necessary to maintain California's strong agricultural industry.

In this paper, we present the methodology and processes used to develop a project that will contribute toward protecting the economic viability of critical Central Valley agricultural land and enhance wetlands in Butte County, California. In addition, the project will contribute toward enhancing the Bay-Delta ecosystem. By implementing a conjunctive use project that accomplishes both agricultural, fish and wildlife objectives, the project has been widely supported by wildlife interests, farmers and the local community.

ABSENT FISH FRIENDLY WATER

Big Chico Creek, a tributary to the Sacramento River, once supported healthy runs of spring, fall and late-fall runs of chinook salmon and steelhead trout. In 1958, spring-run chinook salmon populations were estimated at 1,000 adults and steelhead populations are thought to have averaged 150 returning adults. Recent estimates indicate that a low steelhead population, a highly variable spawning population of fall and late-fall chinook salmon and only a remnant of spring-run chinook salmon remain in Big Chico Creek.

One obstacle to restoring the spring-run chinook salmon and steelhead in Big Chico Creek system is water exported from the lower reaches of the creek during the critical emigration/immigration period of juvenile and adult fish. Water diversions from the M&T/Parrott Pumping Station significantly contributed to the fish mortality on Big Chico Creek.

In the early 1900s, the M&T/ Parrott Pump Station was installed. This pump station, comprising five large pumps, had a combined capacity to divert more than 135 cfs of water. Further complicating the situation, the bank of pumps were not screened. During peak demands in the irrigation system, these pumps caused stream flow reversals during the critical emigration period, resulting in a substantial loss of downstream migrants during stream flow reversal in Big Chico Creek.

The water diverted by the M&T/Parrott Pumping Station was used on approximately 8,000 acres (3,237 ha) of privately owned and very productive agricultural land. The water was used to irrigate crops such as rice, sugar beets, almonds, other cereal crops, and irrigated pasture. The pump station was also used by the California State Department of Fish and Game (CDFG), the United States Fish and Wildlife Service (USFWS), and a private landowner to irrigate approximately 8,000 acres (3,237 ha) of seasonal and permanent wetlands that are adjacent to the agricultural lands.

The CDFG and USFWS manage the state and federal wildlife and refuge areas to benefit many species of threatened and endangered species. In addition, the areas support millions of migrating waterfowl that are dependent upon this area during their winter migration through the Central Valley. Specifically, ducks, geese, swans and hundreds of other wetland species are dependent upon Central Valley wetlands for their winter food supplies.

The CDFG and USFWS were dependent upon the M&T/Parrott Pump Station to properly manage the wetland areas. In recent years, both the State and Federal agencies elected not to exercise their legal right to this water because of the negative impact the pumping had on the winter run salmon (a federally listed species). Absent a "fish-friendly" water pumping and diversion alternative, the state and federal agencies were unable to utilize their riparian water rights.

Electing not to exercise their riparian water rights resulted in a limited opportunity to pump water without drastically impacting winter run salmon and steelhead populations. As such, because of the unreliable and limited water supply, approximately 80 percent of the wetland areas were functioning at 60 percent efficiency. Stated differently, the habitat needed to support the millions of migrating ducks, geese, swans and other wetland dependent species, was not functioning at its maximum potential because of an inadequate and unreliable water supply at critical times of the year.

DEVELOPING A CONJUNCTIVE USE SOLUTION

Increasing demands on the use of water in California, coupled with the competing and conflicting interests of agriculture, urban and environmental groups, has created a polarized and often confrontational situation regarding the allocation of water. Balancing the needs of diverse interests has forced stakeholders to seek new ways to achieve long-term, reliable sources of water that is environmentally responsible, affordable and of sufficient quality for all interests.

By relocating the M&T/Parrott Pump Station and screening the diversion, a "fish-friendly" water supply could be made available to the agricultural land, as well as the state and federal wildlife areas and refuges. In addition, by removing one of the barriers associated with the number of spring, fall and late-fall runs of chinook salmon reaching the Bay-Delta, the fisheries associated with the Bay-Delta ecosystem would be improved. However, to relocate and screen the new diversion, $4.5 million was needed. Because the M&T/Parrott Pump Station was privately owned, the landowners did not have $4.5 million needed to complete this project.

Recognizing the multitude of public and private benefits associated with relocating and screening the pump station, a Joint Management Committee was developed. This committee consisted of representatives from the agricultural landowners, the CDFG, and the USFWS. The purpose of this ongoing committee is collectively to manage the various issues affecting the private agricultural operations and public wildlife areas. In addition, the Joint Management Committee was responsible for identifying a new location and design for the new pump station. Working through the public/private, Joint Management Committee, the location and design of the new pump station was planned that met the divergent needs of agriculture, fishery and wetland/waterfowl interests.

THE CONJUNCTIVE USE SOLUTION

The M&T/Parrott Pump Station and Fish Screen is at MP 192.8 on the right bank of the Sacramento River. This location is about one half mile below the mouth of Big Chico Creek. The pump station consists of four vertical propeller pumps driven by four 240-horsepower natural gas engines. The intake for the pumps is in the Sacramento River. The positive barrier fish screens consist of four cylindrical wedge wire screens 54-inch in diameter and 15 feet in length. These screens meet the criteria approach velocity of .3 feet per second and there is sufficient current in the Sacramento River to meet the sweeping flow requirements. The 84-inch intake pipe penetrates the river levee, connecting the fish screens to the pump manifold, with a gate structure in the center of the levee. The four vertical pumps discharge into a 72-inch diameter pipe that conveys the diversion 4,300 feet into the present conveyance system.

The fish screens will be cleaned utilizing high pressure air. The air is supplied by two 75 HP air compressors and a 1,800 cf pressure storage tank. The screen manufacturer provided the volume of air required to "clean" the screen from growths and particles sucked onto the screen or those that would try to permanently attach to the screens. The National Marine Fisheries Service criteria established the five-minute frequency for cleaning each screen. The cleaning system must provide the required volume of air at the specific pressure to be available for each of the four individual screens every five minutes.

Obtaining necessary permits and environmental documentation on construction projects designed to relocate and screen major water diversions, typically takes a year or more to complete. However, in-part because of the tremendous support and collective effort to build this project, all environmental documents were completed and permits were obtained in less than one year from the time this project was approved at the conceptual level. The State Reclamation Board granted permission to place the intake through the levee. The U.S. Army Corps of Engineers granted permits and issued regulations to protect the river bank and navigation in the river. The California Fish and Game Commission granted streambed alteration permits. The Regional Water Quality Control Board granted permits to protect the water quality in the Sacramento River. The National Marine Fisheries Service issued a non-jeopardy biological opinion on the project for the listed winter-run salmon. The State Water Resources Control Board accepted the change in point of diversion from the present pumping plant to the new pumping station on the Sacramento River.

The environmental documentation included a public scoping meeting, a Proposed Finding of No Significant Impact/Mitigated Negative Declaration, and a Draft Environmental Assessment/Initial Study document. In addition, all public comments obtained during the public review period and responses were included as part of the official record. All documents were filed with the respective state and federal authorities before permitting could be completed and construction to proceed.

The state agency of record was the CDFG, while the lead federal agency was the USFWS. The potential impacts due to the construction and relocation of the facilities were examined. There were no negative impacts on endangered or threatened species that required mitigation. The environmental review and documentation also addressed the transfer of 40 cfs of water from Butte Creek to the Sacramento River from October 1 through June 30 of each water year, in perpetuity. This water transfer will provide additional fish flow water in Butte Creek.

FINANCING CONJUNCTIVE USE EFFORTS

While the relocation and design of the pump station was accomplished through the Joint Management Committee, there remained the problem of raising $4.5 million necessary to build the new pump station. Again, through the process of developing public/private partnerships, and recognizing that the goals and objectives of seemingly divergent interests groups could be met if the pumps were relocated, additional partners were identified to finance the entire project. Specifically, the Wildlife Conservation Board joined the partnership because of the wetland and waterfowl benefits that were to be achieved if "fish-friendly" water were available to the state and federal wildlife and refuge areas. Further, Ducks Unlimited, Inc., a nonprofit conservation organization joined the partnership because of the importance of "fish-friendly" water to the millions of migrating waterfowl dependent upon Central Valley wetlands.

In addition, because of the Bay-Delta ecosystem benefits, the Bay-Delta Accord joined the partnership. The Bay-Delta Accord, an agreement among several federal and state agencies, urban and agricultural water users and environmental and conservation interests established temporary standards for resolving the multitude of issues affecting the Bay-Delta ecosystem. Accompanying the temporary standards was the commitment of fiscal resources to fund improvements to the Bay-Delta ecosystem. As such, the fishery benefits associated with relocating and screening the pump station, attracted Category III, and an additional funding partner to the project.

The project also qualified for funding through the Central Valley Project Improvement Act (CVPIA), Section 3406 (b) (21). These restoration funds, provided through the Bureau of Reclamation represented the commitment from the agricultural community to help the agricultural industry in resolving environmental issues. The money is paid into the CVPIA Restoration Fund by the agricultural users that receive Central Valley Project water supply.

Finally, the private landowners contributed significantly to this effort. Besides actual cash contributions, the landowners have agreed to provide, in perpetuity, 40 cfs of water in Butte Creek, a tributary to the Sacramento River.

The 40 cfs will remain in Butte Creek from the Parrott/Phelan Diversion Dam down to the outfall on the Sacramento River at MP 138. This change provides Butte Creek the additional flow for about 60 miles. This exchange occurs from October 1 through June 30. The CDFG will administer these flows.

BENEFITS OF AN INTEGRATED APPROACH

What started as a project to address a major problem to spring, fall and late-fall runs of chinook salmon and steelhead trout, became an opportunity to carry out a conjunctive use effort that integrated the needs of the agricultural community, wetland and waterfowl interests and urban water users who benefit from the Bay-Delta ecosystem. The public/private partnership that started this project reflects a commitment and recognition by each "partner," that unless "fish-friendly" solutions are developed and implemented, watersheds and ecosystems will not be restored to their healthy states. Further, the partners recognize that unless environmental projects are implemented that make social, environmental and economic sense, the problems facing our wetlands, fisheries and agricultural industries will not be resolved.

This project represented an opportunity for federal, state, and private organizations to carry out a project that far outweighs the direct beneficiary, i.e., the salmon and steelhead populations that once dominated Big Chico Creek, Butte Creek and the Sacramento River. It represents an opportunity for the public and private sector to address a watershed problem that will benefit not only the fisheries and millions of waterfowl and other wetland dependent species, but also the economic viability of an agricultural industry that is critical to Butte County and the citizens of California. In addition, this project demonstrates that Bay-Delta ecosystem benefits can be achieved by eliminating upstream impacts and ultimately the availability of drinking water to almost 22 million Californians.

Acknowledgments

The success of this project is attributed to the individuals and organizations that believe the protection of natural resources can make environmental, as well as social and economic sense. Further, the project is a tribute to the dedication, commitment, technical expertise, advise and encouragement provided by Mr. Gary Kramer, and Mr. Ramon Vega, U.S. Fish and Wildlife Service, Sacramento National Wildlife Refuge, Mr. Paul Ward, Mr. John Nelson, and Mr. Paul Hofmann, California Department of Fish and Game; and the private landowners, represented by Mr. Les Heringer and Mr. Richard Thierrot.

REFERENCES

American Farmland Trust. 1995. Alternatives for future urban growth in California's Central Valley: the bottom line for agriculture and taxpayers. Washington, D.C. 18 pp.

Bellrose, F.C. 1980. Ducks, geese, and swans of North America. Third ed. Stackpole Books, Harrisburg, Pa. 540 pp.

Central Valley Habitat Joint Venture. 1990. Central Valley Habitat Joint Venture Implementation Plan. Sacramento, Ca. 102 pp.

Gilmer, D.S., M.R. Miller, R.D. Bauer, and J. R. LeDonne. 1982. California's Central Valley wintering waterfowl: concerns and challenges. Trans. N. Amer. Wildl. And Nat. Res. Conf. 47:441-4521

Heitmeyer, M. E., D.P. Connelly, and R.L. Pederson. 1989a. The Central, Imperial and Coachella Valleys in California. In L. Smith, R.l Pederson, and R. Kaminski, eds. Habitat management for migrating and wintering waterfowl in North America. Texas Tech. Univ. Lubbock. Pp.475-505.

GROUNDWATER MANAGEMENT - BUILDING CONSENSUS

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ABSTRACT

Located in western Riverside County, in southern California, the Eastern Municipal Water District (EMWD) covers over 555 square miles with a population of nearly 400,000. Only about 20% of the total water sold by EMWD for municipal use is groundwater, the remaining 80% is imported. With the increasing uncertainty of imported water, both in terms of cost and availability, EMWD has identified groundwater resources management, reclaimed water reuse, and conservation as priorities.

The West San Jacinto Groundwater Management Plan was adopted by EMWD's Board of Directors on June 8, 1995. This is the first and most comprehensive plan adopted in southern California under the authority of California State Assembly Bill 3030, now part of the State Water Code. The plan area covers 256 square miles, nearly half of EMWD's service area. Groundwater quality is marginal in many of the subbasins, such that agricultural and municipal uses are restricted. Potential water shortages, increasing costs, and water quality problems provide the need for a comprehensive groundwater management plan. Plan objectives include meeting future water demands, increasing the reliability of water, minimizing water costs, maximizing reclaimed water use, protecting and/or enhancing basin-wide water quality, protecting local water rights, enhancing basin yields, and maximizing groundwater basin storage. Initially, public reaction, particularly from the farming community, was one of concern and suspicion that the District would try to put a limit on groundwater production by farmers, would try to finance the plan through a replenishment assessment or "pump tax" on groundwater produced and would try to force the farmers to use lower quality reclaimed water rather than groundwater. Ten public meetings with presentations were held along with six information workshops and fourteen individual meetings. In all, over one hundred interested parties - property owners, cities, agencies, groups, and attorneys - attended meetings and/or provided comments.

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Prior to adoption, the plan was modified to more accurately address concerns. Finally a plan evolved that most of the agricultural community supported, some enthusiastically. As a result, protest at the adoption hearing was minimal, far less than 1%, with only one individual speaking against adoption and many speaking in favor.

The West San Jacinto Groundwater Management Plan is an historic development that will ensure water for domestic and agricultural users, help protect the interests of existing groundwater producers, provide a framework for new water supply projects for the benefit of the groundwater producers and the public, and ensure the economic viability of the region.

INTRODUCTION - EMWD

When the Eastern Municipal Water District (EMWD) was formed in 1950, local farmers needed to secure a source of water to supplement groundwater supplies which were declining in some basins, and were expected to decline in others as agricultural development expanded. EMWD became a member agency of the Metropolitan Water District of Southern California (MWD) to secure access to imported water from Northern California and the Colorado River. At that time, the District covered an area of 86 square miles. In the intervening 46 years, EMWD's service area has expanded considerably to over 555 square miles (See Fig. 1) and the character of the District has changed from a rural agricultural area to one of mixed urban development and continued agricultural use with increasing urbanization. Projections to the year 2010 indicate that while agricultural use will decline slightly, municipal demand will increase dramatically. In the absence of a management plan, increased demand would have to be met with imported water at an increasing cost; some projections show MWD's price increasing to over $600.00 per AF by 2010. With increased demand and future increases in the cost of imported water, the development of local water resources becomes even more important. There is not enough water in the San Jacinto basin to meet current needs, let alone projected increases.

THE NEED FOR GROUNDWATER MANAGEMENT

Most western states have instituted state control of groundwater. California and Texas remain the only two western states without statewide controls. There is no comprehensive law in California that determines the right to groundwater. Some form of control is on the horizon. However, most feel local control is better than dictates from Sacramento, the state capitol, five hundred miles to the north.

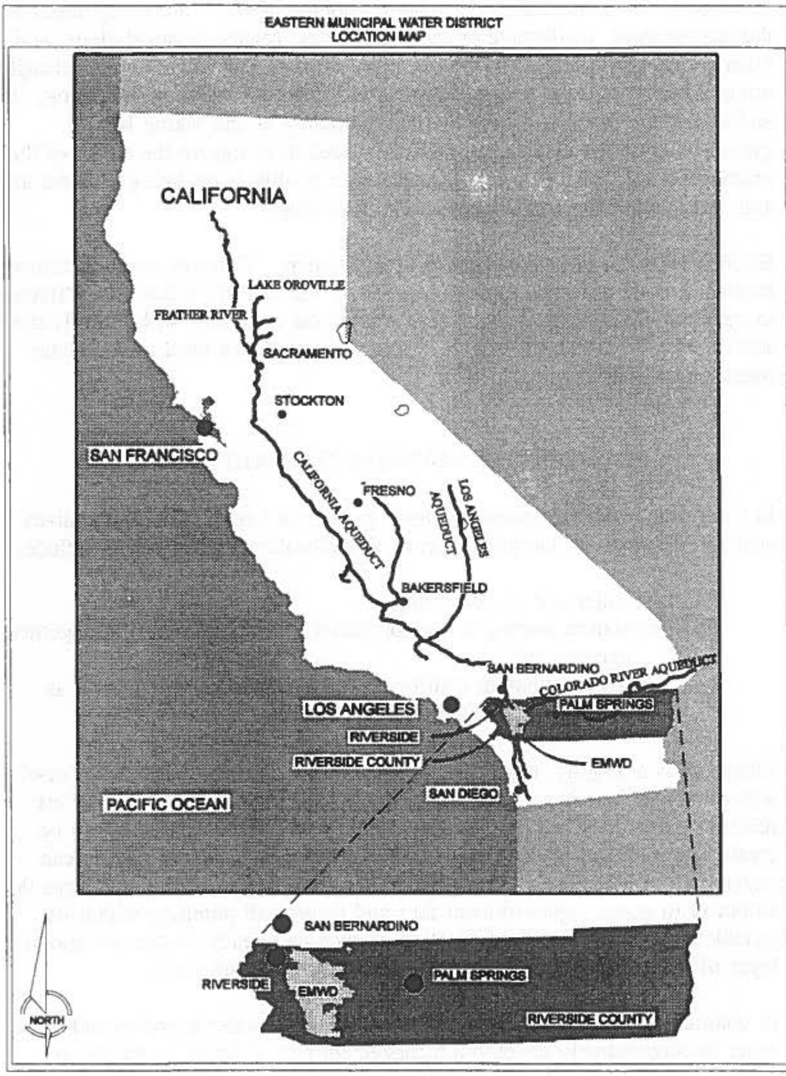

Fig. 1. Location of EMWD service area.

Why is any form of control or management needed? Water demands are increasing in the area; imported water is not as reliable as local resources; the need for water is increasing; increased amounts of water are being allotted for the environment; inadequate or out-dated pipes, canals, pump stations, and other transmission facilities threaten delivery; weather uncertainties (droughts) are an ever-present danger; and the cost of imported water is increasing. In addition, there is the potential for others coming in and taking local groundwater to use elsewhere; there is a need to recognize the rights of the existing groundwater pumpers; groundwater quality is declining in some areas; and, the amount of groundwater is also declining.

EMWD exists to meet the needs of its customers. Concern over the future availability and cost of imported water have led EMWD's Board of Directors to conclude that it is imperative that local water resources within the District's service area be protected through the development of a local groundwater management plan.

GROUNDWATER MANAGEMENT ALTERNATIVES

In California, water agencies and local producers have several alternatives available to them for the protection of groundwater basins. These include:

1) Litigation and adjudication;
2) Legislation leading to the formation of a groundwater management agency; and,
3) Using provisions of California Water Code §10750 (known as Assembly Bill 3030 or AB 3030).

Litigation is a lengthy, expensive process which does not create any "new" water nor alleviate future economic impacts due to production limitations resulting from court rulings. A groundwater management agency can be created through special legislation at the state level. Such an agency can develop and implement a groundwater management plan and would have the authority to assess replenishment fees and control all pumping within its jurisdiction. However, the formation of such an agency creates yet another layer of bureaucracy and increases costs for local water users.

In contrast, the AB 3030 approach allows existing water agencies and private users to cooperatively develop a management plan tailored to maximize benefits to all users. A plan developed using this approach could protect the historic production levels of private groundwater users, while allowing public agencies to use their facilities and access to supplemental supplies to recharge suitable basins for public use. Over-drafted basins could be protected from uncontrolled pumping without impacting historic private production or recharged using supplemental water from public agencies. Private producers in over-drafted basins who need to increase pumping beyond historic production levels would have the option of participating in a replenishment program and would share the same benefits as public agencies.

There are four major reasons why EMWD took the lead in developing a groundwater management plan. They are:

1) The groundwater subbasins in the management area are unregulated and have no legal means of being protected from over-pumping or from being used by agencies from outside the area other than lengthy and expensive litigation;

2) As a member agency of MWD and as a regional water reclamation agency, EMWD has access to inexpensive supplemental water supplies (reclaimed water and lower-cost, off-season water from MWD), that could be used to replenish local groundwater basins for use by all groundwater producers. These supplemental supplies cannot be fully utilized without an effective management plan in place;

3) EMWD already has in place much of the major regional infrastructure (pipelines, pumping plants, surface storage) that will be required to optimally manage local water resources; and,

4) If EMWD and local groundwater producers fail to develop a management plan, it is probable that state regulatory agencies will do it resulting in a loss of control of local resources.

EMWD, like other water purveyors, was not happy to be in a position where it could be accused of social engineering. However, the District believed it was obligated by its values and beliefs and social responsibility to address the issues of water supply reliability and rising costs in an effort to meet its mission, which is "to provide safe and reliable water and wastewater management services to our community in an economical, efficient, and responsible manner, now and in the future."

STEPS IN THE AB 3030 PROCESS

State Assembly Bill 3030 was passed by the State Legislature in 1992 to encourage local agencies to work cooperatively to manage groundwater resources within their jurisdictions. The process, as now outlined in State Water Code §10750, is as follows:

1. A public hearing on a Resolution of Intent to draft a groundwater management plan is held by the Local Agency.

After the hearing, the Local Agency drafts the Resolution. The Resolution of Intent is published.

2. The Draft Groundwater Management Plan is prepared and must be completed within two years.

3. A second public hearing is held at the time of Plan adoption. Landowners may protest adoption of the Plan. The Plan can be adopted if there is no majority protest. A majority is made up of land owners representing land equaling more than fifty percent of the assessed land valuation in the plan area.

THE WEST SAN JACINTO GROUNDWATER MANAGEMENT PLAN

The Goal of the West San Jacinto Groundwater Basin Management Plan (Plan) is to:

> Maximize the use of groundwater for all beneficial uses in such a way as to lower the cost of water supply and to improve the reliability of the <u>total</u> water supply for <u>all water users</u> in the West San Jacinto Groundwater Basin Management Area.

Criteria for the Plan were developed. The Plan had to meet future water demands; minimize dependence on imported water; provide for adequate, safe water supply quality; minimize cost; and, be implementable.

The Plan area covers some 164,200 acres. Approximately 98,000 acres overlie groundwater subbasins and the remaining 66,200 acres overlie non-waterbearing areas. The Plan area includes approximately 45,200 acres of agricultural land and about 24,700 acres of urbanized land. The total population in the Plan area is approximately 225,000 with most of the population located in the Perris North Subbasin. Figure 2 shows the nine subbasins in the Plan area.

During development of the Plan, cooperative agreements with local water agencies were executed; data was collected and compiled; and a Draft Environmental Impact Report, with public meeting, was completed. Some of the management elements that were incorporated into the Plan follow:

1) Groundwater Basin Manager - the decision-making body for the Plan is the EMWD Board of Directors. They are supported by an Advisory Committee made up of seven members representing the cities, water purveyors, and private groundwater producers.

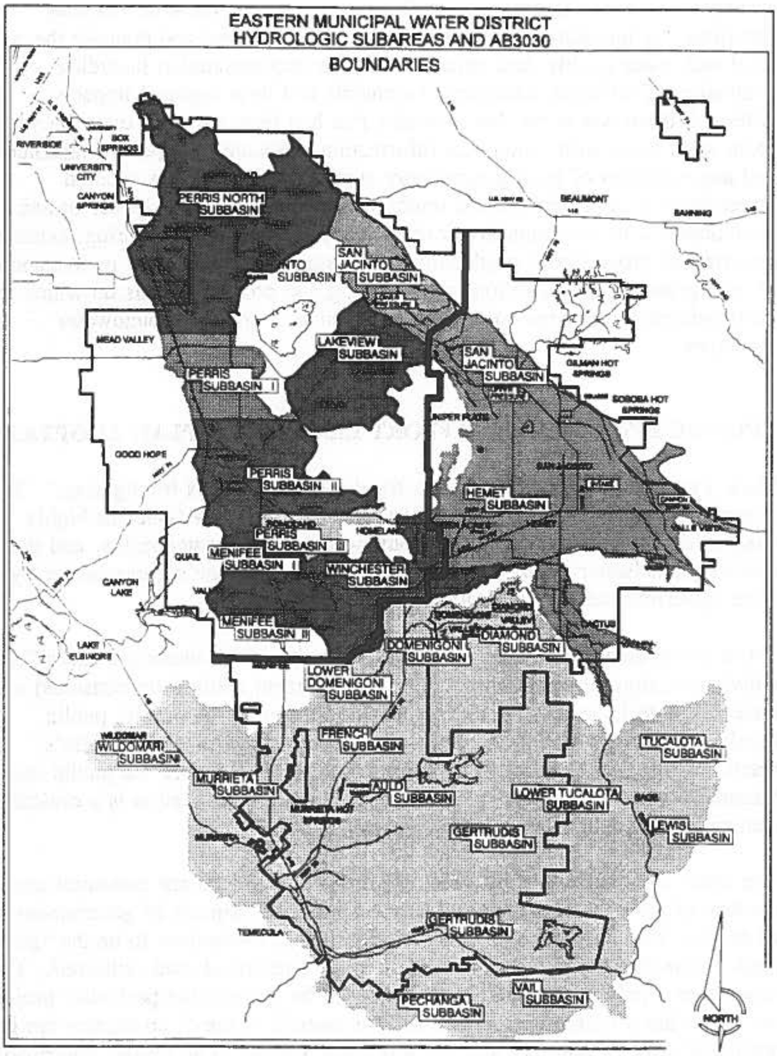

Fig. 2. Groundwater Subbasins in the Management Plan area: Perris North; Perris South I, II, and III; Menifee I and II; Winchester; Lakeview; and San Jacinto Lower Pressure.

2) Groundwater Monitoring - In order to implement any sound groundwater management plan it is necessary to have adequate data on which to base decisions. A monitoring program is necessary to collect and compile the water level and water quality data required for plan implementation including evaluation of different management elements and their regional impacts. Although there was some data available that had been gathered over the years, there were areas with little or no information available. Proper management and augmentation of local groundwater supplies also require a detailed understanding of conditions and trends within the local groundwater basins. In conjunction with the groundwater quality and water level monitoring, accurate metering of groundwater production is necessary to allow for an understanding of how groundwater conditions are changing and provide a basis on which to make informed decisions on how best to manage available groundwater resources.

PUBLIC INVOLVEMENT EFFORT LEADING TO PLAN ADOPTION

Mark Twain once said, "Whiskey is for drinking, water is for fighting." This is certainly true in the arid southwest where there are few issues as highly charged or emotionally intense as groundwater, groundwater rights, and the fear of groundwater management or interference with one's groundwater by some governmental or regulatory agency.

Public involvement is a process, or processes, by which interested and affected individuals, organizations, agencies and government entities are consulted and included in decision-making. In addition to informing the public, public involvement programs solicit community response regarding the public's needs, values, and evaluations of proposed solutions. Before the public can become involved, they must be informed. Therefore, education is a critical element of any public involvement program.

The shifts in social values by which governmental actions are measured and the loss of governmental credibility have affected all aspects of government at all levels. Many agencies, which once considered themselves to be the "good guys," now find themselves being challenged, questioned, and criticized. The benefits of a public involvement program can far surpass the particular project for which the program was designed. The overall image of an agency can be positively affected and the program originator viewed as an aware, concerned, and responsible agency. Additionally, public input can provide unanticipated perspectives and information which can greatly enhance any project. The use of a public involvement program is analogous to preventive medicine. If any proposed project is controversial, or contains potentially misunderstood or controversial elements, the use of a public involvement program can redirect opposition into positive participation.

Initially, public reaction to the proposed groundwater management plan, particularly from the agricultural community, was one of concern and suspicion that the District would try to put a limit on groundwater production by farmers, would try to finance the plan through a replenishment assessment or "pump tax" on groundwater produced, and would try to force the farmers to use lower quality reclaimed water rather than groundwater. Farmers also questioned the reliability of the reclaimed water supply. Although the law only requires two public meetings, one for the Declaration of Notice of Intent and the other at Plan Adoption, EMWD initiated an aggressive public involvement program. Thirty meetings were conducted by EMWD within a twenty-two month period to inform and provide data to the public. Any individual or group that wanted to meet was accorded a meeting. Ten public meetings with presentations were held along with six information workshops and fourteen meetings with cities, agencies, regulators, private groundwater producers, downstream water rights holders, and attorneys. The information workshops provided a forum in which to share the groundwater data developed during the initial stages of development, to test possible elements or concepts to be included in the Plan, and to receive public input regarding concerns, perceptions, and needs. In all, over one hundred interested parties - property owners, cities, agencies, regulators, and attorneys - attended meetings and/or provided comments.

In addition, a programmatic Environmental Impact Report (EIR) was prepared. The rationale for preparing this type of EIR was that it would provide a more comprehensive consideration of environmental effects, mitigation measures and alternative actions than would be practical in each project-specific EIR. The programmatic EIR characterized the overall program, addressing broad policy alternatives and program-wide mitigation measures. It sets the stage for, but does not eliminate, further California Environmental Quality Act reviews. Finally, the programmatic EIR served to give agencies and the public an overview of the entire groundwater management planning process, identifying the key points at which agency and public input will drive the development and implementation of the Plan.

Prior to adoption, the Plan was modified to more accurately address concerns and give farmers written assurance that the Plan did not and would not seek to impose any limit on groundwater production, would not charge a pump tax, that the urban sector would underwrite the costs of implementation, and that participation in the groundwater/reclaimed water exchange program would be voluntary. Finally a Plan evolved that most of the agricultural community supported, some of them enthusiastically. As a result of all of the above, protest at the adoption hearing was minimal, far less than 1%, with only one individual speaking against adoption and many speaking in favor - including the attorney representing the farmers who originally opposed any groundwater management plan. By informing and involving the public, support for the adoption of the Plan was assured and perception of the District as a trustworthy, aware, and concerned service agency was achieved.

PLAN IMPLEMENTATION - THE FIRST YEAR

The Implementation Phase began immediately following adoption of the Plan on June 8, 1995. During the first year of implementation, the Advisory Committee was formed; Guidelines and Procedures to govern the Committee's operation were developed; groundwater subbasins in the plan area were prioritized; an Advisory Committee Newsletter was established; groundwater resources were evaluated and monitoring programs were implemented including groundwater monitoring of water levels in 106 wells semi-annually and water quality in 65 wells annually; the Extraction Monitoring Program was implemented including evaluation and installation of 11 groundwater production meters and reading of those plus eight additional meters and estimation of groundwater production in the remaining wells in the Lakeview Subbasin; the Lakeview Subbasin Interim Stabilization Plan was developed and a working committee was formed; and geophysical and other groundwater-related studies and surveys within the Plan area were compiled and summarized.

Advisory Committee - The Advisory Committee is comprised of one representative each from the Nuevo Water Company, Moreno Valley Mutual Water Company, EMWD, the City of Perris and the City of Moreno Valley; and two members elected by and representing the private groundwater producers. This Committee assures the continued representation of the public and private groundwater producers in the Plan area. Following adoption of Procedures and Guidelines, the Advisory Committee prioritized the nine groundwater subbasins within the Plan area to better focus efforts on Plan implementation. Such prioritization was necessary to be able to address immediate problems with limited financial and personnel resources. The prioritized areas are: A) Lakeview/Nuevo, B) Perris North, C) Perris South, D) Perris South/Winchester, E) San Jacinto Lower Pressure, and F) Sun City/Menifee. See Fig. 3. The Advisory Committee Newsletter keeps private groundwater producers and interested individuals apprised of plan implementation and other issues of interest.

Data Gathering and Research - Groundwater quality for the subbasins was characterized by generating Stiff diagrams of the water quality from the wells sampled in the 1995 Groundwater Monitoring Program. Water levels were measured semi-annually on one hundred and six wells, and sixty-five wells were tested for water quality. Water level and quality (TDS and nitrate-NO_3) contours were prepared from the data collected in that effort. Thirteen lithologic profiles were prepared based on drillers' log information to indicate

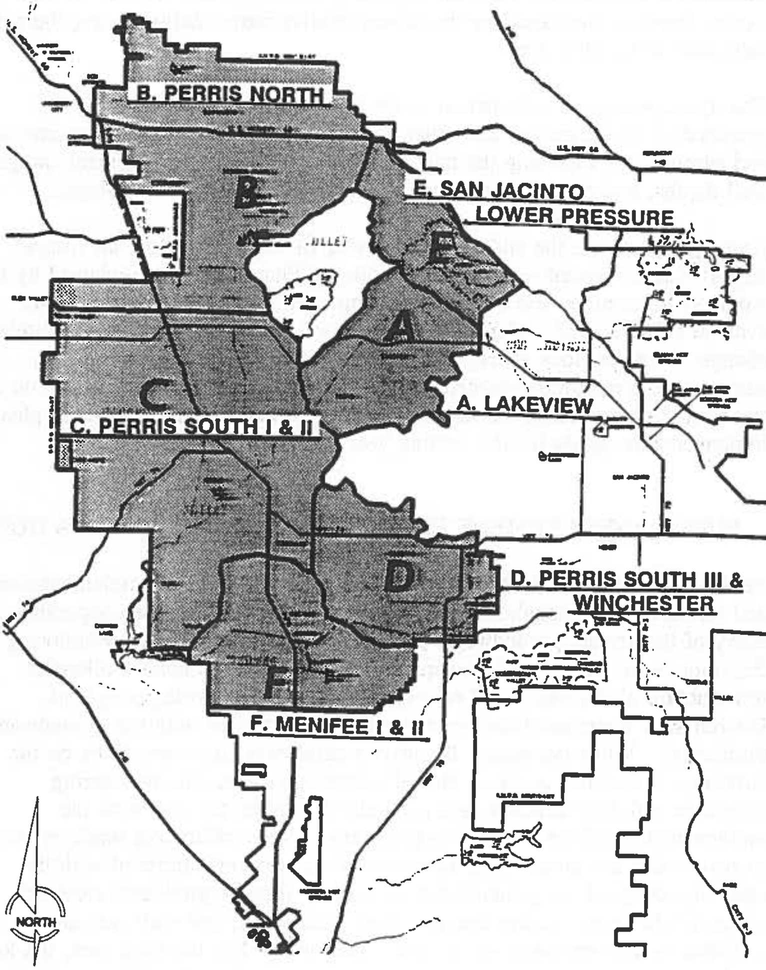

Fig. 3. West San Jacinto Groundwater Basin Management Plan Prioritized Areas: A) Lakeview, B) Perris North, C) Perris South I & II, D) Perris South III and Winchester, E) San Jacinto Lower Pressure, and F) Menifee I & II.

the relative permeability of the groundwater subbasins. The Lakeview Subbasin is estimated to have the highest permeability and the San Jacinto Lower Pressure Subbasin has the lowest relative permeability among the nine subbasins in the Plan area.

The hydrogeological information in the Plan area, based on several geophysical investigations and other groundwater-related studies, was compiled and summarized including the maximum estimated depth to basement, range of well depths, and range of estimated production rates for each subbasin.

<u>Annual Report</u> - At the end of the first year of implementation, an Annual Report was developed in compliance with the Plan and it was reviewed by the Advisory Committee and unanimously approved. The report reviews and evaluates data compiled during the prior year; summarizes groundwater-related changes from previous years, revises groundwater monitoring programs, summarizes groundwater-related studies; provides a technical document on the status of the groundwater subbasins for future planning; and, identifies plan implementation goals for the coming year.

PUBLIC INVOLVEMENT EFFORTS DURING IMPLEMENTATION

Public Involvement efforts continued during the first year of implementation and will continue throughout plan implementation. Getting the cooperation of many of the private groundwater producers in the Groundwater Monitoring Program (water level and water quality) was not too difficult. Following introduction of field staff and education about the monitoring programs, District staff maintained contact and shared information with the groundwater producers. When necessary, the private producers' representatives on the Advisory Committee assisted, shared information about the monitoring programs and their benefits, and generally smoothed the way with the implementation of the monitoring programs. Every effort was made by staff to ensure that the sampling or sounding of wells never interfered with the operating plans of the groundwater producers; that the producers received copies of the water quality analyses from their wells; and staff was always available to answer questions or offer assistance. For the most part, the local producers were cooperative and were pleased to participate. These programs were carried out over the entire Plan area.

The Extraction Monitoring Program proved to be a greater challenge. The program was initiated in the Lakeview/Nuevo area which received the highest priority for action from the Advisory Committee. This was due to the declining water levels, changing hydraulic gradient and expanding groundwater degradation from the adjacent Perris South I Subbasin. In addition to the water quality and water level monitoring, the monitoring of groundwater production was essential to provide information necessary for any future activities in that subbasin. This subbasin covers a little over twenty square miles. A field survey was conducted and twenty-seven production wells were identified. An information meeting was held and all groundwater producers in the area were invited. Presentations on the present conditions in the subbasin, the monitoring programs, the management plan, and groundwater rights were given. The Question and Answer Session was, at times, quite lively. Assurances were made as to the intentions of the District, the voluntary nature of the program was stressed, and private pumpers who had been cooperating with the District in the water level and water quality monitoring programs spoke of their experiences. Options for dealing with this declining and degrading basin were discussed, including the "do nothing" option. As a result, of the twenty-seven wells identified, it was learned that already eight had owner-installed meters, eleven were provided with meters paid for and installed by EMWD, and the remaining eight wells are not metered - either because it was not physically possible to do so or because the well owner chose not to participate. Production from those wells is currently being estimated based on crop and acreage or the number of cows in the case of dairies. District personnel read all the meters monthly, as well as monitor irrigated areas to develop the estimated production figures. Currently, more than 72% of the groundwater production in this subbasin is metered. The voluntary metering and sharing of the production data of the majority of wells in a single subbasin is a rather unique achievement and the data thus gathered is demonstrating that the subbasin is, in fact, over-drafted.

Recommendations resulting from the efforts of the first year include continuing and expanding the Groundwater Quality and Water Level Monitoring Programs by selectively increasing the number of wells; expanding the Extraction Monitoring Program to the Perris North and South I Subbasins; instituting geophysical studies to correlate the data obtained in the existing studies to develop a comprehensive view of the entire Plan area; evaluating Lakeview Subbasin hydrogeologic characteristics; completing development of the Lakeview Interim Stabilization Program; participating in the Mystic Lake management program; identifying potential participants for the Groundwater Exchange Program; using the results of the Reclaimed Water Master Plan currently being developed by EMWD's Planning Department to refine the Groundwater Exchange Program; testing the feasibility of aquifer storage and recovery (ASR) in the Perris South I Subbasin by conducting an ASR demonstration project; and, initiating extraction well site selection for future desalination projects. Implementation of many of these recommendations has already begun and it is anticipated that all will be accomplished. These recommendations are included in the annual report.

The Extraction Monitoring Program in the Perris North and South I subbasins was initiated at the end of 1996. As was done in the Lakeview subbasin, an information meeting for all groundwater producers was held and the Plan, status of the subbasins, and the monitoring programs were described. Information handouts on the Plan, the programs, and groundwater rights were made available. The voluntary nature of the program was stressed. The meeting was a success and meters are currently being installed on wells in the area. At the present time, it appears that over 75% of the groundwater production within the two subbasins will be metered.

To continue public education and participation efforts, the annual report was distributed to all participants in the groundwater monitoring and extraction monitoring programs, as well as to Riverside County's Department of Health Services and Flood Control and Conservation District; California's Regional Water Quality Control Board, Department of Fish and Game, and Department of Water Resources; March Air Force Base; the University of California at Riverside; and, adjacent and downstream water agencies.

CONCLUSION

Benefits of the West San Jacinto Groundwater Management plan include decreased reliance on imported water, cost savings and cost avoidance, potential for creation of "new" water, water quality improvement, protection of local resources, maximization of beneficial use of resources, protection of groundwater rights, and allowing for continuing support of agriculture through the provision of irrigation water. By decreasing local dependence upon imported water supplies, the management area has a more secure, less costly water supply. However, benefits of the Plan reach beyond the local area. Other areas of the state benefit by having that imported supply not used in the management area available for their use. By involving the local communities and respecting and recognizing the land owners and water rights holders, this cooperative effort is assured success. In fact, the Plan efforts have already been recognized as successful as evidenced by the receipt of the California Water Resources Association 1995 Edmund G. "Pat" Brown Water Resources Leadership Award.

The Plan would not currently be in existence nor would it have been successful thus far without the efforts involved in the public involvement program. The focus of the program was on communicating EMWD's willingness to modify the Plan to accommodate the concerns of the private groundwater producers as well as educating the public on the hazards of not implementing a plan. The need for a plan, the problems existing in the groundwater subbasins, anticipated future problems if nothing is done, assurances not to interfere with the rights of the private producers, and the cooperative nature of Plan development were essential. Most importantly, an element of trust was developed and it is considered critical to follow through with implementation in a manner consistent with that trust. Eleven precepts to follow when conducting public meetings developed and they would be of use to anyone, particularly with regard to public meetings on potentially controversial issues.

Always ...

... be completely truthful.
... follow through and do what you say you will do.
... keep focused on the goal of the meeting.
... talk to your audience, not over their heads.
... discuss the "do nothing" option.
... be sympathetic about real or imagined past misdeeds, but keep them in the past.
... give your critics an out, allow them to save face.
... be pleasant, keep a smile on your face, and don't get angry.
... be professional, don't take attacks personally.
... listen, be receptive to better ideas, and be flexible.
... be agreeable to additional meetings with individuals or groups.

The award-winning West San Jacinto Groundwater Management Plan has been successful because of its cooperative nature and because all interested and affected parties were able to provide input that was respected, considered, and frequently implemented. It is an historic development that will ensure water for domestic and agricultural users, help protect the vested interests of existing groundwater producers, provide a framework for new water supply projects for the benefit of the private groundwater producers and the public, and ensure the economic viability of the region.

REFERENCES

Eastern Municipal Water District, Groundwater Management Plan West San Jacinto Groundwater Basin, Draft September 1994, Addendum May 1995, Adopted and Final, June 1995.

------, Environmental Impact Report for the Groundwater Management Plan for the West San Jacinto Groundwater Basin, Draft September 1994, Final June 1995.

------, West San Jacinto Groundwater Basin Management Plan 1995 Annual Report on the Status of the Groundwater Subbasins, October 1996.

COMPETING WATER DEMANDS IN JORDAN:

THE NEED AND OPPORTUNITY FOR IMPROVED WATER MANAGEMENT

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ABSTRACT

Jordan does not have a water supply sufficient for current and future irrigation, domestic, and industrial needs. The Jordan Valley Authority (JVA) provides irrigation water to about 23,000 hectares (57,000 acres) of land in the Jordan Valley where a variety of crops are raised. Water supplied from the Jordan River and its tributaries is limited, and storage is very limited. Domestic and industrial water supplies are also taken from the river, and demands will increase as the population and industrial base expands. Per capita water use is very low, so opportunities to conserve domestic water are limited. Thus the agricultural sector is faced with losing an ever increasing amount of water to domestic and industrial uses; however, much of this water will return to the agricultural sector as treated waste water.

There are several opportunities for improving the efficiency of water use in the Jordan Valley including: rehabilitation of the irrigation water delivery system; improvement of the operation and maintenance of the system; upgrading the skills of JVA operations and maintenance personnel; development of water delivery schedules that are compatible with cropping patterns and on-farm irrigation systems, particularly micro-irrigation systems; providing water of adequate quality for use with micro-irrigation delivery systems; training and providing information and technical assistance to farmers; and assisting in the development of water user organizations.

This paper discusses the activities that are currently underway and are proposed to conserve water in the Jordan Valley.

INTRODUCTION

In 1993, the population of Jordan was about 4,000,000 and water use was estimated as shown in Table 1.

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By the year 2025, the population of Jordan is projected to grow to 12,300,000. In the Amman area, the population is expected to grow from an estimated 1,500,000 in 1993 to 5,360,000 in 2025, with water use increasing from 57 million cubic meters (MCM) (46,000 acre feet) to 266 MCM (216,000 acre feet). While there are alternatives for developing new water supplies for the increased population, they are expensive and/or involve international considerations. There will be continued pressure to reallocate water from irrigation to domestic use, and therefore there will be a need to conserve irrigation water to the extent possible. Fortunately, there are many opportunities for improved water management and water savings in the Jordan Valley. In addition much of the Jordan Valley is ideally situated to receive waste water from the Amman area, so that as Amman obtains additional fresh water supplies and provides adequate waste water treatment, there will be an increasing water supply for the Jordan Valley.

Table 1. Water Use in Jordan in 1993.

Type of Use	Million Cubic Meters	Acre Feet	% of Total Use
Municipal	214	175,000	22
Industrial	33	27,000	3
Livestock	10	8,000	1
Irrigation	726	590,000	74
Total	983	800,000	100

The United States Agency for International Development (USAID) is currently assisting Jordan in water conservation efforts by sponsoring the Water Quality Improvement and Conservation (WQIC) Project. Development Alternatives, Inc. (DAI) is the primary contractor on the WQIC Project, and is working with the JVA to conserve and improve the quality of water delivered for irrigation in the Jordan Valley.

IRRIGATION IN THE JORDAN VALLEY

The Jordan Valley, Figure 1, is Jordan's most important agricultural production area. The area has fertile, flat-lying soils, and varies from 200 to 406 meters (656 to 1332 feet) below sea level. The valley is about 150 km (93 miles) long and varies from 4 km (2.5 miles) to 16 km (10 miles) wide. The mild winters make it an ideal area for growing off-season fruits and vegetables. Crops grown include citrus, banana, many varieties of vegetables, and field crops such as alfalfa and wheat. Irrigable land in the valley totals about 36,000 hectares (89,000 acres), with about 29,000 hectares (72,000 acres) equipped with an irrigation distribution network developed by the Jordan Valley Authority (JVA). About 6,000 hectares

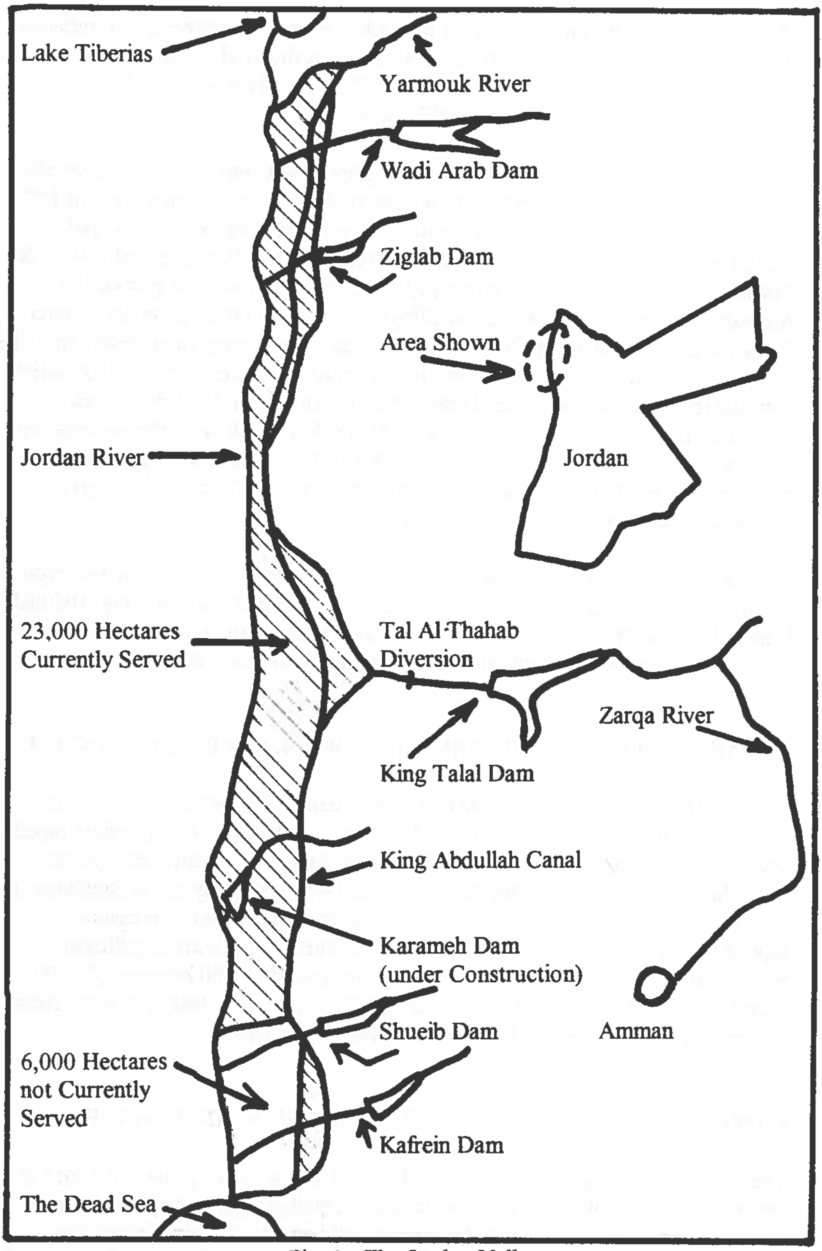

Fig. 1. The Jordan Valley

(15,000 acres) in the southern end of the valley are not currently served, reflecting the scarcity of water in the valley. In 1995 the JVA diverted about 234 MCM (190,000 acre feet) to irrigate the estimated 23,000 hectares (57,000 acres) served, for an average of 1.0 meters (3.3 feet).

The main sources of water for the Jordan Valley include the Yarmouk River, the Zarqa River, and several side wadis. Yarmouk River flows averaging about 100 MCM (81,000 acre feet) per year are diverted into the King Abdullah Canal, including 20 MCM (16,000 acre feet) that are stored and later released from Lake Tiberias. 40 MCM (32,000 acre feet) of the flow in the canal are pumped to Amman for domestic use; the rest is delivered for irrigation in the valley. Zarqa River water is stored in the 75 MCM (61,000 acre feet) King Talal Reservoir. The natural flow in the river averages 65 MCM (53,000 acre feet) per year, but varies considerably from year to year. Treated waste water from the Amman area also flows into the reservoir; the 1994 flow of 51 MCM (41,000 acre feet) is expected to increase to 232 MCM (188,000 acre feet) by 2025. There are small storage reservoirs on Wadi Arab, Wadi Ziglab, Wadi Shueib, and Wadi Kafrein, and diversion structures on other small wadis.

Karameh Dam will be completed in 1997, and will create an off-stream reservoir of 55 MCM (45,000 acre feet) to store winter flows diverted into the King Abdullah Canal. Releases from the reservoir will be used to serve the 6,000 hectares (15,000 acres) in the southern end of the valley that are not yet served.

REHABILITATION OF THE IRRIGATION WATER DELIVERY SYSTEM

Construction of the irrigation system in the Jordan Valley began in 1956. The system was developed as an open canal system. Starting in 1975, pressure pipeline systems were added to serve new areas, and to replace the open canal system. With the exception of the King Abdullah Canal which remains as the backbone of the delivery system, the entire system has now been converted to pressure pipelines, and water savings from reduced seepage and spills are significant. Savings in the North Directorate, where approximately 9,200 hectares (22,700 acres) are served, are estimated to be 20MCM (16,200 acre feet) per year. Similar savings are occurring in the Middle and South Directorates.

IMPROVEMENT OF SYSTEM OPERATION AND MAINTENANCE

There is a need for upgrading the operation and maintenance procedures for the irrigation system. In many cases the pressure pipeline system is operated as if it were an open canal system, and the operational benefits of a pipeline are not realized. Maintenance is carried out on a “repair as needed” basis, the system is allowed to deteriorate until it reaches the point where complete rehabilitation or reconstruction is required. Many of the pipeline accessories, such as pressure control and air relief valves, are in need of overhaul or replacement. Many of the flow meters at the farm turnouts are broken; mostly by debris in the water carried by the pipeline. Another problem area is the poor condition of many of the vehicles and heavy equipment used for day-to-day operation and maintenance activities. There are also existing shortages of some types of vehicles used for daily operation and maintenance.

Studies have shown that the efficiency of the pipeline delivery system is about 70%. This efficiency is based on inaccurate information and is not a true measurement of the physical efficiency of the pipeline. Daily gate opening measurements at the river offtake head works are used to determine inflow to the Zarqa Carriers I and II pipelines. The gates have been through several major repairs and have not been recalibrated for flow measurement, and a daily reading does not adequately account for rise and fall of the river level. Discharges from the pipeline, and billing, are based on measurements of the time between opening and closing the farm turnout valve by JVA field personnel; all farm turnouts have a flow limiting device. The low efficiencies derive because many farmers have illegal keys to the farm turnout control structure and turn on the water after JVA employees finish work for the day. This illegal water is not accounted for in billing and therefore is considered lost water in calculating delivery efficiency. In fact, physical efficiency of the pipelines is significantly higher than 70% and may be close to the desired 90%. However, management efficiency, as measured by the fees collected for delivered water, is low and can be improved.

Operation and maintenance manuals are now being prepared to assist the JVA in providing good operation and maintenance of the rehabilitated irrigation water delivery system. The manuals emphasize regular inspections, preventive maintenance, and proper procedures for operating and maintaining the pressure pipeline system.

UPGRADING THE SKILLS OF JVA OPERATIONS AND MAINTENANCE PERSONNEL

Staff training in operation and maintenance of irrigation water delivery systems is another need that has been identified. In 1995 and 1996 several groups of engineers from the Jordan Valley Authority travelled to the United States for tours of irrigation projects and intensive training on operation and maintenance of pressure pipeline irrigation systems, irrigation water delivery scheduling, and on-farm water management. In November and December 1995 a training program was conducted in the Jordan Valley on Pressure Pipeline Operation and Maintenance. 23 engineers and field supervisors of the JVA attended the program.

The training programs emphasized the need for developing the above mentioned operation and maintenance manuals, and stressed the need for regular inspections, preventive maintenance, and proper procedures for operating and maintaining the pressure pipeline system.

IRRIGATION WATER DELIVERY SCHEDULING

Irrigation water delivery scheduling has the potential for saving a significant amount of water in the Jordan Valley. On-farm irrigation is in transition from surface methods, primarily furrow for vegetables and small basins for orchards, to trickle and micro-spray irrigation. The more modern methods offer savings in labor costs, higher yield potentials (giving higher returns per cubic meter of water used), and less fertilizer and chemical usage. Compared to surface irrigation methods, trickle and micro-spray irrigation offers opportunities for reductions in the volume of water used for a crop because a smaller surface area and soil volume should be wetted at each irrigation.

A baseline survey of irrigation practices in the Central Jordan Valley showed that irrigation water use efficiencies for the "high technology" or trickle irrigation systems are significantly lower than efficiencies for surface irrigation. These low efficiencies are due to several factors, two of which are discussed below.

Currently the irrigation water delivery system is not operated to service on-farm trickle irrigation systems. Trickle irrigation is designed to give the plant a small quantity of water frequently to meet it's transpiration demand. The small quantity of water only wets from to 50% to 60% of the volume of soil containing the roots of the crop, studies have shown that this wetted root volume is sufficient to achieve 100% yield. Therefore, to efficiently use trickle irrigation for some crops, farms must irrigate several times a week during the peak water use period of the crop season. Currently JVA delivers water two times weekly; a schedule suited to surface irrigation at the peak water use period. As a result the farmer is forced to over-irrigate to ensure that enough water is retained in the root zone to carry the plant to the next irrigation period.

Another not insignificant cost to farmers connected directly to the JVA delivery line is the over design of his on-farm delivery system. Because water is delivered twice weekly, the micro irrigation system must have larger main lines to allow irrigation of the entire farm each day water is delivered. All micro irrigation systems evaluated to date have main and submain lines that are significantly oversized, most diameters are double the size that would be needed if demand delivery of water was practiced.

About one half of the farmers have coped with the water delivery schedule by installing reservoirs and pumps to reregulate the water; however in so doing they lose the pressure provided by the pipe delivery system, lose some productive land to the reservoir, and incur fuel and maintenance costs for the pump.

Technical assistance on trickle irrigation system design, installation, and operation is not generally available to the farmers. Most equipment sales agents and manufacturers do not offer no-cost or low-cost services to farmers. It is because of this that most systems are farmer designed. There are private consulting engineers who sell services to wealthier farmers, but most farmers cannot afford to purchase such services. Farmers seeking free or low cost information or assistance in the design and installation of their irrigation system have difficulty in obtaining either. Trickle irrigation is equipment oriented and to achieve high efficiencies of water use requires sophisticated management. As shown in the baseline study, without training and on-going assistance the full benefits from trickle irrigation will not be obtained.

Two pilot study programs are proposed for start-up during the fall 1996 cropping season. An Irrigation Water Delivery Scheduling study will assess the feasibility of JVA changing from the current rotation delivery schedule to a limited-rate on-demand delivery schedule. Under this pilot program farmers will be able to order water for delivery any day and in any quantity, up to a set maximum, throughout the crop season. The total quantity of water used for a crop will not change from current levels, only the water delivery pattern will change. A limited-rate on-demand water delivery pattern is more appropriate for trickle irrigation than is a rotation schedule.

The second pilot program is the establishment of an Irrigation Advisory Service to train and assist farmers in the operation and management of their irrigation systems. The pilot service is envisioned to comprise one junior level field engineer and one supervising engineer from the JVA and one extension agent from the Ministry of Agriculture (MOA). The two pilot programs will work closely together and the primary focus will be the farmers participating in the scheduling pilot program.

QUALITY OF DELIVERED WATER

About 40% of the inflow to the King Talal Reservoir on the Zarqa River is treated municipal waste water from Amman and the surrounding area. The water is high in nutrients and picks up sand and debris as it flow down the Zarqa River to the Tal Al-Thahab intake to the Zarqa Carriers I and II Pipelines. Existing screens and settling basins at the intake are inadequate to remove the algae, moss, and other suspended material in the river. Inspection of non-functioning water meters returned to the JVA workshop shows that trash removal efforts are inadequate. The effect of the trash and debris on drip irrigation systems is also significant.

Those farmers who are using drip irrigation systems use media and screen filters to clean the delivered irrigation water before it is introduced into the lateral lines. However, the smallest media used is about 12.5 mm (0.5 inch) in size and does not remove the smaller inorganic and organic particles. This large media is supplied by companies providing media filters, there are no suppliers of smaller media, though one can find smaller media at crushing plants. In effect, only the large debris is removed from the water, small organic and inorganic particles pass easily through the media filter.

Emitters used typically deliver about 4 liters per hour for vegetable crops, and the small water passages are easily clogged by any sediment or debris in the water. When operated correctly, media filters are ideal for removing organic contaminants, such as algae. Algae is trapped in the upper layers of the filter media bed and removed from the system when the filter is backwashed. Fine inorganic particles are also captured on the upper layers of the bed and in the algae that accumulates on the surface of the filter bed. Screen filters are designed to remove inorganic particles larger than the openings in the screen. When organic material, primarily algae, as well as fine sand are present in the water, and the media filter is not operated properly, screens plug frequently and require manual cleaning. Because it requires frequent cleaning, often the screen element is removed from the filter tank and discarded. The result is that about 75% of all farms experience significant emitter plugging problems beginning the second year of lateral line use.

The Tal Al-Thahab diversion and intake structures on the Zarqa River need to be upgraded to improve the quality of water provided to the JVA distribution system. A bar screen with an automatic power operated rake at the river diversion, enlarged settling basins, and screens below the settling basins need to be installed. Improving the quality of the delivered water would allow farmers to use the proper media sizes in filters and reduce the need for frequent back flushing of media filters and cleaning of screens. USAID and the JVA have agreed to share the cost of rehabilitating this weir. The work is scheduled for completion by the end of 1997.

TRAINING, INFORMATION, AND TECHNICAL ASSISTANCE FOR FARMERS

A lack of training and the unavailability of information on management and maintenance of micro irrigation systems are two reasons the performance of such systems in the Jordan Valley is well below an optimum level. Under the WQIC Project, materials for training farmers and assisting personnel in micro-irrigation system operation and maintenance, on-farm irrigation system management, and irrigation practices and equipment evaluation are being prepared.

The training material is being prepared in a modular format. A total of 20 modules are being prepared in the three areas. Most modules are independent and do not depend upon another for material. This format requires some duplication of material but allows the trainer to select modules to suit the training requirement and time restrictions for a given program.

Currently most farmer are applying quantities based on JVA crop water allocations. These allocations were derived in the early 1960's for surface irrigation and assume average levels of efficiency in water delivery and application and include a leaching factor. Now many on-farm systems are pressurized, application efficiencies are higher, and soil salinities have been reduced. Neither JVA nor farmers take these changes into consideration when determining application amounts. Everyone assumes water applications should be the same as before. Farmers use all the water they can get and complain that they are not getting enough. The end result is significant over irrigation. An example of the significance of the problem is available.

One of the better educated farmers (MS Agronomy) in the Middle Jordan Valley has been cooperating with researchers from the University of Jordan, the work is co-sponsored by the French Mission Règionale Eau Agriculture and the WQIC Project, in determining proper irrigation schedules and application quantities for open field and greenhouse tomato and cucumber crops. The research program is using Water Mark™ soil moisture sensors and Class A evaporation pans to provide the necessary data. In the first crop season the farmer reduced his water use on tomato and cucumber by 50% with no negative effect on crop yields. For a strawberry crop irrigated using Water Mark™ soil moisture information, water use was reduced by 75%.

The cooperating farmer has a new system and high distribution uniformities (>80%). The water use savings derive from using soil-water tensions to indicate plant moisture needs and determine irrigation application schedules. These numbers are indicative of the savings possible when farmers have the information available to allow them to properly operate their on-farm irrigation water application system.

WATER USER ORGANIZATIONS AND ORGANIZATIONAL LINKAGES

A pilot Water User Organization (WUO) is being considered for the Jordan Valley with the following purposes:

- Making bulk sales of water to the head unit on the line;
- Having farmers manage distribution along the line, ending the need for farmers to confirm deliveries individually;
- Assisting users in resolving potential or actual water conflicts on the line;
- Introducing irrigation extension information and/or water conservation measures;
- Working with farmers to produce seasonal cropping plans;
- Assigning JVA staff to work closely with the lateral group, mirroring what was done in the 1960s, before the rapid expansion of the system;
- Providing sensitization and training to both farmers and JVA staff; and
- Assisting with or linking to marketing imperatives.

Sustainable irrigation water conservation can only occur where there is a concerted and co-ordinated effort by all players in the arena. To effectively conserve irrigation water the farmer needs information on daily crop water use, irrigation scheduling, quantities of water to apply at each irrigation, and efficient operation of the irrigation system. At a minimum, programs concerning irrigated agriculture conducted by the JVA, MOA, National Center for Agricultural Research and Technology Transfer (NCARTT), and the universities in Jordan should be co-ordinated. Each organization's contribution can complement input from others to support irrigation water conservation.

CONCLUSION

There are many opportunities for the conservation of irrigation water in the Jordan Valley. The efficiency of the JVA irrigation water delivery system can be increased from about 70% to 90%, distribution uniformity of drip systems can be increased from about 64% to 80%, and crop water applications can be better matched with crop water needs. Taken together, the saved water could exceed 88 MCM (71,000 acre feet) of the current annual water usage in the Valley. The saved water could be used to increase the cropping intensity factor (winter and summer season crops) on existing cultivated lands and to reclaim and bring new land under irrigation.

TRUMBULL BASIN SURFACE WATER MANAGEMENT PLAN

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ABSTRACT

Addressing resource management issues and solving conflicting resource management problems is most effective as a grass roots "bottom up" approach. However, assuring federal and state agency technical specialists support in the process requires high level administrative support for local decision making and empowerment. Even moderately complex resource issues addressed on a small watershed scale require involvement of a broad number of technical disciplines and considerable staff time. Assuring the participation of local citizens requires designing public participation meetings which allow local citizens to participate in developing unique and innovative solutions rather than being asked to evaluate plans prepared by agencies.

The Trumbull Basin Surface Water Management Plan was initiated when the Rainwater Basin Joint Venture approached landowners of a converted wetland basin and asked if they would consider managing spring runoff to create areas of shallow water habitat for migrating waterfowl. Their response "We'll help you with 18 inches of water in the spring if you'll help us deal with the 2 feet that comes in July!" was the basis for a beginning. The planning effort has assembled engineers, conservationists, biologists, and regulatory specialists from state, federal, and local agencies to support the planning process driven by local participation. The effort has integrated water issues dealing with wetland habitat, irrigation water management, and flood control. Perhaps most important, the process has provided a communication avenue where landowners could overlook past animosities and grievances to cooperatively address common problems. As one landowner said "We know the solutions to our problems are simple if we could just sit down and talk about them. If you can help us talk to one another, we're interested."

INTRODUCTION

The general process of developing a resource management plan on a watershed scale has been to identify a problem, submit the problem to the local people, ask them if it is a problem they would like solved, and then return at a later date (sometimes much later) with several alternative solutions for them to select from. Most of the decisions which formulated the plan were made in an agency planning office far away from the problem and the people. The alternatives were developed by people who were not familiar with the specific features of the landscape but applied planning alternatives which had been developed on similar problems. The

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local people did not have opportunities for reviews of the process, but only a review of the product. Their decisions where about which alternative to select rather than what alternatives should be considered. Science was integrated in the process by professional planners who were trained to include science and technical information in the plan development. As resource planning changes to a locally driven process with landowner involvement in every phase of plan development, what is the avenue or vehicle to bring technical information and science to the table? As planning moves from the office to the field and from interdisciplinary day long meetings to evening meetings in cafe meeting rooms, how is technical information exchanged with those landowners who will be involved in making planning decisions?

If developing resource plans is going to change from an effort done primarily by agency professional for local people to planning done by local people with support from agency professionals, the transition will require many changes in communication methods, plan development processes, the locations where meetings are held, and the time of day when people meet. The planning arena will move from the government offices to the local meeting rooms. Meetings schedules will compete with planting, cultivation, and irrigation demands as well as social and business commitments. Information will need to be presented quickly and succinctly with follow-up to assure understanding. Timelines will be shorter with more urgency for completion and accountability will increase. This transition is happening as local people become more involved in the decisions which affect them and their environment. The smoothness and efficiency of the transition will be helped by everyone, private citizen and government employees, recognizing that the planning process provides opportunities and invitations to participate but can not demand it. Science, technical information, and local involvement will be in the mix as long as someone recognizes the opportunity and brings these elements to the planning table.

TRUMBULL BASIN

The Trumbull/Hansen Basin is located in northeast Hall County in South Central NE. The basin is essentially a 1800 acre oblong windblown depression lying north-south in the landscape. Runoff from the upland landscape ends up in the lowest elevations of the basin bowl with the bottom of the bowl being 500 acres in size. Once the water level in the basin gets high enough it spills out the southeast side of the basin and travels two miles to the West Fork of the Big Blue River.

Long ago, the bottom of the basin was a 400 acre semi-permanent and permanent wetland. Extensive modifications in the basin have been done to convert much of the wetland area to cropland. Landowners have built dikes to direct water and built above ground storage pits to store water pumped from cropland areas. Eight landowners farm in the basin bottom. Each has methods to deal with the water that runs onto their property, but there is no comprehensive strategy to deal with the water. When the watershed is hit with a large rain, crops are flooded because there is limited storage and little opportunity to move water through the basin. Downstream landowners have erosion and field saturation problems from prolonged flow of overflow runoff.

INITIATING THE PROCESS

In the late winter of 1995, the Rainwater Basin Joint Venture approached the landowners to discuss the situation in the basin. The Joint Venture was interested in whether there was any potential for creation of temporary migratory habitat in the basin during the late winter before crops were planted. The results of the discussion was that the farmers and landowners were willing to discuss creating seasonal wetland habitat for migrating waterfowl if the Joint Venture would find someone who would help them solve problems associated with flooding of cropland, shortage of irrigation water due to low yielding irrigation wells, erosion control problems downstream of the basin outlet, and create a forum where the landowners could get together to discuss common sense solutions to common problems.

Before the Joint Venture was willing to proceed, they needed to hear from a larger audience of landowners to see if a representative number would be willing to work on developing the plan. After sparse attendance at a meeting (which was scheduled two weeks in advance and ended up being a beautiful and mild winter day) a landowner suggested the meeting be called the day after the next heavy rain and that the meeting be held early in the morning so breakfast could also be taken care of. A calling tree was set up among three agency people so that all of the landowners could be informed quickly the next time it rained. Twelve landowners and farmers attended the breakfast meeting. The issues the farmers wanted addresses were reviewed. The Joint Venture agreed to help assemble those agencies and specialists and guide the development of a Surface Water management Plan IF the landowners would promise that they would be active participates in the process. The agreement would mean they would commit to the time it would take to develop the plan. The landowners unanimously agreed to be a part of the planning process.

The Joint Venture recognized that this type of interactive planning involving agencies and landowners had not been done to often in Nebraska. It was also recognized that the landowners had put their trust in the joint Venture to oversee a process in which they would participate equally with agency personnel in making planning decisions. The effort was a high risk endeavor for which there would be no second chances if someone felt they were not being given equal opportunity or treated fairly.

MEETING DESIGN & FACILITATION

The Heartland Center for Leadership Development is a non-profit Community and Regional Planning consultant which provides assistance to communities for developing strategic plans. The Joint Venture asked Heartland to adapt processes normally used by communities developing plans addressing urban issues to a rural situation where farmers and landowners would develop a strategic plan to address resource and farm economics issues. A Natural Resources Conservation Service Grant arranged through the Great Plains Partnership and a grant from the Nebraska Environmental Trust paid for the Heartland Centers services.

DEVELOPING THE PLAN

Issues and needs for the watershed were developed with two separate methods. A telephone interview was used to question 24 agency representatives on which needs and issues should be addresses in a strategic plan, what roadblocks they might anticipate in developing the plan, what strengths their agency could bring to the planning process, and what they might anticipate as a final outcome. The landowners and farmers were asked the same questions at an evening "town hall" meeting and their ideas and opinions were gathered through conversation. The two lists were combined so that the issues and needs could be prioritized.

Meanwhile, the Joint Venture was promoting the planning effort to agencies as the type of effort which was being discussed throughout government. The plan was broad based and not single issue, involved local people in the processes, was targeted to a geographical area, and required a committed partnership. However, many agencies had a difficult time figuring out how they fit into the process. They understood how to develop a plan when they were the primary provider. But how they would function in a support role for an effort conducted in the field was not clear to them. The Joint Venture had concerns that a lack of involvement by agencies in the planning process could result in implementation roadblocks because all of the bases had not been covered in the plan. Rather than slow the planning process to allow time for agencies to digest the process and then participate, an effort was made to assure that field level agency representatives were informed and would attend planning meetings. Agencies were not recognizing the invitations to participate as opportunities to bring their concerns and issues to the discussion but were evaluating the invitation as to whether it was an obligation to participate and what commitments the obligation would bring.

An evening meeting for both agencies and landowners was held November 20, 1995. The three hour meeting was devoted to developing a Vision Statement for the planning effort and to prioritize the issues developed from the telephone interviews and landowner meeting.

Hansen/Trumbull Basin Vision

> A water management plan for the basin will be developed by landowners with the cooperation and participation o federal, state, and local agencies. Implementation of this plan will result in improved water management throughout the watershed which will increase wildlife habitat, sediment and erosion control, and irrigation water availability, while reducing flood damages and economic risk. Land and water management will benefit waterfowl during the migration season and farming during the cropping season with management solutions compatible with farming and wildlife.

The following results of the prioritization are listed as issues(votes): Wildlife Habitat -migratory waterfowl (14); Water Management -depth, flooding, erosion (12); Economics -effect of solution on neighboring landowners especially downstream (13); Water Management - use, irrigation, alternative uses (8); Ongoing management - county maintenance of flood management systems, fixing culverts, raising road, cleaning ditches, (8); Wetland Preservation (7); Water Management - duration, drainage (6); Water Management -storage (5); Economics - compensation(2); Economics -land values(2); Economics -taxation(0); Ongoing

Management -transfer of ownership of land(0); Ongoing Management - transportation, roads(0)

Agency participation at planning sessions gradually increased. Some of this increase was due to the extensive mailing list which grew in an effort to keep people informed of the progress and future plans. This effort resulted in a gain of credibility for the planning process by landowners and agencies. People who couldn't attend meetings because of conflicts were genuinely apologetic and emphasized that they knew the effort was important and the process could serve as a model for future planning efforts. Both landowners and agencies began to see that preconceptions about how others would participate were wrong. Initially, agency people asked if landowners would really consider anything except economics in their decisions while farmers wondered if agencies could consider anything but the environment. Both groups witnessed the other placing votes next to issues which were also important to them. These experiences elevated the trust that each group was putting a sincere effort into looking at the water management plan as a broad effort working toward mutual benefits.

A January 10th meeting was devoted to developing goals addressing the priority issues and to develop strategies toward accomplishing the goals. The dialogue during this meeting also surprised some as landowners discussed the pros and cons of pumping scarce groundwater to create late winter migratory habitat in dry years. At one point a landowner also expressed concern about developing a plan without input from agencies knowledgeable about wetland rules and regulations. The landowner wanted assurances that there were agencies present who could help address regulatory issues during the process to avoid problems during implementation. These conversations showed that the group was coming together to the point that concerns and issues were no longer "landowner" or "agency" but were indeed concerns of the entire planning group.

The meeting was preceded by a tour of the watershed for the benefit of those who were not from the area. Landowners were asked to explain the present methods of water movement and management. The problems were described and potential solutions mentioned though not discussed in detail. During the tour some of the solutions which would mutually benefit landowners became evident as well as irrigation water storage and wetland habitat compatibility. Many landowners and tenants were on the tour who had not attended meetings. At the tour conclusion they asked where the effort was heading. The Joint Venture Coordinator reviewed the concept of local people involved in developing solutions to their own problems in concert with agencies. The outcome of the plan will reflect the local participation because the best solutions will come from those people most familiar with the problem. The planning effort was not intended to make everything in the basin perfect but to make most things better.

Goals were developed to address the high and medium priority issues. Small breakout groups brainstormed goals for each issue. The goals identified concepts which would address issues. For example, two goals under the Migratory Wildlife Habitat issue are "Manage water depth with storage and runoff" and "Provide wetland habitat" . Goals under the Water Management Storage issues included "Develop Downstream Reservoir" and "Increase Ability to Move Water". The breakout groups were organized so that each had representation from wildlife agency, regulatory agency, and landowners. The balance helped to develop goals without the large group becoming bogged down in the process. Seventeen goals were developed for the eight priority issues.

Strategies, or Action Items, were then developed to describe what actions were required to accomplish the goals. The brainstorming breakout groups developed fifty three (53) strategies which included what was to be done, who (which agency) should do it, and a date by which it should be accomplished.

The Issues, Goals, and Strategies were then sent to the agencies for review. It was explained that they were developed by the planning group as suggestions. Each agency was charged with determining if the assigned strategy was something they could or should do. If not, they could recommend an alternative group or agency.

This step in the process was where the "bottom up' approach blended with the "top down" agency structure. The agency administrators now had concrete requests from the local group. Up to this point, many had maintained an arms length from commitment because it was unclear as to what would be required. The Strategies listed specific requests which the agencies could either commit to doing, decline, or agree to share specific requests without agreeing to all of them. In addition, the decision was taken to the lowest administrative level. Those requests which could be addressed by field staff were answered at that level. Requests which needed additional support from "above" were referred up.

The next meeting was held in the late spring and provided for agency feedback to the support requested through the Strategies. It was a relatively simple matter to go through the list and note whether the agency agreed to the request, denied, or suggested a modification where they would share the commitment with another. At this same meeting a timeline was developed which anticipated when items would be completed and the plan implemented. The next meeting was planned for after harvest. The summer would be used to develop inventories and designs as listed in the strategies.

One of the significant events at this meeting symbolized the coming together of the landowners and agencies in the planning effort. The landowners recognized the commitment of the agencies through the adoption of the assigned strategies. They suggested that it was time for the landowners to re-commit to the planning process and implementation. They asked the Joint Venture Coordinator to contact each landowner in the watershed and ask them to sign the Vision Statement as a symbol of their continued support. Only after a significant number of the landowners had signed did they recommend proceeding with the strategies.

A Geographical Information System (GIS) was used to prepare maps which located potential temporary shallow water habitat areas along with surface acres and water volumes. In addition, existing surface water storage facility capacities were calculated and compared against the 2, 5, and 10 year frequency runoff events. The obligation of the Joint Venture was to address the landowners problems first .and to not forget that "We'll help you with 18 inches of water in the spring if you'll help us deal with the 2 feet that comes in July!" was the basis for a beginning of the plan development.

One of the benefits which wetlands provide is flood protection. A concept for using an 80 acre hydric soil tract for storing storm runoff became the cornerstone for providing summer flood protection. A large percentage of the watershed runoff could be directed to the tract for storage. In addition, spring runoff could be moved to the tract after waterfowl migration to assure extended benefits for other migrants and wildlife. The affected landowner was interested in discussing the alternative further since the land had been in a Waterbank Contract and was not integrated into the farming operation. An evaluation of the affect of additional water on the wetland wildlife functions was done by wildlife agency biologists.

An inventory of potential migratory waterfowl shallow water habitat sites was developed using the elevation survey and GIS. Ten potential sites could provide 159.3 acres of shallow water habitat. This does not include the 80 acres which would provide year round wetland benefits.

WHERE TO FROM HERE?

The planning effort is not finished. This narrative has taken us to the present. Completion of the plan is expected early 1997. The Trumbull/Hansen Basin has been selected by the Natural Resources Conservation Service as a multi-farm and multi-resource planning pilot. The selection will bring resources and emphasis to the implementation of the finished plan. Once the storm-water storage concept is designed, the NRCS will develop individual plans with landowners. The landowners will mesh their irrigation water management, shallow water habitat, and storm runoff with the overall plan. Once completed, a comprehensive surface water management plan will be in place for the watershed.

A three person steering committee will direct the implementation phase to assure the Vision developed by the planers is realized. The implementation will be monitored by the people involved in writing the plan to assure the issues and needs are addressed. A sketchy process has been outlined to assure this but we must also be flexible, vigilant, and ready to react to changes. The planning process has been a truly learning experience to this point and we know we have much to learn in the future.

COMPETITION IN THE SAN JUAN RIVER BASIN

Rick L. Gold[1] Errol Jensen[2]

ABSTRACT

The San Juan River Basin (Basin) located in southwest Colorado, northwest New Mexico, northeast Arizona, and southeast Utah is becoming a classic case study in conflicting demands for the available water supply. At work in the Basin are the conflicts among the existing historic users, the settlement of the Native American claims of the four tribes, the future growth needs, and the soon-to-be identified needs of two endangered fish. The solutions to managing these competing demands must all be made within the States' allocations within the Upper Colorado River Basin Compact and within the supplies of the San Juan River and its tributaries. The developments of the Basin have occurred primarily since the early 1900's while the reservations of the tribes of the Basin were established in about 1863. These 1863 beginnings for the reservations provide an early priority date compared to almost all of the non-Indian rights. Ongoing Indian projects and settlement implementations are being challenged by the contemporary consideration of the needs of the Colorado squawfish and razorback sucker and their critical habitat. The implementation of the Endangered Species Act (ESA) in the Basin is characterized by section 7 consultations on the Navajo Indian Irrigation Project (NIIP) and the Animas-La Plata Project (ALP) which have both resulted in Reasonable and Prudent Alternatives to avoid jeopardy that have limited the amount of water which can be depleted. A research period is nearing completion which will determine the needs of the endangered fish with the expectation being that once that task is complete, the additional water not needed for the fish will be available for the remainder of these two projects and the other future needs of the Basin. Pending the outcome of the research, there is much anticipation in the Basin about the ultimate resolution and the interaction of the various priorities in any final solution.

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THE ISSUE

There are a number of likely volatile and sensitive issues that will stem from the dilemmas in the Basin. We expect this Basin to become one of the most contentious in the Western States. Of primary concern is the issue of the needs of the endangered fish and the potential rights of the tribes in the Basin. When the tribes complete their planned (or reserved right based) developments, the additional water supply needed, while maintaining the viability of the endangered fish, will likely have to come from current users. This process may be possible, but could be very expensive for the United States and may not be an effective way to transfer water from the existing users to the tribal citizens of the States.

The basic issue at this point is that there does not appear to be sufficient water available within the Basin to allow current and planned depletions to take place and still recover the two endangered fish and protect their critical habitat. This dilemma does not address the potential need for additional water supplies to sustain any additional growth anticipated by any of the States or tribes of the Basin. This problem is at the center of many current and future issues in the Basin.

BASIN BACKGROUND

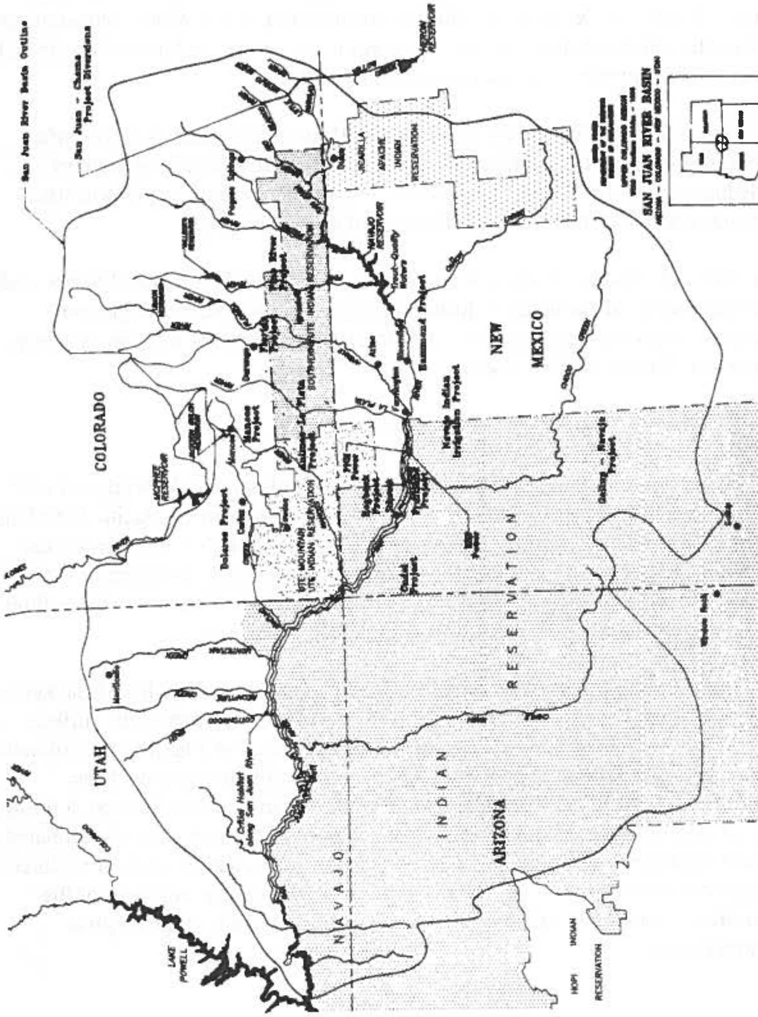
Location

The Basin is located in the Four Corners area of Arizona, Colorado, New Mexico, and Utah (see map on following page). The Basin extends approximately 250 miles east and west and 160 miles north and south. The New Mexico portion comprises 39 percent of the Basin, slightly more than 23 percent of the Basin is within Colorado. Arizona has a little over 20 percent of the area of the Basin with the remaining 18 percent in Utah.

The Basin drains an area of approximately 25,000 square miles, an area equal to West Virginia and makes up about one-fourth of the Upper Colorado River Basin. The San Juan River is the second largest tributary to the Colorado River. Its source is on the Continental Divide in southern Colorado, and it flows approximately 350 river miles westerly to its confluence with Lake Powell.

Climate

The climate of the Basin varies from alpine in the high mountains to desert at the low elevations. The higher part of the Basin is in Colorado with more than 30


San Juan River Basin Outline
San Juan - Chama Project Diversions
COLORADO
UTAH
NEW MEXICO
ARIZONA
NAVAJO INDIAN RESERVATION
SOUTHERN UTE INDIAN RESERVATION
UTE MOUNTAIN UTE INDIAN RESERVATION
JICARILLA APACHE INDIAN RESERVATION
NAVAJO RESERVOIR
HERON RESERVOIR
LAKE POWELL
HOPI INDIAN RESERVATION
Dolores Project
Animas - La Plata Project
Navajo Indian Irrigation Project
Hammond Project
Gallup - Navajo Project
Critical Habitat along San Juan River
Window Rock
SAN JUAN RIVER BASIN

peaks of the San Juan Mountains ranging from 12,000 to over 14,000 feet elevation. The lowest elevation of the Basin is at the confluence of San Juan River with Lake Powell, approximately 3,700 feet above sea level. The areas above 10,000 feet elevation have higher precipitation, lower winter temperatures and cooler summer temperatures. The areas under 7,000 feet have relatively mild winters, hot summers, and low precipitation.

The wide range of climatic conditions in the Basin has resulted in a diversified agriculture ranging from alfalfa, grass hay, and pasture at locations of short growing seasons and cooler temperatures to corn, small grain, dry beans, truck gardens, orchards, and melons in the areas of milder climates.

The Basin has several developed recreations areas, including national forest lands, national parks and monuments, historical and scenic locations, and private recreation sites and developments. The tourist and recreation industry is a very important element in the economy.

Minerals

Natural gas, crude oil, uranium, vanadium, zinc, lead, sand and gravel, and coal are the most important minerals being currently produced in the Basin. Petroleum products, including helium as well as natural gas and crude oil, account for the largest percentage of this production. The total natural gas resources of the Basin have been estimated at about 12 trillion cubic feet. The associated helium resources have been estimated at about 13 billion cubic feet.

The coal resources (mineable) of the Basin are located mainly in the Mesa Verde group of Upper Cretaceous Age which is at or within 3,000 feet of the surface around the margins of the San Juan structural basin in New Mexico and Colorado. A total of 9,646 million tons of bituminous coal is estimated to have been originally present in the Colorado portion of the Basin. In New Mexico, 4 billion tons of bituminous coal and 28 billion tons of sub-bituminous coal are estimated to have been originally present. In Colorado and Utah, additional coal resources are present as thin beds in the Dakota formation, but no firm estimates of the quantities present are available. At present coal production in the Basin is relatively low.

Land

The Basin has four Indian reservations which are prominent in the land ownership pattern of the Basin. The lands of the Navajo Nation include about 11,550 square miles and extend into New Mexico, Arizona, and Utah. The Ute Mountain Ute Indian land is composed of about 890 square miles in Colorado and New Mexico.

The Southern Ute Indian land is composed of 470 square miles in Colorado. Jicarilla Apache land area occupies about 960 square miles in New Mexico. Approximately 60 percent of the land in the Basin is owned by the four Indian Tribes. The private non-Indian land is 13.1 percent of the Basin total and is in all States except Arizona. All Basin lands in Arizona are Tribal lands. State and local government land is 2.9 percent of the Basin total with the majority being State land.

Federal land is administered by the Bureau of Land Management, Forest Service, and National Park Service. Forest Service land in the Basin includes a large part of the San Juan National Forest in Colorado, portions of the Carson and Santa Fe National Forests in New Mexico, and a portion of Manti-La Sal National Forest in Utah.

National Park land is composed of Mesa Verde National Park, Yucca House National Monument, and a portion of Hovenweep National Monument in Colorado. In New Mexico, the National Park Service has Aztec Ruins and Chaco Canyon National Monuments. In Arizona, National Park Service areas include a portion of Navajo National Monument, and all of Canyon de Chelly National Monument. However, the Canyon de Chelly land area is considered in Navajo Indian ownership. In Utah, a small number of acres of Natural Bridges and Hovenweep National Monuments are in the Basin.

Water

Annual precipitation varies considerably with elevation. Average values range from 50 inches in the high slopes of the San Juan Mountains to 6 inches near Mexican Hat at the confluence of the San Juan River with the Colorado River. The San Juan River and its principal tributaries, the Navajo, Piedra, Mancos, Los Pinos (Pine), Animas, and La Plata Rivers, originate in the high slopes of the San Juan Mountains. Several other tributaries drain large areas but contribute little to sustained stream flow. Less than 20 percent of the Basin area produces more than 90 percent of the water supply.

High spring runoff months of April through June produce more than 56 percent of the stream discharge from the Basin. This results from melting winter snowpacks which accumulate during October through April.

There is considerable variation of annual discharge over a period of years. For example, a discharge rate of 1,300 cubic feet per second (cfs) is equaled or exceeded 50 percent of the time at the San Juan River near Bluff, Utah, whereby a discharge of 600 cfs is equaled or exceeded 80 percent of the time. Surface runoff is the major component of the water supply and accounts for 98 percent of the water used.

At its confluence with Lake Powell, the San Juan River produces an average of about 2 million acre-feet of natural flow. About half of this amount is controlled upstream by Navajo Dam. While this is a relatively small part of the 15 million acre-feet of Upper Basin flow at Lee Ferry, the San Juan is the source of all New Mexico's use of Colorado River water.

NAVAJO DAM AND RESERVOIR

The primary storage facility on the San Juan River is Navajo Dam and Reservoir. This dam was authorized as one of the initial units of the Colorado River Storage Project in the 1956 Act. The dam is 402 feet high and 2,566 feet long and has a total storage capacity of 1,708,600 acre feet. Construction was complete in 1963 and the dam and reservoir is truly the quintessential cornerstone of the future potential management options in the San Juan River Basin. Navajo Dam plays a critical role in providing an assured water supply for the Navajo Indian Irrigation Project, as well as allowing for contracting for municipal and industrial water within the basin.

Water users, such as the Navajo Indian Irrigation Project, San Juan-Chama Project, Animas-La Plata Project, and municipal and industrial uses along the river, all depend on both the natural runoff and on the regulation of Navajo Reservoir. Their use is constrained by historical compacts and statutes, primarily the Colorado River Compact and the Upper Colorado River Basin Compact. The former allocated the flow at Lees Ferry between the Upper and Lower Basins while the latter divided the Upper Basin allocation.

COMPACT AND CURRENT USE

While the primary water supplies between the upper and lower basin are allocated in the Colorado River Compact of 1922, the supplies of the upper basin are further allocated in the 1948 Upper Colorado River Basin Compact. Within that compact the State of Colorado is allocated 51.75 percent, Utah is allocated 23 percent, Wyoming is allocated 14 percent, New Mexico is allocated 11.25 percent, and Arizona is allocated 50,000 acre feet of water per annum.

Current levels of development are characterized by total depletions in the New Mexico portion of the basin of about 500,000 acre feet. This is made up of all of the historic private development in the basin plus the State, Federal, and tribal development projects. It also includes contracts in place for municipal and industrial use, as well as for reservoir evaporation.

KEY ISSUES OF COMPETITION

While the construction of Navajo Dam was essential for the development of water storage and flood control that construction and operation altered the natural river ecosystem. Natural riverine habitats were altered and migration routes were blocked.

These physical and biological changes to the environment led to the endangerment of four native fish species in the San Juan River, two of which currently inhabit the San Juan River (Colorado squawfish and razorback sucker) and two that may have historically occupied the river (bonytail and humpback chub).

The Colorado squawfish and the razorback sucker were listed, respectively, in 1967 and 1991 as endangered. As required under section 7 of the ESA, all actions of Federal agencies that may affect these listed species must undergo consultation with the U.S. Fish and Wildlife Service (Service). This is to ensure that actions undertaken by a Federal agency are not likely to jeopardize the continued existence of listed species.
The San Juan River Basin Recovery Implementation Program was developed as a cooperative effort of the: Bureau of Reclamation, Bureau of Indian Affairs, and Service; States of Colorado, New Mexico, and Utah; and Navajo Nation, Southern Ute Indian, Ute Mountain Ute, and Jicarilla Apache Tribes. In late 1992, a cooperative agreement was entered into by most of the above parties to establish the foundation for a long-term program to recover the endangered fish species of the Basin. The signatories to the Cooperative Agreement agreed to participate in and support the San Juan River Basin Recovery Implementation Program, including the committees established by the program. The effective date of this Cooperative Agreement was November 1, 1992, and will remain in effect for a period of 15 years.

Endangered fish concerns have increased the pressure on the San Juan River water supply. Proposals to release large amounts of water in the spring from Navajo Dam would reduce the water available in storage for delivery to Navajo Indian Irrigation Project and other downstream users. Instream flow requirements may not, per se, reduce the allowable consumptive use in the Basin but may well lead to a situation requiring significant compromise and discussion about meeting the needs of all the uses in the Basin, including instream flow needs. Clearly, those uses which depend on Navajo Dam releases, such as Navajo Indian Irrigation Project, are at the greatest risk due to the endangered fish instream flow requirements.

Native American Rights

For most of its path from Navajo Dam to Lake Powell, the San Juan River either flows through or forms the northern boundary of the Navajo Nation. The San Juan River represents a critical resource for the Navajo Nation. Their reserved water rights in the Basin have not been quantified.

Under various legal doctrines including the reserved water rights doctrine Winters v. United States, the Navajo Nation claims sufficient water from the San Juan River necessary to create a permanent homeland for the Navajo people. Pursuant to legal precedent in Arizona v. California, the Navajo Nation possesses sufficient "practicably irrigable acreage" within the Basin to fully utilize the entire flow of the San Juan River. The Navajo Nation believes that the provisions of the Upper Colorado River Basin Compact of 1948 cannot diminish or constrain its water rights. They assert a claim to the river in New Mexico that exceeds New Mexico's Compact allocation of 669,500 acre-feet.

The Navajo Nation claims that the amount of water congressionally authorized to be diverted annually for the NIIP for irrigation, municipal, industrial, and recreational purposes is 508,000 acre-feet. Due to NIIP being redesigned for pivot sprinklers, the total amount of water estimated to be depleted annually under full project development is 267,000 acre-feet. The Navajo Nation maintains that the difference of about 250,000 acre-feet is still authorized for their municipal, industrial, and recreational uses. This is one of the reasons they oppose the commitment to the release of water from Navajo Dam to mimic the natural hydrograph of the river. They claim that there is not "excess water" stored in Navajo Dam and that water stored there includes water reserved for full development of the NIIP and to the Navajo Nation as part of its claim to the paramount water right in the San Juan River.

The Navajo Nation asserts that any large-scale water development in the Basin could adversely affect their ability to fully develop their water resources. They support the ability of the Colorado Ute Tribes to fully exercise their water rights secured by the Colorado Ute Indian Water Rights Settlement Act. Although they have never actively supported the ALP Project, they fully support and encourage the implementation of the Settlement Act and the delivery of water to the Colorado Ute Tribes as promised by the United States.

Until a decision is made on the quantification of Navajo Nation water rights, development and use of the available water will continue. However, if and when quantification does occur through negotiation or litigation and the Navajo Nation reserved water rights are quantified with the most senior priority date on the river, many of the junior water users could be without a dependable water supply. The priority date could be based on the establishment of the reservation which occurred in 1868, prior to most of the non-Indian development in the Basin.

In June 1986, the United States, the State of Colorado, Ute Mountain Ute Tribe, Southern Ute Indian Tribe, and certain non-Indian water users were successful in reaching an Agreement in Principle Concerning the Colorado Ute Indian Water Rights Settlement and Binding Agreement for Animas-La Plata Cost Sharing (Cost Sharing Agreement). Continued negotiation led to the December 10, 1986, Colorado Ute Indian Water Rights Final Settlement Agreement (Settlement Agreement). The Ute Mountain Ute and Southern Ute Indian Tribes, by resolution of their respective Tribal councils, approved the Settlement Agreement and sought Federal implementation of its terms. Special legislation, the Colorado Ute Indian Water Rights Settlement Act (Settlement Act), Public Law 100-585, implementing the Settlement Agreement, was enacted by the U.S. Congress on November 3, 1988.

The Settlement Act was the culminating event of years of effort and negotiation by the Tribes and non-Indian water users to settle outstanding water rights claims by the Tribes in the Animas and La Plata Rivers drainages, as well as in other rivers and streams arising on or flowing through the Tribal reservations in Colorado.

The Colorado Ute Indian reservations were created in 1868, and as such, the Tribes have a priority date for their water rights that precedes the priority dates for most, if not all, of the non-Indian water rights. In the absence of the Settlement Act, development of senior Tribal water rights claims could adversely impact non-Indian water rights and users, including cities and municipalities, throughout southwestern Colorado and northwest New Mexico.

The Settlement Act mandates delivery of Animas-La Plata Project water to the Tribes by January 1, 2000, to avoid future litigation or renegotiation of Tribal water rights claims. Final settlement of the Tribes' reserved water rights claims on the Animas and La Plata Rivers is subject to the following conditions in the Settlement Act:

- Ridges Basin Reservoir, Long Hollow Tunnel, and Dry Side Canal to the turnout to Dry Side Lateral are to be completed so as to enable delivery of water to the Tribes on or before January 1, 2000.

- If those features are not completed by January 1, 2000, then by January 1, 2005, the Tribes must elect to either retain the Project water rights or commence litigation or renegotiation of their pending reserved water rights claims.

The provisions of the Settlement Act satisfy the water rights claims of both Tribes. A portion of the Ute Mountain Ute water rights claim is settled by development of water in McPhee Reservoir and the construction of the Towaoc-Highline Canal, features of the Dolores Project.
Final consent decrees, which implemented certain provisions of the Settlement Agreement and the Settlement Act, were signed in U.S. District Court for Water Division No. 7, State of Colorado, on December 19, 1991. With the consent decrees in place, the Tribes waive any and all claims to water rights in the State of Colorado not expressly identified in the decree after certain requirements are completed. Decrees addressing the Tribes' water rights settlement on the Animas and La Plata Rivers have yet to be entered. These are pending completion of certain portions of the Animas-La Plata Project.

The settlement of the Jicarilla Apache water rights claims was negotiated over a period of about 8 years and culminated in congressional approval of the settlement pursuant to the Jicarilla Apache Water Rights Settlement Act of October 23, 1992 (106 Stat. 2237). This act included a contractual arrangement with the Tribe for the diversion and depletion of 6,500 acre-feet of San Juan-Chama Project water from Heron Reservoir, and the diversion of 33,500 acre feet of Navajo River water of which 25,500 acre feet will be depleted, for a total divertable supply of 40,000 acre feet and a total depletion of 32,000 acre feet. The Tribe has the ability to market this water through third-party contracts, with the approval of the Secretary.

San Juan River Basin water rights are administered by the States of Arizona, Colorado, New Mexico, and Utah under State laws and interstate compacts. The Service has issued Biological Opinions for the NIIP and the Animas-La Plata Project under the ESA. While these projects have valid State water rights for development and use of water, the ESA opinions place limitations on project development and restricted water use to levels significantly below the limit of the water rights. This situation has caused some to believe that restrictions stipulated in ESA opinions now supersede the priority and administration of valid State water rights. The Service points out that their opinions deal with biological and hydrologic information and should in no way be viewed as affecting State water rights. However, others point out that they are prevented from exercising their water rights through development of Federal projects because of ESA opinion restrictions, thus their water rights are impaired.

If fully developed, the NIIP would deplete 267,000 acre-feet/year and the ALP would deplete 149,220 acre-feet/year in the San Juan Basin. Current Biological Opinions limit depletions for NIIP to 149,400 acre-feet/year and ALP to 57,100 acre-feet/year. An environmental baseline, which includes existing depletions, was established for the Basin. Current baseline depletions total 570,500 acre-feet/year and includes the above listed NIIP amount. Depletions for ALP would be in addition to the baseline amount and are allowed only because of "reasonable and prudent alternative" elements in the ALP Biological Opinion that the Service determined is likely to avoid jeopardy to endangered species.

The San Juan River Basin Recovery Implementation Program was established to perform research and recovery activities. Until the estimated 7-year research program is completed, the Service does not believe it has sufficient data to determine flow needs for endangered fish and that additional water depletions in the Basin from ALP or NIIP will result in jeopardy to the endangered fish in the San Juan River. Tribal entities and other water user organizations contend that such decisions by the Service have severely hampered their ability to exercise their water rights. The Navajo Nation has plans for additional water development (e.g., Gallup-Navajo Project) and is particularly concerned about the administration of the ESA in the Basin.

Non-Indian entities are concerned, but the Tribes are especially upset. They believe that much of the non-Indian development in the Basin has occurred but Tribal water adjudications and Tribal water development are lagging and will now be prevented because of ESA restrictions.

The Service is required by law to render ESA opinions within certain timeframes when requested. Opinions must be based upon the best available information. Biological and hydrologic information represent the predominant data sources for the opinions. Water rights and the priority of those rights are not the determining factor in depletion amounts allowed in the Biological Opinions. For example, the water right for a Federal (or Tribal) project may have seniority over rights that were filed and perfected since the Federal application. However, the long timeframes required for developing the Federal right may create a situation where the senior Federal right is not included in the baseline, junior rights that have been perfected are in the baseline, and a Biological Opinion on the proposed Federal project has determined that the senior Federal depletion creates jeopardy to endangered species and is not allowed. This scenario is not hypothetical in the San Juan Basin and is the source of frustration and possible lawsuits from water users and Tribes.

Existing Diversion and Growth

The San Juan River provides for the principle opportunity for New Mexico to utilize Colorado River water. The current usage in the upper basin states is collectively below the amount available for their use under the 1948 compact . For New Mexico, however, the planned future developments will virtually bring

New Mexico to its compact limit. This limit, in a practical sense, will prohibit any further development of the Colorado River waters (the San Juan River) in the State. This point in the development history brings with it some significant dilemmas regarding future growth in the basin whether it be in the agricultural, municipal, industrial, or tribal arenas.

Water Quality

In addition, there are some emerging water quality issues within the basin. There exists significant activities in the oil and gas fields of the basin with the resultant potential for hydrocarbon contamination. There are also signs that selenium may be a factor in the water chemistry of the basin. There is some concern that this water quality issue may be impacting the potential for reproduction and recruitment of endangered species.

The Future

Reclamation is continuing with development of the NIIP in San Juan County, New Mexico, by providing engineering and construction management services for development of water conveyance facilities for the Bureau of Indian Affairs (BIA). Under this process, funding is sought by BIA through the U.S. Department of the Interior's appropriation process and then transferred to Reclamation.

The President's fiscal year 1997 budget included $29 million for the continued design and construction of the project's Block 8. The NIIP is being developed in blocks of irrigatible land amounting to about 10,000 acres each. Construction of facilities to serve Block 8 was started in 1992.

Currently, Blocks 1 through 7 are producing high value crops (including potatoes, wheat, corn, and beans) on approximately 65,000 acres of land. At full development, NIIP will consist of 11 blocks having a total of 110,630 acres of irrigated land.

A reasonable and prudent alternative to jeopardy under the ESA has been implemented for construction and irrigation of Blocks 1 through 8. Further consultation for construction and irrigation of the remaining blocks is being planned.

The BIA is presently performing studies and gathering data to obtain the necessary clearances on Blocks 9 through 11. Either a finding of no-jeopardy or a reasonable and prudent alterative is needed under the ESA before construction can begin for Block 9, now scheduled in 1999.

Clearances are being held pending completion of the San Juan River Basin Recovery Implementation Program studies. Two potential concerns have arisen: (1) elevated selenium levels in return flows and (2) depletion of approximately 270,000 acre-feet annually. The selenium concern appears solvable by technological means, and the depletion concern relates to the water requirements for the endangered fish. These requirements will be determined in 1998.

The Navajos believe that implementation of the ESA is superseding the Navajo Nation's 1976 water delivery contract for diversion of 508,000 acre-feet annually from Navajo Reservoir. In exchange for construction of NIIP, the Navajos agreed to an annual diversion of 110,000 acre-feet by the San Juan-Chama Project and to share shortages of the water supply along with the other users from Navajo Reservoir.

Following the filing of the Final Supplement to the Final Environmental Impact Statement on the Animas-La Plata, Reclamation granted EPA an extension to their review period. The purpose of the extension was to attempt resolution potential water quality issues that could be caused by the project. A process, being set up by the Governor of Colorado, to resolve concerns surrounding the ALP Project is now underway. This process involves all project stakeholders in attempting to find options that can be implemented. The project sponsors have filed suit against the EPA for obstructing Project construction.

The Public Service of New Mexico Company (PNM) has requested Reclamation renew and extend through 2025 the water service contract for the San Juan Generating Station. The operations at San Juan Generating Station require a dependable supply of water through July 1, 2022; post project decommissioning and Reclamation would require until approximately 2025. The current contract allows the PNM to withdraw and consume 16,200 acre-feet per year through December 31, 2005. The 16,200 acre-feet is included in the baseline for the hydrology studies for the San Juan River Basin Recovery Implementation Program. The PNM's long-range investment-driven decisions (possible sale of facility and negotiating new long-term power line easements with the Navajo Nation) require long-term, reliable sources of water be secured.

A Draft Environmental Assessment for the contract renewal has been prepared and distributed for public review. The Environmental Assessment cannot be finalized until agreements can be obtained and Indian Trust assets satisfactorily addressed.

The Navajo Nation opposed Reclamation's issuance of contracts for water from the San Juan River because it is concerned there will not be sufficient water for the NIIP. The Navajo Nation asserts its paramount water right to waters of the San Juan River. The Southern Ute Indian and Ute Mountain Ute Tribes oppose the proposed action because it may interfere with the completion of the Animas-La Project, preventing them from securing the balance of water they are entitled to, and affecting their Indian Trust Assets. Both Tribes assert that all such depletion contracts from the San Juan River have the same effect. Reclamation recognizes this is a precedent-setting issue and the Tribes will probably voice the same objections and opinion on other similar proposed actions.

In a letter to Commissioner Martinez, dated June 3, 1996, President Hale of the Navajo Nation requested that the Commissioner "take appropriate action to assure the Bureau refrains from executing new contracts or extend existing contracts for water from Navajo Reservoir until it is determined that water will be available for NIIP." Because of the number of Navajo people employed by the San Juan Generating Station or support facilities, the Navajo Nation does not want to shut down the plant. In a letter sent to President Benjamin F. Montoya, Public Service Company of New Mexico, dated June 3, 1996, President Hale stated that he wanted "to assure PNM that the Navajo Nation considers the long-term operation of SJGS to be in the Nation's best interest."

A draft Biological Opinion on the contract renewal action was issued January 29, 1996. After review and discussions with the Service, a second draft was issued on July 2, 1996. Language that may be included in the Final Biological Opinion, the Final Environmental Assessment, and water service contract which would satisfy the Indian trusts concerns of the three Indian Tribes is being reviewed and discussions are continuing with the Navajo Nation.

New information indicates that some modified operation of Navajo Dam may be crucial to the protection and recovery of endangered fish in the San Juan River. It is believed the modified operation may be critical for success of the San Juan River Basin Recovery Implementation Program for endangered fish in the San Juan River. In addition, past ESA, section 7 consultation affecting the NIIP and future ESA, section 7 consultation for other Federal actions, activities, and projects in the Basin are dependent on future Navajo Dam operations.

Reclamation has committed to operate Navajo Dam to provide flow releases needed for research purposes and for the long-term operation after necessary flows are determined by the research studies. At the conclusion of the research studies the Service will render a Biological Opinion on the effects of operation of Navajo Dam on endangered species.

The potential, long-term operational changes at Navajo Reservoir that could occur will be the result of the ongoing studies that are expected to be completed by the end of fiscal year 1997. These studies will culminate in a Biological Opinion for the endangered species in the San Juan River and could result in significant changes in Navajo Reservoir operations. However, since the studies have not been completed and the operational changes that may be required to protect the endangered fish are not known, it is not possible to address the long term, operational changes of Navajo Reservoir at this time. Navajo Reservoir operations, after the studies are complete, are anticipated to include lower winter flows and higher spring flows to mimic the natural hydrography. It is anticipated that additional National Environmental Policy Act compliance will be completed before implementation of any significant, long-term, operational changes are made. Reclamation will prepare the necessary National Environmental Policy Act document to address the long term environmental consequences of future changes in the operation of Navajo Dam.

SUMMARY

Before the controversy generated by additional resource allocation associated with the endangered fish recovery, the San Juan River was a known quantity. The major issues of how much and where the Indian water rights settlements would be made were factors in the future of the San Juan River but the principles of those future decisions were in place. The recent events that have seen the Service declare that few additional depletions are possible have potentially changed the situation. If the endangered fish are to have reserved for their recovery essentially the remaining flow of the San Juan River, then all those who envisioned completion of some ongoing planning, construction or contracting process now view those possibilities with considerable skepticism. Among these future actions are the completion of NIIP, the construction of Animas-La Plata Project, and the extension of the PNM contract. Some potential solutions might include: the purchase of water supplies from willing sellers, the section 7 reconsultation on all Federal activities in the Basin to broaden the base of the participants in the solution, a modification of the amount of water likely needed by the fish, and a purposeful resolution of the water rights priority versus ESA consultation priority issue among the stakeholders including the Service and the State of New Mexico.

FARMER ADOPTION OF IRRIGATION WATER CONSERVATION MEASURES IN THE SOUTH PLATTE RIVER BASIN

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ABSTRACT

The potential of demand management as a water management tool in the South Platte River basin is limited by a lack of information regarding existing irrigation practices. A study was conducted to obtain information regarding irrigation water use practices in the basin, to determine the frequency of adoption of water conservation practices, and to relate the frequency of adoption of water conserving measures to various demographic factors. The results were based on 285 responses to a voluntary survey sent to a random sample of 1000 irrigators in eight counties within the basin during the winter of 1995. The survey sought information on farming practices, the adoption of water conservation practices, and grower characteristics.

Although disincentives for irrigation water conservation appeared to be significant, the results indicated a high rate of adoption. Seventy-four percent of the survey respondents had adopted some type of water conservation measure on their farms. Adoption of various irrigation water conservation practices was associated most frequently with farm size, but factors such as method of irrigation, water source, knowledge of water law, and level of education were also associated with adoption of one or more conservation measures. Respondents indicated that the primary incentive for adopting water conservation measures was "water conservation." The typical reason for conserving water was to improve existing operations. This suggests that in many instances conservation is being used as a method of extending existing supplies on farms operating under water-short decrees.

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INTRODUCTION

Competition for limited water supplies in the South Platte River basin is becoming more pronounced because of greater demand caused by increasing population. This competition will likely intensify in the future with increased demands for recreation and enhancement of wildlife habitat. Given the difficulties associated with developing new sources of water, nonagricultural users in the basin are looking toward agricultural water as a potential source of future water supplies. Many have suggested that the necessary supplies could be obtained through water conservation resulting from increases in irrigation efficiency.

Agricultural water is an attractive source of water because of the relative magnitude of irrigation water use in the South Platte River basin. Irrigation accounts for more than 80% of the total surface water diversions and consumptive use in the basin (Litke and Appel, 1989). The water is used by 5,100 irrigators farming approximately 904,000 acres of irrigated cropland (U.S. Department of Commerce, 1994). More than 540 ditches divert water for irrigation purposes, while there are over 4,500 direct flow and 1,300 storage rights operative (Caulfield et al., 1987). The economic value of total agricultural production in the basin in 1992 was approximately $278 million (Colorado Department of Agriculture, 1994). The vast majority of irrigation diversions and acreage within the basin occur along the main stem and its major tributaries on the plains of eastern Colorado at elevations in the approximate range of 3,500 to 6,000 ft.

Both sprinkler and surface irrigation systems are used in the basin. The exact distribution between the two classes of methods is unknown, but estimates indicate that surface irrigation, including flood and furrow types, is used for 80 to 85% of the total irrigated acreage. The results from a limited number of controlled studies indicate that on-farm irrigation efficiencies are highly variable, with surface methods being less efficient than sprinklers. Typical values for surface systems are in the range of 20 to 50% (Emond, 1993; Hoffner and Crookston, 1994). Emond (1993) found an average efficiency value of 60% for sprinklers.

Institutional and economic issues play a large role in determining the potential for greater irrigation water conservation in the South Platte basin. The basic law under which all water rights are administered in Colorado, the prior appropriation doctrine, is frequently viewed as a major barrier to improved irrigation efficiency at the farm level (Wilkinson, 1989). Because the value of a water right is based on historic beneficial consumptive use, any effort to maximize historic consumptive use will, in turn, increase the inherent value of the right. In addition, water saved through improvements in on-farm application or conveyance efficiencies can not be transferred, sold, or used on land other than that specified in the original decree. Because many farms in the basin experience supply shortages, the incentive exists to implement measures that increase the efficiency of diversion for the purpose of extending supplies for the existing decreed acreage. Other economic factors acting as disincentives for conservation include the low cost of water in relation to other inputs and the cost of improvements that will enhance application efficiency.

Legitimate concern exists about the potential effects of widespread changes in irrigation practices on basin hydrology (Smith et al., 1996). The amount of surface and tributary ground water diverted for irrigation in the basin greatly exceeds the sum of imports and native water yield of the basin (Caulfield et al., 1987). Thus, many irrigation water rights in the basin are dependent on return flows. Changes in irrigation practices at the basin level that would significantly increase diversion efficiencies could negatively impact water users dependent on these flows.

Although there is significant potential for increasing on-farm irrigation efficiencies in the South Platte basin, there is no consensus on the desirability of encouraging increased water use efficiency. Another factor affecting potential initiatives is the lack of information on current irrigation practices used in the basin. Our objectives were to obtain information on the practices currently being used, the frequency with which conservation methods have been adopted, and farmer interest and attitudes regarding adoption of measures to improve efficiency.

METHODOLOGY

A survey of irrigators in the South Platte River basin was conducted to obtain information on current irrigation practices and to assess interest in the adoption of various measures. The survey instrument was developed in consultation with the State Statistician of the Colorado Agricultural Statistics Service. The questionnaire was sent to approximately 1,000 randomly selected irrigation farmers residing in eight counties (Adams, Boulder, Larimer, Logan, Morgan, Sedgwick, Washington, and Weld) that comprise the South Platte River drainage basin (including tributaries) east of the front range.

The questionnaire contained inquiries about the county in which the operation was located, the number of irrigated acres and methods of irrigation used, the source of water (surface, river basin groundwater, or deep aquifer ground water), and the major crops grown under irrigation and acreage of each. Operators were then presented with a list of 23 different water conservation practices or strategies and asked to respond to each by indicating whether the practice was currently being used. The list was assembled from a similar survey of ground water users in the Ogallala region of the Great Plains conducted by Kromm and White (1990). Respondents who indicated that they had taken actions to reduce water use were asked to note which of several designated factors accounted for their actions. The list of factors included the common reasons for adoption of water conservation practices including conserving water, reducing labor, saving energy, improving water quality, replacing equipment, increasing acreage, increasing income from rental of saved water, and acting in response to educational programs sponsored by either Cooperative Extension or water conservancy districts. These respondents were also asked to estimate the extent to which they had reduced their water use (expressed as a percentage of total irrigation water use) by adopting various conservation practices. Respondents who indicated that they had not adopted water conservation measures were also asked to give reasons for their decision.

Other survey questions asked for additional information about respondents to determine whether the adoption of various conservation practices was associated with specific demographic characteristics of the respondents or their operations. The questionnaire also contained space at the end to allow respondents to provide general comments on agricultural water use and conservation practices.

The questionnaire was mailed on 15 January 1995 by the Colorado Agricultural Statistics Service along with a return envelope addressed to the Department of Soil and Crop Sciences and a letter requesting a response by 31 January. The letter indicated the purpose of the survey and guaranteed the anonymity of respondents. Responses were accumulated until 1 March 1995.

The survey responses were compiled and tabulated using a spreadsheet format. Individual narrative comments were also recorded for analysis. Chi-square analysis was used to determine whether the frequency of adoption of the various conservation practices indicated on the questionnaire was associated with various demographic characteristics based on five different classification categories. The demographic categories used were the source of water (tributary or nontributary), type of irrigation system (furrow/flood or sprinkler), farm size (equal to and greater than 400 acres or less than 400 acres), knowledge of water rights (generally knowledgeable or not generally knowledgeable), and education level (through high school and less or college and above).

RESULTS AND DISCUSSION

Respondent Demographics

A total of 285 responses were received from a survey of 1000 irrigators in the South Platte River basin. Just over 72% of the respondents indicated the county in which their primary operation was located. Responses were received from each of the eight counties surveyed, and the distribution of questionnaires received among counties was similar to that for the distribution of irrigated acreage among these counties. Weld county, which contains approximately 46% of the total irrigated acreage in the eight counties, accounted for 44% of the respondents identifying the location of their primary operation. The total amount of land owned by the respondents was 62,617 acres, with an additional 53,621 acres leased. While average farm size varied among counties, the average farm size of respondents indicating they owned their properties was 278 acres.

The total irrigated acreage reported was 84,681 acres, with 60% of this total (50,142 acres) devoted to flood or furrow irrigation. Sprinklers were used on 40% (33,870 acres) of the total irrigated acres reported. The average amount of irrigated land reported by the respondents was 297 acres.

For the purposes of this survey, the source of water was an extremely important factor. Our objective was to obtain information about irrigation practices and factors affecting conservation decisions from farmers using water within the alluvial basin. Some of the counties surveyed contained land irrigated not only with surface and tributary ground water, but also from deep ground water aquifers. Because of the method of selecting potential respondents, we could not identify and select against those in areas outside of the alluvial basin. Fortunately, only 9% of the respondents indicated that they used only deep aquifer wells. The majority of respondents, 39%, relied on surface water alone for irrigation, and another 17% relied on tributary ground water alone for irrigation. Seventy-one respondents, or 25% of the total, indicated that they used both surface and tributary groundwater sources. Ten percent indicated that they used a combination of tributary and nontributary ground water. In view of these survey responses, we felt the overall survey results would generally represent characteristics and attitudes of surface water and tributary ground water users.

Respondents indicated that the primary irrigated crop being grown was corn, which accounted for 46% of the irrigated acreage devoted to growers' three principle crops. Alfalfa and hay combined accounted for 25% of the total acreage, with the remaining 29% comprised of beans, sugar beets, wheat, barley, and vegetables. Beans made up the largest portion of the balance, accounting for 8% of the total.

The vast majority of the respondents (90%) indicated that they were at least somewhat knowledgeable about water laws. Nearly half of the respondents had received some level of high school education, but had not gone on to college. A large percentage had received some level of college education (44%), with twenty-two people (8%) possessing M.S. degrees. Twelve respondents (4% of the total) indicated that they had received Ph.D. degrees.

The most popular sources of information on irrigation technology were farm magazines and journals (32% of the respondents). Cooperative Extension was noted as a resource by 18% of the respondents, while 16% relied upon conservancy districts and ditch companies. Personal experience and the Natural

Resources Conservation Service were each cited by 14% of the respondents as sources of information, and consulting firms were used by 6%.

Water Conservation Measures

The results of the survey indicated that 74% of the respondents had adopted water-conserving irrigation practices. Of the 210 who had adopted measures, 169 (80%) indicated that they had done so to conserve water. The desire to reduce labor costs was noted by 56% of those who had adopted measures, while energy cost reduction and the desire to increase yields were also noted by 41%. Equipment replacement, increasing productive acreage, improving water quality, increasing income from rental water, and educational programs sponsored by conservancy districts and Cooperative Extension were reasons cited less frequently for changing operations. Reasons given for the 26% of respondents who had chosen not to adopt conservation methods were, in order of importance, cost or budget-related factors, leased land, availability of sufficient water supply, fear of water-right abandonment, and low water cost.

Irrigators who had employed water-saving measures were also asked to estimate the extent to which they had reduced their water use. Responses ranged from 0 to 100%, with many respondents leaving the question blank. Of those who responded, the average estimate of reduction of total water use was 20%.

The 23 individual water conservation practices provided for response on the questionnaire and a summary of responses are presented in Table 1. The survey results indicated that scheduling irrigation based on moisture need was the most popular water conserving practice, which was used by over 50% of the survey respondents. Half of the respondents also applied fertilizer at appropriate growth stages and monitored soil moisture. Reduced tillage, land leveling, replacing open ditches with underground pipe, planting drought tolerant crops, and converting from furrow to sprinkler irrigation were measures adopted by about one-third of the respondents. Of the top ten practices adopted, eight were management practices involving minimal capital expense to implement.

Demographic Factors Associated With Adoption

One of the objectives of this study was to identify factors associated with farmer decisions regarding adoption of water-saving practices. In looking at the entire array of water conservation practices, variation in frequency of adoption the different measures was dependent on four of the five demographic variables observed. The four variables were farm size, source of water, type of irrigation system, and knowledge of water rights.

Table 1. Water conservation measures adopted by survey respondents, South Platte River basin, Colorado.

Conservation measures	Number adopting	Percent adopting
Schedule irrigation	153	54
Practice timely fertilization	136	48
Monitor soil moisture	109	38
Use minimum tillage	98	34
Level land	98	34
Install underground pipe	96	34
Use drought tolerant crops	93	33
Convert to sprinkler irrigation	91	32
Replace underground pipe	79	28
Line ditches	77	27
Install low-pressure spray heads	69	24
Install tailwater recovery system	63	22
Use alternate furrow irrigation	59	21
Practice deficit irrigation	42	15
Meter water use	40	14
Use surge valves	35	12
Use LEPA systems	32	11
Reduce irrigated acreage	20	7
Use furrow diking	12	4
Use drip irrigation	11	4
Begin transition to dryland farming	10	4
Use cablegation systems	6	2
Build conservation bench terracing	6	2

To determine whether one or more of the demographic factors were associated with the adoption of specific conservation measures, the ten measures with the highest adoption frequency were analyzed independently. Results of these analyses are summarized in Table 2. Farm size was the characteristic most consistently associated with adoption of water conservation measures. Larger farms (those of 400 acres or more) had a higher frequency of adoption for nine of the 10 conservation practices. The method of irrigation used was not associated with any conservation practices other than those inherently linked to either surface methods (ditch lining) or sprinkler methods (conversion to sprinklers).

Table 2. Relationships between adoption frequency and demographic characteristics for survey respondents in the South Platte River Basin.

	Demographic characteristics				
Conservation measure	Farm[1] size	Irrig.[2] method	Water[3] source	Water[4] rights knowl.	Educ.[5] Level
Schedule irrigation	X[6]				
Timely fertilization	X		X		
Monitor soil moisture	X				
Use minimum tillage	X		X		
Level land					
Install underground pipe	X	X		X	
Use drought tol. crops	X				
Convert to sprinklers	X	X			
Replace underground pipe	X				
Line ditches	X	X			X

[1] Farm size: Equal to and greater than 400 acres or less than 400 acres.
[2] Irrigation method: Furrow/flood or sprinkler
[3] Water source: Tributary or nontributary
[4] Water Right Knowledge: Knowledgeable or not knowledgeable
[5] Education level: Through high school and less or college and above
[6] Indicates frequency of adoption of conservation measure is associated with variation in indicated demographic characteristic based on Chi-square test (P = 0.05).

We anticipated that knowledge of water rights would influence adoption rates for one or more of the most popular individual conservation practices. However, the analyses indicated that knowledge of water rights was only significant with regard to replacing ditches with underground pipe. Perhaps the most interesting finding was that the source of water was a factor associated with frequency of adoption for only two of the 10 most often used conservation measures, timing fertilization and using minimum tillage. These results indicate that surface water and tributary ground water users within the South Platte basin appear to respond to some of the same incentives as deep ground water users.

CONCLUSIONS

As with any survey, questions arise as to how representative the respondents were of the general target population. The 285 respondents comprised approximately 6% of the total number of irrigated farms in the basin and represented about 10% of the total irrigated acreage in the study area. Respondent characteristics such as farm size and crops grown were similar to actual census data for the eight counties in the target area. Average irrigated farm size of respondents was 297 acres, compared to an average irrigated farm size in the region of 200 acres (U.S. Department of Commerce, 1994). However, the majority of responses originated from Weld County, where the average acreage from questionnaire responses was 222 acres per farm. The federal census indicates that average irrigated farm size in Weld County was 224 acres in 1992 (U.S. Department of Commerce, 1994). From this cursory analysis, we concluded that the survey respondents were generally representative of the target population in this basin.

The results suggest that differences existed in some cases between the purpose of various questions on the survey instrument and the perceptions of respondents. The most popular conservation measure indicated by the respondents was scheduling irrigations based on moisture need. Unfortunately, a follow-up question to determine the actual methods used to accomplish scheduling was not included. It seems likely that there is considerable variation among the respondents in the magnitude of technical inputs used for scheduling. Thus, one would expect some variability among irrigators in the effectiveness of their irrigation scheduling efforts. Another example of problems with perception is observed in responses indicating that 33% of those surveyed used drought tolerant crops. This clearly conflicts with survey responses indicating corn and alfalfa as the major irrigated crops being grown.

Despite the problems of perception cited above, the overall indication of interest in water conservation is significant. A large fraction of irrigation farmers in the basin are implementing practices to improve their water use efficiency even though there are apparently few institutional or economic incentives for these actions. This suggests indirectly that some farmers are using conservation as a method of extending existing supplies because they have historically been operating under water shortages. Provided this occurs under the terms of the existing decree, it is permissible and potentially results in greater consumptive use per unit of water applied. More importantly, from a policy standpoint, these conservation efforts by individual farmers are likely producing little if any water for other uses in the basin. Thus, without significant changes in policy, it is doubtful that increased efforts to encourage irrigation water conservation in the South Platte basin will yield additional water for alternative uses.

REFERENCES

Caulfield, H.P, N.A. Evans, J.E. Flack, N.S. Grigg, D.W. Hendricks, J.W. Labadie, D. McWhorter, H.J. Morel-Seytoux, W.L. Raley, R.A. Young, and J.G. Milliken. 1987. Voluntary basinwide management, South Platte River basin, Colorado. Completion Report No. 133, Colorado Water Resources Research Institute.

Colorado Department of Agriculture. 1994. Colorado agricultural statistics, 1993 preliminary-1992 revised. Lakewood, CO.

Emond, H. 1993. Final report on irrigation water use for the project on sustainable agriculture. Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, CO.

Hoffner, G. and M. Crookston. 1994. 1993 nutrient and irrigation management education program. Northern Colorado Water Conservancy District, Irrigation Management Service. Loveland, CO.

Kromm, D.E. and S.E. White. 1990. Adoption of water-saving practices by irrigators in the High Plains. Water Res. Bull. 26: 999-1012.

Litke, D. W. and C. L. Appel. 1989. Estimated water use in Colorado, 1985. Water-resources investigations report 88-4101. U.S. Geological Survey.

Smith, D. H., K. Klein, R. Bartholomay, I. Broner, G. E. Cardon, and W. M. Frasier. 1996. Irrigation water conservation: Opportunities and limitations in Colorado. Completion Report No. 190. Colorado Water Resources Research Institute.

U.S. Department of Commerce. 1994. 1992 Census of agriculture. Vol.I, Part 6. U.S. Govt. Printing Office, Washington, D.C.

Wilkinson, C. F. 1989. Aldo Leopold and western water law: Thinking perpendicular to the prior appropriation doctrine. Land and Water Law Rev. 24:1-38.

MARKETING YUMA DESALTING PLANT WATER WHILE SATISFYING AMERICAN, MEXICAN, AND ENVIRONMENTAL NEEDS

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ABSTRACT

In 1961 the Wellton-Mohawk Irrigation and Drainage District (WMIDD) began discharging irrigation drainage flows, with an average salinity of 6,000 parts per million, into the Colorado River system. WMIDD's saline drainage return flows raised the salinity of the Colorado River just before it entered Mexico and damaged crops being grown in Mexico's Mexicali Valley. Mexico complained about the salinity increase. The U.S. negotiated an agreement, Minute No. 242, that required controlling salinity levels in the water being delivered to Mexico. Morelos Dam is the last dam on the Colordo River and diverts Mexico's Colorado River water. To control salinities, the federal government constructed a 73-million-gallon-per-day desalting plant in Yuma, called the Yuma Desalting Plant (YDP). During construction of YDP, Reclamation controlled water quality by bypassing WMIDD return flows via canal, around Morelos Dam, to a wetland in Mexico known as the Cienega de Santa Clara. Reclamation replaces the bypassed return flows with water conserved by lining the Coachella Canal in California. Over 130,000 acre-feet per year flows past the YDP, unused. That water could be treated and used for light industrial purposes or made potable and delivered to a drinking water system. The law authorizes the Secretary of Interior to exchange excess desalted water at prices and under terms he/she finds satisfactory. Reclamation is currently seeking customers to purchase the water. The customers must meet several criteria, one of them being the requirement to hold an entitlement to Colorado River water.

WHY YDP WAS BUILT

<u>History of the Salinity Issue</u>

The salinity problem with Mexico began in 1961 when the Wellton-Mohawk Irrigation and Drainage District (WMIDD) started discharging saline water from

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drainage wells (average salinity of 6,000 parts per million [p/m]) to the Gila River. The Gila River drains into the Colorado River upstream of the Northerly International Boundary (NIB) with Mexico but downstream of all United States water diversions.

Also, at this time Reclamation was filling Lake Mead in anticipation of the completion of Glen Canyon Dam, so excess deliveries to Mexico were reduced and less water flowed down the Colorado River to dilute the WMIDD return flows. As a result of these actions, the salinity levels in water delivered to Mexico at the NIB increased to, at times, more than 2000 p/m. Mexico's objections to these high salinity levels resulted in three successive minutes to the Mexican Water Treaty of 1944 to resolve the salinity problem: Minutes 218, 241, and 242. Minute No. 242 was to be the "permanent and definitive solution to the international problem of salinity of the Colorado River," and established water quality criteria. The Minute requires that the average annual salinity of water delivered to Mexico at the NIB be within 115 +/- 30 parts per million of the average annual salinity of water arriving at Imperial Dam.

The Act supplemented Minute No. 242. The purpose of the Act was to provide measures to ensure the salinity requirements of Minute No. 242 would be met without adversely impacting the seven Colorado River basin states, either in terms of dollars or water resources. The basin states consist of California, Arizona, New Mexico, Nevada, Utah, Colorado, and Wyoming. The Act authorized, among other things, the reduction of irrigated acreage and improved irrigation efficiencies in the WMIDD to reduce its drainage return flows, construction of a bypass drain to the Gulf of California, lining of 49 miles of the Coachella Canal, construction of a well field within the 5-mile zone along the State of Arizona's Southerly International Boundary with Mexico, and construction of the YDP.

Article 102(a) of the Act authorized the concrete lining of 49 miles of the Coachella Canal to allow the United States to temporarily offset the water lost by implementing Minute No. 242. The Act authorized the United States to bypass WMIDD drainage return flows around Morelos Dam and replace those flows with an equal volume of waters saved by lining the Coachella Canal, approximately 132,000 acre-feet per year (acre-ft/yr). This allowed the United States to satisfy Mexican salinity requirements without impacting the basin states' water resources.

Article 102(a) further stated that the United States could use the water conserved by lining the Coachella Canal during a period of time known as the interim period. The interim period commenced the first year the federal government was able to use water Coachella Canal water to replace bypassed WMIDD flows. The interim period ends "the first year that the Secretary delivers main stream Colorado River water to California in an amount less than the sum of the quantities requested by (1) the California agencies under contracts made pursuant to section 5 of the Boulder Canyon Act and (2) Federal establishments to meet their water rights acquired in California in accordance with the Supreme Court decreed in Arizona against California." After the interim period ends, Reclamation may use the YDP to satisfy the salinity requirements of Minute No. 242 and to salvage water to conserve system storage by delivering the salvaged water as part of someone's Colorado River water entitlement.

Capabilities of the YDP

The Yuma Desalting Plant has the capacity to desalt 73 million gallons of WMIDD water per day, or 96,500 acre-ft /yr. After desalting 96,500 acre-ft/yr, 68,500 acre-ft/yr of product water at approximately 300 p/m remains for delivery to Mexico. The product water may be blended with some untreated drainage water before it is delivered to Mexico. The water remaining in the bypass drain downstream of YDP would consist of unblended, untreated WMIDD drainage water and YDP reject water--approximately 27,000 acre-ft/yr of water with a salinity of approximately 10,000 p/m.

YDP was constructed to meet a dual purpose: to control salinities in the Colorado River between the Imperial Dam and the Northerly International Boundary; and to do this without using basin state water reserves. Had the YDP been constructed only the meet the salinity requirements of Minute No. 242, the plant would have been built with less treatment capacity than 73 mgd. However, because it was built to replace the same quantity of water WMIDD bypassed around Morelos Dam, it possesses more treatment capacity than is required to only meet salinity requirements. This capacity is what Reclamation plans to tap to treat water for non-federal users.

Environmental Issues

During YDP's construction, the WMIDD drainage water flowed via the Bypass Canal system almost to the Gulf of California, nourishing a wetland at its terminus -- the Santa Clara Wetland (Cienega de Santa Clara). Over time the wetland increased in size from about 40 acres to about 10,000 acres and now provides habitat for several endangered species of animals and plants, and between 50 and 100 species of non-endangered plants. Mexico recently declared the Cienega de Santa Clara a national environmental preserve. Recent Reclamation environmental assessments predict that operating YDP at one-third capacity will have a minimal effect on the wetland (loss of approximately 2,000 acres). However, full operation of YDP will have a greater effect on the wetland.

While Reclamation hasn't performed an in depth analysis, we have identified potential sources of water that could be routed to the Cienega de Santa Clara to mitigate YDP operation. Water could be sent from drains in the Mexicali or Yuma Valley to the Cienega.

Reclamation is currently collaborating with several environmental groups on an inter-agency, international study of the Colorado River delta. In this way, Reclamation can help develop alternative methods of supplying the Cienega de Santa Clara with the water that sustains it. This partnership also provides Reclamation an opportunity to evaluate impacts to the Cienega under various operating conditions of the YDP and to develop mitigation for impacts to the existing Cienega wetland.

CURRENT STATUS

The YDP was essentially completed and placed into operation in April 1992. It successfully operated at one-third capacity until early January 1993 when it became apparent that, as a result of more than five million acre-feet of flood flow releases from Painted Rock Dam on the Gila River, the amount of water required by the Mexican Water Treaty would be exceeded and salinity levels of the delivered water would be better than that required to meet Minute No. 242. It has not operated since January 1993, as Reclamation has met the salinity requirements of Minute No. 242 through:

- bypassing all WMIDD drainage water to the Santa Clara wetlands and replacing the water with water conserved by lining the Coachella Canal,
- controlling drainage pumping below Imperial Dam,
- taking advantage of recent floods on the Gila and Colorado Rivers that naturally freshened the groundwater drainage returns.

In 1993, the Commissioner of Reclamation solicited feedback from the basin states, Mexico, and other stakeholders about YDP being maintained in ready reserve during the interim period or until it was needed for salinity control. The basin states have generally supported not operating the YDP, as long as it can be restarted within one years' notice should salinity control for Mexico be required, or should the interim period terminate and recovery of WMIDD drainage water for reuse and conservation of system storage be required.

Since the YDP is not currently being operated to meet salinity requirements or the Basin States' water apportionment, Reclamation hasn't requested appropriations for operation through fiscal year 1997. However, Reclamation is required to manage the salinity program, maintain the salinity canal system, and maintain the YDP as necessary to hold it in ready reserve status. The total annual appropriated funds required for these activities are approximately $6 million.

Need for Future Operation of the YDP

Surplus flows in the Bill Williams, the Gila, and the Colorado Rivers during the 80s and 90s lowered the salinity of drainage returns below Imperial Dam to less than what occurred in the 70s. But, the salinity of the drainage returns is expected to eventually return to levels that will require Reclamation to take additional measures to meet the required salinity differential. These measures may involve operating the YDP or finding alternative sources of water to dilute deliveries made to Mexico to acceptable salinity levels. After the interim period ends, the YDP will either have to be operated to reduce replacement obligations, or alternate sources of water to replace water not treated by the YDP will have to be found. Purchasing water from entitlement holders is one way of obtaining an alternate source of water.

While salinity levels in the Colorado River system are rising, expected increased flows in the system will counteract some of this effect during the next few years. Reclamation forecasts making surplus releases during the next five years, which would mean that the YDP may not be needed to meet the terms of Minute No. 242 for several years--assuming Mexico will be allowed to receive some of the surplus flows.

Ongoing Dicussions Between the United States and Mexico

Currently, the United States and Mexico are discussing salinity conditions at both the Southerly and Northerly International Boundaries. Depending on the outcome of these discussions and contrary to Minute 242, which sets no water quality standard at SIB, Reclamation could be required to operate the YDP to control salinity at the SIB in addition to the NIB. In years Reclamation would need to run YDP to control salinity at one or both boundaries, the actual amount of plant capacity Reclamation would need to reserve to satisfy the Minute would depend on the salinity of flows arriving at Imperial Dam, the salinity of return flows below the dam, and the level of salinity acceptable to Mexico at the SIB.

Currently, we have determined that retaining two-thirds of the YDP capacity will allow the U.S. to meet salinity requirements of Mexico at the NIB and SIB, leaving one-third capacity of the YDP that could be marketed. This one-third capacity is based on meeting the terms of Minute No. 242 and supplying water of 1200 p/m at SIB.

Proposal to Market Product Water from the YDP

The Lower Colorado Region of the Bureau of Reclamation proposes marketing YDP product water to non-Federal sources. This would make beneficial use of WMIDD drain water which otherwise flows to Mexico, unused.

Marketing YDP water represents a supplemental purpose in the use of the facility as described in Article 101(a) of the Act. Treating and marketing water will not impact Reclamation's ability to satisfy the requirements of the Mexican Water Treaty of 1944, Minute No. 242, and potential requirements to provide SIB with better quality water.

Authority to Market Water from the YDP

Article 101(e) of the Act authorizes the United States to exchange any desalted water not needed for the purposes of the Act "... at prices and under terms and conditions satisfactory to the Secretary..." The city of Yuma, Arizona (City) has the first right of refusal and has expressed interest in marketing this water with Reclamation, and possibly utilizing the plant for some of its water supply in approximately 20 years.

Yuma is a city of approximately 60,000 residents located near a tri-point border of California, Arizona, and Mexico. Local economy consists primarily of agriculture, government, and tourism.

Protecting Existing Entitlement Holders

After the interim period ends, Reclamation loses the use of Coachella Canal conserved water to replace WMIDD water bypassed to the Santa Clara Wetland. To protect the basin states' water resources while providing for a long term commitment of YDP water, Reclamation would only execute contracts with entities that hold or can prove access to an established Colorado River water entitlement. Reclamation will also reserve enough capacity (two-thirds of the YDP or approximately 64,300 acre-ft/yr of raw-water-treatment capacity) in the YDP to ensure that marketing will not impact the ability to meet the salinity requirements of Minute No. 242 and potential requirements at SIX.

How Deliveries Will Work

A customer purchasing all 23,000 acre-ft/yr of available YDP product water would hold an entitlement for approximately 29,000 acre-ft/yr (YDP is only 75% efficient. 25% of the water is rejected as brine). At the end of the interim period and when salinity conditions are such that Reclamation is required to meet Minute No. 242, Reclamation would continue to sell the 23,000 acre-ft/yr of water and would increase plant operations to full capacity, unless we buy water to offset the replacement obligation incurred by not operating the YDP, and deliver approximately 46,000 acre-ft/yr of YDP water to Mexico. We would also release 29,000 acre-ft/yr from system storage, the amount of the entitlement held by the YDP-product-water customer, for delivery to Mexico. The surface water that would have been delivered to the entitlement holder via the river is replaced by water rreated at the YDP. Thus, Mexico is provided the requisite amount of water at the required quality. Reclamation has reduced the federal obligation to replace water and the basin states' water supply is protected.

Price of Water
Reclamation plans to sell YDP product water (300 p/m, non-potable) at a price of $515 per acre-ft/yr. This will enable us to recover full costs associated with producing the water and to recover some expenses associated with holding the YDP in ready reserve.

Length of Contract
Reclamation, via a Colorado River water entitlement holder, would enter into long-term service agreements (15 to 25 years) with water customers. This will allow them time to recover their capital investment required to economically justify use of the treated water from the YDP.

Potential Clients
So far, seven entities have expressed an interest in obtaining water from the plant. These include two powerplants, the City of Yuma, the Quechan and Cocopah Indian Tribes, and two private entities. In addition, entities in California and Nevada are making plans to commit large sums of capital to develop additional sources of water. Water from the YDP could be used to meet some of these needs where water from the plant can be produced at a lower cost than other sources of water.

While Reclamation intends to market the YDP water primarily through the City of Yuma, we could also contract directly with a single large customer or a consortium of small water customers--provided they show proof of a water entitlement, or access to one.

As part of our efforts to create awareness that YDP product water is available for purchase, Reclamation will prepare and circulate news releases to news papers and periodicals, is maintaining a home page and developing an electronic mailing promotion on the Internet, and, if necessary, will advertise in specific industry journals.

CONCLUSION

The marketing of treated water from the YDP to non-Federal entities would benefit both the United States and the taxpayers. The advantages include:

- Marketing water treated by the YDP would help recover, in addition to costs associated with operating and maintaining the YDP to satisfy customer water orders, a portion or all of the funding required to maintain the plant in ready reserve. The annual appropriation from Congress for maintaining YDP in ready reserve will be reduced or eliminated.
- The WMIDD drainage water is currently bypassing the YDP and flowing unused into the Cienega de Santa Clara in Mexico at a rate of more than 108,000 acre-ft\yr. Reserving two-thirds of plant treatment capacity (64,300 acre-feet/year) for federal use leaves 43,600 acre-feet/year to be desalted; YDP will produce approximately 22,851 acre-feet/year that can be marketed.
- An additional source of reasonable cost, high quality water would be available for municipal and industrial uses.
- The product provided by YDP would be used by various types of industries, the development of which would enhance the local community.
- Construction of YDP cost the United States approximately $250 million. This taxpayer investment should be fully utilized. The unique, cyclic Federal use of the YDP facility provides an opportunity to:
    - reduce Federal funding requests by marketing water not immediately needed to meet the Federal obligations,
    - take advantage of the Federal investment and immense available capacity for productive use,
    - maintain the YDP in an operable condition for eventual Federal use,
    - increase expertise and technology required to run such a plant,
    - increase flexibility to meet unforeseen circumstances which might necessitate increasing operations of the plant.

SELECTED REFERENCES

DeSantiago, Julian, 1996: *Colorado River Basin Salinity Control Project--Environmental Assessment.* U.S. Bureau of Reclamation. Unpublished.

U.S. Bureau of Reclamation, 1996: *Projected Lower Basin States Usage of Colorado River Water, 1996-2060.* Unpublished.

U. S. Congress, 1974: *Public Law 93-320--Colorado River Basin Salinity Control Act.* June 24, 1974.

U.S. Congress, 1944: *Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande--Treaty between the United States of America and Mexico.* February 3, 1944.

U.S. Department of State, International Boundary and Water Commission: *Minute No. 242--August 30, 1973.*

U.S. Supreme Court, 1964, *State of Arizona, plaintiff v. State of California, et al., defendants*: U.S. Supreme Court Decree--March 9, 1964.

TRANSFER OF WATER RIGHTS FROM AGRICULTURAL

TO MUNICIPAL USES IN NORTHERN COLORADO

A CASE STUDY

Bruce E. Kroeker[1] Dennis A. Bode[2]

ABSTRACT

Growing municipalities and agricultural water users often compete for available water supplies in Colorado and other western states. This paper will discuss the institutional processes that enable water transfers to occur in Colorado, and will describe how a water rights transfer was formulated to allow the City of Fort Collins to transfer agricultural water rights totalling about 6,000 acre-feet per year to municipal uses. Colorado water law requires that such changes be accomplished without injury to other users. A plan was developed to maintain historic return flow patterns (and thus protect other water users who relied upon those return flows) by replacement with municipal wastewater discharges, credits from lawn irrigation return flows, and/or reservoir releases. In addition, mutually beneficial exchanges of water with agricultural users were proposed. The technical elements of the plan were presented to representatives of competing water users on the Cache la Poudre River. Agreements were negotiated with most parties, and a trial was held to resolve the remaining issues. A water court decree has now been issued, and the City plans to initiate use of this water in 1997.

INTRODUCTION

The Cache la Poudre River is located in north central Colorado, on the east side of the continental divide (Figure 1). Its headwaters begin in Rocky Mountain National Park, and it drains over 1,890 square miles above its confluence with the South Platte River near

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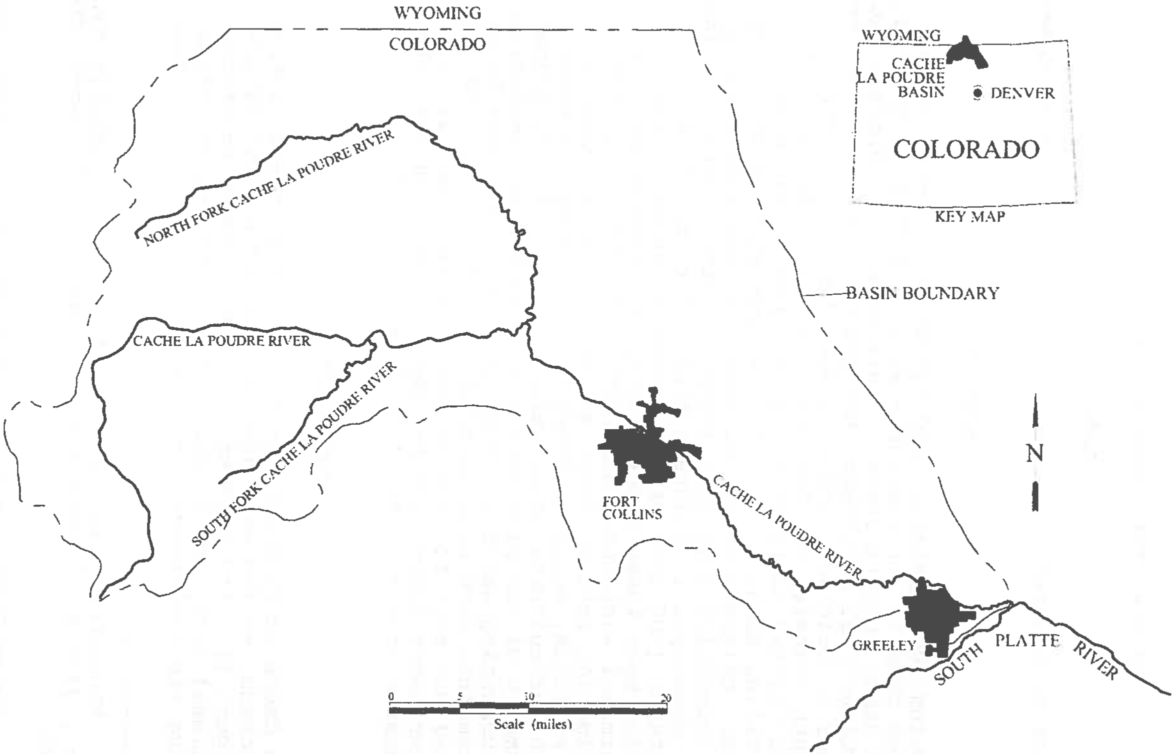

FIGURE 1. CACHE LA POUDRE RIVER BASIN

Greeley. Most of the basin's water supply results from runoff of snow melt in the mountainous upper basin. The native runoff is supplemented by trans-basin importation of water from the Colorado, Laramie, and North Platte River Basins. The average annual surface water supply of the basin is about 430,000 acre-feet per year (af/yr).

Most of the water use occurs in the plains which comprise the lower basin. The competing interests which rely upon the water supplies within the Cache la Poudre Basin are as follows. Agriculture is by far the largest water user in the basin, with over 200,000 acres of very productive farmland being irrigated with water diverted from the river. The Cities of Fort Collins and Greeley have long obtained municipal water supplies from the river; the City of Thornton, a suburb in the northern Denver metropolitan area, recently purchased senior agricultural water rights and appropriated additional river flows for its uses. Industrial facilities supplied by water available in the river basin include an Anheuser Busch Brewery, an Eastman Kodak plant, and a coal-fired power plant operated by the Platte River Power Authority. The Colorado Division of Wildlife operates a fish hatchery which uses river supplies. Recreational uses of the river are also very important, including white-water boating and fishing. Congress passed a bill designating the upper 75 miles of the Cache la Poudre River as a Wild and Scenic River in 1986.

The Arthur Irrigation Company, Larimer County Canal No. 2 Irrigating Company, New Mercer Ditch Company, and Warren Lake Reservoir Company (collectively known as the "southside ditches") operate canals and/or reservoirs which divert water from the Cache la Poudre River for irrigation of lands in and near the City of Fort Collins. As Fort Collins has grown through the years, significant portions of the areas historically irrigated by the southside ditches have been urbanized, and the City has acquired a considerable portion of the companies' water rights in fulfillment of water rights dedication requirements and through purchase agreements.

Fort Collins filed an application in December, 1992 with the Colorado water court requesting approval of a change of water rights and exchanges which will enable the City to utilize its southside ditch water for various purposes. The water court issued a decree approving these uses in September, 1996. A description of the institutional processes which enable water transfers to occur in Colorado, as well as a case history of Fort Collins' southside ditch transfer are presented below.

COLORADO'S WATER RIGHTS SYSTEM

Overview

Surface water laws were written into the Colorado Constitution at the time of statehood. Due to the limited availability of water supplies, it was clear that an orderly system for allocating the supplies between various users was necessary. The solution was the development of the doctrine of prior appropriation, which holds that first-in-time is first-in-right. In times of water shortage, the water right with the most senior (oldest) priority is entitled to divert water in preference to all junior water rights within a particular stream system. Similarly, the second most senior priority is entitled to divert water in preference to all other more junior rights.

The doctrine of prior appropriation imposes two requirements for acquiring a water right. A water right is obtained when an individual takes water from the natural stream and applies it to beneficial use. Water rights are established through court hearings known as adjudication proceedings. The court will establish by decree the priority date of the right, the amount of water which may be diverted, the location of the point of diversion, and the type of use for the diverted water. Currently, all water matters are heard in water courts which have been established for each major river basin (water division) in Colorado. Each division has a special water judge who acts on all water matters within that division.

Water rights in Colorado are considered private real property, and thus can be bought, sold or leased like other real property. They are not attached to the land, and can be transferred to another place and/or type of use. Water right transfers must be approved through Water Court proceedings, which allow other water users to object to the proposed change. The entity applying for a change of use bears the burden of proving that the proposed change will not injure or adversely affect any other water users. In order to prevent injury, conditions are generally imposed upon the new use so that:

1. consumptive use of water is no more than the historic consumptive use,

2. the timing and patterns of return flows resulting from historic use are maintained, and

3. the rate of diversion and season of diversion are no different than that which historically occurred.

Virtually all of the most senior water rights were originally decreed for agricultural use, and it is common for these rights to be purchased and transferred to municipal or industrial use. Water transfers have been occurring for decades in Colorado, and well established procedures have evolved for accomplishing the reallocation of water supplies.

Change of Use Proceedings

Population growth within Colorado has resulted in the need for growing municipalities to obtain additional water supplies. The decision is often made to acquire existing agricultural water rights and change the type of use through Water Court proceedings. The applicant proposing the change of use must perform studies to:

1. document the hydrologic effects of the historic use of the acquired water right,

2. determine the hydrologic effects of the proposed municipal use of the water right, and

3. determine appropriate terms and conditions to ensure that the new use does not detrimentally alter the streamflow conditions relied upon by other water users.

In order to evaluate the historic use of an agricultural water right, it is necessary to:

1. obtain records of stream diversions,

2. estimate the portion of the diversions which were consumptively used and therefore lost from the local hydrologic system,

3. estimate the portion of the diversions which may have returned to the stream system as return flow, and

4. determine the location and timing of return flow patterns.

An important first step in conducting historic use studies is to select an appropriate period of record for use in the analyses. The study period must adequately represent the historic use of the water right, and should be of sufficient length to include a range of hydrologic conditions. Consumptive use and return flow are typically quantified by conducting a water budget analysis of the irrigation system. Headgate diversions are reduced by the conveyance losses to determine the amount of water actually delivered to individual farms served by the ditch systems. Farm deliveries are reduced by the amounts attributable to surface runoff (tailwater) and deep percolation, depending upon the site characteristics and irrigation practices. The remaining water supplies are allocated to meet the irrigation water requirements of the crops grown and to soil moisture storage. Water applications in excess of crop requirements and soil moisture holding capacity are usually assumed to result in additional surface runoff and/or deep percolation.

The results of the water budget analysis are then used to estimate the timing and location of return flow accretions to the stream system. Depending upon the complexity of the subsurface conditions, typical techniques may include the application of analytical or numerical models to estimate the timing of ground water return flows. The difference between the historic diversions and return flows are termed the "net stream depletion," and determine the amount of water which can be consumptively used by another type of use.

The hydrologic effects of the proposed municipal use of the water right are evaluated in much the same manner. Water usage and wastewater treatment records are analyzed to determine the amounts of water use attributable to in-house, industrial, and outdoor irrigation uses. The consumptive use and return flow patterns resulting from each of the various uses are also determined.

Once the hydrologic patterns resulting from both the historic use and proposed use of the water right have been identified, it is necessary to compare the two. The new use cannot increase the burden previously imposed upon the stream system by the historic exercise of the water right. Return flows which historically supplied water to downstream water rights usually must be maintained in quantity, time, and location. On the other hand, if the new use results in less consumption and greater return flows, the excess water may sometimes be reclaimed and reused. These factors are incorporated into a plan identifying the criteria upon which future use of the water will be allowed. If these criteria are based upon sound legal principles, appropriate hydrologic analyses, and careful consideration of potential impacts, the proposed change of water rights should not adversely affect other water users.

The entity proposing the change of water rights will present its technical studies to the parties which have objected to the proposed change. Objecting parties often include other agricultural, municipal, and industrial water users which rely upon water rights from the same stream system. If the various parties can agree upon the technical and legal issues involved, the change of use application may be resolved by mutual consent. If not, the parties present evidence to the water court in formal hearings. After hearing the evidence, the water judge may grant the change of use as proposed by the applicant, impose additional limitations upon the future use of the water right, or deny the application entirely.

CASE STUDY - FORT COLLINS' SOUTHSIDE DITCH TRANSFER

The case study of the Fort Collins southside ditch transfer can be separated into several distinct activities, including: preparation of technical studies, filing of the water court application and identification of objectors, pre-trial negotiation with objectors, trial proceedings, and receipt of a court decision. These activities are described below.

Technical Studies

The historic diversions attributable to Fort Collins' ownership of southside ditch water were determined by analyzing diversion records maintained by the Colorado

State Engineer's Office. These diversions averaged 7,120 af/yr during the selected study period of 1913 through 1970. Water budget studies were performed on each of the ditch systems. These studies included consideration of the following factors: the amount of water diverted into the ditches, conveyance losses in the ditches, acreage irrigated under the ditches, types of crops grown, potential evapotranspiration for the crops grown, soil moisture holding capacity, and irrigation efficiencies. It was determined that the historical consumptive use of irrigation water averaged about 3,890 af/yr. Accordingly, an average of about 3,230 af/yr of the diversions historically returned to stream system as either surface or subsurface return flows. The stream reaches to which the historic return flows accrued were identified, and the timing of subsurface return flows determined by analytical methods.

As is the case with agricultural water use, a portion of the water used for municipal purposes is consumed, and the remainder returns to the stream system as surface and subsurface return flows. Return flows resulting from municipal water use are generally greater than those resulting from agricultural use of an equal quantity of water. The City planned to utilize the return flows resulting from its municipal use of southside ditch water to maintain historic return flows, and to reclaim for reuse, successive use, or disposition any excess[3] municipal return flows which may occur. Therefore, engineering studies were also performed in order to quantify the return flows which result from municipal water use in Fort Collins.

Municipal water use patterns within the City of Fort Collins were analyzed for the period of 1987 through 1992. The City's water use averaged 24,351 acre-feet per year during the 1987 through 1992 period. This represents an average water use of about 238 gallons per capita per day. Approximately 56 percent of the total City water use is attributable to indoor uses, and 44 percent to outdoor uses. Base use is considered to be the average use which occurs during the winter period of December through February when essentially all water is used indoors. Outdoor use is considered to be the use in excess of the base use during the April through October period.

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[3]Amounts over and above that which occurred due to the historic agricultural use of the water.

A small portion of the water used indoors in Fort Collins is consumed during use, and the remainder is collected by the City's sanitary sewer system for treatment and then discharged as surface return flows. Ninety-five percent of the base use within the City of Fort Collins is considered to return to the stream system by discharges from the City's wastewater treatment plants.

The City's total water use increases dramatically during the April through October period of each year. This is due to outdoor water uses which are primarily irrigation of lawn and other landscaped areas. A portion of the municipal water applied to lawns is consumed through evaporation and transpiration, a portion is stored as soil moisture in the soil profile, and the remainder returns to the stream system as surface runoff or deep percolation.

A representative sample of 173 single family/duplex residential, multi-family residential, and commercial accounts was selected from the City's utility database for participation in a field sampling program designed to collect information about landscaping and watering patterns within the City. Based on this field study and accepted engineering methodologies, the average subsurface return flow of lawn irrigation water within Fort Collins was determined to be 23 percent of the outdoor water use. An additional 2 percent of the water used outdoors was surface runoff.

Because the municipal return flows resulting from indoor and outdoor water uses in Fort Collins occur in the same vicinity and in a manner similar to return flows resulting from the historic irrigation uses under the southside ditches it is possible to use the municipal return flows to offset the obligations to maintain the historic irrigation return flows. Based upon the studies of historic agricultural use and municipal water use in Fort Collins, accounting procedures and terms and conditions were designed to: 1) ensure that future municipal diversions do not exceed the historic diversions by the water rights; and 2) ensure the maintenance of the return flows (in quantity, time, and place) that occurred as a result of the historic agricultural use of the water rights.

The results of the technical studies were compiled in an engineering report which was provided to other interested parties, objectors to the City's water court application, and as evidence to the water court.

Water Court Application

One of the primary purposes of the required application to the water court is to provide sufficient information about the proposed new appropriation and/or change in water rights that other water users can determine if their water rights may be adversely affected by the application. Other parties have two months after the month the application is submitted to file statements of opposition. Once statements of opposition are filed, an objector has party status to the proceedings and can participate in negotiations toward settlement and the trial proceedings.

Fort Collins filed its water court application in Water Division 1, Case No. 92CW129, in December of 1992. The application requested approval of a change in water rights for the southside ditch water owned by the City including: alternate points of diversion at sixteen structures; a change from direct flow to storage and alternate places of storage in twenty-eight reservoirs; and a change in type, place, and time of use. The application also requested approval of an appropriative right of exchange[4] between the City's downstream points of discharge from its wastewater treatment plants and its upstream points of diversion and storage.

The City requested the alternate points of diversion and storage, and rights of exchange, for the following reasons. The appropriation dates for the various southside ditch water rights range from very senior to relatively junior within the priority system. The water yielded by some of the rights will occur at times when it is not presently needed for immediate treatment and use by the City. It is therefore desirable for the City to be able to store its water for subsequent use and/or use its water for various other purposes. Furthermore, the original points of diversion for the southside ditch water rights are located downstream of the diversion point for the

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[4]An exchange of water refers to an operation in which a diversion which would otherwise be out-of-priority is made at an upstream location, and a replacement supply of a like amount of water is returned to the river at a downstream location. Such operations can only be performed when all intervening water rights with senior priority dates are fully satisfied.

City's water treatment facilities. In order to efficiently utilize its southside ditch water as a source of supply for treatment and potable use, the City will need the operational flexibility which can be provided by alternate points of diversion and river exchanges.

Statements of opposition to the City's application were filed by about twenty parties, including: Cache la Poudre Water Users Association (hereinafter CLP Water Users), Northern Colorado Water Conservancy District, Colorado State Engineer, Colorado Wildlife Commission and Colorado Division of Wildlife, City of Thornton, City of Greeley, and others including many of the individual ditch companies that operate irrigation facilities which divert water from the Cache la Poudre River (these companies are also represented collectively by the CLP Water Users). The number of opponents to the City's application is reflective of the fact that many water users relying upon the flows of the Cache la Poudre River believe they must carefully monitor the plans of others in order to protect their own water rights from impairment.

Pre-trial Negotiations

Once the identity of objectors had been identified, representatives of Fort Collins began to meet with the other parties and to determine what issues were of concern and whether those issues could be resolved through settlement discussions. Substantive issues which were identified as a concern to various objectors included the following:

1. Were the quantities of consumptive use and return flows attributable to the historic agricultural use of the City's southside ditch water properly determined?

2. Were the timing and locations of return flows attributable to the historic agricultural use of the City's southside ditch water properly identified?

3. Were the subsurface return flows resulting from lawn irrigation within Fort Collins properly quantified?

4. Were terms and conditions in addition to those proposed by the City necessary to protect other water rights from injury?

5. Were all of the multiple points of diversion, places of storage, and requested exchanges actually needed by the City; and, as a legal matter, could the water court properly issue a decree allowing the use of facilities which the City did not own or have agreements in place to use?

Numerous meetings were held to attempt to resolve the above issues. The concerns of a number of objectors were satisfied through the exchange of additional technical information and/or inclusion of agreed upon language in stipulations.

Other objectors, most notably the CLP Water Users, Thornton, and the State Engineer's Office, chose to more closely scrutinize the City's technical studies. After many months of negotiations, the City set the case for a one-week trial which was scheduled for November, 1995. In the meanwhile, Fort Collins and the remaining objectors continued settlement discussions.

In the final weeks before trial, Fort Collins reached agreement on remaining technical issues with the State Engineer's Office and Thornton. Fort Collins agreed to reduce its claimed credits for subsurface lawn irrigation return flows on the basis that the City's outdoor water use will likely be more efficient in the future than it has been in the past. This resolved the concerns of the State Engineer.

Fort Collins and Thornton reached settlement by compromising on several outstanding technical issues. Fort Collins agreed to reduce its claimed historic consumptive use by about 260 af/yr. In return, Thornton agreed to drop several other issues regarding the historic use analyses. Thornton agreed that the timing and location of historic return flows had been satisfactorily determined. Lastly, an additional term and condition providing monthly volumetric limits on Fort Collins future diversions of its southside ditch water was agreed upon.

Although the CLP Water Users agreed not to dispute any issues regarding the historic use of the City's water rights and the change of use portion of the case, issue (5) regarding the multiple exchanges and points of diversion and storage was not resolved through negotiations.

TRIAL

The matter proceeded to a trial that was held in the Division 1 water court in Greeley from November 13 to 16, 1995. The opposers CLP Water Users asserted that the City should not receive a decree allowing the right to use certain facilities nor should it be granted the requested appropriative rights of exchange. They argued that agreements between the City and the owners of diversion and storage facilities the City wishes the option to use should be a prerequisite to granting a decree, that granting the exchange rights would remove all or most of the remaining exchange potential from appropriation by others, and that many of the proposed exchanges were not practical.

On the other hand, the City asserted that it intended to obtain agreements with the owners of facilities it wishes to use prior to initiating such uses, but that obtaining the decreed right to do so was the logical first step. Also, that as a legal matter, the granting of conditional appropriative rights of exchange did not reduce the amount of water which can be appropriated by others, and lastly, that the City needed flexibility in pursuing its future alternatives for diverting and storing water and thus was entitled to be granted its requests for multiple points of diversion and storage.

Court Decision

The court issued a ruling on the disputed issues on August 15, 1996. The court agreed with the City that it was not necessary for the City to have agreements in place prior to obtaining a decree allowing the use of facilities owned by others. Also, it ruled that the exchange potential remaining in the Cache la Poudre River system will not be reduced by the volume of exchange conditionally decreed to the City, but rather will be limited only to the extent that the City perfects its conditional water rights and obtains an absolute decree.

Lastly, the court ruled that it was granting all the exchanges requested by the City, but noted that time will tell if some of the exchanges are not practical and whether or not Fort Collins will actually obtain agreements to use certain facilities. The City is required to return to court every six years to demonstrate diligence toward perfecting its conditional water rights, and the court indicated it would take a close look at what Fort Collins had done to acquire access to structures and to operate its exchanges during those future proceedings.

A decree incorporating the judge's decision was entered by the court on October 2, 1996. Thus, Fort Collins is planning on utilizing its southside ditch water within its municipal system during 1997.

CONCLUSION

Are there competing interests for water use in the Cache la Poudre Basin in northern Colorado? Most definitely! Was consensus reached in the matter of Fort Collins application to transfer its southside ditch water rights? The answer is less definitive.

After countless meetings, many proposals and counter-proposals, and compromise by several parties, consensus was reached on a large number of complex technical issues. Thus, the need for a trial to litigate these issues was avoided.

On the other hand, consensus was not reached between the City and the irrigation companies on the issues involving the future use of facilities and the new appropriative rights of exchange. Perhaps this was because the City and irrigators were no longer in direct competition for water that could not be used for agriculture due to urbanization, but the competition for new uses remains in place and made compromise more difficult.

WATER TRANSFERS AND WATER PRICING IN SHARED RIVER BASINS

A. Alvares Ribeiro[1] Rodrigo Maia[2]

ABSTRACT

When international rivers are involved, water management is no longer compatible with administrative units confined to political boundaries but to all the river basin; nevertheless, planning and management of hydraulic resources, involving multiple interposers, make agreement difficult.

Nowadays, International Law principles are not compatible with the unrestricted use of the territorial waters by one State to the detriment of other riparian States. All the developed countries accept, at least in terms of principles, a limited sovereignty on hydraulic resources; this is reflected by the International Conventions and Agreements.

Sustainable water projects must have water available in sufficient quantity and quality at acceptable prices to meet demands now and in the future without causing the environment to deteriorate. Inter-basins water transfers for agriculture use are opposed to sustainable development.

Portugal and Spain's shared rivers institutional policy, in connection with the International and European Union (EU) water main rules previous analysis, will be described. The current and previewed environmental situation of the shared river basins will also be presented. The (in)adequacy of the dual water basins management policy and the social effects of inter-basin water transfers to attend to super-exploited agricultural zones will be focused.

Also, the water pricing policy of both countries shall be compared, with water prices compared with other EU countries.

INTRODUCTION

The importance of international river basins is enormous, all over the world. In Portuguese speaking countries (more than 200 million inhabitants), the percentage of the ratio of the international river basins to the total area of the country is (Álvares Ribeiro, 1987):

- Africa (Fig.1): Angola, 69%; Guinea-Bissau, 46%; Mozambique, 53%.
- America (Fig.2): Brazil, 61%.
- Europe: Portugal, 56%.

Actually, two of four doctrines of International Law (Vlachos, 1996) are mostly followed:
- Community of Interests;
- Limited Territorial Sovereignty.

The first corresponds to envisage the optimum development of the river, considering the unity of the river basin regardless of political frontiers. The latter, the most accepted by all the

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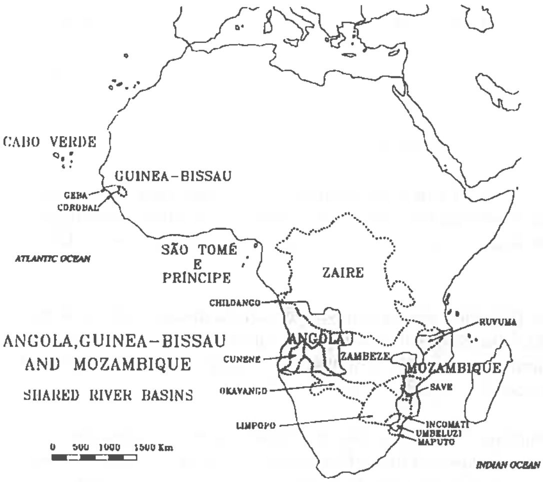

Fig. 1. Angola, Guinea-Bissau and Mozambique Shared River Basins.

Fig. 2. Brazil Shared River Basins.

developed countries, respects the sovereignty of a riparian State over watercourses within its borders but restricts it by the equal and correlative rights of other riparian States; it is based on two main principles:
-Principle of Equitable Utilisation; and
-Principle of No-Appreciable Harm,
increasingly accepted as a basis for international water rights negotiations.
A fifth doctrine, identified as "Prior Appropriation" (World Bank, 1992) tries to enclose the riparian's definition of equitable use based on its past utilisation of waters.

Having in mind the two referred principles, the interrelations between upstream (Spain) and downstream (Portugal) countries will be analysed.

PORTUGAL AND SPAIN HYDRAULIC RESOURCES

Europe Southwest peninsula (Iberian Peninsula) has an area of about 597 000 km^2, 15% of it occupied by Portugal and 85% by Spain. In terms of population, about 10 million (21%) are Portuguese and 38 million (79%) are Spanish. Figure 3 shows (CEC, 1992) the hydraulic resources per capita of Portugal, Spain and some other European countries.

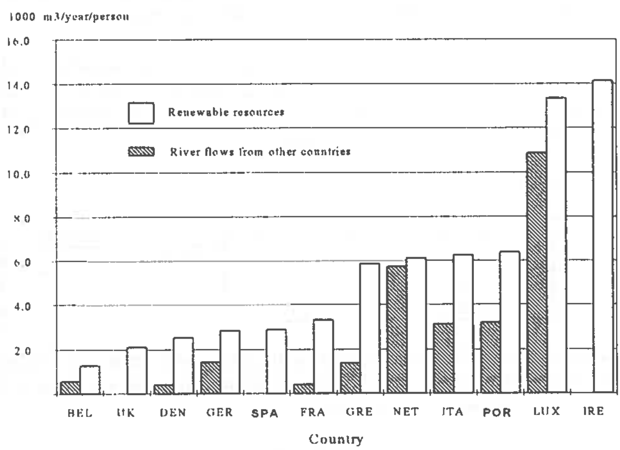

Fig. 3. EU Water Availibility (per Capita)

It can be concluded from the presented values that in Portugal almost 50% of its flows are "external", i.e., with sources in Spain. Although the population density is bigger in Portugal than in Spain (about 110 and 75 inhab/km^2, respectively), the hydraulic resources correspond to a mean precipitation per year in Portugal more than double than in Spain (about 700 and 325 mm/year, respectively), with a maximum space variation ratio of 1/10 for Portugal (minimum resources for Sado and Guadiana basins, with mean values of 140 and 150 mm/year) and 1/18 for Spain (minimum for Segura basin), with a 1/10 ratio when considering the total of Sur, Segura e Jucar basins (mean value of 95 mm/year).

In terms of allocation of water by use, Table 1 (INAG (a), 1995; CNA, 1992, for Spain data) compares Portugal and Spain with some other European countries.

TABLE 1 - Uses of Water

	Water Supply	Agriculture	Industry
France	39 %	31 %	30 %
Germany	33 %	12 %	55 %
Netherlands	44 %	22 %	34 %
UK	77 %	6 %	17 %
Portugal	8 %	76 %	16 %
Spain	14 %	80 %	6 %

The great importance of agricultural water use in both countries is obvious.

During the 90's, in both Spain and Portugal water demand is supposed to grow, respectively, (i) globally, 8% and 10% and (ii) by sectors, 7 and 10% in agriculture, 20 and 15% in water supply, and also in industry (whereas in most industrialised EU States it is decreasing). Actually, Spain is considered a country of marginal water resources (CEC, 1992); Portugal, with mean natural water resources around 6400 m^3/inhab/year and a consumption of hydraulic resources lower than 25%, is considered a country with adequate water resources.

Both Portugal and Spain have built dams for storage capacity, to attend namely to: a) the hydrological irregularities of the river flows; b) to the seasonal irregularity of the most important demand, irrigation for agriculture; and, c) in Spain, to the big percentage of consumption of hydraulic resources (40%, the biggest in EU).

TABLE 2 - Storage Capacity Characterization

	Capacity (hm^3)	Nb. Of Dams	Use (%)	
		-----	Hydroelectric	Others
Portugal	7 400	65	56%	44%
Spain	50 000	1000	40%	60%

The Portuguese actual storage capacity is similar to the predicted increase in the Spanish capacity (7250 hm^3) in the next 20 years. The consumption of hydraulic resources will then attain about 49% in Spain and 21% in Portugal.

PORTUGAL AND SPAIN SHARED WATERCOURSES

Portugal and Spain share five international rivers- Minho, Lima, Douro, Tejo and Guadiana. The total basin area of these rivers being 268 500 km^2, the Portuguese part (65% of the Portuguese territory) represents 21% of it (Fig. 4), most of it (about 95%) due to only three rivers (Douro, Tejo and Guadiana); the border of the two countries is 1 000 Km long, two thirds of it being established by rivers.

Bilateral Agreements

The Treaty of the Limits (Portugal and Spain "Tratado dos Limites ") of 1864 defined most of the borders between the two countries. The Annex 1 to this Treaty, relative to the bordering rivers, specifies that those rivers belong to each of the Nations by half of their flows and that any construction to be done on their bordering stretches shall be licensed by both countries; a complementary agreement in 1912 establishes that both Nations have the same rights on those river stretches and, in consequence, each one can dispose of half of the correspondent flows at anytime. The bordering definition was completed at the 1926 Convention.

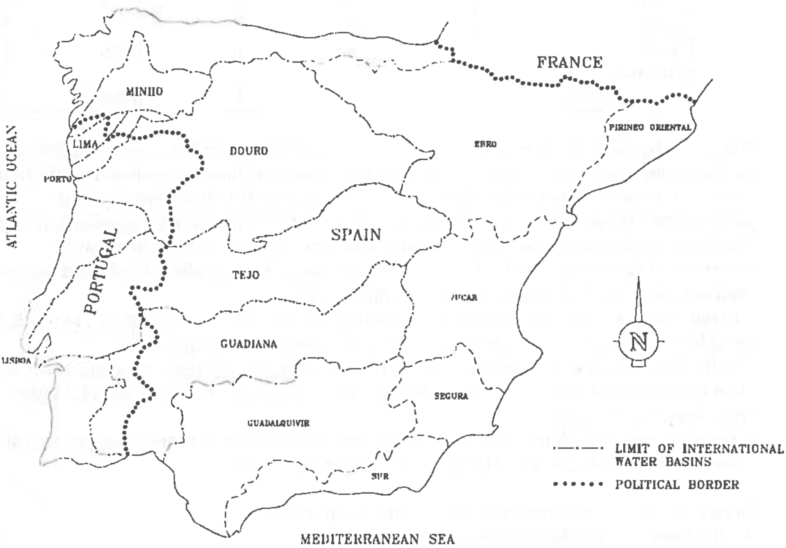

Fig. 4. Portugal and Spain Shared River Basins.

A "Convention on the Regulation of the Hydro-electric Utilization of the International Part of the River Douro", signed in 1927, was the first specific river agreement between Portugal and Spain. Its main aim was to rule the hydroelectric production; consequently:
- It divides the international stretch into two parts with similar hydropower potential, one for each country.
-It establishes that, other than for hydroelectric production, water can only be diverted for public health reasons, or similar, but always with previous agreement and compensations of both States.

A bilateral Commission for managing the technical and juridical application of the Convention was formed and is still in operation.

In 1964, the Douro Convention was extended to the affluents on the international stretch. The possibility of using remainder flows (flows that cannot be used downstream for hydroelectric production) and disposable flows (flows exceeding an average weekly flow) was then stated.

In 1968, a "Convention on the Regulation of the Hydro-electric Utilization of the International Parts of the Rivers Minho, Lima, Tejo, Chança and their Tributaries" was signed between the two countries. A global partition of the hydroelectric potential was agreed (Table 3), being settled that Portugal could build hydraulic plants on the Guadiana international river and Spain on the Tejo international river, the global parity being achieved by a joint construction and exploitation in the Minho river.

TABLE 3 - Shared Rivers Energetic Potential Partition

Rivers	Brut Energetic Potential attributed to: (GWh/year)	
	Portugal	Spain
Minho	151,8	590,4
Lima	522	
Tejo		542,6
Guadiana	277,9	
Chança		103,0

The evaluation of the energetic potential was done considering the flows at the beginning of each international stretch, this time deducting the volumes to attend to upstream needs. In the Tejo river, in addition to the provision for irrigation areas (470 000 ha) upstream the international stretch, the transfer of a yearly volume of 1000 hm^3 from the Spanish part of the Tejo basin to the Spanish Segura river basin (waterway Tejo-Segura) was previewed.
Apart from hydroelectric production, other uses for water are also referred and ruled, together with some basic environmental measures, following that:
- In the Lima and Tejo international river stretches, the diverting of water the use of which is ruled by the Convention will only be possible with mutual previous agreement;
- In the Guadiana and (its tributary) Chança international river stretches, each State has the right to divert water from its correspondent stretch for execution of official plans for water irrigation or water supply;
- The water use from all the stretches ruled by the Convention shall be done with reserve of minimum summer flows and of the flows for current water needs.

In fact, all these Conventions have actual limitations, because:
- their aim is to regulate hydro-electric water use;
- their scope is limited to the bordering zones and not to all the river basins;
- they do not refer any water quality commitments,

with no direct concern with the protection of the environment and not ensuring an equitable utilisation of the water.

In fact, the law of international watercourses has accompanied the changes in their uses; the recent agreements trend is to deal with different issues (irrigation, water supply, hydro-electric production, pollution, etc.) bearing in mind not the isolated river but the river basin system. This way, and recognizing the need of a sustainable utilisation of the water of their shared river basins, both governments declared to agree to a bilateral Convention on water resources, as soon as possible (Joint Declaration, 1994).
Apart from those bilateral Agreements, both countries have subscribed the Espoo Convention and also, as EU members, the Helsinki Convention.

Present and Future Situation

In terms of "natural mean flow" (NMF, flow values without considering any human uses) per year, the three main international rivers, Douro, Tejo and Guadiana are responsible for 74% of the total Portuguese flow, with almost 66% of it generated in Spain; however, in terms of storage capacity, the relative importance of those rivers seems to be greater in Spain (Table 4)- in Guadiana, namely, the storage capacity being about the double of its natural resources.

TABLE 4 - Population, Natural Resources and Actual Storage Capacity

		Douro	Tejo	Guadiana
Basin Population (10^6 inhab)	Spain	2,27	6,14	0,23
	Portugal	1,73	2,89	1,67
	Total	**4,00**	**9,03**	**1,90**
NMF (km^3/year)	Spain	15,00	12,23	4,97
	Portugal	8,15	6,40	1,70
	Total	**23,15**	**18,63**	**6,67**
Actual Storage Capacity (km^3)	Spain	8,00	11,00	8,90
	Portugal	1,00	2,70	0,30
	Total	**9,00**	**13,70**	**9,20**

In fact, comparing those rivers water intensity utilisation ratio (comparison of water demand with water disposability, this last identified with: Spanish NMF, for Spain; river basin NMF deduced by Spanish net consumptions, for Portugal) in both countries (Álvares Ribeiro, 1996), its values are actually always bigger in Spain and, in the near future, only in the Tejo is it predicted that they will be similar.

TABLE 5 - Water Intensity Utilisation Ratio (in %)

		Douro	Tejo	Guadiana
Portugal	Actual	13 %	19 %	12 %
	Future	16 %	25 %	44 %
Spain	Actual	26 %	22 %	48 %
	Future	36 %	24 %	60 %

In Spain, the agriculture water demand percentage is about 70% in the Tejo and more than 90% in the Douro and Guadiana rivers. In Portugal, the agriculture water demand is currently about 85% for all the three Portuguese river basins; in the future, in the Guadiana river it will attain a percentage similar to Spain.

From Table 4 and Table 5 values it can be concluded that, in both countries:
- the potential utilisable resources decrease from the humid North (Douro) to the dry South (Guadiana);
- the water utilisation ratio increases when North and South are compared, with consumption of hydraulic resources in the Guadiana, in the future, bigger than 40 % (actually already 48 % in Spain)

Table 6 presents both countries' present and future (next 15 to 20 years) utilisable resources and demands (agriculture, water supply and industry) for Guadiana river basin, according to MOPT(1993) data for Spain and INAG (Serra, 1996) for Portugal.

TABLE 6 - Utilisable Resources and Demands in the Guadiana Bassin

(km^3/year)		Utilisable resources	Demand
Spain	Actual	3,0	2,3
	Future	3,5	2,7
Portugal	Actual	0,5	0,4
	Future	1,6	1,3

An inter-basin water transfer of (max.) about 0,3 km^3/year from the Guadiana basin to adjacent south coastal basin of Algarve is envisaged, and should be added to the future demand from that basin.

In fact, in Portugal, according to INAG (Serra, 1996), some local deficit in the Portuguese basins are predicted but, if no inter-basin water transfers occour, they shall be corrected by an increase in flow regularization, by the construction of dams; also, no inter-basin water transfers from the Portuguese humid North to the dry South are predicted in the next 20 years. For Spain, no deficit is predicted for these basins; anyhow, the PNHE[3] states some inter-basin water transfers, in global terms to transfer water from the Douro basin to the Spanish South basins.

The analysis of the Conventions terms between the two countries does not seem to be taken into account in those rivers bilateral water policy. For example:

- The 1968 Convention regulated, as a compensation for the inter-basin water transfer of 1000 hm^3/year (max.) between the Spanish Tejo basin to the Spanish Guadiana basin (waterway Tejo-Segura), for agricultural use, the right of Portugal to deviate the flow on the upstream part of Guadiana international river stretch, mainly for agricultural use, for the hydraulic plant of Alqueva, expected to be under construction shortly. Due to the already intense Spanish agricultural use, supported by an enormous reservoir capacity, a deficit of 200 hm^3/year is already predicted for this plan (INAG (c), 1995); only a Portuguese-Spanish co-ordination on the exploitation of the regularization reservoirs will allow this deficit to be avoided.
- According to what is established in one of the Acts of the 1968 Convention in terms of water disposability and water uses in the Guadiana Spanish basin, the actual annual mean Spanish watercourse upstream border inflow should be 2400 hm^3/year, well over 1000 hm^3 than the measured one (mean value of last 20 years), LNEC (1994).

This kind of analysis, in terms of mean flow per year, is in fact, optimistic compared to reality, due to the very irregular distribution in space and in time of the water resources, with great seasonal and inter-annual irregularities, in both countries; in addition, also the demands for agriculture (irrigation) and water supply (tourism) are very irregular, and the greatest when the resources are scarcer (in summer). This way, and based on those facts, Álvares Ribeiro (1996):
- configured a future stress hydric situation for the Guadiana basin;
- demonstrated actual (Guadiana and Tejo) and future (Douro) problems of minimum ambiental flows.

In terms of quality of water, measurements made by INAG (Silva, 1996) show that the Spanish border inflow is of poor quality (grade C4, on a four scale classification) in all cases, unfit for any specific use (the worst in Guadiana).

WATER CONSERVATION AND WATER PRICING

The described actual and medium term situation of Portugal and Spain's hydraulic resources foresee a lack of water and problematic increasing demands, without taking into account climatic changes effects; in fact, predictions indicate a decrease in precipitation in Southern Spain and Portugal, "*where a 2-3°C temperature increase (by the year 2030) is expected to be accompanied by a 5-15% decrease in summer precipitation and a 15-25% decrease in summer soil moisture*" (CEC, 1992). If this occurs, difficulties will be considerably aggravated.

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[3] Spain has presented but not yet internally approved the so called "Plan Nacional Hidrologico Espanhol", PNHE (National Spanish Hydrologic Plan).

The major issues in the twenty-first century (Biskas, 1993) will be (i) water conservation and efficient use of water, (ii) water pricing and cost recovery, (iii) social and environmental considerations, (iv) institutional response to better management, (v) management of international water bodies and (vi) proper analytical frameworks. Water Conservation and efficient use of water apply for techniques of, namely:

- agricultural water demand reduction;
- industrial water demand reduction;
- leakage detection, control and reduction;
- water reuse;
- exploitation of aquifers;
- inter basin transfer.

We will analyse this last aspect and also water pricing policy from the standpoint of a Portuguese-Spanish bilateral effort to better fulfill the above referred issues.

Inter-Basin Transfers

Actually, relevant inter-basin water transfers occur only in Spain, in the Tejo basin, with a transfer of a yearly maximum of 300 hm^3 to the Segura basin, following the described 1964 Convention (where this transfer was accorded to be up to 1000 hm^3/year).

National Spanish Hydrologic Plan, PNHE (MOPT, 1993), pointed to a water transfer from the North/ Douro basins and also from the low Ebro in order to eliminate within 20 years actual local deficits and aquifer super-exploitation (3000 hm^3/year) and satisfy the total predicted water demand increase (6600 hm^3/year) for that period; this would imply - together with an 8300 hm^3 increase of storage capacity and groundwater extraction-, the volume of internal inter-basin water transfers to increase about 700% (from the 1992 value of 550 hm^3/year to 3770 hm^3/year in 20 years). Basically:
- The North/Douro transfer would send water to (i) the head of the Ebro river and,(ii) through the waterway Tejo-Segura, to the basins of the Guadiana, Guadalquivir, Segura, Júcar and Sur, all water deficient zones;
- Ebro transfer would feed the basins of Pirineo Oriental and also the Júcar and Segura basins. In addition, those transfers would adequately assure Madrid's water supply (Tejo basin), at this moment partly compromised by the actual Tejo-Segura water transfer.

Table 7 presents the balance of predicted inter-basin water transfers from the three main international rivers, based on the PHNE values for Spain and the INAG (1995 b), 1995 c) and 1996) values for Portugal.

TABLE 7 - Predicted Inter-Basin Water Transfers (hm^3/year)

	Douro		Tejo*		Guadiana	
Volume:	Portugal	Spain	Portugal	Spain	Portugal	Spain
Exported	60	900	0	200	700	0
Imported	0	0	0	150	0	170
Total	**-60**	**-900**	**0**	**-50**	**-700**	**+170**

* Balance not considering the Tejo-Segura transfer (max. 1000 hm^3/year)

The Portuguese transfers (i) in Douro are due to agriculture and (ii) in Guadiana are due to agriculture (Sado and Algarve basins) and water supply (Algarve) - those last (ii) based on the Alqueva hydraulic plant exploitation right, as agreed at the 1968 bilateral Convention.

The Spanish transfers are mainly concentrated in the Mediterranean basins and some adjacent zones, as the Atlantic basins of Guadalete/Barbate at the head of the Guadiana basin- all areas of intense irrigation for agricultural use, with hydraulic resources already exhausted.

TABLE 8 - Solutions (for Spain) Proposed by PHNE (values in hm^3/year)

Basin	Natural Resources	Total Demands (1)	Resources			Balance (2)-(1)
			Transfers		Total* (2)	
			Imported	Exported		
Guadiana	4872	2884	170		3636	+752
Guadalet/Barbate	860	617	110		617	0
Sur	2418	1492	155	110	1492	0
Segura	1000	2145	1045	30	2145	0
Júcar	4142	4282	890		4519	+237

* Available resources + water consumption returns + transfers

Table 8 shows (i) the natural resources and (ii) the 2012 hydrologic balance, based on predicted demands and resources, for some of those Spanish basins. It should be emphasised that:

- the demands in the Júcar and Segura basins are larger than their natural resources (114% bigger in the Segura basin);
- the Sur basin had in 1992 a deficit of its oriental zone (152 hm^3/year) due to a recent development of intensive agriculture; anyhow, its occidental zone is intended to provide a water transfer of 110 hm^3 to the deficient basin of Guadalete/Barbate;
- a transfer of 170 hm3/year to the head of Guadiana basin is supposed to compensate the actual over-exploitation of aquifers, due to intense agricultural use, in the so called Tablas del Damiel, causing problems of saline intrusion.

These transfers are, according to PHNE (MOPT, 1993), "*justified by the good profitability* (!) *of the agriculture irrigation areas and call for an effort of solidarity from the Spanish society*".

In fact, solidarity is due from both countries. As an example, when analysing the effects of these transfers, PHNE could conclude that the water transfers from the North/Douro basins would affect the hydroelectric production of those basins; anyhow, this would be compensated by the increase of production on the Tejo river, due to the deviated water transfer volume- in fact, due to the bilateral Conventions, this is valid only for Spain. Portugal was not considered as an affected part and it should have been. This loss of productivity would add, in the Douro, to the 10% loss of hydro-electric productivity due to the predicted Spanish total demand increase (INAG b) , 1995).

<u>Inviolability of the River Basin as an Ecosystem,</u> together with the prevailing rights of the populations over the administrative law are (or should be), in fact, the main obstacles to inter-basin water transfers.

In Spain, when the water transfer Tejo-Segura was decided, a volume of 1000 hm^3/year was internally proposed (as agreed with Portugal). This volume was finally limited to a maximum of 600 hm^3/year, conditioned to the fact that only the excess water from the basin needs could be transferred; in fact, up to now, 300 hm^3/year was the maximum attained Tejo-Segura water transfer. Recently (February 1996), the verdict of the Supreme Administrative Court of Spain, deciding on the appeal lodged by the "Junta de Castilla-La Mancha" decided to annul the previous decision of the Spanish Cabinet on the transfer of 35 hm^3 of water from the Tejo basin to the Segura basin, for agricultural purposes, because only the surplus or excess water can be transferred. The respective verdict was officially published as a " criteria verdict".

In the near future, according to the PNHE, a maximum surplus transfer of 50 hm^3/year (see Table 7) from the Tejo is envisaged, due to the ambiental degradation of this basin. The erroneous prevision for the Tejo can easily be repeated for the Douro and Ebro rivers, if the water transfer plans of PNHE are confirmed.
As Diaz-Marta (1993) refers, " *water transfers had their top in the first third of this century, but then they were put aside and nowadays are anachronistic. In the thirties, California approved a plan to transfer 5000 hm^3/year of water, only having managed to transfer 3000 hm^3/year because of a public referendum.* "

Sahuquillo (1983), in connection with a transfer from the Colorado river to the Arizona, also refers that " *water transfers were not approved without great opposition coming from the water origin areas. The Colorado water transfer was in litigation for 36 years and was only decided in 1964.* "

The PNHE water transfers previews were made considering that the super-exploitation of resources is natural and acceptable. Also, water resources policy cannot be referenced by the minimum acceptable protection levels (see Table 8).

Water transfers cannot be done if there is no excess water in the basin that provides the water and nobody can vouch that in the distant future there will be excess water. The inhabitants of the hydrographical basin that eventually remise water have to be continuously consulted, as there must be political and social agreements between the populations involved.

Water Pricing Policy

The Spanish water planning has been made in order to regulate water offer, without having in mind the sustainability of hydraulic resources. Also, the hydrological irregularities of its rivers, the big percentage of consumption of hydraulic resources and the irregularity of the most important demand - irrigation for agriculture-, obliged Spain to invest strongly in water infrastructures, namely in reservoir capacity, making Spain the EU country with the most expensive water cost at source (Egea, 1995).

The agricultural water demand of both Portugal and Spain is more than 75% of the total demand consumptions, more than double than any of the EU industrialised countries (see Table 1), and is predicted to increase more than 15% in the next 20 years. Anyhow, the revised European Common Agriculture Policy (CAP), since May 1992, promotes the reduction of the agricultural land.

"*What is the economical sense of an irrigation economy consuming about 80% of the water demand only to produce 1,4% of the GNP?*" , asked GREENPEACE (1994) referring to Spain; similar question could be formulated for Portugal. In fact, this is only possible by the artificial agriculture water prices, i.e. (Álvares Ribeiro, 1996; 1Ecu = 1,23 $US):

- Portugal: 0,016 $US/m3,
- Spain: 0,008 $US/m3.

The low agriculture water charges enhance the policy of both countries, with prices unchanged for decades; the prices in Portugal are anyhow double comparing to Spain.

In terms of drinking water prices, Table 9 compares the charge rates in some EU members, showing wide variations between those countries (Buckland, 1995). The mean value for the EU members is 0,812 $US/m3 (0,66 Ecu/$m^3$ - CEC, 1992), similar to the price of Portugal, showing that the drinking water prices in Spain are also subsidised ; if the correction for purchasing power would be made, the water prices ratio would still be significantly bigger-about 3:1 and 2:1 between the Portuguese and the Spanish, respectively, agriculture and water supply prices, for a correction proportional to GDP/capita ratio (11 753 $US/capita in Spain; 7293 $US/capita in Portugal, IWSA, 1995).

TABLE 9 - Index and Charges of Drinking Water

	Index of water prices*	$US/m3
Belgium	58	0,963
Denmark	101	1,676
Germany	100	1,661
Greece	15	0,248
UK	76	0,886
France	54	1,084
Italy	21	0,349
Luxembourg	80	1,328
Netherlands	55	1,093
Portugal	**45**	**0,747**
Spain	**33**	**0,549**

* referenced to Germany (index 100)

The biased situation in terms of exploitation of shared hydraulic resources tends to reflect, apart from different water policy enforcement, also a bias on water price policy of both countries. In fact, in the near future, the price of water should reflect its real price (Álvares Ribeiro, 1996). Appropriate strategies need to be focused on restraining growth in per capita consumption, namely in agriculture, improving basin water resources management and controlling demand through tariff setting based on economical and social reasons.

CONCLUSIONS

The actual and foreseen environmental situation of the shared Portuguese-Spanish river basins and the social effects of the bilateral water resources management policy, lead to some simple and more general conclusions:

- The environmental situation of shared river basins is strongly dependant on upstream reservoir capacity;
- The river basin should be developed and managed as an inviolable ecosystem, with a commitment of all the countries involved to principles of co-operation and solidarity;
- The development of any region leading to water consumptions bigger than the basin natural water resources is unsustainable and, if is based on a strict economic profitability analysis, shall not justify inter-basin transfers;
- A lucid analysis of the social and economical profability of the agriculture products and production shall be done;
- Inter-basins water transfers should only be admissible based on public health or water supply needs and not for agriculture use, as opposed to sustainable development;
- Water transfers cannot be done if there is no excess of water in the donating basin and should always be dependant on a periodic and participatory agreement with its population;
- Water tariff settings in the shared basins and in the water sector shall be harmonized, tending to reflect real costs, attending to different uses, to social effects and to the geopolitical nature of water;
- Water conservation, temperance and efficient use of water shall be also promoted and related to water tariff settings, always attending to the minimum welfare and quality water standards.

REFERENCES

1. Álvares Ribeiro, A. "Rios Internacionais. Legislação Aplicável a Países de Língua Oficial Portuguesa (International Rivers. Portuguese Official Language Countries Applicable Legislation)". 2ª Jornadas de Engenharia dos Países de Língua Oficial Portuguesa, Rio de Janeiro, Brazil; 1987.
2. Álvares Ribeiro, A.; Maia, Rodrigo. "Environmental and Social Effects of Reservoirs Upstream of International Rivers". International Conference on aspects of Conflicts in Reservoir Development and Management, City University, London, 1996.
3. Biskas, A. " Water for Sustainable Development in the 21st Century: a Global Perspective" Water Resources Management Series: 1, Oxford University Press; 1993.
4. Buckland, J.; Zabel, T. " Economic Instruments of Water Management and Financing of Infrastructure". International Conference on Institutional Dimensions of Water Resources Management, Instituto Superior Técnico, Lisbon, Portugal; 1995.
5. CEC. "Research and Technological Development for the Supply and Use of Freshwater Resources". Strategic Dossier, SAST (Strategic Analysis in Science and Technology) Project nº 6, Commission of the European Communities, 1992.
6. CNA. " Informe sobre Planificacion Hidrologica para el Consejo Nacional del Agua (Information for the Water National Council about the Hydrologic Planning)", Spain; 1992.
7. Diaz-Marta, M. "Notas para un Analisis del Plan Hidrologico en Preparacion (Notes for an Analysis of the Expected National (Spanish) Hydrologic Plan)". Revista de Obras Publicas, nº 3318, Spain; 1993.
8. Egea, J. M. G." El Gran Dilema Hidrológico: Convergencia o Divergencia con Europa (The Big Hydrologic Question: Convergence or Divergence with Europe)".El Agua, El Campo, Servicio de Estudios del Banco Bilbao Vizcaya, Bilbao; 1995.
9. GREENPEACE. " Greenpeace Ante El Plan Hidrologico Nacional". Greenpeace; 1994.
10. INAG a). "Recursos Hídricos de Portugal Continental e Sua Utilização (Portuguese Water Resources and its Utilisation)". Ministério do Ambiente; 1995.
11. INAG b). "Recursos Hídricos do Rio Douro e Sua Utilização (Douro River Water Resources and its Utilisation)". Ministério do Ambiente; 1995.
12. INAG c). "Recursos Hídricos do Rio Guadiana e Sua Utilização (Guadiana River Water Resources and its Utilisation)". Ministério do Ambiente; 1995.
13. INAG. "Recursos Hídricos do Rio Tejo e Sua Utilização (Tejo River Water Resources and its Utilisation)". Ministério do Ambiente; 1996.
14. IWSA. "International Statistiques For Water Supply". Brochure of the International Water Supply Association for the IWSA Congress 1995, Durban, South Africa; 1995.
15. LNEC. " Análise do Plano Hidrológico Nacional de Espanha (Analysis of the Hydrologic National Spanish Plan) ". Rel. 62/94, Laboratório Nacional de Engenharia Civil, Lisbon; 1994.
16. MOPT. "Plan Hidrologico Nacional. Memoria" (National (Spanish) Hydrologic Plan. Memory)". Ministerio de Obras Públicas y Transportes, Spain, 1993.
17. Sahuquillo Herraiz, A. " Panoramica Mundial. Tipologia del Uso Conjunto (Broad World View on the Joint Use of Superficial and Ground Water)". Curso sobre Utilización Conjunta de Aguas Superficiales Y Subterráneas, Valencia, Spain; 1983.
18. Serra, P. " Perspectivas dos Transvases no Plano Nacional da Água. (The perspective of Water Transfers into the National (Portuguese) Hydrologic Plan)". 3º Congresso da Água, Lisbon; 1996.
19. Silva, V. M.; Costa, V. B. ; Guerreiro, N."Rios Transfonteiriços. Que Qualidade ? (Transboundary Rivers. What Quality?)". 3º Congresso da Água, Lisbon; 1996.
20. Vlachos, E. " Transboundary Water Conflicts and Alternative Dispute Resolution" (Revision), Water Resources Management, Springer (in Association with NATO Scientific Affairs Division); 1996.
21. World Bank. "Country Experiences with Water Resources", Technical Paper nº 175, 1992.

ACQUIRING WATER FOR FLOW AUGMENTATION

Richard M. Rigby[1]

ABSTRACT

Flow augmentation from Snake and Columbia River Reservoirs has been identified as one of the key elements of a multi-component region wide effort to protect endangered Snake River salmon. The Northwest Power Planning Council's Fish and Wildlife Program and the National Marine Fisheries Service's Biological Opinions on operation of the Federal Columbia River Power System, have called for water from Reclamation's Idaho and Oregon projects on the Snake River and its tributaries. The current Biological Opinion calls on Reclamation to provide 427,000 acre-feet each year for flow augmentation, and to firm up the ability to provide this water in dry years. The Opinion stipulates that the water will be provided only from willing sellers and in accordance with state water law. Reclamation accepted this assignment in its Record of Decision and expanded the efforts to include privately-held natural flow water rights.

Annual rentals of stored water from Idaho rental pools has helped Reclamation provide 427,000 acre-feet each since 1993. In addition, Reclamation has permanently reacquired some 57,000 acre-feet of storage space from reservoir spaceholders and is completing an acquisition of some 18,000 acre-feet of natural flow rights. Reclamation's ability to accomplish acquisitions has improved through these experiences and the acquisition process has been streamlined.

FLOW AUGMENTATION REQUIREMENT

In 1990, several parties filed petitions with the National Marine Fisheries Service (NMFS) to list species of Snake River and Columbia River salmon as threatened or endangered under the Endangered Species Act. Senator Hatfield convened a regional "Salmon Summit," to seek to reverse declines in the petitioned stocks outside the formal ESA process. The summit was followed by the Northwest Power Planning Council's (NPPC) Regional Salmon Program for 1991 that called on Reclamation to provide water for flow augmentation. NMFS subsequently listed the Snake River sockeye salmon as endangered in December, 1991. In May, 1992 NMFS listed Snake River Chinook as threatened. This listing was upgraded to endangered in August 1994. Columbia River Coho were considered not eligible for listing. Reclamation, with the

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Corps of Engineers and the Bonneville Power Administration has consulted with NMFS on operation of the Federal Columbia River Power System in accordance with Section 7 of the Endangered Species Act, and NMFS has issued Biological Opinions on these operations starting in 1992.

Flow augmentation is a key component of NMFS' Biological Opinions and the NPPC's Fish and Wildlife Program. Like almost all salmon protection measures, the biological effectiveness of enhanced flows is not universally accepted. Water users and other upstream interests oppose flow augmentation. NMFS and the NPPC have the distinctly unenviable task of protecting salmon in a swirl of controversy. Not unexpectedly, each involved group argues that their actions are not significant when it comes to protecting salmon. There is no universally accepted single cause of decline.

ESTABLISHMENT OF VOLUNTARY SELLER PRINCIPLE

Past Activities

Reclamation looks to three primary sources each year to provide water for flow augmentation:

- Uncontracted and uncommitted storage space in Reclamation reservoirs. Some 98,500 acre-feet of storage space was available in 1991.
- Rentals, through the Idaho water bank and three rental pools. In 1996 Reclamation relied on rentals of Oregon natural flow.
- Storage space reacquired for flow augmentation, totaling 57,396 acre-feet.

In the drought years of 1993 and 1994 these primary sources weren't adequate to meet Reclamation's commitments for 427,000 acre-feet. As a last resort, Reclamation released water held in previously never used power head space in Palisades, Minidoka, and Anderson Ranch Reservoirs and winter streamflow maintenance space in Lucky Peak and Deadwood Reservoirs. The availability of powerhead space made it possible to provide the water needed without affecting the contract entitlements of reservoir spaceholders.

The volumes of water Reclamation has provided for flow augmentation are shown on Table 1:

Table 1.--Water Provided for Flow Augmentation To Meet Reclamation's Flow Augmentation Volumes - 1991 Through 1996 (values in acre-feet)

	1991	1992	1993	1994	1995	1996[2]
Upper Snake						
USBR Space	15,000		206,617	285,954	22,396	22,896
Rentals	84,000		65,000	44,325	232,839	194,667
Subtotal	99,000		271,617	330,279	255,235	217,563
Payette						
USBR Space	28,874	90,000	95,000	61,883	94,242	95,000
Rentals	73,651		34,971		50,758	56,300
Subtotal	102,525		129,971	61,883	145,000	151,300
Boise						
USBR Space			23,000	35,950	25,000	38,000
Rentals					2,000	
Subtotal			23,000	35,950	27,000	38,000
Oregon Natural Flows						
Skyline						20,073
OR Wtr Trust						64
Subtotal						20,137
Grand Total	201,525	90,000	424,588	428,112	427,235	427,000

[2] Estimated pending final confirmation with State water resource agencies.

<u>1995 Biological Opinion</u>

While water users and others may not agree that Reclamation's Snake River flow augmentation efforts are meaningful to salmon protection, various protection and recovery plans proposed by NMFS, the NPPC, State fish and wildlife agencies, Tribes and other groups universally call on Reclamation to provide water for flow augmentation. The volume of water desired ranges upward from 427,000 acre-feet. In legal challenges filed by the Idaho Department of Fish and Game and others, Federal District Court in Portland ruled that NMFS' 1993 Biological Opinion was inadequate. The then recently completed 1994-1998 Biological Opinion had been patterned after the 1993 opinion, and a legal challenge to the 1994 Opinion appeared inevitable. To comply with Judge Marsh's order, the plaintiffs and defendants to the suit agreed to develop a new multi-year Biological Opinion, effective in 1995.

In the extensive consultations that preceded NMFS 1995 Biological Opinion, the volume of flow augmentation water to be provided by the Bureau of Reclamation was considered in depth. The Actions Workgroup, established by the executives of the parties involved in the litigation, identified and analyzed alternative operations of the FCRPS, including different volumes of flow augmentation to be provided by the Bureau of Reclamation.

Voluntary Seller Principle

Volumes of 427,000, 927,000, 1,427,000, and 1,927,000 acre-feet were selected for analysis by the work group. Each of these volumes had been suggested in different proposals by NMFS, the NPPC, and Tribes and fish agencies. In calling on the Bureau of Reclamation to provide water for flow augmentation, these groups left the details of how to provide the water up to Reclamation. There are a wide range of views, each supported by legal analysis, on Reclamation's responsibilities to endangered salmon vis a vis existing contract and water right holders. They range from the concept that Tribal trust responsibilities constitute a prior right not requiring compensation to the view that existing water rights and contracts are supreme, and no water, even uncontracted supplies, can be released from project reservoirs without state and water user permission. State water law, Federal Reclamation law, Tribal trust responsibilities, and other Federal law are cited by advocates of different approaches as governing. The specter of an all-out fight over authority in the face of serious declines in salmon runs was not appealing to Reclamation.

Reclamation believed that additional water supplies would need to be acquired in order to provide 427,000 acre-feet in drought conditions, and that they could effectively be acquired only from willing sellers. [3] This approach would avoid

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[3] April 1, 1994 letter to Senator Craig from Daniel P. Beard, Commissioner of Reclamation, and Rollie Schmitten, Assistant Administrator for Fisheries, National Marine Fisheries Service. The letter states, in pertinent part: "Regarding your concerns for water rights, the Federal Government will not condemn water rights to carry-out the biological opinion in the Columbia and Snake River basins. The flows outlined in the biological opinion are target flows to be met in four out of five years by taking the actions outlined in the biological opinion. If the water to meet these flows is not available on a willing buyer/willing seller basis, consultation will be reinitiated and NMFS, the Bureau of Reclamation, and the other action agencies will work together to find alternatives to minimize impacts to listed salmon." The July 22, 1994 Idaho Statesman, reported on Secretary of the Interior Bruce Babbitt's visit to Idaho: "...Babbitt opposes forcibly taking the water from southern Idaho farmers. They are worried about statements by federal attorneys that the government can strip them of water rights. 'I recognize they have vested rights. I intend to stand by those'..."

the extended and perhaps equally expensive approach that would undoubtedly have resulted if Reclamation had adopted either extreme.

During consultations, Reclamation expressed serious misgivings as to the implementability of any upper Snake flow augmentation volume in excess of 427,000 acre-feet, including concerns that Idaho and Oregon agencies would not support such actions.[4] When combined with other FCRPS measures to be taken, 427,000 acre feet of flow augmentation was determined adequate to avoid jeopardy. The Biological Opinion reflected Reclamation's concerns by specifying that upper Snake flow augmentation water would be provided from willing sellers only and in accordance with state water law.[5] Reclamation accepted this component of the Biological Opinion in its March 15, 1995, Record of Decision (ROD)[6] and still believes that these are essential caveats in any actions to provide water for flow augmentation.

Current Expectations

The urgency of the consultations leading up to the 1995 Biological Opinion caused Reclamation (and perhaps others) to consider flow augmentation as a one-time activity. Reclamation would round up the necessary water supplies, and the task would be complete. In retrospect, providing 427,000 acre-feet of water for flow augmentation each year will require continuing effort. Rental pools will be a significant source of water for flow augmentation for the foreseeable future. Improving access to rental pool supplies appears to be a necessary and viable approach to providing water in future years. Strengthening existing rental markets and developing new ones appears to be an approach that can be supported by varied interests. In any event, it is the author's view that water acquisition will continue to be a front-burner issue for the Bureau of Reclamation and local water users for many years to come.

ACQUISITIONS

The Canyon View acquisition involved stored water that had been acquired under spaceholder contract with the Aberdeen-Springfield Canal Company. A suborganization held the water for patrons within the Aberdeen-Springfield Canal Company service area, pursuant to contract with the Canal Company. The suborganization decided to rely on ground water for its water supply and

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[4] February 10, 1995 letter to NMFS and the U.S. Fish and Wildlife Service from Regional Director John Keys.

[5] Biological Opinion, page 99.

[6] Record of Decision, pages 12 and 13.

executed an agreement to sell their surface natural flow rights and storage entitlements to the Canyon View Irrigation Company in 1975. Canyon View wanted the water supply for lands in the vicinity of Twin Falls, Idaho that Canyon View intended to develop under the Desert Land Act. Right of way problems delayed the project until agricultural economic conditions and other issues made it impractical to develop the land. Canyon View was able to put the stored water to use through the Upper Snake rental pool and also avoided forfeiture of its natural flow rights.[7] This acquisition was in many respects the most difficult, because it was the first one considered, had a complex chain of title, and required title approval by the Department of Justice. The Canyon View Irrigation Company and Reclamation's other three completed acquisitions are summarized on Table 2 below.

Table 2.--Permanent Acquisitions for Flow Augmentation

Entity	Acquisition Agreement	Closing	Right Acquired
Canyon View Irrigation Company	August 8, 1995	August 18, 1995	Repayment contract entitlement to 15,878 acre-feet of space in American Falls, Jackson, and Palisades Reservoirs
Salmon River Canal Company	November 30, 1994	December 21, 1994	Repayment contract entitlement to 6,518 acre-feet of space in American Falls Reservoir
Nampa & Meridian Irrigation District	July 22, 1996	July 30, 1996	Water service contract entitlement to 35,000 acre-feet of space in Lucky Peak Reservoir
Skyline Farms	September 30, 1996	Pending	Approximately 18,000 acre-feet of natural flow rights appurtenant to 4,419.5 acres

Salmon River Canal Company (SRCC) was actually the second acquisition initiated, but closed first, to Canyon View's exasperation. The reason was title, where federal bankruptcy court rendered a binding opinion thus confirming clear title to the SRCC water entitlement. SRCC had acquired the storage entitlement of a company in 1985. Reclamation was proposing to construct the Salmon Falls Division and SRCC acquired the water to help secure the project. As it turned out, the project was never funded and the storage was surplus to SRCC's needs.

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[7] Opinion from John A. Rosholt, Rosholt, Robertson & Tucker, subject: <u>Purchase of Upper Snake River (Id. And Wyo.) Reservoir Storage Water Rights of Canyon View Irrigation Company by the United States.</u>

Skyline Farms is a natural flow acquisition. Full agreement on price and other sale issues has been reached and closing is pending close of the comment period on water right transfer applications for most of the water. Closing on the remaining water (about a third of that acquired) is pending approval of a water right transfer by the Oregon Water Resources Department.

KEY WATER ACQUISITION ISSUES

Each of the four acquisitions has been unique in some aspects and Reclamation is still learning. The following discussion should be viewed not as a final pronouncement of how Reclamation acquires water in the Pacific Northwest. As new issues are confronted, adjustments will be made and the process streamlined.

Four issues stand out as critically important in the technical process of acquiring water for flow augmentation:

- Title--What are you buying?
- Value--What does it cost?
- Water rights--Can you use it?
- Water supply--Will it be available when you need it?

Title

No prudent buyer will acquire property without making sure that adequate title is being conveyed. The first major hurdle Reclamation faced in acquiring water was how to assure that clear title was conveyed. In considering the title question, Reclamation and the Field Solicitor considered that water has attributes of real property, because it is appurtenant to land. Accordingly, the decision was made initially to follow the paradigms for acquiring real property. In some cases such as acquisition of natural flow rights, there is a close match to the processes followed in acquiring land. In other cases, such as partial recision of water service or repayment contracts involving surplus storage space, the process is different.

Table 3.--Title Assurance For Completed Flow Augmentation Acquisition Agreements

Entity	Type of Title Assurance
Canyon View Irrigation Company	Abstract of Title and Department of Justice review
Salmon River Canal Company	US Bankruptcy Court Opinion and Abstract of Title
Nampa & Meridian Irrigation District	IC 43-318 (Sale Personal or Real Property - Procedure - Sale of federal or state license or permit)
Skyline	Title insurance

The requirements followed by the federal government in acquiring land, or interests therein include: (1) the requirements of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, as amended,(84 Stat. 1894; 42 U.S.C. 4601 et seq.; P.L. 91-646) often referred to as the "Relocation Act"; and, (2) the requirements of the Department of Justice as outlined in the Standards for the Preparation of Title Evidence in Land Acquisitions by the United States.

The Relocation Act: The Relocation Act and its implementing regulations (49 CFR Part 24) provide, among other things, that:

(1) landowners be offered, in writing, just compensation for their property based on an approved appraisal;

(2) the amount offered cannot be less than the approved appraisal of the fair market value of the property; and,

(3) the owner is to be given the opportunity to accompany the appraiser during the inspection of the property.

Other major provisions of the Act involve benefits for any "displaced persons"--not generally applicable to water right acquisitions.

The Department of Justice Requirements: The Standards require that title to all land or interests in land to be acquired by the United States must be approved by the Attorney General, or her delegee (pursuant to 40 U.S.C. 255) unless Congress has specifically provided otherwise. This applies to all types of acquisitions, including direct purchase from the owner, exchange, donation, settlement of litigation and condemnation.

The Interior Department Field Solicitor in Boise has been delegated this authority to approve title. The delegation is without limit when the title evidence being reviewed is in the form of Title Insurance from a title company approved by the Department of Justice. However, when an Abstract of Title is the title evidence provided for review (no title insurance), and the value of the rights to be acquired exceeds $1 million, the title must be approved by attorneys with the Department of Justice in Washington D.C. The additional step in obtaining review of complex water title issues by the Department of Justice can result in lengthy delays.

Therefore, the preferred form of title evidence in all acquisitions is, naturally, Title Insurance. In acquiring water rights, that is where the hitch is--as a longstanding rule, TITLE COMPANIES DON'T INSURE WATER RIGHTS.

The apparent reason that most title companies will not insure water rights is complex. For one thing, the "repository" for all water rights information resides with the State. Title companies' work is usually focused specifically on the county land records. Certainly, bad things can happen that can cloud the title to land, and many of these can impair title to water. Other bad things can happen to water rights that are outside the real property arena where title companies deal exclusively. While land is fixed in place, water can be moved around. Water rights can be forfeited or abandoned, and can even be sold apart from the land. It has been our experience that most of the attorney time involved in water acquisitions is spent clearing up, or dealing with, water right issues.

To streamline the title clearance process in water acquisitions, we have arranged with Stewart Title Company of Houston to issue a water right title insurance policy. They have agreed to furnish the United States a title insurance policy - insuring the title to the water right acquired - against attacks on the title to the land appurtenant. That means we can resolve the land-based (real property related) threats to the water right title in the same fashion as when we are acquiring land, and deal with approval of the water right title (related to personal property) locally, rather than through the Department of Justice in Washington D.C.

In the case of Nampa & Meridian Irrigation District, Idaho law (I.C. 43-318) provided specific authority for an irrigation district to dispose of property held through a federal permit or license, in this case a water service contract that would expire in 8 years.

Holders of repayment contracts have also approached Reclamation about selling part of their storage entitlements that may be considered surplus to the district's water supply. Here too, state law (I.C. 43-1831)provides a mechanism to secure a partial contract recision.

Table 4.--Tools to Assure Title[8] of Water Acquired for Flow Augmentation

Tool	Applicability	Procedural Requirements
IC- 43-318 (Sale of personal or real property - Procedure - Sale of federal or state license or permit)	Water service contract recision	Notice and Publication, opportunity for district patrons to request election or file suit contesting sale
IC 43-1831 (Districts embracing lands subject to Federal Liens - New and amended contracts with the United States)	Repayment contract recision	District election, court confirmation
Title Insurance	Natural flow acquisitions or sale of storage rights resulting in lands no longer being irrigated	Same as for title insurance to real property.

<u>Value</u>

In the case of stored water, Reclamation has been able to identify a standing price. This value is adjusted for the reliability of the reservoir and the type of contract entitlement (water service or repayment). Natural flow rights involve cite specific issues and are subject to a case by case determination:

Table 5.--Determining Value of Water Acquired for Flow Augmentation

Source	Basis
Repayment contract recision	Rate is based on storage space. $150 per acre-foot is value of the most reliable reservoir space, and adjustments are made for reservoirs will poorer refill potential
Water service contract recision	Rate per acre-foot of storage space is adjusted to reflect reservoir refill potential, then rate of return is established based on current interest rate. Acquisition cost reflects present worth of rate of return over the remaining contract term.
Natural flow	Case by case appraisal based on the difference between irrigated land values and dry land values.

[8] Reclamation continues to learn and adapt in acquiring water. The tools listed in this table may well change as additional experience is gained.

Water Rights

As mentioned above, the requirement to provide flow augmentation in accordance with state water law was embodied in the current Biological Opinion and Reclamation's Record of Decision. Reclamation sees this requirement as important for two key reasons. First, flow augmentation water must be protected in order to be of sure value to salmon, and recognition of these rights by state water administrators is a highly efficient time tested mechanism to protect the water. Second, Reclamation wants state approval of water right changes in order to promote wider consensus in flow augmentation activities. If water users and state water officials aren't involved in providing flow augmentation water, the gap between the irrigation community and fish interests widens. When Reclamation seeks water right changes, water users and state water officials must become involved. We think better decisions result.

Reclamation has filed change in use applications to seek Idaho's approval of flow augmentation releases. Following Reclamation's 1992 application the Idaho Legislature enacted I.C. 42-1763A, and later extended it through the 1995 augmentation season. This statute provided temporary authority to provide stored water for flow augmentation. Reclamation filed additional change of use applications on May 15, 1995 in anticipation of expiration of 42-1763A. Before the May 15 filing Reclamation shared a draft application with state and water user representatives for their input. Some 90 parties formally protested or requested intervention in the Idaho Department of Water Resource's deliberations on the change of use request. Reclamation staff and representatives of the Solicitor's office met with many protestants and intervenors individually, seeking consensus in accomodating the change of use. All parties agreed to a stipulation that was approved by Idaho Department of Water Resources Director Karl Dreher, and contested hearings over the change of use were stayed. In accordance with the stipulation, the parties developed draft legislation that was submitted to the legislature in January, 1996. All of the approximately 90 protestants and intervenors agreed to the stipulation and the draft legislation, and legislation was enacted. This legislation expires on December 31, 1999. Barring significant changes, Reclamation will refile water right change of use applications in 1999.

Reclamation expects to approach Idaho about the legislation to allow the use of natural flows for flow augmentation.

The Oregon Water Resources Department is now processing change of use requests associated with Skyline Farms. Reclamation anticipates OWRD's approval of the transfer on schedule.

Since Oregon reservoirs have not been used to provide flow augmentation, Reclamation has yet to file transfer applications for reservoir storage in Oregon, but does expect to make such filings in the future.

Water Availability

With each acquisition, Reclamation reviews the relative reliability of the water right. For storage acquisitions, Reclamation has good data to rely on. Natural flow acquisitions can require more work. The raw priority date of a water right can be quite misleading. A more appropriate question is "how often has the right been regulated in the past. The Snake River water rights with 1960's priority dates associated with Skyline farms have to Reclamation's knowledge never been regulated. However, in the Snake River above Milner Dam near Twin Falls Idaho, water rights as early as 1890 are curtailed in most years.

SUMMARY

The Bureau of Reclamation has successfully acquired over 57,000 acre-feet of storage space in Idaho and is on track to acquire some 18,000 acre-feet of natural flow rights in Oregon. Each acquisition has proven to be unique in some way. Through the capable and dedicated assistance of the Interior Department Field Solicitor's office, the process is becoming more streamlined. As long as funding is available, Reclamation expects to continue making good progress in acquiring water for flow augmentation.

Water acquired for flow augmentation meets needs other than protecting endangered salmon. Water quality is a significant concern along the Snake and other rivers. The experience and tools gained in acquiring water may well prove to be the closest thing to a win-win solution to water problems.

WATER ALLOCATION USING THE EFFICIENT MARKETPLACE

Kenneth R. Wright, P.E.[1] Patricia K. Flood, P.E.[2]

ABSTRACT

Competing interests and demands for water lead to pressures for water reallocation. An effective means for achieving fair and even-handed water reallocation is through the existing institutional framework of the real estate marketplace, coupled with precisely-defined interests in the water ownership.

The efficiency of the marketplace is well established and the ownership interest in water is usually susceptible to specific definition using location, rate or volume of water, reliability, beneficial use, and burden on the stream. A suitably defined water right can be, and should be, appraised for fair market value in the same way as normal real estate property.

Reliance on the public trust doctrine, reallocation of water by a state agency, or using special legislation to satisfy the highest and best use for water can lead to uncertainty and disruption among long-time water users. Uncertainty is the bane of economic progress. Certainty helps create wealth.

Case studies are presented which illustrate the principles of water reallocation using the free market system and the already-established mechanisms for fair and even-handed water transfers using the common denominator of the dollar to equitably balance benefits and losses.

To satisfy changing social values and economic forces, the procedures and laws related to water reallocation should focus on relative values and orderly transfers of the right for use of the public waters.

INTRODUCTION

Reliable water supplies in the west are, for the most part, fully developed and utilized. The growing competition for water between economic and environmental needs tends to add a complicating dimension to water reallocation along with a sense of uncertainty. Changing federal policies introduce additional uncertainties for the water manager. The reduced number of large federal water development

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projects means that industrial and municipal demands will increasingly be met through reallocation and conservation of water.

Reallocation of water using a marketplace made up of willing buyers and willing sellers is an efficient process for the transfer of water (Mac Donnell, 1990a). Reasons for the efficiency relate to near universal support in America for the free enterprise system, the respect for free markets and the existing institutional real estate framework already in place (AIREA, 1987).

The obstacles to the marketplace reallocation of water lie mostly in the offices of the various state engineers or natural resources departments where water transfers must often be approved and where such approvals can be time-consuming and uncertain. While the uncertainty related to state approval of a water transfer can be discouraging, better and more thorough transfer applications can reduce the uncertainty and can speed up the approval process. Transfer applications which ask for too much and which might not leave the public and other users whole are more likely to be rejected. On the other hand, applications which are socially responsible and respectful of the environment are more likely to be approved. Nevertheless, most applications for water transfers come to fruition (Mac Donnell, 1990).

WATER TRANSFERS

Many water transfers in the West are short-term and seasonal in nature. Most occur within a single irrigation district. Such transfers are simple and are generally not subject to state review and approval (Mac Donnell, 1990).

Water transfers, as referred to here, where the point of diversion is changed and where the transfer is subject to state review and approval, were reported upon by Mac Donnell (1990) for the years between 1975 and 1984 in six western states (Water Transfer Working Group, 1990). He found that:

1. The number of applications ranged from 3,853 in Utah to only 3 in California.

2. In states with a high level of activity, the quantities of water involved in the transfers was generally small.

3. Most transfer applications involved a shift from agricultural to municipal or industrial use.

4. Most transfer applications were approved.

5. The approval rate ranged from 75 percent in Wyoming to 94 percent in New Mexico.

6. Colorado had the highest number of protests at 60 percent while, in New Mexico, only 6 percent of the applications were protested.

7. The time required for approval tended to range from 6 months in New Mexico to 21 months in Colorado.

8. Average water transfer cost tended to range between $200 and $400 per acre-foot of perpetual yield transferred.

FAIR MARKET VALUE

The fair market value of a water right is determined by trained appraisers using the uniform standards of Professional Appraisal Practice and the rules outlined in Title XI of the Financial Institution Reform, Recovery and Enforcement Act of 1989 (FIRREA).

Appraisal procedures utilized include one or more of the accepted techniques of comparable sales, replacement cost, or income method (AIREA, 1987). The appraisal is typically based on the historic beneficial use in terms of the "burden on the stream" (consumptive use) and the estimate of how much of the water can be actually transferred to a new use. By using professional appraisers to determine the fair market value of a water right, the arena of speculation on the value is avoided. The market value of a water right is:

> *the most probable price, as of a specified date, in cash for which the specified water rights should sell after reasonable exposure in a competitive market under all conditions requisite to fair sale, with the buyer and seller each acting prudently, knowledgeably, and for self-interest, and assuming that neither is under undue duress.*

The market value is *not* what the buyers or seller "thinks it should bring."

TRANSFER PROCEDURES

The process for the transfer of water, where state approval is required, is orderly, logical, and designed to protect other water users from diminishment of their water rights, to insure that the burden on the stream is not increased, to protect the general public and to insure against the degradation of the environment (Meyers and Posner, 1971).

The processes for two states are illustrated in Figures 1 and 2. For the Nevada example, the public interest question has tended to be troublesome because the interpretation of public interest is left to the State Engineer.

The Long-Term Reallocation

For purposes of this discussion, a water transfer is a permanent reallocation of an appropriated water right or a share in a water right where:

a) There is a change in ownership;

b) There is a change in the use of the water and the place of use; or

c) There is a change in the point of diversion from the stream.

Reasonable concerns and objections to permanent reallocations of water are typically as follows:

a) The transfer would result in the sale of excess water, that is, the water involved represents that portion of the water right of the seller which is over and above the historic need;

b) The water transfer would move water to a new use resulting in a higher depletion to the stream;

c) The transfer would result in a new point of diversion resulting in more water available in the stream;

d) Moving the point of diversion of a senior water right downstream would mean that junior water rights not previously "called" would, after the transfer, be subject to a new downstream demand;

e) The return flow patterns of the new use would be changed as to both increased quantity and location. Downstream appropriators who previously enjoyed a particular return flow pattern could no longer rely on that historic pattern of return flow; and

f) The water demand pattern of the new use would be different than under the old use even if the rate and quantity of diversion might be less on an annual basis.

The concerns and objections listed above are ones which must be accounted for in the water transfer application; otherwise, the transfer is likely to be unsuccessful.

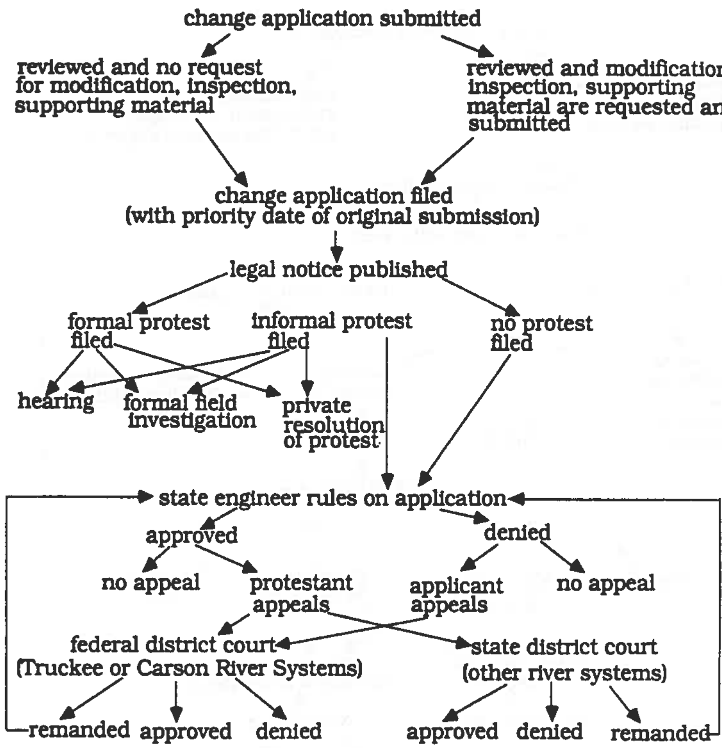


Fig. 1. Nevada Change of Water Right Process

(Colby 1989)

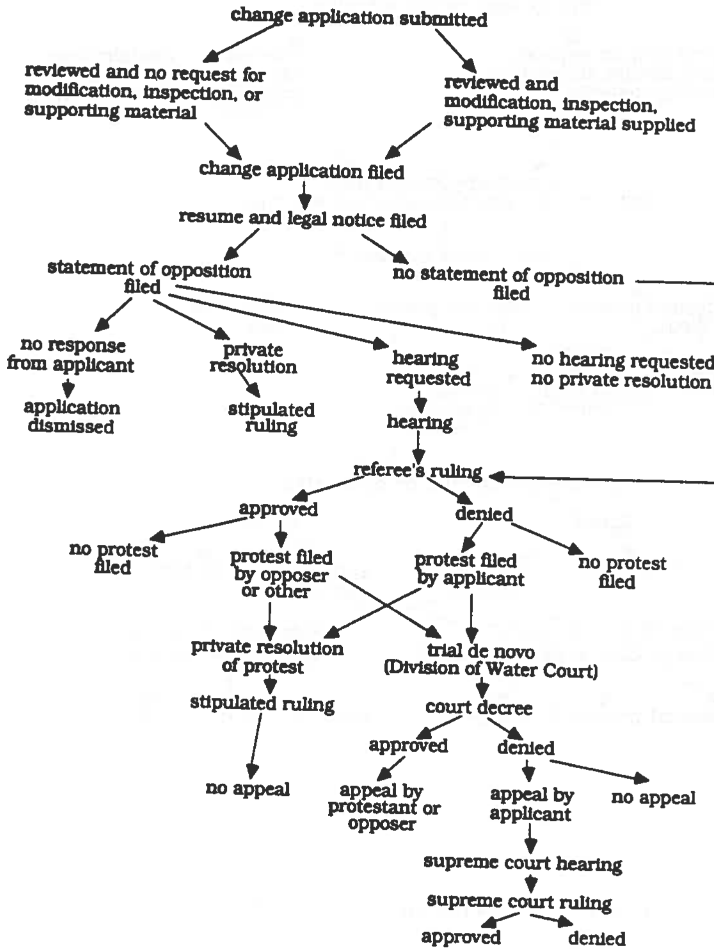


Fig. 2. Colorado Change of Water Right Process

(Colby 1989)

Statutory Obstacles

There are states which require the following:

1. The prior approval of an affected irrigation district or water users association.

2. The consideration of economic losses to the local community and the state.

3. The consideration of the availability of other sources of water.

4. That the transfer not unreasonably affect fish, wildlife, or other in-stream uses.

5. That the transfer not be detrimental to the public welfare.

6. That the water transfer must pass a "public interest" review or test.

Such obstacles to water transfers can often be used to hold up or stop an unpopular new use of water or where an otherwise suitable water transfer is considered to be excessive and which may not suitably represent a socially acceptable water move. As a result, water transfer applications should be properly balanced and crafted to avoid the waving of red flags in the face of approval agencies, other water users, and the public.

CASE STUDIES

Several case studies of water transfers are presented. There are thousands of potential examples of water transfers from which to choose; however, the case studies selected represent a wide variety of hydrological conditions—from simple to complex.

Adolph Coors Brewing Company, Golden, Colorado

The Adolph Coors Brewing Company at Golden, Colorado is the world's largest brewery plant with capacity well in excess of 20,000,000 barrels per year.

The Coors plant commenced substantial growth commencing in about 1960. The acquisition of a firm water supply for future growth was commenced in 1963 with a 30-year-long program which included four fundamental steps.

1. Evaluation of needs and identification of potential water sources;

2. Purchase of existing irrigation water rights and construction of storage capacity;

3. Applications to the water court to transfer the irrigation rights to industrial use and to change the points of diversion and return flow via a master water plan which balances out new depletions against historic depletions so as to leave the river whole (Colorado, 1993).

4. Receipt of appropriate court decrees approving the water transfers, new appropriations and master planned industrial water use.

The 30-year period of water acquisition and transfer reflected a general bull market in water rights where market prices increased steadily at a compound rate of about 15 percent per year. Cost of firm water rose about $400 per acre-foot in the initial acquisition period to about $10,000 per acre-foot of consumptive use during later years.

The three-decade-long water purchase and transfer process was carefully managed and implemented providing Coors with one of the most economical and reliable high-quality industrial water supplies in the west. The Coors Water Resources Program is founded on a drought scenario so severe that the chances of it occurring are about once in 500 years or more. The giant brewery is well set to withstand deficient runoff periods.

Rocky Flats Environmental Technology Site and Broomfield, Colorado

One of the purest of the free market water right transactions in the country occurred in 1993 in a North Denver bedroom community. The City of Broomfield, Colorado, sold its existing Clear Creek and related water rights through a public bid opening process in January 1993.

A consortium of cities including Westminster, Northglenn, Arvada and Blackhawk assembled a bid for the 2,235 inch-shares of Church Ditch and related Clear Creek water. The submitted bid price was $17,223,149 for water rights yielding an estimated average-year yield of 2,526-acre feet (approximately $6,820 per acre-foot).

The City of Westminster alone submitted a bid of $2,064,640 for 197.231 inch-shares of the Marshall Division of FRICO, South Boulder Creek. The estimated average yield of the Marshall Division rights is a 288 acre-feet (approximately $7,170 per acre-foot) yield.

Phoenix, Arizona Purchase of Ground Water Ranch

The 1980 Arizona Groundwater Code established four Active Management Areas (AMA) where the groundwater overdraft is most severe. The Phoenix AMA, as required by the code of the Arizona Department of Water Resources, developed a series of management plans to achieve safe yield of the groundwater resources.

The City of Phoenix, in its efforts to meet the deficiency in supply, sought to bring in new supplies from outside of the AMA.

The City of Phoenix purchased 15,724 acres in the McMullen Valley basin to obtain an estimated annual yield of 30,000 acre-feet (Ales, 1988 and Burke, 1988). The land purchase price in 1986 was $28,560,000 (approximately $952 per acre-foot excluding costs of physical delivery facilities). Additional costs for delivering the water to the surface and to Phoenix would include well fields and pipelines to deliver water to the Central Arizona Project canal. Therefore, the $952 per acre-foot can be equated to the cost of the water rights alone.

City of Aurora Purchase of Arkansas River Irrigation Water, Colorado

The City of Aurora purchased water rights in three major Arkansas River irrigation companies in southeastern Colorado. Aurora, located in the South Platte basin, plans to transfer the water through a series of exchanges, first from the subject ditches to Pueblo Reservoir, and then from there to a high-mountain reservoir where the water can be delivered into the South Platte basin (Water Market Update, 1987).

Rocky Ford Ditch water, purchased in 1986 and 1987, involved an average of approximately 8,250 acre-feet per year with a purchase price ranging from $2,200 to $2,300 per acre-foot.

The second transaction by Aurora involved approximately 3,000 acre-feet of foreign water purchased in the Busk-Ivanhoe Ditch Company at a cost of approximately $3,500 per acre-foot on the average. This purchase of 45 percent of the company brought the municipal ownership interests in the ditch company to 95 percent.

Aurora also purchased 5,600 acre-feet from the Colorado Canal Company at an estimated cost of $2,500 per acre-foot. Likely conditions for the transfer were established by earlier transfers from the ditch by the City of Colorado Springs.

Thornton Purchase of 100 Farms in Cache La Poudre Basin

The City of Thornton, Colorado, a suburb of Denver, in 1986 began purchasing water rights from farms in Weld and Larimer Counties in northern Colorado during a period of depressed farm prices. The "Northern Project" included the purchase of approximately 100 farms with an associated 21,000 acres of highly productive agricultural land.

This water acquisition project is one of the largest Colorado municipal water supply projects in recent years. The city acquired ownership interests in the Water Supply and Storage Company and the Jackson Ditch Company in the Cache la

Poudre basin. The cost of the acquisition and related new appropriations to Thornton is approximately $60,000,000. Delivery costs are not included in this acquisition cost. The water right costs represent a unit cost of roughly $1,200 per acre-foot of average yield.

The water transfer was actively opposed by numerous objectors. The Division 1 Water Court proceedings included 57 days of testimony. The trial court issued a Memorandum of Decision in August of 1993. The decree granted transfer of portions of the rights requested but also imposed conditions on Thornton's acquired rights. The City of Thornton filed an appeal with the State Supreme Court, with several objectors filing cross-appeals with the court (Colorado, 1996).

The Colorado Supreme Court issued a lengthy and well-considered decision on October 15, 1996. The 221-page decision addresses numerous previously unresolved issues in Colorado law. Participants in the case are currently digesting this important decision.

SUMMARY

Use of the water marketplace is a relatively efficient means for the reallocation of water supplies from agriculture to municipal and industrial uses. The marketplace relies on well-established principles of supply, demand, and fair market value. When water rights seem to be unavailable to thirsty potential buyers, the likely problem is that the offering price is too low.

Water transfer applications, for the most part, are approved throughout the west with the success rate ranging from 75 to 94 percent. Potential protests to an application are too often looked at by municipal and industrial water managers as major obstacles. Sometimes water transfers are publicized or tried in the media, however, in the world of water transfers, publicized protests are the exceptions.

Statutory or court-based procedures for water transfers are relatively complex, as they should be to assure that the public interest is well served. Typically, water transfers take less time than, say, gaining zoning and building permit approval for a new shopping center or major residential development. The typical time required for approval of a water transfer ranges from 6 months to 21 months. Of course, large transfers with inter-basin ramifications may take many years simply because of the complicated issues and politics involved. Sometimes the appeal process will add time to the process. A summary of transfer statistics for six western states are presented in Figures 3 to 9.

The most significant road blocks to the transfers of water between willing sellers and willing buyers are the various state laws requiring special public interest tests or requirements and where recreational or wildlife limitations are impaired.

Overall, the allocation of short water supplies using the marketplace is an efficient means for transferring water. The process, success rate, and cost all tend to be reasonable on the average.

REFERENCES

American Institute of Real Estate Appraisers (AIREA), 1987. *The Appraisal of Real Estate.* Chicago, IL: AIREA.

Ales, Frank, telephone conversation with the authors, 3 May 1988.

Burke, John, telephone conversation with the authors, 5 May 1988.

Colby, Bonnie, et al 1989. *Transerring Water Rights in the Western States—A Comparison of the Policies and Procedures.* Boulder, CO: Natural Resource Law Center.

Colorado District Court Water Division No. 1. *Finding of Fact, Conclusions of Law, Judgment and Decree Concerning the Application for Water Rights of Adolph Coors in Clear Creek and Jefferson Counties.* Greeley, March 26, 1993.

Colorado Supreme Court. City of Thornton V Bijou Irrigation et at and Alan Berryman, Division Engineer Water Division No. 1 and Northern Colorado Water Conservancy District et al, Appeal from the District Court Water Division No. 1. Denver, October 15, 1996.

Mac Donnell, Lawrence, 1990. "Shifting the Uses of Water in the West: An Overview". Moving the West's Water to New Uses: Winners and Losers. A Short Course Sponsored by the Natural Resources Law Center.

Mac Donnell, Lawrence J., 1990a. "Transferring Water Uses in the West". *Oklahoma Law Review* 43(1)119.

Meyers, Charles and Richard Posner, 1971. *Market Transfers of Water Rights" Toward an Improved Market in Water Transfers.* Arlington, VA: National Water Commission.

Water Market Update, February 1987 p. 3.

Saliba, Bonnie and David Bush, 1987. *Water Markets in Theory and Practice: Market Transfers, Water Values and Public Policy.* Boulder, CO: Westview Press.

Water Transfer Working Group, 1990. *The Water Transfer Process as a Management Option for Meeting Changing Water Demands*. Boulder, CO: Natural Resources Law Center.

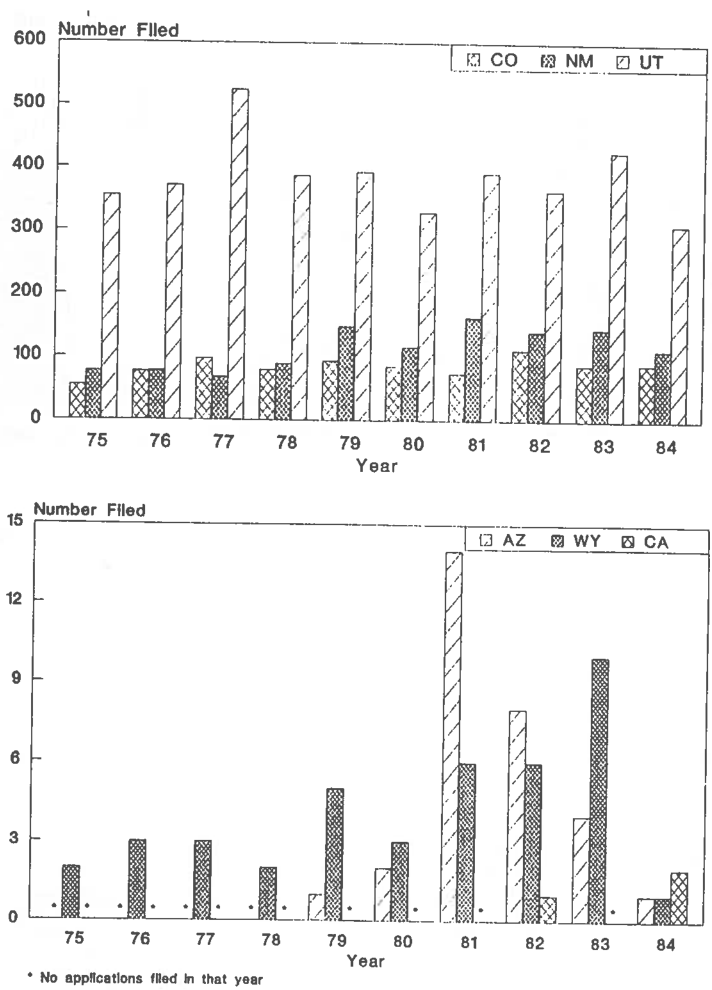
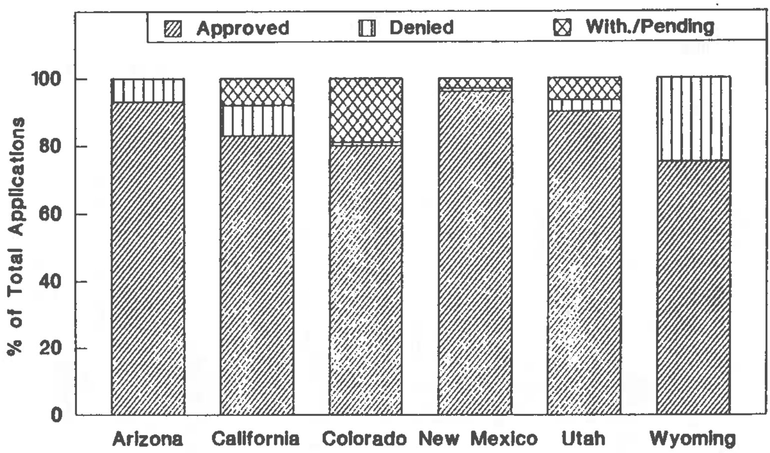


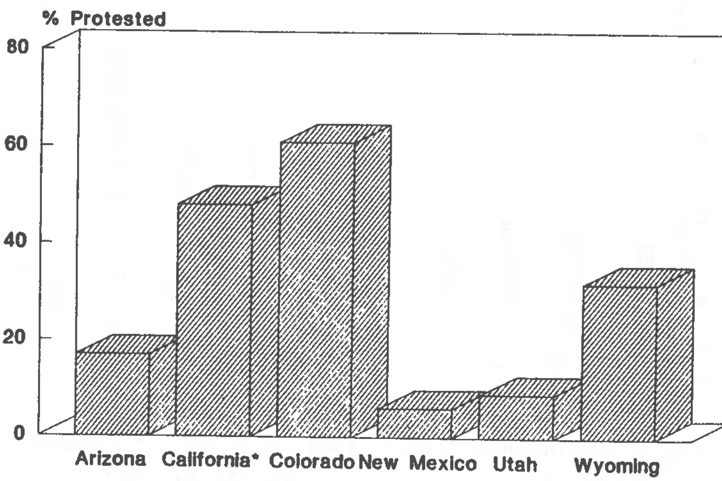
Fig. 3. Applications Filed by Year, 1975-1984, in Colorado, New Mexico, Utah, Arizona, Wyoming and California

(Mac Donnell 1990a)



* California data reflect cases filed between 1982 and 1989

Fig. 4. Disposition of Applications Filed Between 1975 and 1984, by State



* For applications filed between 1982 and 1989

Fig. 5. Percentage of All Applications Formally Protested or Opposed, by State

(Mac Donnell 1990a)

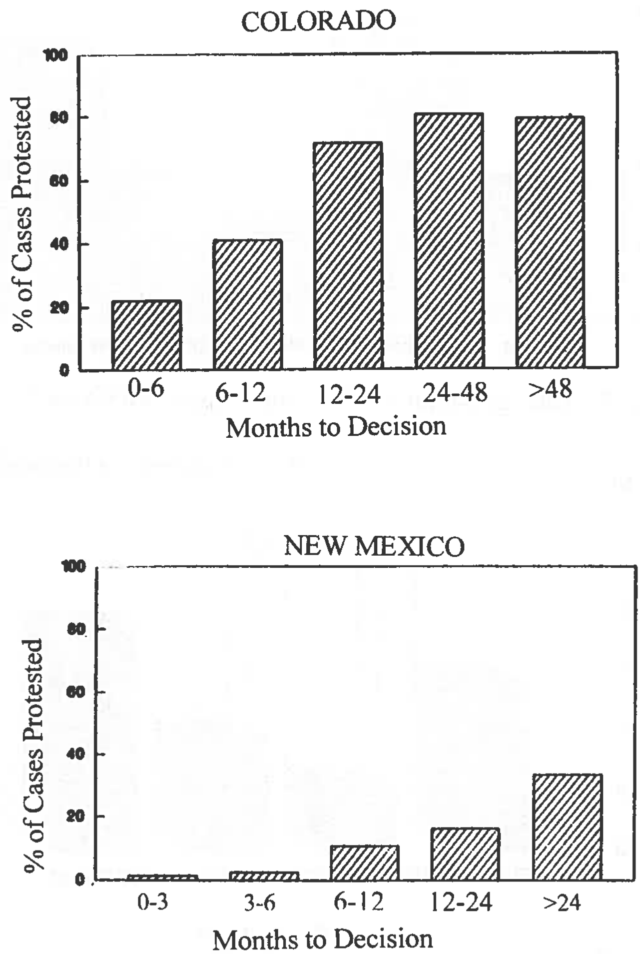


Fig. 6. Percent Protested of Approved Cases Versus Months to Decision by State 1975-1984

(Mac Donnell 1990a)

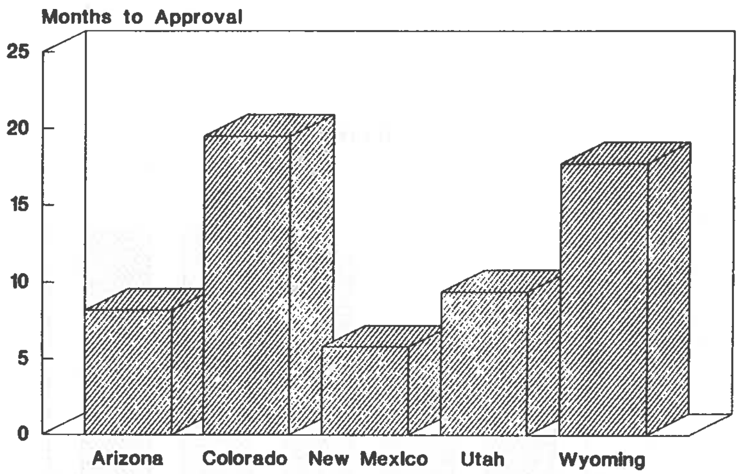


Fig. 7. Average Months to Decision, Approved Cases, by State

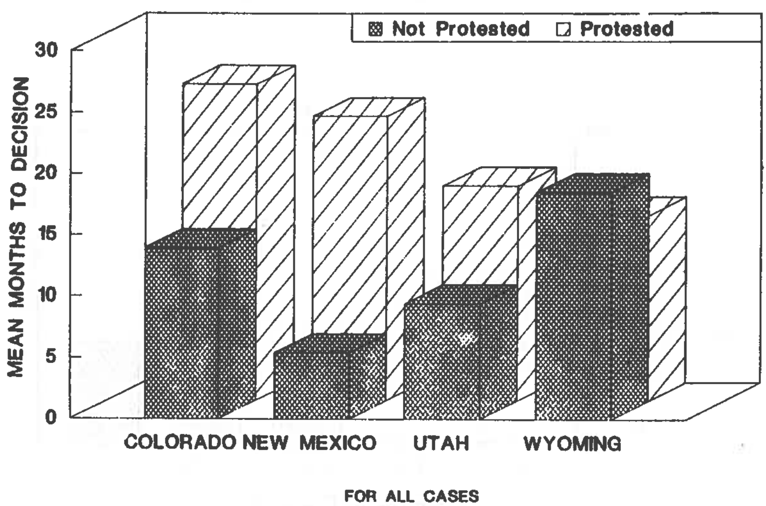


Fig. 8. Mean Months to Decision Vs. Protested or Not Protested by State 1975-1984

(Mac Donnell 1990a)

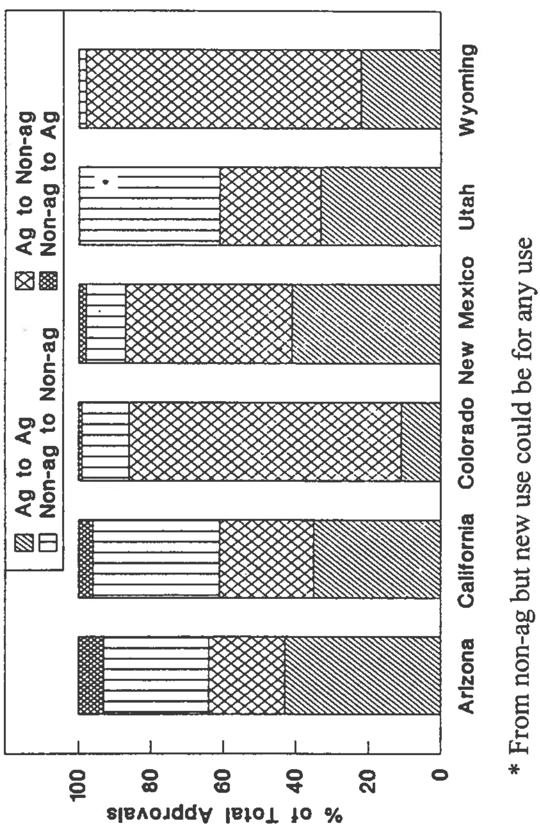


Fig. 9. Approved Changes of Water Rights by Purpose of Use, by State (Percent of Total Approvals)

(Mac Donnell 1990a)

BALANCING THE INCREASING DEMANDS ON WATER RESOURCES WITHIN HEBER VALLEY, UTAH

Karen M. Ricks[1] Reed R. Murray[2]

ABSTRACT

The Heber Valley area is located in Wasatch County, Utah just east of the large metropolitan area of Salt Lake City and the Wasatch Front. The historically rural agricultural lifestyle is experiencing tremendous pressure due to growth and the increasing demands of the local population within the valley as well as demands and needs from the Wasatch Front. These pressures are compounded by the joint planning efforts of the United States Department of Interior, Utah Reclamation Conservation and Mitigation Commission, and the Central Utah Water Conservancy District to implement two new Federal projects in this conservative yet progressive community. The water conservation, environmental mitigation and environmental enhancement aspects of the planned Federal projects are viewed as both benefits and impacts by the citizens of Heber Valley. Recognizing that rapid growth will continue with or without these Federal projects is slowly dawning on the population and we believe that the comprehensive public involvement manner in which the projects are being planned is providing the best mechanism possible to balance the competing needs and interest of the Heber Valley as well as the nearby population of the Wasatch Front.

INTRODUCTION

Established as an agricultural community by 1859, the Heber residents worked to develop a livable, thriving community based on traditional farming for the sole purpose of subsistence. During the early 1900's the railroad provided an opportunity for the farmers to begin the transition from subsistence to commercial agriculture. The fertile valley produced a wide variety and an abundance of products including

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alfalfa, barley, oats, wheat and sugar beets. Heber Valley livestock thrived, and lamb, beef, pork, eggs, wool and milk were produced for the expanding commercial market. Despite severe setbacks during the Great Depression, the Heber Valley continued the trend toward commercial farming as new technological advancements forced small-scale farmers out of business.

Agriculture is still a way of life and the livestock industry continues to thrive in this region. However, four nearby Federal water projects--Deer Creek Reservoir, Strawberry Reservoir, Current Creek Reservoir and the most recent addition of Jordanelle Reservoir--each built for the purpose of providing water for both municipal and industrial use and irrigation use, have increased recreational opportunities in the area. The addition of Wasatch State Park in the valley has also contributed in making recreation one of the newest and largest industries in the area. Many of the events in the 2002 Winter Olympics will be held within 15 miles of the Heber Valley, which will likely add to the population growth, recreation demand and water demand in this area. The population has grown significantly from the original 19 families who settled the valley in 1859 to more than 6,000 residents in 1985 and doubling to 12,000 residents by 1995. Increasingly, Heber Valley is also becoming a bedroom community. Each year people move from crowded areas in Salt Lake City, Park City, other communities along the east slope of the Wasatch Mountain range commonly called the Wasatch Front, and other states to the rural atmosphere of Heber City and surrounding small towns as it has become more common to commute fairly long distances to work in larger urban centers.

The Wasatch County Water Efficiency Project with Daniel Replacement Pipeline

The Wasatch County Water Efficiency Project with Daniel Replacement Pipeline (WCWEP) is a comprehensive project to address water conservation, environmental mitigation to fulfill longstanding mitigation requirements associated with previously constructed Central Utah Project features, and environmental enhancement within the Heber Valley. This project results from the combined efforts of the United States Department of Interior (DOI), a Federal Agency, the Utah Reclamation Conservation and Mitigation Commission (Mitigation Commission), a Federal agency, and the Central Utah Water Conservancy District (CUWCD), which has the authority to act as a Federal

Agency for purposes of this project.

WCWEP consists of physical improvements to the two largest irrigation supply canals, installation of some 37 miles of pressurized distribution pipe which will replace the same 37 miles of open irrigation canals in use at this time.

Daniel Irrigation Company, located in the Heber Valley, currently diverts water from the Colorado River Basin in Upper Strawberry Valley to the Great Basin via a series of diversion structures, tunnels, siphons and canals.
Partial mitigation for the Strawberry Collection System of the Central Utah Project is to terminate the diversion of water from the Upper Strawberry Valley. WCWEP provides the replacement water supply to allow this mitigation to occur.

This project will conserve in excess of 23,000 acre-feet of water each year. The conserved water will be used to maintain year round flows in five of the local streams in order to improve and protect the fishery and habitat provided by the streams. A portion of the conserved water will also be used to replace the Daniel Irrigation Company water supply which will provide significant environmental benefits for fish and wildlife habitat.

In direct relation to WCWEP, the Natural Resource Conservation Service (NRCS) is developing a watershed plan for Heber Valley. New water quality management techniques and sprinkler irrigation conversions will be partially funded by the NRCS and implemented by eligible local farmers and ranchers.

<u>Provo River Riverine Habitat Restoration Project</u>

This project results from the combined efforts of the Mitigation Commission and DOI. The Provo River Restoration Project (PRRP), also located in Wasatch County, would reconstruct and realign a majority of the nearly ten miles of existing Provo River channel and floodplain system between Jordanelle Dam and Deer Creek Reservoir. Restoration to a naturally functioning river channel with the floodplain and in dynamic equilibrium with the current valley and hydraulic conditions is the goal for this project. The Provo River has been extensively modified by man's activities, including impoundment, water diversions, channel straightening, dredging and diking. These actions have resulted in degradation of the natural functions and features of the riverine ecosystem, including loss of habitat for fish and wildlife, altered vegetative communities and altered sediment transport and deposition patterns. With this project we propose to naturalize the river channel and restore the ecosystem.

Balancing The Water Demands

The WCWEP will likely be the last agricultural project in the Heber Valley. Currently there are no more than four individuals who make their living exclusively in the agricultural sector in Heber Valley. There are, however, a majority of landowners who have five to ten acres on which they may raise a few cows or horses or grow hay, but these are categorized as hobby farms. Although future growth in the valley is inevitable, it appears the long-term development will continue to include agriculture in the form of hobby farms and ranchettes. All residents of the valley will benefit from the installation of an area-wide pressurized distribution system and elimination of many of the open canals and ditches under the WCWEP. There is a very distinct and evenly divided conflict between those who do not want to see the rural lifestyle changed and are opposed to any additional growth and those individuals who believe that progress toward urbanization is desirable and inevitable. It seems that the Daniel Replacement Pipeline component makes the total package much more palatable to the environmental community, in particular, as well as to those who truly support the preservation and enhancement of environmental benefits.

It is interesting to contrast the generally widespread support for the WCWEP project with the opposition for the PRRP. The project would require the acquisition of a corridor for the meandering river, floodplain and access for Operation and Maintenance. The local residents are violently opposed to the perception of "more Federal control", the fear that condemnation may be used as necessary, the loss of more land to Federal or State ownership, and the requirement for fisherman access to the river. The most prevalent perception voiced is that the project will encourage more people to play in or move to their rural little valley which will bring a tremendous increase in crime and trash, damage to property or livestock, and a changing lifestyle. Residents contend that the benefits of the previous Federal projects located in their county as well as the PRRP will accrue primarily to people living on the Wasatch Front. A frustration that the playground for the Wasatch Front residents is being forced upon Wasatch County has often been expressed. On the other hand, these emotions play havoc with their desire for the increased property values which are certain to come with restoration of the river and the desire of many to get out of the farming business and make big bucks on land sales.

Endangered species located in this area include the spotted frog, Ute-ladies'-tresses (an orchid), and the June sucker. These create significant additional demand on the water resources within the basin and must be given the appropriate consideration.

Public Involvement

The key to any successful project is involvement of the stakeholders. These projects are not exceptions to that rule. A comprehensive public involvement program was mandated by the authorizing legislation contained in Public Law 102-575, the Central Utah Project Completion Act. Public involvement techniques were used throughout each stage of planning for both Federal projects. Consultation and coordination with 29 agencies and organizations, as well as, hundreds of interested or affected individuals, the use of several issue-specific technical advisory committees, work shops, opinion surveys and public meetings were among the many resources which contributed to the successful planning of the projects in Heber Valley.

By inviting the interested and affected parties to participate in the planning process, each party tends to gain a "stake" in the final outcome and becomes an advocate for developing win-win solutions wherever possible.

Conclusion

Two facts are abundantly clear. The population of Wasatch County and the Heber Valley will continue to grow with or without these two projects and agriculture will play an increasingly smaller role in the economic and social development of this area. Water is the common denominator in both of these trends. We believe that the WCWEP and the PRRP provide the best mechanism available to balance the needs and interests of Heber Valley, Wasatch County and the state of Utah. The Wasatch County Commission has recognized that the PRRP will help preserve open space and help them put some controls on the virtually unregulated development pace which currently exists. More importantly, is the appeal that this can be accomplished at Federal expense rather than County expense.

Outside of Heber Valley there is tremendous pressure to provide for recreation along the Provo River through improved habitat, access, a parkway and hiking paths or bike trails. Utah residents believe they are entitled to access the rivers and streams of the state. The compromise included in the PRRP is to provide for strategically located public access points and contiguous right-of-way along the river to allow movement up and down the river but not to provide a parkway or hard surfaced paths. This decision will tend to allow the river to remain in a more natural state and to allow for maximum enjoyment by the public.

It appears that harmony can be achieved.

ECONOMIC IMPACTS OF SHORT-TERM WATER TRANSFER PROGRAMS-THE PALO VERDE LAND FALLOWING PROGRAM CASE STUDY

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ABSTRACT

The Metropolitan Water District of Southern California (Metropolitan) and the Palo Verde Irrigation District implemented a two-year test land fallowing program (Program) from August 1, 1992 through July 31, 1994. Under the Program, 20,215 acres of agricultural farm land in the Palo Verde Valley were fallowed. The saved water, approximately 186,000 acre-feet, was stored in Lake Mead by the United States for use by Metropolitan prior to the year 2000. Metropolitan compensated participating farmers $620 per fallowed acre per year which equated to $135 per acre-foot of water saved. Four surveys were conducted in the Palo Verde Valley during and after the Program to evaluate the economic impacts of the Program on the participating farmers and the community as a whole. Results showed that the Program was well received by the farmers and various community representatives, and that the Program contributed to a slight reduction in the average regional employment, approximately 1.3 percent. Participating farmers reportedly spent 93 percent of Program payments in excess of fallowing and maintenance costs on farm-related investments, purchases, and debt repayment. Although this Program had relatively small economic impacts, nevertheless it is a difficult task to quantify the positive and negative impacts of water transfer programs. Further details relating to the Program, third party impacts, and the regional economic impacts of the Program are presented.

INTRODUCTION

Metropolitan Water District of Southern California (Metropolitan) is a public agency which obtains water from the Colorado River and other sources and

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distributes it at wholesale rates to 27 member public agencies in southern California. These supplies account for 50 to 60 percent of the water used in southern California by nearly 16 million people, supporting a $475 billion economy. Metropolitan's 5,200 square mile service area spans portions of six counties -- Ventura, Los Angeles, Orange, Riverside, San Bernardino, and San Diego. Metropolitan holds the fourth and fifth priorities to use of Colorado River water in California.

Faced with the prospect of future water supply shortages within its service area, Metropolitan is pursuing a full range of programs to increase its water supplies and to improve the reliability of these supplies. One of these programs is the Palo Verde test land fallowing program (Program).

Palo Verde Irrigation District (Palo Verde), headquartered in Blythe, California, delivers Colorado River water to about 93,000 irrigated acres in the Palo Verde Valley, of which 85,000 acres are valley lands that were eligible to participate in the Program. Palo Verde holds the first priority to use of Colorado River water in California for these lands. The Palo Verde Valley, located at the eastern edge of California and separated from Arizona by the Colorado River, is about 30 miles long and 9 miles wide. It lies primarily in eastern Riverside County with a small portion extending into northern Imperial County. Major crops grown include alfalfa, cotton, wheat, sudan grass, melons, and lettuce. Palo Verde's net annual Colorado River water diversions for the period 1981-91 averaged 420,793 acre-feet. Drainage water collected by a system of open channels flows southerly by gravity and is discharged back to the Colorado River at the southern end of the district.

In the mid-1980s, Metropolitan and Palo Verde began discussions related to certain water saving programs in Palo Verde which could be implemented in years when urban water supplies were limited. However, it was May 1992 when the two agencies finally reached agreement to implement the two-year test Program.

Under the Program, 20,215 acres of agricultural farm land in Palo Verde (approximately 22 percent of the total cropped acreage) were fallowed for two years saving approximately 186,000 acre-feet of Colorado River water. The saved water was stored in Lake Mead for use by Metropolitan prior to the year 2000. To evaluate the economic impacts of the Program on participating farmers and the community at large, three surveys of Program participants were conducted during and after the Program, and a fourth survey of the local community was conducted after the Program. The purpose of this paper is to present the results of these surveys.

In devising the Program, specific measures were taken to insure the equitability of the Program and to minimize its economic impacts on farming operations and the community at large. Only up to 25 percent of a participating farmer's farm land was allowed to be included in the Program. Metropolitan compensated participating farmers $1,240 per acre over the two-year period. Participating farmers had to pay taxes on the farm land, water tolls, and land maintenance costs. Fallowed fields were not to be irrigated for the two-year period, and were required to be maintained weed free and managed in accordance with preapproved management plans for controlling dust and complying with existing wind erosion regulations.

Regional Economy Prior to Start of Program

The City of Blythe is the economic center of the Palo Verde Valley. Its population in 1994 was about 9,800. Other communities within the valley, including the small towns of Ripley and Palo Verde, account for an additional 8,400 people. In Arizona, the towns of Ehrenberg and Quartzsite lie approximately 6 and 20 miles east of Blythe, respectively. These two cities and southern La Paz County, Arizona account for an additional 4,900 people. The region's year-round population is approximately 23,100.

Prior to the start of the Program, several events had affected regional economic activity either positively or negatively. To assess the effects the Program had on the local economy, it was necessary to first identify the impacts of these other events. These events included the construction of two state prisons, a substantial increase in housing and commercial construction, a statewide economic recession, and a depressed agricultural economy.

The opening of the two state prisons created over 1,600 jobs. The Chuckawalla Valley State Prison was opened in November 1993, and the Ironwood State Prison was opened in October 1994. The new prisons were a significant source of income to the region and had invigorated the Blythe economy. They contributed to the significant increase in new construction in the region due largely to the additional demand for housing. Similarly, requests for new telephone service had increased significantly during the period from 1992 to 1994.

The Palo Verde Valley has been and continues to be founded in agriculture. However, between 1988 and 1991, the gross value of crops produced in the valley dropped from $189 million in 1988 to $79 million in 1991, a drop of 58 percent (all in 1992 dollars). In particular, the gross value of vegetable production fell by 86 percent during the same period resulting in significant impacts on the region's farm employment. This regional decline in vegetable production and, consequently, the reduction in the region's farm employment was in no way related to the Program. There were three primary causes for this decline: (1) the whitefly infestation, (2) the collapse of the alfalfa market in 1991, and (3) the long-term decline in the region's vegetable production. The whitefly infestation started in 1986 and had a significant impact on the production of crops in the valley. Between 1990 and 1991, the average price per ton received for alfalfa in the valley fell by 36 percent while the average revenue per acre fell by 43 percent. The alfalfa market did not recover until 1993 after the Program had begun. Vegetable production within the valley had declined steadily since 1984. By 1992, vegetable acreage was 76 percent below its 1984 level. Other base economic activity in the region includes light manufacturing and tourism.

RESULTS

Economic Impacts of the Program

The net change in field crop production due to the Program was approximated using the Riverside Agricultural Commissioner's Acreage and Agricultural Crop Report data for 1992 and 1993. Wheat, sudan grass, and alfalfa were the crops most likely to have been affected by the Program. It was estimated that 1,521 acres of wheat, 2,413 acres of sudan grass, and 16,281 acres of alfalfa (for a total of 20,215 acres) were not planted due to the Program. Estimated changes in gross farm revenue as well as the purchase of farm inputs (such as seed, fertilizer, chemicals, and custom services) due to the Program were based on these estimated acres of unplanted crops.

Gross farm revenue was estimated to have declined by $33.7 million (in nominal dollars) over the two-year Program period. Program payments of $25.1 million partially offset this decrease resulting in a net reduction of $8.6 million over the two-year period or $4.3 million per year. This net reduction of $4.3 million per year in gross farm revenue is 4.5 percent below what might have occurred absent the Program and assuming 1993 average prices and yields, i.e. $96.1 million. It must be emphasized, however, that the Program altered the distribution of farm revenue within the valley.

To explore the effects of this altered distribution of farm revenue, the net change in farm input purchases was evaluated. It was estimated, based on the surveys conducted, that Program participants spent approximately $862,000 and $143,000 during the first and second years of the Program, respectively, to comply with fallowing, weed control, and wind erosion requirements. A net decrease in farm input purchases over the two-year period was estimated to be approximately $4.0 million per year. As a comparison the reduction in farm input purchases caused by the lettuce acreage reduction from 1988 to 1991 was estimated to be $8.3 million per year, approximately 2.1 times greater than that caused by the Program.

Furthermore, three surveys of Program participants revealed that 93 percent of Program payments in excess of fallowing costs were reinvested into the farm economy either to pay down debt (37%), make farm improvements (11%), or cover operating expenses and rent (45%). Evaluation of the economic benefits resulting from Program payments was beyond the scope of the conducted surveys.

Program participant surveys also revealed that the Program contributed to the loss of 27 full-time farm jobs. For comparison purposes, the decrease in demand for farm labor associated with the reduction in vegetable production between 1988 and 1991 was estimated at 1,400 full-time-equivalent jobs. The Program was assumed to not have any impact on seasonal labor since only field crops were not planted.

Results from the fourth survey conducted in the Blythe market area showed that the Program's negative economic impacts were concentrated within farm-related businesses providing services or supplies to the region's farmers. Three of four businesses surveyed providing farm services characterized the Program as causing a significant decrease in their revenues in 1993, while three of four respondents providing farm supplies characterized it as causing a minor decrease. These impacts were perceived to have had contributed to the loss of 25 full-time and 7 part-time jobs in these farm-related businesses. Based on the Employment Development Department employment counts for the region, the total employment losses associated with the Program (52 full-time and 7 part-time jobs) were estimated to be equal to approximately 1.3 percent of the average regional employment for 1991-92. Since it was beyond the scope of the conducted surveys to estimate the employment stimulus associated with regional spending of Program payments, estimated employment losses due to the Program may in fact have been less than estimated.

The Program was found not to have caused reductions in employment or revenues for non-farm-related businesses in the region. Surveyed and interviewed non-farm-related businesses indicated that the Program had no perceptible effect on their revenues, and did not cause them to adjust their employment. Businesses surveyed whose farm-related sales in the region comprised less than 20 percent of their total revenue also indicated that the Program did not affect their businesses in any significant way.

In conclusion, the Program was not found to have affected overall regional economic performance to any significant degree. City officials and local bank representatives characterized the state of the regional economy during the Program as improved relative to pre-Program conditions. Additionally, the Program was not found to have affected the region's property or sales tax bases, or the provision of governmental services. In fact, the Program provided for timely financial relief to the region's agricultural producers who had been under significant hardship due to a major pest infestation and low prices for key commodities such as alfalfa.

ADDRESSING SELENIUM PROBLEMS IN IRRIGATION RETURN FLOWS BY SUPPORTING AND ENHANCING EXISTING PROGRAMS, WESTERN COLORADO

Richard A. Engberg[1] N. John Harb[2]

ABSTRACT

The National Irrigation Water Quality Program (NIWQP) of the U.S. Department of the Interior is planning the remediation of problems related to selenium in return flow from the federally sponsored Grand Valley and Uncompahgre Irrigation Projects in western Colorado. Four fish species native to the Upper Colorado River Basin are federally listed as endangered; they are the Colorado squawfish, the razorback sucker, the bonytail chub, and the humpback chub. Twenty-nine of the 60 roundtail chubs, a surrogate species for the Colorado squawfish collected in 1992 from the Colorado and Gunnison Rivers which receive return flow from the Grand Valley and Uncompahgre Projects respectively, had selenium concentrations greater than 6 micrograms per gram (ug/g) dry weight. Previous research indicates that reproductive impacts may occur in fish at concentrations greater than 6 ug/g. However, only 2 of the 60 flannel mouth suckers, another surrogate species collected at the same locations in 1992 had concentrations exceeding 6 ug/g. It is not known how much of a factor, if any, these somewhat elevated selenium concentrations have played in the decline of the endangered species because no cause/effect relationships have been established. Other factors such as dams, diversions, loss of wetlands or other backwater habitats, river regulation, water temperature, and predation by introduced species of nonnative fish, are known to or may interfere with reproduction and could be responsible for the loss of young fish.

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Solution of selenium problems may include wetland enhancement by providing consistent sources of freshwater for wetland flushing, and, if needed, sediment treatment. The existing Recovery Program for Endangered Fish of the Upper Colorado River Basin is engaged in some of these activities. Other solutions include the reduction of seepage and irrigation return flow by lining or piping canals and laterals and by on-farm improvements including sprinkler irrigation and irrigation scheduling. The Colorado River Basin Salinity Control Program and the Natural Resources Conservation Service of the Department of Agriculture are addressing these questions.

NIWQP is faced with several considerations in determining what remediation is reasonable and proper: (a) how is responsibility for remediation assessed; should public funds be used to remediate contaminant problems, should irrigators bear these costs (private funds), or should the costs be shared between public and private funds, (b) how best to predict impacts on endangered species if selenium contamination is reduced, (c) how to ensure that NIWQP efforts compliment those of other ongoing programs in the Upper Colorado River Basin, and (d) how best to ensure the least economic or social disruption of communities or individuals affected by remedial activities.

NIWQP BACKGROUND

Introduction

Since the first federally sponsored irrigation project was authorized in Nevada early in the 20th Century, irrigation projects have been constructed by the Department of Interior (DOI) bureaus in western states. Over 10 million acres of previously non-arable land have been converted to agricultural land, representing about 20 percent of the total irrigated land in western states. Drainage from irrigation projects has long been known to affect the quality of water in receiving streams, wetlands or lakes. Most frequently, this has been manifested by increased dissolved solids concentrations in drainwater as a result of increases in dissolved constituents such as sodium and chloride. Waterfowl reproductive failures, deformities, and mortalities were found in 1983 at Kesterson Reservoir in the San Joaquin River Valley in California. Researchers determined that elevated concentrations of selenium in irrigation drainage reaching the reservoir were responsible. This was the first reported example of irrigation drainwater-mobilized trace constituent contamination besides boron to be reported.

Infiltrating irrigation water mobilized selenium in soils on the west side of the San Joaquin Valley. The enriched water was carried by buried tile drains to a canal and was used subsequently to augment water supplies at Kesterson Reservoir. Bio-available forms of selenium from the drain water delivered to the Kesterson Reservoir were incorporated into the food chain. Within three years after the first delivery of drainwater, waterfowl problems were observed.

The DOI National Irrigation Water Quality Program was initiated in 1985 in response to concerns raised by the problems at Kesterson Reservoir about contamination of water, bottom sediment and biota in National Wildlife Refuges or migratory bird use areas by trace constituents or pesticides contained in drain water from the DOI constructed or managed irrigation projects in the western United States. The program has five phases. In site identification (phase 1), over 600 irrigation projects were aggregated, studied, and categorized. Thirty-four aggregated areas were selected for further study. By 1993, reconnaissance investigations (phase 2) were completed or underway in 26 areas and detailed studies (phase 3) were completed or underway in 8 areas. Planning for remediation (phase 4) studies began in 1991 for 4 areas and, in 1994, a fifth study was initiated for the the Gunnison and Grand Valley areas in western Colorado. Remediation (phase 5) is not yet underway for any areas.

Program Goals and Responsibilities

A general goal of the NIWQP is to ensure that irrigation drainage from DOI projects is not responsible for violations of the Endangered Species Act (ESA) and the Migratory Bird Treaty Act (MBTA). The purpose of the ESA is to provide protection for animal and plant species that are currently in danger of extinction or may become so in the foreseeable future. All federal agencies are to ensure that their activities do not have an adverse impact on these species or their habitats. The MBTA was enacted to implement conventions between the United States and other countries in the Western Hemisphere to protect migratory birds. Provisions in the act make it a crime for an individual, or corporation, to take or kill a migratory bird including its eggs or young.

A more specific goal of the NIWQP is to reduce or eliminate impacts clearly known to be caused by contaminants from DOI projects while minimizing adverse social and economic impacts to the local communities and individuals. NIWQP responsibilities take into account a variety of complicating factors, including the following:

Federal vs. Non-Federal Irrigation: NIWQP responsibilities for remediation require an understanding of impacts that are the results of federal programs. NIWQP has no role or responsibility for remediation at non-federal irrigation projects. In many areas, it is difficult to separate the drainage impacts that are due to federal irrigation projects from those caused by non-federal irrigation projects.

Contaminants and Impacts on Biota: The relationship between the chemical contaminants and the biota are often unclear and difficult to quantify. Laboratory studies have been completed to evaluate the levels at which biological impacts can be expected. Also, substantial field observations have been made about the presence or absence of indigenous species in the area of study. Presently, there is still no guarantee that the elimination of a contaminant in water, food, or sediments will cause dramatic or noticeable improvements for the biota. Besides agricultural-related influences, other anthropogenic or nonanthropogenic factors affect the biological population in a system including water management, water temperature, stream sediment and the resultant turbidity, salinity, mining activities, impoundments, channelization and loss of wetlands or other habitats, fish removal projects, and competition with nonnative organisms.

PREVIOUS NIWQP STUDIES - WESTERN COLORADO

Background and Problem

The Gunnison River Basin and the Grand Valley areas were opened to settlers in about 1881. Almost immediately upon the opening of the valley, privately developed irrigation systems using water diverted from the Colorado and Gunnison Rivers began converting the landscape, bringing thousands of acres of fertile land into production. In 1907, Secretary of the Interior, James R. Garfield, approved the plan for the construction of the Grand Valley Project by the Bureau of Reclamation (BOR), then known as the United States Reclamation Service. The project, located in the Colorado River valley near the confluence of the Colorado and Gunnison Rivers, provided a significant boost to the valley by supplying a reliable source of irrigation water to about 42,000 acres of farmlands and orchards on the north side of the Colorado River. Irrigated lands in the Grand Valley including the federal project are shown in Figure 1.

In approximately the same period, other private and federal irrigation systems including the Uncompahgre Project in the Gunnison River Basin were installed. Development of these projects involved construction of

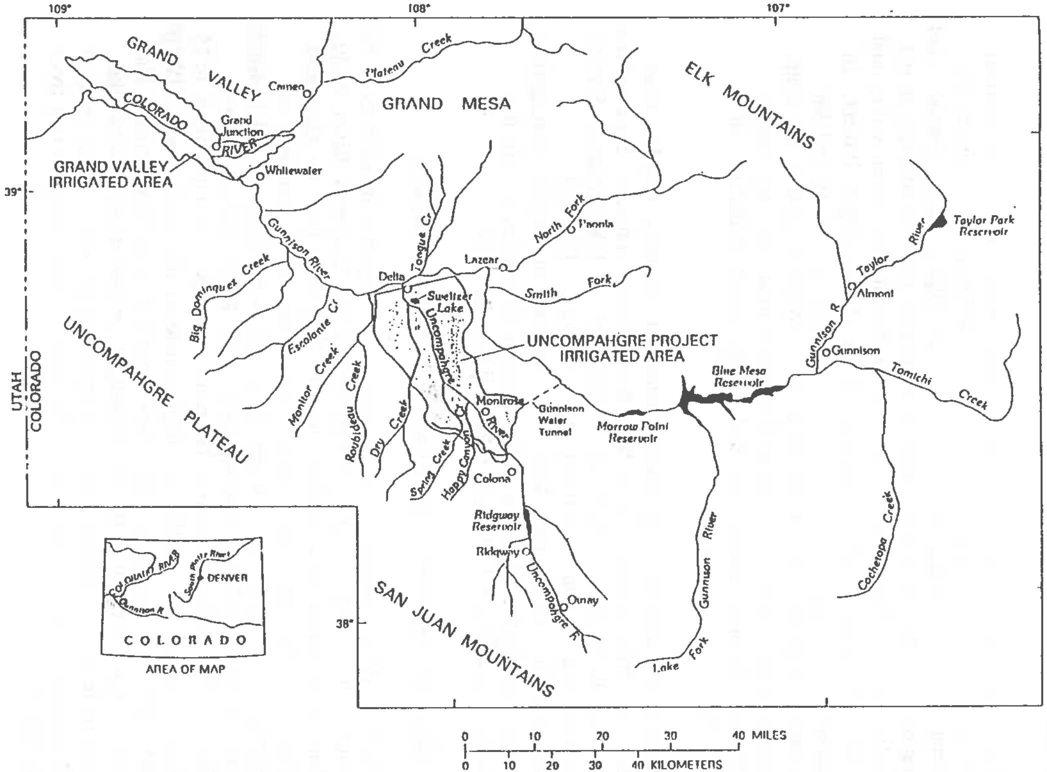

Figure 1. Location of the Uncompahgre Project and the Grand Valley.
(from Butler and others, 1994)

additional facilities on the Colorado River system, including the Uncomphagre and Gunnison Rivers. The Uncompahgre Project is shown in Figure 1.

The social and economic impacts of these projects have been dramatic. The areas presently produce corn, beans, alfalfa, onions, squash, and tomatoes. Fruits raised in the areas include apples, pears, peaches, and grapes. In 1992, crop production from federal projects resulted in net profits of about $19 million from 33,000 acres in the Grand Valley and about $38 million from 72,000 acres in the Uncompahgre Project. In addition to irrigation, water is used to generate electricity and for domestic purposes. Beneficial social and economic impacts are even greater when support services such as food processing, equipment suppliers, financial institutions, and transportation industries are considered.

While there have been significant social and economic benefits from these irrigation projects, there have been adverse impacts. Some of the irrigated lands both in the Grand Valley and the Uncompahgre Project are underlain by the seleniferous Mancos Shale. Elevated concentrations of selenium have been observed in samples of irrigation return flow from both projects, in sediment downstream from the projects, and in the biological food chain in the areas.

NIWQP Reconnaissance Investigation and Detailed Studies

The NIWQP conducted a reconnaissance investigation in 1988-89 of the water quality, bottom sediment and biota in the Gunnison River Basin. This was followed by a detailed study in 1991-93 in both the Gunnison River Basin and the Grand Valley area. Table 1 is a summary of selenium concentrations observed in surface water samples and in whole body fish from both the Uncompahgre project area and the Grand Valley. The median value for 399 water samples from both areas is 35 micrograms per liter (ug/l), the highest median observed at any NIWQP study site. All maximum values were observed in project drains. The median value for fish in the Uncompahgre Project approximated the concern level of 6.0 micrograms per gram (ug/g) above which adverse reproductive impacts may occur. The median was 9 ug/g in fish from the Grand Valley.

Table 1. - Summary of Selenium Concentrations Observed in Surface Water Samples and in Whole Body Fish Samples from the Uncompahgre Project Area and the Grand Valley, 1991-92. (Units are micrograms per liter for water and

micrograms per gram dry weight for fish. Names following maximum concentrations are the drain in whose water the maximum was observed.)

	Number of Observations	Minimum	Maximum	Median
		Water		
Uncompahgre	294	<1	260 Relief Ditch	37
Grand Valley	105	1	380 Reed Wash	32
		Whole Body Fish (concern level 6.0)		
Uncompahgre	31	1.2	37 Loutsenhizer Arroyo	5.9
Grand Valley	51	3.3	22 Persigo Wash	9.0

A major thrust of these investigations has been the health and well-being of the fish species that are listed under ESA. These species are the Colorado squawfish, the Razorback sucker, the humpback chub and the bonytail chub. Twenty-nine of the 60 roundtail chubs, a surrogate species for the Colorado squawfish, collected in 1992 from the Colorado and Gunnison Rivers which receive return flow from the Grand Valley and Uncompahgre Projects respectively, had selenium concentrations greater than 6 ug/g dry weight. However, only 2 of 60 flannelmouth suckers, a surrogate to the razorback sucker collected at the same locations in 1992 had concentrations exceeding 6 ug/g. It is not known how much of a factor, if any, these somewhat elevated selenium concentrations have played in the decline of the endangered species because no cause/effect relationships have been established.

Nevertheless in 1994, NIWQP began the remedial planning phase of its work in the Gunnison River Basin and Grand Valley areas. Because of several ongoing activities by other Federal entities in the Gunnison and Grand Valley areas, the NIWQP planning effort is proceeding deliberately to ensure that it is not duplicating but rather is complimenting the efforts of other Federal programs.

OTHER FEDERAL PROGRAMS

The Colorado River Basin Salinity Control Program and the Recovery Program for the Endangered Fishes of the Upper Colorado River Basin are existing programs in the Gunnison River Basin and Grand Valley area whose goals and objectives are similar to those of NIWQP or whose activities compliment those of NIWQP.

Colorado River Basin Salinity Control Program

The non-mountainous parts of the Colorado River Basin are arid to semiarid. In this environment naturally-occurring chemical constituents in soils and underlying deposits remain concentrated near the land surface. Rainfall events or snow melt flush large quantities of salts into flowing streams. Construction of irrigation projects in the Upper Colorado River Basin has hastened this natural process. Infiltrating irrigation water flushes salts into the Colorado River system as some irrigation water moves through underlying formations. Over 9 million tons of salt are carried by the Colorado River every year. This salt is diluted by the flow of the river, and depending upon the quantity of flow, the concentrations of salt can be relatively high or low.

The majority of impacts of salinity are in the Lower Colorado River Basin, both in the United States and Mexico. High salinity can significantly reduce crop production, especially for salt-sensitive crops. Besides direct impacts to agriculture, other activities such as, food processing, shipping, marketing, and banking are indirectly impacted. High salinity also can impact residential water users, by increasing their dependence on bottled water and water softeners and by requiring more frequent replacement of water pipes, clothes washers, garbage disposals, water heaters, and dishwashers. In 1995, estimated costs of dealing with high salinity in the Colorado River Basin were over $750 million.

BOR has conducted the Colorado River Basin Salinity Control Program (CRBSCP) since 1974. Most of the CRBSCP activities have occurred in the Upper Basin. BOR has expended about $300 million to date for salinity control features that were authorized in 1974 and 1984. These facilities prevent an estimated 372,000 tons of salt from entering the river system each year. In addition, the U.S. Department of Agriculture (USDA) has expended about $108 million to implement on-farm improvements which ultimately will control an estimated 230,000 tons per year of salt loading.

The CRBSCP has resulted in significant economic and social benefits to Upper Basin communities in which salinity control features were constructed. This investment in local communities has improved water delivery systems and on-farm usage of water. Farmers are better able to manage their agricultural activities and frequently, improve their crop yields. In many cases, the application of smaller amounts of water allows farmers to use the water saved for irrigation of other fields. Water districts have been able to reduce their maintenance costs through the use of piped delivery systems or lined canals even though operation and maintenance costs of the improved systems are greater. Additionally, there are economic benefits to communities and individuals to whom the projects have brought employment or the need for goods and services.

In 1994, with the CRBSCP reaching the induced financial ceiling in the original legislation, BOR began a public review to evaluate plans to continue the program. Based on the results of the review, BOR recommended the adoption of a basin-wide program in lieu of unit-by-unit authorizations required by past legislation. The goal of the basin-wide authority is to allow BOR to react and pursue cost-effective alternatives wherever and however the opportunities arise. Funds to setup and begin the new program were appropriated by Congress in FY 96.

In 1996, Public Law 104-127 (the 1996 Farm Bill) combined the USDA Salinity Control Program into the Environmental Quality Incentive Program (EQIP). The USDA is in the process of developing rules of the implementation of the new program. EQIP is a $200 million per year program that will direct 80 percent of its funds to priority areas established by the program.

Irrigated areas in the Gunnison River Basin and the Grand Valley contribute approximately 12 percent of the over 9 million tons of salt carried each year by the Colorado River. Likewise about 60 percent of the selenium carried by the Colorado River system to Lake Powell is mobilized from these areas. BOR and the USDA began the salinity control work in 1979 in western Colorado and by the year 2010, will have invested an estimated $360 million to prevent about 470,000 tons of salt from entering the Colorado River system each year. This amounts to a reduction of about 43 percent of the total salt load contributed by these irrigated areas.

The CRBSCP has improved conveyance systems by lining canals and piping laterals (ditches) to reduce off-farm seepage and salt loading.

On-farm improvements, including upgrading irrigation systems and improving irrigation management to reduce deep percolation from farm operations, have been implemented. On-farm irrigation improvements include installing underground pipelines, ditch lining, land leveling, sprinkler systems, gated pipe and surge irrigation systems.

The CRBSCP may provide additional salinity control improvements in the Uncompahgre and Grand Valleys in future years. One proposal currently competing for funding is to pipe all the irrigation laterals (ditches) within the Uncompahgre Project 's South Canal distribution system southeast of Montrose, Colorado. Cost of this proposal is estimated at $15 million and will prevent about 21,000 tons of salt from entering the river system.

Experience with the CRBSCP indicates that the mechanisms that move salt to the rivers, also move selenium and other contaminants. In the future, the NIWQP may help with the salinity control projects in the Gunnison River Basin and the Grand Valley by defraying part of the costs and thereby making them more competitive under the new cost effectiveness requirements.

Recovery Program for Endangered Fish

The Recovery Program for the Endangered Fishes of the Upper Colorado River Basin is a 15 year effort that started in 1988. It is designed to help re-establish self-sustaining populations of Colorado squawfish, humpback and bonytail chubs and razorback suckers, while providing for new water development. The program participants include federal agencies, states, and public interest groups. Early phases of this program focused on river regulation and designation of critical habitat. Until recently water quality had not been recognized as an issue by the program, but lately the program has acknowledged that contaminants may be more of a concern to the recovery efforts than was previously thought.

The Recovery Program consists of five elements: habitat management; habitat development; native fish propagation; non-native species and sport-fishing; and research, monitoring and data management. Highlights of the program related to the Gunnison River Basin and the Grand Valley included the construction of nearly 30 fish growout ponds in Colorado and Utah to rear endangered fish. A fish ladder constructed at Redlands Dam on the Gunnison River near Grand Junction, Colorado, has opened up about 50 miles of designated critical habitat along the river above the Dam to endangered species. Flooded bottom lands have been restored on the Colorado River. Razorback suckers have been stocked in the Gunnison River. Since the inception of the Recovery Program, 200 water projects have been approved in the upper Colorado River basin without any water project litigation.

NIWQP presently is conducting joint research with the Recovery Program on the threat to the Colorado squawfish from selenium-contaminated food and water in the San Juan River Basin. NIWQP will be working with the Recovery Program to evaluate the success of their ongoing remediation efforts at the Walter Walker Wildlife Refuge adjacent to the Colorado River west of the city of Grand Junction Colorado. NIWQP also will conduct selected water quality and biological monitoring activities in support of the Recovery Program.

NIWQP REMEDIATION PLANNING

Issues

NIWQP remedial planning for the Gunnison River Basin-Grand Valley areas began in 1994 with the establishment of an interagency Core Team headed by BOR and including members from the Fish and Wildlife Service and the U.S. Geological Survey. NIWQP remedial efforts are focused on identification of drain water impacts to the biota; identifying solutions that reduce impacts on the endangered fish and migratory birds from selenium; developing remediation options; and working with the appropriate agencies or programs to implement those options. These activities also will help develop a better understanding of the relationship between selenium and observed biological impacts. Several factors create a high level of uncertainty in terms of determining responsibility for impacts to biota. These factors discussed below bear directly on the ability of the NIWQP to request compliance with the ESA or MBTA or to require repayment for implementation of remediation options.

<u>Cause and Effect</u>: The cause and effect relationships between drainage water and impacts on the biota in the Gunnison River Basin and the Grand Valley have not been established. The cost of research and studies to better determine or understand these factors and the cause-effect relationship can be prohibitively high. While useful generalizations can be made about risks to biota, there are a variety of complicating factors that must be considered in planning cause and effect studies including:

(a). Impact of selenium contamination varies by species and for the different lifestages of species.

(b). The same concentrations of selenium may affect individual species differently in free flowing streams than in backwater areas.

(c). Laboratory data that relate the selenium to biological impacts may be at odds with field data because of the variety of other chemical constituents in natural systems. These constituents may have either synergistic or antagonistic affects when combined with selenium.

(d). Surrogate species that are used to conduct laboratory research may or may not provide accurate information that relates to species of concern at NIWQP remediation sites.

(e). Impacts on species may be due to cumulative or differential effects of several environmental factors. Effects also may be interactive. For example, when water discharges are elevated for an extended period, selenium concentrations in fish collected during that period are reduced. This may make it impossible to determine the impact of a single activity and assign responsibility for biological impacts to specific water users.

(f). Natural changes in hydrology and biological activity may be greater than those imposed on the systems by irrigation projects or other man-induced activities on the Colorado River system.

(g). Confirmation of biological and chemical impacts from a project requires an understanding of pre-project conditions so that a comparison can be made. This is especially difficult to determine when pre-project information is unavailable or when the impacts from year-to-year changes are so small as to escape detection. Pre-project conditions cannot be reliably determined in most cases.

(h). Selenium occurs in a variety of forms, some of which are bioavailable, and some of which are not. Historic data may not provide sufficient information on selenium speciation as it relates to exposure paths.

Cause and effect studies were started recently by the Recovery Program in cooperation with NIWQP. Preliminary results indicate a direct relationship between selenium concentrations in local invertebrates and larval razorback sucker survivability (R. Krueger, verbal communication, 1996).

Federal and Non-federal Responsibilities: It is difficult to quantify impacts from DOI projects versus those from other irrigation projects or from natural conditions. Frequently, the drains contain water and chemicals that have been applied to adjacent fields, or chemicals that occur naturally in the irrigated area but have been mobilized by sub-surface water-chemical interactions. The quantification of drainage impacts from federal and non-federal activities requires an understanding of these mechanisms. A thorough understanding of farming practices on each field also is required, especially in those cases where different crops are grown and different chemicals are applied. Further, it is necessary to understand the groundwater hydrology and surface and sub-surface chemical interactions well enough to predict the resulting chemical and water characteristics in receiving drains.

Remediation Costs: In general, there is a requirement under Reclamation law that those who benefit from a federal project should bear the costs of mitigating project impacts. In a BOR-constructed project area, Reclamation law can require that remediation costs are considered as new BOR project costs. This requires that BOR prepare a feasibility report that is submitted to Congress. The report asks Congress to increase the original cost ceiling for the project, allow the treatment of remediation costs as new irrigation costs, and permit the costs to be repaid with no interest. Futhermore, the report may ask Congress to require power users to pick up those costs that exceed the irrigator's ability to repay, and allow a long-term repayment period. This approach can easily result in a contentious situation with both water users and power users and may be difficult to apply on existing projects that have been in operation many years. There is a strong likelihood that this approach will result in no significant or timely action to resolve problems that affect the biota.

Impacts on Species: The primary biological issue that concerns the DOI in the Uncompahgre Project and Grand Valley areas, is the recovery of endangered fish species. It is clear that there is a relationship between contaminants and biological impacts. It is also clear that the endangered fish have also been impacted by a multitude of factors, such as the construction and operation of dams, reduced flow, turbidity, temperature changes, loss of habitat, and the introduction of nonnative fish. It may be virtually impossible to quantify the degree which each of these may have impacted a species.

Approach

Several remediation options normally are considered by NIWQP. These include: changes to the drainage systems to allow discharge into less sensitive areas; modification of fresh water delivery systems to provide a clean water supply to sensitive wetland areas; sediment treatment; both on-farm and off-farm water conservation measures to reduce the amount of drain water and related contaminants; and selective voluntary land retirement. These options all will be considered by NIWQP for the Gunnison River Basin and Grand Valley areas and many are being addressed by existing programs.

NIWQP remediation will be designed to reduce or eliminate impacts caused by contaminants from the DOI projects rather than to recover species. In doing this, extensive efforts will be made to involve irrigators from both federal and non-federal projects. All parties are encouraged to understand the limits of science as they apply to proposed remediation and accept the risks that are inherent in predicting program success. Other considerations in the NIWQP approach include:

(a). How to determine responsibility for remediation costs, i.e., should public funds be used, should irrigators bear these costs (private funds) or should the costs be shared.

(b). How best to predict impacts on endangered species if selenium contamination is reduced.

(c). How to ensure that NIWQP efforts compliment those of other ongoing programs in the upper Colorado River Basin.

(d). How best to minimize social and economic impacts (e.g. no or minimal disruption of local economies and lifestyles).

To accomplish this remedial approach NIWQP will do the following:

(a). Work closely with the affected publics and interest groups to ensure their full support.

(b). Emphasize low cost options.

(c). Implement monitoring programs including water quality and biota to determine results of remediation.

(d). Encourage the use of existing facilities and rights of way to reduce federal remediation costs.

(e). Adopt a wait and see attitude to evaluate the need for additional remediation.

For remedial actitivies in the Uncompahgre Project and the Grand Valley, funding will be accomplished, to the extent possible, using authorities that currently exist in the Department of the Interior to lessen the economic impact on individuals in the project area. This approach will also take into account how these authorities are currently being used by the Department and any congressional restrictions that may have been placed on the use of appropriated funds. The NIWQP will seek new congressional authorities only when a specific NIWQP activity falls outside what congress has accepted as "reasonable " in past appropriation considerations. For example, if the NIWQP requires substantial funds for remediation, and social and economic impacts are significant, the NIWQP could pursue specific congressional action.

Alternative approaches for funding remediation options are being considered within the NIWQP. There are precedents for treating the costs of environmental remediation as a non-reimbursable costs. Part of the costs of the "Recovery Program for the Endangered Fishes of the Upper Colorado" are non-reimbursable. Also, the U.S. Fish and Wildlife Service conducts its "Partners for Wildlife " program as a non-reimbursable program that can be used to remediate environmental problems on non-federal lands.

The NIWQP remedial approach requires a heavy reliance on mutual cooperation between the NIWQP, other existing programs, other federal agencies and their programs, and irrigators. These cooperative efforts will be emphasized to ensure that proposed remediation is acceptable from a communities ' or water district 's standpoint. NIWQP will continue to support both financially and verbally the appropriate activities of both the Colorado River Salinity Control Program and the Recovery Program for the Endangered Fishes in the Gunnison River Basin and the Grand Valley. For remedial activities beyond existing programs, NIWQP will look to partnerships with local and state entities to accomplish the proposed activities.

Compliance and use of regulatory approaches, that might be available through the ESA or MBTA, will be used only in those situations where the hazards are clear, the risk is imminent, and cooperative efforts appear unlikely to succeed. This approach is intended to balance statutory requirements, with the uncertainty of program results, limited federal and non-federal dollars, and the need to minimize social and economic impacts on irrigators.

NIWQP believes that the approach to remediation in the Gunnison River Basin and Grand Valley must be a balanced one that will minimize economic impacts and social disruptions in the areas where remediation takes place. Costs to individual irrigators should be low as possible while allowing for compliance to ESA and MBTA. Benefits to individual irrigators could include improved canal and delivery systems requiring less manpower at reduce costs. Environmental improvements will result with enhanced recreational possibilities.

Remediation may require a substantial amount of data collection over many years. Data are needed to understand cause and relationship and natural conditions. Data collection may not be doable in those areas where farming practices are undergoing significant changes. For example, substantial costs can be incurred for monitoring and eventual development of groundwater models to address chemical and water movement beneath each agricultural area. These costs have to be fully understood before decisions are undertaken to conduct long-term monitoring and develop and operate computer models.

Remedial planning should be completed in 1999. NIWQP management is convinced that partnership approaches with the public and with existing programs can solve selenium problems in the Gunnison River Basin and the Grand Valley in a win-win situation for all parties.

REFERENCE

Butler, D.L., Wright, W.G., Hahn, D.A., Krueger, R.P., and Osmundson, B.C., 1994, Physical, chemical, and biological data for detailed study of irrigation drainage in the Uncompahgre Project area and in the Grand Valley, west-Central Colorado, 1991-92: U.S. Geological Survey Open-File Report 94-110, 146 p., 2 pl.

ECONOMIC AND ENVIRONMENTAL EFFECTS OF THE GLEN CANYON BEACH/HABITAT-BUILDING TEST FLOW

David A. Harpman[1]

ABSTRACT

Prior to construction of Glen Canyon Dam, the Colorado River transported tremendous amounts of sediment through Glen and Grand Canyons. Since dam construction, downstream tributaries have provided the only source of sediment. Operation of the dam to produce peaking power results in hourly fluctuations in release and river stage. Unconstrained fluctuations have been shown to significantly affect aquatic resources and sediment deposits on the channel margins. The elimination of sediment laden floods has prevented the replenishment of high predam terrace deposits.

A 7-day controlled flood was conducted in late March and early April of 1996 for research purposes. This short duration high release was designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. The goal was to test hypotheses about sediment movements and the response of aquatic and terrestrial habitats to flood events. Approximately 217,000 acre-feet of water bypassed the powerplant during the test and the opportunity to generate 104,000 megawatt hours of electricity was foregone. Voluminous amounts of physical, biological, and economic data were collected. This paper explores the rationale behind the test flow and describes the preliminary economic and environmental findings.

INTRODUCTION

Glen Canyon Dam was completed by the U.S. Bureau of Reclamation in 1963. It is located on the Colorado River upstream from Grand Canyon National Park. This 710-foot high concrete arch dam controls a drainage basin of approximately 108,335 square miles. There are eight hydroelectric generators at the dam which can produce up to 1,288 megawatts (MW) of electric power.

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The Operation of Glen Canyon Dam Environmental Impact Statement (GCDEIS) was initiated in 1989 to examine options which, "...minimize—consistent with law—adverse impacts on downstream environmental and cultural resources and Native American interests..." (Reclamation 1995a, p. 1). The environmental impacts of nine operational alternatives were examined in the final GCDEIS.

A beach/habitat-building test flow was proposed as an element of the preferred alternative in the GCDEIS. This scheduled high release of short-duration was designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system.

RATIONALE FOR THE TEST FLOW

The purposes of the test flow include rebuilding eroded sandbars, reforming backwater habitats for native fish, and mimicking the natural processes that create a dynamic Grand Canyon ecosystem. Periodic high flows occurred regularly prior to the construction of Glen Canyon Dam and are believed to be necessary to maintain ecosystem diversity.

The beach/habitat-building flow of 1996 was needed to test the hypotheses that the dynamic nature of fluvial landforms and aquatic and terrestrial habitats can be restored by short-duration releases substantially greater than powerplant capacity. Such an experiment would provide the opportunity to measure essential geomorphic and ecologic processes during flood passage and recession. Data collected during the test flow would provide the information needed to verify predictive models and to help establish an operational regime to maintain, manage, and protect the riparian and aquatic resources of the Colorado River in Glen and Grand Canyons.

CURRENT DAM OPERATIONS

In water year 1996, Glen Canyon Dam was operated under what is known as the Interim Operating Criteria. These criteria were established by the Secretary of the Interior in November 1991 and are described in further detail in Reclamation (1991). As summarized in table 1, Interim Operating Criteria were designed to reduce daily flow fluctuations well below historic levels, with the goal of protecting or enhancing downstream resources while allowing limited flexibility for power operations. Minimum flows, maximum flows, ramp rates, and allowable daily fluctuations were established to protect downstream resources until the final GCDEIS was completed and a Record of

Decision had been signed. The ramp rate is the rate of change in discharge, either up or down, required to meet electrical load.

Table 1. Summary of Interim Operating Criteria.

Minimum Releases (cfs)	Maximum Releases (cfs)	Allowable Daily Fluctuations (cfs/24 hrs)[1]	Ramp Rate (cfs/hr)
8,000 between 7 a.m. and 7 p.m. 5,000 at night	20,000	5,000 6,000 or 8,000	2,500 up 1,500 down

[1] Five-thousand cfs per 24 hours (cfs/24 hrs) for monthly release volumes of 600,000 acre-feet and less; 6,000 cfs/24 hrs for monthly release volumes between 600,000 and 800,000 acre-feet; and 8,000 cfs/24 hrs for monthly release volumes 800,000 acre-feet and greater.

Annual and monthly releases are consistent with the Long-Range Operating Criteria objectives of 8.23-million acre-feet (maf) minimum annual release and equalized storage between Lake Powell and Lake Mead. Annual releases greater than the minimum are permitted to avoid anticipated spills and equalize storage. Monthly and annual release volumes are projected for different hydrologic conditions prior to the beginning of the water year and are described in the Annual Operating Plan (Reclamation 1995b).

Within these criteria (table 1), the actual minimum and maximum releases from the dam during any given day depend on the monthly release volume, the allowable daily fluctuation, and the demand for hydroelectric power. Actual releases are usually higher than the minimum and lower than the maximum allowed. The minimum release is maintained higher during the daytime hours to protect the aquatic food base from exposure. The maximum release was conservatively set to reduce sand transport in the river so that sand could accumulate along the riverbed. The allowable daily fluctuation (either 5,000, 6,000, or 8,000 cfs/24 hrs) depends on the monthly release volume and was determined so that the maximum daily change in river stage would be nearly the same during all months—about 3 feet in most reaches.

The down ramp rate was set to reduce seepage based erosion of sandbars in Glen and Grand Canyons and to avoid stranding fish. The up ramp rate was conservatively set to reduce potential operation-related impacts to canyon resources.

DESCRIPTION OF KEY RESOURCES

A comprehensive treatment of all of the resources potentially or actually affected by the beach/habitat-building flow would be quite extensive. For discussion purposes, this paper focusses on the three most critical resources: the sediment resource, the biological resource, and the hydropower resource. Other resources are discussed in detail in Reclamation (1995a, 1996).

Sediment Resource

The Grand Canyon ecosystem originally developed in a sediment-laden, seasonally and sometimes daily, fluctuating environment. Historically, large annual flood flows—often greater than 100,000 cfs—transported approximately 85.9 million tons of sediment through the canyon. This sediment accumulated in high deposits and sometimes formed terraces along the river. Wind and water eroded these deposits after the return to lower flows. Natural cycles of deposition and erosion generally prevented establishment of vegetation near the river. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River by trapping water, sediment, and associated nutrients that previously traveled downstream.

Today, the ecological resources of Glen and Grand Canyons depend on the water releases from the dam and variable sediment input from tributaries. The major sources for resupplying sediment to the river below the dam are tributaries—primarily the Paria River, Little Colorado River, and Kanab Creek. The sediment supply has been reduced to approximately 12.3 million tons per year (Andrews 1991) and the regulated release regime now supports aquatic and terrestrial systems that did not exist before Glen Canyon Dam.

Exposed and submerged sediment deposits throughout Glen and Grand Canyons are very important for cultural, recreational, and biological resources. Sediment is critical for stabilizing archeological sites and camping beaches, for developing and maintaining backwater fish habitats, and for supporting vegetation that provides wildlife habitat.

Riverbed sand and sandbars are the sediment resources of primary interest affected by riverflows below Glen Canyon Dam. For sandbars to exist, sufficient amounts of sand must be stored on the riverbed, and flows must be periodically large enough to move the sand and redeposit it on sandbars. In general, sandbars are built during periods of high flow and then erode over time following the return to low flow. In a natural system, this cycle repeats itself annually. Since the Interim Operating Criteria were implemented, sandbar erosion rates have declined, but erosion still occurs due to rain, wind, human use, and waves—especially on higher sandbar portions above the river stage associated with a flow of 20,000 cfs.

After the Interim Operating Criteria had been in place for several years, investigations determined that riverbed sand storage in Grand Canyon (along the riverbed and in eddies) had reached near capacity and additional sand supplied from tributaries was mostly transported to Lake Mead over a period of months (Andrews 1995). Because peak flows are relatively low throughout the year—less than 20,000 cfs—there is little or no potential to rebuild sandbars, except during a very large and rare tributary flood. As a result, sandbars continued to experience slow rates of erosion which were not offset by seasonal deposition under the Interim Operations Criteria.

Biological Resource

The present aquatic ecosystem below Glen Canyon Dam is the result of complex interactions between released water, habitat, and the native and non-native organisms that inhabit it. The biological foundation of the aquatic system is *Cladophora glomerata*, a filamentous green algae. River conditions created by the dam make possible the abundant growth of *Cladophora*. Together, *Cladophora*, diatoms, associated invertebrates particularly the freshwater shrimp, *Gammarus lacustris*, and various insects provide an important food source for other organisms in the aquatic food chain. Both native and non-native fish, as well as terrestrial organisms, depend on this food base.

These postdam conditions, including the *Cladophora-Gammarus* food chain, support a blue ribbon non-native rainbow trout fishery in the Glen Canyon reach and for some distance downstream.

The native fish of the Colorado River make up one of the most unusual assemblages of fish specially adapted to their environment found anywhere in the world. The construction of dams has drastically modified the fishes' evolutionary environment. Of the eight species of fish native to the Colorado River, three have been extirpated from Glen and Grand Canyons, two are listed as endangered, one is a candidate species for listing under the Endangered Species Act, and the remaining two are relatively common. One of the endangered species, the humpback chub, is the subject of considerable research.

Return-current channels (backwaters) of reattachment bars and shallow nearshore areas along the main channel are important refuges for young native fish exiting tributaries and serve as nursery areas in the mainstem. Native fish utilize these shallow, productive, warm refuges during their first year of life.

Compared to mainstem eddy habitats, backwaters offer higher zooplankton and benthic invertebrate densities (Kubly 1990; Arizona Game and Fish Department 1994), lower current velocities, and refuge from predatory fish.

Backwaters have a tendency to fill with sediment through time. Comparisons of backwater counts at near 5,000-cfs flows made in 1985 with backwater counts during 5,000-cfs releases made in 1991, showed a nearly 80-percent decline in the number of backwaters over the 6-year period (Weiss 1993). This decline is attributed to backwaters filling with sediment and vegetative encroachment. Backwaters were continuing to fill under interim operations.

In addition to trout, non-native warmwater fish such as carp, fathead minnow, killifish, catfish, and red shiners have been introduced into the Colorado River. As a group, these non-natives may displace native fish from their preferred habitat and compete for the same foods. Some non-natives have also been shown to prey on native fish eggs, larva, and juveniles.

Plant communities affected by Glen Canyon Dam releases exist in a restricted riparian zone between the river's edge and upland desert. Water and sediment interact in this riparian zone, and vegetation occupies suitable sites from the dam downstream into Lake Mead. Water transports and deposits sediment, and the availability of water at sediment deposits supports plants that otherwise could not survive in a desert climate. Riparian vegetation plays an important role as wildlife habitat by providing food and cover for numerous mammals, birds, reptiles, amphibians, and invertebrates.

Hydropower Resource

Glen Canyon Dam and Powerplant are part of the Colorado River Storage Project (CRSP), one of the Federal projects from which Western Area Power Administration (Western) markets power. Glen Canyon Dam generates approximately 70 percent of the total CRSP power.

The total annual amount of energy produced at the dam is based on actual water conditions. Western's Salt Lake City Area Integrated Project (SLCA/IP) annually markets more than 4 million megawatt hours (MWh) from Glen Canyon Powerplant to 198 entities.

DESCRIPTION OF THE TEST FLOW

With the exception of the test flow period, Glen Canyon Dam was operated in accordance with the Interim Operating Criteria during water year 1996

(October 1995 through September 1996). In order to accommodate the test flow, water volumes had to be redistributed during the water year. The water release volumes scheduled for water year 1996 are shown in table 2 (Peterson 1995).

Table 2. Monthly Release Volumes With and Without the Test Flow.

Month	No Action Release Volume (acre-feet)	With Test Flow Release Volume (acre-feet)	Release Volume Difference (acre-feet)
October	899,000	899,000	
November	900,000	900,000	
December	950,000	950,000	
January	1,100,000	950,000	-150,000
February	950,000	900,000	-50,000
March	850,000	1,100,000	+250,000
April	825,000	950,000	+125,000
May	850,000	750,000	-100,000
June	950,000	900,000	-50,000
July	1,075,000	1,100,000	+25,000
August	1,100,000	1,100,000	
September	871,000	821,000	-50,000
Annual Total	11,320,000	11,320,000	0

The timing of the beach/habitat-building test flow during the months of March and April was carefully considered. Specifically, this time frame was selected to reduce impacts on river resources by conducting the test flow (1) prior to native fish spawning and larval dispersal periods, (2) after the period when rainbow trout spawn at Lees Ferry, (3) after concentrations of wintering bald eagles and waterfowl have largely dispersed, (4) prior to the peak release of tamarisk seeds to reduce germination, (5) prior to the peak river rafting season, and, (6) prior to nesting of the endangered southwestern willow flycatcher.

The test flow was carried out from March 22 to April 8, 1996. As shown in Figure 1, a 4-day period of 8,000 cfs low steady flows was initiated at approximately 0200 hours on 22 March. Beginning at approximately 0200 hours on 26 March, releases were increased by 4,000 cfs/hr until a maximum flow of 45,000 cfs was attained at 1200 hours on 26 March. This high release was maintained for 7 days. At approximately 1100 hours on 2 April, the flow rate was decreased by 1,500 cfs/hr until the discharge reached 35,000 cfs. At this point, flow rates were decreased by 1,000 cfs/hr until a discharge of 20,000 cfs was reached. Releases were then decreased at a rate of 500 cfs/hr until a discharge of 8,000 cfs was attained at 0800 hours on 4 April. A low steady release of 8,000 cfs was then maintained for 4 days. Interim Operations were resumed at approximately 0200 hours on April 8, 1996.

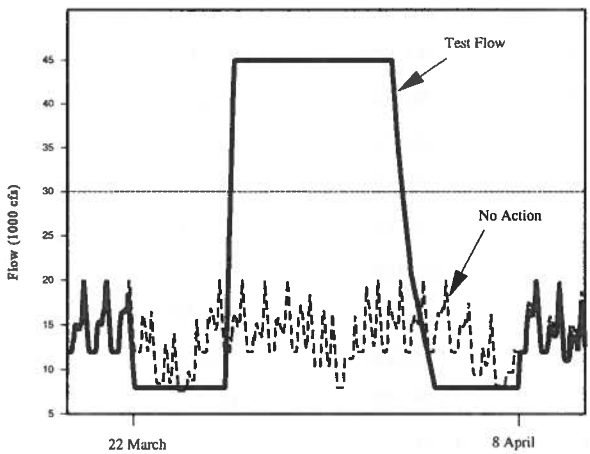

Fig. 1. Hydrograph of Beach/Habitat-Building Test Flow.

PRELIMINARY FINDINGS

The Glen Canyon Environmental Studies program coordinated the approximately 30 different scientific investigations which were undertaken before, during, and after the test flow. Over 150 scientists from various academic institutions, government agencies, Native American tribes, and consulting firms took part in these studies. This intensive effort resulted in the collection of immense amounts of data. While the analysis of this data is still ongoing, some preliminary findings are available.

Sediment Resource

Data obtained by sediment researchers during the test flow suggest the following results:

- River stage was increased by 5 to 11 feet above the highest stage normally observed under Interim Operation Criteria.

- Sand was scoured from the deepest part of the channel and eddies and deposited along the channel margins.

- Sandbar aggradation was more rapid than anticipated. For example, at the sandbar above Tanner Rapid (river mile 68), 80 percent of the total sandbar deposition occurred in the first 24 hours of the test flow and 90 percent of the deposition occurred in the first 48 hours (Randle 1996).

- Some sandbars were created, some sandbars increased in size, some remained essentially unchanged, and some sandbars decreased in size. Of the camping beaches assessed, 50 percent increased in size, 39 percent remained the same, and 12 percent were reduced in size.

- Topographic and bathymetric mapping of 34 sites revealed that sandbars gained a significant amount of sediment during the test flow. Sandbar volumes at these sites increased by an average of 53 percent. Considerable sand was deposited at elevations above the 20,000 cfs stage where the most significant erosion had occurred under Interim Operations Criteria.

- Mapping indicated sandbar deposition resulted in only a slight increase in planimetric area of from 5 to 7 percent on the average. This suggests that although sand was deposited at higher elevations, the areal extent of the bars was only slightly increased.

- Erosion of newly rebuilt sandbars is anticipated to occur over time. The rate of erosion is unknown but is dependent on local channel morphology, subsequent river flows, rainstorms, wind, human use, and debris flows. Sediment conditions will continue to be monitored to ascertain the appropriate timing for the next beach/habitat-building flow.

Biological Resource

Data obtained by researchers during the test flow suggest the following results:

- The standing stock of *Cladophora* and the associated populations of *Gammarus* were initially reduced. However, populations returned to pre-test flow levels within a short time after the event (McKinney, et al. 1996).

- There was no immediate negative impact on the distribution, density, and health of the non-native trout fishery in Glen Canyon. A subsequent localized decline in the condition of some fish was noted, although this was followed by relatively rapid recovery (McKinney, et al. 1996).

- The number and size of backwater habitats was increased by the test flow.

- No significant decrease in warmwater non-native fish density resulted from the test flow. Most non-native fish moved to submerged riparian vegetation and tributary mouth cover during the event.

- Radiotelemetry and netting studies of humpback chub revealed that many adults moved to low velocity areas during the test flow. No significant adverse impacts on adults were observed.

- The population of many riparian herbaceous plants, especially annuals, was significantly reduced in flooded areas. There was little observable effect on perennials.

Power Resource

The test flow affected power operations in two periods: the 2 months when the test flow occurred and the other 10 months in the water year.

The impacts during the test flow period were:

- During the 4 days of steady flows preceding the high release, on average, less power was generated than needed to supply firm load (see figure 1).

- During the high release, the outlet works were used to release flows in excess of 30,000 cfs, bypassing the powerplant. Water released through the outlet works is considered "spilled" and is unavailable to produce electricity at Glen Canyon Dam. In figure 1, all releases above the 30,000-cfs line were spilled.

- During the high release, more power was generated than was needed to supply firm load.

- During the 4 days of steady flows following the high release, on average, less power was generated than needed to supply firm load (see figure 1).

Impacts on the power system also occurred during the other months in water year 1996. These impacts occurred because water volumes were shifted from the months of January, February, May, June, and September, to March and April for the test flow. From a power perspective, the resulting pattern of monthly release volumes was less desirable. For example, there was less water available in January—a peak power demand month—than there would have been without the test flow.

As shown in table 3, approximately 103,711 MWh less energy (2 percent less) was generated as a result of the test flow. This difference primarily reflects the approximately 217,000 acre-feet of water that was released through the outlet works or "spilled."

An analysis of the economic costs of the test flow was undertaken prior to the test flow (Reclamation 1996). For this analysis, an aggregate hourly load curve was assumed to represent system demand during water year 1996. Most probable monthly release volumes and end-of-month reservoir elevations with and without the test flow were obtained from the Colorado River Simulation System model (Reclamation 1988). Using these inputs, hourly power operations for all 12 months without the test flow and 10 months of the with test flow case were simulated using a variant of the peak-shaving model (Environmental Defense Fund 1995). For March and April with the test flow, the hourly pattern of releases shown in figure 1 was used for the 22 March - 8 April period and the remaining hours were simulated using the peak-shaving model.

Estimates indicate the economic impact of the test flow on the power system was approximately $1.848 million during water year 1996 (Reclamation 1996). In addition, approximately $1.5 million was expended on related research. The total economic cost of the 1996 beach/habitat-building test flow was approximately $3.348 million.

Table 3. Monthly Energy Generated at Glen Canyon Dam With and Without the Test Flow.

Month	No Action (MWh)	With Test Flow (MWh)	Difference (MWh)
October	432,765	432,765	0
November	431,910	431,910	0
December	454,150	454,150	0
January	522,096	451,734	-70,362
February	448,481	425,980	-22,501
March	403,398	456,094	52,696
April	406,257	427,691	21,434
May	406,043	357,947	-48,096
June	461,574	437,203	-24,371
July	523,346	535,234	11,888
August	532,429	532,131	-298
September	419,972	395,871	-24,101
Total	5,442,421	5,338,710	-103,711

CONCLUSIONS

The beach/habitat-building flow of 1996 was conducted to test hypotheses about the dynamic nature of geomorphic processes and the aquatic and terrestrial habitats which are dependent on them. This experiment provided an unparalleled opportunity to measure large river sediment erosion, transport, and deposition processes, to observe the effects on the aquatic and terrestrial ecosystems, and to measure the economic effects of a controlled flood event on the power system. Analysis and interpretation of the information obtained is ongoing and it may be several years before final conclusions can be drawn. Nonetheless, data collected during the test flow should help to verify predictive models, help shape future resource management strategies, and help to protect the riparian and aquatic resources of the Colorado River in Glen and Grand Canyons.

REFERENCES

Andrews, E.D., U.S. Geological Survey, Tucson, Arizona, verbal communication, November 1995.

Andrews, E.D., "Sediment Transport in the Colorado River Basin," in *Colorado River Ecology and Dam Management*, Proceedings of a symposium, May 24-25, 1990, Santa Fe, New Mexico, National Academy Press, Washington, DC., pp. 54-74.

Arizona Game and Fish Department, *Glen Canyon Environmental Studies Phase II 1993 Annual Report*, Prepared for U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Phoenix, 1994.

Environmental Defense Fund, *Elfin User's Manual*, Oakland, 1995.

Kubly, D.M., *The Endangered Humpback Chub (Gila cypha) in Arizona: A Review of Past Studies and Suggestions for Future Research*, draft report, prepared for U.S. Bureau of Reclamation, Salt Lake City, Arizona Game and Fish Department, Phoenix, 1990.

McKinney, T., S.R. Rogers, A. Ayers, and W.R. Persons, *Effects of Experimental Flooding on Algae, Macroinvertebrates, Rainbow Trout, and Flannelmouth Suckers in the Glen Canyon Dam Tailwater*, review draft report submitted to Glen Canyon Environmental Studies, Arizona Game and Fish Department, Phoenix, October 8, 1996.

Peterson, Randall, U.S. Bureau of Reclamation, Salt Lake City, Utah, written communication, November 1995.

Randle, Timothy J., U.S. Bureau of Reclamation, Denver, Colorado, verbal communication, November 1996.

U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, *Glen Canyon Dam Beach/Habitat-Building Test Flow: Final Environmental Assessment and Finding of No Significant Impact*, Salt Lake City, February 1996.

U.S. Department of the Interior, Bureau of Reclamation, *Operation of Glen Canyon Dam: Final Environmental Impact Statement*, Denver, March 1995a.

U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region, *Annual Operating Plan for Colorado River Reservoirs for Water Year 1996*, Boulder City, August 1995b.

U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, *Glen Canyon Dam Interim Operating Criteria: Finding of No Significant Impact and Environmental Assessment,* Salt Lake City, October 1991.

U.S. Department of the Interior, Bureau of Reclamation, *Colorado River Simulation System User's Manual,* Denver, 1988.

Weiss, J., *The Relationship Between Flow and Backwater Fish Habitat of the Colorado River in Grand Canyon,* Glen Canyon Environmental Studies Draft Technical Report, Bureau of Reclamation, Flagstaff, 1993.

MOU ON EFFICIENT WATER MANAGEMENT PRACTICES BY CALIFORNIA AGRICULTURAL WATER SUPPLIERS -- CAN IT WORK?

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ABSTRACT

In September 1990, AB 3616, "The Agricultural Water Suppliers Act," became law in California. This law required the Department of Water Resources (DWR) to establish an advisory committee to review and study potential Efficient Water Management Practices (EWMPs) and to determine which were feasible for achieving water conservation. The advisory committee was comprised of representatives of the California farming community, agricultural water suppliers, the Department of Food and Agriculture, the University of California, the California State University, public interest groups, and other interested parties.

During 1992, the last year of California's six year drought, Governor Wilson, in a speech discussing California's water needs, referred to the many water conservation practices developed by California's farmers and expressed his support for the development of EWMPs for agricultural water use. He further emphasized the AB 3616 Advisory Committee should develop a strategy for implementing these practices.

An Urban Memorandum of Understanding (MOU) had recently been signed by urban water suppliers and public interest groups (environmentalists). The urban signatories committed to implement certain Best Management Practices during a specific time frame to help reduce future demand and conserve water supplies. The Governor was hopeful a similar MOU could be developed for agricultural water suppliers which would encourage further improvements in water management.

The Governor's directive changed the purpose of the AB 3616 Advisory

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Committee. Not only was a list of efficient water management practices to be prepared, but a document was also needed which outlined a reasonable implementation plan acceptable to both agricultural and environmental representatives.

Since 1992, the Advisory Committee members have been working to develop an acceptable MOU. There have been many meetings, disagreements, and at times uncertainty over whether a workable product could be developed. The Advisory Committee approved the Final Draft MOU on October 15, 1996. Can it work and will it be effective in further improving agricultural water management or is it just another layer of bureaucracy? This paper will discuss the process followed, areas of disagreement, and what steps were taken to reach a consensus.

BACKGROUND

From 1987 through 1992 California experienced a prolonged and devastating drought. Precipitation and surface runoff during this six (6) year period were the lowest for any comparable period in recorded history. Both agriculture and urban areas dependent on surface water supplies were severely impacted. Carryover reservoir storage during the first few years minimized the impacts but as the drought continued water suppliers were required to significantly cut back on deliveries. Many agricultural State Water Project and Federal Contractors had their surface water supplies cut by 80 to 90 percent for a few years and some did not receive any surface water at all during 1991. Agricultural lands were fallowed and water rationing was the norm as supplies were stretched to meet both urban and agricultural requirements. The economic impacts were severe in both the urban and agricultural arenas. Water rationing and conservation were terms commonly mentioned and all water users were urged to use their water supplies in the most efficient manner possible.

The water shortage and water supply restrictions in the urban areas encouraged pointed attacks on agriculture's water use and water application efficiency. Since agriculture controls and utilizes approximately 80 percent of California's developed water supply, a comment often heard was, "If agriculture conserved only 10 percent on water use, all urban areas of the state would have plenty of water to meet their present and future water demands." The implication was that agriculture was not efficiently using its water supply, and it would be a straightforward procedure for agriculture to reduce its water use by 10 percent.

The drought and resulting reduced instream flows into the San Joaquin - Bay Delta increased the comments and concerns from San Francisco - Bay Area environmentalists that agricultural and urban water suppliers were wasteful in their use of water. Questions were also raised regarding the production of rice, alfalfa and other high water use crops. People wondered if it was economically feasible to continue the production of these crops in water short California when urban and industrial areas were experiencing severe economic impacts and restrictions on growth due to water rationing.

It was during the last two years of the drought, during the fall of 1990, that Assembly Bill NO. 3616 was signed into law. The primary emphasis of AB 3616 was for the Department of Water Resources (DWR) to establish an Advisory Committee to study and periodically review potential Efficient Water Management Practices (EWMPs) to determine which would be feasible to implement to achieve improved water conservation.

INITIAL AB 3616 ADVISORY COMMITTEE MEETINGS

The initial meetings of the Advisory Committee began in 1991. The meetings were chaired by the Chief of the Department of Water Resources - Office of Water Conservation. Membership on the committee, in accordance with the bill, included representatives of the farming community, agriculture water suppliers, Department of Food and Agriculture, the University of California and California State University system, public interest groups (environmentalists) and other interested parties. The first meetings were typically attended by less than 25 representatives from the above-mentioned groups.

In attempting to establish an agreed to list of EWMPs for agricultural water suppliers, representatives often split into two factions, agricultural and environmental, debating over the need for various EWMPs. The environmental representatives argued that water conservation should be achieved by implementing mandatory practices such as water metering, lining or piping canals, automating water supplier operations, and raising the cost of water. Even in a water deficient area, they supported the implementation of some type of tiered water pricing that increased the rate structure when more water was used. They mentioned it worked for the electrical power industry and it should work just as well for agriculture. The agricultural representatives from all areas of the state were often put into a defensive position explaining how irrigation occurs and how water rates were established in their respective service areas. They also described conjunctive use practices and the balance needed in water rates to prevent farmers from switching from surface water to groundwater. They emphasized the need to charge less for water in a wet year to help encourage increased recharge. Many of the environmental representatives did not have a basic understanding of irrigation and crop water requirements. They did not understand that in areas where available surface water supplies were not adequate to meet crop water requirements a tiered water pricing plan would not help reduce water usage.

The initial meetings often resulted in debate, division, and some animosity between the various representatives. This process was very frustrating and although unproductive, continued from meeting to meeting. Agricultural representatives attended the meetings hoping to establish a reasonable list of EWMPs, fearful that an unreasonable list of EWMPs might become mandatory by future legislation. Environmental representatives, primarily from the San Francisco Bay Area, continued to attend hoping to rectify what they perceived were water wasting practices in agriculture which if addressed could help improve water quality concerns and ecosystem problems in the San Francisco Bay-Delta.

During the fall of 1991, urban water agencies implemented their Memorandum of Understanding Regarding Urban Water Conservation in California. This MOU was a consensus effort developed by urban agencies working in concert with environmental organizations. The purpose was to encourage the implementation of Best Management Practices which would conserve existing urban water supplies and reduce long term urban water demands while protecting the environment.

GOVERNOR'S WATER SPEECH

In April 1992, Governor Wilson, in what has become known as his "Water Policy Speech," stated he supported the development of the Urban MOU and that he strongly supported the development of agricultural EWMPs and a comparable consensus MOU between agricultural, environmental, and other representatives. He added that an implementation plan should be developed by the committee presently working on agricultural EWMPs (the AB 3616 Advisory Committee) by the end of 1992.

The Governor's directive dramatically changed the AB 3616 Advisory Committee's charge from just developing a list of EWMPs to developing a workable agricultural MOU which would encourage the implementation of EWMPs by water suppliers and hopefully further improve water management where possible. The directive gave new purpose to the committee. A retired U.C. Extension Service Farm Advisor was named Chairman of the Advisory Committee, and was directed by the Director of the Department of Water Resources to proceed with the development of an acceptable MOU which would have broad-based support.

The Governor's speech came at the end of the six-year California drought. His proposal appeared to be an attempt to end the water wars and promote a cooperative understanding and consensus on state agricultural water issues among the various interested parties.

ADVISORY COMMITTEE MEETINGS WITH NEGOTIATION FOCUS

AB 3616 Advisory Committee meetings, under the new leadership, changed in scope, content, and purpose. An increased number of agricultural, environmental, and government representatives initially began attending the first few meetings curious to see what would happen. Other than the Governor's speech, the committee had no specific instructions or goals on what should be accomplished. Negotiations were required to understand all the expectations and concerns of the different participants. The environmentalists looked to the Urban MOU and felt a future Agricultural MOU should be modeled after it with specific implementation objectives and performance goals required. The agricultural representatives were coming to the table generally skeptical regarding performance goals of any type and uncertain regarding what the future MOU should contain, but anxious to stay involved to defend and protect their existing water use practices, and rights. Due to the large number of people in attendance, a recommendation was made to establish a drafting subcommittee with equal numbers of agricultural and environmental representatives (six members from each side) to begin the negotiating process for an MOU. These meetings began with an attempt to determine the areas of agreement and any outstanding issues between the two groups. Meetings continued during the summer and fall of 1992 with the drafting subcommittee identifying issues of agreement and disagreement.

During this time period the agricultural and environmental representatives each held separate caucus meetings to discuss the issues and reach consensus within their own group. Some of the issues in dispute or in disagreement included the following:

1. The environmental (enviro) representatives wanted an MOU that required implementation of all EWMPs unless a detailed economic and environmental analysis exempted the water supplier from implementing the practice. They wanted assurances that justified EWMPs would be implemented and not summarily dismissed. They wanted to limit the ability of a board of directors from saying no, they wouldn't implement a given practice. Agricultural (ag) representatives said they would be willing to implement a given EWMP only if it was cost effective to do so. The ag representatives also wanted some flexibility in any implementation requirements due to regional variations in water use practices. They also emphasized a water supplier board must have

the ability to make the final decision on implementation of a given practice.

2. The enviros thought water measurement should be a required EWMP not dependent on any analysis for implementation. They felt a volumetric meter at every farm and field should be installed. Ag stated that measurement may be beneficial, but potential water savings might not justify the cost of installing volumetric measuring device and therefore, analysis before implementation was needed. There was also a similar disagreement regarding water pricing.

3. The enviros were concerned about subsurface drainage problems and impacts to wildlife documented in numerous drainage studies following the Kesterson Reservoir fiasco. In essence, enviros wanted to stop or restrict all on farm drainage as much as possible. The ag representatives emphasized that drainage included surface and subsurface drainage issues and problems were different for each. Ag also emphasized drainage was not a water supplier problem but an on-farm problem which should be addressed in a different format.

4. There was also concern on whether or not the MOU should be written with all water suppliers in mind or should it be geared for the larger agencies that exceed a certain size or use of water.

During one of the agricultural caucus meetings it was recommended that a series of tours be held in the various agricultural areas to help educate subcommittee members on existing water management and water use practices in California. Tours were planned by the ag representatives for nine different farming areas from the Sacramento Valley, various regions of the San Joaquin Valley, and the Imperial and Coachella Valleys. Subcommittee meetings and field trips were eventually held in only five different locations during the first four months of 1993.

The field trips were successful in letting the enviro and ag representatives see first hand several of the water management problems and techniques presently being employed and investigated by different water suppliers. Water suppliers were asked specific questions on how or if EWMPs could be implemented. Water management operations beneficial for waterfowl were discussed and viewed at a water district in the Sacramento Valley, and endangered species concerns on the operation of a southern San Joaquin Valley groundwater recharge program were discussed and viewed at that site.

Although the field tours were educational and informative, the subcommittee was having a difficult time reaching a consensus on the operative details required for the MOU. There were still serious divisions on what should be included. During one subcommittee meeting, a proposal was made to let the ag representatives draft their own version of what should be included in the MOU. Following the preparation of this draft MOU the enviros would be given the opportunity to review it and then would work with the ag representatives to try and reach a consensus. This proposal was accepted by the full AB 3616 Advisory Committee and for the next three months the ag representatives worked with a smaller drafting committee to develop a draft ag MOU.

MEETING TO REVIEW DRAFT MOUs

The ag draft MOU was presented to the enviros for their review and comment. The enviros wanted many changes and during the next two months met to revise the ag MOU sections they felt were unacceptable. Many of their concerns were similar to ones expressed earlier. In an attempt to resolve disagreements on an acceptable MOU, a two-day meeting was scheduled to discuss the two draft MOUs and see if some compromises could be reached. The divisions were significant, however, and both groups were skeptical whether an agreement of any type could be reached.

Two people were hired to help facilitate the meeting. An agenda was prepared and ground rules were established before the meeting. There were nearly 50 fifty people in attendance. The meeting began with introductions and opening statements from each side. Then specific areas of disagreement were brought up and discussed. One serious area of disagreement was on the implementation of EWMPs. Enviros were concerned water suppliers would only half heartedly attempt to follow the MOU. There were no assurances water suppliers would make a good faith effort to follow the MOU. They felt a definitive methodology for analyzing the financial and environmental benefits of a practice had to be developed. The application of this methodology would be the basis for a water supplier requesting an exemption from a given practice. The ag representatives could not understand why a typical engineering analysis on the feasibility of implementing a given practice would not be acceptable. They also emphasized there was a need to develop some type of screening criteria to simplify any future agreed to analysis procedure.

After a long period of give and take, one enviro, in an attempt to resolve the deadlock, proposed a simplification of measurement and drainage requirements if there was an agreement to develop a detailed analysis methodology for EWMP implementation. He also suggested an exemption process for the implementation of practices that would include a review of 1) financial feasibility (benefit/cost ratio greater than one), 2) environmental and third party impact feasibility, and 3) legality. A water supplier would have to implement the practice if it were financially feasible, legal, and also had positive environmental and third party benefits. The practice would not have to be implemented, however, if only one of items 1) or 2) was determined to have positive benefits and was legal. This was a turning point of the meeting. The enviros were saying a practice only had to be implemented if it were cost effective to do so for the water supplier. They did want the water supplier, at a minimum, however, to make an analysis of the environmental and third party impacts to see if consideration should still be given to implementing the practice.

The enviro and ag representatives broke into separate groups to discuss the proposals. The ag group, although skeptical of what might develop, agreed it was best to continue working toward the development of an acceptable MOU. The description of how implementation requirements might be established appeared reasonable and there was a willingness to continue the process. A general Letter of Intent was drafted summarizing the agreements made at the meeting. The primary purpose of the Letter of Intent was to document that " . . . cooperative efforts to define, approve and implement appropriate water management plans by agricultural water suppliers is desirable and can be beneficial for both agricultural and environmental communities . . . " (and that the) participants agree in good faith to attempt to negotiate a Memorandum of Understanding ("MOU") to which both agricultural and environmental organizations can become signatories."

The Letter of Intent memorialized the agreements reached at the meeting and outlined a general framework for proceeding ahead with negotiations and drafting of an MOU. The smaller drafting subcommittee began meeting again. A new draft MOU was developed in accordance with the Letter of Intent. This document became the eventual working document for the final MOU. The development of the MOU went through many rewrites and revisions by the enviro and ag representatives. One of the biggest concerns for the enviros was the need to develop a detailed set of criteria for the screening, evaluation, and potential exemption of EWMPs. Who would or could develop the detailed criteria needed to evaluate the EWMPS? The enviros stated they would not sign the MOU until an acceptable set of criteria had been developed.

ANALYTICAL PROCEDURE TO EVALUATE EWMPs

The Letter of Intent required the development of a rigorous evaluation criteria by which water suppliers would determine the applicability of certain EWMPs. In return, the environmental community agreed they would not insist on the

MOU containing a long prescriptive list of EWMPs that all signatory water suppliers would be required to implement regardless of site specific conditions or resulting economic impacts. The AB 3616 Committee had agreed the evaluation criteria for each EWMP would include a screening procedure which would allow a water supplier to determine if they should implement a given EWMP. This agreement gave water suppliers and enviros certain assurances. Water suppliers would not be expected to implement practices which were not cost effective, and environmental interests would benefit by having screens which required an analysis of environmental and social factors.

The drafting subcommittee was assigned the task of overseeing the development of the criteria for evaluating the EWMPs. Two major points of contention arose. How was a water supplier to arrive at the value of any conserved water, and how were environmental or third party benefits or impacts to be quantified? The subcommittee consulted with agricultural economists from the University of California and private industry to obtain background on these two issues. Environmental members of the subcommittee felt a major study was needed to respond to these concerns. At this time, the California Department of Water Resources expressed a willingness to fund a study to develop potential criteria for the evaluation of EWMPs. DWR had already begun working on the 1998 California Water Plan Update, a report prepared every five years describing the status and needs of water use and supply in California. DWR staff felt the development of criteria for the evaluation of EWMPs would supplement information already being prepared for the 1998 California Water Plan Update. Staff also felt they could incorporate previous work done regarding the evaluation of proposals from water suppliers on low interest loan requests for water management improvements.

This proposal was taken back to the Full Advisory Committee where it was approved and DWR started an intensive two-year process to develop an acceptable evaluation criteria. A new Oversight Subcommittee was formed with a few different members to meet with DWR to review their progress and provide input. DWR concluded that no established criteria existed for quantifying environmental or third party impacts on a monetary basis. In addition, they recommended the value of conserved water should be left to the water supplier to determine, based on whether any conserved water would avoid present or future costs or could be sold to another party.

In consultation with the committee, DWR developed what is now titled the *Net Benefit Analysis* (NBA). This is Exhibit E of the MOU. During the summer and fall of 1995 they asked several water districts throughout the state to utilize the NBA methodology to evaluate EWMPs for their specific circumstances. A major concern voiced by the water suppliers and committee members was the amount of "paper work" required to complete the evaluation. With this in mind, DWR staff spent several months reorganizing and streamlining the process.

WHAT IS INCLUDED IN THE MOU?

The Final MOU is less complicated than earlier drafts. Section 1 includes definitions for several of the terms used, and Section 2, *Purposes*, consists of the following simple and direct paragraph describing the purposes of the MOU:

The purposes of this MOU are to: (1) create a constructive working relationship between agricultural water suppliers, environmental interest groups, and other interested parties; (2) establish a dynamic list of EWMPs; (3) establish criteria to evaluate the appropriateness of EWMPs; and (4) implement appropriate EWMPs, while avoiding unnecessary or unreasonable planning, paperwork, or expense for water suppliers, thereby voluntarily achieving more efficient water management than currently exists or may be required by existing law.

To address many of the agricultural concerns, Section 3 lists specific limitations on the applicability of the MOU. Some of the limitations are that the MOU will not address on-farm water management, land conversion, land retirement, crop selection, or groundwater production. Also emphasized is that this MOU is not to alter in any way the rights and duties of signatories under existing law.

Every water supplier signatory to the MOU is required to prepare and implement a Water Management Plan (WMP) which will discuss the analysis and implementation of applicable EWMPs. Section 4 outlines the general guidelines for preparing a WMP including exemption criteria for implementing EWMPs, a commitment to good faith effort, submittal of WMPs for endorsement, schedules on implementation, and progress reports.

Section 5 describes the Agricultural Water Management Council which will be established to oversee and coordinate the activities specified in the MOU. The Council will consist of the MOU signatories and will be divided into three groups; (1) Water Suppliers, (2) Environmental Interest Groups, and (3) Other Interested Parties. The Council will initially be housed by DWR and DWR will be responsible for the Council's administrative functions. The Council will attempt to provide assistance to water suppliers in their effort to implement EWMPs. It will review, endorse, or take no action on submitted WMPs. It will prepare and submit reports on signatories' activities, as appropriate, and it will make recommendations to modify the MOU and/or any of its exhibits as necessary.

Voting to modify the MOU and/or its Exhibits, or to undertake or impose additional responsibilities on signatories, requires a two-thirds vote in favor of the action by both Groups 1 and 2. All other Council actions, including the endorsement of WMPs and Progress Reports requires a simple majority vote of both Groups 1 and 2. Group 3 members can fully participate in Council meetings but they do not have any voting rights under the MOU.

General provisions of the MOU including its effective date, how signatories may withdraw from it, and a strong statement of support for participating signatories are included in Section 6. The MOU also includes exhibits. Exhibit (A) lists all of the EWMPs, (B) and (C) provide guidelines for the development of Water Management Plans and Progress Reports, (D) summarizes a typical Council report outline, and (E) outlines the requirements of the Net Benefit Analysis for the evaluation and implementation of EWMPs.

AB 3616 WORKSHOPS

As the Net Benefit Analysis methodology was being reviewed and modified during the fall and winter of 1995-96, the Oversight Subcommittee discussed the need to hold workshops in the agricultural regions of the state to inform agricultural water suppliers and their respective board members of the history, purpose, and requirements of the draft MOU. The AB 3616 Advisory Committee was well aware of the various details, but the process had been going on for a long time, and many in the agricultural community were not fully aware of the details or requirements.

Seven workshops were held in agricultural areas of the state and one was held in San Francisco during the summer of 1996. The workshops were convened and moderated by the California Farm Water Coalition under contract with DWR. The Coalition prepared a report summarizing the history and purpose of the MOU and made this available to all participants. An attorney from the Natural Heritage Institute, the environmentalists' representative on the Oversight Subcommittee, attended most of the workshops and provided an environmental perspective on the benefits of the MOU.

Various comments and reactions to the MOU were received from agriculture representatives. Concern was mentioned on the time and cost which would be required for some water suppliers to prepare a water management plan pursuant to the MOU. Concern was also expressed regarding the plan to let enviros sit on the Council created by the MOU. The fear was enviros would be able to deny the endorsement of a water supplier's water management plan with a type of "Russian veto." One manager stated, "I don't want a sandal wearing environmentalist from Berkeley telling me how to manage water in my District." Others wondered why agriculture should consider working in this manner with the environmentalists. Some stated they did not trust the environmental community and the proposed Council would give them access to materials and information which could be used incorrectly against them. "They have done this in the past and would do it again."

The environmental representative responded that the MOU would give the environmental community the opportunity to obtain a better technical understanding of problems related to water management. He felt the MOU would give water suppliers a better understanding of environmental concerns and may help water suppliers reconsider options for better water management. He mentioned the MOU might also provide the opportunity to improve the relationship between environmental and agricultural interests and possibly resolve some of the ongoing water wars.

CALFED, a joint California and Federal program working to establish the best economic and environmental solution for long term water supply and fishery problems in the San Joaquin Delta, became a critical last minute factor in the MOU process. CALFED had established a committee which was reviewing irrigation use efficiency, and a concern was expressed by some agricultural representatives that CALFED might recommend some type of mandatory water management program for water suppliers tributary to or receiving surface water supplies from the San Joaquin Delta. As work on the AB 3616 MOU was nearing completion, many Sacramento and San Joaquin Valley water suppliers would have to consider this possibility when deciding whether to support the MOU.

ADOPTION OF FINAL DRAFT MOU

Following a review of comments received at the summer workshops, the Oversight Subcommittee recommended appropriate revisions to the MOU and DWR submitted the Final Draft to the full AB 3616 Advisory Committee for approval. A final Advisory Committee meeting was scheduled for October 15, 1996. The meeting was attended by approximately fifty agricultural representatives, but only three environmental representatives were in attendance. The Director of the Department of Water Resources, the Mid-Pacific Director of the U.S. Bureau of Reclamation, and the CALFED Executive Director were in attendance and all expressed their support for the MOU. The CALFED Executive Director stated that unless some type of irrigation water use efficiency program for agriculture was established, CALFED would not be able to move forward with a Delta solution. He said he supported the voluntary AB 3616 MOU as an acceptable water management program. It would provide a "Menu of Actions" for the implementation of reasonable water management practices. If it was not supported by agriculture, however, he said CALFED would have to consider other options.

Many strong statements in support of the MOU were made by Advisory Committee members. Some said urban areas still felt agriculture was not being efficient in its use of water. An endorsed water management plan, prepared pursuant to the MOU, would provide positive public relations regarding the reasonable and beneficial use of agricultural water supplies. This would become critical during the next twenty years as the Sacramento and San Joaquin Valleys' population doubles and existing surface water supplies are unable to meet all of the anticipated urban and agricultural demands. Others mentioned the likelihood that if agriculture did not support this voluntary water management program, a mandatory program would be implemented which would not have the flexibility included in this MOU. The voluntary AB 3616 program would be far preferable.

The Advisory Committee unanimously approved the MOU. DWR said they would print copies of the Final MOU and transmit them to potential signatories during November 1996. The MOU would become effective when at least 15 water suppliers, representing at least two million irrigated acres, became signatories.

WHAT WAS LEARNED?

Several factors contributed to the completion of the MOU. Of prime importance was keeping the AB 3616 Committee focused over the four-year development period. This was accomplished by appointing a chairperson who was able to work with both sides, and who was able to adjust his schedule to accommodate the limited scheduling windows of the Advisory Committee and Oversight Subcommittee. In addition, the process would not have succeeded without the institutional support provided by the California Department of Water Resources. DWR provided compensation to the chairperson and in-house technical and administrative support. This included rewriting and faxing countless drafts of the MOU and related documents to members of all committees so that the process could be expedited and agreements made at pivotal stages.

The AB 3616 Advisory Committee appointed subcommittees to explore areas of agreement and to develop draft materials for the full committee's consideration. The small working groups were vital to the success of the process and were comprised of individuals with a wide range of expertise. In addition to having experts in water management, there was participation by legal representatives which was advantageous to the success of the process.

Finally, the participants realized that there is no textbook approach to reaching consensus agreements. Several approaches were used throughout the development of the MOU. These included using neutral facilitators to overcome division and conducting field tours to provide committee members with a better understanding of the agricultural and environmental factors that were of concern to the various interest groups.

WILL IT WORK?

For the MOU to succeed, it must be embraced and implemented by agricultural water suppliers. Agriculture realizes that because it utilizes the largest share of the developed water resources in the state, its water use practices will continue to be viewed as if under a public microscope. In light of this scrutiny, agricultural water suppliers are likely to be willing to commit to a process that encourages reasonable water management planning and implementation. If environmental groups do not embrace the MOU, improved water management beyond what already exists may still occur, but the MOU would become an agricultural document alone, and the environmental concerns of water management would not be heard as envisioned.

As mentioned, the current deliberations by urban and agricultural water suppliers, and environmental interests on "fixing" the San Francisco Bay Delta may also encourage agricultural water suppliers to become MOU signatories. This process, referred to as *CALFED* because of state and federal agency participation, is attempting to come up with a solution to balance the Bay-Delta environment, and the urban and agricultural needs dependent on the water supplies that travel through the delta. With the allotment of water supplies at stake, it is likely that water management planning and the implementation of EWMPs will be a component of any proposed solution. This can be either as a voluntary MOU or as a mandatory water conservation requirement of some type. There are many agricultural water suppliers who favor the voluntary approach the MOU offers.

Several questions remain to be answered and will determine the success of the MOU. These include: How will the Council function? Will agricultural water suppliers and environmental representatives be able to work together on the Council as a constructive team? Will the Council be sufficiently funded and organized so that it can effectively carry out its responsibilities? Will the public see the implementation of this voluntary process as evidence that agricultural water suppliers are being responsible stewards of their water resources? The answers to these questions will determine whether the years of effort and expense in developing the AB 3616 MOU will result in a practical approach for managing California's agricultural water resources.

COMPETING INTERESTS IN WATER RESOURCES - A RURAL AND URBAN SCENARIO IN ANDHRA PRADESH, INDIA

P.Lakshminarayana[1] B.Venkateswara Rao[2]

ABSTRACT

Increased demographic pressure results in the fast emergence of acute water scarcity for both drinking and agricultural purposes. Surface and ground water resources show widespread signs of degradation and depletion even as demands for water continue to multiply. Water scarcity is a constraint on meeting the human needs and protection of the environment particularly in arid and semiarid regions India is geologically covered by vast tracts of hard rocks and scarcity of water in these regions naturally leads to competing interests in water resources. Irrigation, drinking water and industry and other sectors are considered as the three distinct and important sectors of water use. As water resources dwindle competition is mounting not only among the various water use sectors but also within each of the sectors turning water scarcity as a potential source of conflict. As a result each sector attempts to draw its share of water demand at the expense of other sectors. The occurrence of such competing interests for water resources is witnessed among the various sectors as irrigation versus drinking water sectors, irrigation versus industrial and other sectors,

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drinking water versus industrial sectors and also within each of the irrigation, drinking water and industrial sectors in both rural and urban environments. In the present paper, the related issues on the competing interests for water resources in the aforementioned water use sectors in the rural and urban context of Andhra Pradesh, India are discussed. It is concluded that the remedy to the problems, conflicts and competing interests for water resources among the various sectors discussed in the paper lies in planning and implementing better water management strategies, co-operation among the water users and consumers, improvements in the water conveyance and distribution mechanisms of irrigation water, bringing a change in the traditional thinking of farmers to suit modern requirements and educating them on the water management in the practice of appropriate methods of water application on the field, adopting artificial recharge of rain water falling in the cities to conserve more water, enactment and strict implementation of water laws to control large scale abstraction and over exploitation of ground water and enforcement of provisions of the existing pollution control acts on such industries which pollute the surface and ground water resources.

INTRODUCTION

Andhra Pradesh is the fifth largest state of India. It lies between 12^0 to 20^0 N latitudes and 76^0 to 84^0 E longitudes. It has an area of nearly 1.07 lakh Sq.M (2.77 lakh km^2) occupying 8.4 % of India and a population of about 66.5 millions. The eastern part is a fertile coastal plain with deltas of rivers Godavari and Krishna. Beyond the plain lie the Eastern Ghats and part of the rocky Deccan Plateau from 492 to 1968 ft. (150 to 600 m) above sea level which is also a drought prone area. Hyderabad city, the capital of Andhra Pradesh is situated on Deccan plateau. The location map of Andhra Pradesh is presented in Fig. 1.

The per capita annual availability of water in India is about 2877 cyds (2200 m^3) which is approximately one fourth of the world average. The important river basins Godavari and Krishna in Andhra Pradesh have

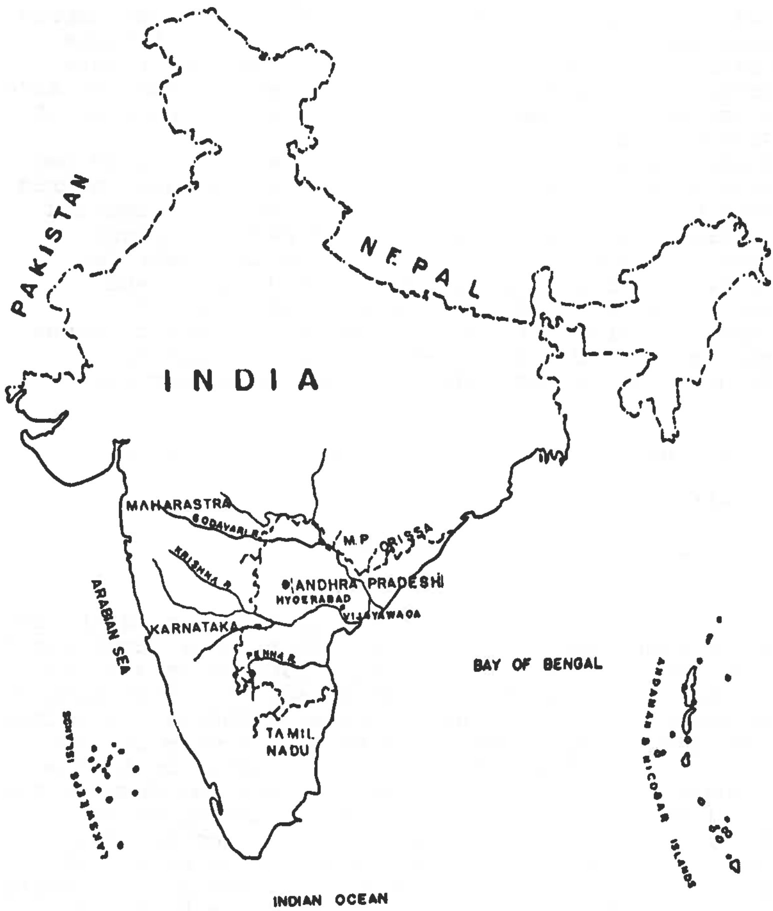

Fig.1. Location Map of Andhra Pradesh

the annual water resources potential of 3900 TM cft (110.5 km^3) and(78.1 km^3)2758 TMcft which on the per capita basis work out to 2650 cyds(2026 m^3)and 1716 cyds(1312 m^3) respectively. This indicates that the per capita annual availability of water in Godavari basin is nearer to the country's per capita availability of water than in the case of Krishna basin for which it is much lower than that figure. Hence the competing interests for water under Krishna river basin are more noticeable than in the case of Godavari basin.
Water scarcity is generally more severe in arid and semi arid regions particularly when they are covered with hard rocks and are devoid of major irrigation systems. Problem of scarcity of water in these regions naturally led to competing interests for water and is posing many associated social and environmental problems. Broadly speaking the important and vital sectors which make use of water may be divided into three, namely, irrigation, drinking water and industrial and other sectors.

Competing interests can be identified to exist

1. within the same sector and

2. among the different sectors

In the context of interstate competing interests for water resources Cauvery river and Krishna river water disputes in India are the best examples related to interests within the irrigation sector. Provision of drinking water to Chennai (formerly Madras) city from the river Krishna has agitated the farmers of the chronic drought prone Rayalaseema region of Andhra Pradesh. This is an example of competing demands for water between the irrigation and drinking water sectors. Many a time the industrial sector is in conflict with the drinking water sector by way of polluting the precious ground water and surface water sources. The industrial areas of Patancheru and Saroornagar in the capital city of Hyderabad, Andhra Pradesh stand testimony to this grave situation. Thus competing interests among the various sectors as well as within the same sector are ever increasing and causing conflicts of national and international concern apart from regional and local disputes creating much tension in the society. The competing interests in the various sectors of water use in rural and urban contexts of Andhra Pradesh are discussed in the next few paragraphs. Fig.2 shows the block diagram of competing interests among the different sectors.

Competing Interests of Water Resources in Rural Context

Competition within the irrigation sector: Even today about 70 % of population of India live in villages and their main occupation is cultivation. Since 65% of total land area of the country and 80 % of peninsular India is occupied by hard rocks (Pathak, 1984) naturally water for agriculture and their allied activities require major share among other uses. Today in India 83 % of available water is used for agricultural purposes(Mohile, 1996). Andhra Pradesh being predominantly agricultural state, the above situation in Andhra Pradesh is not much different.

Since ancient times, large number of tanks and wells were constructed in various parts of India including Andhra Pradesh and they are utilised for irrigation purposes. As the population grew from time to time increase in food production is necessitated which in turn resulted in bringing more and more land under irrigation. Consequently large scale irrigation projects and deep tube wells are constructed. Therefore conflicts and competition in irrigation through tanks, wells and canals are discussed below.

In all these irrigation systems one common problem that is encountered is the non availability of sufficient water to tailenders as compared to the users in the upstream reaches of the canal. Thus there is always a competition for water between these users. The problem is mainly due to poor management of water in the field, conveyance losses and non co-operation among the users. The water should be judiciously utilised and conserved by drawing only the required amounts by the users at the upstream and tail end reaches of the canal.

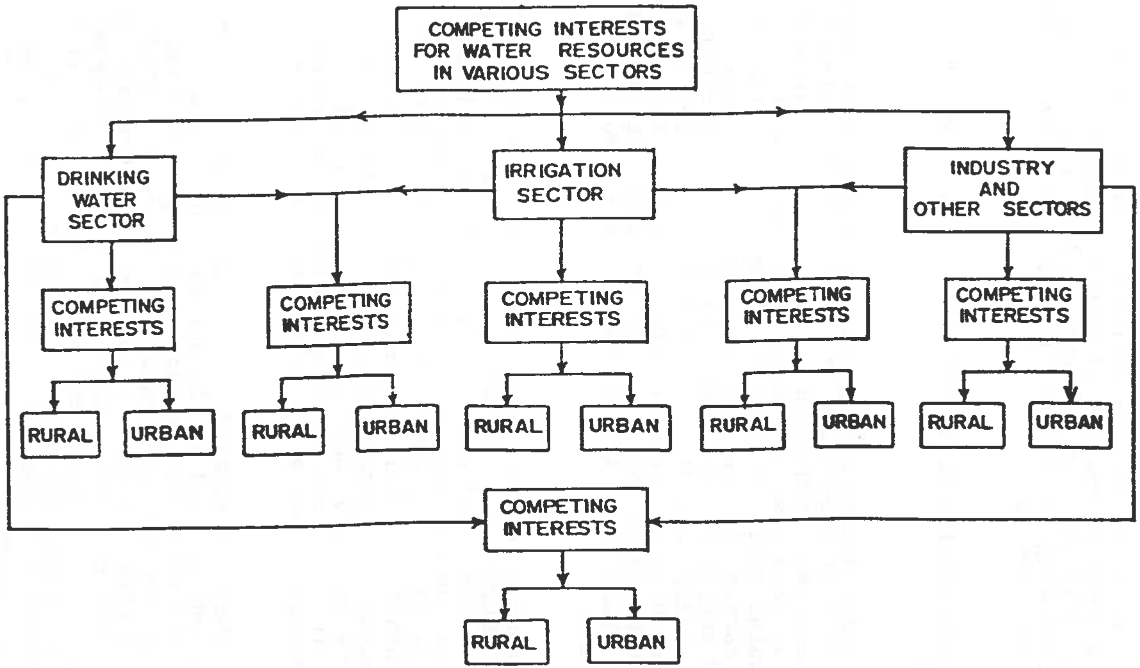

Fig.2. Block Diagram of Competing Interests for Water Resources in Various Sectors

The remedy to this problem lies to a large extent in lining of the main canals and pipe conveyance at the field levels in the case of canal, tank and high yielding bore well irrigation systems. In the case of low yielding bore wells particularly in the arid and semi arid regions, adoption of sprinkler and drip irrigation methods are highly beneficial. Some of the important and highly seepage prone canals have been lined in India but the sprinkler and drip irrigation systems are not widely practised though the government is extending more than 50 % subsidy for creating necessary infrastructure facilities to these systems. This scenario is due to high investment costs and low agricultural returns. Lack of awareness and enterpreneurship on the part of farmers is one of the main reasons for the above situation. At least the cultivation of irrigated dry crops in the water scarce arid to semi-arid hard rock regions will solve the above problem to certain extent. This is because many bore wells in hard rock areas have limited quantum of water usually yielding around 1500 gallons per hour (6820 lph) or even less than that discharge. Under these bore wells a traditional farmer used to grow paddy hardly irrigating an acre or so. But it is seen that the same amount of water can irrigate 3 to 4 acres (1.2 to 1.6 hectares) of land when irrigated dry crops are grown. This calls for a change in the traditional thinking of the farmers to suit modern requirements. Hence farmers are to be educated on the water management (Venkateswara Rao,1996)

Competition between Irrigation and Drinking Water Sectors: Though the quantum of water requirement is relatively small drinking water sector competes with irrigation sector in rural India. Since agriculture consumes nearly 90 % of available water resources it is felt in the fifth Stockholm Water Symposium, 1995 that its share can be reduced by 30 % by adopting better water management practices to meet other demands like drinking water. For example while recommending a deep bore well for irrigation purposes in the vicinity of a village drinking water requirements of a village should also be taken into account as many a time it is observed that deep bore well pumping nearby a village has dried up the open wells as well as shallow borewells using hand pumps for drinking water in the villages.

Competition between Irrigation and Other Sectors: Competing interests are observed between the irrigation and other sectors in the utilisation as well as maintenance of water levels of canal and tank irrigation systems. Certain water levels are to be maintained in the canals to meet inland navigation demands and from water quality considerations. In the case of tanks entire water cannot be used due to the demands of the fisheries department for the survival of fish culture. These restriction on the maintenance of water levels impose limitations on the amounts of water available for irrigation needs. The case history of Prakasam Barrage on river Krishna at Vijayawada town in Andhra Pradesh makes an interesting study in this context.

The prakasam barrage is provided with regulator gates and scour gates. The condition of the barrage has become precarious for want of regular maintenance posing danger not only to irrigation of 13.5 lakh acres(5.46 lakh hectares) in the century old Krishna delta but also 1260 MW power generation at Vijayawada Thermal Power Station situated 7.5 miles (12 km) upstream of the barrage. The thermal power station requires 2000 cusecs (56.63 cumecs) of water for cooling purposes which is provided from the barrage by gravity flow by maintaining water level of 12 ft.(3.657 mt). throughout the year. This resulted in the corrosion and jamming of regulator gates and scour gates as there is no water regulation at the barrage for want of maintaining 12 ft of water level for thermal power station. Irrigation officials feel that the power station has to make its own arrangements to pump water for its cooling purposes and state electricity board officials contend that it would be prohibitively costly to pump 2000 Cusecs of water over a height of 12 ft continuously. This will naturally increase the cost of power generation and hence the unit cost of power supply (The Hindu, 1996).

Competition within the Drinking Water Sector: Even today in many villages community differences on caste basis still continue to exist. The people of higher castes do not allow the poor and the underprivileged lower caste people in the village to draw water from the same well. If the other open wells in the village go dry or do not exist this unfortunate section of the people have to go to distant places to fetch water for their drinking purposes.

Competing Interests in Water Resources in Urban Context:

Competition within the Drinking Water Sector: In the urban context the competition is mostly between the drinking water versus other sectors as large quantities are required for an ever increasing thickly populated mega city. With the exception of a few, most of the cities in India are provided with only interrupted municipal water supply. The situation is more critical for cities located in hard rock terrains. For example, Hyderabad, the capital of Andhra Pradesh is one such city where water is supplied only for a couple hours per day during the monsoon and winter seasons. The situation becomes more severe as summer approaches and the water supply will be restricted to alternate days releasing water for about an hour or so. Hence tapping of ground water has become inevitable in almost all residential buildings and industrial establishments in and around Hyderabad city. This situation is not much different in other major towns of Andhra Pradesh.

An important observation in cities like Hyderabad is that the people living in multistoried apartments, the affluent sections of the society who have constructed their luxurious bungalows on the hill tops and the star hotels get their water from sub-urban areas by transporting water by tanker throughout the day. This has resulted in completely absence of the water table in the open wells at the nearby villages, for example, Shamshabad area near Hyderabad where one has no other alternative to get water except through sinking of borewells. On account of this situation small and marginal farmers are deprived of water for their agricultural activities as the open wells are no longer useful. Consequently they are either becoming agricultural labourers under a big landlord or migrating to the city for employment and contributing to the slums of the city.

The solution to this problem lies in the artificial recharge of the rainwater falling within the city and conservation of more water for daily purposes. Competing interests within the drinking water sector of the urban environment can be clearly noticed with the growth of the multistoried apartments. For a well developed colony where independent houses with one layer or two layer population exist, local ground water available at relatively shallow depths is generally adequate for the domestic needs of the residents. But with the rising up of multistoried apartments in the same colony or in its vicinity, water table is depleted due to deep pumpage by the apartment dwellers. The residents of adjacent houses have to either deepen their existing wells or get water transported from outside. In the absence of stringent ground water legislation excessive abstraction of ground water and consequent lowering of ground water table becomes a recurring feature.

Drinking Water Sector versus Industrial Sector: It has been mentioned earlier that in the urban environment the industrial sector is in conflict with the drinking water sector by way of polluting the precious ground water and fresh surface water sources. In Hyderabad city, Patancheru and Saroornagar industrial areas are the classic examples in this direction. In Patancheru area an ephemeral stream Nakkavagu supplies water to the adjacent lands and is used as an effluent stream to provide drinking water in the shallow open wells to the surrounding population prior to the industrialisation of the area. After the establishment of a number of chemical industries in the area untreated or partially treated effluents are being discharged into the stream there by completely polluting the surface water as well as ground water. The result is that cultivation along the stream was given up and drinking water wells were abandoned (Sudhakar, 1995).

In Saroornagar area of Hyderabad a pharmaceutical factory has injected its effluents into the aquifer by forming a number of ditches in the ground and filling them with the untreated or partially treated effluents. This has caused pollution of ground water beyond proportions and led to the migration of some of the residents of the area to other parts of the city. Now a pipeline is laid by the factory to discharge its effluents to the nearby Musi river. But already much damage has been done to the groundwater resources. Only large scale pumping and artificial recharge can only bring the situation to normal conditions (Yadaiah, 1992).

The above examples amply demonstrate that although there are legislative provisions to control if not totally prevent the pollution, gross violation of the pollution control act by the industries and their apathy towards the well being of the society defeats the very purpose of the act. Thus the competition for fresh water in the city environment is increasing day by day. Recently the Andhra Pradesh government has formulated some draft regulations to check and control groundwater extraction by borewells in the urban conglomerations and to pass it into an act. Inspite of the existence of pollution control act and other water laws that may be enacted later, some times political considerations play a vital role to hinder the implementation of the provisions of the acts.

CONCLUSIONS

Competing interests in water resources are identified between the various sectors and within the same sector in rural and urban contexts of Andhra Pradesh, India. Better water management for irrigation will bring down the competition for water within the irrigation sector as well as other sectors such as drinking water. Drinking water priorities should be taken into account while creating infrastructure facilities for irrigation water in the context of rural environment. Transporting of ground water to the cities from suburban areas has to be seriously viewed as there is the danger of water table being lowered in the suburban areas and giving rise to environmental problems. Drilling of deep bore wells within the city without the creation of proper recharge facilities for storm runoff will render many existing and relatively shallow well structures infructuous. Strict adherence to the provisions of existing laws or laws to be enacted in respect of the ground water utilisation should be practised by the city dwellers while it is imperative for the industries to scrupulously adopt the preventive and control measures of pollution of water sources as per the existing provisions of the pollution control act. Political interests should not come in the way as an impediment for the Government to strictly implement the provisions of the law concerning pollution control and water management.

REFERENCES

1. Mohile, A.D., T.S. Bhathija, V.K. Jyothi, A.D. Bharadwaj, R.S.Pathak and M.Sivadas, 1996. " Water Resources Day -1996. Theme Paper on Inter Basin Transfer of Water for National Development Problems and Prospects", Journal of Indian Water Resources Soc., Vol. 2, No.2, pp. 1-26.

2. Pathak, B.K. 1984. "Hydrogeological Surveys and Ground Water Resource Evaluation in Hard Rock areas of India", Procs. of International Workshop on Rural Hydrogeology and Hydraulics in Fissured Basement Zones, Roorkee, India, pp. 14- 15.

3. Sudhakar Babu, B. 1995. " Hydrogeochemical and Geoelectrical Investigations for Pollution Studies", M.Tech. Thesis (unpublished) submitted to J N T University, Hyderabad, India.

4. The Hindu, 1996, "A Barrage Badly Maintained", A Report Published in the english daily.

5. Venkateswara Rao, B., 1996. " Sustainability measures for water resources in the context of Indian Village System", Procs. of 3rd National Water Congress held at I.I.T., Delhi, India, pp.9.

6. Yadaiah, Y. 1992. "Assessment of Ground Water Contamination Levels and Prognostics of Pollutant Dispersion by Finite Element Method in Saroornagar Micro Basin", M.Tech. thesis (unpublished) submitted to J N T University.

A PROBABILISTIC ASSESSMENT OF RESERVOIR FILL UNDER A RANGE OF WINTER FLOW REGIMES

Lyn Benjamin[1]

ABSTRACT

Regulated flow regimes below irrigation reservoirs frequently create undesirable conditions for downstream biota. In order to meet reservoir fill deadlines, winter discharge below Island Park reservoir on the Henry's Fork of the Snake River, eastern Idaho, has been dramatically reduced from pre-dam flows of approximately 400 cfs, affecting trout and trumpeter swan populations. The purpose of this study was to model the probability of meeting storage deadlines while providing minimum instream flows during the winter months. Five different winter release scenarios were simulated using actual outflow and reservoir storage data for each water year from 1940 to 1995, and the probability of reservoir fill was calculated for each of these scenarios. The sensitivities of reservoir fill to reservoir starting levels and fill deadlines were also compared by running the simulations with different reservoir starting levels and fill deadlines. Results indicate that the probabilities of meeting the April 1st fill deadline with winter flows of 200 and 300 cfs are 55% and 42%, respectively. Bureau of Reclamation operating procedures that link all reservoirs within the Minidoka system mandate filling Island Park by April 1st, despite the observations that irrigation water is rarely needed from Island Park before July 1st and spring runoff occurs in April and May. When later fill dates were modeled, probabilities of reservoir fill became greater. Reservoir fill is very sensitive to reservoir levels at the start of storage season; fill occurs 100% of the time by May 1st with winter outflows of 200 cfs when starting contents exceed 65,000 acre feet. These results suggest that in order to provide for both instream flow and irrigation needs, water managers consider the moving the mandated fill date for Island Park Reservoir later in the spring and implementing water conservation measures that will maximize reservoir contents at the end of irrigation season.

INTRODUCTION

The character and quality of stream ecosystems is ultimately dependent on the geomorphology and hydrology of the system. However, human use of both land and water are substantially altering hydrologic regimes throughout the western United States. Irrigation, hydropower, and flood-control demands often produce hydrologic regimes that create undesirable conditions for downstream ecosystems. Irrigation or hydropower needs can generally be quantified, but it is difficult to know the optimal flow regime for all parts of the aquatic and riparian ecosystems.

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It is more productive to gain an understanding of the unaltered flow regime, how it differs from the regulated regime, and where flexibility exists to bring the two flow regimes closer together. In any watershed, allocation of available water resources requires balancing the needs of all the surrounding communities. The 1996 spring flood through the Grand Canyon is an example of a recent trend in managing regulated river systems with a broad range of objectives, which include protecting the downstream ecosystem.

The Henry's Fork of the Snake River in Eastern Idaho supports a world renowned blue-ribbon trout fishery and provides winter habitat for a large trumpeter swan population. Recent fluctuations in fish and swan populations, and the macrophytes that support both fish and swans, have prompted inquiry into the relationship between the regulated flow regime and population changes. Island Park Reservoir is primarily operated for irrigation purposes, which results in reduction of flows during storage season. Until 1972 winter flows were held at an extremely low level; since 1972 the winter flows have been higher, with only five years of flows below 20 cfs. It is thought that fish and swan populations remained depressed because of low winter flows prior to 1972 and that subsequent improvements in winter flows resulted in at least temporarily increased population numbers. However on the Henry's Fork the relationship between winter flow and population numbers hasn't proven to be as simple as "more water equals more fish and wildlife." Indeed, over the past ten years rapid increases in wintering swan numbers has negatively impacted the macrophyte community and, in turn, trout habitat. Although the relationship between flow regime and downstream biological response is still being studied, it is evident that large changes from year to year in winter flows have precipitated population fluctuations. Attempts to achieve more consistent winter flows through cooperative management of water resources in the basin have initiated a study to assess the feasibility of meeting both irrigation requirements and winter flow needs. The objectives of this paper are to use statistical methods to provide a probabilistic assessment of Island Park reservoir fill with a range of winter flow regimes and to compare the sensitivity of reservoir fill to reservoir starting levels and fill deadlines.

.STUDY AREA

The focus of this study is Island Park Reservoir in the Upper Henry's Fork of the Snake River basin, Eastern Idaho. Figure 1.

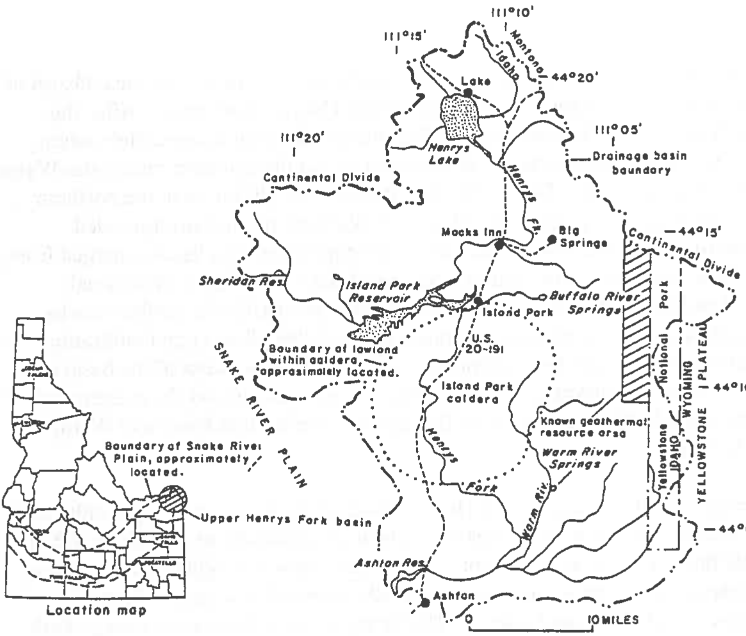

Fig. 1. Map of Upper Henry's Fork basin.

The upper basin, generally considered to extend downstream to Ashton, drains an area of 1,070 mi^2 and has an estimated permanent population of 4,000 residents. The basin is bounded to the north by the crest of the Continental Divide, to the east by the Yellowstone Plateau, and to the south and west by the northeastern end of the Snake River Plain. Altitudes range from over 10,000 feet along the Continental Divide to 5,200 feet at Ashton, with a mean elevation of 6,700 ft. The basin has one of the coldest climates in the western United States. Mean annual temperatures at Ashton and Island Park Reservoir are 5.3° and 2.3° C, respectively; freeze free periods are 90 and 40 days, respectively. Annual precipitation averages 16.9 inches in Ashton and 28.9 inches at Island Park Reservoir. Annual basinwide precipitation, most of which falls as snow, is estimated to average 35 inches (Whitehead, 1978). Vegetative cover at higher elevations in the upper basin consists of lodgepole pine and open meadow communities, and land use is timber production and grazing. The lower plains near Ashton are irrigated croplands producing grain, potatoes and hay (Idaho Water Resource Board, 1992).

The Island Park area forms a geologic and topographic transition between the Yellowstone Plateau and the Snake River Plain (Anderson, 1994). During Cenzoic time the Island Park caldera, a large elliptical bowl, was formed by the collapse of a shield volcano in the south-central part of the Henry's Fork basin. After the caldera formed, rhyolitic ash from the Yellowstone Plateau covered the eastern part of the caldera rim and basalt flows impinged on the southern rim (Idaho Water Resource Board, 1992). During the late Pleistocene, glaciation in the northern and eastern parts (the present-day Henry's Lake flats) of the basin provided outwash to valleys and stream channels. Contemporaneously, basalt emerged from vents south and west of the caldera and flowed onto the caldera (Whitehead, 1978). The Plateau Rhyolite, in the eastern basin, has particular significance to basin hydrology due to its highly permeable nature that allows rapid infiltration with little surface runoff or evaporation. As a result, these areas of the basin are characterized by an absence of well-defined stream patterns and the presence of large downgradient springs, such as Big Springs, the Buffalo River and Warm River Springs.

The unregulated hydrology of the Henry's Fork of the Snake is strongly influenced by the presence of these spring systems, which are estimated to contribute 42% to the total flow of the river at Ashton. Winter base flows are higher, and the range of discharges is narrower, than those generally observed in a typical Rocky Mountain runoff-dominated stream. The timing of peak flows is influenced both by snowmelt on the Island Park plateau and by the later melt in the high elevation Centennial Mountains. Figure 2.

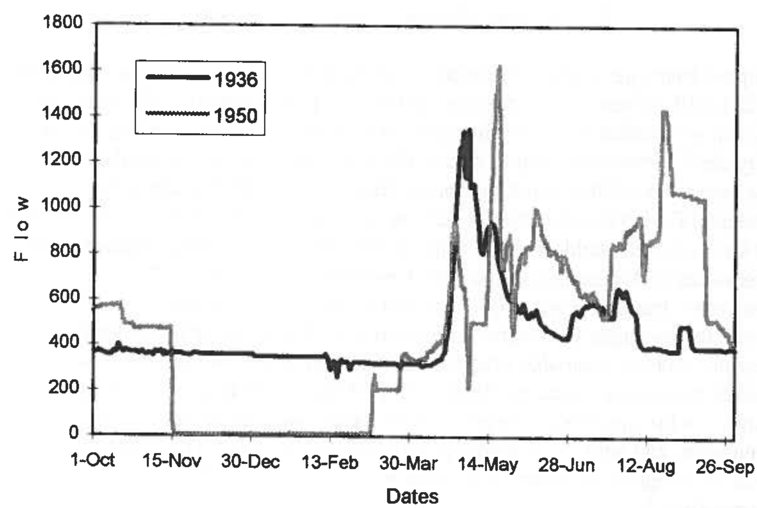

Fig. 2. Hydrograph of Unregulated and Regulated Flow at Island Park, Henry's Fork of the Snake, Id. Water Year 1936 and 1950.

Since 1923 and 1939, streamflow below Henry's Lake and Island Park reservoir respectively has been regulated, as part of the Minidoka system, to meet irrigation demands. As a result, flows on the Henry's Fork below Island Park reservoir now show characteristics of an irrigation-based hydrograph with reduced flows during the storage season (November 15th to April 1st), a short spring runoff peak with a steep recession limb, and prolonged high flows in late summer. Figure 2.

Recent declines in the downstream fisheries and high mortality rates among wintering trumpeter swan populations (fig. 3) have prompted studies into the relationship between the altered flow regime, specifically reduced winter flows, and the status of trout, swan and aquatic macrophyte communities. Preliminary studies indicate that early winter, when river temperatures are coldest, is the most critical time for the survival of juvenile trout, which must find cover in cobbles where temperatures are 0.2°-1.0° C higher than overlying water (Smith and Griffith, 1994). High winter flows make this cover available, but low flows out of Island Park Reservoir make this habitat unavailable. Aquatic macrophytes, which provide fish habitat and food for wintering swan populations, are adversely affected by prolonged ice cover and mechanical damage that results from freeze and scour; both of which are exacerbated by low winter flows.

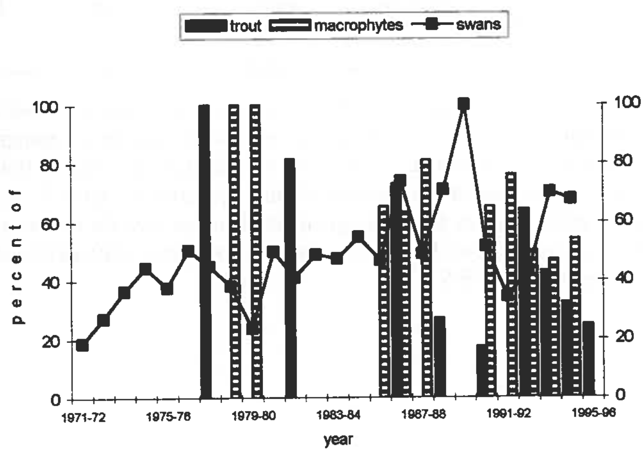

Fig. 3. Recent Trends in Fish, Swan and Macrophyte Populations.

Minimum winter flow recommendations developed to protect downstream biota on the Henry's Fork below Island Park are summarized in Table 1.

Table 1. Minimum Instream Flow Recommendations for Henry's Fork at Island Park.

	RECOMENDED FLOWS	RESOURCE	METHOD OF ASSESSMENT	LOCATION OF STUDY TRANSECTS
COCHNAUER AND BUETTNER, 1978	**Minimum flows** 250 cfs March-May, 177 cfs June-February between Island Park Dam and Warm River	**Fisheries** Fish Rearing Habitat	Wetted Perimeter and Discharge Relationships. Velocity, Depth and Discharge relationships for spawning.	Harriman State Park Wendell Bridge 4 miles upstream of St Anthony
	Maximum Flows 1,350 cfs March-May at Harriman State Park	**Waterfowl** Nesting Season Protection	Water surface elevations and Discharge	Harriman State Park
VINSON, 1991	**Minimum Flows** 300 cfs **Optimal Flows** 500 cfs	**Trumpeter Swan** Maintenance of Habitat	Stage-Discharge Relationships (Water Surface Elevations)	Big Bend East and West, Railroad Ranch, Osbourne Bridge and Harriman East
IDAHO DEPARTMENT OF WATER RESOURCES, 1992	**Minimum Flow year round** 100 cfs Priority Date 9/23/81	**Fisheries and Recreation**		Island Park Reservoir to 1 mile above Mesa Falls
SHEA, 1996	Not Quantified. "Higher winter flows without the abrupt increases from near-zero. Generally moderate and later peak flows"	**Macrophytes** increase winter water depths, habitat complexity for fish and invertebrates	Comparison of composition and biomass of historical and current macrophyte study sites	68 transects in Harriman Stae Park

Prior to 1972 winter flows from Island Park reservoir were frequently reduced to below 20 cfs; however, since 1972 the Bureau of Reclamation, in an attempt to meet fish and wildlife instream flow needs, has increased storage season flows to at least 100 cfs. This change in management strategy is shown in Figure 3, which gives mean monthly flows as a percentage of annual mean flow for the pre-dam period, reconstructed inflows 1940-1996, observed outflows 1940-1972 and observed outflows 1972-1995

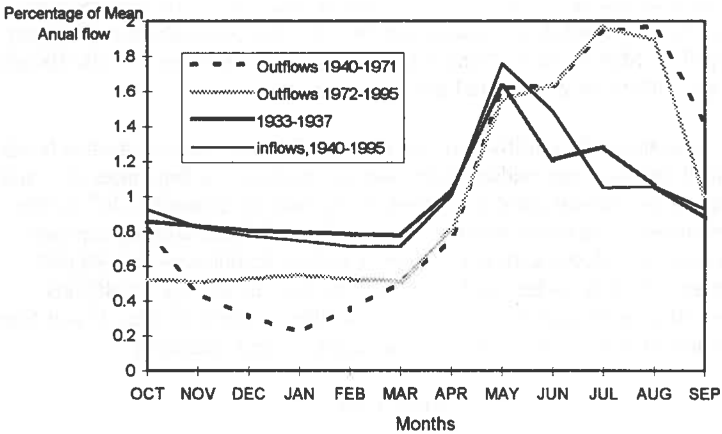

Fig. 4. Mean Monthly Flows as a Percentage of Annual Mean Flows for 1933-1937 (Pre-Dam), Reconstructed Inflows 1940-1996, Observed Outflows 1940-1972, Observed Outflows 1972-1995.

Operation of Island Park within the Minidoka system has mandated reservoir fill by April 1st, the start of irrigation season at lower elevations on the Snake River plain, despite the fact that runoff into Island Park occurs during April and May and irrigation demands for Island Park water rarely occur before July 1st.

METHODS

In order to reconstruct daily inflows to Island Park reservoir from 1940 to 1995, daily records of reservoir levels and outflows from the reservoir were obtained from the U.S. Geologic Survey and Bureau of Reclamation. From the daily change in reservoir storage and average daily outflows, inflows were calculated using the mass balance equation:

$$\text{Change in storage} = \text{inflow-outflow} \quad (1)$$

Using reconstructed daily inflows, outflows of 0 cfs, 100 cfs, 200 cfs and 300 cfs and the reservoir level on September 30th (the end of irrigation season) daily reservoir contents until the following July 1st were modeled for each year of record. This was done by adding the difference between each outflow and daily reconstructed inflows to successive reservoir contents to project daily reservoir contents until July 1st. The date of reservoir fill, which occurs with 135,000 acre-feet, for each year and outflow was recorded. Reservoir levels were converted into contents in acre-feet by the Bureau of Reclamation, and cubic feet/sec were converted into acre-feet/day by multiplying by 1.98. The probabilities of reservoir fill by April 1st, May 1st, June 1st and July 1st, with winter outflows of 0 cfs, 100 cfs, 200 cfs and 300cfs were calculated from these results.

In order to examine the sensitivity of reservoir fill dates to reservoir starting levels I calculated the mean and median of the reservoir contents on September 30th, and also graphed the chronological time series of contents on September 30th for the period of record. The model was then rerun with six different starting contents (15,000 acre-feet, 35,000 acre-feet, 55,000 acre-feet, 85,000 acre feet, 95,000 acre feet and 65,000acre-feet) and 0 cfs, 100 cfs, 200 cfs, 300 cfs and 400 cfs outflows. The percentage of time the reservoir filled by April 1st, May 1st and June 1st as a function of these start contents was calculated and compared.

RESULTS

Results from the reservoir content simulation modeling are shown in Table 2. For the 56 years of record, reservoir fill would occur by April 1st, 83% of the years with 100 cfs outflow, 55% of the years, with 200 cfs outflows, and 42% of years, with 300 cfs outflows. Fill would occur by May 1st, 97% of the years with 100 cfs outflow, 85% of years, with 200 cfs outflows, and 48% of years, with 300 cfs outflows. Fill would occur by June 1st, 100% of the years with 100cfs outflow, 97% of years, with 200 cfs outflow, and 70% of time with 300 cfs outflows. By July 1st, fill would occur 100% of years with outflow of 100 cfs, fill occurs 98% of years, with 200 cfs outflows, and 96% of time, with 300 cfs outflows.

Table 2. Percentage of Years that Island Park Reservoir would Fill by April 1st, May 1st, June 1st and July 1st with winter outflows of 0, 100, 200 and 300 cfs.

	0 CFS OUTFLOW	100 CFS OUTFLOW	200 CFS OUTFLOW	300 CFS OUTFLOW
Percent fill by April 1st	98%	83%	55%	42%
Percent Fill by May 1st	100%	97%	85%	48%
Percent Fill by June 1st	100%	100%	97%	70%
Percent Fill by July 1st	100%	100%	98%	90%

Reservoir contents on September 30th, for the years of record, range from 15,000 acre-feet to 115,000 acre-feet, with mean value of 72,000 acre-feet. Mean reservoir contents on April 1st are 118,000 acre feet, for May 1st are 124,000 acre feet and for June 1st are 135,000 acre feet.

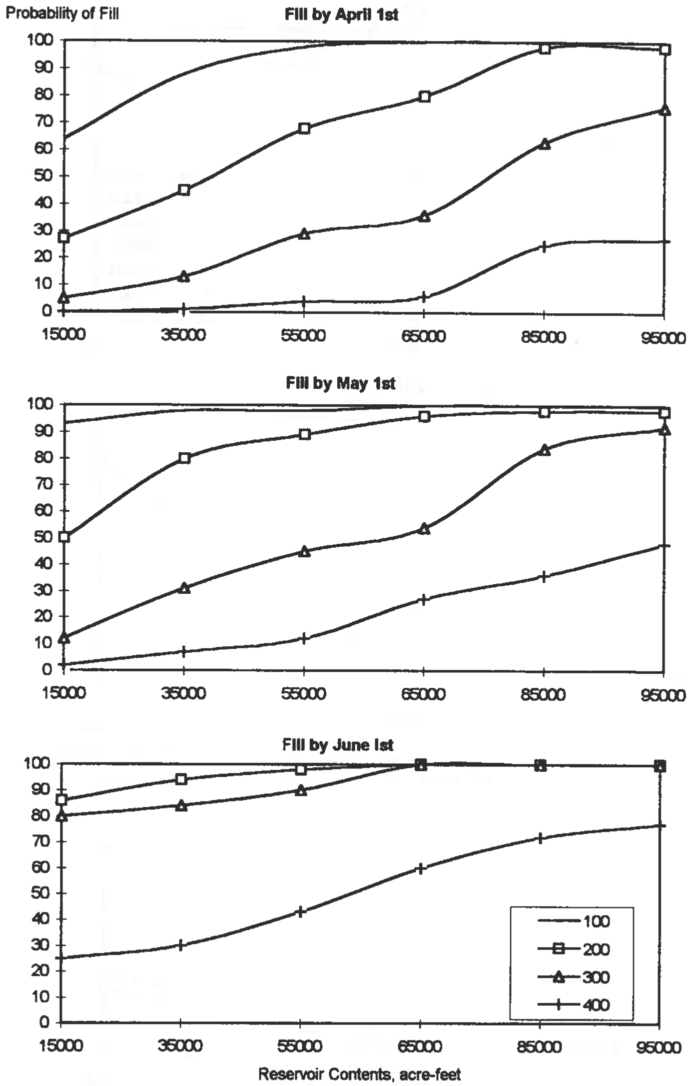

Fig.5. Probability of Reservoir Fill as a Function of Reservoir Contents on September 30th, with 100, 200 300 and 400 cfs Winter Outflows

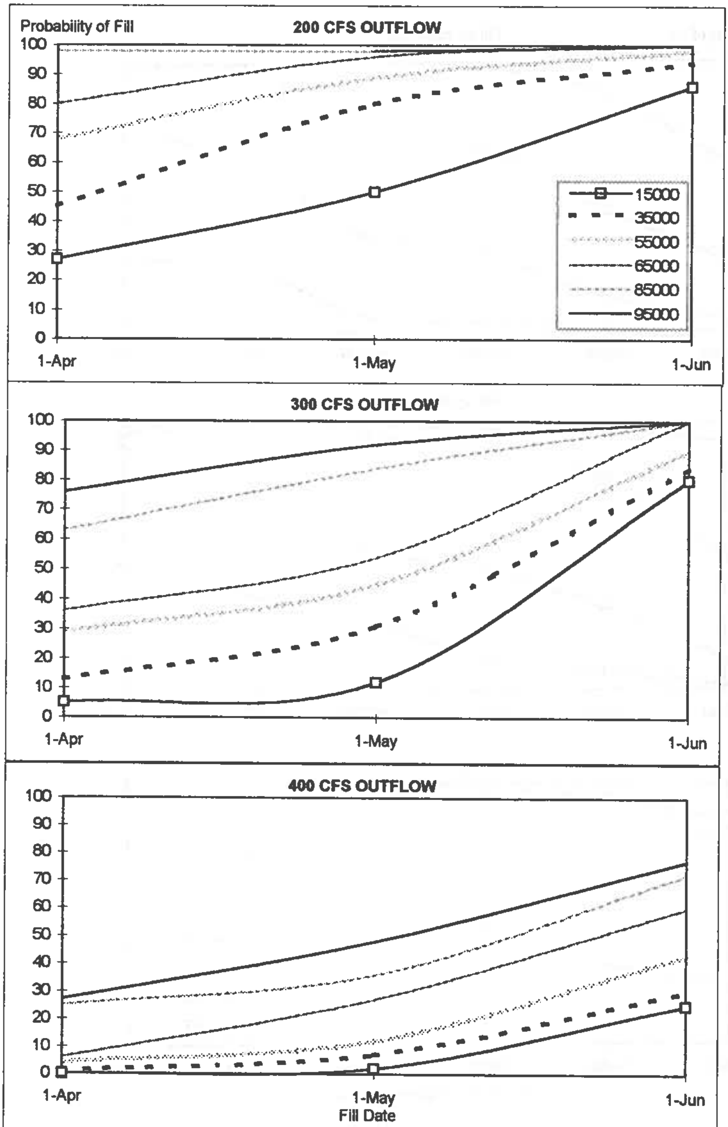

Fig. 6. Probability of Reservoir Fill as a Function of Reservoir Contents on Sep 30th and Fill Dates, with 200, 300 and 400 cfs winter Outflows

Sensitivity of reservoir fill to reservoir contents on September 30th is illustrated in Figure 5. Fill by April 1st , with outflows of 100 cfs, is most sensitive to start contents between 15,000 and 45,000 acre feet, above this the probability of fill does not increase greatly. Sensitivity to start contents with 200 cfs outflows ends at 85,000 af above which probability of fill does not increase. 300 cfs outflows show start content sensitivity throughout the range but between 55,000 and 65,000 af sensitivity is reduced. With 400 cfs outflows sensitivity to start contents is only shown between 65,000 and 85,000 acre feet. Fill by May 1st with 200 cfs outflows is only sensitive to start contents up to 35,000 af, with 300 cfs outflows fill is most sensitive between 65,000 and 85,000 af and outflows of 400 cfs show moderate sensitvity throughout the range. Fill by June 1st with outflows of 200 and 300 cfs has a 100% probability of occurrence with start contents above 62,000 acre feet, with 400 cfs outflows sensitivity to fill is fairly consistent through the range.

A comparison between the sensitivity of reservoir fill to reservoir start contents and fill deadlines is shown in Figure 6. At 200 cfs outflow maximum increases in fill probability occur between May 1st and June 1st with 15,000 acre feet start contents (35%); between April and May with 35,000 acre feet start contents (32%) and on April 1st between 35,000 acre feet and 55,000 acre feet start contents (33%). At 200 cfs these adjustments in start contents or fill deadlines are roughly equivalent to each other. At 300 cfs outflow maximum increases in fill probability occur between May 1st and June 1st with 15,000 acre feet (65%); between May 1st and June 1st with start contents of 55,000 acre feet (38%) and 65,000 acre feet (45%); and on April 1st and May 1st between 65,000 and 85,000 acre feet (29%). At 300 cfs a 45% increase in probability can result from moving the fill deadline or increasing the reservoir start contents from 65,000 acre feet to 95,000 acre feet with a fill deadline of May 1st. At 400 cfs outflow a maximum increase in fill probability occurs between May 1st and June 1st with start contents of 85,000 acre feet (47%) and is most sensitive between 65,000 and 85,000 acre feet start contents on April 1st (20%). The 47% increase due to change in fill deadline is approximately equivalent to an increase in start contents from 35,000 to 85,000 acre feet with a June 1st fill deadline.

DISCUSSION

The objective of the study was to provide a quantitative basis to establish minimum winter flows on the Henry's Fork below Island Park within the constraints of irrigation needs. Results from the model furnish several options for meeting this objective, including using 118,000 acre feet as the fill objective for April 1st, moving the fill deadline forward to May 1st or 15th and starting the storage season with as high reservoir levels as possible. The following recommendations that optimize the probability of reservoir fill while maximizing winter flows.

For the period of record the mean reservoir contents on April 1st is 118,000 acre-feet, and mean contents on May 1st and June 1st are 124,000 and 135,000 acre-feet, respectively. At present the Bureau of Reclamation uses 135,000 acre feet on April 1st as the objective with which to calculate winter flows; however this is unrealistic because flood control curves rarely allow for this amount of water to be in the reservoir on this date. If instead an objective of 118,000 acre feet on April 1st was used an extra 40 cfs would be available for daily winter flows, which represents a significant proportion of winter base flows.

Fill occurs most frequently (40% of the years) between May 1st and 15th, which suggests that a more realistic fill deadline to use in calculating winter flows is May 1st or 15th. Moving the fill deadline has previously been viewed as posing a risk to irrigation water supply, but inflow reconstruction and a new gauge station on the Henry's Fork above Island Park have both provided a more accurate assessment of the constant nature of winter inflows into the reservoir. Figure 3 shows that the lowest inflows into the reservoir occur in March and that these flows are only 12% below October flows. This information indicates that dramatic decreases in inputs to the reservoir do not occur over the winter and that October inflows give a reasonable approximation of inflows throughout the winter months. Additionally, snowmelt runoff is known to occur in late April and May so the probability of adding additional water to fill the reservoir is high.

The probability of reservoir fill is clearly sensitive to reservoir contents at the start of the irrigation season. Higher reservoir levels at the end of the irrigation season provide a higher likelihood of biologically adequate winter flows and reservoir fill. Although the amount of water used from the reservoir during irrigation season is largely climatically controlled, conservation efforts will improve the following year's refill probability. If the reservoir level at the start of storage season is low, winter outflows from the reservoir should be distributed to release a greater portion earlier and decrease flows later, if needed. This is a more appropriate strategy than reducing flows early in the winter because the critical survival period for juvenile trout appears to be early winter, and more accurate predictions of snow runoff are available in later winter.

The model provides a method to assess winter flow options for the Henry's Fork below Island Park and quantify the probability of Island Park reservoir fill under a range of scenarios. The sets of curves shown in Figs. 5 and 6 show the sensitivity of reservoir fill to starting levels and fill deadline dates with given winter flows. Decisions about the size of winter flows can be made using these curves to predict the likelihood of fill under each scenario. Each year presents a different set of hydrologic conditions that determine the way irrigation and instream flow needs can be met. This type of analysis can apply different conditions to the constraints of a given reservoir system and be used as a tool to manage water resources and balance potentially conflicting demands.

Literature Cited

Bureau of Reclamation. 1996. A Description of Bureau of Reclamation Systems Operations above Milner Dam. Bureau of Reclamation, Boise, ID.

Cochauer, T. and E. Buettner. 1978. Stream Resource Maintenance Flow Determinations on Idaho Streams. Job #2. Idaho Department of Fish and Game, Boise, Idaho.

Shea, R.S., E.O. Garton and I.J. Ball. 1987. The history, ecology and management of the Rocky Mountain population of trumpeter swans. U.S. Fish and Wildlife Service and Montana Wildlife Resources Cooperative, Missoula, MT.

Shea, R. 1996. Assessment of Aquatic Macrophytes at Harriman State Park and at other Key Wintering Sites within the Henry's Fork Watershed, Idaho. Executive Summary. Unpubl.

Smith, R.W. and J.S. Griffith. 1994. Survival of Rainbow Trout during Their First Winter in the Henry's Fork of the Snake River, Idaho. Transactions of the American Fisheries Society 123:747-756

Vinson, D.K. 1991. Base Flow Determination for wintering trumpeter swans on the Henry's Fork of the Snake River. U.S. Fish and Wildlife Service, Boise, ID.

CURRENT COLORADO RIVER ISSUES RELATIVE TO WATER DELIVERIES TO MEXICO

John M. Bernal[1]

ABSTRACT

The United States and Mexico, through the International Boundary and Water Commission (IBWC) are dealing with concerns of the Government of Mexico regarding salinity and conveyance of waters of the Colorado delivered by the United States to Mexico under the 1944 Water Treaty. The United States is in compliance with the salinity obligations in force since 1973 and both countries may make use of the channel of the international streams for the discharge of floods.

The IBWC has utilized an international task force of the federal water management agencies of each country to allow the two countries to better understand the concerns of Mexico and limitations in the United States in improving the quality of the water delivered and the conveyance capacity of the river channel.

Mexico expressed concern over high salinity peaks at its its principal delivery point and that high saline concentrations dissolved in the water delivered at San Luis have caused decreased crop yields and deteriorated agricultural lands on the left bank of the Colorado River. Mexico is also concerned that sediment from the 1993 and 1995 Gila River floods deposited in the Colorado River from the confluence of the Gila River to Morelos Dam, and in Mexico's irrigation canal system. In addition the two countries expressed a need to improve the conveyance capacity of the Colorado River from the Gila River to the Gulf of California.

Improvements have taken place in the case of salinity peaks at the point where Mexico receives most of its treaty waters upstream of Morelos Dam and short term sediment removal has taken place. However, further consultations are underway regarding the salinity of waters delivered to Mexico across the land boundary at San Luis, Sonora and for studies for the longer term conveyance capacity of the Colorado River from its confluence with the Gila River to its mouth at the Gulf of California.

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[1] United States Commissioner, United States Section, International Boundary and Water Commission, 4171 North Mesa, Suite C-310, El Paso, Texas 79902

The United States and Mexico are addressing concerns of the Government of Mexico over the quality and the conveyance of Colorado River waters delivered by the United States to Mexico under a treaty signed in 1944.. The United States has the obligation to deliver 1.5 million acre-feet or maf (1,850,234,000 cubic meters or cm) annually of these waters in accordance to a scheduled provided by Mexico and within salinity standards established by the two Governments in 1973. At times of surpluses in excess of United States needs, Mexico may schedule an additional 200,000 acre feet (246,696,000 cm). At times of extraordinary drought the United States may reduce these deliveries proportionate to reductions as are made in the United States. The United States and Mexico have the right to use the channel of the Colorado River for discharge of flood and other excess waters.

The United States and Mexico entrust to the International Boundary and Water Commission (IBWC) the application of the 1944 Treaty[2] and the regulation and exercise of rights and obligations assumed by both Governments under the treaty. The IBWC is also entrusted to settle differences that may arise from observance and execution of this treaty. The IBWC is made up of a United States Section and a Mexican Section, each headed by an Engineer Commissioner appointed by his respective Government. The United States Section is authorized to participate in United States - Mexico activities under this and other treaties and agreements by legislation passed by the United States Congress. Where activities or works in the United States may be used in part to meet treaty obligations, the functions or jurisdictions shall be carried out by the domestic federal agencies in cooperation with the U.S. Section of the IBWC.

The Binational Task Force Cooperative Approach

The IBWC, in 1996, established a binational task force involving the federal water resource agencies of both countries that each country has charged with managing the Colorado River system waters. In this manner questions that may arise over the delivery of these waters are addressed in a cooperative manner utilizing the U.S. Bureau of Reclamation's (Reclamation) Lower Colorado River office's existing resources and management practices and those of Mexico's Comisión Nacional del Agua (CNA) Two issues are currently being addressed in this manner:

- **Salinity, and**
- **Conveyance**

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[2] United States Department of State, "United States - Mexico Treaty for Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande," February 3, 1944, Washington, D.C. (TS 994; 59 Stat. 1219).

Salinity

- ***Mexico is concerned with occasional salinity peaks in waters delivered at the Northerly International Boundary (NIB).[3]***

- ***Mexico is concerned that over time, drainage waters delivered to Mexico at the Southerly International Boundary (SIB)[4] may be a source of increased soils and groundwater salinity.***

A general drawing of the Lower Colorado River from Imperial Dam to the Gulf of California is at Exhibit 1 and a detailed drawing of the 24 mile international boundary segment and delivery points is at Exhibit 2.

Under the Colorado River Salinity Agreement in IBWC Minute No. 242 of August 30, 1973[5] of the 1.50 (1,850,234,000 cm) per year of Colorado River waters guaranteed to Mexico under the 1944 Treaty, the United States is obligated to deliver:

1) At NIB - Approximately 1.36 maf (1,677,545,000 cm) per year, with an average annual salinity of more that 115±30 parts per million (ppm) over the average annual salinity of those waters arriving at Imperial Dam, and

2) At SIB -- Approximately 140,000 af (172,689,000 cm) per year with a salinity substantially the same as the of the waters customarily delivered there.

The Colorado River Salinity Agreement of 1973 resolved a major difference between the two governments that began in the 1960s as a result of an increased salinity in the waters delivered to Mexico under the 1944 Treaty. The salinity in those waters increased by nearly 300 per cent as the result of the discharge of highly saline

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[3] The IBWC applies this name to the northernmost point where the Colorado River forms the international boundary downstream for 24 miles (38 kilometers)

[4] The IBWC applies this name to the southernmost point of the 24 mi (38 km) international boundary. Under Minute No. 42 the two Governments memorialized an arrangement by which the United States continues to deliver to Mexico water through the Yuma Valley drainage conveyance system across the land boundary to Mexico's Sanchez Mejorada Canal at San Luis, Sonora.

[5] United States Department of State, Agreement Confirming Minute No. 242 of the International Boundary and Water Commission of August 30, 1973 (TIAS 7708; 24 UST 1968)

drainage waters from the Wellton-Mohawk Irrigation District in Arizona to the Gila River, and in turn to the Colorado River. The salinity question was the subject of several meetings of the United States and Mexican Presidents and several international agreements in 1965 and 1972 until arriving at the 1973 agreement.[6] The United States is meeting the salinity established in the 1973 agreement through legislation approved by the Congress in 1974.[7] with a number of salvage measures, including canal lining that permit the use of stored waters in place of saline drainage waters that are bypassed by a lined canal to the Gulf of California. To facilitate compliance, the 1974 legislation authorized the construction, operation and maintenance of a desalting plant in Yuma, Arizona to salvage the some 140,000 acre-feet (172,689,000 cm) annually that are discharged to marshlands at the mouth of Colorado River at the Gulf of California. Reclamation began desalting plant operations, but placed the facilities on standby following the Gila River floods of 1993.

At the NIB, Mexico diverts the treaty waters diverted at Morelos Dam and utilized these waters for irrigation and domestic use in the Mexicali Valley and conveys some of these waters via aqueduct to Tecate and Tijuana. Mexico's concern with an occasional salinity peak comes at those times when Mexico's water delivery demands are low. Beginning in early 1996, the binational task force, exchanged information regarding operations in the United States and Mexico. In this technical forum, each country's federal water resources managers extended their understanding of the other's country's needs and limitations. Salinity readings during 1996 indicate insignificant peaks at this delivery point. The annual average differential established in the Salinity Agreement will again be met in 1996.

At the SIB, Mexico also utilizes some of the NIB delivered waters along with wells from near San Luis, Sonora for mixing the drainage waters that the United States continues to deliver at the SIB. Mexico uses this dilution to irrigate 93,860 acres in the area of the Mexicali Valley in Sonora known as the Left Bank Unit. Mexico is concerned with reduced crop yields and increased soil and groundwater salinity.

In this case also, the binational task force met several times to exchange information on United States operations and Mexico's management of the delivered waters. Mexico, in this respect, requested that all its treaty deliveries be made at the NIB.

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[6] United States Department of State, Agreement Effected by Minute No. 218 of the International Boundary and Water Commission, United States and Mexico of March 22, 1965 (TIAS 7404; 23 UST 1286) and United States Department of State, Agreement Extending Minute No. 218 of the International Boundary and Water Commission of March 22, 1965, November 16, 1970.

[7] United States Congress Colorado River Basin Salinity Control Act, Washington, June 24, 1974, (82 Stat. 885)

Further, Mexico is carrying out a silt removal program in its internal canal system and in the Colorado River in the lower reaches below Morelos Dam.

The task force is considering scenarios for improving the conveyance capacity of the Colorado River from the mouth of the Gila River to its discharge in the Gulf of California. The group is currently reviewing five rectification alternatives presented by Mexico for the channelization and preservation of the international reach of the Colorado River.

Regarding the sediment related issues in the lower Colorado River, the United States Section of the IBWC, through the Corps of Engineers, is undertaking a comprehensive sediment transport analysis that would provide the technical basis for evaluating alternative solutions, their relative life-cycle costs, and for reaching agreement between the United States and Mexico or the best coordinated approach.

Conclusion

The United States and Mexico share a 24 mile (38 kilometer) segment of the Colorado River system as their international boundary. Mexico is guaranteed an annual amount of its waters under a treaty signed in 1944 and those waters must meet a salinity standard under an agreement signed in 1973. The United States continues to meet that standard. The two countries share the benefits and the burdens that attempts to maximize the beneficial uses of the waters of this international stream bring to its inhabitants. Salinity and sedimentation problems in this international stream are of concern to Mexico even though each country's activities in this area are within are within the rights and obligations incurred by each country under treaties and agreements in force. The United States continues to meet the salinity standard adopted by the two Governments. Sediment transport is a natural phenomenon in alluvial streams. In response, the IBWC has used the international task force mechanism, with the participation of the technical water resource agencies of both countries, to exchange information in order to better understand each other's operational limitations and opportunities for cooperation between the United States and Mexico to manage for the benefit of inhabitants of both countries, what in other regions of the world would be competing interests in water resources that give rise to serious conflict.

BAHR EL BAQAR DRAIN AND LAKE MANZALA AS AFFECTED BY WASTEWATER (Case Study)

By

Hesham. Kandil[1] Safwat Abdel Dayem[2]
Shaden Abdel Gawad[3] Mohamed Abdel Khalik[4]

ABSTRACT

Egypt is an arid country with limited water resources of 55.5 BCM/year and is suffering from escalating water demands due to population increase and recent development in various sectors in the country. In addition to limitation of water resource, increasing pollution of water ways is complicating the situation and erecting the competition among the water users and the water provider communities. Most of Egypt's agricultural lands are served by subsurface drainage system which discharge by gravity to open drains ending to either the River Nile in the Nile valley or to the northern lakes and the Mediterranean sea in the Delta. One of the national plans to increase the irrigation system overall efficiency is to adopt the policy of reusing agricultural drainage water. However, the escalating deterioration of drainage water quality due to pollution with municipal, industrial, and agricultural wastes hinder the plans to transfer drainage water with low salinity content to other community uses. On the other hand, recreation and fishery activities of water bodies at which these drains discharge are negatively affected.

One of the highly polluted drains in the Nile Delta of Egypt is Bahr El-Baqar Drain. It disposes its water into Lake Manzala in the north. Bahr El-Baqar Drain carries sewage effluent from the Greater Cairo urban and industrial areas and has quite high heavy metal contents, high ammonia content, BOD and suspended solids contents. The drainage water also

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and its waters are generally brackish but range from low salinity in the south to high salinity in the north. The lake is remarkably rich with its flora and fauna, as well as an important wintering and nesting site for many species of migrating birds. The lake is subject to high pollutant loading from five drains (Fig. 1) and municipalities and industries around the lake, especially at the Port Said City side.

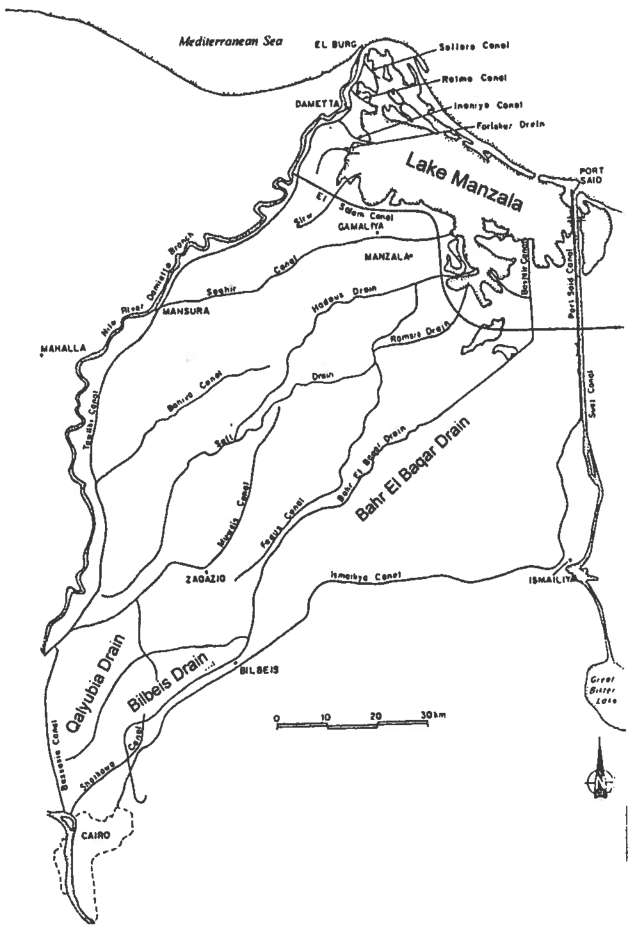

Fig. 1. General Layout of Bahr El Baqar Drain System and Lake Manzala with other Major Drains Entering the Lake

Table 1. The Area Served and Sources of Drainage Water to Bahr El-Baqar Drain System.

Sources of Drainage Water	Area served (acres)
(A) By gravity	
Qalyubia Drain area	304,000
Bilbeis Drain area	61,000
Area discharging directly into Bahr El-Baqar Drain	110,000
Total area served by gravity (A)	**475,000**
(B) By pumping	
Bahr El-Baqar Pumping Station	81,000
Saada Pumping Station	17,000
South Sahl El Hussania P. S	64,000
Total area served by pumping (B)	**162,000**
Total area served by Bahr El-Baqar Drain System (A + B)	**637,000**

CURRENT STATUS OF WATER QUALITY

The status of water quality in Bahr El-Baqar drainage system and Lake Manzala depends on effluent discharged into these water bodies from the different sources. While agricultural drainage stands for the bulk volume of received water, sewage and industrial wastewater are the major sources of pollution into Bahr El-Baqar drain and Lake Manzala.

Pollution Sources to Drains

Industrial Wastewater: Industrial wastewater can be characterized as point sources of a wide variety of pollutants such as heavy metals and toxic organic compounds. The majority of Egypt's industries that were mainly established in the fifties and sixties discharge their wastewater without any treatment to open water systems (mainly agriculture drains). As the drains in the Delta discharge to the Northern lakes, they eventually get their share of water pollution. Greater Cairo Area encompasses many industrial and commercial activities. Heavy industries are mainly located around Shoubra El Kheima, the major industrial area, which impacts the quality of the drainage water in Bahr El Baqar drain system. The industrial activities include metal production, food processing, detergent and soap manufacturing, textile finishing and paper production. The total organic loads are about 15 ton/day BOD5 and 54 ton/day COD. This means that the organic loads contain a high

the Delta with a total number of water quality parameters exceeding 30. The survey reconnaissance conducted for one year provides an overall impression on the water quality status and temporal variation in the relevant areas. The survey aims at water sample collection from as many as possible locations in the major drains. Out of these locations around 115 monitoring location will be established. These sites were chosen according to criteria taking into account that the maximum distance (between two successive locations should not be more than 25 km), confluence, catchment area (not less than 50,000 acres and availability of distinct structure. The samples were analyzed for about 31 parameters taking into consideration the basic classic water quality analysis, toxicological, microbiological, oxygen budget related and extended cations, nutrients metals and trace elements. The average results of the four reconnaissance surveys of locations on Bahr El-Baqar (Fig 3) in Bahr El-Baqar Drain system are presented in Table 2.

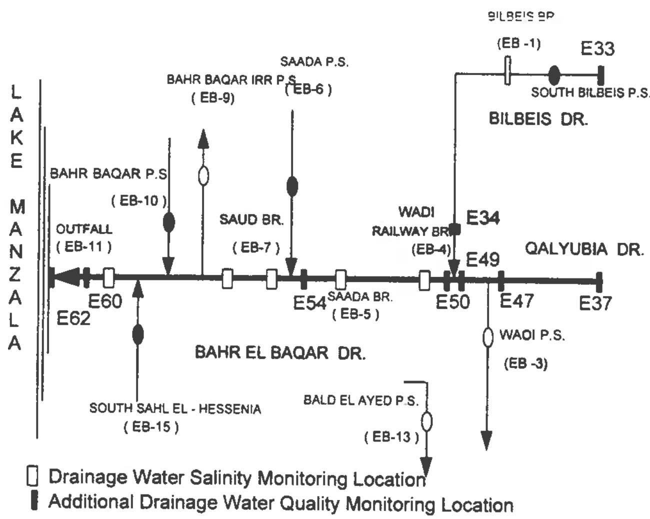

Fig. 3. DRI Monitoring Locations at Bahr El - Baqar Drain System.

In addition to the information given under pollution sources to drain the following remarks can be made:

Table 2. Average Results of the Reconnaissance Survey for Monitoring Locations on Bahr El Baqar Drain System.

Quality Parameter	Unit	Location Code along Bar El Baqar and Its Tributaries									
		Qalyubia Drain			Bilbeis Drain			Bahr El Baqar Drain			
		E-37	E-47	E-49	E-33	E-34	E-50	E-54	E-60	E-62	Standard *
Total Coliform	**MPN/100 ml**	**1.57E+06**	**3.40E+06**	**7.98E+05**	**1.34E+07**	**3.12E+06**	**1.54E+07**	**1.70E+06**	**5.13E+05**	**2.60E+03**	**< 5000**
BOD	**mg/l**	**95**	**73**	**70**	**94**	**83**	**60**	**52**	**50**	**33**	**< 10**
COD	**mg/l**	**184**	**121**	**189**	**222**	**174**	**151**	**133**	**173**	**178**	**< 15**
Turbidity	NTU/l	52	60	34	54	57	69	21	62	56	
TSS	mg/l	510	400	443	480	620	343	129	250	213	
TVS	mg/l	56	42	48	41	55	41	19	19	17	
NO3	mg/l	28.33	5.97	5.32	1.68	1.38	0.83	4.57	0.79	1.53	< 45
NH4	**mg/l**	**58.91**	**18.05**	**36.98**	**158.67**	**124.81**	**199.10**	**19.65**	**8.71**	**8.03**	**< 0.5**
P	mg/l	0.950	1.105	0.970	0.658	0.705	0.633	0.707	0.648	0.717	< 1
Cu	mg/l	0.006	0.008	0.003	0.005	0.004	0.002	0.006	0.014	0.004	< 1
Fe	mg/l	0.159	0.237	0.275	0.328	0.187	0.203	0.232	0.152	0.077	< 1
Zn	mg/l	0.029	0.063	0.017	0.030	0.014	0.019	0.007	0.005	0.027	< 1
Pb	mg/l	0.077	0.050	0.006	0.013	0.026	0.003	0.002	0.003	0.005	
pH		7.3	7.5	7.7	7.4	7.4	7.5	7.2	7.6	7.6	7 - 8.5
EC	dS/m	1.19	1.34	1.37	1.42	1.43	1.42	1.35	3.38	4.99	
TDS	ppm	846	972	874	892	876	874	855	2028	2986	
Ca	meq/l	4.62	4.29	3.92	4.44	4.24	4.30	4.02	6.34	7.45	
Mg	meq/l	1.80	2.23	2.01	1.82	1.68	1.82	2.08	5.68	9.37	
Na	meq/l	5.49	7.08	6.42	6.23	6.33	6.23	6.02	19.65	31.13	
K	meq/l	0.36	0.46	0.39	0.53	0.50	0.48	0.41	0.54	0.65	
HCO3	meq/l	3.12	3.24	3.35	3.39	3.42	3.46	3.46	3.46	3.53	
SO4	meq/l	5.95	7.47	5.49	5.24	5.07	5.28	4.74	9.54	12.23	
Cl	meq/l	3.21	3.36	3.89	4.40	4.26	4.09	4.34	19.22	32.84	
SAR		3.0	3.9	3.7	3.5	3.7	3.6	3.4	7.8	10.7	
Adj_SAR		6.5	8.5	8.0	7.7	7.9	7.3	7.5	18.3	25.7	
Temperature	C°	23.4	26.3	26.6	26.0	25.8	26.4	26.2	27.6	28.2	> 5 degree
pH_f**		7.2	7.6	7.5	7.4	7.5	7.4	7.5	7.5	7.6	
EC_f	dS/m	1.20	1.39	1.34	1.38	1.39	1.38	1.29	3.26	4.79	
Salinity	%	0.25	0.40	0.40	0.50	0.50	0.50	0.35	1.35	2.30	
TDS_f	ppm	657	768	766	838	842	832	744	1313		
DO	mg/l	1.05	0.40	0.30	0.30	0.85	0.20	0.45	0.25	0.20	
DO_sat	mg/l	13.50	4.00	3.50	3.00	8.50	3.50	5.00	2.50	2.50	
Turbidity_f	NTU/l	12	42	62	109	51	79	69	53	137	
Visibility Disk		13	15	10	10	10	10	10	10	10	

* Standards for water to be used for irrigation according to Law 48.
** Field Measurements

(DRI 1,1995). The drain has slightly depressed oxygen content, moderately high salinity and appreciable nutrient content. Ramsis Drain enters Lake Manzala through Bahr El Baqar drain. The flow of Ramsis Drain to South El Hussania P.S. is 340 x 10^6 m3/year and is predominantly agricultural run-off with salinity of 3.4 dS/m. Faraskur Drain enters the Western shore of the Lake through Faraskur pump station and serves 20,000 acres of agricultural land with average annual flow of 356 x 10^6 m3/year. Its water quality reflects agricultural drainage characteristics with salinity of 1.91 dS/m. Matariya Pumping discharges the drainage water from 50,000 acres of agricultural land with an average annual flow of 446 x 10^6 m3/yr. Salt content of 3.89 dS/m, which is higher than average agricultural drainage due to the leaching of newly reclaimed land.

Table 3. Flow and Water Quality Characteristics of Drains Entering Lake Manzala (Lane and Keckes, 1992).

Parameter		Bahr El-Baqar	Hado-us	Ramsis	El-Serw	Mata-riya	Fara-skur
Discharge $10^6 m^3$ /year		1678	3276	252	847	154	292
Salinity (EC dS/m)		1.91	2.71	3.4	2.15	3.89	1.91
(TSS) mg/l		3215	2405				6400
pH		7.6	7.6				7.8
BOD (mg/l)		72	14				30
COD (mg/l)		135	25				18
nitrogen	mg/l N	3683	0.73	0.63	1144	0.04	0.45
phosphorus	mg/l P	1013	0.19	0.14	0.18	0.18	0.14
nutrient load	L/yr	7880	3020	196	1122	87	171
max. Lindane	ug/l	12.4	11.6				
max. Endrin	ug/l	12.0	18.6				

Water Quality of Lake Manzala

Lake Manzala receives a variety of pollutants from the drains described before, which carry sewage, industrial and agricultural pollutants throughout the year. These pollutants include nutrients such as phosphorus, and nitrogen, heavy metals, pesticide and herbicide residues, and sediments. The drains carry very high loads of suspended solids which produce high turbidity, severely restricting light penetration into the water.

Most of the pollutants such as nutrients, chemicals and heavy metals are in the insoluble phase, being strongly adsorbed to the colloidal solids. High concentrations of heavy metals and chemical residues have produced toxic effects on the fish populations in the Lake. High nutrient concentrations have generated highly eutrophic conditions rendering the Lake unfit for recreation and extended commercial fishery.
Due to the input of organic and inorganic nutrients from the drainage systems entering the Lake, the southern portion of the Lake is slowly undergoing eutrophication resulting in loss of species diversity in the freshwater fish. This has resulted in the fish population in this area becoming predominantly a mono culture of Tilapia-spp with loss of the Mullet and other marine species. Tilapia-spp presently represent 85 % of the total fish production of the Lake. There is a gradual but steady deterioration of fish habitats in some parts of the Lake. The obvious deleterious impact of polluted water on the fish populations is reflected on appearance of some deformed fish, absence of fins in some fish and accumulation of heavy metals in different fish organs, and appearance of infected fish with internal or external parasites (Lane and Keckes, 1992).

REMEDIES AND SUGGESTIONS FOR IMPROVEMENT

The alarming deterioration of Bahr El-Baqar Drain System and Lake Manzala can only be addressed through a comprehensive program with a priority to manage the wastes entering the system. There is a great effort from the Government of Egypt to apply law 4 of 1994 through the construction of three treatment plants at the upstream of both Qalyubia and Bilbies drains of discharge capacity of 600,000 m^3/day each which will reduce the pollution load added to main agricultural drain. Shoubra El Kheima treatment plant is under construction for primary and secondary treatment. Water quality improvement is expected for Qalyubia Drain with respect to BOD, COD, suspended matter, heavy metals and microbial parameters. In addition to enforcing factories to dispose treated water only which complies with law standards. However, classical treatment facilities are prohibitively expensive and difficult to operate successfully in the developing countries. Often the level of treatment afforded by these facilities is not sufficient to protect the receiving environment. In the Lane and Keckes, 1992 report, engineered wetlands are proposed as a practical strategy that would not only treat the large volumes of waste in the drains entering the Lake but would have a number of other benefits such as enhance biodiversity and improved economic opportunities for the people of the area.

REFERENCES

DRI. 1995. Drainage Water Reuse Monitoring Program, yearbooks 1990-1995. Drainage water reuse in the Delta. Drainage Research Institute, National Water Research Center, Cairo, Egypt.

El-Gohary, F. A. 1993. Industrial Wastewater management in Egypt. Seminar on Industrial Wastewater management, pp. 1-21, Cairo, Egypt.

El-Sayed, A. 1994. Effects of wastewater discharges on the water quality of Bahr El-Baqar Drain, Master Thesis, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Cairo, Egypt.

EPADP. 1995. Proposed ... pump stations ... Egyptian Public Authority of Drainage Projects, Ministry of Public Works and Water Resources, Cairo, Egypt.

... 1995. ... Environmental ... Volume I ... and ...

precautions and safeguards against misuse.

INTRODUCTION

Egypt is a predominantly arid country and the scattered rain showers in the north can hardly support any agricultural crops. It is evident now that Egypt consumes all of its share from the river (55.5 BCM) to satisfy water demands for different users, and for a present population of about 58 millions. The needed increase in food production to support the acceleration of population growth (2.7 %), compels the country to use all sources of water (i.e. drainage water and sewage water) for the expansion of irrigated agriculture.
The policy of the Egyptian Government is to use drainage water (up to salinity 4.5 ds/m) after it is mixed with fresh Nile water to form blended water of a salinity equivalent to 1.5 ds/m. The drainage water and Wastewater reuse has been applied at small scale in Egypt for many years ago, but was formally initiated in 1915 at Gabal El- Asfar (north east of Cairo) for cultivation of 2500 feddans[3], with wastewater that has been primary treated. As new treatment plants using secondary treatment being built in some cities, the re-use of treated wastewater in agriculture will be increased in the future from the present estimate of 0.6 BCM per year to 1.67 BCM per year in year 2000 and to 2.4 BCM per year in 2027.

It is important to carry out careful and intensive studies to determine the effect of using such low quality water for irrigation on soil properties as well as on the response of different crops under the Egyptian climate. A series of studies have been carried out in several pilot areas in the

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[3] 1 hectar = 2.4 feddans

Nile Delta where drainage water or sewage water are used since long time ago in irrigation, some of these areas have been reclaimed about 30 years ago and are still irrigated with drainage water either directly or after mixed with fresh water.

The present paper is concerned with the collection and interpretation of some results in addition to final findings and conclusions on the reuse of such recycled water in irrigation. Because the suitability of drainage water for irrigation is governed mainly by its salt concentration, this study will present only the impact of the drainage water salinity.

REUSE OF DRAINAGE WATER

Quality of Drainage Water

The amount of agricultural drainage water presently reused in irrigation is 5.0 BCM of annually of which 4.0 BCM applied in the Nile Delta, and 1.0 BCM in Fayoum area in addition to the return flow to the Nile from the Upper Egypt drainage system. This re-used drainage water in the Delta is expected to increase gradually to reach 7.0 BCM by the year 2000. The total annual volume of agriculture drainage water for the year 1993 amounts to 12 BCM which varies in both quantity and quality with time of the year and the location. It is to be noted that part of this water is from industrial and municipal wastes discharge to the drainage system.

The Effect of Irrigation with Drainage Water on Soils and Crops

In the southern part of the Delta, the soils are generally non saline (less than 1.5 ds/m) as shown in Figure 1, however the soil texture is

main winter crops are : Rice, Cotton, Maize and Onion.
Table 1 presents the average productivity of the different crops for the years (1985-1990)

Table 1: Average Crop Productivity for Years (1986- 1992) at The Studied Pilot Areas (Tons/feddan)

Irrigation water	Winter season		Summer season		
	Wheat	Broan-bean	Cot ton	Rise	Maize
Fresh Nilewater (EC = 0.4 ds/m)	2.8	2.5	1.0	4.0	2.4
Drainage water Behaira Governorate EC = 1.5-2.5ds/m	3.2	2.4	1.0	4.2	2.0

The crop productivity illustrates that the salinity of irrigation water is not the only factor which affect soil salinity and crop productivity, where the continuous irrigation with low water quality up to 2 ds/m gives higher productivity comparing to the productivity of other areas irrigated with fresh water. This important fact can be attributed to some other main factors, light soil, good drainage systems, leaching requirements and active management of farmers.

The major portion of the salt - affected soils is found in the region which extended from east to west parallel to the sea coast. The salt accumulates has resulted in this soil from saline water intrusion from the sea, the north lakes, and tidal marches. This has been accelerated by the flat topography and low land level in that area bringing the water table close to the soil surface. In the absence of adequate drainage system. The dominant salts in these areas are Soduim Chloride and Sulphate due to the contamination from the sea water. The soil texture ranges from clay to heavy clay soil with higher content of $CaCo_3$ and $CaSo_4$.

In the most northern parts of the Delta parallel to the sea coast, drainage water, salinity is considerably high and reaches to more than 3000 ppm in some locations due to the following :

* The salt originating from upward seepage of saline groundwater, particularly in those parts which are below the sea level;
* The non - official re-use of drainage water which causes a corresponding substantial increase in drainage water salinity;
* The seepage of sea water inland coupled with the lateral flow of subsoil water which should have already acquired some salinity

Table 2 : Average productivity of the two pilot areas for years (1985 - 1992) in Tons/fed.

Crop	National Average Ton/fed.	Productivity Ton/fed.
<u>Winter crops :</u>		
Wheat	2.0	1.7
Barley	1.8	1.5
Bean	0.9	0.6
Berseem	N.A	9.0
Winter vegetables :		
Tomatoes	N.A	10.0
<u>Summer crops :</u>		
Rice	2.60	1.5
Cotton	1.0	0.8
Summer maize	1.9	1.0

The assessment of the Suitability of the Drainage Water for Irrigation and Land Reclamation

The study reflect the possibility of using drainage water or mixed with fresh water (with salinity about 1.5-2 ds/m) safely for irrigating all soils and crops taking into consideration good farm management, leaching requirements, good drainage and suitable fertilizers.

It was observed that most of the areas in Edco and El-Hamoul responded well to reclamation processes by using drainage water in leaching and irrigation (EC reaches to 4 ds/m). Figure 2 reflects that

there is an obvious improvement in soil salinity specially in surface layers where the salt concentration dropped to about one tenth of that prevailed at the beginning of land reclamation. There is also a noticeable reduction in the concentration of soluble anions and cations with the proceeding of reclamation operation. The highest reduction in ion concentration obtained with Na, Cl and So_4 respectively.
Concerning the water table depth and salinity it could be shown from figure 3 that in barren places salt concentration in the groundwater is now higher than it was at the start of reclamation operation, and the groundwater table is raised as a result of successive irrigation in the absence of field drainage.
These findings proved using drainage water in land reclamation and leaching as long as the salt concentration in water less than that of the soil, provided that a complete, good and sound drainage system should be available.

Management Considerations

Farmers in the area follow a special irrigation system owing to the utilization of drainage water. Night irrigation is practiced daily to avoid the effect of the high soil temperature by day time on the solubility of soil salts in irrigation water, and also to avoid the effect of high evapotranspiration by day on increasing salt concentration in irrigation water. They also try to maintain a downward flux to avoid the harmful impact of surface soil salinity on plant growth.

Surface leaching is made from time to time through flooding the land by water followed by surface drainage.
The farmers at El-Hamoul area face another problem as regards the quality of irrigation water apart from high salinity, namely, water biological pollution, which results in the presence of some

cotton. For the five main crops grown in the Nile Delta, the study made it possible to derive the yield decrease at the soil salinity level exceeding the threshold value

Table 3 : Salinity threshold values and yield decrease per unit soil salinity

Crop	Threshold value Ec_{ex} in ds/m	Yielddecrease (Kg/Fed.) per 1 ds/m
Cotton	6.5	150
Wheat	4.5	200
Barley	5.0	180
Clover(berseem)	3.0	650
Rice	3.5	250

REUSE OF TREATED MUNICIPAL WASTEWATER

Sinario and criteria for crop selection

The first use of treated waste water in Egypt was in the eastern desert north east of Cairo. An area of 2500 fed. still under irrigation with waste water receives only primary treatment. With the scarcity of water resources, it is planned to irrigate 150,000 fed. with treated waste water up to the year 2000.

All urban waste water projects include facilities for treatment up to the tertiary level and allows re-use for irrigation. Many of the rural areas still lacking such facilities. It is estimated that by year 2000, the amount of wastewater from major cities and urban areas are as given in to the following table.

Table.4 Waste Water from Urban and Major cities

Area	Year 1992 BCM	Year 2000 BCM
Cairo	1.36	1.70
Alexandria	0.53	0.65
Other Urban Areas	1.54	2.58
Total	3.43	4.93

Currently in Egypt, detailed criteria for wastewater reuse in agriculture is under review and preparation.

Several pilot programs have started and under continuous monitoring for some years.

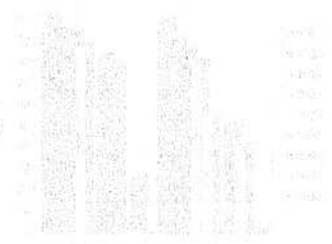
The possible effects of chemical constituents of wastewater may be outlined as follows:-

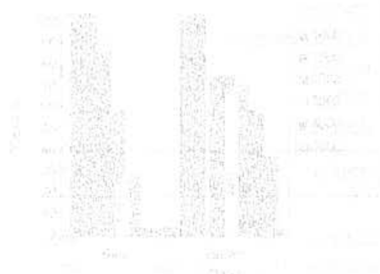
* Effect on plant growth
  ** Osmatic effects due to high water salinity
  ** Phytotoxic effects due to excessive amounts of specific ions

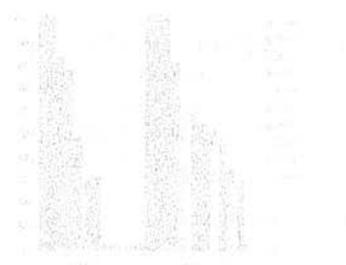
* Effects on the physical and chemical properties of soil due to changes in its exchangeable sodium percentage (ESP)

* Effect on crop quality
  ** Nutrient imbalance introduced by plant nutrient elements in water
  ** Translocation of hazards constituents to consumers

An important measure to minimize health hazards from irrigation with treated wastewater is the selection of the right crop.







Crops grown in irrigation schemes may be classified as follows:

* crops not for consumption;
* Crops for animal fodder and pastures;
* Crops for human consumption that are always cooked;
* Crops for human consumption that can be eaten raw.

Another distribution according to the way crops are grown can be made:

* Crops grown on trees or high off the ground (orchards, vineyards);
* Crops grown near the ground or in the ground.

It is quite obvious that crops not intended for consumption (e.g. fibre crops) and crops grown on trees, can be irrigated with effluents of low quality. In certain countries, primary effluent or its equivalent is acceptable for this purpose, provided dropped fruit (windfalls) is not eaten by humans. In this case, however, high vigilance concerning the farm workers' health and measures to protect them are advocated. If this cannot be guaranteed, and if the personal standard of hygiene is not high among the workers, primary effluent should not be permitted for any irrigation.

Another primary effluents are considered good enough to irrigate pastures and other crops depends largely on the efficiency of the removal of helminth ova, in particular Taenia (beef tapeworm) eggs, by primary treatment. A distribution is sometimes made between fodder crops that are cut and stored prior to animal consumption and pastures grazed by milking animals. Primary effluents may be sufficient for the former, but fully treated and disinfected waster is recommended for the latter.

Crops for human consumption that are always cooked before eaten will at least need secondary effluents are equivalent for irrigation. This may suffice for vegetables that do not touch the ground and are surface irrigated by subsoil or drip irrigation. It is, however, better practice to irrigate with disinfected secondary effluents, or effluents from maturation ponds, in particular for root crops and when spray irrigation is used. This effluent should meet the standard of 1,000 coliform organisms in 100 ml, although there is also a suggestion that 10,000 coliform per 100 ml may be good enough for this purpose.

Crops for human consumption in a raw state need high quality irrigation water in particular if there is any possibility that they may come in touch with the irrigation water. Whenever such crops are included in an irrigation scheme it is referred to as unrestricted irrigation. If they are excluded, the irrigation scheme is called restricted. The minimum requirement for unrestricted irrigation is a fully treated and disifected effluent that does not contain more than 100 coliform organisms per 100 ml. If the effluent comes from a maturation pond, it is suggested that faecal coliform and faecal streptococci counts should be below 100 per 100 ml. More stringent standards do exist in developed countries such as the USA. They are, however, not practical for the Region.

The Effect of Irrigation with Sewagewater on Soil and Crops

The pilot are in Abu Rawash treatment plants(west of Cairo) shows significant results of crop productivity after four years irrigation with primary treated water.
The irrigated water quality could be accepted, however the Concentration of TDS less than 1000 mg/l. Levels of boron, chloride, sodium, magnesium

and calcium are in the favourable range for irrigation, (adj. SAR < 10) heavy metals concentration are presented in table 5.

Table 5: The International allowable Concentrations of Heavy Metals in Irrigation Water Compared to the Concentrations of Heavy Metals in Abu Rawash Sewagewater

Constit-uent	Allowable concentration		Sewage water Abu Rawish					
			Max.		Min		Average	
	All soils	PH 6-8-5	raw	pri-mary tre-ated	raw	pri-mary tre-ated	raw	Prim-ary trea-ted
cadmium	0.01	0.05	0.06	0.02	0.011	0.00	0.03	o.01
chromium	0.10	1.0	5.90	1.95	1.90	8	3.62	0.89
cobalt	0.05	5.0	0.51	0.20	0.13	0.33	0.30	0.16
lead	5.0	5.0	2.37	1.48	0.26	0.12	1.08	0.67
nickel	0.20	2.0	0.35	0.26	0.17	0.18	0.25	0.22
manginess	0.20	10.0	1.0	1.0	0.40	0.17	0.70	0.67
zenk	2.0	10.0	2.30	0.67	0.35	0.33	1.40	0.48
iron	5.0	20.0	30.0	25.0	5.62	0.28	15.3	10.70
copper	0.20	5.0	0.61	0.35	0.11	1.50	0.40	0.22
						0.07		

As a result of the irrigation with the sewage influent, the fertility of the soil increased, especially organic matter, nitrogen and phosphorus contents. Because the soil texture is light, the salinity of the soil did not be affected. In the mean time the sodium content still below the formal limits.

Table 6 shows the effect of the irrigation with raw sewage water on the concentration of the heavy metals in the soil after three seasons.
The most important factors, determining the migration of the heavy metals in the soil are, the texture, the sorption capacity, the organic matter and the pH.

Table 6 : The effect of irrigation with Sewagewater on the heavy metals concentrations in soils of Abu Rawish in ppm

	depth cm	Heavy metals ppm								
		Zn	Cu	Fe	Mn	Cd	Co	Cr	NI	Pb
before irrigation	0-15	0.70	0.78	1.60	1.30	0.08	0.50	0.67	0.29	0.36
	15-30	0.31	0.34	0.29	0.40	0.05	0.33	0.56	0.11	0.20
after one crop season	0-15	4.58	1.55	11.4 7	13.2	0.15	0.75	0.67	0.87	1.27
	15-30	1.97	0.41	9.80	4.60	0.05	0.50	6.46	0.25	0.50
after two crop season	0-15	17.6	8.20	70.5	15.6	0.17	0.75	0.56	0.99	3.75
	15-30	4.60	1.15	30.6	6.2	0.05	0.55	0.40	0.50	0.36
after three crop season	0-15	26.7	20.4	64.6	20.0	0.18	0.80	0.65	1.00	6.2
	15-30	7.08	3.0	29.4	7.3	0.05	0.60	0.56	0.65	0.60

* Zn : Zinc
* Cu : copper
* Fe : Iron
* Mn : Manganese
* Cd : Cadmium
* Co : Cobalt
* Cr : Chromium
* Ni : Nickel
* Pb : Lead

The following cropping pattern has been recommended as most favourable considering the chemical, pedological, macro economical, sociological and macro economical aspects of this areas :

25% fruits (Cilrus, Banana), 25% field crops (potatoes broadbeans), 5% pomegranates, 5% palm, 25% forest, 5% sunflower.

Citrus yields are high specially grapefruit gives 100 kg/tree.
Also the productivity of Broadbean is relatively high (1 ton/feddan . Sunflower grows very well, however its seeds product is 1000 kg/feddan.

Fertilization is not necessary as the water contains sufficient concentrations of plant nutrients and essential trace elements.

<u>Concerns and Considerations</u>

Regarding the hygienic aspects of the agricultural production, it must be mentioned that irrigation with treated wastewater is not dangerous for public health if the recommended crops are grown and the health protection far from workers concerned.

* Enforce and follow the Environmental protection guidelines:

  ** The Decree No. 649/1962 regulating implication of law No. 93/1962 regarding " Liquid discharge : it has been stipulated that for irrigation of agricultural lands with liquid waste.
  It is forbidden to grow vegetables, fruit or plants eaten crude in farms irrigated by sewage water. It is also forbidden to raise animals or milk producing cattle in these farms.

  ** The new American Guidelines recommended that the type of treatment and the quality of effluent used for the agricultural reuse by spray or surface irrigation of any food crops including crops eaten row which are not commercially processed should be as follows :

Type of treatment : Secondary+filtration+Disinfection

Effluent quality :	
BOD	10 mg/l
Turbidity	2 NTU
Microbial	No detectable fecalcoli/100 ml
Chlorine Residual	1 Mg/1C_{12} (after 30 minutes)

CONCLUSIONS

The information collected during the study enabled a full evaluation on the effects of low water quality reuse to be undertaken. For future agricultural uses, the reuse of drainage water and treated wastewater are considered important elements of the water polices. Both these resources have health and environmental implications. The following should be taken in consideration :

* Long term potential environmental impacts of reuse of drainage water and criteria for use should be clearly identified;

* Drainage water is suitable for reuse in :

  ** In land reclamation at the fringes of the Delta where the soil texture is light and the soil salinity is higher than the salinity of the drainage water. As an example, the reuse of drainage water after mixing with Nile water (El/Salam canal) in land reclamation in Sinai;

  ** In existing drainage water reuse areas which have certain water and farm management and developed suitable cropping pattern.

* Utilization of wastewater for irrigation should be done in such a way so as to provide protection to the operators and the

general public against deseases. A functional system of monitoring and continuous evaluation is absolutely essential.

REFERENCES

Abdel Naeem,E., 1988, " Reuse of Sewagewater in the Irrigation of Desert Soils ", National Conference on Field Irrigation , Soil and Water Research Institute, Cairo.

Abu Zeid,M., 1994, " Egypt's Effects Towards Management of Agricultural Water Demands ", IWRA-World Congress on Water Resources, Cairo, Egypt.

El-Guindy,S., and Abu Bakr,A., 1987, " The Reuse of Drainage Water in Land Reclamation and Irrigation ", Third ICID Workshop on Land Drainage ", Ohio, USA.

El-Guindy,S., and Nijland,H., 1983, " Crop Yield, Water Table Depth, and Soil Salinity in the Nile Delta", Egypt - ILTRI Annual Report, Wagennigen, The Netherlands.

SCS Engineers, 1979, " Health Effects Associated with Wastewater Treatment and Disposal Systems ", (EPA 600/ 1-79-0160)Us EPA.

Shilfgrade,J., and Rhoades,J., 1979, " Benefits from Reuse of Drainage Water for Irrigation ASAE " paper No. 79-2551.

USEPA/USAID, " Guidelines for Water Reuse ", 1992, EPA/625/R-92/004 USEPA Washington D.C.

LINEAR PROGRAMMING APPLIED IN THE COMBINED OPERATION OF THE LATERALS AND THE PONDS

Wen-Tsun Fang[1]

Mei-Jen Peng[2]

ABSTRACT

This study investigated the combined operation of the laterals and the ponds by applying the linear programming. The linear programming is able to give an optimal operation schedule so that the irrigation water requirement is reduced.

As an important irrigation area with high density of ponds in Taiwan, the Chungli lateral and the neighborhood were thoroughly surveyed and the irrigation network was completed. Based on the water balance equations, the linear programming considered the spatial and temporal operation relation between the lateral, the ponds and the whole irrigation area. Due to limited water resources, the objective function of the linear programming is the minimum of the total requirement for the Chungli lateral. The combination in series or in parallel of ponds with the overflow either from one pond to the following fields or from one field to the other one was taken into account in order for an accurate numerical simulation. Besides from the ponds and the laterals, the supplementary water resources for irrigation include those from diversion weirs and effective rainfall.

The ways to improve the present irrigation system for better utilization of water resources were also proposed. As an estimation, the pond dredging can reduce the water requirement by the amount of about $1 \times 10^4 m^3$ for the original requirement $988.92 \times 10^4 m^3$ in the Chungli laterals.

INTRODUCTION

The demand of water resource is increasing at a very rapid pace, however the searching for the sources of available water is more difficult than before. At the

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same time, the cost for a new water-resources planning is incommensurable in some aspects. In Taiwan the construction of a water-resources project becomes the concern of engineers, biologists, as well as political scientists. Therefore, in stead of paying more attention in new water-resources projects, how to efficiently utilize existing water resources becomes the most important challenge in Taiwan.

There are 17 irrigation associations in Taiwan which are responsible for the maintenance and construction of irrigation facilities as well as the arrangement of water for the farmland. Located at the one of the most important area for foodstuff production, the Shihmen Irrigation Association (SIA) operates a complete irrigation network, which is the combination of the Shihmen reservoir, 1 leading canal (4,489m), 1 main canal (27,363m), 18 lateral canals (101km), 43 sub-lateral canals (176km), ditches (1,700km), 460 water ponds and 156 diversion weirs. According to the original construction design of the Shihmen reservoir, the reservoir can only supply about 48% of the total irrigation demand, while the other water resources such as water ponds, effective rainfall, and diversion weirs cover the rest. All the water resources are supposed to be allocated to the farmland through the effective utilization of the water ponds.

The SIA irrigation area is all cultivated as paddy fields. The fields which contain complete irrigation and drainage ditches are called rotational fields. The SIA posts irrigation plans for the whole area at the beginning of every year. The SIA management persons operate the facilities, such as intake gates, to supply the scheduled water allocation to the fields. The pond owners cooperate with the SIA to let the ponds either in series or in parallel serve as water buffers for adjustment. The farmers can draw irrigation water from sub-laterals or ditches according to the irrigation plan. Thus the above constitutes a very special feature of irrigation water allocation in Shihmen. Because the simulation of all the irrigation facilities in combination needs tremendous numerical calculation, only the Chungli lateral area is thoroughly studied.

An efficient irrigation water allocation needs cooperation among irrigation facilities. The SIA (1978) studied the pond operation problems and the study area was limited to a pond and a rotational field. The SIA's report (1978) is therefore lack of application value. This study will consider actual situation and adopt linear programming model to find out the minimum of the lateral supply under restrictions. This thus gives the results which can be used by the SIA in routine operation.

IRRIGATION NETWORK

The Chungli lateral area is isolated from the whole SIA irrigation area for simplification. The area irrigated by the Chungli lateral was investigated to obtain a complete network diagram (c.f. Huang 1995 & Huang 1996). The meanings for each symbol used in the network diagram are explained in Fig. 1. The symbol design is based on the ones used by Wu *et al.* (1995). The first symbol stands for water resources which are the Shihmen reservoir, Hsinjie creek, or Loujie creek. The second symbol is a rotational field which has complete irrigation and drainage ditches. The water needed for this area is called the gate demand of the rotational field. The triangle block means a water pond and the effective rainfall collected by ponds is represented by inclined lines. Diversion works include the intakes along the Chungli lateral or the diversion weirs along Hsinjie creek or Loujie creek. Solid lines are for canals, laterals, or ditches. Dotted lines show the overflow either from one pond to the following fields or from one field to the

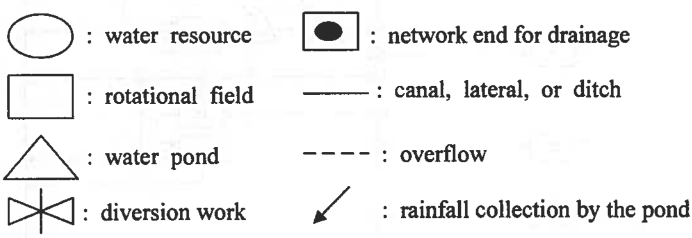

Fig. 1. Symbol design for the irrigation network

other one. Based on the symbol design in Fig. 1, the network for the Chungli lateral is shown as in Fig. 2. The Shihmen reservoir is located at the top of Fig. 2. The other lateral networks are not in our study and therefore not shown in Fig. 2. There are 12 water ponds and 19 rotational fields. The supplementary water resources on the left-hand side and the right-hand side are Hsinjie and Loujie creeks respectively. The overflow direction in Fig. 2 is decided according to the topographical trend as well as the available ditches over the area. The conveyance loss for the overflow is assumed to be the same as those used for the ditches in the SIA, which are 14.5% of the total conveyance amount of water. Although this is not a precise way to calculate conveyance loss, it is a conventional and convenient way to calculate the conveyance loss in Shihmen Reservoir Irrigation Area.

LINEAR PROGRAMMING

The time interval for the mathematical model is ten-days, which is the traditional operational interval used by the farmers in Taiwan. During this interval, the supply and demand are fixed. Under the circumstances, there is no need to adjust the intake gates or other related irrigation facilities. Because the study

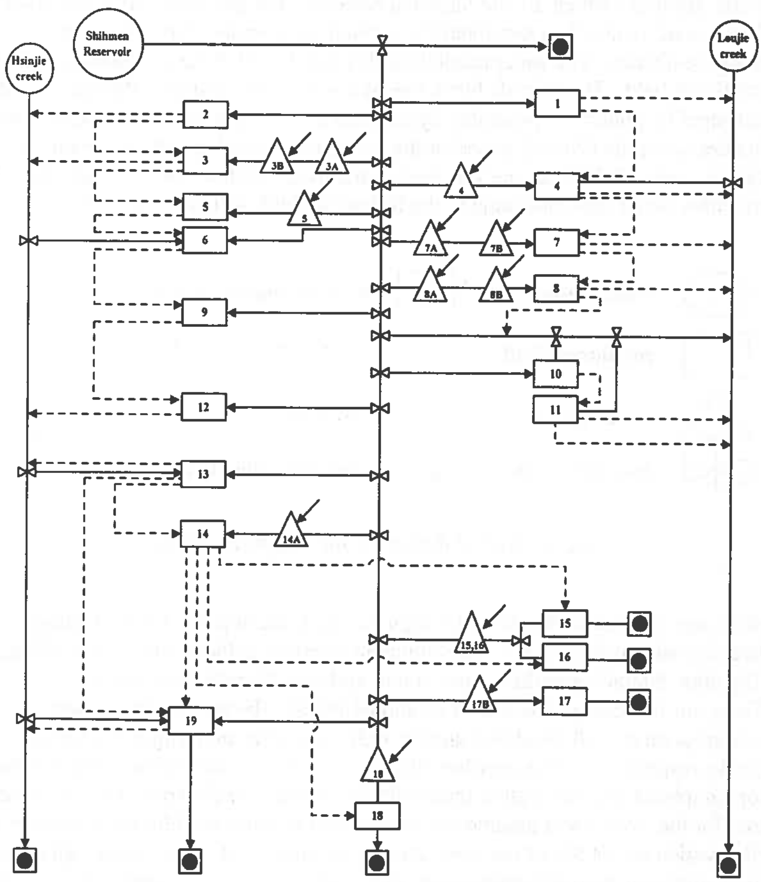

Fig. 2. The schematic diagram of the Chungli lateral irrigation network

investigates the change of irrigation supply and demand over a year, the amount for each demand consists of 36 variables. To understand the only function of the water ponds, the seasonal change of the reservoir's storage is not taken into account. The objective function of the linear model is to minimize the supply amount of the Chungli lateral with the established effective capacity of water ponds. The restrictions for the linear model are the following:

A. The water ponds show no change in the storage from year to year;

B. The gate demand for all rotational fields is satisfied;

C. The total input and yield for the water ponds are in balance;

D. The pond storage is less than the maximum effective capacity at any time.

The linear model has 36 variables for each demand and supply. It is suggested not to show here all the restriction equations. Figure 3 is the schematic diagram for a simple irrigation system and the restriction equations are given in the next paragraph for Fig. 3. Figure 3 uses the symbol design depicted in Fig. 1. The water drawing from the right-hand side is the supply from the lateral. The water drawing from the left-hand side is the supplementary source which is the water diverted by the weirs along rivers or creeks. In Fig. 3, the above four restrictions

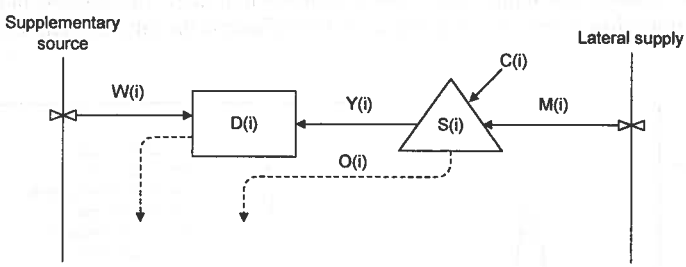

Fig. 3. The schematic diagram for a simple irrigation system

can be expressed in the mathematical forms of array and they are the following:

$$S(1)=S(37), \tag{1}$$

$$Y(i)+W(i)\geq D(i), \quad i=1,2,\ldots,36 \tag{2}$$

$$S(i)+C(i)+M(i)=S(i+1)+O(i)+Y(i), \quad i=1,2,\ldots,36 \tag{3}$$

$$S(i)\leq Smax, \quad i=1,2,\ldots,36 \tag{4}$$

where the index of the array indicates the i-th ten-days, S(i) is the storage of the pond, Y(i) is the yield of the pond, W(i) is the water amount diverted by the weir, D(i) is the gate demand, C(i) is the pond collection from effective rainfall, M(i) is the supply of the lateral, O(i) is the overflow of the pond, and Smax is the maximum effective capacity of the pond. The conveyance loss for the overflow of the ponds, the flow from the weirs to the ponds or to the rotational fields is all assumed to be the same as those used for the ditches inside the fields in SIA, which is 14.5% of the total conveyance amount of water. The objective function is the following:

$$\text{Minimize } [M(1)+M(2)+\ldots+M(36)], \tag{5}$$

i.e., the total ten-days supply of the lateral is minimum. The whole mathematical model for the Chungli lateral can be constructed by following the same way in Eqs. (1) to (5).

RESULTS

The linear programming gives optimal schedule in the study area and the results of total demand and supply over a year are shown in Fig. 4. The abscissa in Fig. 4 is the time change in unit of ten-days and the ordinate is the total amount for water

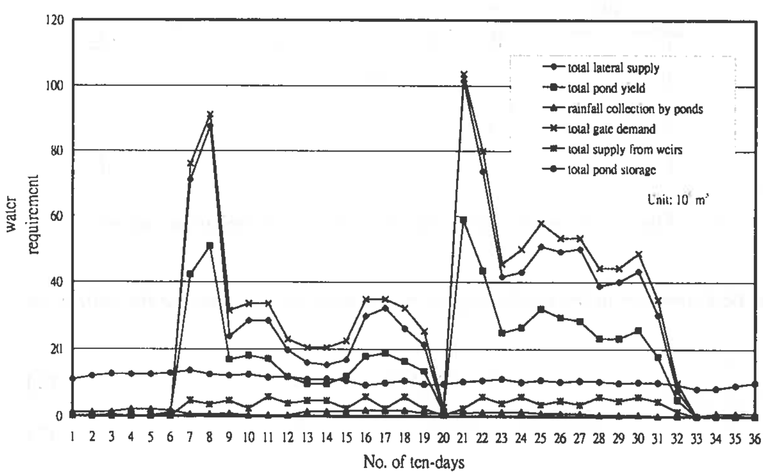

Fig. 4. The change for water requirement in the Chungli lateral area over a year

demands and supply. According to the irrigation plan of 1993 scheduled by SIA, the gate demand for the Chungli lateral for the year is $1{,}108.13 \times 10^4 m^3$, the amount diverted by the weirs is $90 \times 10^4 m^3$, and the pond rainfall collection is 36 $\times 10^4 m^3$. The results from the linear programming in Fig. 4 give that the minimum total supply of the Chungli lateral is $988.92 \times 10^4 m^3$. These indicate that the whole irrigation system of the Chungli lateral carries water amount of about $119.31 \times 10^4 m^3$ for a year from the supplementary resources of diversion weirs and water ponds according to Restriction A. In the meantime, there is about $6.69 \times 10^4 m^3$ of water being lost during the conveyance either over the ditches, the sub-laterals, or the overflow.

DISCUSSION

1. It is obviously shown that there are two peaks for water requirement in Fig. 4. The two peaks come at the time for ponding and plowing. The field ponding and plowing irrigation last for about 30 days. This can be understood from the irrigation plan of the SIA because the ponding and plowing are the time when the farm needs water most. The gate demand and the lateral supply have the similar trend but with about $5 \times 10^4 m^3$ of difference. The water from pond yield, pond rainfall collection and the diversion weirs accounts for the difference.

2. Essentially the gate demand of the rotational fields is supplied by the lateral through the water ponds, however the original design in the Chungli lateral system has been changed because of the effect of urbanization in Chungli. According to our field investigation, the urbanization in Chungli forced a number of water ponds to be abandoned or filled with soil (The abandoned ponds may be still in the SIA's pond list.). As a result, there are 9 out of 19 rotational fields being irrigated directly from the Chungli without the adjustment by the ponds. Therefore, the function of ponds for the Chungli lateral may be reduced to a certain degree.

3. The supply from Chungli lateral has two peaks as discussed in the above. This is not an ideal way for operation management although the results satisfy the linear programming model. In the model the Chungli lateral area is isolated from the other lateral area for simplification. However, the main water resource, i.e., Shihmen reservoir, supplies water requirement for 18 laterals at the same time. An ideal operation management is to smooth out the peaks of water requirement so that the combination of 18 laterals will not ask Shihmen reservoir for peak water demand which may not be satisfied during a draught period. On the other hand, smoothing the peak demand will increase the conveyance loss during water transporting. The total lateral supply will be accordingly higher than the present results and will not be able to reach the objective function of Eq. (5).

4. In addition to the efficient pond operation, the minimizing of lateral supply can be achieved by dredging the ponds. This can increase pond's effective capacity. A pond with large effective capacity can store and yield more during drought. With the built mathematical model, the linear programming gives the Chungli lateral supply for the changing of pond's maximum effective capacity. The result is depicted in Fig. 5 and it shows that the Chungli lateral supply can be reduced by the amount of $1 \times 10^4 m^3$ for the original requirement $988.92 \times 10^4 m^3$. This is at best a rough estimation because the increasing of pond capacity adds difficulties in transporting water in or out of ponds. On the other hand, when pond dredging takes the financial factors into account, the final decision may be on the negative side. As described in the results, there is a notable amount of water being lost during the conveyance. The loss percentage of 14.5% can be reduced if the ditches and sub-laterals have entire lining and complete maintenance.

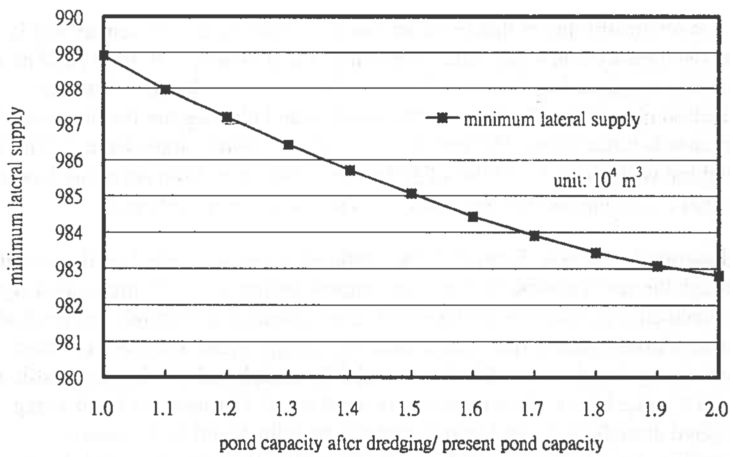

Fig. 5. The change of the Chungli lateral supply after dredging the ponds

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REFERENCES

Huang, C.-P. 1995, *Study on the Most Rational Irrigation Requirement over Shihmen Reservoir Irrigation Area (I)*, Report: AERC-95-RR-07, Agricultural Engineering Research Center, Chungli

Huang, C.-P. 1996, *Study on the Most Rational Irrigation Requirement over Shihmen Reservoir Irrigation Area (II)*, Report: AERC-96-RR-11, Agricultural Engineering Research Center, Chungli

Shihmen Irrigation Association 1978, *Planning on Farm Pond Improved in Shihmen Canal Irrigated Area*, Report: 77-B31-E-728, Taoyuan

Wu, T.-R.; Chien, C.-B. & Huang, C.-P. 1995, "Study on the Model for Dividing Irrigation Water of Reservoir and Pond Irrigation System", Proceeding of the Conference of Chinese Society of Agriculture Engineering in 1995, Taipei

SOME ENVIRONMENTAL AND SOCIAL ASPECTS OF WATER RESOURCES DEVELOPMENT

By George H. Hargreaves[1]

ABSTRACT

Carbon emissions from the use of fossil fuels are increasing. Global warming continues resulting in more violent and destructive storms. The world population is increasing by nearly 90 million annually. Forests are rapidly being destroyed in the developing countries. Irrigated area per capita and food grain production are declining. The competition from the cities for water is increasing. Many aquifers are being polluted and/or over pumped. However, deforestation, soil erosion, population growth, and flooding decrease with water resources and other economic developments. Large new areas can be brought into agricultural production through the construction of irrigation and drainage facilities. There are many good sites for large dams in the developing countries. These dams can be used for hydropower, flood storage, irrigation supplies, and domestic water. Hydropower is clean energy and should be substituted for a large portion of the present use of fossil fuels. Benefits from fertilizers increase with increasing availability of water. Governments and politicians are poor managers of water resources. Many large development possibilities are international in scope. Electrical grids should be more interconnected and possibly continental in scope. Few if any developing countries have an institutional capacity for coordinated water resources developments. The international lending agencies should give priority to the financing of national and international water resources development authorities that at least partially privatize water resource management. Also priority should be given to those projects and activities that improve the environment.

INTRODUCTION

A brief summary is given in order to indicate some

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aspects of the environment and how they relate to water resource development. Brown et al. (1996) give an overview of trends that are shaping our future. Carbon emissions from burning fossil fuels are increasing. This results in global warming. As temperatures rise, warmer oceans release more energy into the atmosphere. Storms are becoming more intense, violent, and destructive. Increased temperatures are decreasing corn and wheat yields. The deforestation of the planet continues unabated. This results in more runoff, soil erosion, flooding, and silting of reservoirs. Forests once covered 40 percent of the earth's surface. Now they blanket only 27 percent of it. Most deforestation has occurred since 1950. In 1995 the world population increased by an estimated 87 million people. World grain land area is shrinking. Grain harvested per person declined by more than one percent per year during the last 11 years.

The need for water resources development is now more urgent than ever. Some of the needs are given as follows:

1. To increase production of clean energy to substitute for that from fossil fuels.
2. To increase water storage for flood control in order to reduce flood damage.
3. To increase irrigation and drainage in order to meet the needs for food and fiber of our increasing population.
4. To improve national economies, particularly those of developing nations.
5. To create employment opportunities
6. To decrease, and if possible eliminate the perceived need for destroying forests to provide lands for the production of food crops and of forage for livestock.

Some case histories are given and recommendations are made with respect to actions to be taken and policies changed. The problems are global. The solutions require world-wide concern and action.

IRRIGATION

Irrigated area per capita has been declining since 1979. About 40 percent of the world's food supply is produced on irrigated lands. In some countries more than 50% of foreign exchange earnings come from irrigated crops. Given the need to increase global food supplies the importance of irrigation has never been greater. However prospects for expansion are limited in many countries. Over-pumped aquifers face depletion or pollution. An estimated cultivated area of 10 percent in China, 33 percent in Iran, large areas in India, Texas, and 75 percent of the water for crops in the Arabian peninsula depend on over-drafted groundwater (Brown et al., 1996).

FAO (1995) prepared a study of water resources in Africa. The average costs per hectare given for irrigation development range from $5,000 to $25,000 USD. Of the irrigated area 64 percent is for food grain production and 13 percent is in fruits and vegetables. Brown et al. (1996) indicate that the U.S. export price of corn is roughly at $150 US per ton. At this price very few new irrigation projects for food grain production will be profitable.

Hargreaves (1995) used data from California to compare labor requirements and net farm gate profits for various other crops with those for food grains. The other crops were mainly fruits and vegetables. These required an average of 13 times as much labor and produced 13 times as much profit as the food grains. The use of fossil aquifers or the depletion of aquifers for food grain production can not be justified when the use of the water could produce much greater benefits when used for the irrigation of high value crops. In many cases groundwater should be largely reserved to make up defects in surface supplies during drought years.

Agriculture is facing increasing competition from cities for water supplies. Demands for industrial and domestic water will increase with urbanization and with population growth. In California and the South West, cities have purchased water rights from farmers.

The need for water conservation in the western United States is urgent. Various States and organizations have established weather station nets for the computation of reference evapotranspiration (ET_o). Usually a well-watered site is required for ET_o computations. The Hargreaves 1985 equation (Hargreaves et al.,1985; Hargreaves and Samani, 1985; Jensen et al 1990; and Hargreaves, 1994) requires only temperature measurements. When the weather data are from well-watered reference sites, estimates of ET_0 are very comparable with those from some of the Penman equations including the FAO Penman-Montieth for periods of five or more days. For arid and semi-arid non reference weather sites the bias due to aridity of the Hargreaves method is significantly less than for ET_o computed with the more complex methods.

There is some possibility of water conservation by means of defect irrigation. If Y is relative yield and is equal to one for the maximum yield under prevailing conditions with adequate water. Adequate water is assumed to be when X=1. The equation for relative yield based on field research with several crops is:

$$y = 0.8x + 1.3x^2 - 1.1x^3 \quad (1)$$

The data used were for X between 0.30 and 1.20. The equation is not valid for lower values of X. Its validity for values above 1.20 depends upon crop, variety, fertility, and other conditions. Equation 1 from Hargreaves (1975) was used by Hargreaves and Samani(1984) to calculate the amount of defect irrigation required to maximize profits for various crops and conditions.

Increasing demands for food production and for economic growth will make it necessary to investigate possibilities for increased water storage and more water transfers over long distances. One possibility is storage on the Yukon and other western rivers for irrigation in western Canada western United States and northern Mexico. In Latin America, there are numerous sites for large multipurpose dams. These could provide storage for irrigation and hydroelectric energy. The electricity can greatly increase the feasibility of pumping and for pressurized irrigation. In some countries there is a very large potential for new irrigation developments.

DRAINAGE

Gupta et al. (1992) found an average yield decline of 10 percent per day of submergence. This is from 11 trials in India. The yield decline varied with crop and with temperature. The decline increased significantly with increasing temperature. With excessive rainfall, crop growth is slowed due to decreased availability of oxygen in the root zone.

Hargreaves and Lasso (1994) used the ratio of the 75 percent probable expected precipitation (P_{75}) to ET_o to define excessive precipitation. Ratios of P_{75}/ET_o for 10 day intervals were used. It was found that 83 percent of Colombia has 10 or more consecutive 10 day periods of excessive rainfall with ratios of P_{75}/ET_o exceeding 1.33. In Latin America and Africa a total of 33 countries have regions with excessive rainfall for periods of three or more months. In Colombia, only 18 percent of the area has a dry season of 100 or more days.

An area of 38,550 km^2 of the eastern piedmont and plains of Colombia is considered suitable for capitalized agriculture. The soils lack fertility but have good internal drainage, are nearly level, and have favorable structure. With some flood control, drainage, and fertilization, this area could become very productive. It is believed that the potential for increased agricultural production in Colombia and other high rainfall areas is very large. Unfortunately, few if any of these countries have an institutional capacity for multipurpose water resources development planning.

The areas or regions requiring drainage are frequently best developed by a well coordinated water resources development program. This is illustrated by eastern Bolivia. This area comprises 30 million hectares of recent and Pleistocene alluvium. Only a small portion of this region has been developed for crop production. The northern portion has excessive rainfall for several months. Much of the southern portion is too dry form crop production without irrigation. Large areas flood and vast regions have a high water table requiring drainage.

Sites for large dams on the Rio Grande and Rio Beni in Bolivia appear excellent. The hydropower potential appears to be outstanding. Although there is great potential for development, Bolivia has one of the lowest per capita incomes in the Americas. Much of the food is imported. Development of these and other areas can alleviate possible future food shortages. The hydropower generated could also reduce dependence on fossil fuels.

Brown and Kane (1994) list 25 developed countries with essentially stable populations. These countries are increasing the forested area. Water resources development in the developing nations can assist in reducing the population growth and deforestation. In the developed countries, increased production of electricity can at least partially substitute for the use of fossil fuels. The costs of developing clean energy sources may be less than the losses that otherwise might occur from flood and hurricane damage if the global warning trend continues.

FERTILIZERS

Crop yields and profits may be increased significantly by the use of fertilizers. However, benefits from fertilization depend on water adequacy. The element of greatest influence on crop yields is nitrogen (N). Lines of equal yields (isoquants) may be graphed as functions of water use or crop evapotranspiration (ET_c) and N. If ET_c is not seriously limiting at any stage of growth, isoquants of yield indicate a line of optimum N as a function of ET_c. Graphs of isoquants for a large number of crops have resulted in a generalized equation. The equation is:

$$N = K_n * ET_c \qquad (2)$$

where N is in kg/ha and ET_c is in total mm per crop season. K_n varies with crop, variety and other conditions. Field research has resulted in values of K_n ranging from 0.10 to 0.38. In each case the optimum N has been approximately proportional to ET_c.

Isoquants of yield and also of net profits, were graphed as functions of N and P_2O_5 with ET_c constant for the average of eight trials with corn in Mexico. The graphs indicated optimum yields and profits with the equation:

$$P_2O_5 = 15 + 0.20N \qquad (3)$$

with a maximum N of about 100 kg/ha. P_2O_5 was also in kg/ha. The maximum net profit increase due to fertilization was 42 percent. Fertilization if used with well managed irrigation can produce large increases in crop yields. However, if the cop suffers much water stress the fertilizer increases the stress and may produce little or even negative benefit.

THE ENVIRONMENT

Reductions in population growth and in the use of fossil fuels would do much to improve the environment. However, deforestation and stream and aquifer pollution are more directly related to water resource development. Deforestation is inversely related to development. Brown et al. (1996) give annual rates of deforestation averaging 79 thousand hectares for the industrial regions and 9874 thousand for the developing regions. The worst region is Latin America and the Caribbean with 6047 thousand hectares deforested annually. Some of the countries with the most rapid rates of deforestation have the most potential for irrigation and hydropower development.

A study by the Canadian International Development Agency (CIDA) gives the irrigable area of Honduras as 885,100 hectares. The irrigated area does not exceed nine percent of the potential. At least 15 sites for large dams have been investigated for hydropower. Most of these can also provide irrigation and/or flood control benefits. Honduras also has one of the most rapid rates of deforestation. Due to unemployment and a continuing per capita economic decline, campesinos have cut mahogany forest and burned the timber in order to plant corn.

In the 1940's Greece was a deforested country with much poverty, flooding, and soil erosion. Construction of large dams, rural electrification, land consolidation, and irrigation made reforestation possible. Vast areas were reforested within a 30 year period. Brown et al. (1996) indicate that the forested area of Europe is now increasing by 191 thousand hectares annually.

Deforested regions can be reforested. Polluted rivers can be restored. Parfit (1993) describes various successful restoration activities in the United States. Too much of the activity in the United States related to the environment obstructs desirable development. More expense and effort is needed for the investigation and implementation of beneficial water resources developments.

The air pollution of the large cities in Brazil has largely been cleaned up. The automobiles are now powered by alcohol. Much of the alcohol comes from sugar cane produced on irrigated lands. The irrigation was made possible by the construction of large dams. Hydropower is also clean energy. A serious effort is needed in order to determine to what degree clean energy can be substituted for energy from fossil fuels.

Albertson (1996) recommended the use of a five percent mixture of hydrogen in gasoline to produce a clean burning fuel. Hydropower from water resource developments could be used to produce the hydrogen.

PRACTICAL APPLICATION

Politicians and governments are seldom good managers of water and other natural resources. There are many good possibilities for water resource development that should involve more than one country. Large regions or continents can benefit from electrical grid interconnections. Large developments can be financed more easily if more than one country is involved.

Few of the developing countries have the institutional organization or capabilities for well coordinated water resources development planning. The Tennessee Valley Authority and the Puerto Rican Water Resource Authority are examples of successful coordinated water resources developments. At one time the Chief of Water Resources Planning of Pakistan attempted to organize an international water resources development authority. International lending agencies should assume a major role in promoting regional and international water resources development agencies. Priority needs to be given to agencies that can develop resources in a manner so as to improve the environment.

The International Irrigation Management Institute (IIMI) in collaboration with the Utah State University Climate Center, the Government of Japan, and with technical review from the Australian National University is developing a World Water and Climate Atlas. The Atlas provides both printed and digital media including temperature and net evapotranspiration (NET). NET is ET_o minus P_{75} and indicates irrigation requirements and also excess precipitation requiring drainage. The Atlas shows NET in color on monthly maps with contours of temperature above 10°C. The digital portion of the Atlas, published on 18 CD-ROM includes graphical 10-day, monthly, and summary information. Data may be retrieved by latitude and longitude or for river basins. The Atlas is being published as a means of improving and facilitating water resources planning and development.

CONCLUSION

The carbon emissions from burning fossil fuels are increasing particularly in the developed countries. Deforestation is increasing in the third world countries. The world population increased by an estimated 87 million in 1995.

The global warming due to carbon emissions has resulted in increased flooding and hurricane damage. Construction of large dams can have a large positive influence on the environment. Electrical energy can be substituted for energy from fossil fuels. Economic development can reduce deforestation and slow population growth. Large areas in the developing countries are suitable for food production providing irrigation, drainage, and flood control facilities are constructed.

REFERENCES

Albertson, M.L. 1996, Personal Communication, Colorado State University.

Brown, L.R., Flavin, C., and Kane, H. 1996, Vital Signs, W.W. Norton & Company, N.Y. 169 pp.

Brown, L.R. and Kane H., 1994, Full House, W.W. Norton & Company, N.Y. 261 pp.

FAO (food and Agriculture Organization of the United Nations), 1995, Irrigation in Africa in Figures, Rome, Italy, 336 pp.

Gupta, S.K., Sing, R.K., and Pandey, R.S., 1992, Surface drainage requirements of crops: Application of a piecewise model for evaluating submergence tolerance. Irrigation and Drainage Systems 6, Kluwer Publishers, the Netherlands, 249-261.

Hargreaves, G.H. 1975, Moisture availability and crop production, Transactions of the ASAE, Vol 18. No 5 980-984.

Hargreaves, G.H. 1994, Defining and using reference evapotranspiration, Journal of Irrigation and Drainage Engineering ASCE Vol 120 No 6 1132-1138.

Hargreaves, G.H., 1995, The importance of cropping choices, ICID (International Commission for Irrigation and Drainage) Special Technical Session, Vol. 1, Rome Italy.

Hargreaves, G.L., Hargreaves, G.H., and Riley, J.P., 1985, Irrigation water requirements for Senegal River Basin, Journal of Irrigation and Drainage Engineering, ASCE Vol III No 3 265-275.

Hargreaves, G.H. and Lasso, L., 1995, Needs for irrigation, drainage, and flood control in Colombia, ICID Journal, Vol 44, No 1 33-40.

Hargreaves, G.H., and Samani,Z.A. 1984, Economic considerations of defect irrigation, Journal of Irrigation and Drainage Engineering, ASCE, Vol 110, No 4. 343-358.

Hargreaves, G.H. and Samani, Z.A., 1985, Reference crop evapotraspiration from temperature, Applied Engineering in Agriculture, Transactions ASAE Vol 1 No 2 96-99.

Jensen, M.E., Burman, R.D., and Allen R.C. 1990 eds. Evapotranspiration and Irrigation Requirements, ASCE Manual No 70. N.Y., New York.

Parfit, M., 1993, Restoration, New Ideas, New understanding, New Hope. National Geographic, Special Issue, Nov 108-119.

THE ARIZONA WATER BANKING AUTHORITY
Storing Colorado River Water in Arizona

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ABSTRACT

Since the 1963 U.S. Supreme Court ruling Arizona vs. California, Arizona has not fully utilized its 2.8 million acre foot (maf) annual Colorado River allocation, with the unused portion being mainly consumed by California.

In the early 1990's, Governor Symington and the State Legislature created several entities in an effort to find potential solutions to maximize utilization of Arizona's Colorado River entitlement and the Central Arizona Project (CAP) aqueduct. These entities are: the Governor's Task Force on CAP Issues; the Governor's CAP Advisory Committee; and the Joint Legislative Committee on Colorado River Issues.

As a result of these efforts, the Arizona Legislature passed HB 2494, creating the Arizona Water Banking Authority. The primary mission of the Water Bank is the recharge of currently unused Colorado River water for future use by municipal and industrial users in times of shortage on the river or disruptions in the CAP delivery system. This is water not currently being used by Arizona's Colorado River communities or CAP subcontractors. Under the "Law of the River", water providers in Southern California, namely the Metropolitan Water District of Southern California (MWD), are allowed to use Arizona's unused apportionment.

Along with recharging Colorado River water in Arizona, the Water Bank is charged with assisting in the settlement of Indian water rights claims; meeting the objectives of the Arizona Groundwater Code by replenishing depleted groundwater aquifers with Colorado River water; and for the benefit of communities along the Colorado River by possible exchange of credits for

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stored water and direct diversion along the river. In addition, the Water Bank is permitted to negotiate interstate water banking agreements with California and Nevada to store water in Arizona for use in the future.

INTRODUCTION

Water has been called the "lifeblood of the West" and since the mid-1900's, Arizona has been at the forefront of developing sound water management policy, implementing water conservation measures and appropriately planning for the future.

In 1963 the U.S. Supreme Court confirmed Arizona's annual entitlement to 2.8 maf of Colorado River water in the landmark case of Arizona vs. California 373 U.S. 546 (1963). It should be noted, that water in the Upper Basin states of Wyoming, Utah, Colorado, New Mexico is appropriated through state appropriation. In the Lower Basin states of Arizona, California and Nevada, Colorado River water is allocated by the Secretary of the Interior based on the Supreme Court decree.

After the confirmation of Arizona's share of Colorado River water by the U.S. Supreme Court, Arizona's leaders went to work in the congress to secure funding for a project to bring a portion of Arizona's water to the population bases of Central Arizona.

Subsequently, the United States Congress passed the Colorado River Basin Project Act in 1968, authorizing construction of the Central Arizona Project (CAP) aqueduct, the largest public works project in the U.S. at the time. The Act included construction of the CAP aqueduct and all associated pumping plants and siphons, the New Waddell Dam, and the raising of Roosevelt Dam.

In 1971 the Arizona State Legislature authorized creation of the Central Arizona Water Conservation District (CAWCD) as a three county (Maricopa, Pinal, Pima) district. The CAWCD operates the canal and is responsible for the repayment of all reimbursable construction costs for the CAP aqueduct. Water was first delivered through the $4 billion CAP to the Phoenix metropolitan area in 1985, to the Pinal County area in early 1987, and finally to the Tucson area in 1992.

Under normal conditions, deliveries to Arizona users on the Colorado River will be 1.3 maf and CAP deliveries will be 1.5 maf, totaling 2.8 maf. According to the Arizona Department of Water Resources, under present scenarios and without considering the impact of the Arizona Water Banking

Authority, Arizona will not fully utilize its share of Colorado River water until the year 2030. Between now and then, the accumulated amount of water left in the River could be as high as 14 maf.

For over 70 years, Arizona leaders have worked to ensure that Arizona's communities have dependable, long-term water supplies to sustain quality of life and to allow for future growth. From securing the State's fair share of Colorado River water and gaining congressional authorization of the CAP to crafting the 1980 Groundwater Management Code, their foresight and planning have provided the water supply that has served and will continue to serve our growing communities and maintain a high quality of life in Arizona for years to come. Full utilization of the state's Colorado River entitlement has been the key to Arizona's water management policy for decades.

During the early 1990's, Governor Symington and the State Legislature continued the tradition of foresight by confronting the issues impeding full utilization of Arizona's CAP allotment. To address these issues, Arizona's leaders created the following entities: the Governor's Task Force on CAP Issues; the Governor's CAP Advisory Committee; and the Joint Legislative Committee on Colorado River Issues. Among the products of these efforts was the creation of the Arizona Water Banking Authority.

HISTORY

Background

The CAP began delivering water to the Phoenix area in 1985, with deliveries increasing every year from 1985 to 1991. However, in 1991 the CAP experienced a sharp decrease in municipal and industrial (M&I) and agriculture orders for CAP water, from 745,000 acre feet (af) in 1990 to only 420,000 af in 1991. The greatest amount of decline occurred because of decreased orders by agricultural districts. Many of the newly formed irrigation districts, along with the agricultural users paying the property taxes to support these districts, were in poor financial condition and CAP water proved cost prohibitive.

Governor's Task Force On CAP Issues

Faced with the growing underutilization of Colorado River water, mainly due to low agricultural demand for CAP water, Governor Fife Symington met with agricultural, municipal and industrial water users to begin exploring possible solutions. Out of those discussions came appointment of a 16 member Governor's Task Force on CAP Issues charged with developing recommendations to be submitted to the Governor for consideration. Task Force membership included a broad representation of municipal, agricultural, financial, legal, Indian and governmental interests from regions of the state affected by the CAP. Elizabeth Ann Rieke, then Director of the Arizona Department of Water Resources, chaired the Task Force.

The Task Force held eleven meetings between February and July that were all very well attended by Task Force members and interested parties. The primary objectives of the Task Force were to address the issues of lost benefits to the State and the perceived jeopardy of Arizona's entitlement due to the under-utilization of Arizona's share of Colorado River water.

As deliberations of the Task Force began, it quickly became apparent that the largest impediment to increased use of CAP water by agricultural users was the high cost of the water. CAP water costs to irrigation districts included, not only the cost of the water, but the debt burden carried by these districts from loans and bonds necessary for construction of distribution systems for the CAP water. Several options were examined in an attempt to help offset these high costs, including increased property taxes, marketing of electric power and possibly leasing a portion of Arizona's Colorado River entitlement to California and/or Nevada. The overriding concern was the risk of Arizona losing a portion of its Colorado River entitlement to California or Nevada due to non-use.

The Task Force ultimately developed recommendations that focused on increasing the use of CAP water by the agricultural sector, including: 1) evaluating irrigation districts ability to repay certain CAP costs; 2) possible restructuring of distribution system debts; 3) payment of delinquent CAP assessments on state land; 4) and potential relief of certain provisions of the 1982 Reclamation Reform Act (RRA). Additional recommendations included increased usage of CAP water by M&I; the intrastate marketing of CAP agricultural and M&I priority water; need for the resolution of Indian water rights claims; and the need for the generation of additional revenues through power marketing agreements and/or the interstate marketing of a portion of Arizona's Colorado River entitlement to reduce CAP water costs.

Although no definitive solutions were reached, much of the work done by the Task Force provided the groundwork for the current successes of the CAP and the near full utilization of Arizona's 2.8 maf entitlement projected for calendar year 1997. The Task Force recommendations were further developed by the Governor's CAP Advisory Committee the next year.

Governor's CAP Advisory Committee

After the September 1992 submission of the report of the Governor's Task Force on CAP Issues, it was quickly decided that additional information and options were needed to deal with the issues associated with the under-utilization of Arizona's share of Colorado River water. In mid-December of 1992, Governor Symington appointed the Governor's CAP Advisory Committee, charged with developing recommendations to assure the long-term viability of the CAP. The 34 member Committee was co-chaired by the Governor and Mark DeMichele, President and CEO of Arizona Public Service Company. Like the Task Force, the Advisory Committee was representative of political, municipal, agricultural, business, legal, Indian and environmental interests. The Committee was also geographically diverse with members from Maricopa, Pinal, Pima, Yavapai and Coconino Counties.

In forming the Advisory Committee, Governor Symington stated:

> *"The Central Arizona Project is Arizona's lifeline. It is our water supply for future growth and the underpinning of our progressive water management policies. It is critical for Arizona to pull together and develop a solution to make the Project work."*

The Advisory Committee used five guiding principals in developing proposed recommendations: 1) protect Arizona's entitlement of Colorado River water to provide a secure long-term water supply; 2) ensure the financial integrity of the CAP; 3) identify how the CAP may be used to enhance the state's environment; 4) possibilities for use of CAP water to assist in Indian water rights settlements; and 5) utilize CAP water to meet the management goals and policy objectives of the state Groundwater Management Code. All five principals were ultimately included in final recommendations of the Committee and are largely reflected in subsequent legislation passed by the State Legislature.

Committee deliberations occurred between January and September of 1993. Various reports and studies were prepared for the Committee and three working groups were appointed to address specific issues in the areas of finance/legal, environment and Indian settlements. These studies and working sessions were supported by an interagency study team comprised of staffs of the Arizona Department of Water Resources, the Central Arizona Water Conservation District and the U.S. Bureau of Reclamation. Additional expertise and support was provided by other entities on an as needed basis.

Public involvement was key in all workings of the Advisory Committee and the development of recommendations. Two groups were formed to assist in providing a broad-base of knowledge throughout the entire process. A public involvement group was organized to review studies performed by the interagency study team, with participation by a wide range of potentially affected parties. In addition, an Indian involvement group was created. This group held meetings with representatives of interested Indian communities to discuss Indian related issues. Indian participation was important because of the large CAP water service contracts held by Indian communities with the federal government.

All meetings and deliberations of the full Advisory Committee and all working and involvement groups were open to the public and participation by non-committee members was encouraged throughout the process.

A six-step investigation process was used in developing the final report and recommendations submitted by the Advisory Committee in October 1993. Step 1 - Description of the CAP as of 1993; Step 2 - Likely future conditions without alternative action; Step 3 - Identification of problems, issues and concerns; Step 4 - Identification of solution elements; Step 5 - Working group analysis; Step 6 - Formulation of Recommendations.

The Governor's CAP Advisory Committee examined a broad spectrum of issues related to state and federal water management policies and objectives relating to the operation of the CAP. The wide variety of interests represented on the Committee and the statewide impact of the issues made any recommendations valuable to elected officials and other decision makers. It is those public officials who would make the ultimate decisions on the degree of implementation of any suggested recommendations.

Out of the reports and working groups, the Committee developed a set of policy issues with specific recommendations concerning the financial, water marketing, Indian and environmental issues surrounding the CAP. The overriding issue continued to be the protection of Arizona's entitlement to Colorado River water to assure an adequate water supply for future economic development and growth. The following statement of policy was adopted by the Advisory Committee:

> *The CAP was envisioned as the primary water management tool for the State to reduce its dependence on mined groundwater and to provide a renewable water supply for municipal, industrial and Indian*

> *related economic growth. The premise of the CAP would be a substitute for existing groundwater use in the agricultural sector was one of the fundamental justifications for the authorization and construction of the Project. Arizona continues to have a need for the full amount of CAP water but the current price of the water makes the agricultural sector's conversion from groundwater to CAP water cost prohibitive. Without the agricultural component of CAP demand, it is likely the state will not fully utilize its entitlement in the near term.*

Additional recommendations included use of the CAP to assist in meeting water management goals of the state's Groundwater Management Code, including safe yield goals; using CAP to assist in Indian water rights settlements; encouraging CAWCD to consider a target pricing policy to increase CAP usage, while maximizing power marketing opportunities; development of an intrastate marketing of water program; studying the feasibility of banking unused Colorado River water in Arizona for use by California and Nevada in future years; and the creation of a state water bank to promote maximum utilization of Arizona's share of CAP water.

Joint Legislative Committee on Colorado River Issues

In the Fall of 1995, the President of the Arizona State Senate and the Speaker of the Arizona House of Representatives created the Joint Legislative Committee on Colorado River Water Issues to examine ways to increase diversions and use of Arizona's share of Colorado River water. Increasing use of Arizona's allocation within Arizona was one of the key recommendations of the Governor's CAP Advisory Committee and this Legislative Committee was formed to legislatively implement some of the recommendations of the CAP Task Force and Advisory Committee.

One of the prime recommendations of the Colorado River Issues Committee was an endorsement of a program to provide the necessary resources and organization to take currently unused Colorado River water and store it for future use by municipalities in Arizona. The Committee's recommendation was translated into House Bill 2494, sponsored by Speaker Mark Killian. HB 2494 was passed almost unanimously by the Legislature and signed by Governor Fife Symington on April 30, 1996, creating the Arizona Water Banking Authority and the Arizona Water Banking Authority Study Commission.

Arizona Water Banking Authority

The Arizona Water Banking Authority is a five person body charged with directing the activities of the AWBA. The Director of the Department of Water Resources chairs the Water Bank and members include the President of the Central Arizona Water Conservation District and three persons appointed by the Governor (of these appointments one person will represent CAP municipal and industrial water users, and one person will represent Colorado River water users along the River, and one person must be knowledgeable in water resource management issues). Additionally, the President of the Senate and Speaker of the House of Representatives each serve as or appoint one non-voting ex officio member to the Water Bank.

Currently, Arizona does not use its full 2.8 maf share of Colorado River water. The Arizona Department of Water Resources projects that the state will not fully use the resource until 2030. Between now and then, the accumulated amount of water left in the River could be as high as 14 maf.

Leaving a portion of Arizona's water in the River, most of which is consumed by southern California, is a lost opportunity. The Arizona Water Banking Authority seizes this opportunity and gives Arizona the capability to further secure the dependable water supplies necessary to ensure the state's long-term prosperity.

The Arizona Water Banking Authority is envisioned to take temporarily underutilized Colorado River water and store it in Arizona for future use by Arizona communities in times of shortages on the Colorado River or outages on the Central Arizona Project aqueduct by: 1) assuring adequate supply to municipal and industrial users in times of shortages on the Colorado River or disruptions of the CAP system; 2) meeting the management plan objectives of the state's groundwater code; 3) assisting in the settlement of Indian water rights claims; and 4) exchanging water to assist Colorado River communities.

Key Benefits of the Arizona Water Banking Authority Include:

Drought Protection - the AWBA will help protect communities dependent on the CAP by providing a stored reserve of water that can be tapped during times of drought on the Colorado River.

Enhanced Water Management - the AWBA provides the ability to replenish depleted groundwater aquifers with CAP water, thereby helping the State to meet its groundwater management goals and objectives.

Indian Water Rights Settlements - Indian tribes in Arizona have significant claims to water rights. Often the affected parties negotiate settlements to resolve these claims. The AWBA could provide another pool of water to be used in settlements. For instance, credits for stored groundwater could be transferred to a tribe as a component of a settlement.

Statewide benefit - Arizona communities along the Colorado River could benefit as well. For example, cities in Mohave County could acquire credits through the AWBA for water stored in central Arizona and cash-in those credits by diverting water directly from the Colorado River.

Interstate Water Transfers - the AWBA could contract with similar authorities in California and Nevada to allow these states to annually acquire a portion of Arizona's temporary surplus of Colorado River water. The contracting state would pay to store water in Arizona, helping to replenish Arizona's aquifers, and in the future would be able to draw a similar quantity directly from the River. The program does not involve the sale of any future rights to water, only a specific quantity of unused water.

Funding: Funds are deposited in the Water Bank Fund. Much of the money comes from existing revenue sources and from fees that will be charged to those benefiting directly from the stored water. Sources of money include:

- Fees for groundwater pumping currently collected within the Phoenix, Pinal and Tucson Active Management Areas. In the Phoenix AMA, Tucson AMA and most areas of the Pinal AMA pumping fees for water banking purposes would be set at $2.50 per acre foot beginning in 1997. For groundwater pumping in areas of the Pinal AMA not served by the CAP, the $2.50 fee would phase-in over seven years. Money from this source will be used to benefit the area in which it was collected.

- The CAWCD is authorized to levy a four cent ad valorem property tax in the CAP service area to pay for water storage beginning in 1997. To help finance the AWBA's efforts, the tax will be initiated in 1996, extended through 2016 and revenues would be deposited in the Fund. The CAWCD retains the option to use this money for capital repayment of the CAP if necessary. CAWCD has determined they do not require these funds for their purposes in 1997. Thus, approximately $8 million will be deposited into the Water Banking Fund for the purchase of water for storage.

- A general fund appropriation based on the level of water storage the legislature and governor believe to be appropriate. This year, the legislature appropriated $2 million to the effort.

- Fees collected from the sale of stored water credits used for drought protection. Fees are charged only if the credits were originally paid for with general fund money.

- Money collected by the sale of stored water credits to out-of-state interests.

AWBA Study Commission

In addition to the Water Bank, the legislature created a Study Commission to investigate opportunities for additional water banking uses, identify mechanisms to help Indian communities with rights to Colorado River water participate in the program, and review the first year operation of the AWBA. The Commission will consist of the AWBA members and two ex officio members as well as nine persons appointed by the director of the Department of Water Resources. DWR is responsible for staffing of the Study Commission.

Update on Workings of the Water Bank

The Water Bank has been working diligently to store Arizona's annual Colorado River allotment in Arizona. This recharge by the Water Bank is not meant as a substitute for existing uses, but as means of utilizing Colorado River water that would otherwise have gone unused by Arizona.

The Water Bank meets monthly to keep the public apprised of the workings of the Water Bank. Meetings are held either at the Arizona Department of Water Resources or in communities around the state such as Tucson, Lake Havasu City and Yuma. These monthly meetings of the Water Bank are in addition to the various other meetings of the AWBA staff with entities interested in potential direct or indirect recharge. Representatives from California and Nevada have attended several of these Water Bank meetings, with Interstate water banking continuing to be a topic of discussion.

The Water Bank met with all potential recharge entities in developing the proposed 1997 Plan of Operation. These entities included: all permitted irrigation districts in Maricopa, Pinal and Pima counties, the Salt River Project (SRP) and CAWCD to determine interest in participating in the Water Bank. All potential recharge opportunities where then matched with delivery capacities of the Central Arizona Project (CAP) aqueduct. The Water Bank systematically adjusted each entities amount to match CAP delivery constraints. An analysis was then made of the amount of potential recharge in each AMA/county and the amount of funds generated in each AMA/county by month to keep monies in the AMA/county of generation.

The Water Bank has approximately $10 million in calendar year 1997 for direct and indirect recharge, including all available pump and 4 cent property taxes and general fund revenues. Recharge opportunities for 1997 are constrained by capacities in the CAP aqueduct.

The Water Bank is scheduled to recharge over 100,000 af by June 30 and approximately 360,000 af by December 30, 1997. Total consumptive use by the State of Arizona for 1997 is estimated to be 2.7 (maf), including: 1.38 maf project Colorado River uses along the river; CAP subcontractor deliveries of an estimated 975,000 af, including M&I, Indian, Agricultural Pool 1,2,3 and incentive recharge water; and approximately 360,000 af for recharge by the Water Bank. CAP capacities are constrained due to the repairs on the Agua Fria siphon and believed to contribute to the fact that Arizona cannot use its full 2.8 maf in 1997.

Conclusion

The Arizona Water Banking Authority legislation is the type of flexible statewide policy that will help guide Arizona water planning into the next century. By storing substantial amounts of water in central Arizona, the Water Bank will help safeguard against future shortages on the CAP system, assist in meeting the goals of the Groundwater Code, and aid neighboring states without harming Arizona. The Water Bank will create a "water savings account," helping to ensure that the water supplies future generations inherit from us are just as secure as those we inherited.

A BINATIONAL APPROACH TO THE WATER MANAGEMENT IN THE LOWER COLORADO RIVER BASIN

Francisco Bernal-Rodriguez[1] Nicolás Zala-Flores[2]

ABSTRACT

The Mexico-United States border is a zone of shared problems for both countries. The Colorado River system stands out among their common rivers, its usefulness benefiting many people, especially if one considers its location in a desert land, the intense competition for the river water has expounded the necessity to come to agreements between both countries, started since 1944. The Colorado river system is the most important in the United States southwest; supplies water for more than 20 million users and for large extensions of agricultural land. Besides, it is a fundamental water source for Northern Mexico, especially for the irrigation of agriculture lands in the Mexicali Valley. Water is a resource of a very high economical value in the region, because of the growing and large human population of the region, the importance of agricultural crops, and in particular, to the fact that the southern part of the basin is a desert. Inasmuch as there is an intense competition for the river water, although highly controlled, the system's management is of great interest for United States as well as for Mexico, for that reason, it corresponds to both of them.

All these factors make the Colorado River management an important subject that influences the neighborhood relationship between Mexico and United States. In 1944, both countries signed a treaty on the water allotment of the three river systems shared : the Colorado, Tijuana and Bravo. According to this document, Mexico obtained the right to receive an annual delivery of 1.5 million acre-feet of Colorado River water. The construction of several dams in the Colorado River basin in the United States has had great impact on the quantity and quality of the water going to Mexico. During the last three decades, the matters related to the salinity of this water have demanded a permanent attention.

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INTRODUCTION

The Colorado River Basin is one of the main basins in the west of the United States, supplying water for the states of Colorado, Wyoming, Nevada, New Mexico, Utah, Arizona and California, as well as Baja California and a portion of Sonora in Mexico. The Basin has an area of approximately 634,840km2 (247,500 square miles) with an annual average flow of approximately 18,502 millions of cubic meters (Mm3), according to the Santa Fe Treaty (Colorado River Compact) signed in 1922, which are distributed in equal shares between the Upper and Lower Basins.

The Colorado river has been called sometimes, as one of the most controversial and regulated rivers in the world, because it counts with an infinity of rivers and streams that make up its flow; besides it has one of the biggest and more complex storage and diversion dams system. It benefits over 20 million people in both countries, in cities as Los Angeles, Las Vegas, San Diego, Phoenix and Tucson in the United States; as well as Tijuana and Mexicali in Mexico.

This condition of sharing the resources, plus the arid characteristics within the basin and the present economic and population growth, as well as the struggle for the resource between the two countries, among the states users and mainly among the different users, makes the situation even more critical and the process very complex to be handled. The above, had favored changes in legislation and a search and implementation of new alternatives of usage with the goal of guaranteeing the supply of the vital liquid to the cities and also making sure of its quality. In the international arena, this has been a fairly discussed subject and of paramount importance in the bilateral agenda between the two countries in history, to date, the Colorado River problems have been worth of the highest priority in the IBWC agenda.

Mexico was recognized as a Colorado River user after the signing of the 1944 Treaty, allowing for assurance of the development of Northern Baja California and the Northwest of Sonora state in Mexico, the former after a solution framework was presented on the controversies in water and international boundaries matters through agreements or minutes worked out by the International Boundary and Water Commission (IBWC). The Treaty referred, basically allots the river waters among the basin users and does not specify about the water quality. The latter produced a crisis in the sixties culminating with an agreement for its attention in minute 242 of the IBWC, which establishes a salty waters management project through the construction, operation and maintenance of the Wellton-Mohawk Canal which basically disposes of these waters directly to the Gulf of California.

THE COLORADO RIVER WATER RESOURCES

International Agreements And Treaties Between Mexico And The United States.

On the 2nd of February of 1848, in Guadalupe Hidalgo, Mexico and the United States signed the Treaty of Peace, Friendship and Boundaries and on the 30th of December of 1853 the Treaty of Mesilla was signed. With these treaties the Colorado and Bravo Rivers were defined as part of the boundary between both countries and the water use was regulated just for navigational aims.

On the 1st of march of 1889, Mexico and United States signed an agreement to establish an International Boundary Commission that would decide on the matters that would come up due to changes on the Colorado and Bravo river channels. In this way, on the 17th of November of 1891, the International Boundary Commission and on the 8th of February of 1894, the International Boundary (Fluvial) Commission were established.

In 1912, Mexico and the United States founded a commission that would be in charge of analyzing the bases for an equal allotment of the Colorado River waters. However, diplomatic relations were broken in 1914, and the negotiations started again until 1922.

In 1922, the seven states of the basin of the United States established the Santa Fe Agreement, in which Mexico was recognized as the 8th user with a water volume of 1,233 Mm3 per year.

After solving many political and diplomatic obstacles, in 1943, the negotiations within the International and Boundary Commission (IBC) between Mexico and United States concluded, setting up the bases for an International Waters Treaty. The treaty was signed on the 3rd of February of 1944, in Washington, DC , ruling over the water allotment of the two international rivers between Mexico and the United States, and establishing as well the International Boundary and Water Commission (IBWC).

Water Resources In The United States

The first hydraulic resource is located at the end of "Glenn Canyon", where a hydropower dam of the same name was built, creating Lake Powell, with a capacity of 30,000 Mm3. Hoover Dam was built at the end of Black Canyon, creating the artificial Lake Mead with a storage capacity of 33,769 Mm3, and 80 km downstream Davis Dam was built, forming Lake Mohave, with a storage capacity of 2,232.4 million of cubic meters. After crossing several valleys, at about 135 km downstream from Davis Dam, Parker Dam was built, and created the artificial Lake Havasu with a storage capacity of 764 Mm3, from this place 1250 Mm3 of water are released for supplies for Los Angeles, Calif. Further downstream at about 230 km is Imperial Dam. From this dam water is diverted to the All American Canal, a short distance downstream from this place is

Laguna Dam. The Colorado River receives water from the Gila River before it gets to the international reach. In the Gila River there are several storage works that as a group add up to a capacity of 6,953 million of cubic meters. (figure 1)

Water Resources In Mexico

The International Waters Treaty signed between Mexico and the United States in February of 1944, established an annual guaranteed allotment of 1,850.234 Mm3 and up to a quantity not to exceed 2,096.931 Mm3 a year. These volumes are delivered to Mexico in two different places: Morelos Dam or the Northerly International Boundary (NIB) and the Southerly International Boundary (SIB) through the Sanchez Mejorada Canal, receiving respectively, 1,677 and 173 Mm3 per year. These quantities are used in the states of Baja California and Sonora, mainly for agricultural use and in a lesser scale for domestic use as water supply for the cities of Mexicali, Tijuana and Tecate, Baja California. The second water resource that supplies an annual average flow of 700 Mm3 are the underground waters form 725 deep wells located in the Irrigation District 014, in the Mexicali Valley. A third water resource are the 67 wells of the Mesa Arenosa system in San Luis Rio Colorado, Sonora, which supply 197 Mm3 per year.

SILTATION PROBLEMS

The Colorado River waters are characterized for transporting a great volume of sediments along its course from Wyoming to the Gulf of California, mainly in the states of Colorado, Nevada and Arizona where the erosion process and the sediment transport has increased considerably. The silt control in the Lower Basin of the Colorado River in the United States is carried out immediately downstream of Imperial Dam. In this place the sediment is removed at the desilting basins from waters to be sent to southern California mainly.
The Colorado and Gila Rivers have an important potential for sediment transport which has been modified from its natural form by the construction and operation of the dam system built in these rivers, modifying the flow downstream, increasing the occurrence of extraordinary sediment transport events.
The sediment transport towards Mexican territory is a antropogenic process that has been taking place for decades (figure 2), usually during the flood periods, as it happened at the beginning of 1993, when intense rains in the Lower Basin of the Colorado River in United States territory, caused an increase of the storage levels of the dam system, generating discharges from Painted Rock Dam to the Gila River and then to the Colorado River. This situation, forced Mexico to take measures to protect the river banks because the conveyance capacity of the river in the Mexican reach was limited to 700 m3/s approximately. The record flows

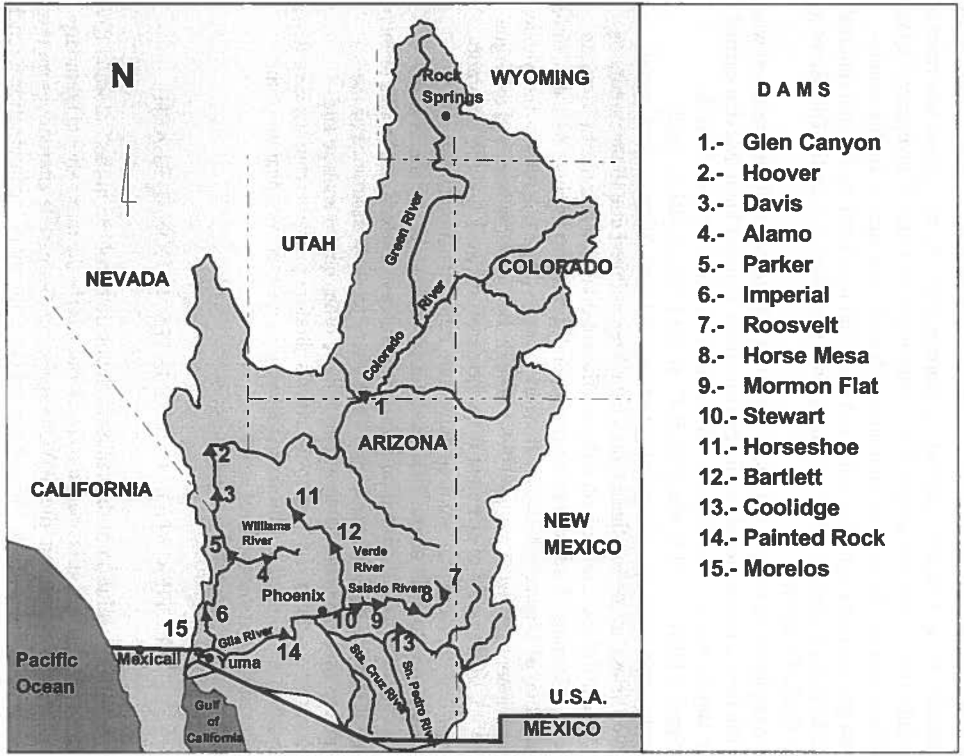

FIGURE 1. COLORADO RIVER BASIN

of the Gila River during the first months of 1993 deposited an approximate volume of 3.358 millions of cubic meters on the Colorado River and the network of canals of the Irrigation District 014, in Mexico (figure 3).
The sediment deposition in Morelos Dam risked the adequate diversion of Mexican waters. For that reason, IBWC carried out immediately, a series of meetings to coordinate the joint execution of the sediment removal works at the Colorado River Channel upstream of Morelos Dam. An agreement was reached on July 16th, 1994, and minute 291 " Improvements to the Conveyance Capacity of the Colorado River in its International Reach" was signed. In this minute, both governments agreed to carry out short and long term studies and removal works in the Colorado River channel from its confluence with the Gila River to the Gulf of California.
In compliance to minute 291, both countries carried out sediment removal works in the river's international reach upstream from Morelos Dam. Mexico carried out similar works in its territory, as well as in the canals network of the Irrigation District 014 in Mexicali, B.C., in the Colorado River reach downstream from the railway bridge and in the Canal Alimentador Central, nevertheless, at present these works have been nullified due to the continuos sediment transport putting on risk the efficient diversion and use of Mexican water, affecting Morelos Dam operation and starting to impinge on the adequate operation of Mexico's hydraulic network of canals. For this reason, the Mexican Government started in august 1996, through the Comisión Nacional del Agua (CNA), the removal of sediment from the canals network and the Colorado River bed in places that required immediate removal action (figure 4).
In the framework of minute 291, the International Boundary and Water Commission established two binational task forces to attend jointly this problem, one of them to propose short term alternatives to allow assurance of the Mexican diversions in Morelos Dam and the other one to analyze and recommend solution options to the river's siltation problem from the Gila River mouth to the Gulf of California considering as well the rectification of the Colorado River international reach.

RECTIFICATION OF THE INTERNATIONAL REACH

As part of the solution of the sediment deposition problem in the Colorado River international reach, it is needed to mark out clearly the international boundary line, and for this reason the IBWC is analyzing the feasible alternatives on this matter. In October 1995, Mexico carried out a survey of the international reach of the Colorado River and presented the first options. The United States Section of the IBWC is in consultations with the Bureau of Reclamation (USBR) on the sediment transport on the Colorado River from its confluence with the Gila River to the Gulf of California.

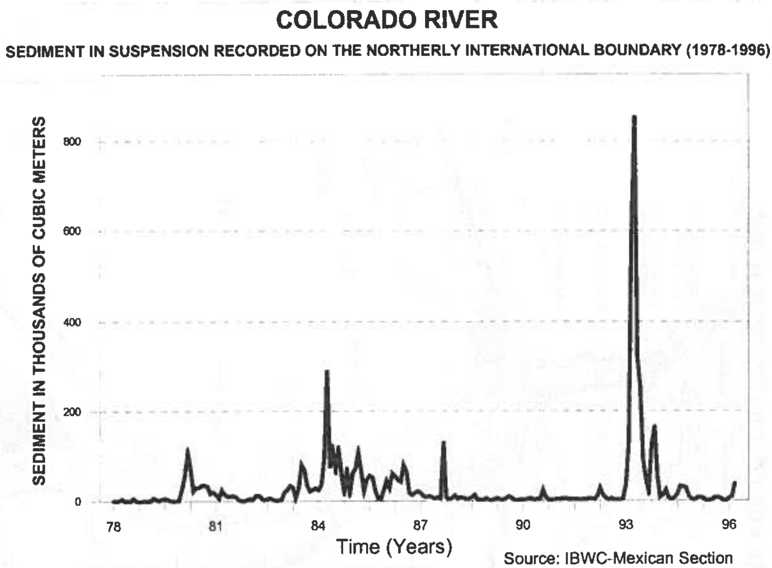

FIGURE 2

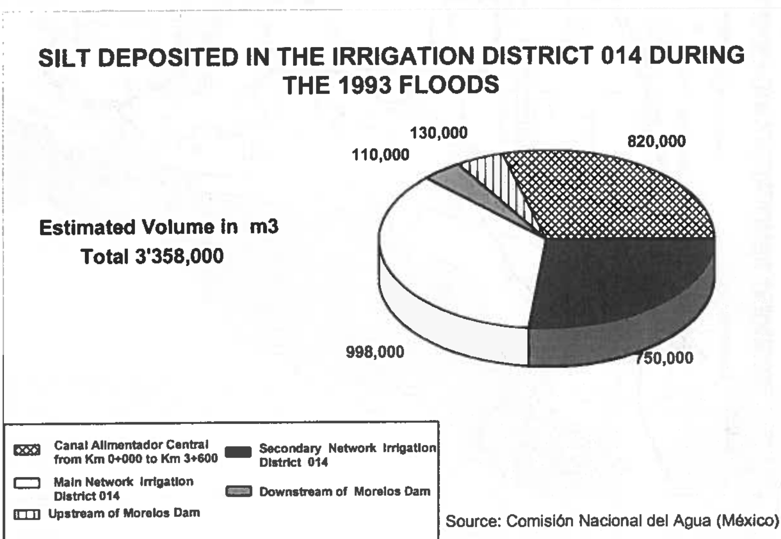

FIGURE 3

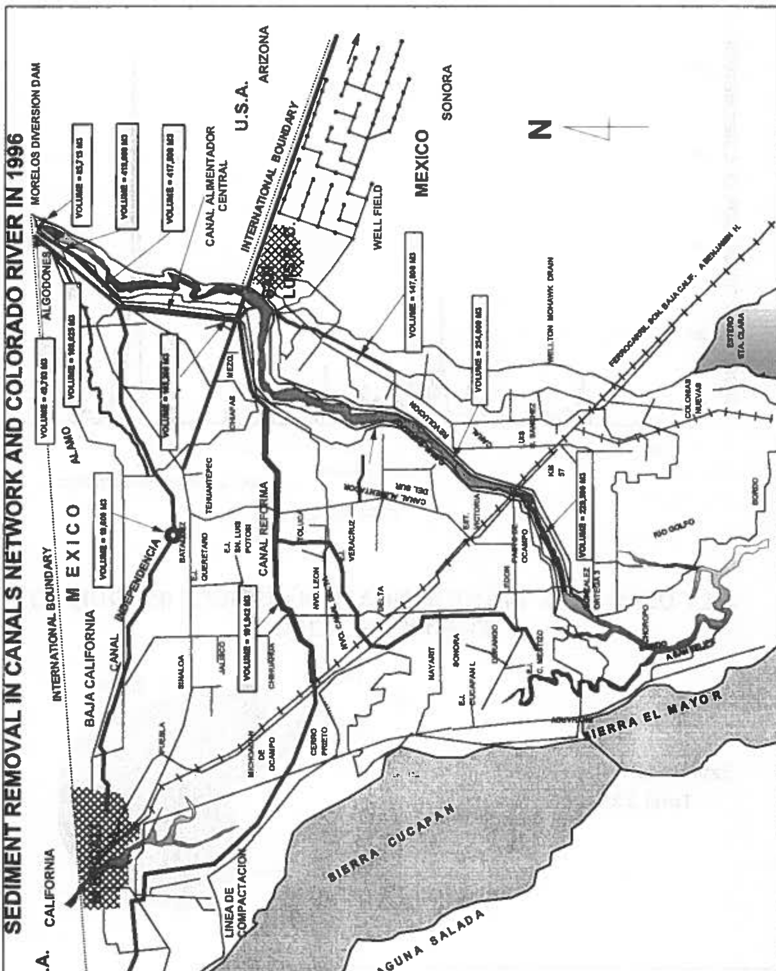
SEDIMENT REMOVAL IN CANALS NETWORK AND COLORADO RIVER IN 1996
U.S.A.
CALIFORNIA
INTERNATIONAL BOUNDARY
BAJA CALIFORNIA
M E X I C O
CANAL INDEPENDENCIA
ALAMO
ALGODONES
MORELOS DIVERSION DAM
CANAL ALIMENTADOR CENTRAL
U.S.A.
ARIZONA
INTERNATIONAL BOUNDARY
WELL FIELD
MEXICO
SONORA
N
CANAL REFORMA
WELLTON MOHAWK DRAIN
FIGURE 4
LINEA DE COMPACTACION
SIERRA CUCAPAN
LAGUNA SALADA
SIERRA EL MAYOR
ESTERO STA. CLARA
COLONIAS NUEVAS
BORDO
REVOLUCION
VOLUME = 147,000 M3
VOLUME = 234,000 M3
VOLUME = 191,943 M3
CERRO PRIETO
MICHOACAN DE OCAMPO
TEHUANTEPEC
BATAQUEZ
DELTA
VERACRUZ
CHAPAS
MEXZO.
SINALOA
JALISCO
CHIHUAHUA
PUEBLA
NAYARIT
SONORA
DURANGO
VICTORIA
PASTOR DE OCAMPO
ORTEGA 3

FIGURE 4

SALINITY PROBLEMS

During the first seventeen years of Treaty enforcement, Mexico received its water allotment from the Colorado River, with a water quality similar to the one of the water used by the farmers in Imperial Valley, California and the Yuma, Arizona, region. At that time the salinity difference between the waters in Imperial Dam and Morelos Dam was similar and did not exceed 900 ppm.
During the 1960's, there was an increase in the salinity of the waters above 2500 ppm, this was because the United States had drilled and started to operate many wells in the Wellton-Mohawk Valley, in order to control and reduce the water table,. The salty waters pumped from the underground were then discharged to the Gila River and later through the Colorado River reached Mexican territory.
In attention to the above, on March 22nd of 1965, minute 218 was signed in the IBWC. Based on this agreement, United States started the construction of a concrete lined canal, with a conveyance capacity of 10 m3/s, which started operations on November 16th of 1965. This canal, on Mexico's choice, was design to discharge to the Colorado River the waters from the pumping in the Wellton-Mohawk Valley, in two points located upstream and downstream of Morelos Dam.
Once more, in 1966-67, there was a significant increment in the salinity of the water from the Southern Gila Region. Mexico then carried out a series of exertions during meetings in Mexico City as well as in Washington, DC that ended up with the signing of minute 242. This minute stipulates that the salinity difference between the waters delivered to Mexico in Morelos Dam and the Colorado River waters in Imperial Dam, would not be over 121 ppm +/- 30 ppm, Mexican count. (figures 5 and 6).
At present, the salinity of the waters delivered to Mexico in the NIB have an annual average of 883 ppm, nevertheless, in some days during the low demand months, it could be above 1200 ppm. The annual average salinity of the waters that Mexico receives in the SIB exceed 1500 ppm and for this reason they have to be mixed with part of the waters received in the NIB and underground waters, so it can be used in agriculture, however, at the present time damage to the soils and low crops yield are observed.
Another situation that at present is of concern for the Mexican users are the daily variations of the salinity (salinity peaks), due to the adverse effects of these on the agricultural production. In order to detect opportunely these variations and ask for the corresponding adjustments to the United States, Mexico installed at its own expense, automated systems for the continuous recording of the salinity in Morelos Dam and the Sanchez Mejorada Canal.
In the same way, to give integral attention to the salinity problem the IBWC established a binational task force, which analyzes the following options set up by Mexico: In a short term to improve the quality of the waters that Mexico

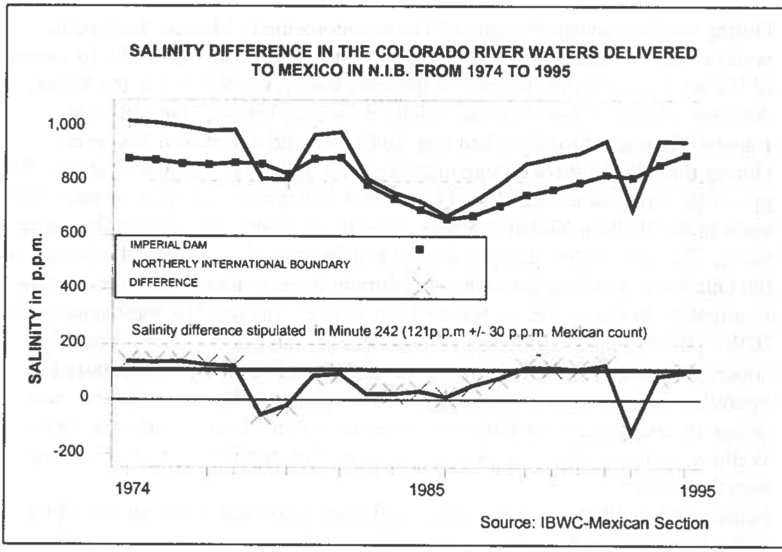

FIGURE 5

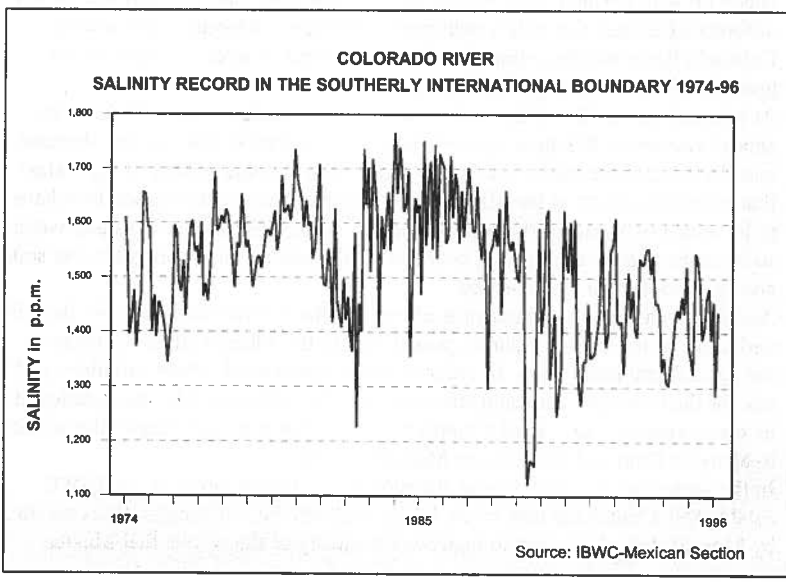

FIGURE 6

receives in the SIB, and in a long term, that all the water allotted to Mexico would come from Imperial Dam and be delivered in the NIB.

CONCLUSIONS

At present the management of the water in the Colorado River, the intensive use of this resource, and the geographical location of the Mexican basin, have an impact on Mexico in several matters as: the waters quality, water supply for domestic and agricultural use, the hydraulic system operation, a null flow of the river on Mexican territory, the Colorado River Delta and the environment in general (Table 1 and figure 7), making water management difficult. Although a Treaty and several minutes have been signed respect to the Colorado River waters allotment, the salinity and the sediments continue to demand the highest priority in order to secure a beneficial use of these waters in Mexico.
Because of the origin and nature of these problems, its solution should be shared by both countries, based on the procedures that they would established concurrently through the IBWC. These procedures should contemplate the jointly development of the actions that could allow in a short term to improve the water quality that Mexico receives in the Southerly International Boundary and to carry on the sediment removal in critical points of the Colorado River hydraulic system that would guarantee diversion, distribution and usage of the Colorado River waters that belong to Mexico. Likewise, they should contemplate the achievement of an integral study that would take into account all the factors that are involved in these problems, (tables 2,3, and 4), establishing jointly plans for its attention in a middle and long term.

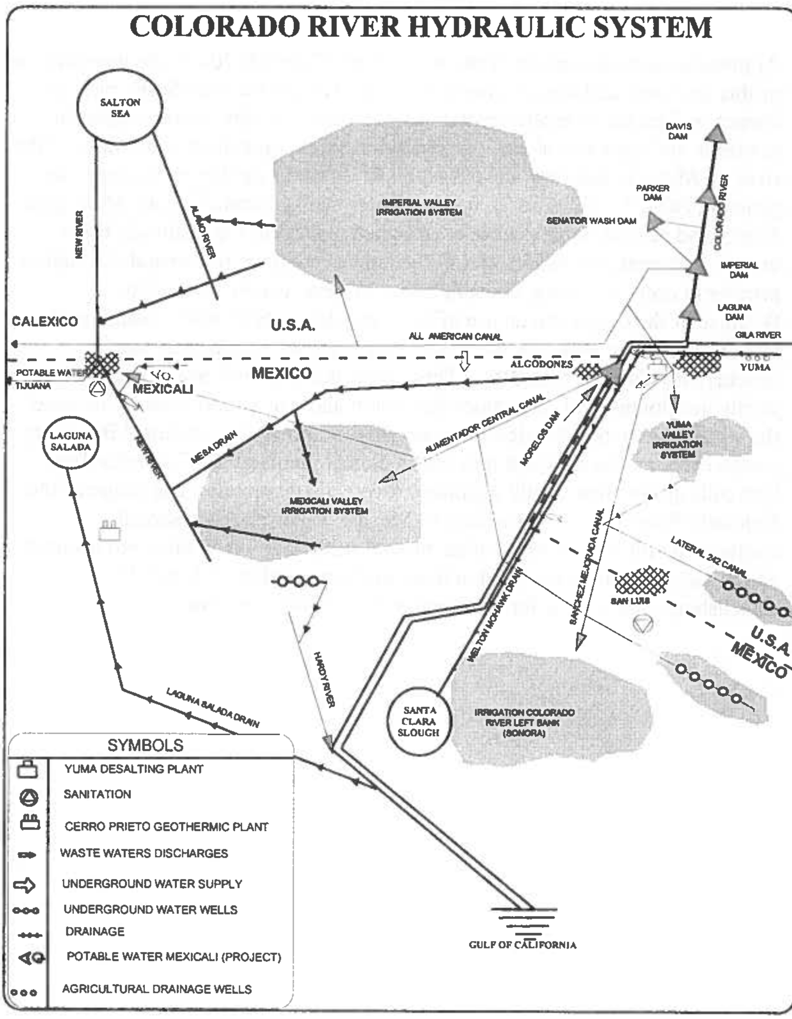
COLORADO RIVER HYDRAULIC SYSTEM
SALTON SEA
NEW RIVER
ALAMO RIVER
IMPERIAL VALLEY IRRIGATION SYSTEM
DAVIS DAM
PARKER DAM
SENATOR WASH DAM
COLORADO RIVER
IMPERIAL DAM
LAGUNA DAM
GILA RIVER
CALEXICO
U.S.A.
ALL AMERICAN CANAL
MEXICO
ALGODONES
YUMA
POTABLE WATER
TIJUANA
MEXICALI
LAGUNA SALADA
NEW RIVER
MESA DRAIN
ALIMENTADOR CENTRAL CANAL
MORELOS DAM
YUMA VALLEY IRRIGATION SYSTEM
MEXICALI VALLEY IRRIGATION SYSTEM
SANCHEZ MEJORADA CANAL
LATERAL 242 CANAL
SAN LUIS
U.S.A.
MEXICO
WELTON MOHAWK DRAIN
HARDY RIVER
LAGUNA SALADA DRAIN
SANTA CLARA SLOUGH
IRRIGATION COLORADO RIVER LEFT BANK (SONORA)
GULF OF CALIFORNIA
SYMBOLS
YUMA DESALTING PLANT
SANITATION
CERRO PRIETO GEOTHERMIC PLANT
WASTE WATERS DISCHARGES
UNDERGROUND WATER SUPPLY
UNDERGROUND WATER WELLS
DRAINAGE
POTABLE WATER MEXICALI (PROJECT)
AGRICULTURAL DRAINAGE WELLS

FIGURE 7

IMPACTS THAT FALL IN THE COLORADO RIVER PROBLEMS	
No.	IMPACTS
1	LOCAL POLITICS
2	INTERNATIONAL POLITICS
3	WATER QUALITY
4	DELIVERY OF WATER TO MEXICO
5	AGRICULTURE
6	WATER SUPPLY
7	PUBLIC HEALTH
8	SAFETY PUBLIC
9	HYDRAULIC SYSTEM OPERATION
10	ENVIRONMENT
11	UNDERGROUND WATERS

TABLE 1

CONDITIONS THAT INTEGRATE THE COLORADO RIVER PROBLEMS AS A FUNCTION OF FLOW CONDITIONS	
No.	CONCEPTS
1	MASS BALANCE
2	ALIMENTADOR CENTRAL CANAL
3	MESA DRAIN
4	FLOODING AREAS
5	SEDIMENT DEPOSITION
6	SEDIMENT CONTROL IN USA
7	FLOOD CONTROL
8	FLOOD PLAIN ENCROACHMENT
9	INTERNATIONAL BOUNDARY LINE
10	IMPERIAL DAM
11	LAGUNA DAM
12	SENATOR WASH DAM
13	PAINTED ROCK DAM
14	MORELOS DAM
15	SANCHEZ MEJORADA CANAL
16	WELLTON-MOHAWK DRAIN
17	ALL AMERICAN CANAL
18	242 LATERAL CANAL
19	WATER SUPPLY
20	SALINITY
21	IRRIGATION AREAS
22	NEW RIVER
23	LAGUNA SALADA
24	HARDY RIVER
25	AGRICULTURAL DRAINAGE
26	MEXICALI DRAIN
27	SANTA CLARA SLOUGH
28	YUMA DESALTING PLANT
29	CERRO PRIETO GEOTHERMIC PLANT
30	SALTON SEA
31	SANITATION OF MEXICALI
32	UNDERGROUND WATERS
33	TOXICS, SOLIDS AND GARBAGE MANAGEMENT

TABLE 2

CONDITIONS THAT INTEGRATE THE COLORADO RIVER PROBLEMS AS A FUNCTION OF FLOW CONDITIONS
NORMAL

CONCEPTS	IMPACTS										
	1	2	3	4	5	6	7	8	9	10	11
1 MASS BALANCE											
2 ALIMENTADOR CENTRAL CANAL				●		●			●		
3 MESA DRAIN											
4 FLOODING AREAS											
5 SEDIMENT DEPOSITION											
6 SEDIMENT CONTROL IN USA	●	●	●			●			●		
7 FLOOD CONTROL											
8 FLOOD PLAIN ENCROACHMENT											
9 INTERNATIONAL BOUNDARY LINE		●									
10 IMPERIAL DAM		●		●					●		
11 LAGUNA DAM			●								
12 SENATOR WASH DAM		●		●							
13 PAINTED ROCK DAM		●	●						●		
14 MORELOS DAM	●	●		●	●	●			●		
15 SANCHEZ MEJORADA CANAL											
16 WELLTON-MOHAWK DRAIN											
17 ALL AMERICAN CANAL	●	●		●		●			●		●
18 242 LATERAL CANAL		●	●	●	●				●		
19 WATER SUPPLY											
20 SALINITY	●	●	●		●						
21 IRRIGATION AREAS											
22 NEW RIVER	●	●	●		●		●			●	
23 LAGUNA SALADA										●	
24 HARDY RIVER									●		
25 AGRICULTURAL DRAINAGE		●		●	●						●
26 MEXICALI DRAIN	●	●					●			●	
27 SANTA CLARA SLOUGH	●	●								●	
28 YUMA DESALTING PLANT		●	●	●							
29 CERRO PRIETO GEOTHERMIC PLANT							●			●	
30 SALTON SEA		●							●		
31 SANITATION OF MEXICALI											
32 UNDERGROUND WATERS	●	●			●						
33 TOXICS, SOLIDS AND GARBAGE MANAGEMENT	●	●					●			●	

TABLE 3

CONDITIONS THAT INTEGRATE THE COLORADO RIVER PROBLEMS AS A FUNCTION OF FLOW CONDITIONS

FLOODS

CONCEPTS	IMPACTS										
	1	2	3	4	5	6	7	8	9	10	11
1 MASS BALANCE											
2 ALIMENTADOR CENTRAL CANAL				●	●	●			●		
3 MESA DRAIN		●			●						●
4 FLOODING AREAS	●	●			●			●	●		
5 SEDIMENT DEPOSITION	●	●			●	●			●		
6 SEDIMENT CONTROL IN USA	●	●									
7 FLOOD CONTROL	●	●	●	●	●	●		●	●		●
8 FLOOD PLAIN ENCROACHMENT									●		
9 INTERNATIONAL BOUNDARY LINE		●									
10 IMPERIAL DAM		●		●					●		
11 LAGUNA DAM											
12 SENATOR WASH DAM											
13 PAINTED ROCK DAM	●	●	●	●		●			●		
14 MORELOS DAM	●	●		●	●	●		●	●		
15 SANCHEZ MEJORADA CANAL		●	●	●					●		●
16 WELLTON-MOHAWK DRAIN	●	●							●	●	
17 ALL AMERICAN CANAL	●	●		●		●			●		●
18 242 LATERAL CANAL		●	●	●	●				●		
19 WATER SUPPLY											
20 SALINITY											
21 IRRIGATION AREAS											
22 NEW RIVER	●	●	●		●		●			●	
23 LAGUNA SALADA									●	●	
24 HARDY RIVER								●	●		
25 AGRICULTURAL DRAINAGE		●		●	●						●
26 MEXICALI DRAIN	●	●					●			●	
27 SANTA CLARA SLOUGH	●	●								●	
28 YUMA DESALTING PLANT		●	●	●							
29 CERRO PRIETO GEOTHERMIC PLANT							●			●	
30 SALTON SEA		●							●		
31 SANITATION OF MEXICALI	●	●					●			●	
32 UNDERGROUND WATERS	●	●			●						
33 TOXICS, SOLIDS AND GARBAGE MANAGEMENT	●	●					●			●	

TABLE 4

STUDY ON WATER USE PLAN FOR REASONABLE IRRIGATION OPERATION AND MANAGEMENT

Chun-E Kan[1] Yu-Chuan Chang[2]

ABSTRACT

The major function of irrigation is to supplement water to growing crops with the quantities which cannot be sufficed by the nature, in order to ensure food productions. The conventional water use plan for irrigation operation and management is made based on the stance of "supply" which takes into account the amount of irrigation water diverted from water sources, then flowing through various levels of canals, and reaching farms for the needs of normal growth of crops. This concept implies that the supply side dominates the "demand" side; and its adjustment to the fluctuating water sources is much dependent on the operator's experience, in case there are not established irrigation operation criteria to cope with changing water sources. Under such a circumstance, when the system operator are absent, and few appropriate personal are available to replace them, then the conventional irrigation operation mechanism is often discontinued. With an aim to solve the aforesaid implication in irrigation operation, in this paper are examined and probed the following issues, on the basis of irrigation at right time and with proper quantities :

1. Relation between diverted amounts of water (Q_s) and farm requirements (Q_d)
2. Distinctions between conveyance loss (S) and factor of loss (K)
3. Influence of diverted amount of water (Q_s) to irrigation efficiencies (E)
4. Relation between irrigation efficiencies (E) and irrigation time (t)

Water use plans for reasonable irrigation operation and then studied and discussed, from the view point of irrigation management.

INTRODUCTION

The most difficult of O&M in irrigation areas with abundant water sources which tap water from river by gravity lies in the formulation of a reasonable water-use plan that would respond to the fluctuations in the river water level and maintain the water level during the conveyance.

The history of irrigation in Taiwan has been over 300 years. The facilities and technologies came mainly from traditional China Mainland, however, they have also merged the technical merits from the Netherlands, Japan and the United

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States, and thus formed the unique Taiwan irrigation system. For example, the three-year rotation cropping system of alternating paddy rice and upland crops, and the drought season measures responding to water shortage.
However, due to lack of basic concepts of water-use plan and the complexity of the irrigation system in Taiwan, problems on balanced supply and demand of water can only be overcome through the experience of the manager. Once the manager left the original irrigation operation system, there is no way to maintain. Nonetheless, it has introduced a set of irrigation programming that would correspond to actual practice.

LITERATURE

Taiwan is a rice producing country with unique characteristics while the Tropic of Cancer trespasses through it, and two crops of rice can be harvested each year. The average annual rainfall reaches 2,510 mm, however, the wet and dry seasons are significant. The amount of rainfall in wet season (May to September) accounts for 80% of the annual total rainfall. Thus in Taiwan, the harvest in dry seasons must be depends on irrigation. The irrigation industry of Taiwan has been developing under this unstable water shortage conditions.
The set of irrigation programming is carried out in three stages as follows in Taiwan.
1. First Stage: The Irrigation Association formulate conveyance system programming. Step as follows:
(1) Formulate irrigation rate for tertiary unit
The Irrigation Association, in accordance with the meteorological and soil parameters estimates irrigation area of paddy that can be completed by the unit discharge(1 cms) of turnout of the tertiary unit based on past experiences. This is the so-called irrigation rate for tertiary unit ($IR_N(I,J)$:ha/cms) as show bellow.

$$Q_N(I,J) = \frac{A}{IR_N(I,J)} \quad \text{......(1)}$$

which I = 1 represents the 1st crop of rice, I = 2 represents the 2nd crop of rice, J =l...m, m represents ten days or half month, $Q_N(I,J)$ (cms) represents discharge needed by farmers to complete irrigation of area A (ha).
(2) Formulate conveyance loss for each degree of cannel
The Irrigation Association uses the discharge of inflow (Q_i:cms) as a foundation to record the discharge of outflow (Q_o:cms) for each degree of cannel after passing through channel during normal period to establish conveyance loss S as shown below:

$$Q_L = Q_i - Q_o \quad \text{......(2)}$$

$$S = \frac{Q_L}{Q_i} \quad \text{......(3)}$$

which Q_L (cms) is loss of discharge in cannel thus:

$$Q_i = \frac{Q_o}{1-S} \quad \text{......(4)}$$

(3) Irrigation Water-Use Plan
Based on equation (1) and equation (4), formulate conveyance system programming. The table 1 shows the discharge of each dergree of cannel .

Table 1 The Discharge of Each Dergree of Cannel

Degree of Cannel	Main (3)	Lateral (2)	Division (1)
Conveyance Loss (S(i))	S(3)	S(2)	S(1)
Discharge of Inflow (Q_i)	$\prod_{i=1}^{3}\frac{1}{(1-S(i))}\times\frac{A}{IR_N}$	$\prod_{i=1}^{2}\frac{1}{(1-S(i))}\times\frac{A}{IR_N}$	$\frac{1}{1-S(1)}\times\frac{A}{IR_N}$
Discharge of Loss (Q_L)	$\prod_{i=1}^{3}\frac{S(3)}{(1-S(i))}\times\frac{A}{IR_N}$	$\prod_{i=1}^{2}\frac{S(2)}{(1-S(i))}\times\frac{A}{IR_N}$	$\frac{S(1)}{1-S(1)}\times\frac{A}{IR_N}$
Discharge of Outflow(Q_o)	$\prod_{i=1}^{2}\frac{1}{(1-S(i))}\times\frac{A}{IR_N}$	$\frac{1}{1-S(1)}\times\frac{A}{IR_N}$	$\frac{A}{IR_N}$

Planned amount of planned diversion of water sources (Q_S) for said tertiary unit is shown in Equation 5.

$$Q_s=\prod_{i=1}^{3}\frac{1}{(1-S(i))}\times\frac{A}{IR_N}\ldots\ldots(5)$$

Upon completion of formulate conveyance system programming, the Irrigation Association will give this to the Working Stations of the Irrigation Association and distribute amount of water in accordance with different phases to intake of each tertiary unit.

2. Second Stage: The Irrigation Groups which are organized by farmers formulate distribution system programming . Steps as follows:

(1) In accordance with distance of location, divided area of tertiary unit into 3 or 4 groups. Based on experience, establish water supply multiple CH(I). Water Supply multiple of relatively distant irrigation group is relatively small.

(2) Upon deciding area of each group and multiple of water supply, calculate irrigation time of each group.

$$AW(I)=\frac{A(I)}{CH(I)}\ldots\ldots(6)$$

$$TT(I)=\frac{AW(I)}{\sum AW(I)}\times(Ped-TL)\ldots\ldots(7)$$

which I is group classification, AW(I) is time to be obtained by each group, A(I) is area for each group, TT(I) is distributed time for each group, Ped is interval of rotational irrigation, TL is time of waterways.

(3) Classify irrigation area of each small group into several rankings and compute distributed irrigation time based on above equation.

(4) With respect to hill mounds of each field, calculate distributed time of each hill mound in accordance with ranking irrigation time using area method.

(5) In accordance with irrigation sequence, accumulate irrigation time of each hill mound and arrange time schedule of irrigation of each hill mound within the rotational irrigation interval.

3. Third Stage: Implemented in accordance with above irrigation plan.

In accordance with the experience of the manager, determine critical values of each operational measures. Water distribution plan are still a part of the irrigation plan. It lacks a water distribution model that meets the requirement of a fair and reasonable principle and timely response to conditions of water sources. Below is a compilation of current method of implementation of each Irrigation Association.

(1) When quantity of actual diversion differs slightly with planned water supply: primary considerations include increase cost of operation and management, common measures taken as follows:

a. Regulate quantity of distributed water: When water quantity of water sources changes, distribute water in accordance with water distribution ratio of each cannel. With respect to supplementary water sources, distribute in coordination with quantity of incoming water from water sources. However, it should be limited to upper limit of planned water use for such region. If it exceed planned water use for said area, then it should not be included.

b. Record time of water-use: After water distribution to each waterway, commence recording time of water use to control the gross quantity of water-use for each group.

c. Trace water-use of each group: The inability of each group to timely regulate floodgate due to rapid changes in water volume of water sources would result to wastage in water. The manager, based on his experience, should observe the time of arrival of discharge of different water sources to each tributary and branches so that operators can regulate floodgate in a timely manner. In addition, in times where discharge is not adequate, the operator may actually trace improper water use to allow for a fair and reasonable distribution and utilization.

(2) When quantity of actual diversion differs greatly with planned water supply (water shortage): primary considerations include loss of profit due to reduced production, complete reliance on experience of manager. Common measures taken as follows:

a. Strengthen irrigation management: in a situation where water shortage is not too serious, strengthen conveyance management and tracing of water sources to minimize unwanted losses.

b. Minimize irrigation water depth method: in accordance with water use ratio of waterways, reduce quantity of supply to each system. Although this method is very simple and convenient, it cannot effectively reduce loss in water delivery. Moreover, it could lead to irrigation difficulties due to low head.

c. Rotational Irrigation By Area and By Sections: In addition to rotational irrigation to tributary and branches of large systems, each rotation value group can further be divided into areas and section rotational irrigation to respond to different water shortage condition of rotational irrigation.

d. Large Division Rotational Irrigation: Divide system into various large division, implement centralized irrigation, reduce conveyance loss, strengthen irrigation management. At the present stage, this is the method commonly used by the Irrigation Association. However, prior communication with farmers must first be undertaken to prevent difficulties in implementation.
e. Extend Rotation Interval Method: In conducting rotational irrigation, establish number of days for rotational irrigation based on the demands of each rotational irrigation group, alter interval of rotational irrigation to increase number of days for dry field to overcome problems of water shortage.
(3) In cases where there is a continuing shortage of water sources: support government policies, interrupt or stop providing irrigation to field areas which consume a large amount of water or which have poor benefits i.e. fallow.
In the past, Taiwan formulate the brought about inadequate head. Farmers do not know where to turn for help. A water shortage would result in scattered fallow farms and interruption of water delivery process, thereby affecting the production value and comprehensiveness of the entire irrigation system. At present, if changes for plans for irrigation water need can be established in advanced from the perspective of demands, (such as establishment of rotational irrigation, crop transfer area, etc.) and reduce farmer's losses to the minimum to maintain the reasonable production value of the field area. Also, alter irrigation water-use plan from time to time in accordance with changes in discharge of water sources to eliminate risk of water shortage and ensure the reasonable irrigation water distribution of the field area.

RATIONAL IRRIGATION OPERATION AND MANAGEMENT PLAN

Irrigation operation and management plan can be primarily divided into water supply plan and water distribution plan. Formulation of water supply plan is relatively simpler as it only needs to be based on irrigation water need and irrigation water loss to compute quantity of irrigation supply. Water distribution plans are primarily focused at formulation of different water supply plans to respond to changes in quantity of water sources so that water supply plan and quantity of actual irrigation water sources can be consistent.
1. Water Supply Plan
All irrigation water supply plan can be divided into amound of irrigation water supply (IWS : m^3), amound of irrigation water need (IWN : m^3) and amound of irrigation water loss (IWL : m^3) as shown in the equation below:

$$IWS = IWN + IWL \qquad (8)$$

(1) Amound of Irrigation Water Need (IWS)
The primary objective of irrigation is to provide water needed in the normal growth environment of crops. Basic condition of crop production is to satisfy amount of evapotranspiration needed by crops in the normal environment. When irrigation is larger than the quantity of evapotranspiration, under excellent drainage and percolation, it could maintain production quantity and production

environment of agricultural fields. When irrigation is smaller than quantity of evaportranspiration, it would rely on the irrigation supplement to maintain the scope of growth endurance of crops. The gradual exacerbation of the production environment would lead to water volume of irrigation to be far smaller than the amount of evaportranspiration. As a result, production and ecology will start to encounter destruction, agricultural fields start to worsen and difficult to recover. The formation of salty and alkaline soil is an example.

For paddy fields, irrigation water need refers to quantity of water used in land leveling to transform dry farmlands into wet farmlands (SAT) to satisfy the amount of evaportranspiration (ETrice) needed by crops for normal growth, prevent dryness of soil, water depth (WL) to maintain suitable for growth temperature of paddy rice and "Adequate Percolation"(Pad) to maintain sustained utilization of land. If effective rainfall (ER) and upstream percolation return water to supplement irrigation water need is considered, per Figure 1, then irrigation water need can be expressed in equation (9).

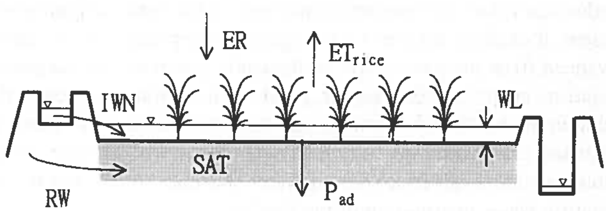


Figure 1 Illustrative Drawing of Irrigation Water Need for Paddy Field

$$IWN = (SAT + ET_{rice} + P_{ad} + WL - ER - RW) \times A = D \times A \quad ....(9)$$

which A is irrigation area, D is depth of irrigation water.p

(2) Amound of Irrigation Water Loss

Reasons causing irrigation water loss can be divided into two categories: water loss caused by poor hardware and loss not caused by human error such as percolation of soil and waterway, damage to internal surface works and water surface evaporation volumn. The second is water loss due to poor software and losses caused by human error such as improper operational management, low irrigation efficiency between the fields, illegal water piracy and water for diluting and polluting use. Traditional paddy field irrigation mostly belong to Open Canal system. During water passage, each water branches have a stoplog to control the water level and flow capacity to maintain a fixed waterhead. When water level reaches needed irrigation waterhead, it could guide water into water intake outlet of tertiary unit to implement irrigation. Thus, loss of delivered water volume caused by poor hardware can be seen as fixed value. Losses caused by poor software would be aggravated with incidents of water shortages. Thus, methods should be devised through regulations, education and moral ethics to prevent losses.

In the past, Taiwan uses conveyance loss S to express irrigation water loss in conveyance system as shown in Equation 10, "Tertiary Area Irrigation Rate IR_t "include irrigation water loss in distribution system.

$$S=\frac{Q_L}{Q_S}=\frac{Q'_L}{Q_a} \qquad (10)$$

In reservoir diversion, as quantity of actual diversion (Q_a:cms) is drawn based on quantity of planned water use (Q_N: cms), the application of the above equation will not create too big a problem. However, in a canal system diversion, to increase effective utilization of water resources, there is a need to regulate actual quantity of diversion in accordance with the abundance or shortage of river discharge. Thus, the application of S is not appropriate . Taking for example water shortage condition, as actual quantity of diversion (Q_a) is lower than quantity of planned water use in normal times ($Q_a<Q_S$), in applying S, there is an underestimated condition ($Q'_L < Q_l$, Q_l :cms) for quantity of loss for delivered water (Q'_L :cms). As a result, actual amount of water to water intake outlet of tertiary unit water intake outlet is inadequate and condition of water shortage in the field is more serious.

Form the logical perspective, the objective of water supply plans are to ensure that under the foundation of irrigation water need estimate irrigation water supply and not to seek the difference between irrigation water suplly and irrigation water loss. Therefore, quantity of water loss in water delivery should be recorded in Factor of Loss (L), as shown in Equations 11, 12 and 13.

$$L=\frac{V_L}{V_O} \qquad (11)$$

$$V_L = L \times V_O \qquad (12)$$

$$V_i=(1+L)\times V_O \qquad (13)$$

which L is factor of loss, V_L is of quantity of water loss in delivered water (m^3). V_O is quantity of water in water outake outlet (m^3). Vi is quantity of water of water intake outlet (m^3)

(3) Establishment of Water Supply Plan.

Utilizing above discussions, the following irrigation water supply can be arrived (Table 2).

From the perspective of balanced supply and demand.

$$IWS=\prod_{i=1}^{3}(1+L(i))\times IWN \qquad (14)$$

which IWS and IWN is function for time. If irrigation area (A), irrigation supply water time (Ts), irrigation water needed time (Tn, normally Tn is ten days or half month) and extension time of water flow ti, then relationship of irrigation water supply discharge Qs and irrigation water needed Qn is as shown in Figure 2.

Table 2 The Discharge of Each Dergree of Cannel

Degree of cannel	Distribution System	Conveyance System		
	field	Diversion (1)	Lateral (2)	Main (3)
Factor of Loss L(i)	L(0)	L(1)	L(2)	L(3)
Amount of outflow $V_o(i)$	IWN	(1+L(0))×IWN	$\prod_{i=0}^{1}(1+L(i))\times IWN$	$\prod_{i=0}^{2}(1+L(i))\times IWN$
Amount of loss $V_L(i)$	L(0)×IWN	L(1)× (1+L(0))×IWN	$L(2)\times\prod_{i=0}^{1}(1+L(i))\times IWN$	$L(3)\times\prod_{i=0}^{2}(1+L(i))\times IWN$
Amound of inflow $V_i(i)$	(1+L(0))×IWN	$\prod_{i=0}^{1}(1+L(i))\times IWN$	$\prod_{i=0}^{2}(1+L(i))\times IWN$	$\prod_{i=0}^{3}(1+L(i))\times IWN$

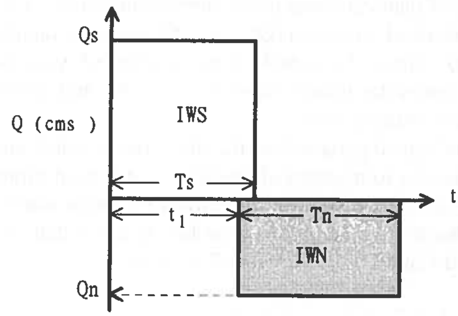


Figure 2 Illustrative Drawing on Relationship of IWS, IWN, Ts, Tn, ti

$$IWS = Q_s(t - t_i) \times T_s \quad \text{.......(15)}$$

$$IWN = Q_n(t) \times T_n \quad \text{.......(16)}$$

$$Q_s(t - t_i) = \frac{T_n}{T_s} \times \left(\prod_{i=0}^{3}(1 + L(i)) \times Q_n(t)\right) \quad \text{.......(17)}$$

(1)In conveyance system, as channels maintain long-term water passages, so Ts =Tn, i.e, i=1 to 3, Ts=Tn.

$$Q_s(t - t_i) = \prod_{i=1}^{3}(1 + L(i)) \times Q_n(t) \quad \text{.......(18)}$$

(2)In distribution system, during actual implementation, farmer will divert more water volume to increase irrigation efficiency and reduce irrigation time, thus, there is a need to centralize fixed flow capacity and implement group irrigation. There are many factors to be considered in group irrigation. Three primary impact equations are enumerated below to serve as examples:

a. Qs < cannel capacity ....(19)

b. $\sum_{i=1}^{N} Ts(i) \leq Tn$ ....(20)

c. Ts(i) > irrigation time of farmers.......(21)

of which Qs is flow capacity of water intake outlet of distribution system, Tn is appropriate irrigation interval for crops in distribution system, ti is waterway traveling time in distribution system, N is number of groupings, Ts(i) is distributed diversion time for each group. For example, when flow capacity of QS is too small, in addition to lowering irrigation efficiency, irrigation time of each set Ts(i) is extended and will cause $\sum_{i=1}^{N} Ts(i) \geq Tn$ thereby losing opportunity for appropriate irrigation. If grouping number N is extremely big, it will cause irrigation time distributed to each set to be shortened, Ts(i) < irrigation time of farmers. As a result, farmer will not be able to catch up with irrigation. Based on experience of the author,distribution system for an area of approximately 50 ha is approximately best at 3 to 4 groups.

Also, factor of loss of different area of each grouping will have a difference. Area of each group should be distributed to achieve a relatively reasonable irrigation distribution time. Assuming factor of loss of distribution system is L, then considering size of area A(i) is directly proportional to loss of factor, then factor of loss distributed to each set is adjusted as follows:

$$A = \Sum A(i) \qquad (22)$$

$$L_0 = \frac{L}{A} \qquad (23)$$

$$L_1 = \frac{\Sigma A(i)}{N} \times L_0 \qquad (24)$$

$$L_2 = \frac{\Sigma A^2(i)}{\Sigma A(i)} \times L_0 \qquad (25)$$

$$K = \frac{L_1}{L_2} \qquad (26)$$

$$L(i) = 1 + (A(i) \times L_0) \times K \qquad (27)$$

A reasonable Ts(i) can be obtained from Equations (17), (19), (20), (21) and (27). However, to allow irrigation water to be send to root system of crops within a specific time and maintain downstream field area return to waterhead, irrigation should within permissible scope of channel capacity, divert water as much as possible to maintain adequate waterhead and increase irrigation efficiency.

(2)Water Distribution Plans

The objective of water distribution plans is to make prior plans to change water supply plan of irrigation water need. From combination of various water supply plan of different irrigation need water and water distribution plan to respond to critical discharge of different waterhead, Equation 9 showed the primary method used as shown in Table 3.

Table 3 Theoretical Foundation for Water Distribution Plans Under Different Water Supply Conditions

Actual Water Supply Condition	Theoretical Foundation	Water Distribution Plan
$Q_c > Q_a > 75\% \times Q_p$	Change Irrigation Depth D	Factor K
$75\% \times Q_p > Q_a$	Change Irrigation Area A	Gilinan (Rotolin)

Note 1 : Q_c:capacity of channel ,Q_p:discharge of planned ,Q_a : discharge of supply

1.Change Irrigation Water Depth D: When sources of water is not stable, distribute changing water quantity to each irrigation area in accordance with ratio and within level acceptable by farmers. as shown in Equation 26.

$$K = \frac{Q_s - Q_{loss}}{Q_p - Q_{loss}} \qquad (28)$$

which K is coefficient for ratio increase or decrease, Qloss is irrigation loss discharge. Just multiply K value with flow capacity of each water intake outlet to find new control flow capacity of each water intake outlet of each area. If it involves different water use of crops, this method can be used to adjust inflow of other water sources and movement of other subjects.

2.Change Irrigation Area A: In cases where water volume is decreased to a level not acceptable to farmers, primary irrigation area could be adjusted by dividing each irrigation area into groups and adopting rotational water supply methods. Focus on relatively large discharge and irrigate one of the group. Groupings and applicable scope are as shown in table 4.

Table 4 Applicable Scope of Rotational Water Supply Plan Grouping

Water Supply Condition	Water Distribution Measures
75% Qp > Q >50% Q	2 rotation groups
50% Q > Q> 33% Q	3 rotation groups
33% Q> Q > 25% Q	4 rotation groups

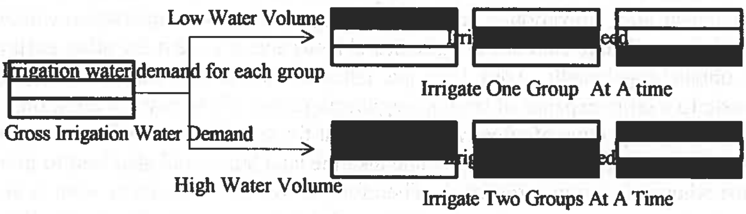
The next step is to consider the direct ratio of length of the waterways l1 and factor of loss. Thus, put more weight on length of waterways. Assuming that loss of factor of irrigation system is L3, area is A1, then, factor of loss of each group should be adjusted as follows:

$$\bar{l} = \frac{\sum(A_i \times l_i)}{\sum A_i} \qquad (29)$$

$$L = \frac{L_3}{\bar{l}} \qquad (30)$$

$$L(i) = L \times l_i \qquad (31$$

For example, with waterway as a unit, divide irrigation area into 3 groups, then, based on amount of water, decide whether to irrigate one group at a time or two groups at a time, as shown in Figure 3. This way, actual amount of diversion of waterway could be adjusted to 1/3 or 2/3 of originally planned irrigation water supply.



CONCLUSION

(1)A comparison between Equation (1) and Table 2 showed that although irrigation rate of tertiary area is similar to quantity of water intake outlet, irrigation rate includes regional return water-use rate and irrigation rate and represents the actual irrigation efficiency of the area. For first line operators, this is practical. In the past, value for said rate is dictated by experience. Now, it can be validated based on factor of irrigation water need, allowing such value to be precise and practical

(2)Maintaining the sustained utilization of agricultural fields is very important to areas where there are limited land resources. In the past, percolation is perceived as the most important aspect in irrigation. In reality, percolation of small field is closely related to soil productivity. Presently, there is the so-called "adequate percolation" which means that it is the best percolation condition for the cultivation of aquatic rice, approximately between 15~25mm/day. Thus,in forecasting irrigation water need,the concept of sustainable utilization of natural resources such as "adequate percolation" should be given much importance.

(3)In the past, planned water supply only takes into account the theoretical applicable irrigation time and condition of actual irrigation is neglected. This has resulted to inadequacy during the days and waste of water during the night, extremely small capacity for medium-sized water supply waterways and extremely large capacity for small-sized water supply waterways or weariness of farmers in an attempt to complete irrigation within distributed irrigation diversion time. Thus, the above should first be taken into consideration when deciding water supply plan for distribution system and capacity of small-sized and medium-sized water supply channel.

(4)If occurrence of water shortage can be known from hstorical data of river discharge, then in accordance with water shortage level adjust water supply plan, and plan a set of distribution plan including the implementation of rotational irrigation and fallow farms. If there is a need to save on irrigation water use during the dry season to support water-use for other areas, then, from the perspective of "beneficiary has to pay compensation", improvement of management, hardware facilities, regulations and moral ethics and strengthening of irrigation rate of fields should be perceived as preferred improvement subjects.

(5)In areas where government provide provisional subsidies to farmers and there is concentrated utilization of land, farmers hope to obtain compensation without working or change land use of agricultural lands and not use it for other purposes to obtain large benefit. Thus, improper fallowing will always lead to creation of waste to a large expanse of land in neighboring areas of the city. In addition, from the perspective of effective management for soil, the result of fallowing will not only result to creation of salty and alkaline land but would also lead to greater cost when cultivation is resumed. Therefore, fallowfarms should be seen as an emergency measure for water distribution plan and not an effective tool in the long term.

RECOMMENDATION

A reasonable irrigation operation and management plan should not only have a healthy and sound water distribution plan but should also consider the effective utilization of natural resources. It should also fully utilize space for flexible water use in field area, i.e., in times of drought, consider increasing effort and expenses in water-use management to upgrade irrigation management and achieve the objective of a reasonable water distribution; in times of abundant supply of water, the unique characteristics of "field is reservoir" should be considered, divert a large amount of water from the riverways to the field, coordinate with sustained utilization concepts of fields by planting crops on fallow fields and creating a water pond, as per Figures 4, 5 and 6. Store excess water in times where water supply is aboundant and adjust water distribution difficulties for mixed planting. Through movement of the soil, break into nonpermeable layer of field area and supplement underground water to promote soil oxidation and reduction and allow for sustained utilization of land. During the dry season, supplement irrigation water of the entire area from pond, conduct conditional transfer of irrigation water for upstream crops for use in other areas.

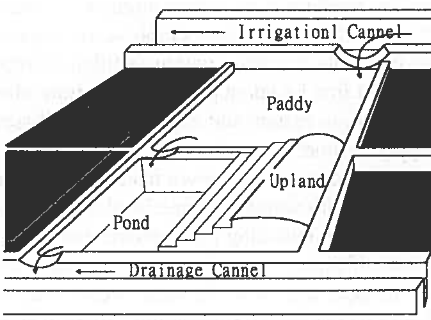


Figure 4 Illustrative Drawing of Sustained Utilization Structure of Fields

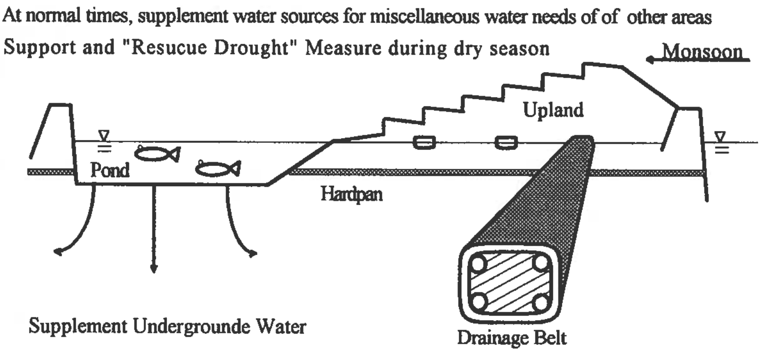


Figure 5 Illustrative Drawing of Sustained Utilization Operation of Fields

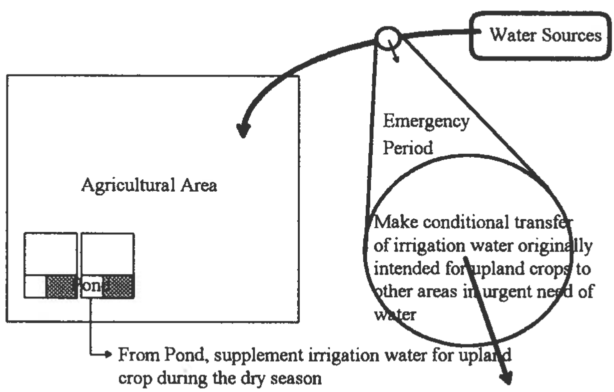


Figure 6 Illustrative Drawing of Field Sustained Utilization Supporting Water Need of Other Areas During the Dry Season

REFERENCE

Indonesia, 1988, West Java Irrigation Project operation and maintenance procedures

C.Brouwer,J.P.M. Hoevenaars,B.E.van Bosch. 1992.Scheme Irrigation Water Needs and Supply ' Training manual no6 .FAO Land and Water Development Division.

Wolters,W.1992.Influences on the Efficiency of Irrigation Water Use.Publication 51. ILRI,Wageningen,The Netherlands.

Bos,M.G. and J.Nugteren.1974(4th Edition 1990).On Irrigation Efficiencies .Publication 19.ILRI,Wageningen,The Netherlands.

DAMS AND ENVIRONMENT

RIDRACOLI: A MODEL ACHIEVEMENT

Pier Paolo Marini[1]

1. ABSTRACT

Controversy about dams and man-made reservoirs is frequently lively, with both sides tending to speak a different language. Our purpose here is to introduce a note of concrete positive experience which we are still living through at the present time. This is the Ridracoli Dam and Romagna Aqueduct. One must rise above preconceived positions based on ideology or principle, for or against dams, and consider the environment and its ecosystems not as static, which man can only influence regatively, but as dinamic systems capable of beneficial change: this is what our experience has taught us. Experience urges us to examine environmental issues not as sectorial issues - about addressing only one aspect or need while disregarding or leaving aside the other issues - but by seeking wider, unifying relationships and programmes, which must always guide our action - action meaning expressing a judgement, making a choice or commencing construction. The Ridracoli Dam project has been implemented with complete respect for the environment and, trough strict management of water resources, as a means for developing the region. Reafforestation, soil conservation, refurbishment of old dwellings, promotion of social, cultural and economic progress in the region has enabled the dam to become part of the countryside, by safeguarding and enriching it. Only if dams are operated properly can the relationship between major engineering projects and environmental conservation be positive.

2. BACKGROUND

Romagna, part of the Emilia-Romagna region, is bounded to the north by the river Po, to the east by the Adriatic sea, and to the south and west by the Apennine mountains. Since man first colonised this corner of Italy, he has complained that the earth, although rich and generous in other ways, yielded water only sparingly.

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Yet strams and marshland are there in abundance. What is missing is good potable water. The Romans built an aqueduct from the Romagna Apennines to the harbour at Ravenna, the old capital of the Western Roman Empire, renowned for its Byzantine churces and now a rich industrial centre. In the Middle Ages, more aqueducts were built to bring precious water to the lords and princes of the plain. There is a saying about this chronic shortage of water. It was told to travellers on the long road to the sea: "You can find out where you are during your journey, just ask for a drink. If you are given a glass of water, you are in Emilia, when you get a nice glass of wine, you have arrived in Romagna". Over the years, neglect and carelessness led to the idea of a pipeline bringing pure water from the Apennine springs being forgotten. But a start was made at draining the Romagna plain at the start of this century, when it was still a vast stretch of marshland and ponds infested with with typhus and malaria. The economic and social structure quickly changed. Faced with rapid growth in population and agricultural development, water was pumped from underground and thousands of artesian wells were opened. The water was not very good but rich in mineral salts and needed for domestic consumption and crop irrigation. Nobody suspected at that there would be a problem with ground subsidence. In the nineteen-fifties, with growing water demand from industry and increasingly intensive farming, groundwater abstrastions became excessive in quantity and rate, causing seawater to encroach into the water tables. To prevent this reaching catastrophic proportions, there had to be a stop to abstractions and another way found of providing the population with water. Parched Romagna therefore looked at the Ridracoli dam project to provide a better quality of water and remedy the deterioration of this scarce resource (pollution of Romagna river channels, unbalanced groundwater depletion/replenishment in the Ravenna plain, with attendant subsidence). All politicians were unanimous in considering the possibility of building a mountain reservoir. In 1966, most of the districts in Romagna joined the Consorzio Acque per le Province di Forli e Ravenna which, in 1994, after a long period of reflection, was made into a joint stock company. The new Romagna Acque S.p.A., most of whose shares were owned by the public, but oper to capital from Italian and foreign private companies and bodies, was preparing to become a "Public Company".

3. PROJECT

3.1 Construction

Preliminary design work for the Romagna Aqueduct dates from the sixties. In 1968, the project was incorporated into the Aqueduct Urbanism Plan adoptedby the Italian government. Funding was accelerated and construction began. Dam construction commenced in 1975 and was completed by 1982.

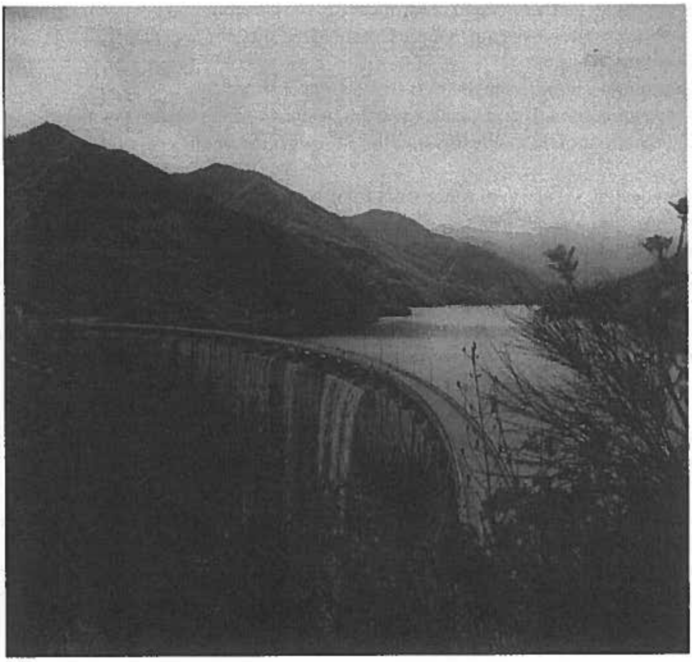

Fig. 1. View of Ridracoli Dam.

While the storage works were proceeding, tenders were received for the other construction contracts for the water supply system. The decision to site the dam at Ridracoli on the Bidente river in the Romagna-Toscana Apennines was due to (i) its central position dominating the service area, (ii) the morphology and structure of the impervious geology capable of holding the (30 hm^3) of water required, (iii) complete lack of residential and industrial buildings and roads, (iv) absence of factories liable to pollute the water, even in the abstraction areas, (v) excellent water chemistry and temperature for domestic supplies, and (vi) surrounding mountains clothed almost entirely with mature trees and thickets preventing erosion and siltation and thereby promising a long economic lifespan for the dam. In view of the size of the project, the Romagna Aqueduct works were split up into five Contracts:

1) Dam and appurtenant works
2) Diversion tunnel, surge chamber and pressure tunnel, forebays and 33 Km of main pipeline

3) Water treatment works and control centre, remote control system for dam and water distribution system, Monte Casale reservoirs at the centroid of the distribution system
4) Distribution lines to the districts in the Consortium
5) Catchwater tunnels and canals diverting water from the Campigna and Fiumicello mountain streams into the Ridracoli reservoir.

The first design did not take water from Fiumicello stream in a neighbouring valley, but from a small tributary to the Bidente, Strabatenza stream, but this was discarded in order not to increase abstractions from a single catchment; it was decided to divert water from a nearby stream, the Fiumicello, into Ridracoli reservoir. This decision was found, post facto, to be an excellent choice. The dam is a double-curvature concrete structure, symmetrical about the crown, sitting on a foundation slab running along the excavation profile, of variable thickness. It is built as 27 cantilevers with near-vertical joints. An instrumentation system was installed to monitor the behaviour of the dam and foundation rock during construction. It monitors temperature, internal strains, displacements, permeability, uplift and pore pressures. Other instruments record micro and macro-seismic events for real-time comparison with best-case data, through a sophisticated electronic system. Upstream of the water treatment plant not far from the dam, there is a hydro-electric powerstation built and operated by ENEL, the national electricity supply body, harnessing a mean head of 220 m and generating approximately 35 GWh per year.

3.2 Results

In 1988, after thirteen years work, water first poured from the taps in homes in Forlì, cool as spring water. Today, the system, now in full swing, meets the following demand:

- The time-old water demand from the Romagna catchment is finally satisfied. Water from Ridracoli lake arrives punctually and conveniently in the homes of more than a milion people in 50 districts in the three provinces of Forlì, Ravenna and Rimini, and in the Republic of San Marino. The Romagna pipeline can supply some 63 hm^2 of water and will shortly reach 90 hm^3. Without it, Romagna would have suffered a very serious domestic water supply crisis over recent years and most districts would have suffered from harmful contaminants.
- Some 60 GWh energy is produced and saved each year, since water from the reservoir is brought to homes by gravity over various changes in level. Previously water was pumped from depths of up to 300 m into reservoirs or directly into the distribution system.
- The environmental damage (subsidence and salt water encroachment) which plagued Romagna for so long because of groundwater depletion has been controlled. This also had serious effects in economic terms, especially on

tourism in the coastal areas and on the historical and artistic heritage, as in the city of Ravenna.

Damage was successfully controlled by diverting only 23 per cent of the Bidente's flow. The overall effect is therefore amply positive for the environment.

4. ENVIRONMENTAL ISSUES

4.1. Problems

It is normal for a project of such scope to have political, economic and environmental repercussions. In Italy in the sixties and seventies, when the Ridracoli project was taking shape, there were no standards controlling the impact of dams on the environment, and there was a reaction from conservationists who by then had become a political force. To this was added the reaction of the population living downstream of the dam. Argument focused on alleged dangers to the public. Protesters feared river depletion and geological and climate changes. They predicted certain disaster for the environment, declining population numbers and a deteriorating socio-economic situation over a vast area in the mountains and foothills. The local WWF office took the matter to the courts to try to stop construction on safety grounds. Romagna Acque managed to overcome the legal problem by submitting analyses from university specialists and providing safety monitoring and control systems for building the works. At a time when environmental issues were still undefined, Romagna Acque had a very positive attitude. It did not confine itself to justifying the project alone, it expressed its will to look deeper and compare its own ideas with those of the local authorities, conservationists and residents on an on-going basis. It continually cross-checked its decisions and offered adequate changes to satisfy its opponents.

4.2 Solutions

In the adversarial atmosphere of the last few years, Romagna Acque based its position on three sound principles:

a) Careful monitoring of the project to control the environmental impact of the dam, with a commitment to giving top priority to public safety.
b) Constructive, rigorous management of the dam, water resource, and land upstream and downstream.
c) Lively interest in social, cultural and economic development in the valley, by capitalising on the resources in the area and the dam and aqueduct, by making them a centre of attraction through their engineering importance.

In this way, there gradually emerged the "Dam and Landscape" project, or "Solidarity Pact" berween man and the environment, between the population and institutions in the plain, between the population and institutions in the mountains. This meant problems could be gradually overcome, a major public works exercise was completed in record time, and significant environmental and social benefits were procured.

4.2.1. Countryside

The dam lies in the upper Bidente valley in the Apennine mountains, the beauty of the ladscape residing in the wooded mountains. Besides the pines and firs forming the main local forest geritage, there are chestnuts, various varieties of oak and beech, some several hundred years old. Lama Forest and Sasso Fratino Nature Reserve undere the aegis of the United Nations, the heart of the Monte Falterona National Park, Campigna and Casentinesi forests, are home to many species of large and small animals including a particular species of newt, freshwater shrimp, salamander, snake, frog, and viper as well as wolves, foxes, stoats, dormice and weasels, buzzards, eagles, wild boar, and various kinds of deer and other ungulates. Once the dam had been built and reservoir filled, it was urgent to repair the scars on the mountainside, encourage abundant plant growth to blend the dam into the landscape, and consolidate the banks upstream and downstream of the dam in a multi-year programme. By finding funds from its own resources to finance the projects of national and regional forest management organisation, Romagna Acque was able to restore the landscape around the dam by planting trees, repairing retaining walls, paths, access and service roads, and refurbishing derelict old stone houses. The total cost was $US 750 000. At the present time, there are various other projects under consideration for re-afforestation, river works, and public footpath rehabilitation, costing $US 6 250 000; $US 1 550 000 has already been spent on bank protection downstream of the dam and on the Bidente. This is an on-going high quality approach which will eventually improve a vast area where population drain and lack of investment in soil conservation had led to worryng situation of deterioration and abandon.

4.2.2. Bidente River Development

Romagna Acque S.p.A. considered it important to improve the Bidente river area a s a positive response to criticism from the local authorities and public.

i) There were Ministry rules as to the amount of water that might be used for operating the powerstation and aqueduct, but Romagna Acque further imposed added restrictions on abstractions to maintain flow in the river in the summer dry season. All diversions from the river are stopped in summer, and an extra 200 litres/s is released to increase river flow by 30 per cent. This means a loss of 3 hm^3 of water and one million dollars per year income.

The same reasoning was behind the design decision not to divert water from the Strabatenza river on the same catchment, but to use the Fiumicello in the Rabbi river valley, despite the higher cost and a loss of 9 hm^3 inflow per year.

ii) In order to promote frank, transparent relations with the local public and authorities, Romagna Acque built a streamgauging station in the square of the first town downstream of the dam, which could be used by anyone to check river flow.

iii) In the interests of public safety, a thorough study was made of seismic activity in the region, and a scale model was made of the structures to ensure the design could withstand exceptional seismic shocks of a magnitude unknown elsewhere in the region, Italy or even Europe.

iv) Romagna Acque omitted nothing in undertaking the most thorough and stringent checks of the static performance of the dam and the influence of all physical phenomena on the reservoir. It also monitors the hydrological situation and the microclimate of the whole region. Working with ISMES, the central station collects all seismic and microseismic data, rainfall records, and water and concrete temperatures. Optical surveys monitor the deformations and displacements of the dam and reservoir rim.

v) All this goes well beyond what is required by law. To date, \$ 4 500 000 has been spent on installation and maintenance of around 800 continually-improved monitoring instruments. Permanent surveillance of the dam requires day and night attendance by eleven technicians and skilled men, at an annual cost of \$ 250 000. Maintenance of the instrumentation system requires the services of a specialist company at an annual cost of \$ 300 000.

4.2.3. Regional Social, Cultural and Economic Development

The following action is taken to promote social, cultural and economic development in the region.

i) *Saving Old Buildings:*
The old village of Ridracoli downstream of the dam was doomed to steady decline after nerarly the whole population had left, with derelict buildings collapsing, river banks deteriorating, and public amenities rotting. Romagna Acque has already restored the more important buildings and set up a programme for saving vestiges of public habitation in the upper Bidente valley with a view to attracting nature lovers. Tourist facilities have been provided for 200 persons, providing young people in the area with jobs that help to safeguard the countryside, maintain its infrastructure and preserve the ecological heritage. The tourist amenities cost \$ 1 850 000. This is included improving roads and drainage, a new bridge at Ridracoli, buinding car parks, pipelines, parks, sports facilities, and children's play area, at a cost of \$ 2 200 000. Where there was once the dam construction area near the old

village, there is now a new tourist centre with full amenities for visitors, who are becoming increasingly numerous.

ii) Dam as Factor for Environmental Conservation

The dam construction site was visited from the outset by specialists and officials from all parts of Italy and other countries. The dam was conceived as a centre of attraction to promote visits by students, private persons, social groups, Italian and foreign tourists. Guides are provided to let people see the true face of the environment around the dam and reservoir. This has developed into what is in effect a school, teaching respect for the environment, knowledge and conservation of plant and animal wildlife, and capitalising on water: a rambler's walk along the main aqueduct route, from the springs down to the cost, attracts 60 000 to 80 000 people annually, of which 20 000 are schoolchildren and students. A short length of reservoir shore has been opened to sport fishing although fish conditions are monitored and the area is regularly inspected to protect the water in the reservoir. The lake can also be visited by boat - with a non-polluting motor - and large numbers use it to enjoy the natural beauty of the shores.

iii) Cultural Centre

The natural resources in the upper Bidente valley and the rich technical heritage formed by the pipeline installations prompted Romagna Acque to institute a number of approaches to boost development of the region. Firstly, it set up the Ridracoli Natural Science Museum in the restored Giovannetti Palace. It contains reconstructions of typical environment for the vertebrates living in the Romagna Park. The cost of this exercise was $ 200 000. Another important project for future relations with the world of culture and university research is the Teaching Centre offering courses that supplement those available in universities, complete with a nearby 35-bed hostel and services. The cost was $ 1 250 000. The Teaching Centre, near Romagna Acque's Control Centre, stands between the dam and the nearest village downstream, and is surrounded by greenery. It is equipped with modern technical instruments. It has already hosted conferences at national and international level, and university courses, attended by senior personalities from the world of culture and research in water engineering, geology and the environment. The Centre is used throughout the year by university students for courses on ecology, public works, water engineering, water chemistry, computers and remote control. They are provided with special teaching aids and can observe the pipeline installations directly. Since the Centre opened, it has attracted several thousand students, teachers, and Italian and foreign scientists.

iv) Regional Development

Romagna Acque has been working continually with the local authorities in the valley to encourage economic and social development and attract inward migration into the area. Renovation of the main road in the valley was charged to the Project, together with land purchases, at a total direct cost of $ 1 060 000, plus aid in bringing methane gas supply to the upper Bidente valley. Many public fountains, supplied from the pipeline, were built in the main

Romagna towns. Sculptors and other artists with reputations spreading throughout Italy and the rest of the world, like Cascella, Somaini and Ghermandi, were commissioned for the fountains, all with the same theme: to send a message on water "stewardship", such a precious resource for the whole human race.

4.3. Multi-criterion assessment of dam impact

In order to have an objective assessment of the outcome of the environmental conservation effort, Romagna Acque approached university experts from the Rural Assessment and Accounting Institute of the University of Bologna and the National Research Council to undertake a scientific study of the environmental impact of the dam. Their work was reported (Q69, R33) in the Proceedings of the 18th Congress of the International Commission on Large Dams held in Durban in 1994. With the aid of an assessment model, they used qualitative indexes to examine the positive and negative impacts which the dam had on the surrounding countryside. They measured an "environment quality index" (EQI) for comparison with an estimate of the antecedent situation, before the dam was built. They also considered factors which are difficult to measure directly, such as air quality, human health, and social and cultural aspects. They adopted a non-monetary approach based on a two-step descriptive (qualitative and quantitative) method, with the use of maps, and an assessment model incorporating multiple criteria. Merging the two steps led to a hierarchical subdivision of the environment into three levels:

- Level 1 examines three domains: ecological, physical, socio-economic.
- Level 2 examines nine environmental components (three in each of the above domains).
- Level 3 introduces 63 environmental factors within the above components.

The "pre-dam" environmental quality index was set at 1000, followed by assigning a dimension calculated by the "pair-comparison" method. In brief:

i) The researches' report reached one very important conclusion. In term of the general environmental situation, the environmental quality index rose from 1000 (pre-dam baseline) to 1219 "post-dam", a 22% improvement.
ii) At level 1, the post-dam index rose in all three (ecological, physical, socio-economic) domains. There was a 50% rise in the socio-economic domain.
iii) At level 2, only two post-dam values out of the nine components drop below the pre-dam baseline: the "habitat-climate" concept which recorded 164,7 post-dam against 176 pre-dam, and the air component, which was 51 post- and 57 pre-dam. All the other components improved in all three domains. The performance of the regional production system rose from 89 to 148.6, a 67% improvement.

iv) At level 3, after analysing the 63 factors, the change between the pre- and post-dam situation is always positive with one exception: the "natural zones" factor drops after construction of the dam.

5. CONCLUSIONS

Romagna Acque amended parts of the design at the start of the construction work in order to mitigate the impact of the dam on the region. Today, the dam is operated with the same firm commitment to ensuring the best level of environmental and social improvement. This is a valid approach if one considers man capable of inducing positive changes in the local environmental balance and puts aside preconceptions about simply preserving nature, preconceptions which arose out of past irresponsible damage. The old way of seeing a man-made lake as just a place for storing water was an expression of indifference and insensitivity to the environment. People were only interested in exploiting a natural resource. Today, good management must defeat this logic and actively seek to develop environmental and social values, which contribute to improving lifestyles. Water is a source of riches which must be carefully preserved and used rationally. If this means building river development works, it is unjust to consider them blindly as causes of damage and disaster. Proper design, careful construction, careful sensitive operation can have outcomes that improve environmental balance in all areas, beginning with the human sphere.

EFFLUENT REUSE FROM A WASTEWATER TREATMENT POND IN NORTHERN COLORADO

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ABSTRACT

Global fresh water supplies continue to dwindle as world population approaches six billion. The demand for food and fiber also continues to increase. To meet the growing global food demand, ICID has projected an annual increase of 3 to 4 percent in crop production from irrigated agriculture. The above stated scenario has required the adoption of a holistic approach to water management.

Prevailing demographic movement toward urban areas coupled with the increasing coverage of both urban and rural populations for water supply and sanitation schemes have greatly increased the demand for fresh domestic water.

An appropriate and sustainable solution to the above stated predicament lies in the reuse of treated wastewater effluent for irrigation at a global scale using low cost, sustainable and appropriate technologies. Thus, freeing up precious fresh water for domestic use.

We are studying seasonal behavior of a wastewater treatment lagoon system located near Colorado State University. Depth profiles of the following water quality parameters are being studied in an effort to better understand the behavior and performance of this alternative wastewater treatment system under varying climatic conditions.

a) Dissolved Oxygen
b) Oxidation Reduction Potential
c) Temperature
d) pH
e) Conductivity
f) Salinity

The effect of various hydrologic and physiographic parameters such as wind speed, air temperature, solar radiation, site elevation and location on pond performance are also investigated.

INTRODUCTION

A look at the global fresh water demands, as shown in Fig.1., reveals that irrigation water consumption has been the highest when compared with water usage for municipal and industrial purposes. Rapid growth in population coupled with increasing industrialization has placed irrigation water demand in stiff competition with municipal and industrial usages of fresh water. Various entities have very aptly resorted to advocating and to adopting nonpotable uses of treated wastewater.

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Over the past few decades wastewater treatment ponds have stood out as an efficient and cost effective means of treating wastewater in regions where the climatic conditions are conducive to the operation of wastewater treatment ponds. The EPA design manual on wastewater stabilization ponds states that about 7000 wastewater stabilization ponds

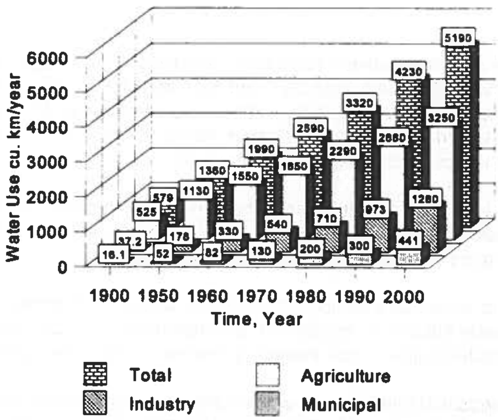

Fig. 1. WORLD WATER USE BY SECTOR (Gleick, 1993)

were in operation in the United States in 1983. Wastewater design publications issued by various multinational agencies draw upon experiences from ponds in regions with temperate to warm climate. This situation has created a very pressing need to study the design and performances of wastewater stabilization ponds in colder climatic regions. We have studied a wastewater treatment pond 5 miles east of Fort Collins, CO which lies on the western slopes of the Rockies.

CONCEPTS RELATED TO LAKES AND PONDS

The transport processes of momentum, heat and mass transfer take place between the lake and reservoir waters and their respective environment. Binder, 1958, has very succinctly summarized the equations governing the above stated transport phenomena for the three flow regimes. Binder's results are shown in Table 1.

Wetzel, 1975, has described the formation and decay of thermoclines in deep lakes and reservoirs. Thermal statification in lakes and deep reservoirs exhibits the formation of a thermocline after summer warming. Similar behavior can be expected in deep ponds. The thermal stratification model proposed by Wetzel is shown in Figure 2.

Table 1. Relations for Fluid Momentum Transfer, Heat Transfer and Mass Transfer (Binder, 1958)

	Fluid Momentum Transfer	Heat Transfer	Mass Transfer
Laminar sub layer	$\frac{\tau}{\rho} = \nu \frac{du}{dy}$	$\frac{q}{A \rho c_p} = -\frac{\nu}{Pr} \frac{dt}{dy}$	$N = -\frac{\nu}{Sc} \frac{dC}{dy}$
Trans-ition layer	$\frac{\tau}{\rho} = (\nu + E_M) \frac{du}{dy}$	$\frac{q}{A \rho c_p} = -(\frac{\nu}{Pr} + E_H) \frac{dt}{dy}$	$N = -(\frac{\nu}{Sc} + E_F) \frac{dC}{dy}$
Turbu-lent layer	$\frac{\tau}{\rho} = E_M \frac{du}{dy}$	$\frac{q}{A \rho c_p} = -E_H \frac{dt}{dy}$	$N = -E_F \frac{dC}{dy}$

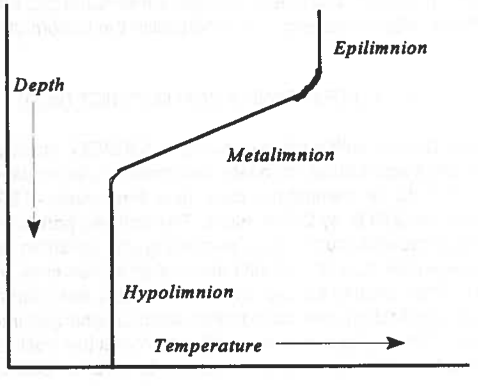

Fig. 2. Lake Thermal Stratification Model (Wetzel, 1975)

Lewis, 1983, has developed a scheme to classify deep lakes and reservoirs in different settings, see Table 2.

Table 2.Pond Classification Scheme (Lewis, 1983)

Pond Type	Description
Amictic	Always ice covered
Cold Monomictic	Ice covered most of the year, ice free during warm season but does not warm above 4°C.
Continuous Cold Polymictic	Ice covered for part of the year, ice free above 4°C and stratifies during warm season at most on a daily basis.
Discontinuous Cold Polymictic	Ice covered part of the year, ice free above 4°C and stratifies during warm season for periods of several days to weeks but with irregular interruption by mixing.
Dimictic	Ice covered part of the year and stably stratified part of the year with mixing once each year.
Warm Monomictic	No seasonal ice cover, stably stratified part of the year, and mixing once each year.
Discontinuous Warm Monomictic	No seasonal ice cover, stratifying for days or weeks at a time, but mixing more than once a year
Continuous Warm Monomictic	No seasonal ice cover, stratifying at most for a few hours at a time.

Oswald et al, 1994, have described the Advanced Integrated Wastewater Pond System (A.I.W.P.S.) which is in operation in Richmond, CA. The A.I.W.P.S. system employs a battery of ponds arranged in a combination of series and parallel to treat wastewater. The first pond in the series is the Advanced Facultative Pond (AFP) which is an earthen pond with a depth of 3m. It has 2m to 3m deep sludge fermentation pits built in its bottom. The incoming raw influent, after screening, is discharged in the bottom of the fermentation pits.

BOXELDER SANITATION DISTRICT (BSD)

Boxelder Sanitation District, with a rated capacity of 1.5 MGD, employs four 10 ft. deep ponds in series to treat agricultural, domestic and commercial wastewaters, see Fig. 2. With side slopes of 3H to 1V, the first two cells have dimensions of 200 ft. by 200 ft. each. Cells three and four are 245 ft. by 200 ft. each. The first two ponds are aerated by six 15 HP aerators. Cells three and four function as settling and polishing lagoons respectively. Based on an average daily flow of 1.64 MG the total detention time, of the system, is 10 days (TEC,1993). After passing through the fourth lagoon, the effluent is guided through chlorination and dechlorination chambers before being discharged into the Poudre River via Boxelder Creek. Thus, properly treated effluent from a low cost alternative wastewater treatment system is in use downstream both for potable and non potable purposes.

Effluent discharge standards set forth for BSD by Colorado Department of Health (CDOH,1991) are listed in Table 3.

Table 3. Discharge Limitations: Maximum Concentrations

Effluent Parameter	30 day Avg.	7-Day Avg.	Daily Max.
Flow, LPD	$5.67*10^6$	N/A	Report
BOD_5 mg/l	30	45	N/A
TSS mg/l	75	110	N/A
Fecal Coliform number/100ml	3710	7420	N/A
Total Residual Cl mg/l	N/A	N/A	0.008
pH min.-max.	N/A	N/A	6.5-9
Oil and Grease mg/l	N/A	N/A	10

<u>Site Description</u>

Figure 3 shows the layout of Boxelder wastewater treatment ponds.

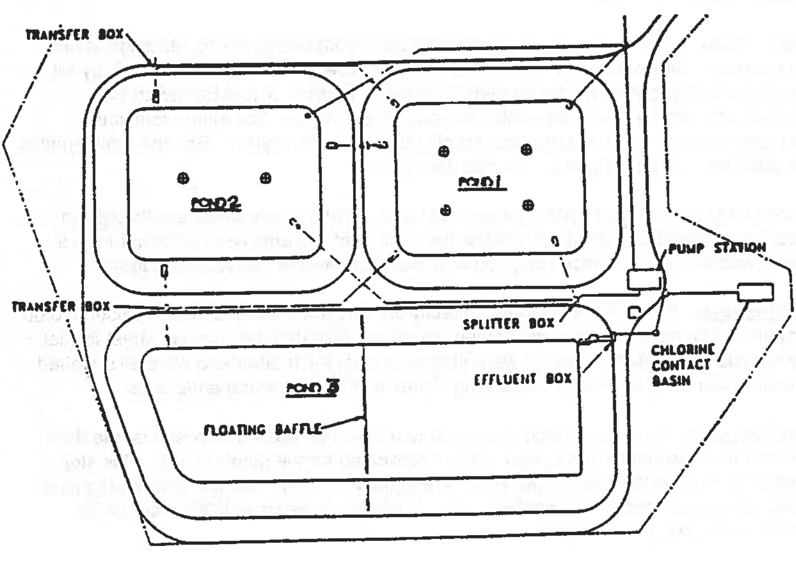

Fig. 3. Boxelder Wastewater Treatment Ponds (TEC, 1993)

<u>Data Collection</u>: Pond number 3 was chosen to collect data of six water quality parameters because the quiescent nature of the pond enabled us to obtain depth profiles

of the parameters under investigation.

A quarter inch diameter cable was stretched across pond three at two thirds distance from the pond inlet. Five equally spaced stations were marked on the cable in order to collect water quality data which may be closely representative of the entire pond. A plan to collect water quality data was chalked out on a frequent basis and regular data collection was conducted from June 1995 through December of 1995 to monitor the effects of summer warm up, fall cooling and winter freeze. Data were collected at various times in order to accommodate for the effect of the time of day on the water quality parameters collected. From January 1995 to May 1995 depth profiles were obtained once a month only at one location in pond 3. As ice had formed on the pond surface in December and stayed till late February it was assumed that the effect of climatic changes was very negligible. So during winter and for the spring thaw period, data taken once a month were deemed representative of the month under investigation.

Data for the following water quality parameters were collected using a Hydrolab, model H20, water quality probe.
1)Temperature (T)
2)pH (pH)
3)Oxidation Reduction Potential (ORP)
4)Conductivity
5)Salinity
6)Dissolved Oxygen (DO)

Depth profiles of the above stated parameters were obtained by taking readings at one foot intervals. Data collection was carried out by a crew of two persons in a 8 ft. by 4ft. fiber glass boat provided by the Boxelder Sanitation District. A reel borrowed from U.S.G.S. was used to lower the probe and record the depth. The instrument was calibrated before each data collection for pH and dissolved oxygen. Routine maintenance and calibration of the pH probe was also carried out.

Historic meteorologic and hydrologic data of various parameters which are thought to influence performance of natural wastewater treatment systems were obtained from a nearby weather station which complied with National Weather Service standards.

<u>Data Retrieval</u>: Field data were saved directly on the hard drive of a 386SX Epson laptop computer. The next step involved conversion of raw field data into spread sheet format. The various parameters collected were plotted against each other and were also plotted for spatial variability to look for underlying trends and their inter-dependencies.

<u>Data Reduction</u>: Data have been converted to a biweekly spaced time series, the data collected from January 1995 to May 1995 is replicated for the same month. This step enables us to have 26 sets of data which are equally spaced. The biweekly space time series have been created by dropping July 31, which leaves us with 364 days or 26 periods which are 14 days apart.

The 14 days spaced time series has been created and the effect of seasonality on the variables gathered over the year is being examined. Variables exhibiting considerable temporal and spatial variability have been retained and the variables remaining constant were eliminated. Eventually a composite temporal and spatial series of the significant water quality variables have been created. The layout of pond number 3 is shown in Fig. 4.

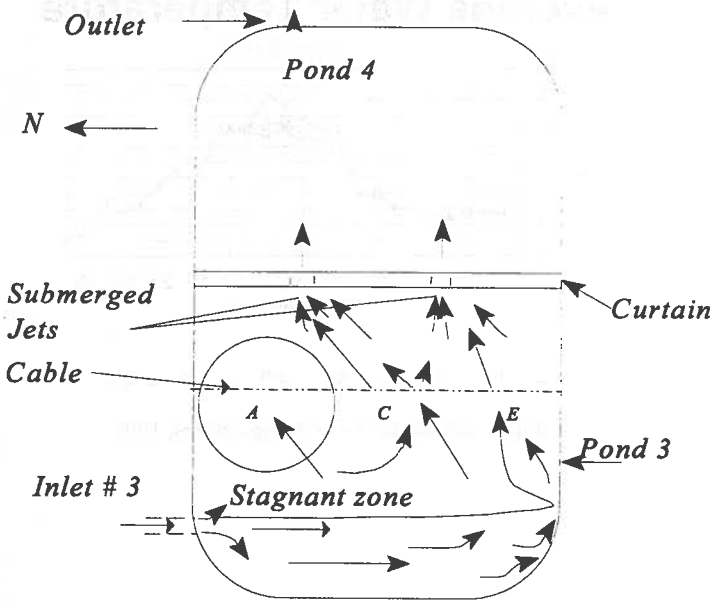

Fig. 4. Plan View of Ponds 3 and 4, Boxelder Sanitation District

SALIENT OBSERVATIONS

Out of the six parameters monitored, water temperature, dissolved oxygen, oxidation reduction potential and pH displayed either stratification or sudden surges or dips. Time series of the above mentioned parameters at six depths and their depth profiles are shown in figures in the following sections.

Water Temperature: Water Temperatures at various depths showed very little variance between surface and bottom temperatures for most of the year. During the summer warming trend a temperature difference of almost 7° C occurred between the surface and bottom waters. At the time of fall cooling the temperature depth profile became almost isothermal. The set-in of severe winter showed colder water to lie on top of warmer water. Figure 5 shows the biweekly time series of water temperatures measured at six depths. The temperature depth profiles are shown in Figure 6. The formation and destruction of a thermocline can be understood from Fig. 6.

Temperature stratification became maximum on 7-26-96 and by mid August the pond started to turn isothermal. So between the periods of warming and cooling a turnover due to density stratification took place. Which led to oxygenation of bottom waters.

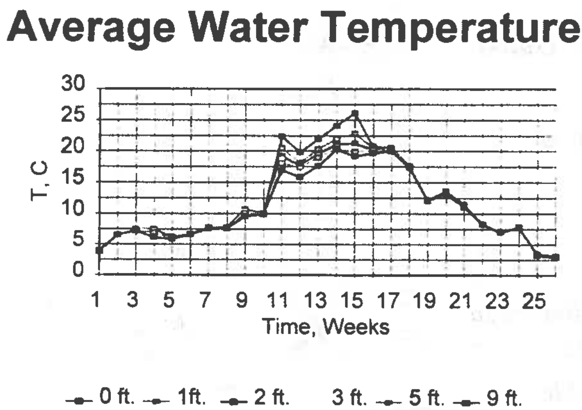

Fig. 5. Biweekly Water Temperatures, 1995

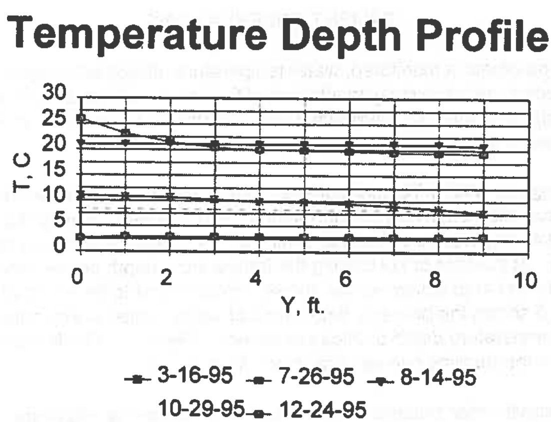

Fig. 6. Depth Temperature Profiles, Pond 3

Dissolved Oxygen: Dissolved oxygen concentrations showed three periods of significant peaks. During summer a three week critical period was noticed when the entire pond turned anaerobic. There were also a couple of individual instances when dissolved oxygen concentration went to zero. Figure 7 indicates the time series of dissolved oxygen concentrations over six depths Examination of depth profiles of dissolved oxygen (D.O.), reveals that for most of the time dissolved oxygen near the pond surface was the highest and the D.O. went towards zero near the pond bottom. There was an occasion when super saturation occurred in the pond. Figure 8 shows some typical dissolved oxygen versus depth (Y) profiles.

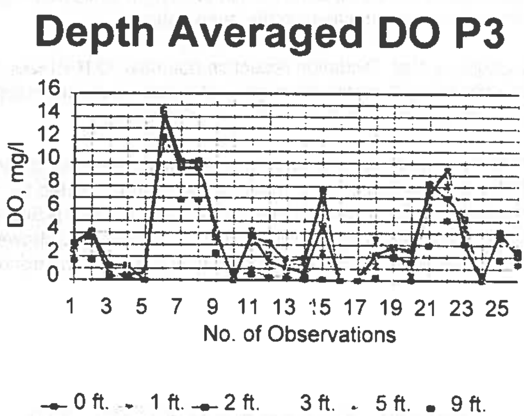

Fig. 7. Biweekly D.O. Concentrations, 1995

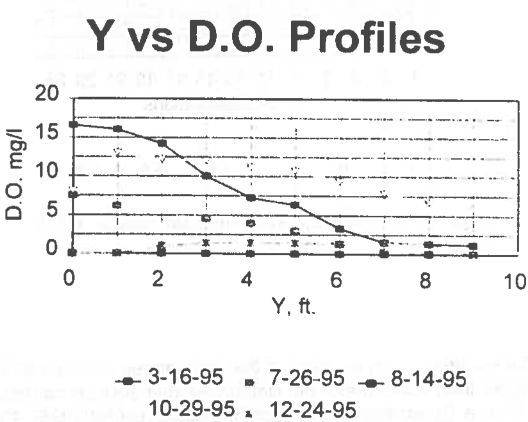

Fig. 8. Depth D.O. Concentration Profiles, 1995

With the spring thaw of March, the surface layers of the pond become richly oxygenated. The pond bottom still remained anaerobic due to the organic material accumulated at its bottom. As the summer heating progresses, the solubility of oxygen in water decreases and the pond starts to turn anaerobic as shown by the depth profile of 7-26-95. The entire pond soon turned anaerobic and remained anaerobic till 8-14-95. Wind induced reaeration coupled with falling temperatures caused the pond to once again become aerobic. By 10-29-95 the entire water column had become highly aerobic. Once the ice cover was formed in December, both surface and bottom pond waters exhibited zero dissolved oxygen concentrations. This was primarily due to the fact that as surface waters lay under a thick layer of ice they could not get reaerated from atmospheric oxygen. Whereas bottom waters became devoid of oxygen while meeting the oxygen demands organic material accumulating in the pond bottom.

<u>Oxidation Reduction Potential</u>: Oxidation reduction potential (O.R.P) was the only parameter which showed stratification throughout the year at various depths of the pond. Figure 9 shows oxidation reduction data plotted for six depths.

For a major part of the year the existence of an anaerobic layer was observed only at pond bottom. This indicated that organic material was being digested by anaerobic bacteria. In late spring the O.R.P values rose significantly to the positive side of the ORP scale. It is noticeable that during the same period D.O. values also showed a spike mostly due to wind reaeration and also due to a continuous warming trend.

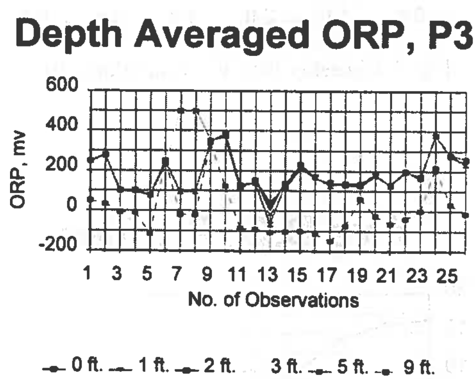

Fig. 9. Biweekly Redox Potential Series, 1995

<u>pH Readings</u>: The readings of pH for most of the time ranged from 6.5 to 7.6. Some times they got higher than 8 and under the December ice cover pH values as low as 4.38 were recorded. Figure 10 represents the depth profiles of pH for 1995. The pH

stratification was more pronounced between the pH values at the pond bottom to those in the water layers near the pond surface. There were zones of pH with a pH range of 6.8 to 7.2, which is considered conducive for anaerobic activity. Such anaerobic activity conducive zones were found mostly at and near the pond bottom. The most interesting phenomenon occurred soon after ice formation when the pond started to turn acidic for a brief period. This behavior may be due to the nature of the influent reaching the pond.

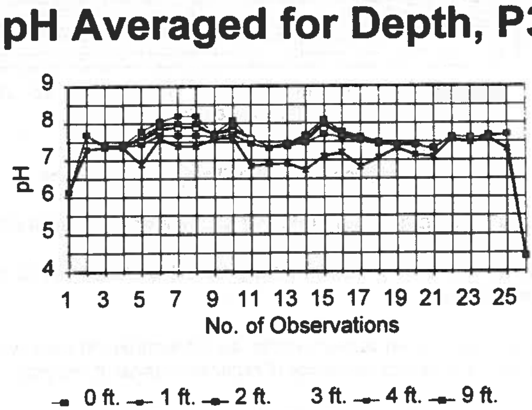

Fig. 10. Biweekly pH Series, 1995

DISCUSSION

The water quality parameters monitored at Boxelder provide us very useful information which may be applicable to ponds located in similar climatic and physiographic regions in other parts of the world. Two distinct periods of oxygen mixing were observed. The first reaeration season started after the ice thaw from middle spring and lasted till mid-summer. The second distinct mixing period occurred in late fall after the fall cooling set-in and it intensified in season of severe winter. In between the two mixing seasons the entire pond became devoid of oxygen from the third week of July till August 15, 1995. This behavior can be classified as dimictic. Also sudden peaks in the values of dissolved oxygen can be attributed to occasional strong gusts of wind, which can also cause mixing and circulation.

Also in December the temperature of surface water was noted to be lower than the temperatures in the pond bottom. This temperature distribution is contrary to the pond water temperatures during summer, spring and fall seasons. Thus the reversal in temperature gradient is most likely to be accompanied by circulation caused by density stratified water. When surface water temperatures approach 4° C, the heavier water at the surface, which was rich with dissolved oxygen, plummeted to the pond bottom destroying the anaerobic zone at the pond bottom. Hence the sludge digestion ability of

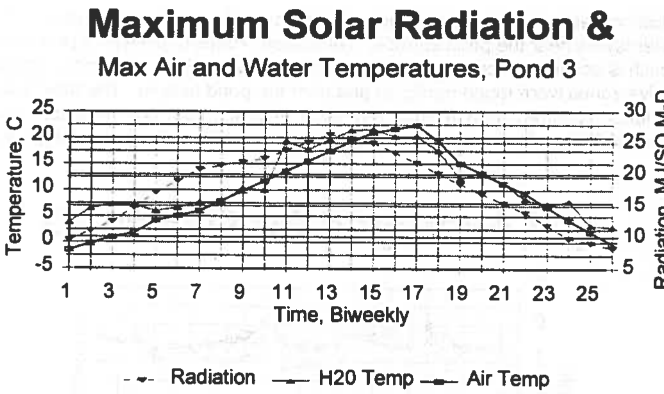

Fig. 11 Maximum Radiation, Air and Water Temperatures, 1995

the anaerobic bacteria in the pond bottom is significantly reduced due to the destruction of the anaerobic environment.

Decreases in dissolved oxygen concentrations during summer, in early winter and after spring thaw can be attributed to the decay of organic material at the pond bottom.

Very little temperature variation, except for mid summer to early fall, was exhibited by pond waters. The period from late July till early September showed stratification in top and bottom water temperatures in the pond. It was during this same period the entire pond tumed anaerobic. In fact the formation and decay of a thermocline can be seen over the year being studied.

It is noteworthy that the Northern Hemisphere receives maximum radiation in June. In Fort Collins, July is the month with maximum monthly air temperatures. Pond water temperatures also peaked in late July. The lag in temperature represents the response time to heating caused by solar radiation and warmer air temperatures carried out through the processes of radiation, conduction and convection. The lag in signal response time is representative of underlying physical phenomena which is a subject of investigation. Figure 11 shows the values of solar radiation, air and water temperatures plotted at fourteen day intervals for 1995.

The above discussed pond behavior suggests the following transport processes take place between the pond waters and their environment:
1) Momentum Transfer
2) Heat Transfer
3) Mass Transfer

Thermal statification in lakes and deep reservoirs exhibits the formation of a thermocline after summer warming. Similar behavior can be expected in deep ponds. It is suggested to adopt classification schemes for wastewater treatment ponds similar to the lake classification scheme developed by Lewis, 1983, as shown in Table 3. This will enable us to predict the behavior and performance of wastewater treatment ponds for different climatic, geographic and hydrologic settings. Thus the entire water and sanitation sector can benefit by the adoption of deep wastewater treatment ponds.

CONCLUSIONS

The data collected indicate that anaerobic sludge digestion is interrupted several times during the year. As an alternative to ensure continuous anaerobic conditions to prevail in the pond bottom it is recommended that:

1) Ponds should be built deep.
2) Deep circular pits should be provided in the bottom of the pond to receive raw influent.
3) Each circular pit should have a protective wall around it to prevent oxygen rich water from entering the pit where anaerobic conditions prevail.
4) To help prevent oxygen rich denser water from plummeting into the receiving pit it is recommended that a gas collector should be placed over the pit, as shown in Fig. 12 .

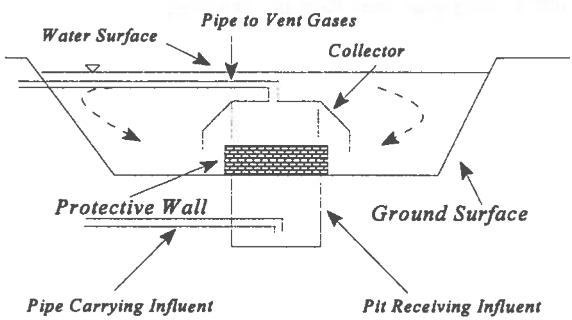

Fig. 12. Wastewater Stabilization Pond with Gas Collector

REFERENCES

Binder, R.C. (1958), Advanced Fluid Mechanics, Vol.2, Prentice Hall, Inc. Englewood Cliffs, N.J.

CDOH, (1991), Discharge Permit Issued. 11-1-1991 CDOH

EPA , (1983), Municipal Stabilization Ponds: Design Manual, EPA-625/1-83-015, U.S.E.P.A., Washington D.C.

FAO, (1985), Treatment and Use of Sewage Effluent for Irrigation. Editors: Pescod, M. B. and A. Arar, Proceedings, FAO Seminar on treatment and use of sewage effluent for irrigation. Nicosia, Cyprus, Oct. 7-9, Butterworths, London, England 1988.

Gleick, P.H. (1993), Water in Crisis, Oxford University Press.

Godfrey, S. (1996), Characteristics of a Wastewater Treatment System in Cold Climate, M.S. Thesis Submitted to Colorado State University.

Lewis, W.M. (1983), A Revised Classification of Lakes Based on Mixing, Canadian Journal of Fisheries and Aquatic Sciences, Vol. 40, No. 10, pp 1779-1793.

Oswald, W.J. et al, (1994), Performance of Methane Fermentation Pits in Advanced Integrated Wastewater Pond System, Proceedings, IAWQ Seventh International Symposium on Anaerobic Digestion, January 23-27, Cape Town, South Africa.

TEC, (1993), Report: Boxelder Treatment Capacity.

U.S.G.P.O, (1979), Dissolved Oxygen Depletion and Other Effects of Storing Water in Flaming Gorge Reservoir, Wyoming and Utah, Geological Survey Water Supply Paper 2058.

Wetzel, R.G. (1975). Limnology, W.B. Saunders Company.

WATER OPERATIONS ON THE PECOS RIVER, NEW MEXICO AND THE PECOS BLUNTNOSE SHINER, A FEDERALLY-LISTED MINNOW

By Lori Robertson[1]

ABSTRACT

To fill a recently-completed reservoir in southeastern New Mexico, all 1989 water deliveries within a 150-mile reach of the Pecos River were condensed into an 8-week period. This operation created a situation that transported Pecos bluntnose shiner (bluntnose shiner) eggs/larvae into the downstream reservoir and exacerbated intermittency and longterm drying of the river channel during the ensuing summer (the state of New Mexico does not recognize in-stream flow as a beneficial use). Because of its responsiblities under the Endangered Species Act of 1973, the U.S. Bureau of Reclamation (Reclamation) entered into consultation with the U.S. Fish and Wildlife Service. In an effort to avoid jeopardizing the continued existence of the bluntnose shiner, Reclamation is funding a 5-year research program. Its purpose is to determine life history and habitat requirements of bluntnose shiner, to develop a hydrologic model for Pecos flows, and develop operational guidelines for water deliveries which will protect native fishes, assist in recovery of the bluntnose shiner, as well as efficiently deliver water to downstream users. Since 1992, modifications of traditional irrigation release structure, duration, and timing have been incorporated into release scenarios for the purpose of studying their effects on fish communities, river channel morphology, aquatic habitat, delivery efficiencies, travel times, etc. Results of the study will assist Reclamation in developing a water operations plan that will benefit the bluntnose shiner without significant effects to downstream irrigators.

BACKGROUND

The U.S. Bureau of Reclamation (Reclamation) was authorized by Congress to construct Brantley Dam to replace McMillan Dam and Reservoir which had filled with sediment and to provide additional downstream flood control protection. Brantley Dam provides irrigation storage and facilitates deliveries

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for the benefit of the Carlsbad Irrigation District (CID). Reclamation is the federal agency responsible for irrigation releases on the Pecos River but has contracted day-to-day operations of Brantley Dam and Sumner Dam upstream to CID. At the request of CID, the U.S. Army Corps of Engineers (Corps) releases irrigation water from Santa Rosa Reservoir, upstream of Sumner Reservoir. Downstream of Brantley is Avalon dam which is a small reregulating reservoir for direct delivery of water to CID's system. Total irrigation storage for CID among four reservoirs on the middle Pecos River is 176,500 ac-ft. The reach from Santa Rosa to Carlsbad is shown in Fig. 1.

In 1987, the Pecos bluntnose shiner (bluntnose shiner) was listed as a federally threatened species under the Endangered Species Act of 1973 with critical habitat designated in two approximately 60-mile reaches between Fort Sumner and Artesia, New Mexico. In 1989, in order to fill newly-completed Brantley Reservoir, downstream water deliveries for the year were made within an 8-week period between April and early June. This action created a situation that transported bluntnose shiner eggs and larvae into Brantley and exacerbated intermittency and longterm drying of the river channel during the ensuing summer. Because of Reclamation's responsibilities under the ESA, Reclamation thereafter consulted with the U.S. Fish and Wildlife Service (Service) and concluded in a biological assessment of Pecos River water operations that deliveries like that of 1989 may affect the continued existence of the bluntnose shiner. In 1991, the Service issued a biological opinion stating that Reclamation's Pecos River operations may jeopardize the continued existence of the bluntnose shiner.

OUTCOME OF CONSULTATION

The outcome of consultation with the Service was the signing of a Memorandum of Understanding (MOU) between CID, the New Mexico Department of Game and Fish, the Service, and Reclamation in January 1992. The MOU's purpose was: (1) to release, monitor, and protect flows of the Pecos River from Santa Rosa Dam to Brantley Reservoir, and (2) to analyze the effects of those flows on native ichthyofauna of the Pecos River. Reclamation was required to fund a 5-year study to (1) determine the biologic and hydrologic needs of the bluntnose shiner; (2) develop a computer model to evaluate the effects of various operational schedules on surface flows in downstream habitats; and (3) develop operational guidelines for Pecos River operations which will protect, maintain, and assist in recovery of the species and the associated native fish community and efficiently deliver water for consumptive uses.

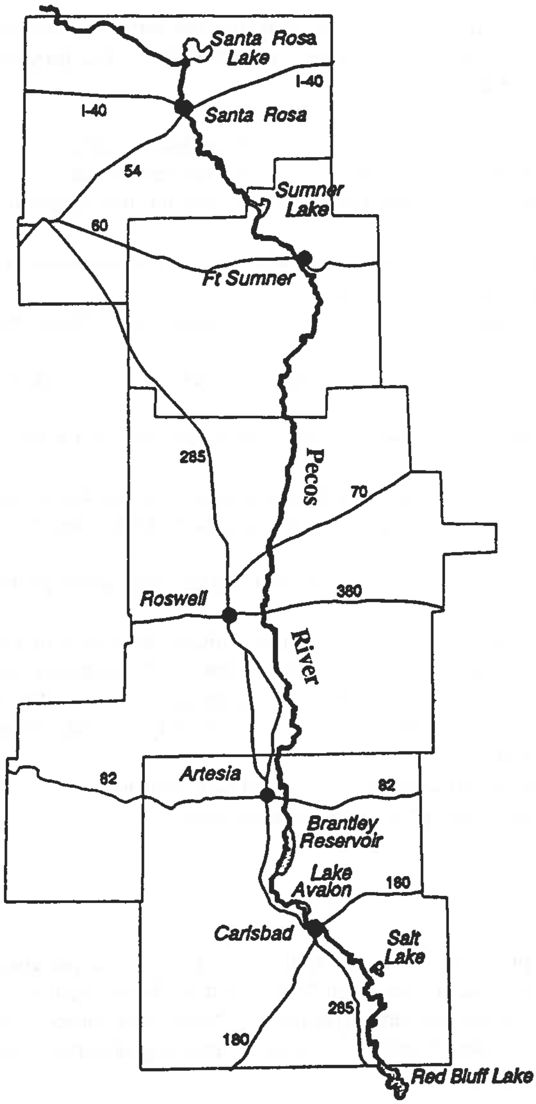

Fig. 1. Middle Pecos River in eastern New Mexico.

FIVE-YEAR STUDY PROGRAM

A multi-agency research group (research team) was formed, and specific research needs were identified. These are listed below. The program of study was initiated in 1992.

1. Determine the distribution and abundance of fishes.
2. Characterize life history of Pecos bluntnose shiner.
3. Evaluate the relationship between flow and native and non-native larval fishes.
4. Prepare description of early life history developmental series of Pecos River larval fishes.
5. Determine the effects of riverine habitat intermittency on resident fishes.
6. Determine the effects of non-native fish species on the native fish community.
7. Identify spatial and temporal habitat use patterns for fishes at varying flows.
8. Quantify available aquatic macrohabitats at varying flows.
9. Identification, verification, and curation of adult and larval fish samples.
10. Quantify stream channel characteristics using aerial photography and videography.
11. Develop an operations model to evaluate the effects of various operational schedules on surface flows in downstream habitats.
12. Characterize water quality seasonally and at varying flows.
13. Determine the presence/extent of contaminants and affects on resident fishes.
14. Develop and maintain a computerized database.
15. Develop management recommendations.

WATER OPERATIONS

Actual hydrographs representing the range of hydrographs experienced on the Pecos River since 1932 are shown in Figs. 2 and 3. These include: 1) Pecos River prior to impoundment and regulation; 2) traditional "block" irrigation releases; 3) an extended "block" release to fill Brantley Reservoir; and 4) ramped releases for study purposes.

Prior to regulation, the natural hydrograph typically consisted of winter baseflows of 100-200 cfs, a high discharge spring runoff that varied in duration, and relatively short high discharge summer thunderstorm flows (see Fig. 2).

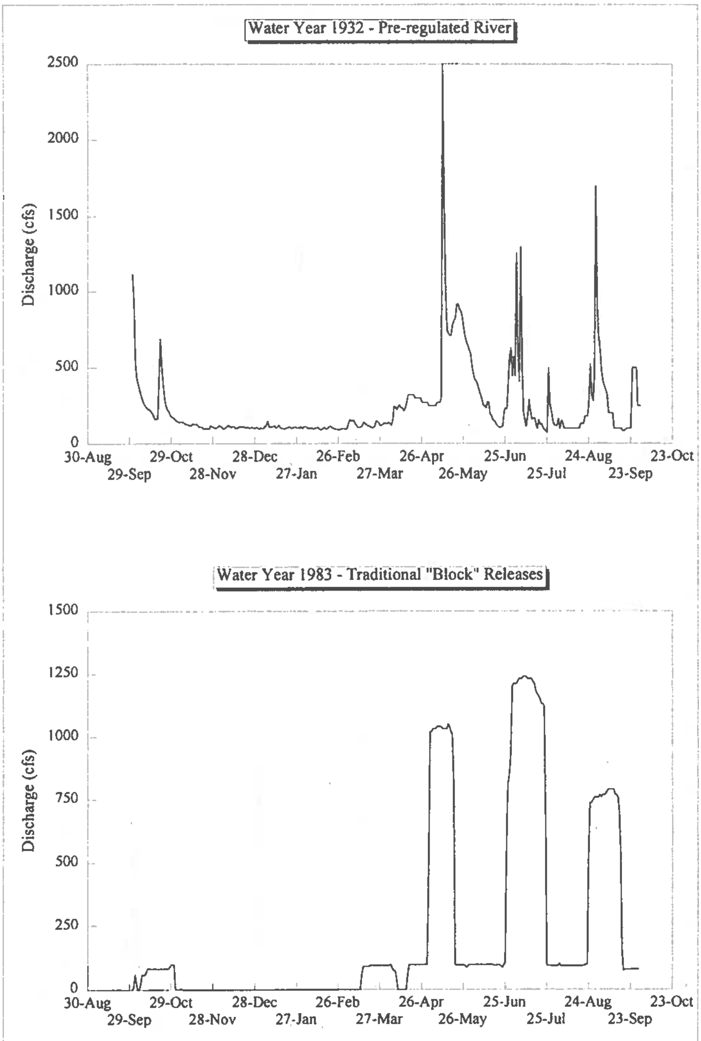

Fig. 2. 1932 hydrograph prior to impoundment and regulation and 1983 traditional "block" release pattern.

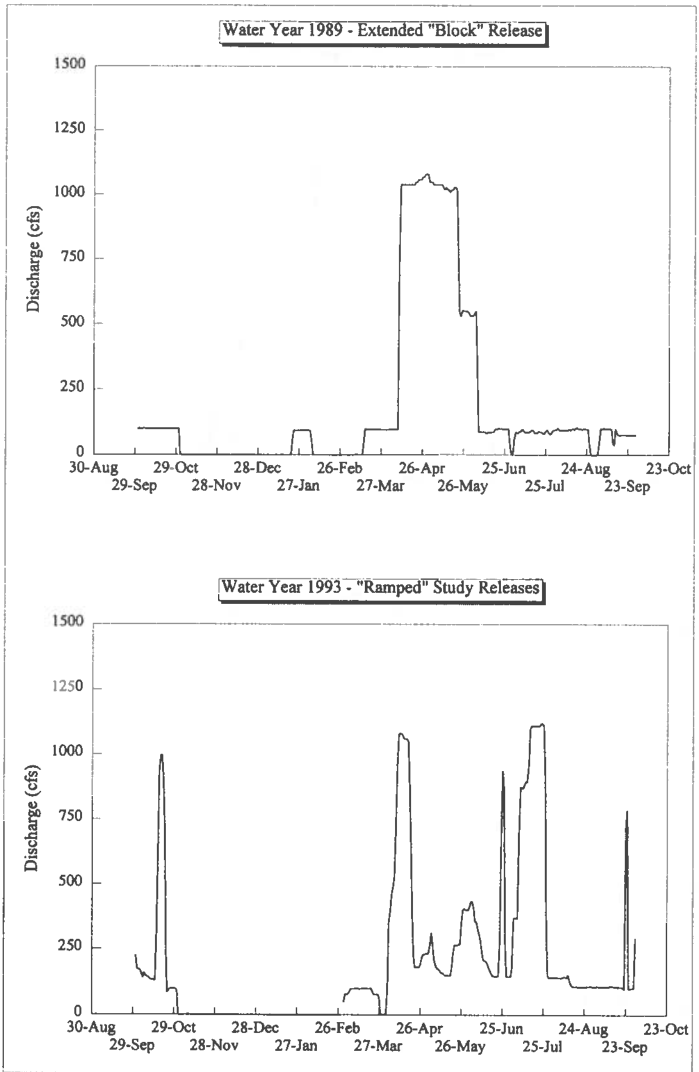

Fig. 3. 1989 extended block release for reservoir-filling and 1993 "ramped" release pattern for study purposes.

The rising and descending limbs of the natural peaks were usually gradual.

Since the construction of Sumner Dam in 1937, traditional water operations have generally consisted of the following. No water releases are made from Sumner during the non-irrigation or winter season that begins November 15 of each year. Beginning February 15, a continuous release of 80-100 cfs is made to supply Fort Sumner Irrigation District (FSID) located approximately 10 miles downstream of Sumner Dam. A late-winter/early-spring release is typically made to increase volume and decrease the concentration of total dissolved solids in Brantley. During the irrigation season, from late-spring through early-fall, periodic "block" irrigation releases (from one to four releases) of 1,100 cfs are made from Sumner (see Fig. 2). The number of releases and their duration vary depending on water supply and demand. The duration of each release is usually 10 to 45 days. Throughout the irrigation season a release of 80 to 100 cfs is made to FSID. Summer rainstorms are common during July and August and provide short duration flows. During years when the summer storms are absent, the river becomes intermittent. Natural sustained inflows during winter keep much of the river wetted but are characteristically highly saline. In addition to the abovementioned irrigation releases, there have also been releases made recently for Pecos River Compact purposes as part of a forebearance program between CID farmers and New Mexico State Engineer Office.

The primary concern for the bluntnose shiner population involved the 1989 filling of Brantley with a 56-day continuous release of approx. 1,050 cfs from Sumner (see Fig. 3). Aside from this delivery, the only other release during the year was the 80-100 cfs release to FSID. The specific concerns were 1) transport of bluntnose shiner eggs and larvae downstream into unsuitable habitats and into Brantley; and 2) intermittent river conditions that occurred during the summer following the release. Traditional water operations also invoke concern for bluntnose shiner and other native species since they do not reflect the pre-impoundment hydrograph of an unregulated river.

Since the beginning of the five-year study, release scenarios from Sumner have been planned by MOU signatories in order to study a range of water operational alternatives. Initially, there was widespread agreement among the research team biologists that traditional "block" water releases may be detrimental to the bluntnose shiner, and that releases should be stepped or ramped to simulate a more naturally-shaped hydrograph. All releases prior to July, 1995 were ramped at ascending and descending limbs (see Fig. 3). Since then, researchers have studied traditional block releases without ramping. During the first 4 study years, irrigation releases peaked at the traditional maximum of approximately 1,100 cfs, but the maximum was increased above 1,200 cfs during the final study year to assess the effect of higher discharge on delivery efficiency and aquatic habitat. During winter, conditions of no-flow, temporary low-flow, and continuous low-flow were also studied.

HYDROLOGY AND GEOMORPHOLOGY

Water supply during the first 4 study years was above average and CID farmers were able to apply about 50 inches per acre-ft per year. During 1996, water supply was relatively low and allotment was set at 36 inches per acre-ft per year. Storage levels in Brantley fluctuated widely, from approx. 10,000 ac-ft to 40,000 ac-ft within any given year. Bank storage in a reservoir operated like Brantley would obviously be an important factor in determining the overall availability of water, as well as the length of time required to fill and lower. Discharge from Sumner varied widely, from 0 cfs to >1,000 cfs within any given year.

There are now 12 continuous stream flow recorders on the main stem of the Pecos River, and one on each of the two FSID return flow drains (5 Reclamation and 9 U.S.Geological Survey). Hydrological data was collected at all sites before, during, and after irrigation releases. Data collected between large irrigation releases (when Sumner releases are 100 cfs or less) will be used in river modeling and studying the salinity behavior of the Pecos River. Other hydrological data collected during flow measurements are Manning's roughness coefficient and cross section geometries. Travel times at each flow rate to the different recorders are obtained from the recorder strip charts. Loss coefficients at the different river stations are calculated from strip chart information and streamflow measurements.

Initial analysis of historical river gage data revealed there is not a direct relationship for the efficiency of water delivery to Brantley from Sumner as a function of discharge (in cfs) alone. The volume of surface water “lost” in the Pecos system is not well correlated with a discharge representing the block release from Sumner. This can be attributed to several factors. Volumetric loss is highly dependent on block flow duration, season (temperature), weather (temperature and precipitation), water utilization, and antecedent river conditions. All these factors influence the evaporation and seepage losses. Mean daily discharges computed for the gaging stations may experience some variability during a 24-hour period because of diurnal variation, seepage losses, irrigation return flows and rainfall/runoff.

There is, however, a very good relationship for the volume of water delivered for block releases. Analyses have shown that higher delivery efficiency is achieved when the mean discharge for the block release approaches the peak discharge. This implies that if the release hydrograph assumes a square block rather than naturally shaped hydrograph, then less water is lost to seepage and evaporation. Also, river loss coefficients for flows greater than 200 cfs have been developed which are functions of river reach location, season of the year, and discharge. In general terms, the percent loss decreases with increasing discharge, and the percent loss tends to be higher in the summer.

Work in developing a predictive daily flow hydrologic model for the Pecos River system from Santa Rosa Dam to Brantley Reservoir is ongoing. Reclamation is using the PRSYM (Power and Reservoir System Model) framework to develop a Pecos version of PRSYM. The PRSYM development is a joint effort between Reclamation, Tennessee Valley Authority, and CADSWES (Center for Advanced Decision Support for Water and Environmental Systems), an organization based at the University of Colorado in Boulder. The focus thusfar has been on field data collection and analysis for determining loss coefficients for routing different release patterns from Sumner. The loss coefficients will be used to develop a river routing method for the PRSYM computer model. Remaining work will involve developing a method to compute bank storage as a component in the mass balance of Brantley and calibrating the model with existing data.

Water quality analyses have been undertaken during each study year to characterize the physiochemical nature of Brantley and Pecos River waters. The focus of these efforts has been on total dissolved solids (TDS) since it is an important consideration for the irrigators and varies with season and water management practices. Historically and currently, the greatest water quality degradation or the Pecos River system is reflected in TDS, and the degradation increases in the downstream direction. A review of EPA's STORET data did not find any indication of metals or organics contamination in the Pecos that would warrant additional studies. TDS concentrations in Brantley Reservoir vary with depth as well as laterally and longitudinally within the reservoir. These patterns are temporary, affected by inflow, outflow, and wind conditions. Highly saline inflows during winter creates an underflow that settles in the deepest parts of the reservoir, and much of this would be drawn off when releases are resumed. Inflows less saline than water stored in Brantley appear to spread laterally, and over the surface of the reservoir. Each year of data collection has shown that TDS concentrations in the inflow to Brantley decrease as discharge increases. TDS stratifies in Brantley, particularly during non-irrigation periods. It was not uncommon to observe differences of more than 1,500 mg/l between surface and bottom TDS readings during the non-irrigation season. From 1992-1995, TDS near the bottom of the dam ranged from 937 to 5,988 mg/l. During 1992 when water supply and storage were high, TDS levels near the bottom did not exceed 3,500 mg/l. In 1993-1995, TDS concentrations near the bottom were greater than 4,500 mg/l during late-winter. Each of these years, the first water release from

Sumner during late-winter induced a drop in TDS levels near the dam bottom to levels that remained above 3,000 mg/l. Subsequent irrigation releases during the summers of 1992-1995 induced further decreases in TDS to levels below 3,000 mg/l. Mass balance analysis for the reservoir showed that Brantley is accumulating salt rather than contributing it downstream. Other parameters (water temperature and pH) are fairly stable with depth, laterally and longitudinally within Brantley. Dissolved oxygen decreases with depth (at least seasonally) and, like other reservoirs, the concentration can reach critical biological levels near the substrate.

Channel morphology was characterized to assess the responsiveness of the river channel and ranges of depths and velocities available to the Pecos bluntnose shiner. Channel profile data show differences between responsive upstream reaches and downstream unresponsive, incised reaches. The channel is most active within the upper critical habitat where it is 100-250 feet wide and cutting and filling in response to higher discharge events. The channel is less active in the lower critical habitat where it is incised up to 6.5 feet and confined within a 55-115 ft wide channel. Depth and velocity profiles for the upper reach reveal a complex channel represented by diverse macrohabitats. Depth and velocity profiles for the lower reach reveal an ubiquitous channel with very low habitat diversity.

An aerial photography and videography study of aquatic habitat was conducted at high and low flow. Discharge during February low-flow conditions was 0 cfs below Sumner and 57 cfs at the inflow to Brantley. Discharge during May high-flow conditions was 1,065 cfs below Sumner and 724 cfs at the inflow to Brantley. Main channel, side channel, backwater, isolated pool, sand bar, and vegetated island habitat were quantified. Low winter flows resulted in a high composition of low velocity habitat (backwater, isolated pool, and side channel) while high spring flows resulted in a significant decrease in the availability of low velocity habitat. Habitat heterogeneity was higher in the upper reach of the middle Pecos than in the lower reach, regardless of high or low discharge. In the upper reach, main channel decreased from 92% to 24% of all habitat when comparing high to low flow. Side channels, pools, and backwaters increased in abundance when flows dropped. In the lower reach, main channel decreased from 98% to 68% of all habitat when comparing high to low flow. As in the upper reach, side channels, pools, and backwaters in the lower reach increased in abundance when flows dropped (although their presence is minimal at any discharge). Backwaters and isolated pools declined more than 80% when flow increased. Since these habitat types are important to the life history of native fishes, high flow events may be expected to have some deleterious impacts on fish communities.

BIOLOGY

Laboratory and field life-history studies of Pecos bluntnose shiner revealed several heretofore unknown facts on the biology of this species. Field studies indicated that 55% of post-juvenile Pecos bluntnose shiners were female. While there was little difference in mean standard length between the sexes (males 41.3 mm, females 41.0 mm), females were generally larger than males. Adults exhibited little sexual dimorphism except during the reproductive period when females abdomens become noticeably distended and males develop fine tubercles on the median and paired fins. Spawning was preceded by males actively pursuing a gravid female, nipping, biting, and nudging her anal fin region. A spawning event occurred when a single male encircled the female at mid-body and fertilized the broadcasted eggs. Wrapping and release of eggs occurred in about 0.25 seconds.

The female released 370 semi-buoyant eggs during a single spawning event. The eggs remained suspended in the water column (as long as there was flow) and hatched in about 24-hours. The free-swimming larvae remained a component of the drift for an additional 3 to 4 days absorbing most of their yolk-sac. They subsequently began to actively forage and selected low-velocity habitats. Pecos bluntnose shiner was omnivorous and presumably relied heavily on input from terrestrial environment. Salt cedar (*Tamarix chinensis*) seeds comprised a majority of the stomach contents of several individuals. Few endo- and ecto-parasites were noted on or in Pecos bluntnose shiner.

Composing scientific illustrations of proto-, meso-and metalarval Pecos River cyprinids (beginning with Pecos bluntnose shiner) began in early 1993. Over 50 rough sketches of laboratory-reared larvae between 6.4-19.8 mm standard length (SL) were made to illustrate growth and development of this species through the juvenile stage. Intense scrutiny of these samples was required to determine the appropriate phases for illustration of each larval stage as well as other members of the associated cyprinid fish community. Morphological and meristic characters deemed diagnostic are being determined from these specimens and will be used in the preparation of a key to the Pecos River cyprinids and to aid in the identification of previously unsorted field collected samples.

Reproductive studies of Pecos River fishes have resulted in the identification of a guild of mainstream cyprinids which have been defined as broadcast spawners that produce semi-buoyant eggs and use a similar reproductive strategy. This guild is composed of the Pecos bluntnose shiner, the plains minnow, the speckled chub, the Arkansas River shiner, and the Rio Grande shiner. Members of this guild exhibit a strong positive correlation between spawning and increases in spring and summer flows. These studies indicate that eggs of these fish are released almost exclusively during flow spikes and are transported an undetermined distance downstream by the flow event. Egg hatching time, while temperature dependent, is relatively rapid (24-48 hrs). Recently hatched larval fish (protolarvae) are also displaced downstream by the same high flows that stimulated spawning and individuals do not have sufficient mobility to move out of the main channel flows until at least 3-4 days after hatching. During the 1996 reproductive season, spawning by the guild was detected beginning May 4 and continued through October 6. Spawning occurred on flow increases and the magnitude of spawning appeared to be greater in response to rainstorms than to irrigation releases.

To evaluate the effects of Pecos River operations on the distribution and abundance of Pecos River fishes including the bluntnose shiner and on bluntnose shiner habitat, efforts focused on flow-related effects on the fish populations, habitat use, and habitat availability. The typical flow regime appeared to impact cyprinid species by transporting eggs, larvae, and juvenile fish downstream. The guild of pelagic spawning cyprinids that includes the bluntnose shiner was impacted more than species that spawn adhesive eggs or bear live young. Population structure of the pelagic spawners is also impacted. Non-pelagic spawner populations, like the red shiner, are comprised of healthy proportions of juvenile (size classes 0 and 1) and adult (size classes 2 and 3) fish throughout the middle Pecos. In contrast, the bluntnose shiner population is virtually devoid of adult fish in the lower reaches. The lower reaches support only juvenile fish displaced from upstream reaches by lengthy releases from Sumner. Habitat in the downstream areas is less suitable for the survival of young fish to adulthood. The number of adults and the amount of reproduction that occurs in the lower reaches is strikingly low. The channel in the lower reaches is narrow and low velocities and low depths are infrequently encountered. The upper reaches are relatively wide with high diversity of macrohabitats (eg. flats, plunges, runs, pools, backwater) and high abundance of low velocity habitats. These conditions support a healthy population structure and higher levels of reproduction. The duration of irrigation releases was shown to be an important factor in distribution of size class 0 juvenile bluntnose shiner. As the duration of irrigation releases increased from 22 to 40 days, the relative abundance of juvenile bluntnose shiners decreased in the upstream reaches and increased in the lower reach. It appeared that releases of 22 days or less did not notably alter the population structure.

Studies of piscivorous (predatory) fishes have shown that piscivory is probably not a major factor for Pecos River cyprinid species when the river is free-flowing. Piscivores have low relative abundance compared to non-piscivores. In 1994, for example, piscivores comprised only 0.8% of the total fish collected in the Pecos.

Most of the piscivores were collected just below Sumner and just above Brantley, although channel catfish and white bass had a more scattered distribution. The most abundant species collected during study years were spotted bass, white bass, white crappie, and channel catfish. Although common in Sumner, no walleye were collected. Of the species examined, stomach contents only of white bass revealed strong fish-eating habits.

MANAGEMENT RECOMMENDATIONS

The fifteen research needs (see 5-Year Study Program section) identified at the outset of the program have all been addressed with the exception of the final task of developing management recommendations. Although all data has been collected, final data analyses and study conclusions are lacking. Also, the hydrology model is not yet calibrated for running operational scenarios. These are major and critical study components that will be finalized during 1997. Progress reports have been produced for individual study years, and a comprehensive report encompassing 1992-1996 will be compiled in 1997. The research team is also tasked with developing management recommendations that will be submitted to Reclamation in 1997. These recommendations may address water operations (timing, duration, and/or shape of releases), habitat restoration and/or enhancement, transfers of water rights, water leasing, and other alternatives as they arise.

PROGRAM FUTURE

The current MOU expires January 1997 and parties are anticipating participation in a new MOU that would extend the partnership to allow for data analysis, report preparation, development of management recommendations, and a mechanism to ensure that water operations management will not be detrimental to the bluntnose shiner or downstream irrigators. As comprehensive findings are produced and management recommendations are made, Reclamation will reconsult with the Service regarding the effects of Pecos River water operations on the Pecos bluntnose shiner. At the same time Reclamation will comply with the National Environment Policy Act (NEPA) regarding water operations.

REFERENCES

Brooks, J. E., S. P. Platania, and D. L. Propst. 1991. Effects of Pecos River reservoir operation on the distribution and status of Pecos bluntnose shiner (Notropis simus pecosensis): preliminary findings. Report to USFWS and USBR, Albuquerque, NM. 14pp.

Brooks, J. E., M. E. Brown, and N. L. Allan. 1994. Pecos River fishery investigations: fish community structure, habitat use, and water quality as a response to reservoir operations. 1992 Annual Progress Report by U.S. Fish and Wildlife Service, Fisheries Resources Office for USBR, Albuquerque, New Mexico. 60pp.

FLO Engineering Inc. 1993. Preliminary analysis of Pecos River historical gaging station data (1938-1993). Report submitted to U.S. Bureau of Reclamation. October, 1993.

Hoagstrom, C.W., N.L. Allan, and J.E. Brooks. 1996. Pecos River fishery investigations: fish community structure and habitat use and availability as a response to reservoir operations. 1994 Annual Report submitted by U.S. Fish and Wildlife Service Fishery Resources Office. 11 pp + appendices. In Pecos River Investigations Annual Research Report - 1994. Printed by U.S. Bureau of Reclamation.

Larson, R.D. and D.L. Propst. 1996. Distribution, abundance, and food habits of piscivorous fishes inhabiting the Pecos River between Sumner Dam and Brantley Reservoir, New Mexico. 1994 Annual Report submitted by New Mexico Department of Game and Fish. 25 pp. In Pecos River Investigations Annual Research Report - 1994. Printed by U.S. Bureau of Reclamation.

Martin, K.A. 1993. Statistical analysis of historical CID block releases. Bureau of Reclamation unpublished report.

Platania, S.P. 1994. Pecos bluntnose shiner (*Notropis simus pecosensis*) life history research. 1992 annual progress report by the Department of Biology, University of New Mexico to the U.S. Bureau of Reclamation, Albuquerque, NM.

Propst, D. L., A. L. Hobbes, and J. S. Pittenger. 1994. Distribution, abundance, and food habits of piscivorous fishes inhabiting the Pecos River between Sumner Dam and Brantley Reservoir, New Mexico. 1992 Annual Report to USBR, Albuquerque, NM.

Robertson, Lori. 1996. Brantley Reservoir Water Quality Studies. 1994 Annual Report. 28 pp. In Pecos River Investigations Annual Research Report - 1994. Printed by U.S. Bureau of Reclamation.

Tashjian, P. 1996. Channel response to flow regimes and habitat diversity under differing flow conditions: Middle Pecos River, New Mexico. 1994 Annual Report submitted by U.S. Fish and Wildlife Service, Branch of Water Resources. 21 pp. In Pecos River Investigations Annual Research Report - 1994. Printed by U.S. Bureau of Reclamation.

Tashjian, P. 1994. Channel morphology, reservoir operations and Pecos bluntnose shiner habitat, Pecos River, New Mexico. 1992 annual report submitted by U. S. Fish and Wildlife Service, Division of Water Management, to U.S. Bureau of Reclamation, Albuquerque, NM.

U.S. Fish and Wildlife Service. 1987. Final rule: endangered and threatened wildlife and plants; *Notropis simus pecosensis* (Pecos bluntnose shiner). Federal Register 52(34):5295-5303.

Wilber, James P. 1995. Pecos River water quality studies. 16 pp. In Pecos River Investigations Annual Research Report - 1993. Printed by U.S. Bureau of Reclamation.

Yahnke, James w. 1994. Pecos river water quality inventory. 7 pp. In Pecos River Investigations Annual Research Report - 1992. Printed by U.S. Bureau of Reclamation.

Young, D. 1994. Aerial photography of the Pecos River. In Pecos River Investigations Annual Research Report - 1992. Printed by U.S. Bureau of Reclamation. Printed by U.S. Bureau of Reclamation, Albuquerque, NM.

COLUMBIA RIVER HYDROSYSTEM OPERATION, 1984-1996

THIRTEEN YEARS OF ADAPTIVE FLOW MANAGEMENT

TO REBUILD PACIFIC SALMON RUNS

Bolyvong Tanovan[1]

ABSTRACT

Several Snake River salmon stocks are considered in danger of extinction. The hydroelectric dams on the lower Columbia and Snake Rivers are one of the many factors that have contributed to the salmon decline. Since its implementation in 1984, the salmon recovery program has significantly affected the operation of the Columbia River system. Increasing amounts of water have been set aside to meet pre-established flow targets at key locations. Spill is scheduled at many dams to improve fish passage conditions. Reservoirs are operated in their lower operating range to increase fish movement. To date, salmon recovery signs are far and few. Impacts on other water users, on the other hand, are already apparent. There have been serious water use conflicts between hydropower, flood control, navigation, resident fish, recreation and irrigation. The road to Pacific Salmon recovery is full of uncertainties. It involves sizable stakes and requires deep faith in the process. Solutions to the problem are costly and affect the welfare of the entire region. Some of them are controversial. Regional consensus is key to being able to operate the river in an adaptive management mode.

BACKGROUND

The Columbia River is the largest river in the American continent that discharges into the Pacific Ocean (see Figure 1). In its 1,270 mile course, the Columbia flows through four mountain ranges and drains 258,000 square miles. Its largest tributary, the Snake, is almost as long. No other twentieth century development brought more economic benefits to the Pacific Northwest than the construction of hydroelectric projects along these two streams. Starting from the midst of the depression, these projects brought jobs to a region suffering from economic collapse and extensive unemployment. They provided irrigation water and inexpensive power that promoted the growth of the aluminum, aircraft and shipbuilding industries. Today, Columbia Basin dams generate an average of 18,500 megawatts annually, serving eight million people. They also create 450 mile of inland waterway to Lewiston, Idaho and supply irrigation water for almost three million acres of land. As the Pacific Northwest continues to develop, balancing the region's many conflicting water needs becomes increasingly difficult. The recent listing of Snake River salmon stocks under the Endangered Species Act (EAS) profoundly changed the way the Columbia River system used to be run.

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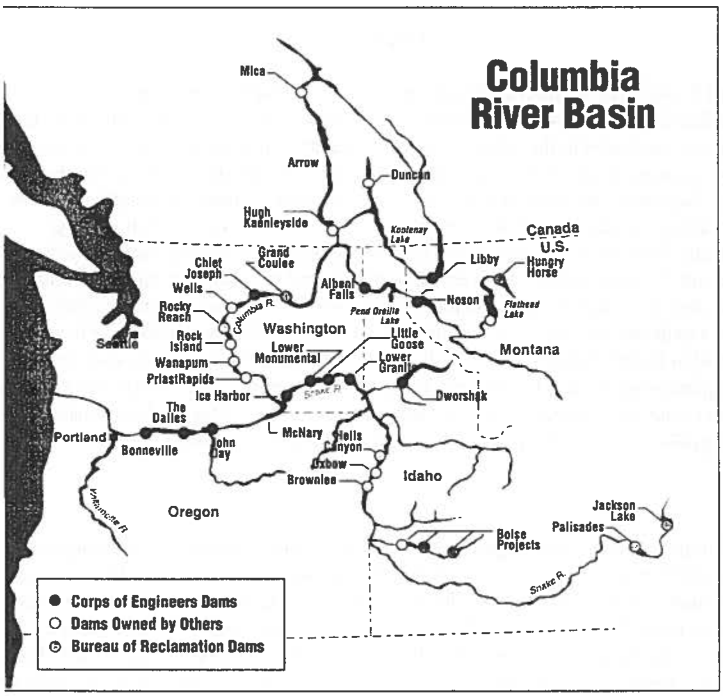

Figure 1. Location of the Columbia and Snake River Hydropower Projects

DECLINE OF THE SALMON

Wild Pacific Salmon have been in existence in the Northwest for at least five million years, supplying an abundant food source to the Native Americans. Salmon begin their lives in freshwater streams, taking two to five years in the ocean to grow. They return to the place of their birth to spawn and, except for steelhead, die after spawning once. When Lewis and Clark explored the region in the early 19th century, huge numbers of fish returned to spawn every year. Commercial salmon fishing was one of the region's earliest and most lucrative industries. In 1983, fishermen harvested forty-two million pounds of salmon on the Columbia, using gillnets, seines, traps and fishwheels. One of these fishwheels once took 70,000 pounds of fish in a single day. By the late 1880s, however, nearly all salmon runs have dramatically declined. In 1954, only seven million pounds were harvested. Last year (1995), the returning adult salmon counts at Bonneville Dam were down to about 10,000 adult spring chinook and 15,000 summer chinook, compared to the 10-year averages of 84,000 and 24,000 respectively.

There is no doubt that hydroelectric development presents a major threat to salmon populations. Dams impede fish movement, cut off or flood their original spawning areas, and create slack-water pools that attract predators and cause unfavorable water quality conditions. The roots of the problems, however, can be traced back to the 19th century, long before the first major dam appeared. Many other factors have contributed to the decline of the salmon runs. Over-harvesting; degradation of habitat from irrigation, agriculture, logging, mining, grazing; pollution from pesticides, herbicides, fertilizers, pulp and paper mills; and increased competition for food and spread of diseases from hatchery fish have caused problems. A variety of ocean conditions, including currents, pollution, and temperature changes such as El Nino have affected salmon survival. In recent years, El Nino caused warmer water off the coasts of Oregon and Washington and attracted warmer water fish (including predators) far north of their usual waters. Ocean warming also caused less food production near the surface where fish live.

MAIN REGIONAL PLAYERS

The nature of the salmon life cycle and the extensive habitat salmon require create a complex stage involving many players, each with its set of rules and priorities, and many with jurisdictions or interests that overlap or conflict.

- **Those who run the River**. The U.S. Army Corps of Engineers (Corps) and the Bureau of Reclamation (BOR) manage the Columbia River federal hydropower dams. BOR also manages numerous irrigation dams. The Bonneville Power Administration (BPA) sells the electricity generated by these dams and helps coordinate their operations. Chelan, Douglas and Grant Counties Public Utilities Districts in Washington operate five non-federal dams on the mainstem Columbia. Idaho Power Company operates three dams on the Snake River. Many other utilities have projects on tributaries within the basin.

• **Those who manage the fish.** Washington, Oregon and Idaho are the managers of salmon and steelhead resources within their waters, including the coastal areas. By Columbia River Treaty rights, several Indian tribes also manage the resources. Under the Endangered Species Act (ESA), specific management responsibilities fall to the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFW)

• **Those who manage habitat.** USFW and the Bureau of Land Management (BLM) manage headwaters and spawning areas on federal land. States and individual tribes also have jurisdiction.

• **Those who catch the fish**. Commercial, sports and tribal fishermen compete for the available fish. By rights, Treaty tribes may take up to 50 percent of the available harvest at their customary fishing sites.

• **Those who balance Fish and Power Uses**. The Northwest Power Planning Council (NPPC) seeks to develop balanced programs to improve fish runs. NMFS is in charge of the listed species. The Federal Energy Regulatory Commission (FERC) imposes conditions to mitigate for fish damages at non-federal dams.

• **Those who have special public interests**. Water user groups (irrigators, navigators, recreationists, special utility consumers, etc.), sportsman's associations, and environmental organizations (Save Our Wild Salmon, American Rivers, Sierra Club, Trout Limited, etc.) represent special public interests.

• **Those who pay for fish program**. Rate-payers of the Northwest state and federal taxes and various license fees pay for fish programs.

Before 1980, decision-making authority on how to operate the Columbia River system rested largely in the hands of the federal government. This authority shifted to NPPC in the early 1980's and reverted back to the federal government in the 1990's. At all times, federal and nonfederal project owners and operators are still ultimately responsible for the ecosystem impacts of their project operation. Utilities, environmental groups, government leaders, irrigators, navigation interests and others also participated in developing plans to conserve and protect fish.

NPPC was created in 1980 with the passage of the Northwest Power and Electric Conservation Act. The Act authorizes the states of Idaho, Montana, Oregon and Washington, through NPPC, to develop a fish and wildlife program to mitigate the effects of the Columbia River dams. It requires federal water and power agencies to take this program into account when they make decisions. NPPC's first Fish & Wildlife Program, developed in 1982, set a goal of doubling the salmon runs from 2.5 to 5 million fish. Its Water Budget, setting aside specific amount of storage water to augment spring and summer flows, constituted a major change in the planning and operation of the Columbia Hydropower system. Two agreements signed between BPA and the fishery agencies and tribes (A&T) also had similar effect. The Vernita Bar Agreement (1988) guaranteed flow levels to protect salmon spawning and hatching below Priest Rapids

Dam, the last major fall chinook salmon spawning area on the mainstem Columbia. The Long-term Spill Agreement (1989) embodied BPA's commitment to spilling water at selected mainstem dams to protect juvenile salmon and steelhead migrants.

NMFS's took a leading role in salmon recovery in 1990 by setting new standards for dam operations under the authority of the ESA. In their Biological Opinion for the operation of the Federal Columbia River Power System NMFS called for spilling the equivalent of 20 percent of average daily discharge at most projects. They also recommended reservoir drawdown to speed up the movement of water and with it, juvenile outmigrants. NMFS issued a revised biological opinion on March 2, 1995, recommending many other operational and structural measures and new technologies to improve fish passage conditions.

Today, NPPC and NMFS continue to be active leaders in salmon recovery, with NPPC representing the Pacific Northwestern States and NMFS, the Federal Government. Both are playing a pivotal role in formulating public policy and defining future directions.

MAIN THRUST AREAS

Salmon recovery measures are generally concentrated on the four "H" areas originally defined in NPPC's Fish and Wildlife Program: habitat, hydropower, hatcheries, and harvest.

- **Habitat.** Fish habitat for all life history stages is enhanced or restored in several ways. Some of the options include building small check dams to increase gravel bars and pools; fencing streams to keep livestock out; adding boulders to provide resting places; planting trees to provide shade in the summer; and rebuilding channels.

- **Hydropower**. Hydropower dams are made safer for fish passage through a variety of structural and operational fish passage improvements. To prevent turbine mortalities, screens are installed in front of the turbines to divert juveniles into a gatewell and other orifices and channels. Spillway gates are opened to pass water and fish over the safer spillways. Spillway deflectors are installed to help reduce the amount of dissolved gas entrained by the spill and prevent gas bubble trauma. Water is released from headwater storage projects to augment flows in the lower river and increase current velocity to "flush" the juvenile fish through the reservoirs. Mainstem reservoirs are kept inside their minimum operating ranges to maximize the "flushing" effect. Control programs are instituted to reduce the number of squawfish and other predators. Juveniles are collected and transported by barges or trucks to a site closer to the estuary, bypassing intermediary reservoirs and dams. This both speeds up fish travel time and reduces their exposure to adverse reservoir and dam passage conditions. Fish ladders are provided at all mainstem dams to allow adult fish to pass the dams in their upstream migration.

- **Hatcheries**. Numerous hatcheries are built and operated as part of a comprehensive compensation program to mitigate for fish losses due to dam construction. These hatcheries artificially increase salmon and steelhead runs.

- **Harvest**. Catch quotas are imposed to both in-river and ocean harvest to ensure there are enough adult fish left in the river for procreation purposes.

Implementation of measures similar to those described under Hydropower started as early as 1951. New technologies for improved dam passage for fish being aggressively explored today include surface bypass systems, system-wide gas abatement techniques, reservoir drawdown, fish bypass improvements, and fish-friendly turbines. Conditions of the ocean, where salmon transform from juvenile into adult, are unfortunately beyond human control. As a result, ocean survival remains the weakest link in the chain of the salmon's life cycle.

COST OF SALMON RECOVERY

The cost of salmon recovery measures includes foregone power sales and transmission revenues, fish facilities' construction and operating costs, and costs created in other user areas (irrigation, navigation, recreation, resident fish, etc.). As shown in Table 1, power costs alone steadily increased from $0.5 million annually in 1978 to $41.6 million in 1992. Structural improvements and other fish-related operating costs, which normally are covered by the project owners and operators, are additional.

Table 1. Annual Power Cost of Northwest Salmon Recovery (in $ million)

Before the Council's Program

Years	1978	1979	1980	1981	1982
Cost	0.5	1.2	1.9	2.9	3.9

After the Council's Program

Years	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Cost	7.8	17.6	25.5	25.5	39.5	35.7	37.0	53.4	46.2	41.6

BPA paid for the bulk of the costs, using rate-payers' money. Other federal and state agencies as well as non-federal project operators also contribute. In 1985, BPA's share was 56%; States, 12%; other Federals, 26%; and others, 6%.

To ensure the solvency of fish recovery programs, a Memorandum of Agreement was signed in October 1996 to define the financial commitment for BPA's fish and wildlife costs. The agreement limits BPA funding commitment to $425 million a year. This includes $183 million for spill and flow augmentation costs, $100 million for directly funded fish and wildlife program activities (research, predation control, captive broodstocks, hatcheries, etc.), $40 million for operation and maintenance of federal fish facilities, and $112 million for capital investment repayment to the U.S. Treasury for costs of constructing fish passage facilities and hatcheries. A contingency fund of $325 million a year will be available under certain conditions (e.g. if additional court-ordered obligations under the ESA drive fish and wildlife costs above $435 million in a given year). Another $15 million will be available annually for certain emergencies.

The total cost of past, present and future modifications to the eight federal dams on the lower Columbia and lower Snake Rivers to improve salmon survival is estimated at about $1.4 billion. Work already completed and activities that have begun or are planned accounts for about $800 million. "Decision-dependent" measures, reflecting the regional adaptive management framework for salmon recovery actions, account for the remaining $600 million.

Funds are appropriated annually. In FY 1996, total expenditures amounted to almost $80 million. Request for FY 97 is $107 million, of which $90.2 million have been appropriated by Congress.

MOVING FLOW AND SPILL TARGETS

Fish flow augmentation and spill for-fish-passage constitute the cornerstone of the salmon recovery program for the improvement of mainstem passage conditions. In the past thirteen years, both the recommended daily average minimum flows and the dam's fish passage efficiency standards have been increased based on more stringent biological criteria.

As shown in Tables 2 and 3, minimum flows recommended by the Columbia River Fisheries Council in 1979 were less than those in force today. These are the flows the federal regulators have to provide, using water releases from storage reservoirs to supplement natural runoff. According to BPA estimates, the volume of water dedicated to fish flow augmentation has gone from 4.81 million acre-feet (maf) in the pre-1991 era to 8.35 maf in 1992, 10.4 maf in 1993, 10.6 maf in 1994, and 10.85 maf in 1995. BPA predicts this volume to reach 11.5 maf in 1998.

Flow augmentation water comes from different sources. The breakdown for the 1994's 10.6 maf volume is as follows: Water Budget (3.45 maf), Upper Snake (0.43 maf), Brownlee (0.33 maf), Dworshak (1.89 maf), Grand Coulee (0.93 maf), Banks Lake (0.20 maf), Non-Treaty Storage (0.20 maf), and Operational Flow Augmentation (3.15 maf).

The sites where the minimum recommended flows are to be measured were also moved farther and farther downstream. In NPPC's original Fish and Wildlife Program (1982), these sites were Priest Rapids for the mid-Columbia and Lower Granite for the lower Snake. In NPPC's amended Program and NMFS's Biological Opinion (1994), the mid-Columbia site was moved to McNary, which is located below the confluence with the Snake River. In the tribal Spirit of the Salmon restoration plan (1995), the McNary target site was replaced by The Dalles.

Table 2. Recommended Minimum Flows, 1979 (kcfs)

Period	Chief Joseph (upper end of mid-Columbia)	Priest Rapids (lower end of mid-Columbia)	Lower Granite (lower Snake River)	McNary (upper end of lower Columbia)	Bonneville (lower end of lower Columbia)
January	30	70	20	60	60
February	30	70	20	60	60
March	30	70	20	60	60
Apr 1-15	50	70	40	100	120
Apr 16-25	60	70	85	150	170
Apr 26-30	90	110	85	200	200
May 1-31	100	130	85	220	225
Jun 1-15	80	110	85	200	210
Jun 16-30	60	80	30	120	120
July 1-15	60	80	30	120	120
July 16-31	90	110	20	140	140
August	120	95	20	120	120
September	95	40	20	60	90
Oct. 1-15	30	40	20	60	95
Oct.16-31	30	70	20	60	95
November	60	70	20	60	60
December	60	70	20	60	60

Table 3. Flow Targets for Lower Granite (Snake River) and McNary (Columbia River), 1994-1995 (in kcfs)

Periods	Council's Fish & Wildlife Program (1994)	NMFS's Bi-Op (1995)	Tribal Spirit of the Salmon Restoration Plan (1995
Lower Granite			
Apr.16-June	85-140	85-100	(*)
July-August	50 (July)	50-55	(*)
McNary			
Apr.16-June	170	200-230	220-300 (4/15-6/15)
May-June	180-300	220-260	200-250 (6/16-6/30)
July	200	200	200
August	160	200	160
September			120

(*) Use 1 to 3 Maf from upper Snake, 450 kaf from Brownlee Reservoir, and 1.5 Maf (spring)+ 1.0 Maf (summer) from Dworshak Reservoir.

Fish passage efficiency (FPE) is the percentage of fish that use a route other than the turbines to pass a dam. Alternate passage routes include fish bypass facilities and spillways. FPE is therefore determined by two elements: (1) efficiency of the fish screens in guiding fish into the bypass facilities, and (2) how much water is being spilled to get fish to use the spillways. As a result, at a given dam with known fish guidance efficiency, spill for-fish-passage is directly proportional to the FPE.

The minimum FPE levels recommended by the A&T in the 1980's were 50 percent for spring migrants and 70 percent for summer migrants. In the early 1990's, the A&T increased these levels to 80 percent for both spring and summer migrants. The tribes increased FPE to 90 percent in their salmon restoration plan developed in 1995. Higher FPE means higher spill. To meet an FPE target of 80 percent, the required spill in percent of the outflow prescribed in the Biological Opinion ranges from 27 to 81 percent at lower Snake River dams, and from 33 to 100 percent at lower Columbia River dams.

Actual spill levels are, however, usually less than indicated because of limitations imposed by the state standards for dissolved gas. In 1994, the states temporarily increased their standards from 110 percent saturation to 120 percent saturation. Despite this relaxation, the levels of the new allowable spill still have not reached those prescribed in the Biological Opinion at many projects.

ELUSIVE CONSENSUS

Because of the complexity of the ecosystem and the magnitude of the remedial costs involved, reaching consensus on salmon recovery measures has so far not been easy. Opinions differ on why past and present salmon recovery efforts have not yet produced the expected results. Disagreement looms at many levels and no uniform consensus exists on the "best" and "most effective" measures to be implemented. "They want balance, and that's tough to do" said Donna Darm, Manager of NMFS's Environment Policy. "On the one hand, we're looking at extinction; on the other hand, we're looking at a recreational need. It's not a balancing act. It calls for erring on the side of the species that is at risk of extinction".

Some scientists are convinced that increasing flows, drawing reservoirs down, and allowing the juveniles to migrate without transportation is the best solution. Others believe that the transportation system has been successful and that too many poor-quality smolts released from upriver hatcheries harmed, rather than helped, the recovery of fish runs. Poor harvest management and increased predation in reservoirs, they said, have hindered the recovery of runs. Reservoir drawdown is supported by the tribes, fish agencies and environmental groups, but not by industry and many other groups. Excessive costs and uncertain outcome are primary reservoir drawdown issues.

There is considerable disagreement over the levels of flow and spill needed for juvenile migrants. These levels have been modified several times. Opposing parties contended that flows past a certain level are of no benefit to fish migration. They also believe that short-term increased passage survival at the dams as a result of spill does not outweigh long-term mortalities in the reservoirs supersatured with dissolved gas created by the same spill.

There is little consensus in the use of sophisticate fish survival models such as the CRiSP model developed at the University of Washington in assessing the effectiveness of recovery measures. The A&T are generally reluctant to use computer models that include many parameters and/or require many assumptions. Results produced by CRiSP had shown that fish survival is less sensitive to flow augmentation than transportation. This conclusion is contrary to current A&T thinking. Model developers and biological statisticians naturally deplore the A&T's lack of interest in using the model to make more informed resource decisions based on the best available science. They claim too much politics governs the stewardship of Pacific salmon.

Another basic disagreement surrounds fish transportation. The A&T's demand that at least half the fish coming downstream be left in the river instead of put into barges for the downriver trip. However, NMFS disagrees, saying that in some conditions barging is safe for the fish. In 1996, they proposed to barge at least 60 percent of the fish.

Finally, there is the age-old dispute between upper and lower river, local versus regional, water users. Montana and Idaho do not want water taken out of their reservoirs to meet the fish flow targets in the lower river; this operation hurts resident fish and local recreation under most runoff conditions. The opposition by the two states is even stronger relative to a deeper reservoir draft to match yet higher flow targets. Deeper reservoir drafts will further increase adverse impacts on resident fish and recreation. They also make it more difficult for the affected reservoirs to completely refill the following year.

All these issues have overshadowed others such as watershed restoration and protection of native salmon. Lack of agreement has fragmented the region's ability to implement a comprehensive recovery plan. The precarious balance between fishery interests and other Columbia River water users has also pushed some parties into seeking justice through the legal system. Many disagreements in facts and in principles did indeed end up in court, forcing river operations into the hands of a federal judge.

ALTERED SYSTEM OPERATION

Implementation of the salmon recovery measures, starting with NPPC's Fish & Wildlife Program in 1984, has had a profound impact on the way the Columbia River system is operated. It has affected project operation in many areas, including project priorities, coordination, and planning and scheduling of real-time system operation.

In the past, projects were operated to meet flood control, power generation, navigation, and other authorized project purposes in that order. Current priority starts with flood control, followed immediately by salmon recovery. Even flood control is now approached in a more liberal context. The region is willing to take more flood control risk to maximize the system's capability to meet fish flow targets. Whenever feasible, less storage space than before is kept in reserve for flood control so that more water can be stored now rather than later in the season. Also, to maximize the chance for meeting flow targets in the lower Snake River, flood control space requirements are shifted from lower Snake River reservoirs to other reservoirs outside the Snake River basin.

The requirement for coordination of reservoir operations is considerably expanded. Any operation that can potentially affect listed fish species has to be coordinated beforehand with NMFS. Routine unit outages for maintenance and service schedules have to be coordinated. Changes to pre-agreed operations also have to be documented and reported to all concerned.

Operation planning has to account for the flow augmentation requirements contained in the Biological Opinion. Adequate volumes of water have to be stored at appropriate headwater reservoirs to try to meet the seasonal spring and summer flow objectives at specified locations on the lower river. In some instances, pre-existing power agreements had to be adjusted or compensated for in order to accommodate these new fish requirements. Actual project releases and spill must be scheduled as part of a plan pre-approved by the region to demonstrate and ensure than fish needs are met first. Spill for-fish-passage is monitored on a real-time basis for its impacts on total dissolved gas saturation. It must be adjusted upward if spill criteria are not met, and downward if the resulting dissolved gas saturation exceeds the state water quality standards.

Normal reservoir operations are continually affected by the fish requirements specified in the Biological Opinion and other regional documents. Operating the lower Snake River reservoirs in their lower operating range reduces normal navigation draft by 2 to 4 feet depending on the locations. This may be a serious limitation under some flow conditions given the reservoir morphology and sedimentation. Operating John Day Reservoir at its minimum irrigation pool could present the same type of potential impact, in addition to creating higher hydraulic heads that could immobilize some irrigation pumps in the area. Restricted operating pool ranges mean that less pool fluctuations are now allowed during power peaking operations. Keeping the turbines running within the 1 % peak efficiency flow range to minimize fish injuries takes some operational flexibility away from BPA. Meeting flow targets at sites located as far downstream as The Dalles also presents additional regulation problems. There are more contributing tributaries to watch for, and no storage reservoir left to control flows in the Portland metropolitan area.

Many ongoing activities involving fish or fish facilities interfere with normal system operation. Installation and testing of prototype surface collectors and extended submersible traveling screens require special unit operation, including interrupting power generation for safety reasons or research and monitoring purposes. Loading and unloading of fish barges, although limited in time and in space, restrict spill and interfere with normal navigation activities.

Considerably less flexibility exists today for scheduling reservoir operations unrelated to fish such as non-firm power generation and special recreation events. Reservoirs like

Dworshak in Idaho used to be kept very high up through the Labor Day week-end for maximum recreational opportunities. Today, those reservoirs would mostly be too dry that time of the year to be able to offer the same recreational amenities.

CONTINUING SEARCH FOR CONSENSUS

Despite difficulties, the search for consensus is still going on. Current efforts are directed at sorting out solutions that work from those that do not work, looking at existing information and identifying its limits, seeking a clearer direction, and streamlining the process. For salmon recovery, consensus building in various forms and at various levels is accepted as an integral part of adaptive management.

NPPC is currently trying to develop consensus to ensure the biological diversity and genetic integrity of wild salmon and steelhead in a regional context. Costs and benefits of various strategies and decisions are weighed in open public process. NPPC has also convened an expert panel of scientists, referred to as the Independent Scientific Group (ISG), to shape a new vision for the Columbia River. It plans to incorporate the group's recommendation for re-regulating the river in its Fish & Wildlife amendment process.

The ISG's work itself is yet another good example of consensus building among professionals. This group began the process with group discussions, broke into subcommittees to address specific topics, and returned for group decisions. On occasion, outside experts were brought in to fill the gap in the group's knowledge or experience. A draft report was prepared, circulated for peer review, and presented to the Council. The group recognized that one cannot go back to the pristine river condition. They recommended that the river be re-regulated without dismantling existing hydropower projects. All political, economical, and biological constraints have to be fully integrated. This proposal may run contrary to running the river with economic benefits as a priority. It does, however, establish a realistic and constructive basis for people with conflicting views to build on.

Another key mechanism to allow the salmon recovery plan to continue smoothly is the creation of real-time management structure open to all the major players in the region. Technical issues are discussed in an open forum, with State, federal and public participation. Unresolved disputes are elevated to a higher policy-level forum; important scientific disagreements are referred to independent scientific groups. In the final resort, issues are settled in courts. Dispute resolution mechanisms are kept as legally binding as possible.

This three-layer process was first put in place in 1994. NMFS then created the Technical Management Team (TMT) consisting of representatives of the five federal agencies directly involved in the salmon recovery (Corps, BOR, BPA, NMFS and USFW). Disputes are elevated from the TMT to an Executive Committee consisting of managers of the same five agencies. Final decisions are at the discretion of the Corps and BOR. In their second Biological Opinion released in 1995, NMFS expanded the TMT membership to the states and the A&T. It added other advisory groups to address dissolved gas, structural modifications, water temperature, field research, etc. and replaced the Executive Committee with the Implementation Team, with extended membership.

BUMPY ROAD AHEAD

Saving the Snake River salmon and other endangered fish species is a matter of extreme urgency, but changing all the adverse river impacts on the salmon will take time and adjustments. Based on the experience of the past thirteen years, much has been accomplished through regional consensus despite conflicting interests, biological uncertainties and escalating costs. However, more challenges still lie ahead. Things have changed to the point that the Snake River salmon no longer run wild; tearing down the dams may not bring them back in our lifetime. Managing the Columbia River system for the sole benefit of fish (or tourists, fishermen or other fun seekers for that matter) would also be extremely difficult, if not impossible. Can the region keep the decision process open, secure the support of the Congress and the administration, and muster the necessary will to weather the hard sacrifices ahead? Will the Pacific Northwest be successful in balancing the needs, equitably distributing the burden, and bringing back the salmon? Only time will tell.

REFERENCES.

1. Alliance Advocate. Columbia River Alliance for Fish, Commerce and Communities. Portland, Oregon
2. Columbia Basin Research, http://www.cqs.washington.edu
3. Dams & Fish – A Primer, 1987. Pacific Northwest Utilities Conference Committee. Portland, Oregon.
4. Fish News, http://www.newsdata.com/enerme…net/fishletter/fishletter.html
5. Northwest Energy News, Northwest Power Planning Council, Portland Oregon
6. Salmon Passage Notes, Snake and Columbia River Fish Programs. US Army Corps of Engineers North Pacific Division Portland Oregon
7. Update, Northwest Power Planning Council. Portland, Oregon
8. NPD TMT Homepage, http:\\www.npd-wc.usace.army.mil

HOW WOULD MULHOLLAND DO TODAY?

John R. Wodraska[1]

ABSTRACT

Successfully managing water resources in today's complex society can no longer be achieved by relying on the decisions of just one leader, no matter how visionary he or she may be. It requires a new style of leadership, based on negotiation and consensus-building among all stakeholders, identifying common ground among varous parties and building agreements based on mutual interests. Rather than spoon-feeding us the answers, this new breeed of leader asks the hard questions and challenges us to face difficult problems for which there are no simple solutions. Comparing current political trends in the states of California and Florida underscores the importance of stakeholder involvement. Florida's Everglades and California's Bay-Delta are two of the most complex issues in water management in the United States. Both are wetlands ecosystems that have experienced significant degradation due to human activity, and both have great impact on the economy of their respective states. But the manner in which disputes arising over these vital national resources have been handled leads us to the conclusion that winning begets lawsuits while consensus leads to progress. Faced with continuing stakeholder involvement as well as steadily increasing competition from the private sector, the water industry must adapt to this new style of leadership if it is to survive the journey into the 21st century.

INTRODUCTION

Most visitors to Las Vegas can hardly wait to try their luck at the gaming tables or the slots. But from my point of view, there's a lot more at stake here than just money. When I walk along the famous Las Vegas strip, with its sea of neon and humanity, and I see all the new construction that's taking place, the water manager in me just naturally takes over. All I can think about is how much water it's going to take to keep up with this phenomenal growth.

Can we manage our water and power resources to reliably support the exponential growth of Southern Nevada, Arizona and California? If we can't, we're gambling on the future of our Western states and our entire country. Are we willing to take such a risky bet or is there a way to better the odds?

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Our political leaders keep referring to "building a bridge into the 21st century." That bridge is a very powerful metaphor, painting a vivid picture of moving from one century into the next. And the natural assumption is that our leaders will be there to guide us safely across the expanse into a new and better life in the future. I think we're all eager to take the journey, but I also believe that we're going to need a new style of leadership to ensure our safe passage into the 21st century.

What qualifies Wodraska to make a case for this new style of leadership? Perhaps it's a simple matter of being in the right place at the right time. Secretary of the Interior Bruce Babbitt recently commented that the two most perplexing issues in water management in the United States are Florida's Everglades and California's Bay-Delta. As the former Executive Director and CEO of the South Florida Water Management District and the current General Manager of the Metropolitan Water District, I find myself in the unique position of having been directly involved with both issues. If these experiences don't exactly make me an "expert" in creative leadership, they've at least given me a road map to follow.

FLORIDA FRICTION

Florida's Everglades are a wetlands ecosystem that has been significantly altered by human development. The significance of the Everglades in Florida's economy underscores the importance of maintaining the ecosystem. Both the state and federal government had created an extensive flood control and water conveyance system that came at a high environmental cost—reducing flows into the Everglades, resulting in the denigration of the natural ecosystem. In response to this environmental dilemma, the Florida legislature expanded South Florida Water District's responsibilities to include water use permits, surface water and stormwater management, land acquisition for habitat restoration and water quality protection.

With so many diverse stakeholder interests, South Florida made the decision to develop the Alternative Dispute Resolution (ADR), an approach to negotiation and consensus-building that seeks to identify common ground among various parties and build agreements based on mutual interests. These good faith negotiations unlocked doors for bolder strategies. And, by requiring technical findings to be made available for scrutiny by others, ADR fostered greater trust and respect for the District's abilities and intentions.

The success of the ADR process in finding a workable solution that was acceptable—at least in part—to all interests paved the way for the emergence of a new leadership dynamic in South Florida. Bringing together stakeholder interests to define the problems, understand the ramifications of each proposed solution and, in effect, "stand in the other guy's shoes," they were able to find enough common ground to finally tackle some complex water resource problems that had remained unresolved for decades. Through creative, adaptive leadership, they restored the Kissimmie River, developed a water quality plan for Lake Okeechobie and increased outflows from the St. Lucie Estuary. They didn't solve these problems by simply telling the stakeholders what to do and how to do it; instead, they asked enough probing questions to get the stakeholders themselves to agree on a plan of action.

CALIFORNIA CONFLICT

A stressed ecosystem also plays a vital role in California's water resource and economic infrastructure. The San Francisco/San Joaquin Bay-Delta, the hub of the state's water supply system, provides water to two-thirds of California's 32 million people. But exports from the Delta and upstream diversions have reduced the amount of freshwater flowing through the Delta. Furthermore, the listing of winter-run Chinook salmon and Delta smelt in the Federal Endangered Species Act resulted in periodic shutdowns which significantly decrease the reliability of supplies from the Delta.

Thus began a decades-long struggle among urban water users, agricultural and environmental interests for California's water resources—a struggle that produced a paralyzing gridlock for the state's long-term water management. When State and federal agencies tried to develop water rights standards to protect the beneficial uses of the Bay-Delta, the result was merely to intensify the controversy.

But as history has shown us, a common cause often makes for the most unlikely partnerships. Water industry leaders finally came to realize that no one's interests could be met without reaching some sort of agreement. A coalition of Northern and Southern California urban agencies came together to develop an "Urban Alternative." This remarkable change in leadership style set the stage for a major transformation in water resource management. In December 1994, Governor Pete Wilson signed into law the Bay-Delta Accord, paving the way for CALFED, a partnership of state and federal agencies, to begin the process of coming up with a long-term "fix" for the Delta. The CALFED process is based on negotiation and consensus-building among all stakeholder interests—urban, agricultural and environmental. It provides a forum for opposing interests to hear all of the issues, all of the various points of view, in order to come up with an equitable, long-term solution.

COAST TO COAST

The parallels between these two states continue to intrigue me. Take for example the recent elections. The November ballots in Florida and California included measures to fund nearly $1 billion each for ecosystem restoration in Florida's Everglades and California's Bay-Delta. Both are wetlands ecosystems that have experienced significant degradation and both have great impact on the economy of their respective states. But here is where the similarities end.

Save Our Everglades, an environmental organization dedicated to cleaning polluted farm drainage water that is damaging the Everglades, decided to go after Florida's mammoth sugar industry. These environmentalists argued that sugar farmers regularly spill the phosphorous-laden runoff from their growing fields into the Everglade waters. Several years ago, when the federal government sued the state of Florida for failing to meet water quality standards in the Everglades, a settlement (Everglades Forever Act) was reached in which sugar growers agreed to pay $295 million—about $25 an acre—as their portion of the clean-up costs. Florida state and federal governments would contribute the balance.

But environmentalists believed the sugar growers got off too lightly and insisted that polluters must pay. In response to this continuing controversy, Save Our Everglades sponsored an amendment to the state constitution that would tax all raw sugar at a penny-a-pound. Revenues, estimated to be about $900 million over 25 years, would be used to fund Everglades restoration.

Voters found themselves polarized over this issue. Sugar growers claimed the penny-a-pound tax would put them out of business—destroying thousands of sugar farming-related jobs. They placed the blame for the Everglades' problems on the South Florida Water Management District, the agency responsible for cleaning up the Everglades, accusing the agency of practicing "lax oversight with taxpayers' money."[2] And so, with the all the angst of a bad melodrama, Floridians made ready for battle, spending more than $30 million dollars on highly emotional, and often misleading, ad campaigns.

The amendment was ultimately defeated and, in a way, everyone lost. The growers are still obligated to come up with the $295 million agreed to in the settlement, but this will fall far short of the funds needed to complete the project. Accusations leveled at the water district have demoralized its employees and diminished confidence in public sector water management. Most importantly, because of the uncertainty, the future of the Everglades remains in jeopardy. The only thing Floridians can count on is years of litigation and vicious cycles of mutual distrust and fear.

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[2] Lori Rozsa, "Water manager strikes back," *Miami Herald*, November 3, 1996.

Ironically, on the West Coast these same competing interests—urban, agricultural and environmental—famous for engaging in decades-long water wars, reached an unprecedented agreement on a plan for restoring the Bay-Delta, one of the West Coast's most significant estuarine systems and through which Californians get 60 percent of their fresh water supply. They too placed a nearly $1 billion bond measure on the ballot, but the referendum, Proposition 204, received statewide bi-partisan support as well as endorsements from both President Clinton and Bob Dole.

In fact, proponents of the bill were worried that the lack of controversy might lead to defeat because so few voters had heard anything about it. Despite the lack of substantial media coverage, the initiative passed with a 63 percent approval rating.

Uncertainty can either bring us together or tear us apart. How was California able to overcome its traditional stalemate on water issues while Florida braces itself for even more conflict? Perhaps it's because the battle-weary West finally realized that insisting on an all out win leads to nothing but gridlock. By bringing all the players to the table and agreeing to negotiate a consensus-based compromise, California transformed its vicious cycles into virtuous ones. Learning, mutual understanding and a commitment to work together is the fundamental dynamic behind the process.

It's a new way of making laws . . . both at the state and federal level. In support of California's efforts to work together for the common good, a Republican Congress passed and a Democratic President signed a bill authorizing $430 million in federal funds for Bay-Delta restoration should Proposition 204 pass. Similarly, when Congress passed the Safe Drinking Water Act, they relied on the consensus approach to find common ground on which all the stakeholders could agree. Of course there was compromise, give and take, but there was also progress—forward progress to enact legislation that will benefit all.

More often than not, winning in today's complex, litigious society leads to nothing but gridlock. Winning begets lawsuits, not progress. It isn't even a matter of that overused buzzword *win/win*. It's rejecting the notion of winning and, instead, accepting learning, mutual understanding and negotiation as the only road to moving forward. Government isn't going to solve all our problems. Stakeholders are coming up with creative, adaptive answers to the hard questions and finding creative solutions everyone can accept.

Despite its progress in developing the ADR, Florida is today where California was in 1982 during the height of its water wars, when the voters overwhelmingly rejected a controversial engineering solution to the state's water problems. But as California has discovered, in today's environmental politics, it is consensus that leads to that "thrill of victory." A run for all the marbles will only reap "the agony of defeat."

THE MULHOLLAND MYSTIQUE

If we look at the history of water resource development, we find this approach to leadership through consensus-building is a relatively new one. When we think of water industry leaders from the past—icons with the vision and foresight to create an infrastructure on which to build our future—we think of "heroes" like Robert Moses, Joe Jensen and William Mulholland, whose leadership styles were crafted to suit a very different period in our history.

An Irish immigrant and self-taught engineer with a vision for a Los Angeles that could be, William Mulholland worked his way up from ditch-digger to become the first chief superintendent of the Los Angeles Water Department. Firm in his belief that "a city quickly finds its level and that level is its water supply,"[3] Mulholland was determined to find a new source of water that would allow the semi-arid desert known as Los Angeles to blossom into a booming port city of great influence.

His fight to claim water from the Owens Valley for Los Angeles is nearly as well known in American folklore as the stories about the American pioneers who tried to cross the famous Donner Pass. The development and construction of the 250-mile Los Angeles Aqueduct, powered solely by gravity, completed ahead of schedule and under budget, is a story of one man's personal drive and determination. Even when faced with the catastrophic failure of the St. Francis Dam, this unique leader never wavered in his belief that building a solid infrastructure to harness natural water resources for the benefit of Los Angeles was the only way to ensure the future growth and prosperity of the city and, indeed, the entire state.

Mulholland truly embodied the ideal of rugged individualism that characterized the building of the American west. Men like Mulholland, Moses and Jensen were superb engineers who were able to take a vision and make it a reality. That's what leadership was back then. And we are thankful for leaders like these whose tenacity and creativity gave us the infrastructure on which we have relied for so many generations.

But times have changed since these pioneers altered the course of history. Do we need another rugged individual to give us a solution to today's water crisis?

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[3] Margaret Leslie David, *Rivers in the Desert*, p. 26

Could the man responsible for creating the "Mulholland Mystique"[4] succeed in today's complex socio-economic-political climate? Or would his unyielding stubbornness in insisting on his own solution to the problem fuel the fires of dissent into Mulholland mania? In the early 1900s there was a clear, natural public interest in water for Southern California. Today's issues are not so clear-cut.

Engineering creativity and vision are still a vital part of any water resource solution. We rely on our project engineers to develop new ways to solve technological and ecological problems. But before the engineers can turn their vision into reality, we need to address the complex issues of the 1990s. And this calls for a different kind of leadership—leadership that brings together competing interests, guides them through the process of understanding each other's concerns and encourages them to work together to develop equitable solutions they can all support.

A NEW PERSPECTIVE

A friend of mine recently recommended a book entitled *Leadership Without Easy Answers*. Written by Ronald A. Heifetz, director of the Leadership Project at the John F. Kennedy School of Government at Harvard University, this book is the first I've read that supports a philosophy I've tried to incorporate into my own leadership style. Heifetz believes that "instead of looking for saviors, we should be calling for leadership that will challenge us to face problems for which there are no simple, painless solutions—problems that require us to learn new ways."[5] He suggests that today's successful leaders are not Mulhollands who say, "I have the solution . . . follow me." Rather they are leaders who induce learning by asking hard questions.

In developing his leadership philosophy, Heifetz makes a distinction between what he calls technical and adaptive problems. A technical problem is one that can be fixed with a simple, straight-forward solution. This was Mulholland's approach. First he identified the problem: Los Angeles needed water. There was water in the Owens Valley. The solution was to design a system to bring the water from its source to where it was needed.

In adaptive situations, however, the problem may be definable but no clear-cut solution is readily available. Heifetz cites the example of a Tacoma, Washington smelting factory faced with problems arising from high levels of arsenic air emissions. One of the largest employers in the area, the factory had become an

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[4] Ibid., p. 145.
[5] Ronald A. Heifetz, *Leadership Without Easy Answers*, p. 2.

economic lifeline for the community. The company was already using the best available technology to reduce emissions from their plant and could not remain in business if the Environmental Protection Agency (EPA) were to impose more stringent emission controls. On the other hand, local residents, fearing for their health, looked to the EPA to protect them.

Instead of issuing an arbitrary ruling, EPA Administrator William Ruckelshaus proposed to involve the community in facing this problem. In a speech delivered at the John F. Kennedy School of Government, Harvard University, this innovative leader had commented, "the role of the EPA Administrator in the 1980s should be that of an educator."[6] In keeping with this leadership philosophy, he arranged to hold local workshops and hearings to solicit the views and wishes of the people who would be most affected by an EPA ruling. Surprisingly, the local citizens were not only able to understand the complex issues of the problem, but they came up with some innovative suggestions for alternatives. After listening to the concerns of the various interest groups, they began to look at the situation in a new light. Rather than view it solely as a conflict between jobs and health, they began to think in terms of diversification of the local economy. They realized that choosing between jobs and health was not the real problem at all.

A year later the owners of the plant decided to close their doors. Had the EPA excluded stakeholders from defining and solving the problem, the town may not have survived. However, the response of the local citizens in first learning about the issues and then coming up with a consensus-based alternative had prepared the community to find new jobs for its workers and attract new businesses to the area.

Adaptive leadership is not an *easy* alternative. Exercising leadership from a position of authority in adaptive situations means going against the grain. It means taking a tremendous risk. In getting people to pay attention to the problem rather than trying to find someone to blame for it, the leader is asking them to change their way of thinking, to view the situation from someone else's perspective.

In Mulholland's day, the engineering challenges were monumental. The building of the Los Angeles Aqueduct was unique in water engineering. But the planning process, the decision-making, was not subject to the scrutiny of so many diverse interest groups. Yes, there was considerable controversy between the city, the farmers of the Owens Valley and the private investors who sought to make huge personal profits. But there were no organized environmental groups seeking to protect fish and wildlife, no serious opposition to the need for water to accommodate the city's growth. A single leader with the knowledge and charisma

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[6] Ibid., p. 110

of a William Mulholland could instill enough confidence in the public to take command of the project and see it through to completion.

Today our leadership challenges are far more complex. We must face not only the technical challenges of modern engineering but the socio-economic-political challenges of meeting the needs of a far more diverse group, of breaking the gridlock. Public process is the only way to get in-put and buy-in from stakeholders. If we fail to include the stakeholders, we run the risk of developing an incomplete solution or a solution to the wrong problem.

Mulholland was a visionary who took a technical problem—meeting the water needs of a growing population—and came up with a practical solution. Ironically, the same problems that confronted him in the early 1900s confront us today. But our problems require creative, adaptive leadership, something beyond the scope of Mulholland, Moses or Jensen. Today's visionary leadership means engaging people to deal with adaptive problems, directing the learning process and encouraging changes in people's attitudes and behaviors. It's a dynamic process that requires everyone's commitment.

LEADERSHIP FOR THE 21ST CENTURY

Unlike the pioneers of the water industry, today's public agencies no longer find themselves in the era of the "privileged monopoly." If we, as water management professionals, hope to lead our industry into the 21st century, we must meet the challenge of competitive marketing. We must create more than just *efficient* water agencies; we must create *effective* agencies that meet the needs of our customers and stakeholders.

At Metropolitan, our strategy to meet this challenge will focus on three key areas: *competitiveness, outreach* and *rate management.* And I firmly believe that these key areas will be embraced by the collective utility industry throughout the nation.

Competitiveness: The key to competitiveness is optimizing efficiency, minimizing costs and establishing additional revenues. This same principle applies to both retail and wholesale agencies and should be the foundation on which to build a revolutionary new approach to resource management.

Through Metropolitan's Business Enterprise Program, we've been examining a number of opportunities to enhance our revenues in a business environment. We're finding out which businesses we can get out of and where we can find some alternative revenue producing areas.

We recently signed an agreement with the Parsons Corporation of Pasadena to design and market a radically new and cheaper method of desalting sea water. This new process was pioneered at Metropolitan. We think it has a chance to be a wonderful alternative revenue producer for us by tapping a $28 billion market world-wide.

We have a patent pending on a break-through method of detecting *Cryptosporidium*. This process, which was pioneered at our Water Quality Lab at LaVerne, has implications for every water utility and water quality lab. It will cut the price in half and greatly reduce the time it takes to do the analysis. This is another potential revenue producer.

Our Real Property Management Program will identify prospective income-generating assets. We'll also be developing specific land use and facility projects as part of a comprehensive asset management program. And we'll be seeking new avenues through which to market Metropolitan's expertise in machine shop, water quality and human resources services.

<u>Outreach</u>: As we move into this new era of competitiveness, public outreach must take on an even greater role than it has in the past. Like our "cousins" in the power industry, we must strive to enhance our relationship with our customers (in Metropolitan's case, our member agencies) and to develop stakeholder and public support for our programs.

In California, developing stakeholder and public support for the CALFED process and proposed solutions is a top priority. When CALFED announces its final recommendations for a long-term Delta fix, we'll be looking at a cost of between $4-and-$8 billion. Even with the passage of Proposition 204 and the commitment of $430 million in federal funds for Bay-Delta restoration, raising the balance will be no easy task. And without broad-based public support, the task may be impossible.

Metropolitan is also committed to establishing an outreach program for the Colorado River. The long-range significance of water allotments, priorities and facilities cannot be overstated. Taking our cue from the consensus-building process that led to the signing of the Bay-Delta Accord, we hope to resolve some of these critical issues by bringing together stakeholders from all seven Colorado River Basin states as well as those diverse groups within our own service area.

But outreach must go far beyond garnering support for any one particular issue. It must be part of an overall plan dedicated to making *customer service* the number one priority of every utility. As part of this outreach effort, Metropolitan plans to develop a master water service plan for each member agency, identifying the types of water we provide, local resources with which Metropolitan may be assisting and other relevant water supply information. We'll then be in a position to prepare a priority list of new services, products and improvements for our member agencies.

Critical programs such as finance workgroups, purchasing and engineering technical forums will expand member agency outreach to a new level of interactive service. And, in response to requests for high-level technical assistance, we're looking into developing a "fee-for-service" member agency program for analytical contracts and training. We're even exploring the issue of Metropolitan's governance, the heart of the inter-relationship between the district and our member agencies.

Rate Management: The third element of meeting the challenge of competitive marketing is rate management. This is a trend you'll be seeing in utilities and businesses across the nation. We need to continue to keep the cost of our product down and realize that we are no longer a monopoly. We have to know how to get people to continue to buy their water from us.

At Metropolitan, our efforts will focus on effectively managing the Operations and Maintenance (O&M) and Capital Improvement Program (CIP) to be consistent with the Integrated Resources Plan and rate refinement goals. For the past three years, we have been implementing an aggressive cost containment plan. In 1993, in anticipation of demands up to 2.5 million acre-feet by 2005, we had a CIP of $6 billion. However, as a result of unusually plentiful rainfall, comprehensive conservation measures and a slowing in the growth of California's economy due to a severe recession, these demands did not materialize. In response to this lessening of demand, Metropolitan and its member agencies reduced the 10-year CIP estimate to just $3.9 billion, which we will invest in infrastructure.

Over this past year, Metropolitan has reduced O&M expenses by cutting 5% of our work force, and we have plans to trim another 10% over the next two years. The board recently adopted a five-year rate refinement plan. By 2001, readiness-to-serve charges—fixed annual payments made by each member agency—will rise nearly 50%, providing the district with a larger fixed revenue source. The remainder of Metropolitan's revenues will continue to be generated by the sale of water at an increase in cost no greater than 1.5% per year, less than half the projected rate of inflation. In real terms, allowing for inflation, the cost of Metropolitan's product will actually decrease over the next five years.

We'll also be focusing on ensuring that long-term, cost-effective power supplies are available to Metropolitan. This means developing a consensus proposal for de-federalization of the Power Marketing Administrations in concert with regional stakeholders; participating in the California Public Utility Commission's implementation process for restructuring the electric utility industry in California; and participating in the Federal Energy Regulatory Commission's open access transmission process.

PRIVATIZATION

I mentioned earlier that today's public agencies no longer find themselves in the era of the "privileged monopoly." What has brought about this change? There is, of course, no simple answer, but one of the most influential factors in the emergence of competitive marketing must be the recent trend toward privatization in the utility industry. Historically, water supply and treatment operations in the United States were small, privately held companies. They tended to be independent operations with few economies of scale. The Great Depression ushered in an era of federalism whereby state and national governments constructed, financed and operated large storage and conveyance facilities. Federal and/or state grants and loans were made available for private construction of water facilities.

But current political sentiment calls for dramatic changes to correct what has been perceived by some as mismanagement of public resources. Of course, privatization is not the single solution for problems that exist within today's water agencies. It is, however, one way to address structural problems that are evident in most public agencies. Metropolitan believes that the lessons learned from privatization can be applied to improve almost all public agencies.

As applied to the water industry, privatization is a broad term, ranging from complete transfer of ownership to something as simple as contracting out a custodial service.

Full Privatization: An example of full privatization is the selling off to the private sector of 10 large British water service companies in 1989.

BOOT: Then there is Build-Own-Operate-Transfer, or BOOT, privatization, patterned after the French concession model in which the facilities revert back to the government at the end of a specified contract. About three-quarters of the water suppliers in France are private. This plan has been very successful where there is a lack of capital or expertise, as in developing countries.

Operation and Maintenance (O&M): Finally, 450 U.S. water and sewer agencies have signed one to five-year contracts with private companies for the operation and maintenance of their facilities. This approach typically saves the agencies 15-30 percent in operating costs. But studies have shown that privatization may not be cheaper in the long run, especially where there is no proprietary knowledge, and technology is critical to the process. Furthermore, the rate of return to the private operator must be built into the rates.

What has happened in the public sector to make privatization seem so attractive? According to the National League of Cities, more than 50 percent of U.S. cities are currently facing budget deficits. Labor remains a volatile issue, with hiring and firing policies strictly monitored. And, due to regulations such as those included in the Safe Drinking Water Act and the Clean Water Act, the cost of providing drinking water and treating wastewater has risen dramatically. There are also a number of mayors who are anxious to reduce the size of government and turn to privatization as a quick fix.

But privatization is not without drawbacks. Profit-driven, tax-paying companies have a 20-30 percent built-in financial disadvantage, and payment of high dividends by private companies leaves little funding for capital improvements. Opposition from organized labor, stemming from corporate down-sizing, is another impediment. There is also an ethical question regarding the use of public assets as "cash cows."

Many public facilities were constructed with government subsidies and favorable depreciation schedules. The sale of assets that have benefited from public financial aid and accelerated depreciation may be a one-shot, short-term remedy for a fiscal crisis and may jeopardize the financial status of the public entity, perhaps in the form of a lower credit rating. Nevertheless, the private companies have had several successes in taking over public-operated facilities. They must be doing something right!

The key seems to be innovation—in productivity and preventative maintenance, work force cross-training, and extensive use of automation and management technology.

Metropolitan is seeking to improve its water resource management skills by applying the principles of privatization. As part of this process, we've undertaken a number of innovative programs including benchmarking against private agencies in terms of overall quality, service and cost-effectiveness; gap analysis comparing our operations to those of private companies; outsourcing selected business engineering and specialized training services; and participating in a Competitiveness Council to identify cost-effective outsourcing opportunities.

A WAKE-UP CALL

These are just a few of the steps all of us can and should take if we want to retain the privilege of leading the water industry into the 21st century. While *privatization* is the hot new buzz word in the utility industry, I prefer the word *competitive*. Just as the electric industry—especially in California—has gotten the wake up call, so too has the water industry. We must make it our goal to be competitive with any other agency, public or private, that wants to do what we do. In the process, we will become better, leaner, more efficient agencies. The impetus to privatize is going to have a beneficial impact on the 16 million people in Metropolitan's service area, and we have committed ourselves to be major players in the creation of those benefits.

My vision for the future of the water industry is a hybrid approach, taking the best of the public and private sectors and integrating them into a well-managed water agency that legitimately represents the public interest. This is where I plan to lead Metropolitan: on a new course of managed competition, providing stewardship in the water industry and responsive service to our customers, and relying on a consensus-building approach to problem solving. We're adapting to protect our financial integrity and reliability while positioning ourselves for the future.

Leadership's a tricky business, a risky business. But I'm an optimist and I believe we're headed on the right course. Let's just keep our fingers crossed that whoever is leading us knows enough to stop and ask for directions along the way.

MACHU PICCHU: ITS ENGINEERING INFRASTRUCTURE

Kenneth R. Wright[1] *Ruth M. Wright*[2]

"Did you say samples from Machu Picchu?" asked the inspector. Our luggage at the Lima airport had just failed the x-ray test as we were checking in for the flight to Miami in January 1996. "Yes," Ken said, "the dark spots on the screen are the Machu Picchu samples." While Ken answered the inspector's question, Ruth extracted a special governmental resolution from her handbag and put it into the inspector's hands who, upon reading a few lines said, "Excuse me for any inconvenience, sir!"

We were at the airport with seventy pounds of moist agricultural soil samples from the ancient Machu Picchu terraces. We were heading to Colorado to test the samples for agronomic characteristics. The bags of soil absorbed the x-rays like lead weights. There was no mistaking the mass in the luggage. The governmental resolution was from the Instituto Nacional de Cultura, signed and dated by the director himself, just the day before. The formal resolution identified us and the Machu Picchu samples and, with proper Peruvian flourish, described the need for scientific testing in the states.

"Why soil samples from Machu Picchu?" you might ask. Well, obtaining the soil analyses was an important step in defining the ancient agricultural potential at this mountain-top royal estate of the Inca ruler Pachacuti. The rich topsoil had been carried to the terraces some 500 years ago to create 4.5 hectares of primary agricultural land on the steep site to help demonstrate the Inca power over the land. In a similar way, the flow of water through the sixteen fountains of Machu Picchu demonstrated the Inca power over the water.

In April of 1994 the Peruvian Embassy in Washington had telephoned us in Denver to say that the long-awaited and much sought-after archaeology permit had been issued for paleohydrological studies at Machu Picchu. What a surprise it was to hear the word "issued," because it had been ten years of waiting, filing applications and justifications, telephoning, and writing proposals for a permit to conduct hydraulic engineering studies at Machu Picchu. Ken hadn't at all given up on the permit, but somehow, when it arrived, he was a little surprised. "What do I do first?" he asked himself. Seeking the permit had been so time consuming that now that it was time for action, Ken realized that his plans needed formulation and the skeleton outline of the engineering research proposal needed substantial flesh.

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[2] Member of Board, Northern Colorado Water Conservancy District, Loveland, Colorado.

In October of 1994, Ken and Ruth Wright arrived in Cusco on a 7:00 a.m. flight from. Our first job was to retain a local registered archaeologist recommended by Dr. Gordon McEwan of the Denver Art Museum. Our permit requires that we employ a local registered archaeologist. Fortunately, Professor Alfredo Valencia Zegarra of the Universidad de Cusco answered our hurried telephone call and met us at the Royal Inca II for coffee; before the day was over, our basic core research team was functioning and formulating detailed plans!

Professor Valencia was tailor-made for our hydrological and engineering research at Machu Picchu. He had served as resident archaeologist at Machu Picchu years earlier; he seemed to know every stone and structure as if each was a friend; he was already studying the water canal which served the Wari administrative center of nearby Pikillacta a thousand years ago; and he understood what we wanted to do. Professor Valencia's wife, Señora Arminda Gibaja Oviedo, serves as director of the Cusco Regional Museum of the Instituto Nacional de Cultura, and the two of them had recently completed the best archaeological summary publication on Machu Picchu entitled, *Machu Picchu: La Investigatión y Conservación del Monumento Arqueológico Después de Hiram Bingham* (Valencia and Gibaja 1992) (Fig. 1).

Fig. 1. Arminda Gibaja Oviedo and Alfredo Valencia Zegarra of Cusco, Peru. Professor Alfredo Valencia is the registered archaeologist for the Machu Picchu Paleohydrological Survey Project. Señora Arminda Gibaja is Director of the Cusco Regional Museum and the spouse of Professor Valencia.

After our third cup of coffee and several hours of discussion which led to a signed agreement between Professor Valencia and the Wrights, Ruth leaned back and said, "Things tend to work out if one has faith!"

THE PROJECT

The permitted paleohydrological and engineering research at Machu Picchu is about sixty percent completed, with good progress being made on our objectives. Our five objectives are:

1. Evaluation of the ancient Inca spring on the north slope of Machu Picchu Mountain and its relationship to the Machu Picchu geologic fault;
2. Hydraulic analysis of the 749-meter-long Inca domestic water supply canal which traverses the steep mountainside, crosses the Lower Agricultural Sector, and terminates at Fountain 1 adjacent to the Temple of the Sun;
3. Study of the hydraulic system of the sixteen fountains in the Urban Sector;
4. Determination the paleo-agronomic character of the agricultural terraces in terms of rainfall adequacy and food production capability; and
5. Study of the urban drainage infrastructure of Machu Picchu to determine how the Inca kept the royal estate from flooding with nearly 2,000 millimeters of rainfall each year.
6. Exploration of new hydraulic components and of miscellaneous general interest features. A gold bracelet was discovered in one of the excavations for our agricultural soil samples (Fig. 2).

THE RESEARCH SITE

Machu Picchu, the royal estate of the Inca ruler Pachacuti (Rowe 1990) is the most well-known of all Inca archaeological sites. It is situated on a high mountain ridge at 2,438 meters above sea level between the two prominent peaks of Machu Picchu and Huayna Picchu. The ridge plunges downward precipitously on both sides some 450 meters to the Urubamba River. It supported a permanent population of about 300 people with a peak of 1000 for nearly a century, from 1450 to 1540 AD (Hemming and Ranney 1982).

Fig. 2. The Machu Picchu gold bracelet found buried adjacent to an early stone wall which itself was buried west of the Temple of the Condor. The bracelet now resides in the Cusco Regional Museum.

Machu Picchu lies about 1,400 kilometers south of the Equator on the eastern slope of the Andes of Peru (Fig. 3). The site lies near the headwaters of the Urubamba River, a tributary to the Amazon River at longitude 72°32' and latitude 13°9'. There are two Inca trails; one to Cusco and the other to the lowlands of the Amazon.

Geologic faults cross the Machu Picchu ridge setting (Fig. 4). The Machu Picchu fault set the stage for the Inca water supply source by helping create the ancient primary spring water supply at elevation 2,458 meters and east of the ancient perimeter wall. A second spring emerges 40 meters higher up on the mountain slope and drains into the domestic water supply canal.

During the time since the Instituto Nacional de Cultura granted the 1994 permit, we have conducted six field trips to collect data, perform instrument surveys of the plans and profile of the canal, measure and test the spring water flow, do mapping, inspect the agricultural terraces, and search for drainage outlets and undocumented structures on the thickly-forested lower slopes of the site. Each time we arrive at Machu Picchu for the continuing research effort, my feeling of admiration for the ancient workmen and planners grows.

Professor Valencia makes it clear that the miracle of Machu Picchu is largely unseen. His many archaeological excavations at Machu Picchu have shown him what lies beneath the ground surface. The miracle is in the underground foundations, the subsurface preparation of the drainage, and the thoughtful underground work which created the structural basis for the walls, terraces, stairs and buildings of Machu Picchu. Their lasting through the centuries is a result of the ancient foundation preparation.

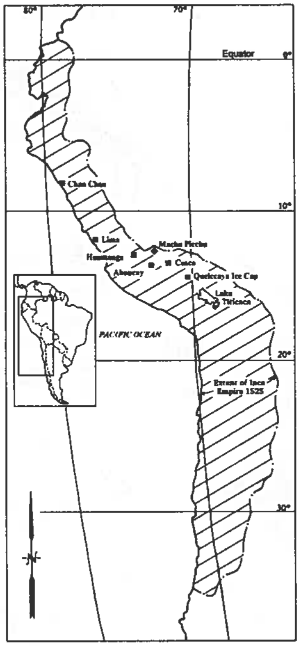

Fig. 3. Map of the Inca Empire in 1525 showing the capital of Cusco and Machu Picchu. The colonial city of Lima is shown for reference purposes.

Similarly, we are now seeing that another miracle of Machu Picchu is the engineering infrastructure consisting of the water supply, canal, fountains, agricultural terraces, and urban drainage network that made the royal estate a habitable, civilized environment with then-appropriate urban amenities. As we study and document these infrastructure facilities, tangential surprises turn up such as the potential ancient figurative wall art "hummingbird" which is judged by Inca period experts to likely be merely "random stone placement". Then there are the utilitarian baths far down on the mountainside incorporated into the little-explored or mapped agricultural terraces seemingly hanging out over the Urubamba River and visible from the peak of Huayna Picchu.

THE MACHU PICCHU WATER SYSTEM

Hiram Bingham was on track in April 1913 when he told *National Geographic Magazine* readers that "the Incas were good engineers". Over eighty years later, we have reaffirmed Bingham's opinion about the Inca workers after intensive field research on the hydraulic and agricultural infrastructure of Machu Picchu (Wright, McGregor, Kelly & Valencia) (Figure 5).

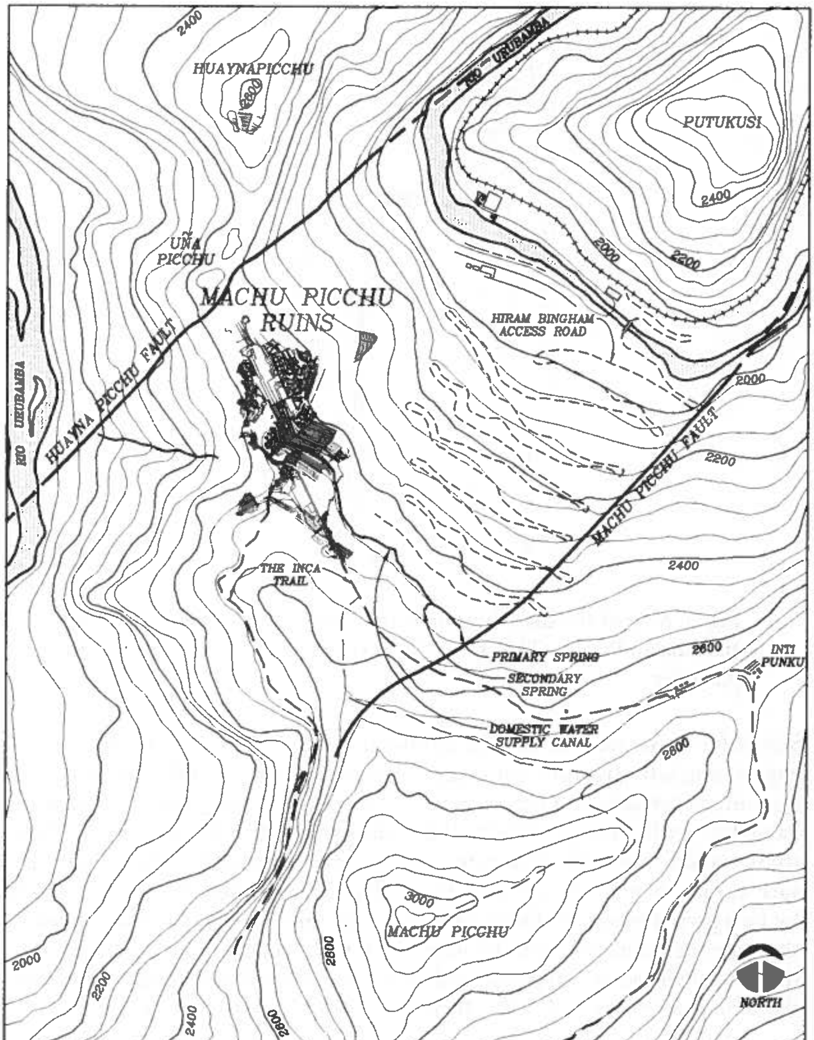

Fig. 4. Machu Picchu and environs showing the two main geologic faults associated with Machu Picchu.

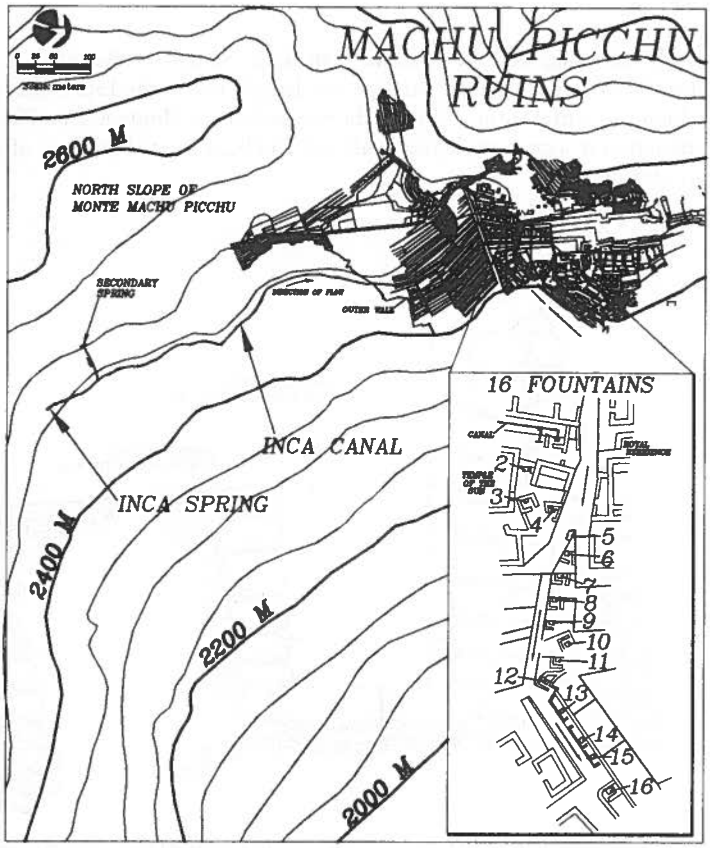

Fig. 5. Site map showing Machu Picchu, the Inca canal and spring, and the sixteen domestic water supply fountains.

The Spring

When the Inca engineers surveyed the high ridge 450 meters above the Urubamba River after cutting through the dense forest in the 15th century, they found a natural spring. It is on the north slope of Monte Machu Picchu—a manifestation of a giant geological fault that had been created millions of years before (Fig. 6).

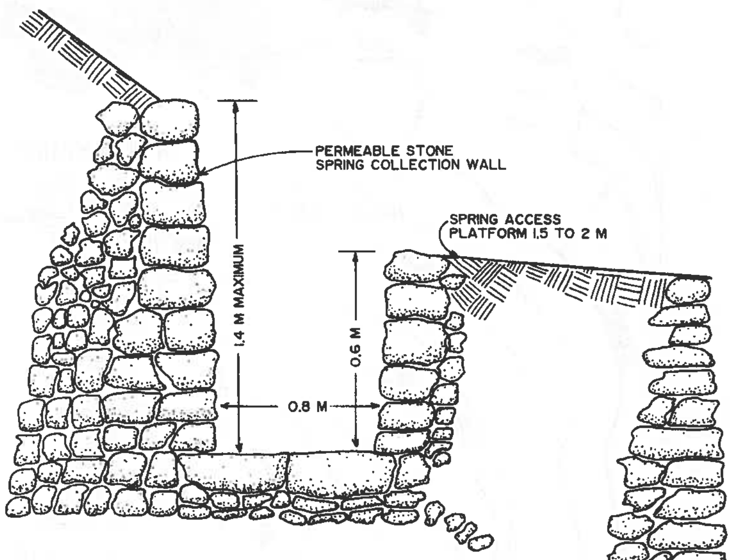

Fig. 6. Spring Cross-Section. Ancient Inca spring collection works at Machu Picchu showing the permeable stone wall inserted into the mountainside to collect groundwater from the steep slope.

Developing the spring with a steep earth cut and then building a sturdy permeable stone wall was the next step for the Inca workmen. When it was completed, water running through the permeable stone wall was pure and clear (Table 1). The basic water supply for the new royal retreat was assured!

Table 1. Machu Picchu Domestic Spring Water Quality Sampling Results

	Units	October 1994	February 1995	January 1996
Inorganics				
Total Dissolved Solids	mg/L	40.00[1]	30.00	35.00[2]
Total Alkalinity	mg/L	11.10[1]	11.40	14.00
Total Kjeldahl Nitrogen	mg/L	<0.20[1]	<0.20	<0.20[3]
Ammonia-N	mg/L	<0.80[1]	–	<0.80[3]
Chloride	mg/L	<0.25[1]	–	0.87
Sulfur	mg/L	0.233[1]	–	4.42
Dissolved Metals				
Manganese	mg/L	<0.004	<0.004	<0.004 (0.0055)[4]
Copper	mg/L	<0.012	<0.003	<0.003
Zinc	mg/L	0.03 (0.04)[4]	<0.10	<0.10
Iron	mg/L	0.035	<0.04	<0.04
Aluminum	mg/L	<0.09	<0.09	<0.12
Sodium	mg/L	1.80	4.30 (2.10)[4]	1.80 (0.23)[4]
Potassium	mg/L	<0.41	<0.41	0.58
Calcium	mg/L	2.60	3.00	3.60 (0.26)[4]
Magnesium	mg/L	0.53	0.48	0.58
Total Metals				
Manganese	mg/L	0.009	<0.004	0.01 (0.0055)[4]
Copper	mg/L	<0.012	<0.003	<0.003
Zinc	mg/L	0.03 (0.04)[4]	<0.10	<0.10
Iron	mg/L	0.20	0.05	0.24
Aluminum	mg/L	0.33	<0.09	0.20
Sodium	mg/L	1.60	3.20 (2.10)[4]	3.00 (0.23)[4]
Potassium	mg/L	<0.41	<0.41	0.65
Calcium	mg/L	2.70	3.00	4.10 (0.26)[4]
Magnesium	mg/L	0.65	0.51	0.74
Radioactivity				
Gross Alpha	pCi/L	0.8 (+/- 1.2)	0.0 (+/- 1.1)	–
Gross Beta	pCi/L	3.2 (+/- 3.2)	0.0 (+/- 2.4)	–
Field Measurements				**July 1995**
Water Temperature	°C	14	14	16
Conductivity	µs/cm	30	25	35
pH		7.2	7.3	6.45

[1] Sample was filtered in lab with 0.45 micron filter to remove suspended material believed to be organic matter.

[2] Sample received and analyzed outside holding time.

[3] Analyses performed on an unpreserved sample.

[4] This element was detected in the reagent blank. The blank value was not subtracted from the sample result. Blank value shown in parentheses.

The Canal

Carrying the water to the new community site was another matter. Walking back and forth to the spring to fill the aryballo water containers would be time consuming and there would not be the sight and sound of rushing water. It was not practical to require inhabitants of the mountain top retreat to hike to the spring to get water. A survey of the spring location showed that it was too low in elevation to deliver water by gravity flow to the actual ridge top; but on the other hand, a canal could deliver running water by gravity to a point about 15 meters lower on the steep sideslope which plunged precipitously to the Urubamba River below.

Getting the water to the city would not be easy as the canal would need to traverse the steep north slope of Monte Machu Picchu which would be exposed to earth slides because of its steepness and the mantle of rich, highly organic soil. The slope of the mountain face was nearly thirty-eight degrees. A canal would need to be built on flat ground supported by stone terrace walls ranging from about 2 to 6 meters in height. This would be no ordinary terrace; it would need to be well-founded and permanent for all time!

The route of the canal was laid out. The terrace wall was built and a canal was constructed on flat ground to carry the spring flow by gravity. To prevent sediment accumulation in the bottom the slope of the canal could not be too flat, and to avoid dangerously high flow velocities which might cause water to jump the canal sides it could not be too steep. The Inca engineer settled on a slope ranging from 4.8 percent near the spring to 1.0 percent reach across the Agricultural Sector within the outer walls (Table 2).

Table 2. Hydraulic Characteristics of Inca Water Supply Canal At Nominal Flow Of 300 L/Min

Reach	Typical Cross-Section								
	Length (m)	Bottom Width (cm)	Top Width (cm)	Depth (cm)	Canal Slope (%)	Flow Depth (%)	Flow Area (cm^2)	Velocity (M/sec)	Froude Number
Urban Sector	48	10	11	16	2.7	41	67	0.76	0.95
Agricultural Sector	153	12	12	12	2.9	68 [1]	98 [1]	0.52 [1]	0.58 [1]
Lower Mountain	461	12	13	10	2.5	54	67	0.74	1.0
Upper Mountain	87	12	14	10	4.8	44	53	0.96	1.5
Total	749								

[1] Based on a limiting 31 meter reach at a slope of 1.0 percent.

The slope and cross-sectional size of the canal were chosen to be a practical balance between three constraints: the elevation loss needed for good gravity flow, the location of the first and the highest fountain in the center of the new community, and the need to efficiently transport the typically small dry season spring yield of about 25 liters per minute and maybe as little as 10 liters per minute in drought years. The Inca engineers settled on a small canal to be lined with cut stone which would then be sealed with clay if needed. The total length of the canal would be 749 meters.

If too much water entered the canal from either the primary spring or the nearby secondary spring, or even from surface runoff during a heavy rainstorm, the water could create an erosion problem. For this reason, the Inca engineers built a relatively flat reach into the canal some 31 meters long in the Agricultural Sector (Fig. 7). Excess water would overflow from the canal, upstream of the Urban Sector, onto the agricultural terraces below. Excess water could also be controlled at the dry moat just upstream of the Urban Wall. Here, the canal was supported on a stone aqueduct over the moat which served as a main drainageway. Excess amounts of water could spill over and into the drainageway.

Fig. 7. Inca domestic water canal entering the Agricultural Sector. Cut granite stones forming the right bank contribute to hydraulic efficiency. The two-story building was for grain storage.

The new canal was carried through the Outer Wall and Urban Wall in small holes just big enough for the canal. When the canal reached the Urban Sector where the priests and high officials would see and have regular access to the canal, it was built straight as an arrow and at a uniform grade. Capacity was provided so that rainfall runoff from a few buildings uphill could be discharged into the canal, but only after the water flowed across a short grassed area (Fig. 8).

Finally, the canal reached a point where the first and highest fountain would be located. It was here that the Inca workmen built the royal residence so that the Inca ruler Pachacuti would have first use of the new water supply. In fact, Fountain 1 was situated nearly at the front door of the residence and just above the Temple of the Sun, which Hiram Bingham described as having a wall containing the most beautiful stonework in all of South America.

The new canal was built in an efficient manner. It would reasonably carry as much as 300 liters per minute, a lot more than needed and more than the mountainside springs would flow, even in the rainy season. The Inca engineers did not want to cut corners on the important water supply canal, so to help guard against canal problems, an access foot path was provided for canal inspection and maintenance for its full length.

Inca Power Over the Water

In planning the new water supply for Machu Picchu the Inca workmen realized that it had to do more than just satisfy the thirst of the inhabitants. The water supply works should be able to create a show of power! This meant that the sight and sound of jetting water plunging into water-filled basins along the "Longest Stairway" was needed. The sight and sound of water in a long line of fountains should be evident for a wide range of flow, from 10 liters per minute to 100 liters per minute, a range of ten times from minimum to maximum flow. For this multiple use of the domestic water supply the Inca builders would call upon their fountain specialists.

Fountains

The elevation of Fountain 1 was controlled by the skill of the Inca canal engineers who were able to define a reasonable grade for the gravity flow canal from the spring water source across the steep mountainside, through the Agricultural Sector and then into the Urban Sector. The "Longest Stairway" in the heart of the community would then define the exact location of Fountain 1 once the fountain elevation was established by the canal grade.

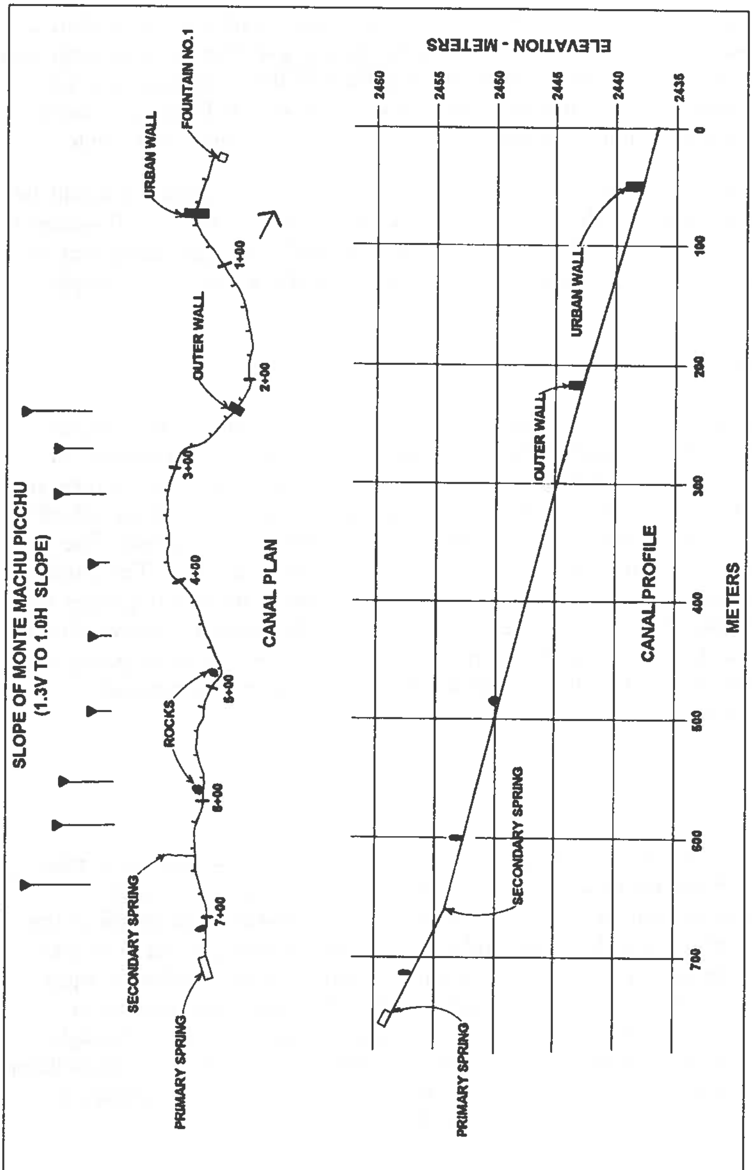

Fig. 8. Plan and profile of Machu Picchu domestic water supply works from the Primary Spring to Fountain 1.

Fountain 1 would have a walk-in enclosure complete with a niche for idols, a rectangular stone basin 45 x 60 centimeters in area and 20 centimeters deep with a circular outlet. To demonstrate the stonecutter's skill, a polished, curved, open channel would carry away water from Fountain 1 to Fountain 2 under and across an important north - south, level walkway about 1 meter wide.

While Fountain 1 would serve the Inca ruler's residence, Fountain 2 would be in the area between the open Wayrona and the Temple of the Sun. Fountain 2 was tucked in between the two buildings at the end of an open passageway to provide a semblance of privacy for the users as well as a ready water supply.

The Sacred Fountain

A special fountain was needed below the Enigmatic Window (a.k.a. Serpent Window) in the Temple of the Sun. This would be the Sacred Fountain, or Fountain 3. This fountain was polished and contained four niches. However, a potential unique feature of Fountain 3 was that it could be turned on and off using a bypass channel, that is, if the bypass channel is of Inca origin. The water could be diverted directly to Fountain 4 from Fountain 2. This would have meant that the priests could have the sight and sound of jetting water into a water filled basin, or relative peace and quiet at the adjacent ceremonial rock platform just to the east of the Enigmatic Window. I will be investigating the origin of the "bypass channel" further with the Machu Picchu resident archaeologist.

Fountains 4-6

To round out the fountain placement and design at the focal point of Machu Picchu, Fountain 4 collected water from either Fountains 2 or 3, or in combination from both. Fountains 5 and 6 were situated in the middle of the bifurcated "Longest Stairway" and provided a roar of falling water to all who might pass by (Fig. 9). These fountains were almost directly below the open wall of the Wayrona which provides a view of the magnificent mountains across the Urubamba River as well as of the ceremonial platform. The sight and sound of the fountains, when coupled with the roar of the Urubamba River below, must have complemented the view of the mountains in a manner to impress even the most indifferent of visitors.

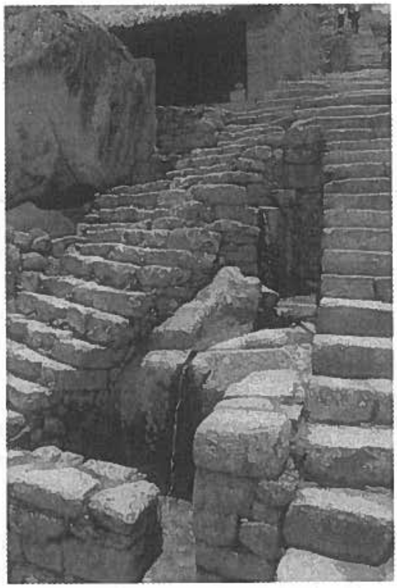

Fig. 9. Fountain Nos. 5 and 6 with the "Longest Stairway" (To the left and out of the picture is the Temple of the Sun).

The stonecutters challenged themselves between Fountains 5 and 6; they cut a bifurcated channel for beauty and hydraulic interest. Downstream of Fountain 6 a special channel was cut in the granite rocks with a plunging entrance to an underground channel leading to the next fountain.

It was planned that there would be a total of sixteen fountains in all. That meant that there would be ten more fountains constructed along Machu Picchu's "Longest Stairway", also known as the "Stairway of the Fountains".

The Private Fountain

Nine of the next ten fountains were for public use with the sixteenth being a private fountain accessible only from the Temple of the Condor area.

Fountain 16 was special with high walls for added privacy, and a 1.6-meter-high water drop into the stone basin at the bottom. Due to the fact that this was the last fountain and the need to protect the purity of the water no longer existed, the engineers routed an important drainage path into the Fountain 16 enclosure, directly to the stone basin at the bottom. During low flow periods, the users of Fountain 16 would not normally dip water from the stone basin as they could have in the other fountains. This would be particularly true if it was raining and there was surface runoff entering the stone basin.

Fountains 7-15

Fountains 7 through 15 would be similar to the rest, with no special hydraulic specialties incorporated into them, except between Fountains 9 and 10 and at No. 12. Here the designers used their ingenuity and engineering skills to reverse the flow direction of Fountain 10 by carrying the water through a channel built within the wall (Fig. 10). Then they proceeded to cut a surface channel with two right angles so the water would flow into the fountain enclosure from the east, rather than from the west as with all the other fountains. A unique feature exists at Fountain 12 where the stonecutters shaped a smooth polished lip for the approach channel terminus to help create a good jet of water which would spring free from the back wall of the fountain enclosure.

What to do with the flow in the fountains following Fountain 16? The water from Fountain 16 was routed underground to discharge into a narrow, steep channel on the west side of a long staircase which conveniently went all the way to the "Dry Moat", a large, steep drainage and flood control channel which separated the Agricultural Sector from the Urban Sector.

The sixteen fountains stretch from west to east a distance of 51 meters with a fall of 26 meters. This allows for adequate slope between fountains to efficiently carry the water flow from one to another and still provide for a typical 1.2-meter drop within the fountain.

The flow through the fountains was limited hydraulically to 100 liters per minute through the use of a smaller circular outlet with a diameter of only 3.8 cm from the basin of Fountain 4. Here, if the flow exceeded 100 liters per minute, the stone basin would fill and overflow relatively harmlessly onto the granite stone staircase until adjustments could be made upstream. To limit fountain overflows, the canal flow could be regulated in the Agricultural Sector where the 31 meters of 1 percent slope canal existed and where the excess water would be easily spilled to the agricultural terraces where an elaborate and well-designed drainage system existed, or the excess flow could be directly spilled into the dry moat where the canal-bridged aqueduct had been constructed over the moat. In either place the canal flow could be easily regulated to limit the flow into the Urban Sector to the desired amount without erosional damage.

Fig. 10. Fountain No. 10 with water jetting from east to west. All other fountains jet from west to east.

Were They Good Engineers?

Hiram Bingham was correct when he said the "Inca were good engineers"(Bingham 1913). Bingham fortunately was a good photographer and documentor of evidence. His classical photo (Bingham 1930) showing the Agricultural Sector and the complete route of the canal across it demonstrates that the canal had not failed even after more than three centuries of abandonment. His photo shows the 1 percent grade reach of 31 meters in length. His 3-D drawing of the community (Bingham 1930) clearly shows the canal aqueduct over the "Dry Moat", the aqueduct which has been lost and the span filled in.

Had Bingham more time and less to do during his 1912 work at Machu Picchu, he might have further mapped the water supply system from its source to its ultimate disposal. Bingham would have likely concluded that the Inca were extraordinarily good at hydraulic engineering planning and design. Their public works infrastructure capabilities were a tribute to their accumulated empirical knowledge and ability to blend what nature provided with man's needs!

Additional Fountains

The clearing of the tropical forest and debris from several lower and less accessible agricultural terraces on the lower flanks of Machu Picchu by the paleohydrology team during 1995 and 1996 resulted in the documentation of additional fountains and baths. The first two structures found in July 1995 were simple baths, but well suited for the workers to wash up in before climbing back up to Machu Picchu with their agricultural bounty (Fig. 11). The water supply for these two baths came from the uphill subsurface drainage system of the adjacent agricultural terraces. This represents an example of water reuse at Machu Picchu.

Fig. 11. Exploration was conducted on the Lower Agricultural Terraces. The author is shown at an agricultural worker's bath area which utilized drainage seepage water.

Then in the winter of 1996 the fountain exploration really paid off. Further north, down at the base of Huayna Picchu and with a spectacular view of the Urubamba River and the granite mountain peaks to the northeast, our team found two ceremonial fountains at the intersection of two grand granite staircases.

Ken had requested that Alfredo Valencia start cutting a trail into the area prior to the August 1996 research trip, and the trail clearing started a few weeks before my arrival (Fig. 12). Already on August 6 people in Cusco were discussing the "new fountain discovery".

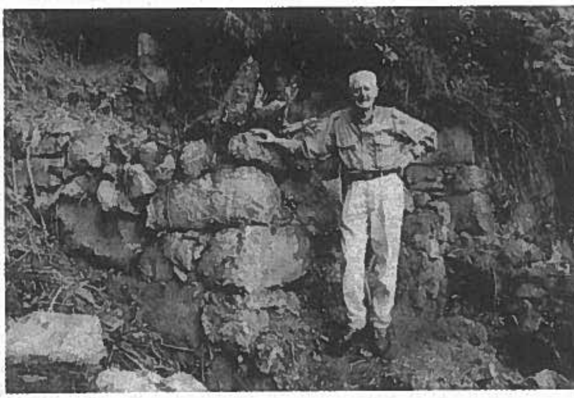

Fig. 12. The author beside one of the new ceremonial fountains recently rediscovered. An additional fountain lies to the author's left which still needs to be excavated under the authority of the Instituto Nacional de Cultura.

Actually, the new ceremonial fountains complete with Inca pottery pieces were not discovered, but "rediscovered". Back in 1969 Alfredo Valencia had spotted the fountains after a forest fire had burned the mountain slopes of their vegetative cover! The locations of the fountains were not documented, but Alfredo, like most top-notch field archaeologists, had a feel for the approximate site. Again this proved that fortune smiled on our project team when we engaged Valencia as our local registered archaeologist.

The lower terrace baths and fountains are a matter for continued study and documentation by the paleohydrologic team; however, the two baths and the two ceremonial fountains have already been cleaned and partially field measured, and show the careful planning and construction performed by the Inca builders of Machu Picchu. One of the two ceremonial fountains will require excavation by the INC prior to final study and measurements. Dr. José Altamirano Vallenas, Director of the Instituto Nacional de Cultural Departamental Cusco, plans to have the area furthered cleared and make the new ceremonial fountains a new tourist area at Machu Picchu.

AGRICULTURE

Our scientific research interests extended to the agricultural production potential of ancient Machu Picchu (Wright, Wright, Jensen & Valencia). We conducted complete agronomic soil tests at the Colorado State University Soils, Water and Plant Testing Laboratory in 1996 on samples excavated by Señorita Elva Torres Pino of the INC. In obtaining a soil sample in one of the plazas, an ancient Inca wall was uncovered. At the foot of this long buried wall a gold bracelet was discovered—the only gold object ever found at Machu Picchu.

It was Dr. José Altamirano Vallenas who turned the soil samples over to me in his corner office of the grand colonial building which serves as the INC Cusco Departmental headquarters. Dr. Altamirano and Ken discussed the scientific need for the soil analyses, but we also talked about the beautiful gold bracelet found by Señorita Torres.

The size of the main agricultural areas was determined from our detailed maps (Fig. 13). It totals 4.5 hectares (11.1 acres). We needed to know what the likely precipitation was in ancient times, so we correlated the modern weather records for 1964-1977 with ice core data from the Quelccaya Ice Cap shared with us by Dr. Lonnie Thompson of the University of Ohio. The ice cap is situated halfway between Machu Picchu and Lake Titicaca. We found that the period of occupation (1450-1540 AD) likely experienced rainfall of 98 percent of the long term average, or 1940 millimeters per year (Table 3). We used the modern record for temperature and wind in our computations.

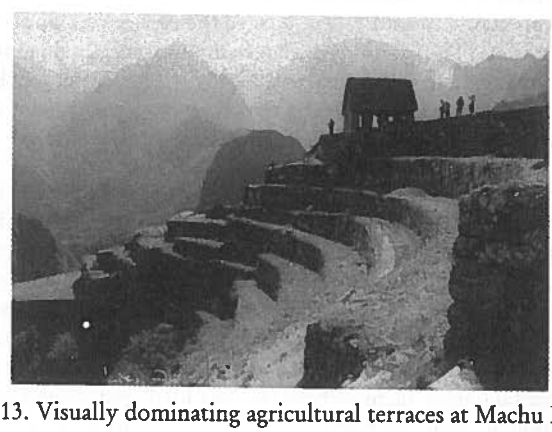

Fig. 13. Visually dominating agricultural terraces at Machu Picchu.

Table 3. Annual Precipitation[1] at Machu Picchu By Decade Relative to Normal Long-Term (540-1984 AD) Precipitation

Decade	Percent of Long-Term Normal	Equivalent Annual Precipitation (mm/yr)
1450-59	89	1770
1460-69	96	1900
1470-79	92	1830
1480-89	89	1770
1490-99	94	1860
1500-09	102	2020
1510-19	108	2150
1520-29	99	1980
1530-39	112	2220
Average	98	1940
1964-1977	99	1960

[1] Ancient precipitation estimates based on correlations with ice core analyses results from the Quelccaya Ice Cap.

Then the real work began. What was the solar radiation at Machu Picchu, what crops should be chosen for the calculations, what was the nutrient content of the crops, and how many calories per day would have been needed by the Inca people? To help with the answers we called in Dr. Marvin Jensen as a consultant to help with the analysis and check our estimates and assumptions. Jensen is a long-time colleague of ours who has spent a lifetime studying food production potential all over the world. Jensen helped us through a complex set of computations.

Because we wanted to know what the likely maximum nutrient production potential could have been, we chose a hypothetical 2.25 hectares of maize and a double-cropping of 2.25 hectares of potatoes. We knew that the length of the growing season and the rainfall would likely have supported two potato crops during most years.

Water requirements for crop growth were computed based on two reference crops, short grass and alfalfa. Evapotranspiration for short grass and alfalfa averaged 4.02 mm/day and 4.82 mm/day, respectively, and was calculated using the Penman-Monteith equation. This data was then translated to maize and potatoes using standard irrigation engineering curves.

The agricultural research found that the 4.5 hectares could potentially have produced 3500 kilograms of maize and 141,000 kilograms of potatoes each year, if the Inca had chosen such crops rather than, say, cocoa, all maize, or herbs. With maize and potatoes, the 4.5 hectares of terraced agricultural land would have supported only fifty adults. To feed the estimated 300 permanent residents of Machu Picchu would have required 27 hectares of land. Our studies also showed that the terraced agricultural land was not irrigated, but relied on the ample precipitation of nearly 2000 mm/year. As a result, it could be concluded that food was brought into Machu Picchu because the agriculture land within the perimeter walls was too small in area to make Machu Picchu self sufficient in nutrient production. The 4.5 hectares was more likely used for growing maize for producing ceremonial beer.

URBAN DRAINAGE

Our research to date has left the urban drainage system to be documented last. One reason for this is the need to develop a strong background before tracing out all the many drainage routes and their contributing basins. It seems as though each time we begin to verify and document the known drainage system, more outlets are found in the various nooks and crannies of the Urban Sector. Nevertheless, we have documented some 127 drainage outlets to date. We are not sure when the drainage surprises will finally cease. A typical drainage outlet is illustrated in Fig. 14.

Our graphic specialists plan to portray the urban drainage system on a computer-generated map which is presently under development. Perhaps more than any other aspect of the engineering infrastructure of Machu Picchu, the urban drainage system represents a high level of planning. For here, the drainage system was incorporated into the walls of the buildings as each wall was built. Even with modern urban development in the USA, one does not usually see the drainage infrastructure so well incorporated into the community. By studying the elevation and location of the drainage outlets, it is obvious that a master plan had to be adhered to in the community construction. That is, the floor elevations of interior rooms and walkways were established even while major conjunto (sector) exterior walls were under construction. Drainage was neither left to chance nor worked out later as is so often the case with modern city planning.

Fig. 14. An example of an Urban Drainage outlet (upper center) with a vertical drop channel cut into the stone wall rocks below the outlet.

THE NEXT STEP

Engineering research at an archaeological site provides rich opportunities to learn more about ancient people because the work deals with numbers, physics and engineering relationships which these people mastered using trial and error. As our research work at Machu Picchu begins to draw to an end, it would seem that our paleohydrological team would plan to just pack up and declare the work completed. It isn't working that way, though!

As we learn more about the engineering infrastructure, the little details tend to take on more significance. For instance, the routes of the storm runoff drainage to the stone basin of the very last fountain, but to no upstream basin, makes it clear that the Inca were aware of the importance of clean water for drinking purposes. The stone lip of Fountain 12 demonstrates their knowledge of forming a free-falling water jet. One carefully planned stone drainage outlet near the Royal Residence illustrated the concern of the builders to ward against ponding at the front door of the royal residence much in the same way that present day builders of department stores are concerned about having good drainage at their front doors.

Following our completion of the study of the urban drainage system we will go into the final mapping stage and the verification of findings and technical facts so that archaeologists and anthropologists can use the engineering evaluations with a degree of confidence to help piece together what the ancient Inca workers did to make their cities work and how the community infrastructure functioned.

Fig. 15. Ruth Wright, the driving force behind the Machu Picchu Paleohydrological Survey work is looking forward to more field expeditions at Machu Picchu

REFERENCES

Bingham, H. 1913. "In the Wonderland of Peru." *National Geographic Magazine*, April 23: 387-574.

Bingham, H. 1930. *Machu Picchu A Citadel of the Incas*. New Haven, CT.: Yale University Press.

Hemming, J. and E. Ranney. 1982. *Monuments of the Incas*. Albuquerque, NM: University of New Mexico Press (1990 Reprint).

Rowe, J.H. 1990. "Machu Picchu a la luz de documentos de siglo XVI." *Historica*, 14(1)139-154.

Valencia Zegarra., A. and A. Gibaja Oviedo. 1992. *Machu Picchu: La Investigatión y Conservación del Monumento Arquelogico Después de Hiram Bingham*. Cusco, Perú: Municipalidad del Qosqo.

Wright, Kenneth R., McGregor, F. Robert, Kelly, Jonathan M., and Zegarra, Alfredo Valencia. "Machu Picchu: Ancient Hydraulic Engineering". Forthcoming publication American Society of Civil Engineers *Journal of Hydraulic Engineering*.

Wright, Kenneth R., Wright, Ruth M., Jensen, Marvin E., and Zegarra, Alfredo Valencia. 1997. "Machu Picchu Ancient Agricultural Potential *Applied Engineering in Agriculture*, 13(1)39-47.

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