Final Report

Irrigation Tailwater Measuring Devices

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Abstract:

Water from the Shasta River is used extensively for summer irrigation throughout the Shasta Valley. Most of the irrigation is done via either wild or partially controlled flooding, resulting in the creation of significant amounts of irrigation tailwater returning to the Shasta River. Water quality is significantly affected, and consequently so is the survival of salmonids. Devising ways to minimize the adverse effects of this irrigation tailwater is a complex process, but one of the first steps is to quantify the problem for a given irrigator, so that an appropriate scale of fix can be devised.

Funds for this grant from the USFWS, through the Klamath River Basin Fishery Task Force were used to purchase portable weirs and flow recording devices to allow the measurement of individual tailwater streams preparatory to developing proper measures to deal with the tailwater.

Description of Study Area:

The Shasta River located in Siskiyou County, California flows out of the Eddy mountains and Mount Shasta northward into the Klamath River approximately twenty miles south of the Oregon border, and 175 miles upstream form the Pacific Ocean. The Shasta Basin area is approximately 800 square miles with a mean annual unimpaired runoff of approximately 171,000 acre-feet. The mainstem Shasta River is approximately 60 miles long, with a permanent winter storage reservoir (Lake Shastina) at river mile 40. That reservoir limits the upstream range of salmon, and generally has no instream flow release other than to meet prior water rights immediately downstream of the reservoir.

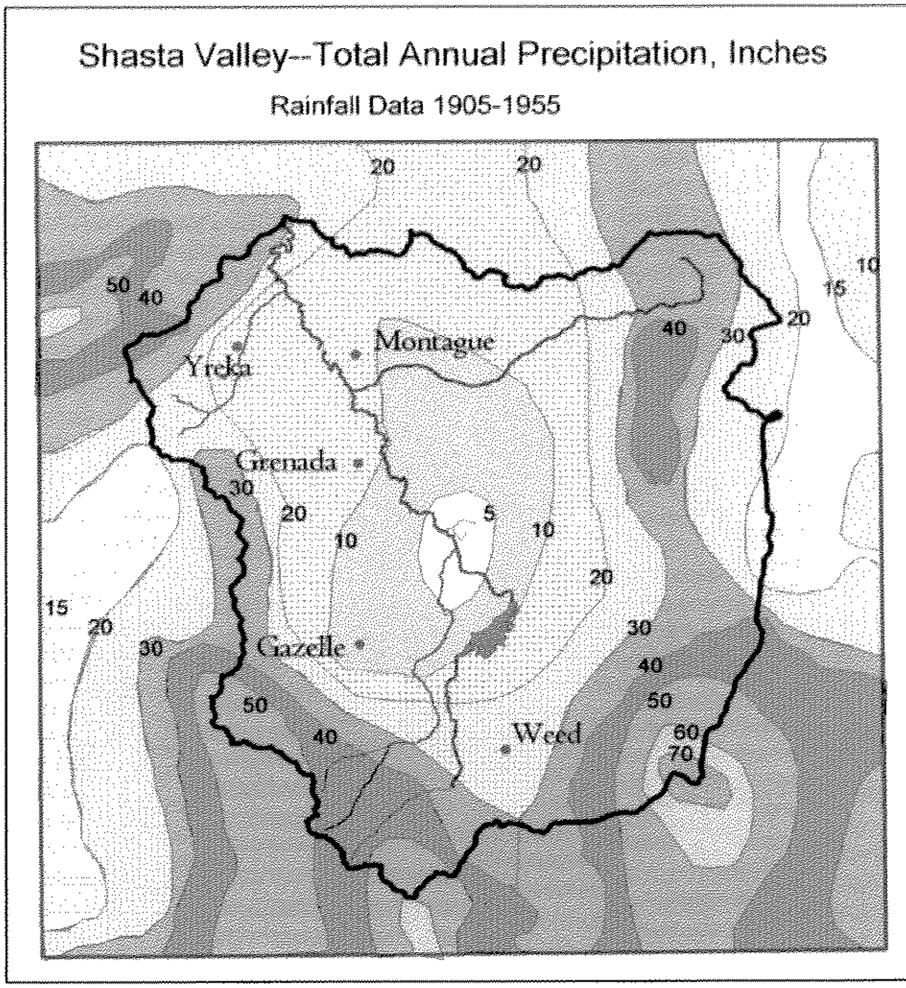
Key features of the Shasta River include significant spring flow in the area below Lake Shastina, increased water development to provide water for irrigation in the middle portions of the Shasta Valley, river inflows and outflows of variable quantity and quality, both natural and irrigation derived, and a range of riparian conditions throughout the system.

Elevated water temperature and reduced dissolved oxygen levels have placed Shasta River on the California 303 (d) list of impaired waterbodies.

Anadromous fish using the system include fall Chinook salmon (Onchorynchus tshawytscha), coho salmon (Onchorynchus kisutch), and steelhead trout (Onchorynchus mykiss).

The climate of the Shasta Valley is extremely dry, with total precipitation ranging between 5 and 70 inches per year, depending on location. Temperatures on the valley floor range from below zero to over 100 degrees F.

Historically the Shasta River was the most productive salmon-bearing stream in the entire Klamath--Trinity Basin. Counts of Fall Chinook spawner returns begun in 1930 (after runs were described as insignificant in comparisons to their previous numbers) were as high as 81,000. The Shasta also produced high numbers of steelhead, and unknown numbers of Spring Chinook and Coho. Spring Chinook are no longer found in the system.



Since the 1930's, Fall Chinook salmon numbers have dropped as low as 530 (in 1992), leading to concerns of extinction of the run, and precipitating the formation of the Shasta CRMP. By 1995, numbers had rebounded to as high as 13,000 demonstrating the continued resiliency of the Shasta system, and possible combined beneficial effects of restoration measures, improvements in harvest management, and improved ocean conditions.

Introduction:

Substantial restoration work has been ongoing throughout the Shasta Watershed since 1989, aimed at improving the survival of native wild salmon and steelhead. Early efforts focused on bioengineered bank stabilization and livestock exclusion fencing (both of which continue), while more recently increasing attention is being directed to trying to address the seemingly intractable problem of irritation tailwater return to the river.

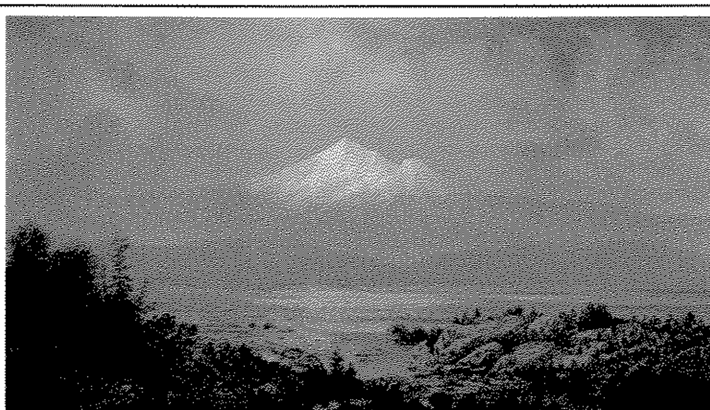


Plate 12. Frederick A. Butman, *Mt. Shasta and Shastina*, ca. 1862–1871. Oil on canvas, 26 x 43 in. *Bancroft Library.*

Early white immigrants found the Shasta Valley in the 1850's to be essentially a vast, dry, treeless plain. From their perspective, most of it was usable only in the spring, when soil moisture supported the growth of grass that could be used to feed horses, cattle and sheep. Once summer arrived, the carrying capacity of the land fell off rapidly, and livestock either moved to the very limited riparian areas, or had to be moved to the mountains where spring arrived later, summers were cooler, and precipitation and soil moisture could provide feed through the summer. Successful ranching required either a balance of low lying ground in the Shasta Valley for winter and spring use, and mountain pastures for summer and fall use, or else a mixture of irrigated and unirrigated ground that could provide a combination of pasture and stored hay for the entire year. Since available mountain pastures were extremely limited, the need to develop irrigation systems became intense.

How people irrigate is determined by several factors, including whether or not water is available from a sufficiently higher elevation to allow it to distribute itself by gravity (allowing flood and furrow irrigation), soil porosity, which may dictate the use of sprinklers, availability of electricity or other source of power, and the nature of the crop grown.

Early irrigation systems were constrained by lack of available power, so were entirely dependent on gravity for the movement of water[1]. The oldest ditches and the oldest water rights all are for flood irrigation, where water is forced out of the stream channel, generally by constructing a seasonal dam in the river or stream to raise the level of the water, then allowing some or all of the stream to run down a ditch that runs downhill with as little a slope as possible[2]. Gradually the ditch is directed away from the river in order to both minimize its slope and maximize the area between the ditch and the river. Given sufficient length, there eventually can be a large area that is downhill from the ditch, where water can be let out of the ditch and run across the ground to keep crops green through the summer. Ditches constructed for this purpose start with a single large ditch, which eventually forks into increasingly smaller ditches to allow the water to be spread as uniformly as possibly over as much ground as possible.

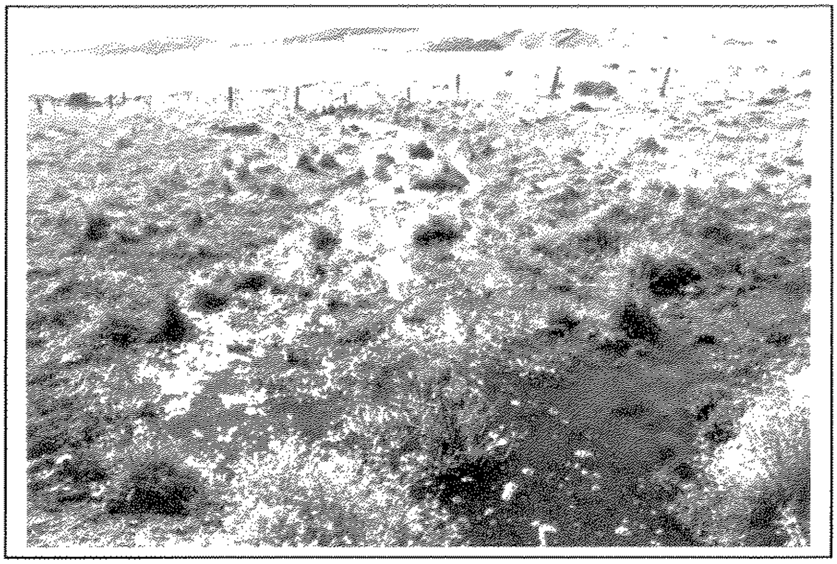
Not all flood irrigation systems are entirely driven solely by the force of gravity. More recent systems often utilize a pump to lift the water out of the river, and discharge it into a ditch at a much higher elevation than the elevation at the source of the water. The water is then distributed in ditches and eventually applied via conventional flood irrigation techniques.

Flood irrigation completely saturates the upper layers of soil with water, displacing oxygen in the soil. If done continuously, only plants tolerant of anaerobic conditions—sedges, rushes and similar wetland plants could survive[3], so irrigation is done intermittently, generally every two to four weeks. Ideally, sufficient water[4] is applied to wet (not saturate) the upper two feet or so of soil. That water is then available either for use by plants, or it can be lost to evaporation. If too great an amount of water is applied, it is likely to either run off the surface and be lost (known as irrigation tailwater)[5], or soak in deeper than the effective root depth of the plants. In either case, nutrients that could have been available

[1] A few old systems did exist that utilized dip wheels to lift the water to a sufficient elevation to allow it to be used on fields near the river, but their capacity was small, and all have been replaced with other methods or long since abandoned.
[2] Generally 1-2 inches per 100 feet.
[3] These plants generally are slow growing and of such low nutritional value that substantial effort is made to minimize their presence.
[4] The quantity varies considerably, but 4 inches is probably a good average amount applied per irrigation cycle.
[5] Unfortunately, the creation of tailwater is inherent in the use of flood irrigation. Roughly 25% more water than the plants need must be applied to provide the "push" required to move water across the field in a timely fashion. That water can be either captured for further irrigation use, or allowed to return to the stream.

to the growing plants tend to be washed away, along with heat during the day and soil and plant and manure residues in the case of surface runoff.

The biggest advantage of a gravity powered irrigation system is that once the infrastructure—dam and ditches—are in place, the out of pocket costs of operation are the lowest of any managed irrigation system. The disadvantages include diminished productivity during those periods of each irrigation cycle when soil oxygen is displaced, difficulties in effectively and uniformly distributing the water, and the necessity for ditch and dam maintenance. (Ditch maintenance especially can become extremely burdensome if the ditch is long).



Typical irrigation tailwater return stream on fairly steep ground.

This form of irrigation is little changed from the practices utilized by the ancient Egyptians, Romans, Mayans, etc., and in normal circumstances flood irrigation will create tailwater equal to 25% of the total amount of water applied to a given field. In some cases it can be substantially more.

More recently, the effects of irrigation runoff on water quality—bringing nutrients, sediment and heat back to the river—have been added to the list of disadvantages inherent to flood irrigation. The magnitude of those "costs" has not yet been fully defined[6], nor is minimizing those costs yet fully integrated into many water managers irrigation thinking. Once those costs are fully defined, in some cases flood irrigation may no longer be the cheapest form of irrigation, and at the very least additional resources will need to be directed at minimizing the ill effects that it can produce.

Small infiltration pond for irrigation tailwater. Vegetation will help remove sediment and nutrients. Subsurface return to river will remove heat.

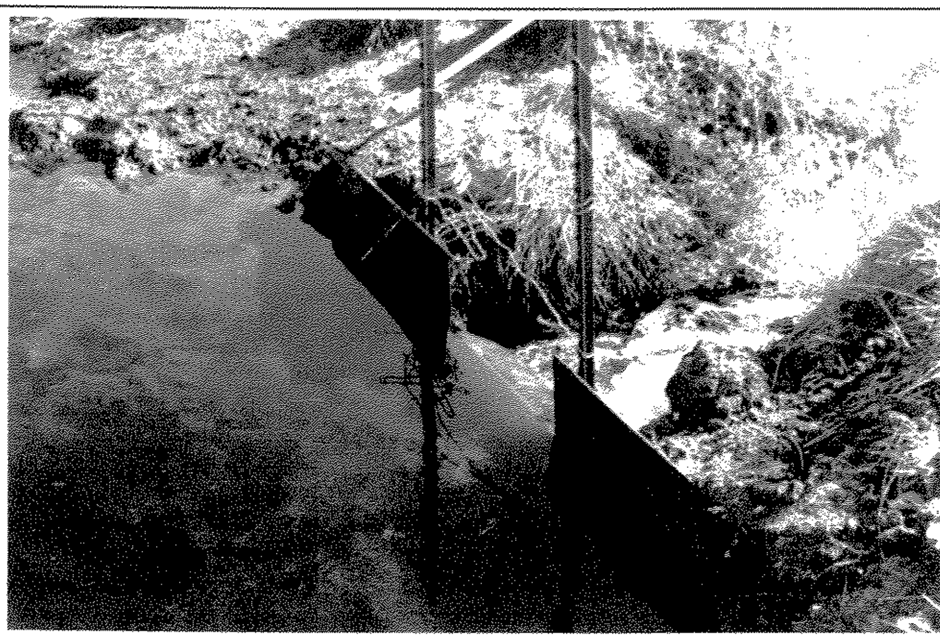
Minimizing those effects of can take many forms including conversion to

[6] The workings of the Federal Clean Water Act, with its required allocation of total maximum daily loading (TMDLs) and the federal Endangered Species Act, with the necessity not to impair further the habitat of listed cold water fish, will force the cost of irrigation runoff to be defined in the near future.

sprinkler systems (which produce little or no tailwater), land leveling and/or installation of border checks[7] to provide better control of flood applied water, berms or ditches along downhill edges of fields to re-direct the water to adjoining fields, infiltration ponds, and tailwater capture and pumpback systems. Both the immediate and long term costs of any of these approaches can be quite variable, and each needs to be custom tailored to the individual irrigators needs and abilities.

Methods and Materials:

Funding available through this grant provided the equipment needed to make initial tailwater volume determinations via the installation of temporary weirs and water level and temperature measuring devices. Once tailwater volumes were known, appropriate approaches could be investigated to reducing it to a minimum.



Irrigation tailwater measuring weir in place. Volume expected to exceed 5 cfs.

Most irrigated fields eventually drain into at least vaguely defined draws or gullies, providing a logical place to install a weir. During the irrigation cycles, tailwater will ebb and flow through this drainage as different parts of a field are irrigated. The record of individual irrigations can then be examined, and peak, average and total flows determined. Heat input to the river can be derived by looking at the temperature of the tailwater and its corresponding volume. Minor changes in irrigation practices intended to produce less or cooler tailwater can be also be readily evaluated on an empirical basis.

At the initial installation stage, a certain amount of judgement must be exercised in selecting the best weir or flume to be used, depending on peak flow anticipated, and the amount of fall available. Generally the smallest available device that will meet anticipated volume will provide the most accurate results. Weirs generally require less effort to install, while flumes will provide accurate results in areas of very low slope. In most cases a certain amount of minor excavation and sand-bagging is required, along with some protection on the downstream end to minimize soil erosion.

[7] Border checks are small berms running downhill in an irrigated field, allowing flood-applied water to be contained in a series of relatively narrow lanes. By containing the water this way, it is more readily possible to assure that a given area is irrigated uniformly without some areas being vastly over irrigated in order to assure minimal water reaches areas that are distant or slightly higher in elevation. Less tailwater is there-by generated.

Water entering a weir needs to have a ponded area upstream where it will loose its velocity before going over the weir, and sufficient fall to assure that air can get behind the spilling water (the nape). A boom or similar device may be desirable to hold back floating materials that would other wise obstruct the weir. If livestock will be present, temporary fencing will be required to assure that the installed devices do not become objects of curiosity or scratching posts.

V- notch weir in place ready to measure relatively small tailwater flow. Vertical pipe at center serves as stilling well for recording device inside it, and has staff gauge mounted on it.

For convenience of data gathering electronic recording devices are nicest, but mechanical devices seem to be the most accurate. Which is chosen depends on the accuracy required. For our purposes electronic devices are suitably accurate. A typical installation will include a temporarily installed staff gauge, an electronic recording device(s) for water depth and temperature, and a weir. The weir site should be visited before and after each irrigation cycle to make certain that livestock have not disturbed the installation, and assure that no undermining or overflow occurs. Discussions with the irrigator will help determine whether each irrigation through the summer is essentially identical, or if they vary greatly and will require repeated measurement in order to document the full range of conditions. Visits during the irrigation provide opportunities to make visual records of water height using the staff gauge, for later comparison to electronic data. Any discrepancies must be resolved in order to minimize erroneous conclusions due to equipment failure.

The recording devices purchased under this grant were produced by Sequoia Scientific and measure water height by changes in capacitance of a dielectric material between two conductors. The water depth data is then stored in the device electronically and can be downloaded to a laptop computer in the field, or the electronic portion of the device can be removed to the office for downloading and later returned to the site.

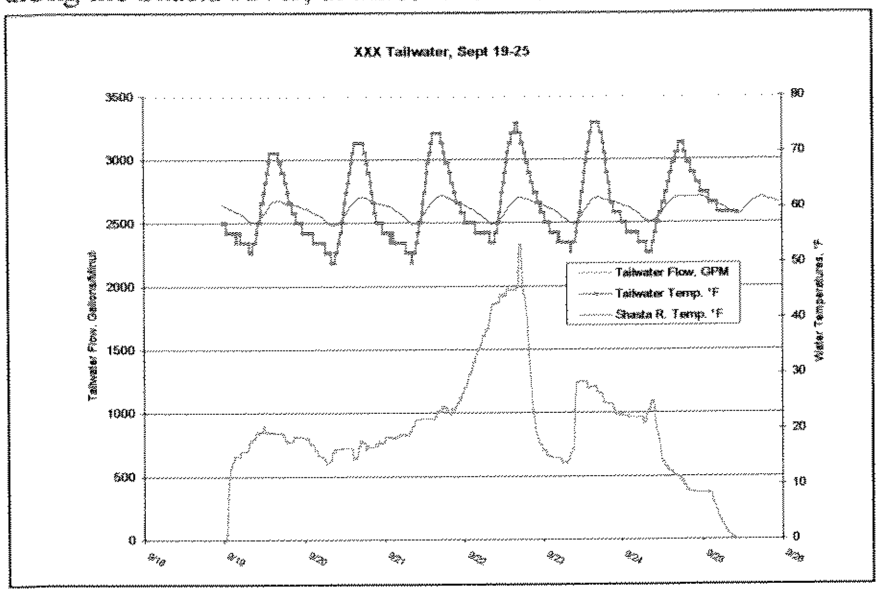
Results and discussion of accomplishments:

Equipment purchased under this grant has been used both as planned for measuring tailwater, and also for measuring irrigation diversion quantities in order to properly size fish screens. Each installation has been temporary, and the equipment was removed once measurements were made, cleaned up and stored for the next use.

Because the potential sensitivity of the data gathered, it was necessary that it remained the property of the individual irrigator, hence detailed and/or site-specific data will not be reported here.

Summary and Conclusions:

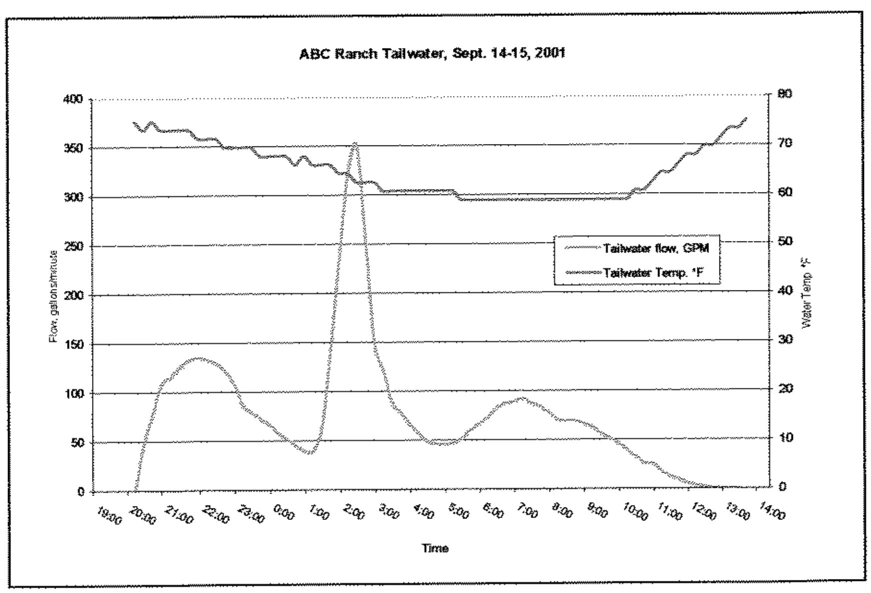
Individual irrigation tailwater return flows of over 2,000 gallons/minute (>5 cfs) have been measured along the Shasta River, at times when the total river flow at its confluence can be less than 20 cfs. Temperatures in the high 80's are common, and the potential impact on water quality is obvious. In the past, irrigation tailwater was given little attention, and inefficiency of water usage could often be compensated for by simply diverting more water.



A single irrigation cycle from one of the larger tailwater return flows into the Shasta River. Note diurnal temperature fluctuations greatly in excess of river temperature at a time when fall Chinook salmon are entering the river to spawn. This tailwater stream alone can be as much as ¼ of the total volume of the river at its mouth, giving it the potential to greatly affect water quality.

State-wide efforts to accelerate implementation of the non-point pollution provisions of the federal Clean Water Act of 1972 through the establishment of "Total Maximum Daily Loads" (TMDL's) led to the realization that irrigation tailwater needed to be successfully addressed. Funding for this equipment was secured 1998 under the expectations that over the course of the next several years, increasing numbers of ranchers would become aware of the legal requirements of TMDL's, and begin looking for opportunities to assure that their operations were in compliance. The Shasta CRMP wanted to be prepared to meet that anticipated demand.

As it happened, the workings of the Clean Water Act were overshadowed for several years by the possible listing of both steelhead by the federal government, and coho by the state government, with the result that people's attention was focused more on trying to fend off future regulation, rather than to comply with soon to be implemented rules.



Tailwater generated from another irrigation cycle on a ranch bordering the Shasta River. This volume is more typical of most small ranches of several hundred acres.

Beyond that, reluctance to document individual tailwater return "sins" when that documentation might fall into unsympathetic hands also held many people back. Despite these hurdles, tailwater measurements have been initiated on 12 different ranches, with remedial projects underway or planned for several of them.

The battles over the two listings have now pretty well passed, and one of the beneficial outcomes is the heightened level of awareness of the value of finding and taking proactive steps to protect natural resources. That, coupled with a steadily increasing level of trust in the help available through the Shasta CRMP will lead to increased utilization of this capability into the future.

In the meantime, discussions are ongoing about setting up to make measurements during 2003 of all the known tailwater returns from one of the irrigation districts in the Shasta Valley, with the hoped-for outcome ultimately being a plan for a comprehensive approach to one of the largest sources of tailwater entering the river, both from within the district, and from several adjoining independent irrigators.

Measurements already taken were instrumental in preparing the design, and in securing funding for a tailwater capture and re-use system on one ranch in the Shasta Valley, and have provided the data needed on two others where solutions are being sought. Possibilities are currently being discussed on a third ranch for developing appropriate tailwater data with which to devise workable approaches for the tailwater generated there. As these efforts have proceeded, additional casual inquires indicate rising interest on the part of additional ranchers to utilize the opportunity to improve their operations.

Summary of Expenditures

See attached budget summary

U.S. Fish & Wildlife - P.O. Box 1006 - Yreka, CA 96097				3038
Irrigation Tailwater Measuring-98-HP-05/1448-11333-98-J068				
(Expires 12/31/01)				
REPORT MONTH: Summary of Grant Expenses				
CURRENT DATE:				
	Contract Budget	Monthly Expenses	Cumulative Expenses	Contract Balance
Expendable Eq/Sppls	$6,764.00	$0.00	$6,764.00	$0.00
General Administration	$747.00	$0.00	$747.00	$0.00
Annual Totals	$7,511.00	$0.00	$7,511.00	$0.00
Contract Totals	$7,511.00		$7,511.00	$0.00
BILLING AMOUNT		**$0.00**		
Paul F. Wagner, Ex. Director				
(I certify that above expenses were incurred for program.)				