

# STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

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## PREDICTING CHANNEL RESPONSES TO FLOW DIVERSIONS

by Melissa L. Stamp and John C. Schmidt

Water diversion projects have the potential to adversely affect the recreational, aesthetic, and ecological resources of mountain streams. The ability to predict channel response to flow diversion can help project designers minimize adverse impacts and design appropriate mitigation measures. Toward this end, we use insights gained from detailed case studies of Lake Fork and Rock Creek – two diverted streams in the Uinta Mountains, Utah – (Stamp 2000, Stamp and Schmidt 2000, Schmidt et al. 2005), in conjunction with the results of previous studies, to develop a conceptual framework for predicting channel response to flow diversion. Specifically, we present a classification of different types of diversion systems and compare their effects on downstream hydrology and sediment supply. We then provide a description of the geomorphic, climatic, and watershed characteristics that affect how alterations to the flow and sediment regime ultimately translate into changes in channel morphology. This conceptual framework for predicting channel response to flow diversion is applicable to common types of municipal and agricultural diversion systems on mountain

streams in the Intermountain West where runoff patterns are predominantly snowmelt-driven.

### Types of Water Diversions

The direct impact of a water diversion structure is to alter the timing, distribution, and variability of water and sediment inputs to the downstream channel. The specific style of hydrologic alteration caused by a water diversion varies widely depending on the size, purpose, engineering design, and temporal operation patterns of the diversion structure. The style of alteration to the sediment supply depends on the existence of an upstream dam, characteristics of the diversion structure, and timing of the diversion.

We attempted to differentiate among types of diversions based on their influence on downstream hydrology and sediment supply. Milhous (1985) distinguished among three common types of diversions based on whether dams were associated with the diversions. Building on this idea, we identified three key features of a water diversion project that determine its specific downstream

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*The PRIMARY AIM is to exchange technical ideas and transfer technology among scientists working with wildland stream systems.*

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### IN THIS ISSUE

- **Predicting Channel Responses to Flow Diversions**
- **Great Basin Riparian Ecosystems: Ecology, Management, and Restoration**
- **Where's Penny?**

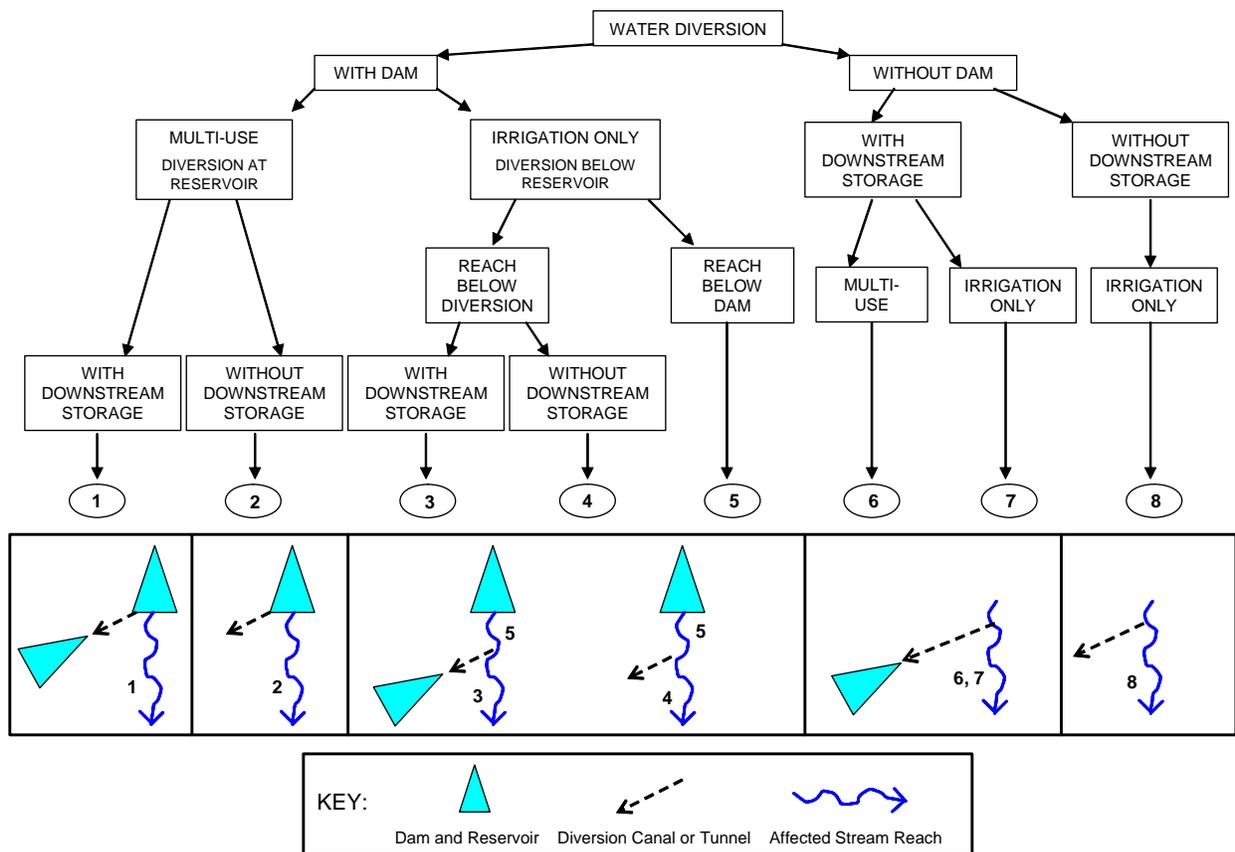


Figure 1. Common types of water diversions in the Intermountain West.

effects on streamflow and sediment supply:

1. the presence or absence of a dam and reservoir at or upstream from the diversion;
2. whether or not the diversion canal flows to a downstream storage reservoir; and,
3. whether the diverted water is used solely for irrigation, or includes a municipal use component.

Using different combinations of these three features, we distinguished eight common types of water diversions (fig. 1).

The presence or absence of an upstream dam and reservoir has an important influence on the style and magnitude of downstream hydrologic effects. For the purposes of this classification, we define a dam as a flow-impeding structure large enough to significantly reduce the magnitude of large floods with recurrence intervals of 5 years or more; small barriers that simply direct flow into a canal or tunnel are not considered dams in this classification. If a dam stores water at or upstream from the diversion, sediment will be trapped in the

reservoir, and the downstream supply of sediment will be reduced. Diversion types 1-5 are associated with dams; types 6-8 are diversions without dams (fig. 1). Depending on the location of a dam-associated diversion, stream reaches may be affected by flow regulation alone, or by the combined influence of the dam and the diversion (diversion types 1-4).

The availability of downstream storage for diverted flows also has an important effect on how a diversion is operated and affects downstream hydrology. Without downstream storage, water will only be diverted during times when sufficient demand exists, such as during the summer irrigation season. Spring floods will probably not be diverted unless they can be captured in a downstream reservoir. Diversion types 1, 3, 6, and 7 include downstream storage (fig. 1).

Another important factor that determines the hydrologic effects of a diversion is the intended use of the water. In the Intermountain West, flows typically peak during the spring snowmelt season



Table 1. Hydrologic effects of different types of water diversions. Arrows indicate direction and degree of effects: downward arrows indicate a decrease; upward arrows indicate an increase; circles indicate no change; single arrows indicate a minor effect; double arrows indicate a significant effect; triple arrows indicate a severe effect.

HYDROLOGIC CHARACTERISTIC	DIVERSION TYPE 1	DIVERSION TYPE 2	DIVERSION TYPE 3	DIVERSION TYPE 4	DIVERSION TYPE 5	DIVERSION TYPE 6	DIVERSION TYPE 7	DIVERSION TYPE 8
TOTAL ANNUAL FLOW	↓↓↓	↓↓	↓↓	↓	○	↓↓	↓	↓
SPRING FLOOD	↓↓↓	↓↓	↓↓↓	↓↓	↓↓	↓	↓	○
SUMMER LOW FLOW	↓↓	↓↓	↑○	↑○	↑↑	↓↓	↓↓	↓↓
WINTER LOW FLOW	↓	↓	↓↓	↓↓	↓↓	↓	○	○
SEDIMENT SUPPLY	↓↓	↓↓	↓↓	↓↓	↓↓	○	○	○

and remain low throughout the remainder of the year. In contrast, the demand for irrigation water typically peaks in mid- to late summer. Therefore, dam and diversion systems used solely for irrigation store as much water as possible during the winter and early spring, and release it during the summer for maximum irrigation supply. This leads to reduced winter base flows and elevated summer flows (diversion types 3-5). In contrast, if a diversion supplies municipal or industrial water in addition to irrigation water, demand will exist throughout the year and both winter and summer flows are typically reduced (diversion types 1, 2, and 6). Large-scale, transbasin diversion systems are commonly built to serve multiple uses, and occur as either diversion type 1 or 2.

### Hydrologic Effects

We developed a conceptual model that qualitatively predicts the relative hydrologic effects of the eight identified diversion types (table 1). In table 1, the directions and relative magnitudes of change indicated by the arrows assume that the diversions and upstream or downstream storage reservoirs in each scenario have equal capacities, so the differences shown are based solely on diversion type. Our predictions of hydrologic effects assume that upstream dams have sufficient storage to moderate annual flood flows. The effects shown in table 1 also assume an average water year; diversions may be operated differently in extremely wet or dry years.

Assuming similar diversion capacities, the effect of a given diversion type on total annual flow is primarily a function of how many days per year water is removed at full diversion capacity. Multi-use dam and diversion systems that flow into downstream storage reservoirs will most severely reduce total annual flow, while irrigation-only diversions that lack upstream and downstream storage will have less effect (table 1).

Because of their ability to store and moderate flood flows, diversions with dams and downstream storage (types 1 and 3) reduce spring flood magnitudes to the greatest degree. In contrast, diversions that lack upstream and downstream storage reservoirs (type 8) generally do not have a significant effect on spring flood volumes (table 1).

Seasonal effects on low flows also vary with diversion type (table 1). Diversion types 1, 2, 6, 7, and 8 significantly reduce summer low flows. Dams built to store irrigation water typically release artificially high flows during the summer, resulting in downstream flows higher than or similar to the natural summer discharge (types 3-5). Because irrigation dams store water during the winter, downstream winter low flows are significantly reduced. Multi-use diversions also withdraw water in the winter (types 1, 2, and 6), while irrigation diversions that lack upstream storage do not affect winter flows (types 7-8).

Different types of diversions also vary in their effects on downstream sediment supply, largely as



a function of engineering design. Certain types of dams have designs that allow periodic sluicing of sediment, while others permanently trap all sediment. The design of the diversion headgate is also important: gates that open at the top withdraw water only; gates that open at the bottom remove sediment also. Although the effects of diversions on sediment supply can be quite complex, for the purposes of our classification scheme, we simply assume that diversions with dams will trap sediment and reduce the downstream supply, while diversions without dams will have no effect (table 1).

In terms of overall effects on streamflow and sediment, diversion types 1-8 represent a general progression from the greatest to least degree of alteration. Type 1 diversions, such as Upper Stillwater Dam and diversion on Rock Creek (Stamp 2000), severely reduce the magnitudes of downstream floods, low flows, sediment supply, and total annual flow volumes. At the other extreme, type 8 diversions only affect summer low flows and total annual flow volumes. The eight scenarios illustrate the diversity of effects that water diversions can have on hydrology, and ultimately on channel condition. Clearly, broad generalizations about the effects of diversions have the potential to be inaccurate and inappropriate.

### **Physical and Temporal Influences on Channel Response**

As discussed above, water diversions directly affect the timing, distribution, and variability of water and sediment inputs to the channel, and different types of diversions alter these characteristics in different ways. However, these changes in hydrology and sediment do not translate directly into changes in channel morphology; rather, they operate through a series of physical and temporal “filters” that influence channel response (fig. 2). Research results demonstrate that water diversions that have similar effects on sediment supply and hydrology, but operate through a different set of filters, will have different effects on channel morphology.

One important filter involves reach characteristics (fig. 2). Various studies have found that certain types of stream reaches are more susceptible to change than others (Ryan 1997, Smelser 1997,

Stamp 2000, Schmidt et al. 2005). Unconfined, low-gradient reaches that flow in relatively wide valleys, contain bars and side channels, and receive a supply of fine sediment from banks and hillslopes, are susceptible to rapid channel narrowing, vegetation encroachment, and aggradation. In contrast, these changes are unlikely on steeper reaches that lack bars and side channels, are confined in narrow valleys, and receive minimal amounts of fine-grained sediment. Climate and natural disturbances constitute a second set of filters that influence the style and timing of channel change (fig. 2). One important factor is the relative aridity and hydrogeologic characteristics of the affected stream. In a dry climate, flow diversion may lower the groundwater table adjacent to the stream channel and cause mortality of riparian trees and shrubs. This loss of stabilizing vegetation can lead to bank erosion and channel widening. In a more humid environment where the groundwater level is less dependent upon streamflow, however, a similar-sized diversion may actually promote an increase in riparian vegetation density by providing newly-dry surfaces for establishment (Collier et al. 1996). This scenario leads to bank accretion and channel narrowing - the opposite of the morphologic effects in a more arid climate.

On a shorter time scale, precipitation patterns in the years immediately following diversion construction can greatly influence the rate of channel response. If construction is followed by a sequence of several drought years, a maximum amount of water is likely to be diverted, and channel adjustment will occur relatively quickly. This appears to have been the case on Rock Creek (Stamp 2000). In contrast, if the years following construction are wetter-than-average, the demand for diverted water will be low, discharge will be minimally affected, and channel change will be delayed.

Time is another important filter that influences the morphologic effects of flow diversion (fig. 2). In general, the older the diversion, the more extensive the changes will be. However, this general relationship falls apart when “reset” events occur. As discussed by Ryan (1997), the periodic occurrence of large floods that exceed the regulating capacity of dam and diversion structures can eliminate evidence of interim channel changes caused by reduced flows.



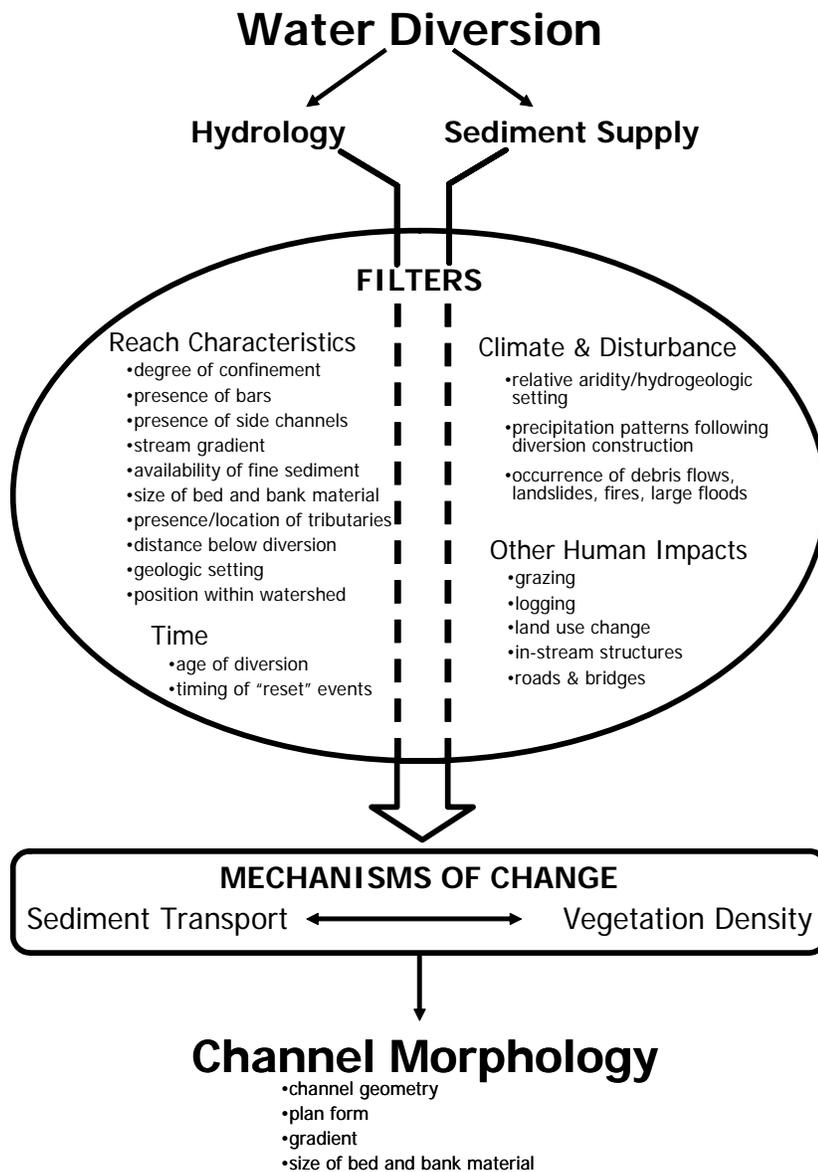


Figure 2. Conceptual framework for predicting channel response to flow diversion.

Operating through these various filters, the diversion-affected water and sediment regime will either increase or decrease sediment transport and vegetation density. Changes in these two parameters are primary mechanisms of channel change. Specific processes include bank erosion or accretion, bed degradation or aggradation, and encroachment or mortality of vegetation. Changes in sediment transport and vegetation tend to operate in a positive feedback loop: newly deposited sediment provides a ready substrate for plant establishment; plants trap additional sediment and increase its cohesive strength; deposition rates are thus enhanced and additional plant establishment is

promoted. The opposite cycle also occurs: vegetation dies, the cohesive strength of the bank sediment is reduced, erosion rates are enhanced, and additional vegetation is scoured away.

Ultimately, changes in vegetation and sediment will translate into changes in morphologic variables such as channel geometry, plan form, gradient, and size of bed and bank material (fig. 2). Our case studies on Rock Creek and Lake Fork in Utah illustrate this process: mid-channel bars on both streams have aggraded and become stabilized with vegetation, causing a reduction in active channel width. On Rock Creek, channel plan form has been



altered because of a reduction in the number of side channels (Stamp 2000).

Figure 2 provides a framework for predicting channel response to flow diversion. One must first understand the details of how an existing or proposed diversion will affect downstream hydrology and sediment supply. The relevant filters should then be characterized through an assessment of watershed and reach characteristics. This assessment should include an evaluation of climate and land-use patterns, identification of bridges, in-stream structures, and tributary locations, and geomorphic classification of stream reaches. Some filters, such as post-diversion precipitation patterns and the timing of future reset and disturbance events, cannot be known with certainty. However, sites where debris flows or landslides have occurred in the past can be identified, and historical records can be reviewed to provide estimates of the recurrence interval of typical disturbance events. Once the style of flow diversion and all relevant filters have been adequately characterized, one can begin to predict how the diversion will affect sediment transport and vegetation density.

Even with a careful, detailed assessment such as the one outlined above, prediction of channel response will still be an imprecise endeavor due to the large number of potentially adjustable geomorphic variables. In some situations, however, response can be predicted with some degree of certainty. A water diversion that severely reduces spring flood peaks and dewateres the channel during the summer growing season will most likely cause significant channel narrowing on unconfined stream reaches that contain an adequate supply of fine-grained sediment. On a similar stream reach in an arid environment, this type of diversion will likely cause mortality of vegetation and channel widening. At the other extreme, a small water diversion that does not affect the magnitude of spring floods and does not trap sediment is unlikely to alter channel morphology on a bedrock-bed stream flowing in a confined canyon.

The majority of diversion scenarios will be intermediate between these extremes, however, making prediction difficult. Field visits to similar diverted streams nearby can provide insight into possible morphologic adjustments. The general relationships outlined here can also be used as

guidelines. Ultimately, though, prediction of channel response to diversion must be a site-specific endeavor that includes a thorough assessment of the (1) magnitude and style of disruption to the flow regime, (2) magnitude and style of disruption to the sediment regime, and (3) geomorphic character of the affected stream reach.

Studies are presently underway to measure the magnitude to which diversions interrupt the water and sediment flux at three large diversions on the Cub River in southeastern Idaho. This work is funded by the USDA Forest Service, Stream Systems Technology Center and seeks to relate the disruption of water and sediment flux to the existing condition of the channel and floodplain in this watershed where diversions have been in place for more than a century.

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# GREAT BASIN RIPARIAN ECOSYSTEMS: ECOLOGY, MANAGEMENT, AND RESTORATION

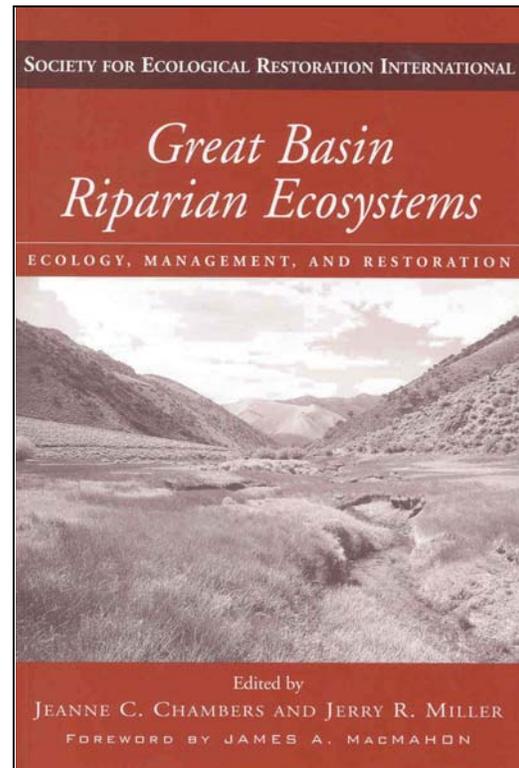
In many semi-arid regions such as the Great Basin, streams and riparian areas have experienced extensive degradation, principally attributed to anthropogenic disturbances. Although stream and riparian areas only encompass a small percentage of the overall area in semi-arid landscapes, they contain a disproportionate large percentage of the habitat utilized by most aquatic and terrestrial organisms and economic resources utilized by humans for water supply, agriculture, and livestock grazing. To address stream and riparian ecosystem degradation in the Great Basin, the USDA Forest Service initiated the Great Basin Ecosystem Management Project in 1992 to (1) better understand the effects of natural and anthropogenic disturbances on riparian ecosystems, (2) better understand the linkages between fluvial geomorphic processes, hydrologic and sediment regimes, and riparian ecosystems, and (3) develop guidelines and methods to rehabilitate, maintain, and manage viable, healthy riparian ecosystems.

***Great Basin Riparian Ecosystems: Ecology, Management, and Restoration*** is a product of this effort and represents an integrated, interdisciplinary collection of papers that describe the relationships between geomorphic, hydrologic, and biotic processes that control riparian ecological conditions, processes, and responses to natural and anthropogenic disturbances in the Great Basin.

The editors, Jeanne C. Chambers and Jerry R. Miller, state that the purposes for the book are to further scientific understanding of the abiotic and biotic processes structuring riparian areas of the Great Basin and to apply that knowledge to developing sound management and restoration strategies. They contend that the latter purpose is especially important as insights gained from research are all too often not passed along to those responsible for land management and restoring degraded ecosystems.

The separately authored chapters can be organized into four sections:

- 1) Climate change, vegetation dynamics, and fluvial geomorphic responses during the Holocene (chapters 2 and 3);



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- 2) The effects of natural and anthropogenic disturbances on fluvial geomorphic processes, hydrological processes, channel responses, and water quality (chapters 4, 5, and 6);
- 3) Riparian vegetation patterns, conditions, and dynamics (chapters 7 and 8); and
- 4) Process-based approach for managing and restoring riparian ecosystems (chapter 9).

Each chapter examines these topics at decreasing spatial and temporal scales.

Although studies in this book are specific to the Great Basin, scientists and resource managers in other eco-regions will find this book a useful reference for understanding and gaining insights in the complex relationships between hydrological, geomorphic, and riparian ecological processes. ***Great Basin Riparian Ecosystems: Ecology, Management, and Restoration*** is published by Island Press and can be purchased for \$70 online at <http://www.islandpress.org/ecosystem/ecorest.html>.



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## IN THIS ISSUE

- **Predicting Channel Responses to Flow Diversions**
- **Great Basin Riparian Ecosystems: Ecology, Management, and Restoration**
- **Where's Penny?**

# STREAM NOTES



## Where's Penny?

Over the years, many readers of this newsletter have requested publications and videos from the Stream Systems Technology Center. Those of you who called in, were greeted by the cheery voice and professionalism of **Penny Williams**, and pleasantly surprised by the quick response to your requests. Unfortunately, Penny Williams, Office Assistant for STREAM since it's beginning in 1992, moved on to new challenges and opportunities earlier this year with the Animal and Plant Health Inspection Service (APHIS) in Fort Collins.

The official contact line for the Stream Systems Technology Center (970-295-5983) is still in place, but you are likely to either get voice mail or be forwarded to the remaining staff. We will still strive to be as responsive as possible, but ask your patience. If you need immediate assistance, fell free to call any of the following staff for assistance:

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