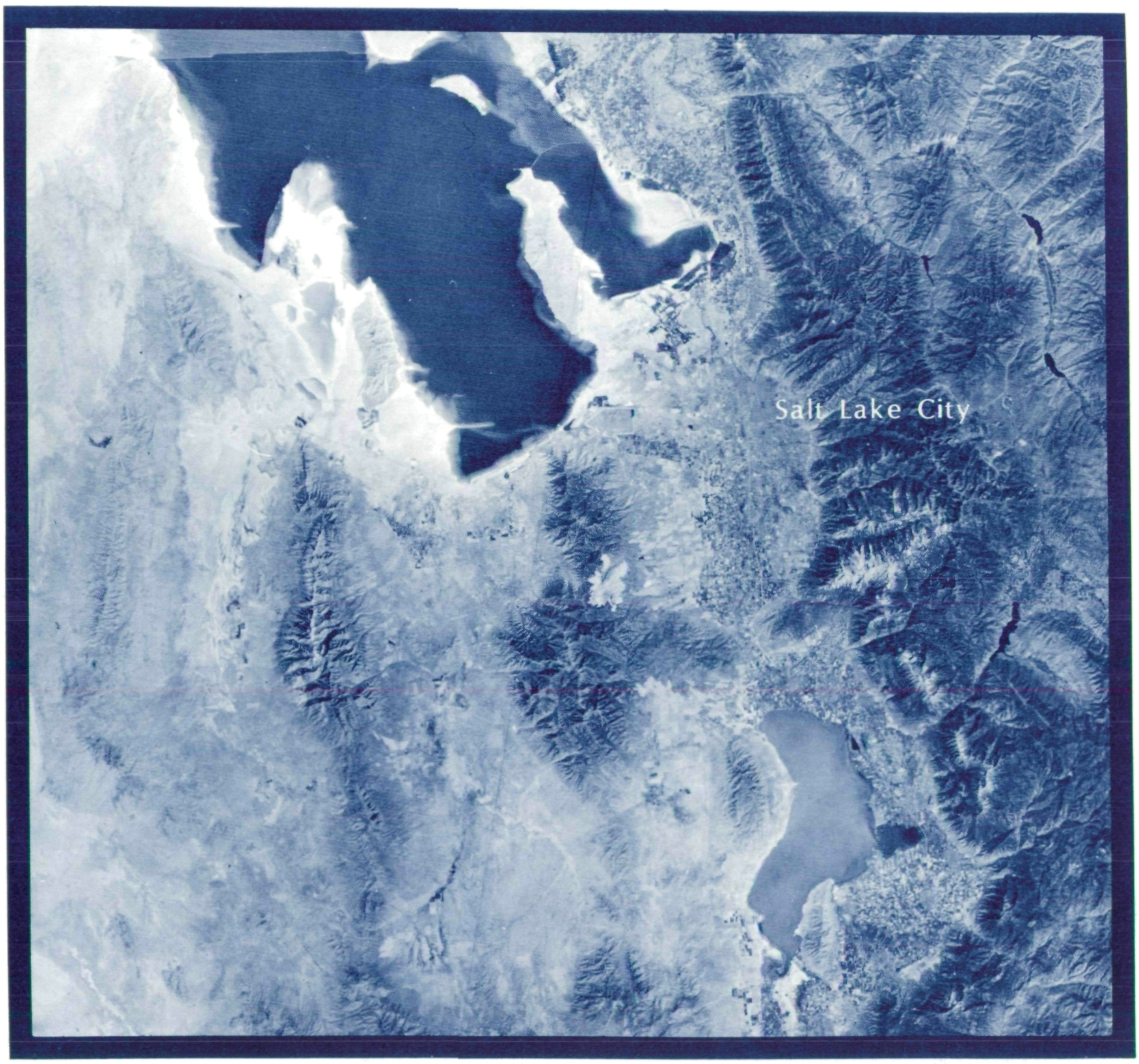
CENTER FOR REMOTE SENSING AND CARTOGRAPHY



UNIVERSITY OF UTAH RESEARCH INSTITUTE

Salt Lake City

RIPARIAN HABITAT ON THE HUMBOLDT RIVER, DEETH TO ELKO, NEVADA 1983

CRSC Report 83-3

December 1983

By

Kevin P. Price and Merrill K. Ridd

Center for Remote Sensing and Cartography
University of Utah Research Institute
420 Chipeta Way, Suite 190
Salt Lake City, Utah 84108

Supported By

Nevada Department of Wildlife and the National Aeronautics and Space Administration (NASA Grant NAGW-95)

TABLE OF CONTENTS

INTRODUCTION

The Humboldt River is the major drainage system in North Central Nevada. The water for the river is supplied by the Humboldt River Basin which collects water from 11 sub-basins. The Humboldt River Basin covers approximately 10,887,900 acres. Most of the land (59%) is managed by the Bureau of Land Management (BLM), 6.4% by the Forest Service, and 33.2% by the private sector. The rest of the land is divided between other federal and state agencies (USDA 1966).

Over the years, improper animal grazing practices have resulted in deterioration of the watershed. Early in the settlement of northern Nevada, the Humboldt Basin watershed was heavily grazed by sheep and cattle. Areas that were once predominately perennial grasses, soon became overrun and the quality of the watershed rapidly deteriorated. The loss of soil due to accelerated erosion has caused immeasurable damage. The flooding has also cost millions of dollars from destroyed property and lost revenue. In an attempt to correct the problem, the federal and state governments have conducted studies to determine solutions to flooding and accelerated erosion. In past years, the government has appointed agencies and allocated funds to control land deterioration and minimize the effects of flooding. Since that time, much work has been done by these agencies in the area of watershed management. Some of the major projects implemented to alleviate flooding include: mountain and hillslope contouring, range revegetation, grazing control, check damming, bank stabilization, and channelization. Several of these management techniques have been successful, while other have proven to be much less than satisfactory, and in many cases, their negative impacts far outweigh their benefits.

Much of the effort to control flooding in the United States has been focused on the lower segments of rivers and streams. Numerous flood control devices have been constructed in and along the waterways. In recent years, there has been a growing concern regarding the impacts associated with various methods of flood control. Most flood control sturctures are located within the riparian zones. This zone provides habitat vital to many forms of animal life. To more fully understand the impacts associated with various flood control techniques, wildlife agencies recognize the need to inventory the wildlife and their habitat.

There are two major objectives to conducting this study. The first is to provide the Nevada Department of Wildlife with a map inventory of the major habitat types existing along the Humboldt River riparian zone. The second objective is to describe the ecological relationships that exist between habitat types and their surrounding environment, and to report impacts to the habitat due to management practices along the river.

STUDY AREA

The study area includes all of the riparian habitat along the Humboldt River from the small farming community of Deeth, down stream past the town of Elko, to just west of the South Fork confluence (Figure 1). The area mapped on the Hunter, Nevada USGS quadrangle was used as the historic study area.

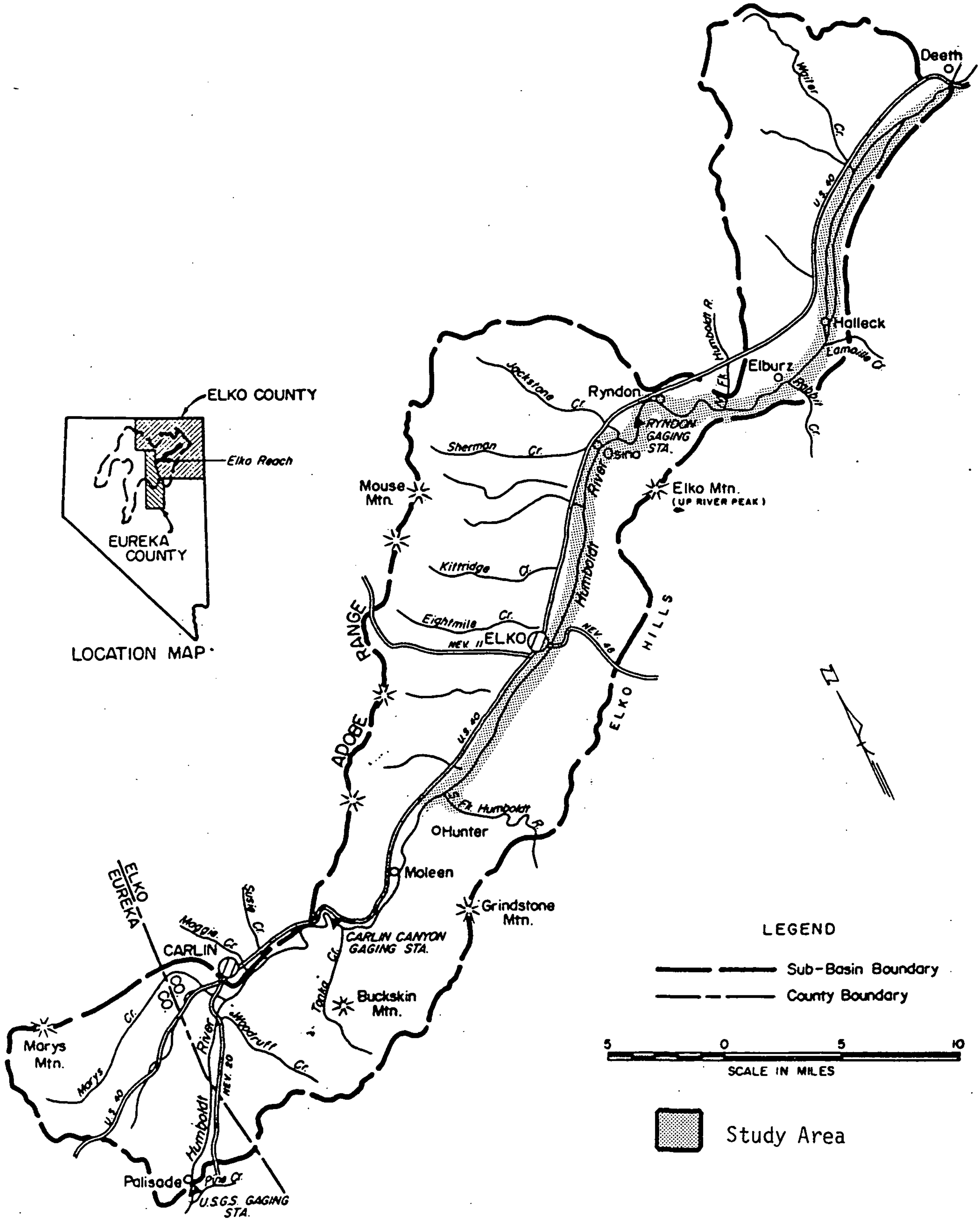


Figure 1. Map of the study area from Deeth to the confluence of the South Fork and Humboldt River. (Base map taken from USDA 1966 report.)

METHODS

Data Acquisition

The principal source of data for this study was aerial photography. Available photography was accessed through Aerial Photography Summary Record System (APSRS) and the National Cartographic Information Center (NCIC) Custom Query. Specific photos were ordered from the several flight indices, providing both the spatial and temporal coverage needed. High altitude color infrared photos were ordered from BLM flights and conventional B/W photos were ordered from ASCS flights.

Due to unusual amounts of precipitation last winter and spring (1982-83), the Humboldt River riparian area was flooded to a greater than usual depth and for a longer period of time during the spring and summer of 1983. This caused some delay in getting onto the ground for beginning preliminary field studies. This rare event, however, provided the opportunity to record the inundated areas along the river. On June 8, most of the river floodplain was photographed from Deeth to approximately 15 miles east of Battle Mountain using EPA's Enviropod panoramic camera. Color infrared film was used at an altitude of 3,000 feet above ground level. This photography was not flown as part of the original contract, but was covered by the Nevada Department of Wildlife under a separate agreement with CRSC, who manages the Enviropod for EPA.

Preliminary examination of the study area began when the BLM and ASCS photos were received. The photographs were examined to identify discernable patterns created by variations in color, shape, tone, texture, and geographic location. These examinations were made using large and small scale black and white, natural color, and color infrared photography.

The next step was a trip to the field to verify the patterns identified in the lab with the vegetation types on the ground. This entailed a trip to Elko by Merrill K. Ridd (CRSC Director) and Kevin P. Price (Project Scientist) on Monday, June 20, 1983. They worked with Marcus (Pete) Rawlings (non-game Biologist), both on the ground and from a helicopter, to identify the various vagetation types associated with the Humboldt River riparian habitat and to correlate the different vegetation types with patterns identified on the aerial photographs. At this time, assessments were made regarding the importance of each vegetative community to the different wildlife types in the area. The next day, June 21, 1983, a helicopter was used to obtain 35 mm slides of the different vegetative communities. The different vegetation types were photographed and documented throughout the entire study area. Each photograph location was identified and marked on a high altitude aerial photograph. A review of these slides aided in associating vegetation with patterns identified on the high altitude photography.

A second three-day trip was made to Elko by Kevin Price on July 27, 1983 to work in the field with Pete Rawlings. While there, much of the time was spent observing and photographing microhabitat variations between vegetative communities. The South Fork of the Humboldt was investigated more extensively due to the dramatic changes noted from multiple dates of aerial photography from 1950 to 1983. This area was observed for clues to explain such phenomena as channel straightening, channel deepening, accelerated bank erosion, increased point bar development, and vegetative responses associated with these changes. Time was also spent in determining, from observation, a moisture gradient based on vegetative stratification along the gradient. River structures such as dams, bridges, bank stabilization, and channelization were noted.

On July 28, 1983 an airplane was contracted by CRSC to once again fly the Humboldt floodplain using the Enviropod. The purpose of this second flight was to rephotograph the study area later in the growing season, when water levels had dropped and most farmers had stopped flood irrigating their fields. This time the photography was flown at 2,000 feet above ground level using natural color film. CRSC invested in this additional photography, which was not part of the original contractual agreement, in order to improve interpretation and mapping accuracy.

Mapping Vegetation

The systematic mapping of riparian habitates of the study area began in the month of August in the CRSC lab. Drafting film overlaying 1:24,000 scale orthophoto quadrangles was used as the mapping base. Vegetative patterns interpreted from the aerial photography were transferred to this map base. This prescribed scale became the deciding factor regarding the choice of map detail and mapable unit sizes. Three major factors were considered when deciding which size and type of vegetative units could be mapped: (1) the needs of the Nevada Department of Wildlife, (2) the amount of detail that could be discerned from the photographs, and (3) the mapping scale of the quadrangle. Actually, through Enviropod photography, greater detail can be interpreted than can be drafted at a scale of 1:24,000. According to the original plan, map unit sizes were determined by the quadrangle scale and the CIR photography (1:30,000). The Enviropod photography provides the interpretive accuracy to assure that the correct cover types were identified and labeled. The end result is that the smallest map units consistent with quadrangle scale were delineated, and identification accuracy of the cover types in those units was assured by examining Enviropod photography. Enviropod photography provided a windfall of information that was unanticipated at the onset of the project.

Historical Study

The purpose of the historical study is to evaluate changes to a section of the river over a span of 33 years (1950-1983). The section of the river selected for study is the South Fork area, approximately 7.5 miles west of Elko. The portion of the river displayed on the Hunter 7.5-minute USGS quadrangle was used as the historical study area. This site was selected because there have been dramatic changes of the river channel and the riparian habitat over the years. Within the historical study area some of the fields that were once native hay meadows are now irrigated alfalfa. As a result of man induced change, natural vegetation has been altered. This section of the river also demonstrates the impacts of channel modification. To make this portion of the study possible, CRSC obtained aerial photographs of the historical study area for the years indicated on Table 1.

Overlays of the vegetation and river patterns were produced for each of the years shown in Table 1. The 1975, 1:24,000 scale orthophoto quad was used as a base map. To maintain consistency in the photo

Table 1. Historical Evaluation Investigation Photography

Date	Years Between Flights	Form	Scale	Source
Sept. 1950	5	B/W	1:20,000	TXPIC
Aug. 1955		B/W	1:23,000	USGS
	10			
July 1965		B/W	1:15,799	BLM
	9			
Sept. 1974		B/W	1:40,000	ASCS (enlarged to 1:24,000)
	1			
July 1975		B/W	1:78,000	ASCS (enlarged to 1:24,000)
	4			
July 1979		CIR	1:24,000	BLM
	1			
Aug. 1980		CIR	1:58,000	ASCS
	3			
July 1983		N/C	1:7,600	CRSC

Interpretation key:

B/W	Black and white photography
CIR	Color infrared photography
N/C	Natural color photography, Enviropod, panoramic
TXPIC	Texas Petroleum Information Center
USGS	United States Geological Survey
BLM	Bureau of Land Management
ASCS	Agricultural Stabilization and Conservation Service
CRSC	Center for Remote Sensing and Cartography

interpretation, one person was responsible for the interpretation and mapping of all dates. The historical overlays were then compared to determine cause and effect relationship on the river and the riparian zone.

RESULTS AND DISCUSSION

Final Product

The final results of the investigation are 16 wildlife habitat maps and this interpretive report. The maps are prepared as clear diazo overlays registered to the 7.5-minute quadrangles. Eight of the habitat maps represent the 1983 growing season from Deeth to South Fork. The other eight represent the historical sequence of the Hunter quadrangle.

As a result of field observations, examination of available aerial photography, and assistance from the Nevada Department of Wildlife, 16 riparian cover (habitat) types were delineated and mapped. A legend showing the 16 types and their corresponding symbols is illustrated in Table 2. All areas which have either moving or standing waters were mapped. These include man-made watering and drainage ponds. The interpreter attempted to represent the width of the river on the map by widening or narrowing the dark lines which represent the river, its side channels, oxbows, and branching irrigation canals. There are many stream deposits or point sandbars along the river which were too small to map at the 1:24,000 scale. In some areas, i.e., South Fork, the point bars were large enough that they were mapped. In most cases, the areas mapped as river deposits are large areas where the river overflows its channel during flood stage and deposits enormous amounts of sediment onto the floodplain.

The majority of the habitat types listed on the legend are vegetative communities. Bulrush (*Scirpus spp.*) and rush (*Juncus spp.*) were mapped collectively as one habitat type. Cattail (*Typha latifolia*) was also

Table 2. Legend of symbols used on the Humboldt River maps.

Water	Black
Stream deposits	S
Bulrush	B
Cattail	C
Willow	
young	1
mature	2
dead (sprayed)	3
Rose	R
Hay meadow	H
Annual weeds	A
Wildrye (Elymus)	E
Greasewood & rabbitbush	G
Upland (sagebrush)	U
Agriculture	Ag
Farmyard	F
Dams	[D]
Bridges	[B]
Bank stabilization	[S]
Channelization	[C]
Aerial photograph number	⊞

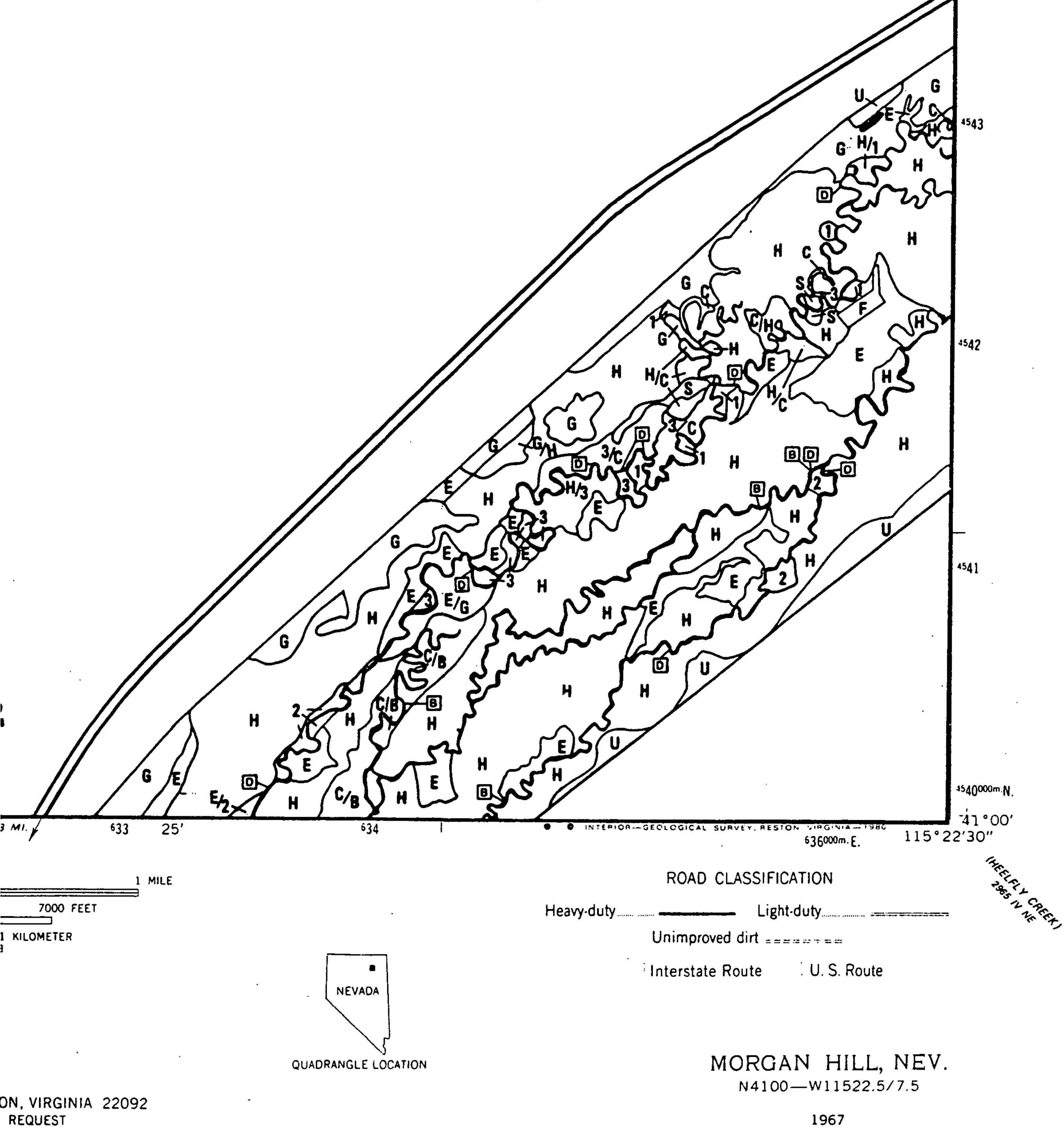
mapped as a habitat type. The willow (Salix exigua) habitat was subclassifed into three habitat types: young willow, mature willow, and dead (sprayed) willow. Wild rose (Rosa woodsii) frequently grows as an understory of the willow community, often making it difficult to differentiate from willows Wherever rose dominates the community, the map is marked with the symbol R. The hay meadows are areas dominated by perennial grasses and forbs. The majority of the meadows are harvested as grass hay in late July and early August. The meadows are then used as pasture lands for livestock from late fall until early spring.

Great Basin Wildrye (Elymus cinereus) was selected as an important habitat type. It supplies forage and cover to both wildlife and livestock. Cheatgrass (Bromus tectorum), or exotic annual sites were also classified and mapped. These sites were mapped because they are an indicator of rapid change and habitat deterioration. Greasewood (Sarcobatus vermiculatus) and rabbitbush (Chrysothamnus nauseosus and Chrysothamnus viscidiflorus) are mapped together as a single habitat type because they were found inhabiting similar sites. The upland type is dominated by sagebrush (Artemesia tridentata) and cheatgrass. Agricultural lands are irrigated areas which commonly contain alfalfa. The farmyard category includes farm houses, buildings, and the surrounding corrals and equipment yards.

The location of dams, bridges, bank stabilizing sturctures, and areas of channelization are indicated on the maps using symbols shown in Table 2. An airplane symbol is used on the maps to represent locations on the ground corresponding to Enviropod photographs. On the maps, this symbol is followed by two frame numbers, one number for N/C, and one for CIR film.

Figure 2 illustrates a sample of the final map product. Cover types were mapped to a detail of approximately one-third of an acre. Where a single symbol is used to label an area, the photo interpreter determined that at least 80% of the area was dominated by a single cover type. When more than one symbol is used, interpreters felt this area was a mixture or complex cover type. The dominant cover type within the complex is represented by the first symbol. In many cases, there are three or more cover types represented within a complex, but it was felt using more than two symbols per area would clutter the map and make it more difficult to use. Hay meadows present a particular problem in this context. Since small inclusions of hay meadow can be found within almost all other cover types (especially cattail and bulrush commnunities), the hay meadow symbol was usually not included as one of the complex symbols. The hay meadow symbol was used, however, when it was the first or second most prevalent cover type. Willows are also commonly found in association with cattail and bulrush. Willow communities are sometimes difficult to map because they are commonly found growing in a narrow band along meander scars and irrigation ditches. Realizing this problem, it should be understood that small ditches supporting a thin band of willows could not be mapped at the 1:24,000 scale. This same problem exists with the wildrye habitat type. Wildrye communities often lie between the hay meadows and greasewood-rabbitbrush cover types. When wildrye communities are narrow, this is generally an indication of a rapid elevation increase from the wet floodplain to the dry floodplain.

Figure 2. Sample of the final map product, fitted to the Morgan Hill USGS 7½ minute quadrangle.



Humboldt River Environmental Ecology

Riparian community ecology. Within the confines of a generally flat environment, such as a river floodplain relatively few factors affect the distribution of plants. Otherwise common variables such as slope, aspect, and soil texture are essentially unimportant factors affecting the distribution of plant communities. Observations made in the field suggest that microrelief, with its influence on soil moisture, is the major factor dictating the spatial distribution of plants. Table 3 shows the relationship of habitat types to the soil moisture gradient. Average soil moisture content would be altered most drastically by changes in the microrelief or changes in the ground water table. The unloading of stream deposits on the floodplain tends to elevate local topography, consequently decreasing soil moisture. The vegetation inhabiting the elevated areas would gradually change to a more drought tolerant vegetation type. Percent soil moisture displays an inverse relationship with distance from the river. With increasing distance from the main channel, percent moisture in the soil decreases. Sudden changes in an area's moisture gradient take place when a river meander is cut off. As the new shortened channel is formed, the stream velocity is increased and the water table drops.

The remainder of this section of the report will give a general overview of the vegetative lateral profile, beginning at the river channel and extending outward to the upland foothills. Plant species inhabit a specific site because of their ability to outcompete other species for the resources of that site. Many plants which inhabit dryer soils can, to a degree, successfully live on wetter sites if the vegetative competition is

Table 3. Soil moisture gradient and related habitat types.

Soil moisture	Habitat type
Wettest	Bulrush and rush
↕	Common cattail
	Sandbar willows
	Wild rose
Moist	Hay meadows
↕	Annual weeds
	Basin wildrye
	Greasewood and rabbitbush
Driest	Upland (sagebrush)

removed. Because these plants are not as effective in competing for the available resources of the wetter locations, they are restricted to sites for which they are best adapted. This principle, as a rule, does not hold true for the opposite situation. Plants requiring wetter soils find it very difficult to survive on a dryer site.

The habitat diversity along the Humboldt River is dependent on the microrelief and the water table of the area. Channel morphology varies from slow river flow with meandering channels, to much faster flow with straighter channels. Fast moving sections of the river are characterized by cut banks and gravel point bars. New point bar deposits are first invaded by willows and other pioneer-type species. Vegetation at the edge of the cut bank is predominately hay meadow, except when a meander begins cutting into a recent point bar and willow communities are eroded and dorpped into the river. Bulrush and cattail will be found in shallow, slow moving or still waters. They characteristically are found in small oxbows and meander loops that have been cut off from the main channel. Bulrush, rush, and cattail are commonly found as inclusions in association with the hay meadow habitat type.

The willow population is more drought tolerant than cattails but require more moisture than the hay meadow type. Willows are commonly found inhabiting a plain one or two feet lower than the hay meadow type.

Wild rose (Rosa woodsii) is often found growing as an understory in the willow habitat type. Roses are slightly more drought tolerant than willows so their habitat usually begins where the willow habitat ends. Solid rose stands are found along railroad tracks throughout the study area. The sprayed willow communities in the Deeth area now show an increased understory of wild rose. This is probably due to protection of roses from herbicides by overstory of willows. Once the willow overstory is killed, more sunlight, nutrients, and moisture are availabe to the understory rose population. Increased populations of wild rose were also noted just west of the mouth of Osino Canyon and west of the South Fork confluence.

Hay meadows were noted to be of two distinct types, dry meadow and wet meadow. The major area dominated by dry hay meadows extends from the South Fork of the Humboldt downstream toward Carlin Canyon. There are smaller dry hay meadows scattered throughout the study area. The hay meadows from Deeth to Osino Canyon are generally a wetter meadow type. Meadows through Osino Canyon, and for approximately 1 1/2 miles west of the canyon, are much dryer. At this piont, the meadows become wetter again until approximately 4 miles east of Elko, here the hay meadows are almost completely destroyed due to a lowered water table. The meadows west of Elko are dry for approximately 2 miles, then become wet again. These wet meadows continue to the South Fork confluence, where they immediately become very dry.

There are fewer bulrush and cattail inclusions within the dry hay meadows due to the lower water table. Plant species found on these sites are indicative of a dryier and poorier hay quality meadow type. The dominant grass inhabiting the dry meadow type is Nevada bluegrass (*Poa nevedensis*), with some alpine timothy (*Phleum alpinum*). It is also common to find rocky mountain iris (*Iris missouriensis*) and poverty sumpweed (*Iva axillaris*) growing on these meadows. The wet meadows are dominated by tufted hair grass (*Deschampsia caespitosa*) and some creeping wildrye (*Elymus triticoides*).

The annual weed habitat is a vegetation type dominated by very competitive invader species. The species dominating this habitat type are cheatgrass, an annual grass, and two annual mustards, clasping pepperweed (Lepidium perforiatum) and tumble mustard (Sisymbrium altissimum).

Prevalence of these invader species is indicative of a declining local water table. As the water table moves down in the soil profile, native plants adapted to the site begin to die. Because the competitive pressures once exerted by the native plants rapidly diminish, circumstances become optimal for an invasion of the site by exotic annuals. Once invaders dominate the area, it becomes very difficult to reclaim the site. The annual dominated site produces marginal forage in the spring and goes into dormancy early in the summer. This community type will be discussed in greater detail later in the report.

Great basin wildrye (Elymus cinereus) inhabits the zone of transition between the lower floodplains and the upper floodplains, with respect to lateral position. The microrelief is an important factor effecting the distribution of this habitat type. Where the transition between lower and upper floodplains is gradual, the area suitable for basin wildrye populations is greatly increased. Where the transition is abrupt, the basin wildrye is found growing as a narrow vegetative band. Elevated land strips throughout the lower floodplain are also commonly populated by basin wildrye. Little rabbitbush (Chrysothamnus viscidiflorus) is also commonly found growing within the basin wildrye habitat type. Increased populations of little rabbitbush within a basin wildrye community usually indicates either overgrazing of the wildrye, or declining soil moisture due to changes in the water table or local microrelief. Transition areas from wildrye to greasewood will also have more little rabbitbush inhabiting this zone.

The greasewood (Sarcobatus vermiculatus) and rabbitbush habitat type dominates the upper floodplain and resides at the highest local elevation along the Humboldt River floodplain. The soil surface within this habitat is commonly covered by a thin layer of alkali minerals. The prevalent shrubs are greasewood, little rabbibush, and rubber rabbitbush. The predominant grass types are saltgrass (Distichlis spicata) and cheatgrass, with some patches of basin wildrye. This habitat type lies on soils which have a relatively deep water table and poor water infiltration. The community size is also controlled by relief and the local water table. Along the upland areas the community distribution is controlled by local relief. Areas which have abrupt topographic changes, from the floodplain to the upland hills, will limit the distribution of this habitat type. Lowering of the water table will also favor the greasewood and rabbitbush community and allow for its invasion onto the dryer site. Areas with deep water tables may be dominated completely to the channel's edge by this habitat type.

The last habitat type included in the study is the upland (sagebrush) community. This type usually begins at the foothills along side the floodplain. The site is dominated by big sagebrush (Artemesia tridentata) and cheatgrass. There are areas within this habitat type which have substantial populations of littleleaf horsebrush (Tetradymia glabrata) and spiny hopsage (Grayia spinosa). This habitat type can also invade onto the lower floodplain if, for some reason, the local water table has been lowered.

River channel ecology. The dominant willow type within the study area is the common sandbar willow (*Salix exiqua*). From an ecological standpoint, this plant is a pioneer species. It is usually one of the first, and one of the few plant species, able to successfully move onto the new point bar deposits. New point bar banks are gently sloped to the waters edge and are very coarse in texture, being a composite of cobble, gravel, and sand. Because of the coarse texture, point bars water holding capacity, as well as available nutrients, are very low. The lack of vegetation on the bars also allow extreme fluctuations between daytime and nighttime temperatures.

During the rivers high runoff and flooding periods, willows stabilize the point bars and effectively slow the sediment laden waters, causing the waters to deposit their finer sediment load. As horizontal deposition continues, point bars will build and migrate into the river channel, leaving behind a new floodplain. The trailing edge of the bar is then covered by layers of finer textured materials and is inhabited and stabilized by willows. The willows influence a sites microenvironment by adding organic matter to the soil, which in turn enhances soil moisture retention and increases soil nutrients. Soil surface temperatures are also tempered as the vegetative canopy increases. As point bars enlarge and opposite banks cut, the river moves laterally away from the point bar deposits, thus decreasing the soil moisture at the willows outer or trailing edge. As soil moisture decreases, the willow species are outcompeted and overtaken by rose and the grass meadow community.

In contrast to the more gently sloped profile of the point bar, the cutbank edge is very steep. The cutbank is often undercut, which will weaken the overhanging soil layer and increase bank failure and erosion. The elevation along the cutbank side is slightly higher than the point bar side. Because of the slightly dryer soils of the cutbank edge, due to greater relief above the water table, the predominant vegetation types are grasses instead of willows. Occasionally, the cutting edge of a river meander will erode into the outer or trailing edge of another meander point bar which might still be covered by willows.

The average rooting depth of grasses is three feet. Most perennial grasses are effective erosion deterents and bank stabilizers because of the quality ground cover they provide and because of their prolific rooting systems. For this reason, it is felt that grasses and willows are the best plants, in terms of site adaptation and bank stabilization, for their respective sites.

The nine habitat types and the river channel ecology just discussed are in a delicate equilibrium with nature and easily become altered by man's various activities along the river. The next part of this report will address management practices implemented on the Humboldt River and the ecological response to these practices.

Humboldt River Management Practices

Willow eradication. Over the years, many acres of willow habitat along the Humboldt River have been eliminated. The most common method of eradication has been through the use of aerial applied 2,4-D. After the willows die, they are sometimes burned in place or mechanically removed.

There are several theoretical reasons behind willow control. The most common reason for controlling willows is to increase forage. The removal of willows increases the acreage available for the production of hay meadows. It is also a common, but questionable belief that the removal of willows will increase stream flow, due to a reduction in evapotranspiration. Another reason for eradication may be to improve the landowners accessibility to his land and livestock.

In recent years, willow control and eradication practices have been implemented on the Humboldt River. According to one landowner, in 1982, a two-mile stretch of the river riparian zone was sprayed, extending downstream from the community of Deeth. The ASCS records also indicate that in 1976 two major sprayings along the Humboldt River were funded. The first spraying originated approximately two miles west of Deeth and extended downstream nearly two miles east of the community of Halleck (about a ten mile distance). The other spraying covered approximately four and one-half miles, beginning at the end of Osino Canyon and extending west towards Elko.

River damming. Several permanent and many temporary water diverting structures are found along the Humboldt River. The most common are the temporary dams (tight dams) which are made by depositing dirt and rocks, or by placing tarps in the channel. This type of dam is used by ranchers to divert water onto their hay meadows. The temporary dam is used commonly early in the growing season and is usually found along the river's smaller side channels. The dams are removed shortly before grasses in the meadows mature, so that hay harvesting equipment can move onto the fields.

Semi-permanent dams are used along the main river channels. These dams usually consist of cement frames spanned by removable wooden planks which divert water down irrigation canals and ditches. Within the study area, there were 64 semi-permanent and temporary dams located and mapped. While no large permanent dams are located this section of the river, one permanent dam several miles up the South Fork is believed responsible for many impacts extending into the study area.

Bridges and bank stabilization. The locations of all bridges crossing the main channel, side channels, and canals have been mapped. Also mapped are areas where bank stabilization methods have been used along the river in an attempt to control bank cutting.

Channelization. There are five sites mapped where mechanical channel modifications were obvious. Channel straightening through the city of Elko is the largest modification within the study area. Other relatively large modifications were mapped, with one at Osino, another is one mile east of Elko, and two near Halleck, one approximately 2 1/2 miles upstream from Halleck and the other approximately 3/4 of a mile downstream. Sites of natural channelization resulting from certain management practices were noted on both the South Fork and North Fork, and several places along the Humboldt. These sites will be discussed in more detail later in the report.

General Discussion of River Geomorphology

Before discussing the impacts of management practices along the Humboldt, it is felt that a review of river morphology will help the reader to appreciate the impacts associated with unnatural modifications on the river. It is important to understand the morphological stages which bring a stream system into equilibrium. As a stream reaches equilibrium between its load and transporting capacity, the channel is said to be "graded." A series of four drawings taken from Strahler's text, The Earth Sciences, (Strahler 1971) show the evolutionary stages of stream development (Figure 3). The first drawing (a) illustrates a young stream. Initially, a stream has many lakes, falls, and rapids because of insufficient time to erode areas of uplift or to fill depressions with sediment. Drawing (b) shows how gorges form as rapids erode the uplifted areas. Once a stream is receiving and transporting sediment to the limit of its capacity, the period of rapid channel downcutting comes to an end and the channel is said to be graded (drawing c). At this time, rapids will have been removed by abrasion and the channel will have formed a smoothly decreasing slope throughout its length. A layer of bed materials (sand, gravel, and cobbles) will normally cover the channel floor and will be continually reworked as the stream stage rises and falls. Once graded, the main stream begins to produce floodplain by cutting horizontally on the outside of the stream bends (drawing d). This activity, termed "lateral planation," is the process responsible for widening the floodplain. Once the floodplain is wide enough, a wave-like succession of channel bends, termed meanders, are formed.

The channel width and depth are influenced by both the volume and

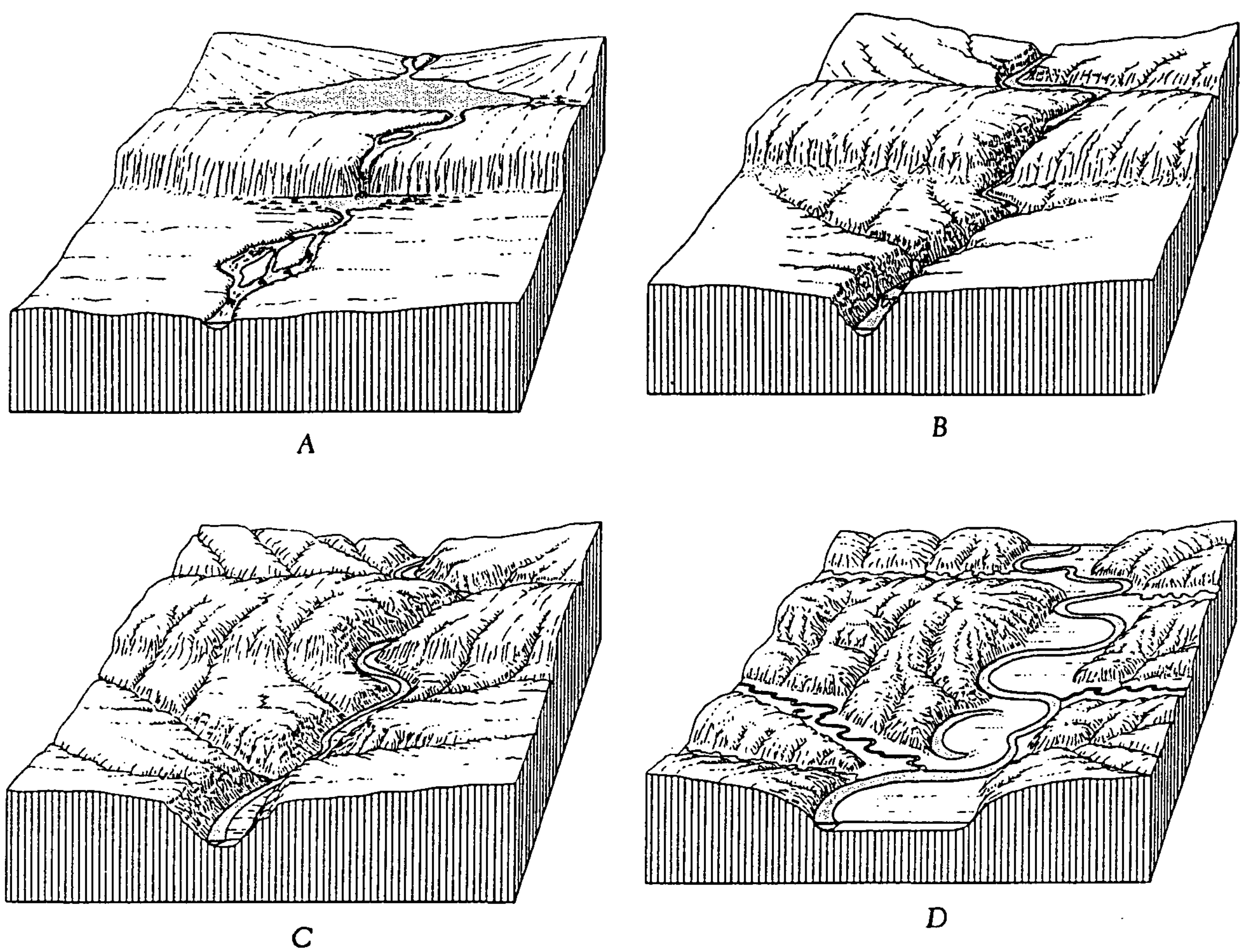


FIGURE 3. Evolution of a stream and its valley. (*A*) Initially the stream has lakes, falls, and rapids. (*B*) Erosion of a rock gorge occurs rapidly, draining the lakes and reducing the falls. (*C*) The stream becomes fully graded, permitting a narrow floodplain to be formed. (*D*) Enlargement of the floodplain allows meanders to shift more freely between valley walls. (© 1960, John Wiley & Sons, New York. Based on drawings by Erwin Raisz.) (Strahler 1971)

velocity of stream discharge and the amount of sediment load transported. As a general rule, a stream transporting larger particles (bedload) of sand, gravel, and cobble will be wider and shallower, while streams transporting small particles (suspended load) of silt and clay form narrower and deeper channels. The amount of sediment carried by a stream is a major factor influence morphological characteristics of the channel.

Erosion is a natural process of nature. The degree of erosion that is considered acceptable will vary depending on the location. Humid environments receive more precipitation but usually have much less soil loss due to a thick vegetative cover. Conversely, the Badlands of South Dakota receive much less precipitation, but this water is responsible for a greater amount of erosion. Mismanagement practices are often the cause of "accelerated erosion." Erosion is considered accelerated when topsoil is eroded faster than it is formed. Accelerated erosion or "denudation" may be natural to some areas, such as the Badlands, but in many cases it is a direct result of man's negligence.

When soils are left unprotected, they become susceptible to several forms of erosion. Splash erosion is initiated when rain droplets hit the ground and their impact dislodges fine soil particles. The fine particles will seal the soil pores which reduces soil permeability. This reduced permeability causes the water to move across the surface of the ground rather than infiltrating into the soil. This type of water movement is termed "sheet erosion." As sheeting water collects into channels, it begins to cause rill and gully erosion. The fine particles collected in gullys eventually drains into streams and rivers and increases the sediment load in these systems. As the suspended sediment load in a river is increased, the river will naturally improve its sediment transporting efficiency or unit stream power (USP) by making horizontal and vertical channel adjustments. A stream will improve its capacity to move fine suspended sediments by increasing water velocity. This is accomplished by straightening of the channel, thereby increasing channel drop per distance traveled. As the channel straightens it also deepens, which in turn lowers the local water table. This drop in the water table causes many other environmental changes to take place. The remainder of this section of the report will discuss environmental impacts resulting from various management practices and channel modifications on the Humboldt River.

Impacts Associated with River Management Practices

The four major river management practices have created significant impacts on wildlife habitat conditions. The impacts are complex and continuous.

Impacts of willow eradication. The elimination of willows has a multiple effect upon the environment and ecology of the area. This section of the report will cover the effects of willow eradication upon the following: soil stabilization; water quality (with regard to trubidity, temperature, oxygen, aquatic plants, and macroinvertibrates); aquatic habitat; waterfowl and other bird habitat; wildlife and livestock habitat.

Willows are usually sprayed from a fixed-wing aircraft. The willows are sprayed with the herbacide 2,4-D, which is used in the control of broadleaf plants. Usually when an area is treated, all locations inhabited by willows are sprayed. After the willows have died, some landowners leave the dead stems in place, while others move onto the grounds with machinery to remove the standing debris. The debris is sometimes dumped into the river. More often, it is merely piled and burned or left to decompose. As the willow canopy and broadleaf understory die, much of the protective ground cover is lost and the soil becomes more susceptable to erosion. This is less of a problem on sites where the debris is left in place, than on sites where soils are disturbed by removal equipment. The problem is also minimized when there is a healthy grass understory. Sites with very dense willow canopies generally have a poor understory covering. Due to the reduced understory ground cover, sprayed high density willow stands are probably more susceptable to soil erosion than lower density stands.

The removal of willows along the river also allows livestock to gain access to the channel banks. As livestock trail along the river banks the remaining vegetation is trampled. This exposes the soil, leading to increased erosion and stream sediments. A study by Platts (1981) concluded that overgrazing along streams will increase the channel gradient, widen the stream, and eliminate undercutting.

Increased sediment in the system effects many aspects of the river's ecology and morphology. As turbidity in the river increases, the effective penetrating depth of sunlight decreases. Decreases in sunlight adversely effect the aquatic plant and animal life. Too much sediment smothers plants and macroinvertibrates, which reduces the food base for aquatic animals and wildlife, and it tends to destablize the channel banks. Heavy sediment loads will also increase nutrient water pollution. Nearly all phosphorus (85%) and most nitrogen (70%) in surface runoff is attached to sediments (Karr and Schlosser 1977). Aquatic plants and animals, which help buffer the effects of increased nutrients and chemicals, are killed as these contaminants increase to lethal levels.

Willow removal generally increases the river temperature. This is especially true for narrower side channels of the river where willow canopy shades much of the water. Vegetation removal along the headwater of streams can increase the temperature from 6 to 9°C (Karr and Schlosser 1977). Stern and Stern (1980) bring up the point that waters unprotected from wind become warmed because riffled waters absorb more sunlight. Increases in temperature effect the biota which are dependent on the system (such as, macroinvertibrates and invertibrates). As temperature increases, the amount of O_2 in the water decreases and the phosphorus concentrations increase. Streams with low O_2 concentrations are less effective in disposing of organic matter. As the water temperature rises, pathogens in the water will also increase. Elevated water temperatures also promotes algae growth, which adversely effects the water appearance, smell, and taste.

Overhanging willows also increases habitat diversity for fish and other animals that are dependent upon the river. Leaves and insects falling from the willows into the river add to the food base for all aquatic life in and around the system. Since macroinvertibrates are very sensitive to changes in water quality, the vitality of a stream is often measured by the amount and type of macroinvertibrates supported by the stream. These organisms are very effective in breaking down organic matter which enters the system. They also play a vital role in the food chain and diet of most fish, as well as many waterfowl and shore birds.

The cover provided by willows is important to both wildlife and livestock. The willows along the Humboldt River provides nesting habitat for both the snowy egret (Egretta thula) and the black-crowned night-heron (Nycticorax nycticorax). The habitat diversity created by willows increases site carrying capacity and species diversity. Bird populations are especially dependent upon the willow habitat. Willows also provide escape and thermal cover to both wildlife and livestock. Livestock managers have found that thermal protection provided by willows can be very important in reducing livestock loss due to exposure.

Impacts of damming. Damming of a stream will effect the channel above, below, and at the site of the dam. There are many morphological changes to a stream channel and its associated environment as a direct result of damming. Much of the information presented on the impacts associated with dams will be taken from an article written by Simons (1979). The discussion of damming will follow in this order, impacts above the dam, at the dam site, and below the dam.

There are several upstream impacts on channels and tributaries that result from damming. The degree of impact associated with a particular dam is highly dependent on both the size of the dam and the stream size. Keeping this in mind, the following is a list of the effects that can be associated with damming.

1. The impoundment of water and the backwater effect of impoundment reduces flow velocity. This increases the depth of flow and

causes deposition of bed material sediments.

2. The deposition of sediments causes general aggradaion (building up) of the upstream channel and its tributaries.
3. The deposition of sediment upstream from the dam results in a general increase in riverbed elevation, which in turn, increases the flood stage and the potential for flood damage.
4. The increase in riverbed elevation and water level in the upstream channel may result in accelerated seepage and heightening of the water table. This can effect riparian land use, riparian vegetation, and drainage requirements.
5. Elevation of the riverbed will upset the equilibrium of the stream. The river now becomes ungraded, which can have a damaging impact downstream from the dam.
6. The aggradation in the river and its system of tributaries will reduce the effective waterway clearance beneath bridges, and in the extreme cases, can result in their failure.

When dealing with small-scale dams which are used for water diversion, rather than retention, there are fewer impacts occuring around the dam site. Impacts which remain of concern regardless of the dam size are: siltation immediately upstream from the dam; waterlogging; and drainage problems on lands surrounding the standing water.

Most environmental impacts associated with damming result downstream below the structure. The degree of influence, as stated before, is greatly dependent on the size of both the dam and stream. The following list demonstrates many of the possible impacts that are found downstream from a dam.

1. Impoundments trap inflowing sediment, resulting in the release of essentially clear (sediment-hungry) water into the downstream system.
2. The relatively clear water derives its equilibrium load by seizing bed sediments and eroding the river banks.
3. The erosion induced by the release of clear water results in degradation of the channel.
4. Degradation of the channel increases the gradient of both the main channel and the local tributaries which enter the stream below the dam.
5. With increased gradients, the main channel, and the tributaries as well, are subjected to an increase in velocity, degradation, and bank erosion.
6. As a result of increased erosion, channel stabilization may be required in the main channel and its tributaries to protect riparian land and adjacent developments.
7. Degradation of the channel system may lower the water table of the surrounding floodplains.
8. Changes in the river morphology and accelerated drainage will also cause changes in the surrounding vegetation.
9. The consequence of eliminating silts and clays from the downstream river system can be very significant. The effects would include increased seepage, decreased channel stability, and decreased moisture-holding capacity of newly-formed banks.

Many of the impacts mentioned in this section can be seen surrounding the dam, located on the South Fork, approximately 2.5 miles above the confluence of the Humboldt River and the South Fork. The channel degradation below the dam is especially impressive, where the channel has become much deeper and straighter. In most cases along the lower South Fork, the natural vegetation associated with the riparian floodplain has been altered. Meadows which once contained valuable perennial grasses and forbs are now dominated by relatively worthless invading annuals, such as cheatgrass, clasping pepperweed, and tumbling mustard weed. Much of the willow and rose habitat has already been destroyed by the lowered water table. The South Fork's channel banks are steep, indicating continual sluffing and bank erosion.

The South Fork channel alterations maintain dominance, even after merging with the main channel of the Humboldt. At the point where the South Fork joins the Humboldt river, there is an immediate change in the Humboldt's channel characteristics. Upstream from the confluence, the Humboldt River subdivided into several smaller channels which have a high meander frequency. The water table is much higher in this area and sustains higher quality hay meadows. The upstream section also contains extensive cattail, rush, and willow habitat, and is generally much more productive with respects to vegetation, livestock, and wildlife. When the South Fork converges with the Humboldt River, all of these smaller side channels, of the Humboldt, converge. At this point, the new main channel deepens, lowering the water table and greatly reducing the surrounding vegetative production. Wildlife habitat was also greatly devalued as a result of decreased vegetation.

The effects associated with damming are in many ways similar to the effects of channelization. For this reason, discussion of many other environmental impacts associated with damming will be deferred to the discussion on the impacts of channelization.

Impacts of bridges and bank stabilization. The effects of bridges and bank stabilization (rip-rapping) on the Humboldt are less severe than impacts associated with willow eradication, damming, and channelization. The degree of impact due to bridges is dependent upon the type of bridge. If the bridge restricts waterflow during high water, then flooding and erosion are increased. A common method of bridging some of the side channels is accomplished by placing a culvert in the stream channel and then backfilling over the culvert. These structures often restrict water flow and temporarily change the stream characteristics, which may either be beneficial or detrimental. The pools behind the structure adds diversity to the stream and often provides habitat that are used by waterfowl and shore birds. This type of structure could also be detrimental due to the increased propensity for flooding and erosion.

Bank stablization efforts are most common along channels which are cutting into railroad track beds, railroad bridges, highway bridges, and farmlands. Bank stabilization leads to channel downcutting and erosion, sections of a river which are rip-rapped will usually be deeper. Streams with stabilized banks will transport coarser bed load, leading to continuous bank maintenance problems (Stern and Stern 1980), bank stabilization precludes meandering and causes a wider range of discharge due to containment of flows in the channel. This prevents normal widening and overflow processes during high stages of the river (Stern and Stern 1980). Bank stabilization can also destroy natural habitat for plant and animal life.

Impacts of channelization. Channelization is a common practice where rivers and streams flow through farmlands or areas of urbanization. City planners often encourage channelization as a means to protect property owners and businesses from flood damage. Channelization is also used in agricultural areas to reduce crop damage due to flooding and to increase tillable lands in areas of poor drainage by lowering the water table. All of these reasons for channelization are desirable and sometimes necessary. However, when compared with the problems associated with channelization, there should be a rigorous economic reevaluation (Karr and Schlosser 1979). Though channelization does originally provide more land for agriculture, it will not pay off in the long run if all costs are considered: de-watering of upstream farmland, flooding and sedimentation of downstream farmlands, damage to bridges and other structures, loss of wildlife and fisheries habitat, and many other problems seen and unseen.

Factors influenced by channel straightening include stream discharge, water temperature, water quality, water table, bank stability, and aquatic and riparian habitat. The impacts of channelization, like other stream modifications, go beyond the channlized area and can be traced up and downstream for miles.

Studies show that channelization does not control flooding, but instead relocates the affected area and intensifies the impact. Areas that were not prone to flooding will more than likely experience it once channelization has been implemented (Emerson 1971). Because channelization increases stream competency and the unit stream power

(USP), discharge is increased and channel erosion accelerated. As the sediment-laden water reaches the end of a modified channel, the discharge is restricted by the unmodified channel. This forces the water to overflow the channel onto the floodplain. Sediments are rapidly deposited on the floodplain near the end of the modified channels. Since erosion is greater along areas that have been channelized, the unmodified channel adjusts to accommodate the increased sediment load. This is accomplished by increasing the channel gradient. Stream gradient is increased by entrenching and straightening of the channel. Since water moves more rapidly through channelized sections, there is a sequential backcutting of the upstream channel. This backcutting will continue upstream until the channel gradient is brought back into equilibrium. A study by Emerson (1971) showed that after channelization work on the Black Water River in Missouri, the channel widened at an average of 1 meter per year and entrenched at a rate of .16 meters per year.

Channel entrenchment effectively lowers the water table within the riparian zone. This creates a drastic change in the riparian communities toward a more xeric condition. As soil moisture diminishes, plants which are drought tolerant outcompete the more mesic vegetation types. Sites that are xeric produce less vegetation, and the plants that are produced are of poorer forage quality. An extensive example of this is seen on the floodplain immediately upstream from Elko. According to Barclay's work in Oklahoma (1980), many plant species, and consequently, many animal life forms were lost as a result of channelization. He reports that due to loss of habitat, bird populations were devastated and reptiles and amphibian populations greatly deminished. Species richness, density, and vertical vegetative density values are all much less along channlized areas.

Also associated with loss of vegetation is the loss of top soil due to erosion. As the more xeric species replace original plants, the soil is often left more exposed and sediment is washed into the channel. Channelization destroys the natural diversity of aquatic habitat by destroying or minimizing riffles, pools, undercuts, and log jams.

All of the above impacts are most damaging to macroinvertibrates, fish, waterfowl, and shore birds. Channelization destroys the food base that is vital to many ducks (Karr and Schlosser 1977). A study by Emerson (1971) on the Black Water River in Missouri showed channelized sections produced 51 Kg. of fish per acre as opposed to 256 Kg. per acre along unchannelized areas.

Many of the impacts associated with channelization can be observed on the Humboldt River. There are three types of channelization noted within the study area. The most obvious modification is the mechanically straightened section of the river which flows through the town of Elko. This type of channelization is the most damaging to the ecological balance of the river system. It can create a multitude of problems and is responsible for tremendous damage to the riparian habitat.

The second type of channelization is similar to the first, but at a smaller scale. Several places on the Humboldt River have small man-made channel modifications. The channel may be rerouted by cutting off a meander, or a short section of the river has been straightened in order to decrease flooding and bankcutting.

The third type of channelization is a natural process which often is a direct result of environmental mismanagement, such as overgrazing of the watershed, trampling of the banks by livestock, increasing sediment load, or changes in channel gradient due to damming. Since many acres of riparian habitat are impacted by this form of channel degradation, it has become a major concern to resource managers.

Obvious impacts resulting from channelization through the city of Elko can be observed at both ends of the structure. Approximately 2.5 miles east of Elko the river side channels converge and the river begins to straighten. The water begins to collect sediment and the channel entrenches deeper as it approaches the city. Natural meadows along this channel are replaced by many acres of annual weeds and scattered communities of greasewood and sagebrush. Willow communities are almost completely lost. Wildlife managers are concerned with loss of meadows because they provide important habitat to many forms of animal life. The local greater sandhill crane (Grus canadensis var. tabida) population is quite dependent on the hay meadows. Downstream, on the other side of town, massive deposits of sediment can be observed. Extensive flood damage is apparent and the unchannelized section of the river becomes straightened in response to the increased sediment load.

Approximately two miles from the mouth of Osino Canyon, massive sediment deposits are now covering approximately 75 acres of hay meadow. Enviropod photography revealed that the vast majority of the sediments appear to be coming from the North Fork of the Humboldt River, which is approximately ten miles upstream. The North Fork channel is deeply entrenched and areas that were once lush hay meadows are now dominated by greasewood and saltgrass. Many of the erosion problems on North Fork have been attributed to overgrazing in past years (USDA 1966). Landowners downstream receive the brunt of these mismanagement practices that occur miles upstream. The river as it leaves Osino Canyon remains deeply entrenched for approximately two miles before unloading its sediments onto adjacent farms. The hay meadows between the deposit site and the mouth of the canyon are also quite dry and of much poorer forage value. The South Fork channelization will be discussed in more detail in the historical study section of this report.

Channelization can be directly caused by man, or be indirectly attributed to his management practices. Either way, the results are very similar, both produce lasting impacts which are damaging to many aspects of the environment. The following diagram shows a one-way sequence of events that summarizes the impacts of channelization (Stern and Stern 1980).

Cutoff of meander to shorten length → Increased stream gradient → Increased flow velocity →

Increases unit stream power → Increases channel erosion, downcutting → Increased sediment solid load → Habitat degradation

Historical Study

The historical study was done by producing a series of eight overlays for the Hunter USGS quadrangle. The overlays were mapped at 1:24,000 scale using aerial photography dating from 1950 to 1983. This area was selected for the historical study due to the extensive environmental changes that have transpired over the years. Photography in 1950 reveals that at the time the riparian zone consisted of native hay meadows, willows, cattail, and bulrush. The river had extensive narrow meanders. Enviropod photography for 1983 shows that both the South Fork and the Humboldt River channels have greatly straightened in comparison with 1950, double or tripled in width, and deeply entrenched.

A common way to calibrate degree of river meander within a valley is to establish a ratio of river course length to distance along the valley. A ratio of 1:1 would indicate an undeviating river course. According to Rayner (1972) a ratio between 1:1 and 1.5:1 is considered "straight." A river with a ratio greater than 1.5:1 is considered "meandering." In the present study, the Humboldt and South Fork channels, within the Hunter quadrangle, had a ratio of 1.9 in the year 1950, and 1.3 in 1983. This is a three-fold reduction in meander length, from 90% above a straight line, to 30% above a straight line.

As a result of man-induced channelization on the river, the vegetation in 1983 is predominantly annual weeds. The sites that are not artificially watered are practically useless. Greasewood and rabbitbush have increased in abundance where willow and cattail have greatly decreased. Point bar deposits are much bigger in 1983 and remain relatively barren. Areas which were once small oxbow ponds and lakes are now willow patches, and areas that are slightly higher in elevation are covered with perennial grasses or annual weeds. Still, artificial watering has preserved some of the areas and a considerable amount of the land is under irrigated alfalfa production.

The historical photography shows a rapid transition from meandering channels to greatly straightened channels around the year 1965. The photography shows that between 1955 and 1965, much of the area to the west of the South Fork River was converted from hay meadow and rabbitbush to irrigated alfalfa. At this same time, a large cement diversion dam was constructed at the mouth of South Fork Canyon. The dam was constructed to divert water to irrigate the alfalfa. The effects of damming the river and the increased sedimentation from irrigation waters caused a drastic change in the surrounding area. The impacts of this channelization continue into the Humboldt River and on past Carlin Canyon.

The historical study depicts the impacts over time associated with altering stream gradient and increasing sediment load. Many acres of hay meadow were taken out of production and much of the wildlife habitat was destroyed.

Upstream Watershed Management Implications

Early settlers to the Humboldt River Basin mismanaged the range by overgrazing. A report by the Nevada Department of Conservation and Natural Resources and the United States Department of Agriculture (1963), states that the North Fork watershed was grazed by several large sheep outfits. Within a few years, the sheep had reduced the range from a well-covered perennial grass and forb understory to the present eroded state. Flooding problems along the Humboldt River will never be totally solved by channelizing, damming, or rip-rapping. These types of modifications simply intensify and shift the point of impact to areas upstream and/or downstream. Until proper management practices of the watershed are attained, the Humboldt River will continue to cost taxpayers and property owners millions of dollars in flood damage and control.

Recommendations

Based on observations from aerial photography and field work, coupled with a review of the literature, the following recommendations are made regarding willow eradication, damming, bank stabilization, and channelization.

Willow eradication. Realizing that willow eradication does offer the landowner increased acreage for forage production, it is felt that there is room for controlled willow eradication. It is also felt that the adverse effects of destroying all willows along the river channels far outweigh any reasons for complete eradication of willows in a particular area. The channel and stream protection, increased habitat, and erosion control provided by a greenbelt of willows offers dividends which, unfortunately, many do not understand. If landowners will leave a willow buffer zone on each side of the channel, it is strongly believed the benefits will far outweight the inconveniences and loss of useable lands. For the purposes of preserving wildlife and livestock habitat, it is recommended that in large willow stands, an island of willows should be left to provide thermal and hiding cover.

Damming. This is a more delicate subject because of the need for irrigation water. The recommendation is to minimize the number of dams constructed on the river. Temporary dams seem to be less damaging than permanent structures. Structures that are still in place during high runoff periods have the potential for most damage. It must be realized that changes in the stream gradient can initiate channelization and loss of valuable hay meadows and wildlife habitat.

Bridges and bank stabilization. Bridges are not as important of an issue as bank stabilization. Usually if accelerated bank erosion is a problem, bank stabilization is not the ultimate answer. Bank stabilization will only encourage channel down cutting. This flood control measure should be used only where it is absolutely necessary. Before initiating a project, careful consideration should be given to the impacts that will be incurred as a result of bank stabilization projects.

Channelization. After observing and studying the impacts associated with channelization, it is felt that in most areas it should be avoided at all costs. City planners should be aware of the flood zones and discourage commercial or urban expansion within this zone. It is felt that more government funding should be allocated to repairing the watershed, which is probably the real answer to most flooding problems.

The natural structure of streams and rivers is easily upset by various activities by man. The consequences of man's mismanagement practices on the river are not yet fully known. Damages to the river structure are often difficult to repair, and in many cases irreversible. Based on the findings of this study, the Humboldt River has already incurred many of the impacts associated with improper conservation practices. Future neglect of such practices will result in increased river destruction and eventual loss of the natural riparian habitat.

BIBLIOGRAPHY

Barclay, J. S., 1980, Impact of stream alterations on riparian communities in south central Oklahoma. USDI. Fish and Wildlife Service. OBS-80/17. 91 pp.

Emerson, J. W., 1971. Channelization: A case study. Science 173:325-326.

Karr, J. R., and I. J. Schlosser, 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. EPA-600/3-77-097. 91 pp.

Platts, W. S., 1981. Effects of sheep grazing on a riparian-stream environment. USDA Forest Service Res. Notes INT-307. 5 pp.

Rayner, J. N., 1972. Conservation, equilibrium, and feedback applied to atmospheric and fluvial processes. Assoc. of Amer. Geographers. Wash. D. C. 1972. Commission on College Geography. Resource Paper No. 15. 23 pp.

Simons, D. B., 1979. Effects of stream regulation on channel morphology. In The Ecology of Regulated Streams (ed.) J. V. Ward and J. A. Stanford. Plenum Press. 398 pp.

Stern, D. H., and M. S. Stern, 1980. Effects of bank stabilization on the physical and chemical characteristics of streams and small rivers: A synthesis. USDI. FWS/OBS-80-11. 43 pp.

Strahler, A. N., 1971. Geologic work of running water. In The Earth Sciences. Harper and Row Publishers. 824 pp.

USDA Humboldt River Basin Field Party and M. C. Fleischmann, 1966. Basin wide report on Humboldt River Basin, Nevada. 120 pp.