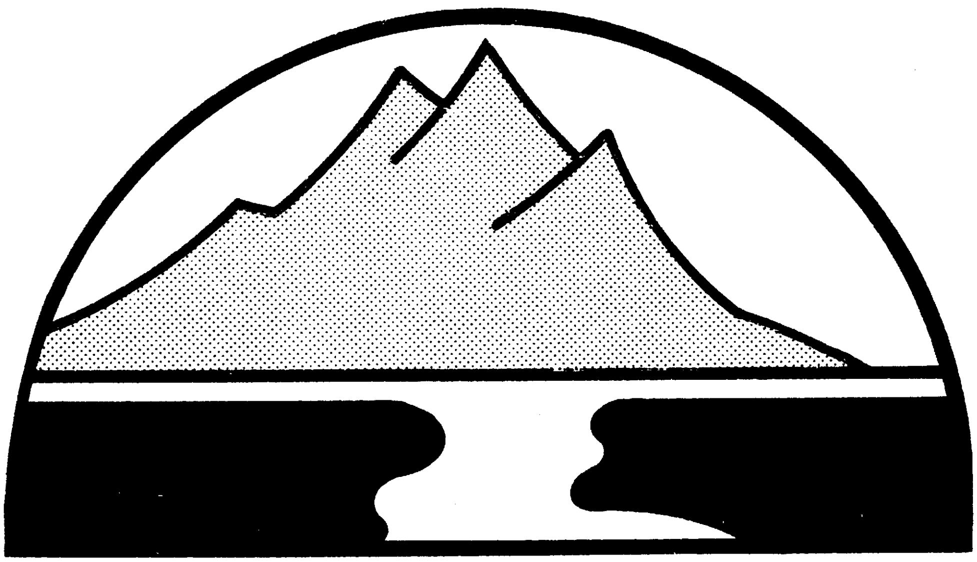
'87 Wyoming Water Development and Streamside Zones Tour



Water-Land-Man

August 31-September 1, 1987
Park County Area

WELCOME

The local 1987 Wyoming Water Development and Streamside Zones Tour Committee welcomes you to Cody, Wyoming. Founded in 1987 by it's namesake Colonel William F. "Buffalo Bill" Cody. It is located in the Absaroka Range of the Rocky Mountains and at the doorstep of the Shoshone National Forest, Wilderness areas, and Yellowstone National Park. Because of it's spectacular location and temperate climate, Cody hosts recreational opportunities year-around, such as: hunting, fishing, snowmobiling, skiing, hiking, horseback riding, photography, and camping.

We, once again, WELCOME you and hope you enjoy your stay.

Local Committee Members:

Forrest Allen, Chairman, Cody Conservation District, Cody

Duane E. Cooperider, Park County Extension Agent, Cody

Bill Sheets, Water Commissioner, Districts 9&10, Division III, Cody

Beryl Churchill, Wyoming Water Development Commission Member, Powell

Richard Kroger, District Fisheries Biologist, Bureau of Land Management, Worland

Ron McKnight, Area Fisheries Supervisor, Wyoming Game and Fish Department, Cody

Jim L. Fischer, Civil Engineer--Staff Officer, Shoshone National Forest, Cody

Fred Christenson, Chief of the Water and Lands Division, Bureau of Reclamation, Cody

Gary W. Jensen, Coordinator, Big Horn Basin Wyoming Resource Conservation and Development Area, (RC&D), Cody

Mitzi Klemp, Program Coordinator, Cody Conservation District, Cody

Noreen Thomas, Communications Coordinator, Extension Service, Powell

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'87 WYOMING WATER DEVELOPMENT AND
STREAMSIDE ZONES TOUR SPONSORS

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'87 WYOMING WATER DEVELOPMENT
AND
STREAMSIDE ZONES TOUR

TOUR OBJECTIVE

How we proceed with the development and management of Wyoming's water and related resources is a very important issue before us today. How to serve the needs for multiple uses including agriculture, municipalities, industry, fish and wildlife and recreation with plentiful and quality water is being debated at numerous forums. Public policies, legislation and mandates are, and will continue to be formulated addressing related water issues. Streamside zones (riparian areas) and their management impact Wyoming's water quantity and quality. Thus, the objective of this tour is to provide a teaching and learning experience for the participants in an attempt to develop a more informed citizenry who can contribute to the future of Wyoming.

WATER TERMS

One reason people have disagreements about water is that they believe their interests conflict. But often these disagreements stem from misunderstandings which occur when technical water terms are used in discussions relating to water resources. Once there is an understanding of certain water terms, there often are not the conflicts between water interests as initially thought. Following are definitions of some water terms that you may hear being used during this streamside tour. There are words that may continue to have no commonly accepted precise definition. But awareness of words and phrases can help clarify communications on water resources.

The following list of words and definitions are far from being complete. The Wyoming Water Research Center has a more complete publication on selected words and definitions relating to hydrologic (water) terms. The publication is available at no charge from the Water Center. You may write to the Wyoming Water Research Center, Box 3067, University Station, University of Wyoming, Laramie, WY 82071 and ask for "Glossary of Selected Hydrologic and Water Quality Terms" (Water Resources Series No. 1 Revised).

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ABSORPTION - The entrance of water into the soil or rocks by all natural processes, including the infiltration of precipitation or snowmelt, gravity flow of streams into the valley alluvium into sinkholes or other large openings, and the movement of atmospheric moisture.

ACRE-FOOT - A unit of volume of water equal to the volume of a prism 1 foot high with a base 1 acre in area; 43,560 cubic feet or 325,851 gallons. Commonly used in measuring volumes of water used or stored.

ALKALINE - An adjective referring to water or soils which contain enough alkali substances to raise the pH-value above 7.0, or to harm the growth of crops.

ALLUVIAL - An adjective referring to soil or earth material which has been deposited by running water.

ALLUVIAL VALLEY FLOOR (legal) - "The unconsolidated stream laid deposits holding streams where water availability is sufficient for subirrigation or flood irrigation agricultural activities but does not include upland areas which are generally overlain by a thin veneer of colluvial deposits composed chiefly of debris from sheet erosion, deposits by unconcentrated runoff or slopewash, together with talus, other mass movement accumulation and wind-blown deposits." (P.L. 95-87, Sec. 701).

APPROPRIATE WATER RIGHT - The legal right to take or divert water for beneficial use.

AQUIFER - A formation, group of formations, or part of a formation that contains enough saturated permeable material to yield significant quantities of water to wells and springs.

ARTESIAN AQUIFER - (1) An aquifer which is bounded above and below by formations of impermeable or relatively impermeable material. (2) An aquifer containing water under sufficient pressure such that when tapped the water level will rise above the confining layer.

ARTIFICIAL RECHARGE - The addition of water to the ground water reservoir by activities of man, such as irrigation or induced infiltration from streams, wells, or spreading basins.

BED LOAD - Sand, silt, gravel, or soil and rock detritus carried by a stream on or immediately above its bed.

BENEFICIAL USE OF WATER - The use of water for any purpose from which benefits are derived, such as for irrigation, hydroelectric power, industrial and domestic use. Benefits vary with locality and custom, and what constitutes beneficial use is often defined by statute or by court decision.

CFS - Abbreviation for cubic feet per second.

CFS-DAY - The volume of water represented by a flow of 1 cubic foot per second for 24 hours; 86,400 cubic feet, 1.983471 acre-feet, or 646,317 gallons. May be abbreviated SFD.

CHANNEL (WATERCOURSE) - A natural or artificial open conduit which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels, which may be single or braided. Canal and floodway are some of the terms used to describe artificial channels.

CHANNEL STORAGE - The volume of water stored in a channel or over the flood plain of the streams in a drainage basin or river reach.

CLOSED BASIN - A basin draining to some depression or pond within its area from which water is lost only by evaporation or percolation. A basin without a surface outlet for precipitation falling thereon.

CONSERVATION STORAGE - Storage of water for later release for beneficial uses, such as municipal water supply, power, or irrigation, in contrast to storage for flood control.

CONSUMPTION, DOMESTIC - The quantity or quantity per capita of water consumed in a municipality or district for domestic uses during a given period, usually one day. Domestic consumption is generally considered to include all uses included in "municipal use of water," in addition to the quantity of water wasted, lost, or otherwise unaccounted for.

CONSUMPTION, INDUSTRIAL - The quantity of water consumed in a municipality or district for mechanical, trade, and manufacturing uses during a given period, usually one day.

CONSUMPTIVE USE - (1) The quantity of water absorbed by crops and transpired or used directly in the building of plant tissue, together with that evaporated from the cropped area; (2) The quantity of water transpired and evaporated from a cropped area, or the normal loss of water from the soil by evaporation and plant transpiration; (3) All activities where the use of water results in a loss in the original water supplied, such as industrial or municipal consumption.

CONSUMPTIVE USE, NET - The consumptive use decreased by the estimated contribution of rainfall toward the production of irrigated crops. Net consumptive use is sometimes called "crop irrigation requirement."

CONVEYANCE LOSS - The loss of water from a conduit due to leakage, seepage, evaporation, or evapotranspiration.

CREEK - A natural stream of water, normally smaller than, and often tributary to, a river.

CREST - (1) The top of a dam, dike, spillway, or weir to which water must rise before passing over the structure. (2) The highest point of a wave. (3) The highest elevation reached by flood waters flowing in a channel.

CUBIC FEET PER SECOND - A unit expressing rates of discharge. One cubic foot per second is equal to the discharge through a rectangular cross section, 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second. Abbreviated as CFS.

DAILY FLOOD PEAK - The maximum mean daily discharge occurring in a stream during a given flood event.

DEAD STORAGE - The volume in a reservoir which lies below the lowest controllable level and is not susceptible to gravity release.

DEEP PERCOLATION LOSS - Water that percolates downward through the soil beyond the reach of plant roots.

DEGRADATION - The geologic process in which parts of the earth's surface, such as cliffs, rocks, and streambeds, disintegrate due to atmospheric and aqueous action. See also DEGRADATION, STREAM-CHANNEL.

DEGRADATION, STREAM-CHANNEL - The removal of channel bed materials and downcutting of natural stream channels. Such erosion may initiate degradation of tributary channels, causing damage similar to that due to gully erosion and valley trenching. See also DEGRADATION.

DEPTH OF RUNOFF - The total runoff from a drainage basin divided by its area. For convenience in comparing runoff with precipitation, depth of runoff is usually expressed in inches during a given period of time over the drainage area expressed in acre-feet per square mile.

DETENTION DAM - A dam constructed for the temporary storage of flood flows where the opening for release is of fixed capacity and is not manually operated.

DETENTION STORAGE - The volume of water, other than depression storage, existing on the land surface as flowing water which has not yet reached the channel.

DISCHARGE - The simplest meaning of discharge is outflow; the use of the term is not restricted as to course or location, and it can describe the flow of water from a pipe, as well as from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, stream, or ocean.

The data on surface water in the reports of the Geological Survey represent the total fluids measured. Thus, the terms discharge, streamflow, and runoff apply to water containing dissolved solids and sediment. Of these terms, discharge is the most comprehensive.

The discharge of drainage basins is distinguished as follows:

Runoff - That part of water yield that appears in streams. See WATER YIELD.

Streamflow - The water flowing in a stream channel.

Yield - Total water runout or crop; consists of runoff plus underflow.

Each of these terms can be reported in total volume (such as acre-feet) or time rates (such as cubic feet per second or acre-feet per year). The differentiation between runoff as a volume and streamflow as a rate is not accepted.

DIVERSION - (1) The act of taking water from a stream or other body of water into a canal, pipe, or other conduit. (2) A man-made structure for taking water from a stream or other body of water.

DOMESTIC USE OF WATER - The use of water primarily for household purposes, the watering of livestock, and the irrigation of gardens, lawns, and shrubbery surrounding a domicile.

DRAINAGE AREA - For a stream at a specified location, that area, measured in a horizontal plane, which is enclosed by a drainage divide. It may be expressed in acres, square miles, or other units of area. See also, WATERSHED.

DRAINAGE BASIN - A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water, together with all tributary surface streams and bodies of impounded surface water.

DRAINAGE DIVIDE - The boundary line along a topographic ridge or subsurface formation which separates two adjacent drainage basins.

DRAINAGE WATER - Water which has been collected by a drainage system. It may derive from surface water or from water passing through soil and may or may not be suitable for reuse.

DRAWDOWN - The lowering of the surface elevation of a body of water, the water surface of a well, the water table, or the potentiometric surface adjacent to a well, resulting from the extraction of water.

EFFECTIVE PRECIPITATION (RAINFALL) - (1) That part of the precipitation that produces runoff. (2) A weighted average of current and antecedent precipitation that is "effective" in correlating with runoff. (3) That part of the precipitation falling on an irrigated area that is effective in meeting the consumptive use requirements.

EPHEMERAL STREAM - A stream that flows only in direct response to precipitation and thus discontinues its flow during dry seasons. Its channel is above the level of the water table.

EROSION - The wearing away of the soil by running water, glaciers, winds, and waves. Erosion can be subdivided into three processes: corrasion, corrosion, and transportation. Weathering, although sometimes included as a type of erosion, is a distinct process which does not imply removal of any material.

EUTROPHICATION - The process of overfertilization of a body of water by nutrients which produce more organic matter than the self-purification processes can overcome.

EVAPORATION - The process by which water is transformed from the liquid or solid state into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

EVAPORATION, LAND - Evaporation from land surfaces, in contrast to evaporation from free water surfaces. See also EVAPORATION.

EVAPORATION, NET RESERVOIR - The difference between the total evaporation from the reservoir water surface and the evapotranspiration from the reservoir area prior to the existence of the reservoir, with identical precipitation.

EVAPORATION RATE - The quantity of water which evaporates from a given surface per unit of time, usually expressed in inches or depth per day, month, or year.

EVAPOTRANSPIRATION - The volume of water evaporated and transpired from soil and plant surfaces per unit land area (essentially the same as "consumptive use" except that it does not include the water retained within the plant tissue).

FIELD-MOISTURE CAPACITY - The quantity of water that can be permanently retained in the soil in opposition to the downward pull of gravity.

FIELD-MOISTURE DEFICIENCY - The quantity of water which would be required to restore the soil moisture to field-moisture capacity.

FLOOD - An overflow on lands that are used or usable by man and are not normally covered by water. Floods have two essential characteristics: (a) the inundation of land is temporary, and (b) the land is inundated by overflow from a river or other body of water.

Normally, a "flood" is considered as any temporary rise in streamflow or stage, but not the ponding of surface water, that results in significant adverse effects in the vicinity. Adverse effects may include damages from overflow of land areas, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions or other unfavorable situations by deposition of materials in stream channels during flood recessions, rise of ground water coincident with increased streamflow, and other problems.

FLOOD-CONTROL CAPACITY - That part of the gross reservoir capacity which, at the time under consideration, is reserved for the temporary storage of flood waters. It can vary from zero to the entire capacity (exclusive of dead storage) according to a predetermined schedule based on such parameters as antecedent precipitation, reservoir inflow, potential snowmelt, or downstream channel capacities.

FLOOD-CONTROL STORAGE - Storage of water in reservoirs to abate flood damage.

FLOOD CREST - The maximum stage or elevation reached by the waters of a flood at a given location.

FLOOD DAMAGE, DIRECT - The damage done by a flood to property, structures, goods, and so on, as measured by the cost of replacement and repairs.

FLOOD DAMAGE, INDIRECT - Expenditures (other than for repairs) made as a result of a flood, such as for relief and rescue work, or for moving silt and debris.

FLOOD, HISTORIC - Any flood for which the stage or flow can be estimated, or has been recorded. See FLOOD; FLOOD, RECORDED.

FLOOD, MAXIMUM PROBABLE - The largest flood for which there is any reasonable expectancy in a particular climatic era.

FLOOD PEAK - The highest value of the stage or discharge attained by a flood; thus, "peak stage" or "peak discharge." "Flood crest" has nearly the same meaning, but since it connotes the top of the flood wave, it is properly used only in referring to stage; thus, "crest stage," but not "crest discharge."

FLOOD PLAIN - (1) A strip of relatively flat land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. A water flood plain is overflowed during times of high water; a fossil flood plain is beyond the reach of the highest flood. (2) That land outside a stream channel described by the perimeter of the maximum probable flood. (3) The relatively flat area or lowlands adjoining an ocean, lake, or other body of standing water which has been or might be covered by floodwater.

FLOOD STAGE - (1) The gage height of the lowest bank of the reach in which the gage is situated. The term "lowest bank" is, however, not to be taken to mean an unusually low place or break in the natural bank through which the water inundates an unimportant and small area. (2) The stage at which overflow of the natural banks of a stream begins to cause damage in the reach in which the elevation is measured.

FLOOD ZONE - The land bordering a stream which is subject to floods of about equal frequency; for example, a strip of the flood plain subject to flooding more often than once, but not as frequently as twice in a century.

FLOWING WELL - A well from an artesian aquifer in which the water is under sufficient pressure to rise above the ground surface.

FLOW, MODIFIED - That streamflow which would have existed had the works of man in or on the stream channels and in the drainage basin been consistent throughout the period of record. Usually used with an adjective such as "present" or a specific year to mean that the flow record was modified to represent the record that would have been obtained had the "present" conditions prevailed throughout the period of record. Modified flow is equal to virgin flow (see FLOW, VIRGIN) minus the amount of STREAMFLOW DEPLETION occurring at the specified time.

FLOW, NATURAL - The rate of water movement past a specified point on a natural stream from a drainage area which has not been affected by stream diversion, storage, import, export, return flow or change in consumptive use resulting from man's modifications of land use. Natural flow rarely occurs in a developed country.

FLOW, OVERLAND - The flow of rainwater or snowmelt over the land surface toward stream channels. Upon entering a stream, it becomes runoff.

FLOW, VIRGIN - That streamflow which would exist had man not modified conditions on or along the stream or in the drainage basin. Same as RUNOFF.

FOREBAY RESERVOIR - A reservoir used to regulate the flow of water to a hydroelectric plant; it may also serve other purposes such as recreation. Sometimes called "forebay."

FREEBOARD - The vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of an open conduit, the top of a dam or levee, etc., which is provided so that waves and other movements of the liquid will not overtop the confining structure.

GEOHYDROLOGY - The branch of hydrology relating to subsurface or subterranean waters.

GEOLOGIC EROSION - The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of flood plains, coastal plains, etc. See also, EROSION.

GEOPHYSICS - The study of the physical characteristics and properties of the earth, including geodesy, seismology, meteorology, oceanography, atmospheric electricity, terrestrial magnetism, and tidal phenomena.

GROSS RESERVOIR CAPACITY - The total amount of storage capacity available in a reservoir for all purposes, from the streambed to the normal maximum operating level. It does not include surcharge but does include dead storage.

GROUND WATER - Subsurface water in the saturated zone, from which wells, springs, and ground water runoff are supplied.

GROUND-WATER BASIN - A physiographic or geologic unit containing at least one aquifer of significant areal extent.

GROUND-WATER HYDROLOGY - The branch of hydrology that treats ground water, its occurrence and movements, its replenishment and depletion, the properties of rocks that control ground-water movement and storage, and the methods of investigation and utilization of ground water.

GROUND-WATER MINING - The pumping of ground water from a basin where the safe yield is very small, thereby extracting ground water which had accumulated over a long period of time. It occurs when withdrawals exceed replenishment or when replenishment is negligible.

GROUND-WATER OUTFLOW - The part of the discharge from a drainage basin that occurs through the ground water. The term "underflow" is often used to describe the ground-water outflow that takes place in valley alluvium (instead of the surface channel) and thus is not measured at a gaging station.

GROUND-WATER OVERDRAFT - Pumpage of ground water in excess of safe yield.

GROUND-WATER RECHARGE - Inflow to a ground-water reservoir.

GROUND-WATER RESERVOIR - An aquifer or aquifer system in which ground water is stored. The water may be placed in the aquifer by either artificial or natural means.

GROUND-WATER STORAGE CAPACITY - The reservoir space contained in a given volume of deposits, or under optimum conditions of use, the usable ground-water storage capacity volume of water that can be alternately extracted and replaced in the deposit, within specified economic limitations.

HEAD-LOSS - (1) The decrease in total head caused by friction. (2) The effect of obstructions, such as narrow bridge openings or buildings, that limit the area through which water must flow, raising the surface of the water upstream from the obstruction.

HYDROGRAPH - A graph showing, for a given point on a stream or conduit, the stage, velocity of flow, available power, or other function of the discharge with respect to time.

HYDROLOGY - The science concerned with the waters of the earth, their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the environment, including living beings.

HYDROPHYTE - A plant which grows naturally in water, or in saturated soils. See MESOPHYTE; PHREATOPHYTE; XEROPHYTE.

INFILTRATION - The flow of a fluid into a substance through pores or small openings.

INFILTRATION CAPACITY - The maximum rate at which the soil, when in a given condition, can absorb falling rain or melting snow.

INSTREAM FLOW NEEDS - Those habitat requirements within the running water ecosystem related to current velocity and depth which present the optimum conditions of density (or diversity) or physiological stability to the aquatic organism being examined.

IRRIGATED AREA - The gross farm area upon which water is artificially applied for the production of crops, with no reduction for access roads, canals, or farm buildings.

IRRIGATION - The controlled application of water to arable lands in order to supply water requirements not satisfied by rainfall.

IRRIGATION EFFICIENCY - The percentage of water applied that can be accounted for in soil-moisture increase for consumptive use.

IRRIGATION REQUIREMENT - The quantity of water, exclusive of precipitation, that is required for crop production. It includes surface-evaporation and other unavoidable waste.

IRRIGATION RETURN FLOW - Applied water which is not consumptively used and returns to a surface or ground-water supply. In water-right litigation the definition may be restricted to measurable water returning to the stream from which it was derived. See also RETURN FLOW.

IRRIGATION, SUPPLEMENTAL - An additional irrigation water supply which supplements the initial, or primary, supply.

JETTY - A structure extending into the body of water on estuaries or open seacoasts, which is designed to prevent shoaling of a channel by littoral materials and to direct or confine the flow.

LEACHING - The removal of soluble constituents from soils or other material by infiltrating or percolating water.

LYSIMETER - An instrument used to measure the quantity or rate of downward water movement through a block of soil usually undisturbed, or to collect such percolated water for analysis of its quality.

MEAN ANNUAL FLOOD - The average of all the annual flood stages or discharges of record. It may be estimated by regionalization, correlation, or any other process that can furnish a better estimate of the long-term average than can the observed data. Some investigators arbitrarily define the mean annual flood as the stage or discharge having an exceedence interval of 2.33 years.

MEAN ANNUAL PRECIPITATION - The average over a period of years of annual amounts of precipitation.

MEAN ANNUAL RUNOFF - The average value of all annual runoff amounts, usually estimated from the period of record or during a specified base period from a specified area. See RUNOFF.

MEAN ANNUAL TEMPERATURE - The average of the monthly mean temperatures for the year.

MEAN DAILY TEMPERATURE - The average of the daily maximum and minimum temperatures.

MEAN MONTHLY TEMPERATURE - The average of the mean monthly maximum and minimum temperatures.

MESOPHYTE - A plant that grows under medium or usual conditions of atmospheric moisture supply, as distinguished from one which grows under dry or desert conditions (xerophyte) or very wet conditions (hydrophyte). See HYDROPHYTE; PHREATOPHYTE; XEROPHYTE.

METEOROLOGY - The science of the atmosphere; the study of atmospheric phenomena.

MICROCLIMATE - The local climatic conditions, brought about by the modification of general climatic conditions by local differences in elevation and exposure. The detailed climate of a very small area of the earth's surface.

MILLIGRAMS PER LITER - The weight in milligrams of any substance contained in one liter of liquid; nearly the same as parts per million.

NONCONSUMPTIVE USE - A use of water that does not reduce the supply, such as for hunting, fishing, boating, water-skiing, and swimming.

PERENNIAL STREAM - A stream which flows at all times. See also, STREAM, Perennial.

pH (HYDROGEN ION CONCENTRATION) - A measure of acidity or alkalinity. Distilled water, which is neutral, has a pH value of 7; a value above 7 indicates the presence of alkalies, while one below 7 indicates acids.

PHREATOPHYTE - A plant that habitually obtains its water supply from the saturated zone, either directly or through the capillary fringe. See also HYDROPHYTE; MESOPHYTE; and XEROPHYTE.

POLLUTION - The alteration of the physical, chemical, or biological properties of water, or a discharge of any substance into water, which adversely affects any beneficial water use.

PRECIPITATION - As used in hydrology, precipitation is the discharge of water, in liquid or solid state, from the atmosphere, generally onto a land or water surface. It is the common process by which atmospheric water becomes surface or subsurface water. The term "precipitation" is also commonly used to designate the quantity of water that is precipitated. Forms of precipitation include drizzle, rainfall, glaze, sleet, snow, graupel, small hail, and hail.

RAINFALL RATE - The amount of precipitation occurring in a unit of time; generally expressed in inches per hour.

REACH - (1) A length of channel which is uniform in discharge depth, area, and slope. (2) A length of channel for which a single gage affords a satisfactory measure of the stage and discharge. (3) The length of a river between two gaging stations. (4) More generally, any length of a river.

RESERVOIR - A pond, lake, or basin, either natural or artificial, used for the storage, regulation, and control of water.

RETARDING RESERVOIR - An ungated reservoir for temporary storage of flood water; sometimes called "detention reservoir."

RETURN FLOW - That part of a diverted flow which is not consumptively used and returns to its source or another body of water.

RIFFLE - A shallow rapids in an open stream, where the water surface is broken into waves by obstructions wholly or partly submerged.

RIVER BASIN - The area drained by a river and its tributaries.

RIVER STAGE - The elevation of the water surface at a specified station above some arbitrary zero datum.

ROOT ZONE - The subsurface zone from the land surface to the depth interwoven by plant roots.

RUNOFF - (1) That part of the precipitation that appears in uncontrolled surface streams, drains or sewers. It is the same as streamflow unaffected by artificial diversions, imports, storage, or other works of man in or on the stream channels. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow, or ground-water runoff. (2) Total discharge of (1) during a specified time.

SALINITY - The relative concentration of salts, usually sodium chloride, in a given water; commonly expressed as parts per million.

SECOND-FEET - An abbreviated expression for cubic feet per second. See CFS.

SEDIMENTATION - The process of subsidence and deposition by gravity of suspended matter carried by water, sewage, or other liquids. It usually occurs when the velocity of the liquid is reduced below the point where it can transport the suspended material.

SEDIMENT DISCHARGE - (1) The rate at which a dry weight of sediment passes a section of a stream. (2) The quantity of sediment, as measured by dry weight, or by volume, that is discharged in a given time period.

SEDIMENT, SUSPENDED - Very fine soil particles which remain in suspension in water for a considerable period of time without contact with the bottom.

SEEPAGE - (1) The slow movement of water through small cracks, pores, interstices, etc. of a material into or out of a body of surface or subsurface water. (2) The loss of water by infiltration into the soil from a canal, reservoir, or other body of water, or from a field. Seepage is generally expressed as flow volume per unit time. During the process of priming, the loss is called "absorption loss."

SHEET EROSION - The erosion which occurs when water flows in a sheet down a sloping surface and removes material in a sheet of relatively uniform thickness.

SNOW COURSE - A line laid out and permanently marked on a drainage area along which during snow surveys the snow is sampled at definite distances or stations and at appropriate times to determine its depth, water equivalent, and density.

SNOWPACK - A field of naturally packed snow that ordinarily melts slowly during the early summer months.

SNOW SURVEY - The process or operation of determining the depth, water content, and density of snow at various selected points on a drainage basin in order to ascertain the amount of water stored in the form of snow, and thus forecast subsequent runoff.

STORAGE - (1) Water artificially impounded in surface or underground reservoirs for future use. (2) Water naturally detained in a drainage basin, such as ground water, channel storage, and depression storage. The term "drainage basin storage" or simply "basin storage," is sometimes used to refer collectively to the amount of water in natural storage in a drainage basin.

STORAGE CAPACITY, ACTIVE - The total amount of usable reservoir capacity available for seasonal or cyclic water storage; gross reservoir capacity minus inactive storage capacity.

STORAGE CAPACITY, INACTIVE - That capacity below which the reservoir is not normally drawn, and which is provided for sedimentation, recreation, fish and wildlife, aesthetic reasons, or for creation of a minimum controlled operational or power head in compliance with operating agreements or restrictions.

STORAGE CAPACITY, TOTAL - The volume of a reservoir below the maximum controllable level, including dead storage.

STREAM - A body of water flowing in a natural surface channel. Also, as in the term "stream gaging," water flowing in any channel, natural or artificial. Streams may be classified as follows:

In Relation to Time:

Ephemeral-A stream that flows only in direct response to precipitation, and whose channel is at all times above the water table.

Intermittent or Seasonal - A stream that carries water most of the time, or over most of its course, but ceases to flow occasionally.

Perennial-A stream that flows continuously.

In Relation to Ground Water:

Gaining-A stream or reach of a stream fed by ground water.

Insulated-A stream or reach of a stream that neither contributes water nor receives water from the saturated zone, and is separated from it by an impermeable bed.

Losing-A stream or reach of a stream that contributes water to the ground water.

Perched-Either a losing stream or an insulated stream that is separated from the underlying ground water by an unsaturated zone.

STREAMFLOW - The discharge that occurs in a natural channel. "Streamflow" is a more general term than "runoff," as streamflow may be applied to discharge whether or not it is affected by diversion or regulation. See also RUNOFF.

STREAMFLOW DEPLETION - The amount of water that flows into a valley or onto a particular land area minus the water that flows out of the valley or off the land area.

STREAMFLOW ROUTING - A technique used to compute the effect of channel storage on the shape and movement of a flood wave.

STREAM GAGING - (1) The operation of measuring the velocity and average cross section of a stream of water in a channel or open conduit in order to determine the discharge. (2) A discharge measurement expressed numerically in appropriate units.

STREAM-GAGING STATION - A gaging station where a continuous record of the discharge of a stream is obtained.

STREAM GRADIENT - A general slope or rate of change in vertical elevation per unit of horizontal distance of the water surface of a flowing stream.

SUBIRRIGATED LAND - Land with a high water table condition, either natural or artificially controlled, that normally supplies a RUNOFF.

TEST HOLE - A well hole drilled for experimental or exploratory purposes.

TRANSPIRATION - (1) The quantity of water absorbed, transpired, and used directly in the building of plant tissue during a specified time period. It does not include soil evaporation. (2) The process by which water vapor escapes from a living plant, principally through the leaves, and enters the atmosphere.

WATER ANALYSIS - The determination of the physical, chemical, and biological characteristics of water. Such analysis usually involves four kinds of examination: bacterial, chemical, microscopic, and physical.

WATER QUALITY - The chemical, physical, and biological characteristics of water in respect to its suitability for a particular purpose.

WATER RIGHT - A legally protected right, granted by law, to take possession of water occurring in a water supply and to divert that water for beneficial use.

WATERSHED - All lands which are enclosed by a continuous hydrologic drainage divide and lie upslope from a specified point on a stream. See also DRAINAGE AREA.

• WATER SPREADING - Controlled application of water to the land in order to recharge ground-water aquifers.

WATER TABLE - The upper surface of a saturated zone, where the body of ground water is not confined by an overlying impermeable formation. Where an overlying confining formation exists, the aquifer in question has no water table.
WATER-TABLE AQUIFER - An unconfined aquifer.

WATER YEAR - The 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1959, is the "1959 water year."

WATER YIELD - (Water Crop or Runout) - The total runoff from a drainage basin through surface channels and aquifers; precipitation minus evapotranspiration.

WELL CAPACITY - The maximum rate at which a well will yield water under a stipulated set of conditions, such as a given drawdown, pump, and motor or engine size. Well capacity may be expressed in terms of gallons per minute, cubic feet per second, or other similar units.

WELL FIELD - A tract of land which contains a number of wells for supplying a large municipality or irrigation district.

WILTING POINT - The minimum quantity of water in a given soil necessary to maintain plant growth. When the quantity of moisture falls below this point, the leaves begin to droop and shrivel up. In any given soil the minimum quantity is practically constant for all plants, but it increases with a decrease in the size of soil particles.

XEROPHYTE - A plant which grows in arid areas. See also HYDROPHYTE; PHREATOPHYTE; MESOPHYTE.

YIELD - (1) The quantity of water expressed either as a continuous rate of flow (e.g., cubic feet per second) or as a volume per unit of time (e.g., acre-feet per year) which can be collected for a given use or uses from surface- or ground-water sources on a watershed. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. "Yield" is more or less synonymous with "water crop." (2) Total runoff. (3) The streamflow in a given interval of time derived from a unit area of watershed. It is determined by dividing the observed streamflow at a given location by the drainage area above that location and is usually expressed in cubic feet per second per square mile. See also YIELD, AVERAGE ANNUAL; YIELD, FIRM; YIELD, PERENNIAL; YIELD, SAFE.

YIELD, AVERAGE ANNUAL - The average annual supply of water produced by a given stream or water development.

YIELD, FIRM - The maximum annual supply of a given water development that is expected to be available on demand, with the understanding that lower yields will occur in accordance with a predetermined schedule or probability.

YIELD, PERENNIAL - The amount of usable water of a ground-water reservoir that can be economically withdrawn and consumed each year for an indefinite period of time. It cannot exceed the natural recharge to that ground-water reservoir and ultimately is limited to the maximum amount of discharge that can be utilized for beneficial use.

HANDY WATER EQUIVALENTS

1 cubic foot. . . . . . . 7.48 gallons. . . . . . 62.4 lbs. of water

1 acre-foot . . . . 43,560 cubic feet . . . 325,850 gallons
An acre-foot covers one acre of land one foot deep

1 cubic foot per second (cfs) . . . . . 448.8 gallons per minute

1 cfs . . . . 646,272 gallons per day
For 24 hours . . . . 1.98 acre-feet
For 30 days. . . . . 59.4 acre-feet
For 1 year . . . . 724 acre-feet

1 million gallons . . . . 3.07 acre-feet

1 million gallons per day (mgd) . . . . 1,120 acre-feet per year

1,000 gallons per minute (gpm). . . . . 2.23 cfs

1,000 gpm . . . . 4.46 acre-feet per day
An acre-foot supplies a family of 5 for 1 year

The standard term for rate of flow of water in an irrigation ditch is cubic feet per second (cfs), often called second-feet (sec-ft) or feet of water. A cubic foot per second of water is flowing when a cubic foot volume of water (equal to 1 ft wide, 1 ft long, and 1 ft high) passes a given point every second. Pumped water and water flow in a pipeline is often expressed in gallons per minute (gpm). One cubic foot per second of water equals:

a) Approximately 450 gallons per minute (gpm). All flows shown in cubic feet per second can be converted to gallons per minute multiplying by 448.8.
b) Approximately 1 acre-inch per hour.
c) Approximately 2 acre-feet per day (24 hours).

An acre-inch is the volume of water required to cover an acre of land with water 1 inch deep or the amount of water falling on an acre in a 1 inch rain. An acre-foot is the volume of water required to cover an acre with water 1 foot deep.

'87 WYOMING WATER DEVELOPMENT AND
STREAMSIDE ZONES TOUR SCHEDULE

August 31, 1987

10:00 a.m.	Regristration - Holiday Inn, Cody
10:30 a.m.	Tour Orientation Program - Introductory Remarks:

-Dorse Miller, Mayor, City of Cody
-Don Brosz, Associate Director, Wyoming Water Research Center and Extension Engineer, University of Wyoming
-Thor Stephenson, Bureau of Land Management, Cody
-Eric Greenquist, Bureau of Land Management, Cody

Issues-Water Resources and Stramside Zones

-Quentin Skinner, Professor, Range Management, University of Wyoming
-Dick Kroger, Fish Biologist, Bureau of Land Management, Worland
-Jim Fischer, Engineer, Minerals and Watershed State Officer, U.S. Forest Service
-Don Brosz, University of Wyoming, Agriculture

Stream Classification and Responses

-Tom Wesche, Research Associate, Wyoming Water Research Center, University of Wyoming

11:45 a.m.	Noon Lunch - Holiday Inn, Cody
12:45 p.m.	Load buses and leave for tour of South Fork of the Shoshone River

NARRATORS FOR THE AFTERNOON TOUR

-Beryl Churchill, Wyoming Water Development Commission and Irrigation Farming, Powell
-Fred Christenson, U.S. Bureau of Reclamation, Cody
-Bill Sheets, District Water Commissioner, Cody
-Dick Kroger, Bureau of Land Management, Worland
-Jim Fischer, U.S. Forest Service, Cody
-Nancy Draper, Draper Ranch, Cody
-Harvey Collins, Draper Ranch, Cody
-Ron McKnight, Wyoming Game and Fish Dept., Cody
-Suzanne Feurot, Nature Conservancy, Helena, MT.
-Mike Carnevale, Department of Enviromental Quality, Cheyenne
-Lucille Hicks, Local History, Cody

NARRATORS FOR THE AFTERNOON TOUR CONTINUED

- -Ed Gooley, Corp of Engineers, Riverton
- -Steve Oddan, Fish and Wildlife Service, Billings
- -Tom Wesche, Wyoming Water Research Center, University of Wyoming
- -Richard Marston, Wyoming Water Research Center, University of Wyoming
- -Vic Hasfurther, Wyoming Research Center, University of Wyoming
- -Quentin Skinner, Range Management, University of Wyoming

1:15 p.m.	Stop - unload buses
	Enlargement of Buffalo Bill Dam and Reservoir and construction of dust abatement dikes.
1:45 p.m.	Load buses
2:00 p.m.	Stop - unload buses
	Habitat along the Cody Irrigation Canal and land area.
2:40 p.m.	Load buses
3:10 p.m.	Stop - unload buses
	Stream tributary impacts - Ishawooa and South Fork
3:30 p.m.	Load buses
3:40 p.m.	Stop - unload buses
	Refreshment break - sponsored by Draper Ranch.
	Stream channel stabilization projects.
4:40 p.m.	Load buses
5:00 p.m.	Turn around at Cabin Creek.
5:20 p.m.	Stop - unload buses
	Boulder Creek - The power of water and summary of this portion of the tour.
5:45 p.m.	Load buses and return to Holiday Inn.
6:30 p.m.	Arrive Holiday Inn, Cody

7:00 p.m.	Social hour and dinner - Holiday Inn, Cody
8:00 p.m.	Program
	-Bob Palmquist, Associate Professor, Geology, Northwest Community College, Powell

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Reclamation Outlinks Status of Buffalo Bill Dam Project

Construction work on the Buffalo Bill Dam Modification Project is proceeding essentially on schedule towards a 1991 completion, according to Bill McCormick, Manager of the Bureau of Reclamation's Bighorn Projects Office, Cody, Wyoming.

The project involves raising the crest of the Buffalo Bill Dam 25 feet; enlarging and gating the spillway; rehabilitating the old Shoshone Powerplant; building a new Buffalo Bill Powerplant, and constructing dust abatement dikes in the North and South Fork areas and a protective dike in the Diamond Creek area.

McCormick said the Bureau of Reclamation has 51 people on board in the Cody office. Thirty-nine employees are employed in construction, six in maintenance in Cody and six are working at Boysen Dam and Powerplant in Thermopolis. Most of the Bureau employees, he said, transferred from other Bureau offices, though several were hired locally. By next year the Bureau anticipates a total of 70 employees working out of the Cody office.

Three construction contracts are ongoing employing a total of 83 people, 75 percent of which are Cody area residents. The number of employees changes as various subcontractors complete different phases of the work.

The Shoshone River Bridge was the first contract awarded on the Project and was completed in August 1986 by Reiman Construction Company of Cheyenne, Wyoming. The steel bridge crosses the Shoshone River upstream of the Hayden Arch Bridge on the old highway road and is visable from Highway 14-16-20 before it enters the highway tunnels on the way to Yellowstone Park. The bridge provides access to the construction site of the new Buffalo Bill powerplant.

K2B Constructors, Marysville, California, has been working on the quarry and riprap contract since February 1986 and the contract is approximately 25 percent complete. K2B is blasting and removing nearly 1 million tons of rock above the dam and spillway. The rock is being removed to provide space for new gate and spillway structure and access to the spillway gates. Quarried rock material will be used as riprap for erosion protection on the highway, dust abatement and for construction of protective dikes.

The quarry and riprap contract, McCormick said, is behind schedule. The contractor encountered considerable difficulty in building a trail to the top of the quarry which resulted in a slowdown in blasting. K2B switched drilling and blasting subcontractors last fall, hiring Northern Piaute Materials of Reno, Nevada. Within the last month K2B has established a work area on the top of the quarry large enough for an air track drill and a small dozer to operate.

The existing spillway has been filled with gravel as planned to expand the work area. This created a larger area to catch the falling rock from the blasting. The gravel in the spillway will be removed prior to spring runoff. Additional shifts of workers will be added as daylight hours increase and temperatures moderate. Rock from the quarry is being hauled to the processing area near Lakeside Lodge on the north side of the reservoir. There it is processed, sorted and hauled to stockpiles at Diamond Creek, Gibbs Bridge, the South Fork, and to a stockpile for the Heart Mountain Canal north of Cody on the Belfry highway. Work on the riprap contract is scheduled for completion in the fall of 1987.

Morgen and Oswood Construction Company, Gillette, Wyoming, is the prime contractor for constructing the Buffalo Bill Powerplant. The powerplant site is visible from the turnout on Highway 14-16-20. The excavation of the powerplant site has been completed. Sims Construction Co., Lander, Wyoming, left the site in early March. Concrete placements in the retaining walls have begun. The contractor has designed a diversion wall to keep the Shoshone River out of the construction area while concrete placements continue through the summer.

According to McCormick, steel penstock sections are arriving onsite. Water for the Shoshone River, normally releases below the dam, is being diverted through the Shoshone Canyon Conduit and the Heart Mountain Powerplant. Beginning April 15, water will again be released below the dam and the conduit will be dewatered and inspected before deliveries begin to the Heart Mountain Irrigation District.

Last May, a portion of the concrete lining in the Shoshone Canyon Conduit collapsed. An emergency repair was completed at a cost of $1.1 million and the conduit returned to service by the end of May for the remainder of the irrigation season. From October to December 1986, $1.1 million was spent to complete repairs in this same section of the conduit.

Turbines, governors, and generators for the Buffalo Bill and Shoshone Powerplants are being built on schedule under a $4 million contract with Toshiba International. The equipment will arrive onsite in late 1988. The plant will produce 18 megawatts of hydroelectric power and the Shoshone Powerplant will be equipped with a new 3 megawatt generator.

Don Driggs Construction, Pinedale, Wyoming, is the contractor currently working to repair Hayden Arch Bridge. The bridge is being repaired to maintain its historical design and appearance. The repairs will be completed this spring.

The Shoshone Canyon Conduit Modification contract has been postponed. Avery Structures Inc., Buena Vista, Colorado, submitted the apparent low bid last fall. The firm claimed a mistake in their bid and was allowed to withdraw. The remianing bids were rejected as being excessive. The second low bidder protested the Government's decision to reject the bids. The protest has been forwarded to the General Accounting Office. The contract calls for pressurizing part of the conduit to provide water to the Buffalo Bill Powerplant. The Bureau of Reclamation is also working to incorporate a domestic water tap in the conduit to supply water for the Shoshone Municipal Pipeline Project.

The North Fork Dike, a dust abatement dike, has been set aside as a Small Business Administration minority contract. The SBA selected a contractor and contract negotiation is underway. Work should begin this summer. The dike will be located on the North Fork area of the Reservoir.

Modification to Buffalo Bill Dam and Spillway is scheduled for award late next winter. This contract raises the dam 25 feet, builds a walkway 15 feet above the crest of the new dam, and modifies the spillway. The new spillway would have gates to control the flow, and a control house.

Fencing of the reservoir boundary will begin next summer to enhance management area lands.

Design data is complete on the South Fork dust abatement dike. The design is being prepared and the contract should be awarded next spring.

Design data is being collected for Diamond Creek Dike and pumping plant. This dike will dam Diamond Creek near the end of Mountain View Drive. The pumping plant will pump water from Diamond Creek into the reservoir. This contract should be awarded in the spring of 1989.

Alternative designs for protecting the Cody Canal from the enlarged reservoir and relocating part of the lower South Fork road are being developed.

The Bureau of Reclamation is working with the Wyoming State Highway Department on the preliminary designs for relocating a portion of US Highway 14-16-20 and the county bridge that would be flooded with the higher reservoir levels. Construction is scheduled for the fall of 1988.

The Wyoming Recreation Commission is planning the relocation of the state recreation area, Red Pole fishing access, and the Bighorn Boat Club. Several public meetings were held and the draft planning report is to be released this spring.

Land acquisition is continuing. Nearly 900 acres involving 33 landowners have already been acquired of the total 1200 acres needed. The remaining land involves 10 private properties plus State and Federal land. All land acquisition should be completed this year. The acquistion is necessary to accommodate the larger reservoir.

Clearing the reservoir area of trees and improvements will be some of the last work performed prior to raising the reservoir level which is scheduled for 1991 or 1992.

This is a March 19, 1987 News Release from William McCormick, Bureau of Reclamation.

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BUFFALO BILL DAM MODIFICATION
SHOSHONE PROJECT, WYOMING

Location

Buffalo Bill Dam and Reservoir are located in a narrow strip of granite gorge at the confluence of the North and South Forks of the Shoshone River in Northwest Wyoming. The Shoshone River is the largest tributary of the Bighorn River, which in turn is the largest tributary of the Yellowstone River. The drainage basin for the reservoir includes 1,500 square miles of rugged mountains and foothills.

Plan

The Recommended Plan for Modification of Buffalo Bill Dam was developed in accordance with the 1973 Principles and Standards. The plan meets National Economic Development (NED) and Enviromental Quality (EQ) objectives. The Recommended Plan includes enlarging the conservation pool of the Buffalo Bill Reservoir by raising the crest of Buffalo Bill Dam 25 feet and enlarging and gating the spillway, replacing the Shoshone Powerplant, building a vistor center at the top of the dam, and constructing dust dikes in the North and South Fork areas and a protective dike in the Diamond Creek area.

The existing storage capacity in Buffalo Bill Reservoir is not adequate to meet the increasing needs. By raising the crest of Buffalo Bill Dam 25 feet and enlarging and gating the spillway, the conservation storage will be increased 271,3000 acre-feet and a firm yield of 74,000 acre-feet will be provided at the mouth of the Shoshone River. The State of Wyoming has made a commitment for the additional water supply and is willing to share in the cost of the project.

Because it will be possible to operate the enlarged reservoir more efficiently, uncontrolled spills will be eliminated and riverflows during nonirrigation season will be increased. Power production will be increased. The flow pattern in the Shoshone River below Buffalo Bill Dam will be more stable, which will improve the water quality.

As part of the gathering data for the modification of Buffalo Bill Dam, a new probable maximum flood was developed. Computations for the new probable maximum flood were begun in December 1982 and completed in January 1983. The volume of the new flood is about 40 percent greater than that of the flood derived in 1965, and the peak discharge into the reservoir nearly doubled. Various flood routings were examined to determine alternative routings for the new probable flood. It is recommended that the spillway be designed as in the DPR, and the dam crest be designed to overtop. This would result in a maximum water surface elevation of 5410. The crest elevation of Diamond Creek Protective Dike will be increased 10 feet, from 5403 (proposed in the DPR) to 5413. Other project features will not change. The maximum water surface elevation for a 500-year flood is between 5394 and 5395. Therefore, no change in the DPR right-of-way acquisition line (5395) is recommended.

Buffalo Bill Dam and Reservoir are located on the highway leading to the east entrance of Yellowstone National Park. The dam, a National Historic Landmark, is a tourist attraction. A vistor center on the thrust block of the left a butment was proposed in the DPR. At this site, the vistor center would be inudated by the new PMF. It is proposed to produce about 270,000 cubic yards of usable granite riprap from the cliff shoulder above the present vistor tunnel access to the top of the dam. Removal of this rock will leave a wide bench area above the left abutment of the dam, which could provide an ideal location for a vistor center.

In the Definite Plan Report, it was proposed that the powerplant would be constructed at the site of the old Shoshone Powerplant. Due to space restrictions in this narrow part of the Shoshone River Canyon, the site was moved approximately 4,350 feet downstream of the dam on the south side of the river. The existing Shoshone Conduit would be used as a penstock. Installation of a powerplant at the South Side Site would require releases from outlet works of the dam to maintain at least the minimum instream flows[1/] below Shoshone Powerplant. To use these flows for power generation, a smaller unit would be installed in the existing Shoshone Powerplant structure. The main plant at the South Side Site would be 18-mw and the unit in the existing structure would be 3-mw. The average annual generation would be 21.2 GWh for the 3.0-mw plant and 50.6 GWh for the 18-mw plant.

To install a 3-mw single-unit generator in the existing structure, the existing obsolete 4-mw unit, valves, penstock, and electrical equipment would be removed from the Shoshone Powerplant structure as necessary; new equipment would be installed; and modifications made to accommodate the new unit. The existing penstock from the dam to the site would be modified for the reduced flows. A new steel penstock 42 inches in diameter would be installed within the existing 8-foot 6-inch horseshoe power tunnel from the dam to the powerplant. At the dam, a connection would be made to the existing river outlet on the downstream side of the dam where new valving would allow the river outlet to function as an outlet in conjunction with the operation of the powerplant, or as an outlet independent of the powerplant.

The Shoshone Canyon Conduit would have to be pressurized to carry the flows for the Heart Mountain Powerplant, the Heart Mountain Canal, and the new powerplant on the south side without enlarging the conduit. The conduit would be pressurized to about Station 37+00, with a new power tunnel and penstock extending from this station to the powerplant. The watercarrying capacity of the pressurized portion of the conduit would be increased from the original capacity of 1,200 ft^3/s to 2,130 ft^3/s. Velocity through the conduit would be approximately 19 ft^2/s to pass the 2,130 ft^3/s. At about station 37+00, up to 930 ft^3/s would enter the penstock to the new powerplant, and up to 1,200 ft^3/s would continue down the conduit. The flows to the powerplant would be under pressure. The flows continuing down the conduit would pass through an energy dissipater structure to reduce the pressure created in the upper end of the conduit.

1/ Minimum instream flow between Shoshone Powerplant and Heart Mountain Powerplant was established in 1982 by an operating agreement with the Wyoming Game and Fish, U.S. Fish and Wildlife Service, and Bureau of Reclamation.

A generating unit could be installed in the energy dissipater structure to recover much of the energy that would otherwise be lost if the flows in the downstream conduit were simply returned to atmospheric pressure means of valves and baffles. Generating units ranging in size from 2 to 7.5-mw were examined. The 4.5-mw unit was selected based upon Economic and Financial Analyses.

The enlarged reservoir will inudate the State Recreation Area along the north shore of the reservoir, the Bartlett Lane Recreation Area, and the Red Pole Fishing Access. These facilities will be relocated as part of the project; no additional recreational facilities will be provided.

About 1,330 acres of privately owned land will be acquired for project purposes. In addition, about 635 acres of public (BLM) grazing land will be inudated. At least 20 families in the Irma Flat, South Fork, and North Fork areas will be relocated.

The dikes will abate an anticipated dust problem. Presently, about 1,700 acres of silty lake bottom are exposed in the upper reaches of the existing reservoir during periods of drawdown. Westerly winds blowing down the valley dry the flat area and carry away dust which is deposited on residents and crops downstream. These dust-producing area are expected to increase to 2,550 acres when full development of the water supply available in the existing reservoir takes place. The dikes included in the Recommended Plan will reduce this area to about 540 acres. (Without the dikes, there would be 1,700 dust-producing acres around the enlarged reservoir.) A pool of water will be maintained behind the North and South Fork Dikes so the area will not be exposed. Diamond Creek Protective Dike will prevent the reservoir from inudating Irma Flat, thereby allowing present land use to continue and at the same time preventing the area from becoming a large dust-producing area.

Project Features

	Present	Modified
Buffalo Bill Dam	5,370	5,395
Height (elevation)*	10	15
Top Width (feet)	200	259
Crest Length (feet)	18,000	66,850
Spillway Capacity (ft^3/s)	(El. 5369.0)	(El. 5395.0)
	3,130	5,500
Outlet Works Capacity (ft^3/s)	(El. 5365.0)	(El. 5395.0)
Reservoir		
Capacity (acre-feet)		
Surcharge	70,030	147,746**
	(El. 5370.0)	(El. 5410.0)
Active Conservation Storage	375,900	647,713**
	(El. 5360.0)	(El. 5395.5)
Inactive Storage	48,197	48,198
	(El. 5259.6)	(El. 5259.6)

*All elevation are Shoshone datum.
**Does reflect reduction in capacity due to constructing protective dike in the Diamond Creek area.

<u>Project Features</u>
(Cont.)

	Present	Modified
Reservoir (continued)		
Deadstorage	3	4
	(El. 5158.5)	(El. 5158.5)
Water Surface (acres)	6,691	8,510
	(El. 5360.0)	(El. 5393.5)
Additional Right-of Way (acres)	--	1,330
Annual Firm Yield - at Mouth of Shoshone River (acre-feet)	--	74,000
Design Flood		
Peak Inflow (ft^3/s)	103,000	206,000
Peak Reservoir Outflow	49,000	125,200
Overtopping Dam	(27,000)	(53,000)
Spillway	(22,000)	(71,700)
Outlet Works	--	(Shut Down)
Powerplants		
Heart Mountain		
Generators	1 @ 5.0 MW	1 @ 5.0 MW
Average Annual Generation	45,9000 MWh*	46,600 MWh
Proposed Powerplant		
Generators	0 **	1 @ 3 MW 3 @ 6 MW
Average Annual Generation	0 **	71,800 MWh
Dikes		
South Fork Dust Abatement Dike		
Maximum Height (feet)	--	30
		(El. 5398)
Crest Length (miles)	--	1.8
Crest Width (feet)	--	20
Slope (Reservoir Side)	--	3:1
(Impoundment Side)	--	4:1
Impoundment behind Dike		
Area (acres)	--	180
Surface Area (acres)	--	155
Pumps		
Capacity (ft^3/s)	--	10
Annual Engery Requirement (kWh)	--	72,500

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* Under the Future-Without Condition, the generation at Heart Mountain Powerplant will decrease to 43,900 MWh due to the limited capacity of the Shoshone Canyon Conduit during peak irrigation.
** Replaces the Shoshone Powerplant which was shut down in 1980. The plant has one 4,000-kW and two 800-kW generators. The average annual generation was 39,000 MWh. The plant utilized 280,280 acre-feet per year.
***The dike will be submerged when the reservoir is above elevation 5370.

Project Features
(Cont.)

	Present	Modified
Dikes (continued)		
North Fork Abatement Dike		
Maximum Height (feet)	--	25 (El. 5370)
Crest Length (miles)	--	1.8
Crest Width (feet)	--	20
Slope (Reservoir Side)	--	3:1
(Impoundment Side)	--	3:1
Impoundment behind Dike		
Surface Area (acres)	--	150 (El. 5365)***
Diamond Creek Protective Dike		
Maximum Height (feet)	--	93 (El. 5413)
Crest Length (feet)	--	8,100
Crest Width (feet)	--	20
Slope	--	4:1
Pumps		
Capacity (ft^3/s)	--	70
Annual Energy Requirement (MWh)	--	2,200

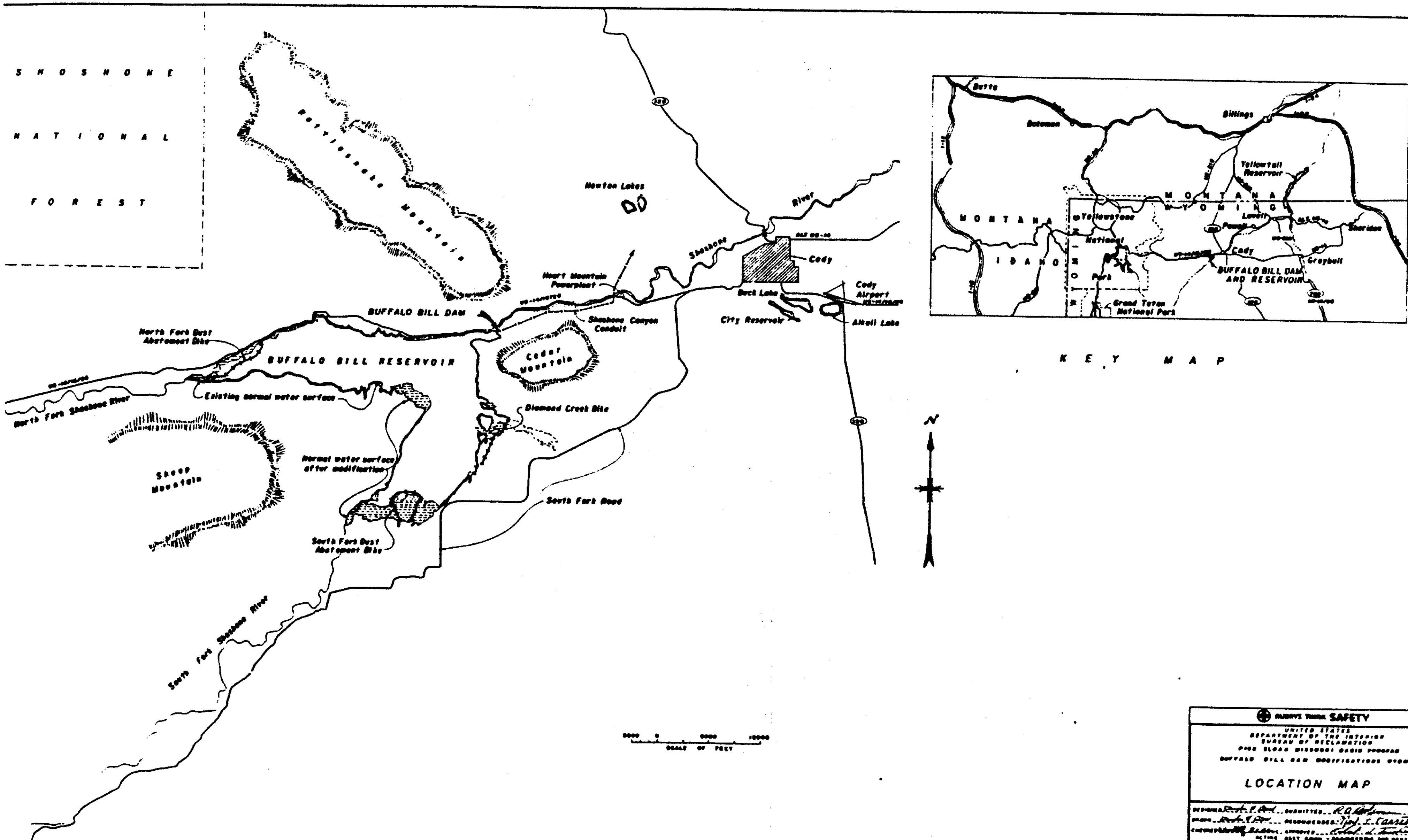
Dust Abatement

	Present Condition	Future With Modification
Average Dust-producing Area (acres)	1,770*	540
Area Potected by North and South Fork Dikes (acres)	--	380
Water Surface behind North and South Fork Dikes (acres)	--	305

Estimated Costs
(October 1985 Cost Level)

Item	Cost
Land and Rights	$ 7,810,000
Relocation of Property of Others	10,155,000
Clearing Reservoir Lands	115,000
Diamond Creek Dike	23,970,000
South Fork Dike	10,195,000
North Fork Dike	8,680,000
Raise Buffalo Bill Dam	1,990,000
Enlarge Spillway	20,435,000
Proposed Powerplant	31,430,000
Electrical Station Equipment	895,000
Vistor's Center	1,390,000
Total Construction Cost	$117,065,000

*Under Future-Without Condition, the dust-producing area will increse to 2,550 acres.



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PICK SLOAN MISSOURI BASIN PROGRAM
BUFFALO BILL DAM MODIFICATIONS STUDIES

LOCATION MAP

1458-D-2

NON ORIGINAL

RELOCATION OF STREAMS BY NATURE AND MAN

Many streams change course naturally as new materials are picked up, carried, and deposited. This instability is demonstrated to a greater extent in the immature streams of the steep mountainous regions. An extreme example of this characteristic occurs in the "Valley Area" of the South Fork of the Shoshone River. Several streams coming down off the west hills in this area change course annually or even with each heavey rainfall. In most places this would not be a problem, but in this particular location it is a constant concern of the County Road Department who tries to locate culverts in the proper places to carry the streams under the road.

The possible relocation of a stream by man exists at the foot of the mountains west of Clark, Wyoming. Little Rocky Creek follows a very unnatural course as it exits a canyon of the mountains. The stream turns and continues out across a plane rather than down a natural draw to the Clark's Fork of the Yellowstone River.

The history of what really happened is unclear, however, there are conflicting records that indicate the possibility that the stream was turned by man for his benefit. There is an old mill site located on the new stream course that may explain why the creek flows there now, or it could have been to deliver irrigation water to a larger land area than would have been possible had the stream remained in it's original course.

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SOUTH FORK SHOSHONE WILDLIFE/RIPARIAN STUDY AREA

This 80-acre tract of public land has been set aside to primarily serve as a nature and wildlife habitat study area. Prior to this designation, the site had been a grazing allotment supporting eleven animal unit months and considerable trespass grazing. The fences around the area were repaired and completed in 1978.

The site exhibits a variety of habitats ranging from the sage-grassland benches to the aquatic type. The canal adds to the habitat diversity by creating a band of dense wetland/riparian vegetation through the tract. The interspersion of various habitat types creates extensive edge effects, which ensures support of a variety of wildlife species.

The concrete structure and foot bridge complex was originally installed as part of a fish-screen facility to recover trout diverted from the South Fork of the Shoshone River. The fish recovery facility was not effective and was subsequently abandoned. Trout and other fish continue to be killed by this agricultural diversion.

Diversion of water from our rivers for irrigation purposes has both positive and negative effects on our fish and wildlife resources. Some of the positive effects to fish and wildlife include creation of wetland/ riparian habitat, provision of food and cover associated with irrigation crops, distribution of drinking water, and increasing late-season base flows. Negative effects include dewatering of streams; diversion of fish; and degradation of water quality with sediments, herbicides, pesticides, and salts. These various impacts will be discussed objectively during the tour.

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CHARACTERIZING RIPARIAN ZONES

Clayton B. Marlow[1]

Prior to 1977, the term "riparian" meant little to the general public. Although water judges and fisheries biologists were familiar with the environmental features described by the word riparian, there were many who secretly believed riparians were cousins of the shy little artesians who flavored a Northwest beer. Public awareness of what is "riparian zone" really was and its role in the human environment began with a series of regional and national conferences in 1977 and 1978. Interest and involvement in riparian protection and rehabilitation has grown steadily with additional conferences in 1980, 1981, and 1984. Concern with riparian issues has grown to the point that in July, 1985, the Bureau of Land Management published a draft Riparian Management policy for public lands under its jurisdiction. The effectiveness of this and any other policy depends upon the knowledge and experience of both those who formulate the policy and those of us who review the drafts. Basic to our understanding of how to manage and protect riparian zones is the knowledge of those characteristics which create this unique landscape feature.

If you were asked to define or describe a riparian zone, what would you say? Lawyers and administrators may describe it as that portion of a stream or river channel which carries water during all or part of the year, an engineer or geohydrologist may define it in terms of flood events and groundwater recharge patterns while a fisheries biologist may discuss the type of streamside vegetation and the shape of banks. Even though it would be more convenient to select one of these definitions for common use, a riparian zone is all of these things and more.

Riparian zones probably support the most complex natural communities in the Intermountain West. Both the number of plant and animal species and the intricate interdependence of living and nonliving components of the community give rise to this complexity. Streamflow duration, wildlife populations and the type of vegetation growing along streambanks are very obvious components of the riparian zone, but the whole ecological community is greater than the sum of these parts. Trout, deer, beaver, songbirds, and livestock depend upon the diverse and abundant vegetation of the riparian zone for all or part of their existence. Although some animal species, such as beaver, may modify the plant community, it is the local hydrologic cycle which shapes the character and structure of the riparian zone. The hydrologic cycle is, in turn, formed by the local and regional climate, geologic structure and soils. Examination of how a riparian zone is formed and develops can illustrate the role of the hydrologic cycle, geology, and soils in creating the character or appearance of a riparian ecosystem.

A drainage will pass through four general phases (Fig. 1) as it progresses to equilibrium or harmony with the physical environment.

Stage I. Flow is intermittent or seasonal and usually destructive, heavily scouring the channel bed and walls. Soil is poorly developed and the vegetation community is dominated by annual or short-lived perennial plants.

Stage II. Channel and bank erosion has been reduced and sediment deposition provides the basic material for soil development. Soil formation is enhanced by increased plant cover. The presence of more vegetation protects banks by slowing streamflow, thereby decreasing its erosive power. Reduced water velocity allows sediment to settle out, further improving soil development.

Stage III. As soil development continues, streamflow gradually becomes perennial rather than seasonal. The vegetative community is developing rapidly with more individual plants and more plant species occupying the banks and immediately adjacent areas. The additional plant cover slows runoff in the channel and overland flow from the uplands which increases sediment deposition and begins the formation of floodplains or terraces. Rather than being straight, the channel has begun to meander, further reducing water velocity and decreasing the destructive potential of runoff events. Because of diverse and abundant vegetation and perennial flow, wildlife numbers increase, and livestock grazing levels are increased.

Stage IV. A meandering stream flowing with deep, well-developed soils provides living space for a diverse plant and animal community. Although extreme runoff events may still occur, damage is minimized because of well-sodded banks and the numerous woody species which reduce streamflow velocity.

The rate at which a riparian zone develops is dependent upon the precipitation pattern generated by the climate and the erodibility of local geologic formations. If precipitation is abundant and occurs regularly and geologic formations weather easily, a riparian zone and its attendant ecosystem will form in a relatively short geologic time span. However, if precipitation is scanty or occurs as irregular, high

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intensity storms or if the local geologic formations weather slowly, development can take a long time. Consequently, the riparian zone is created by the interplay between past and present climatic and geologic processes and the ensuing interaction between colonizing plants and stream channel dynamics. The resulting plant community and streamflow regime are an expression of these conditions and can be used to characterize the riparian zone. As climatic patterns and geology change across the landscape, the character of riparian zones also changes. However, in historic time this general relationship has been altered.

Grazing, mining, logging, farming, highway construction, urban sprawl and recreation can alter streamflow and streambank vegetation whether the use occurs in the riparian zone or adjacent uplands. The alterations tend to disturb the dynamic balance of climate, streamflow, and vegetation and usher in a series of changes which ultimately change the character of the riparian zone. If the disturbance is repeated or continues for a long period of time, the resulting character of the vegetation/stream system may bear little resemblance to the potential ecological community which formed under the existing climatic and geologic conditions.

Riparian zones negatively influenced by human settlement and resource use will go through the following phases of retrogression: (1) accelerated streambank and channel erosion; (2) increased instream sediment loads; (3) loss of resident trout and insects; (4) loss of certain vegetation species or classes; (5) increased incidence of destructive floods; (6) further loss of banks and vegetation; and (7) loss of perennial flow. Those zones formed in areas where geologic weathering is slow or precipitation scanty are more resilient to abuse while those formed in areas with high precipitation or very erodible geologic material will degrade quite rapidly. But, wherever the zone is on the scale from stable to degraded, it will still have characteristics which reflect the local, surface hydrology.

In general, a riparian zone is marked by the presence of a channel, the duration of flow which occurs in that channel, and the plant community which can survive on the amount of water available in the banks. A zone with seasonal flows will have little soil development. Because soil holds the water plants need for survival, only drought tolerant perennials or annuals will occupy the banks. If streamflow is perennial and a deep soil exists along the channel, water is available for a longer period. Drought sensitive plant species can survive on this site and will either protect the riparian zone or enhance its development. Plant species or community types are reliable indicators of streamflow duration and soil development. Because wildlife and humans are dependent upon the availability of water, the presence and abundance of animal life will be greater in well-developed riparian zones. But wildlife, especially terrestrial species, are only indicators of riparian zone health because they rely on the plant community. Eliminate a wildlife species and it can be reintroduced and become established again. Degrade the riparian zone and many species will not survive even if reintroduced because the plants they depend on will be absent. We are no different. Without a stable, well-developed riparian zone there will be few resources (forage, irrigation water, timber) to use, and those that might exist will be too few or stunted to support many people.

RIPARIAN ZONES THEN AND NOW

Quentin Skinner[1]

Introduction

Riparian zones exist because: (1) water is available to plants during their entire growing season, (2) this water promotes dominance of plant species that need a water table near their root zone during their entire growing season, and (3) if the water table near the root zone of water-loving plants is removed they are replaced by plant species capable of occupying more xeric land areas which have no permanent water table during an entire growing season. Because water supply in the semiarid western United States is often limited in quantity and distribution, condition and aerial extent of riparian zones can be the focus of emotional discussion between a multitude of users and managers of wildland drainage basins. This paper will, therefore, provide a general perspective of water storage potential in non-man manipulated western drainage basins before settlement. This effort will set the stage for reflecting on how man has influenced streamside zones and manipulated water thus creating or reducing land mass capable of supporting riparian plant species to present time. This paper, however, only represents this author's first attempt to review historical literature and provide himself with a logical basis to help evaluate current research needs and direction. At best, the content should offer food for thought after also reading, "Hydrologic Impacts in Riparian Zones" of this same proceedings.

Six historical periods are identified for the convenience of presenting this paper. These are: (1) before western immigration, 1804-1840, (2) during western immigration, 1840-1870, (3) during settlement, 1870-1930, (4) after creation of reservoir storage, 1930-1960, (5) while emphasizing multiple use management, 1960-1975, and (6) while emphasizing the need to distinguish riparian zones from other vegetation types for changing land and water management policies, 1975-1986.

Change in riparian zones will be attributed to: (1) natural and introduced large grazing animals, (2) alteration of flow caused by diversion of water for irrigation and reservoir storage, (3) multiple use of watersheds, and (4) present exploration for oil and gas.

Natural Storage of Water

Stream channels adjust to changes in flow regime. Flow regimes are controlled by condition of the entire drainage basin watershed under the influence of climate. A representative annual flow regime in the central semiarid Rocky Mountains region where streams begin in mountains is as follows: (1) base flow occurs during late fall and winter, (2) high flow occurs in spring when snow pack melts, (3) spring runoff declines into summer and drops to base flow conditions during late fall and winter. High intensity short duration summer thunderstorms may produce localized increase in runoff. Excluding user impacts on drainage basins, stream channels and associated riparian zones historically would have had to adjust to this type of flow regime. Each year, with the exception of summer storms, most runoff occured in approximately forty days during spring. The power of this heavy runoff (flushing flow) shaped channels to meet the average annual discharge over a period of years by flushing deposited channel bed material downstream and removing bank deposits not stabilized by vegetation. Low flow conditions existed during the remaining eleven months. Historic pictures and literature show that large low gradient basin streams were often wide, braided with islands, and riparian vegetation as we know it today was isolated to islands, margins along channel banks, on the inside curve of meanders, and at the point where two streams join each other. Late summer stream flow was shallow and often confined within small channels in wide stream beds.

High gradient streams of mountains and foothills in contrast to basin streams are: (1) closer to perennial snowfields, (2) located in areas of higher precipitation distributed more evenly over 12 months, (3) flow through shallow soils over bedrock, (4) located near the top of drainage basins where they drain less area and consequently channel size is smaller, and (5) influenced by bedrock and often biological dams. Potential for storage of groundwater to support riparian plants may cover a broad area at higher elevations when compared to canyons and large basin streams because: (1) water can be replenished often during frequent storm events, (2) bedrock forces groundwater downgradient to depressions or streambanks, (3) shallow soils over bedrock allow roots of plants opportunity to reach shallow water tables season long, (4) bedrock dams, resistant to erosion and which cause lakes of all sizes and shape, trap sediment and are eventually filled with water-reworked fine soil material high in organic matter (alluvium),

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(5) bogs and water related meadow types take on the shape of sediment filled lakes, and (6) groundwater is maintained at a level approximately to the height of the bedrock dam. Additional groundwater at higher elevations is also stored behind biological dams. Because streams are smaller and structual material like willow and trees is often present, beaver are able to construct dams within channels or on top of sediment filled lakes behind bedrock dams. Biological dams are eventually filled with sediment and create a soil/vegetation rise above the original gradient of stream channels or sediment filled lake surfaces behind bedrock dams. Build-up of sediment/vegetation above this original gradient is also enhanced by vegetation debris dams retarding overland and channel flow during flood producing events.

Groundwater storage of snowpack melt, springs, and summer precipitation events at higher elevations prolong flow downstream in canyons and larger basin streams. This slow release of groundwater will continue until water table levels drop to the height of bedrock dams. When this occurs, streams may quit flowing even at high elevations. Additional loss of ponded groundwater occurs because of evapotranspiration. Plants using depression stored water may further reduce reservoir levels behind bedrock and biological dams. Recharge of the system must occur before sustained flow resumes in the stream channel.

Recharge of the high elevation groundwater system, besides being related to shallow soils over bedrock, depends on contributing area between stream channels. Contributing area is the land area between adjoining stream channels. Many small channels tributary to each other exist near the top of headwaters of drainage basins. This high density channel network collects and conveys runoff and groundwater into fewer but larger channels downslope. Acreage between small channels is less near the headwaters and greater between larger streams as they exit mountain or headwater drainage basins. Contributing area promotes stream flow during any one precipitation event or snowmelt in the following manner. Water first enters the channel as runoff from banks. If additional runoff is to become streamflow it must flow across the land surface of the contributing area of the stream. The larger and flatter the contributing area the longer it takes overland flow to reach the channel. Like surface flow, groundwater first enters the channel from bank storage. Travel time is extended as distance is increased into contributing area away from the channel. Channel size, then, adjusts to flow regime caused by: (1) amount and type of precipitation, (2) drainage network, (3) water storage capacity behind geologic and biological dams, and (4) condition of streamside zones as well as biological and physical structure of contributing area.

Stream flow passing from small into larger streams existing in the mountains passes through canyons. In these canyons storage capacity for groundwater is largely confined to narrow streamside zones caused by large particle soil material eroded or falling from canyon walls, which unlike alluvium is lower in organic matter (colluvium,). Colluvium often forms a steep slope between stream channel edge and base of the canyon wall. The stream botton represents bedrock. Peak flow passing though these canyons cause water tables to rise quickly within colluvial fill and drop as fast when flow recedes because colluvium is often porous and low in organic material compared to alluvium.

Riparian zones are confined to colluvium near water tables supported by base stream flow conditions. These are most often narrow because of the steep slope of colluvial deposits, which act as the only potential storage area for water during low flow conditions. Only overland flow of water coming from extensive contributing area between canyons and slow release of spring water from geologic groundwater storage is available to supplement annual flow during summer, fall, and winter downstream. Frankly, canyons act as pass-through conduits for water from mountains to basins. Bedrock, like in mountains, keeps the channel from downcutting but channels may become wider and aggrade temporarily during summer when the flow regime decreases or user impacts occur. Impact to the hydrologic function of the riparian zone, because of user pressure, does little to inhibit water storage capabilities of the colluvial storage system. Many high gradient streams in canyons can be subjected to biological damming of flow. Often this is temporary because of wash out during spring flushing flows. However, any accumulation of alluvial deposits behind dams adds water storage area and regulates velocity of flow downstream. Alluvium is less porous than colluvium, stores more water, and will therefore, release flow longer during periods of less than peak flow.

Rock, tree debris, and beaver dams help curb peak flow velocity caused by higher bedrock gradients in canyons and the funneling of water into larger but more constricted streams than those in the higher mountians. Reduced velocity in canyons curbs power of peak discharge of flow into basin stream channels which are low gradient and often meander across valley from upland to upland slopes. Meanders of developed stream channels and adjoining riparian zones can act as a dam during peak discharge from canyons and cause overbank floods along the valley bottoms.

Because basin streams are often located over deep alluvium deposited on bedrock, storage potential for water is enhanced but confined to valley bottoms. Large arid contributing areas separate basin streams and may provide some water input to main streams as overland flow. The first pulse of this overland flow will occur because of basin snowmelt, perhaps causing an early peak flow event in valley streams before mountain runoff of snow melt occurs. There may or may not be enough melt to cause overbank flooding. Secondary pulses may occur because of summer convective storms which again may or may not cause overbank flooding. Groundwater return to stream flow largely will be in response to stored water from overbank flow events on floodplains. Recharge of groundwater to alluvium surrounding the channel from adjoining contributing area is slow and often to deep aquifers, thus is not visually observed as augmenting surface flow.

Riparian zones are confined to the floodplains of basin streams and are therefore isolated by extensive contributing area covered with vegetation adapted to arid conditions. It is often said that basin riparian zones make up less than 1 percent of a drainage basin area but may be the most important because of the presence of available water for plants and animals. This water supply for support of riparian zones is stored because of overbank flooding mostly during spring snowmelt runoff. The streams in their present condition are often too large and runoff too powerful for beavers to construct and maintain dams. Biological damming often becomes insignificant as cause for overbank flooding.

A real cause for overbank flooding in basin streams is change in channel morphology. Basin streams are low gradient compared to those in canyons and head-waters within mountains. They also have increased meanderings. Low gradient and increased meandering are conditions which promote encroachment of sediment and vegetation during low flow within channels. Encroachment decreases channel width and meandering increases length of stream for length of valley. High flows during spring runoff traveling through basin streams must either scour sediment and vegetation out of the channel to meet peak stream discharge or flood adjoining land. Thus basin riparian zones and channel conditions act like dams for water being discharged from canyons. Their spillway is channel size and their reservoirs are the adjoining floodplains. If you release or decrease water through canyons or from contributing areas then you stand the chance of changing: (1) width, (2) depth, (3) meandering, or (4) area flooded along basin streams.

In summary, water is best stored in alluvium behind geological dams. These deposits are shallow in mountains and deep in basins (Figure 1). Within canyons and in stream reaches where topography confines stream flow to straighter channels, instead of allowing meanders to develop, alluvial deposits are reduced and flow is confined by bedrock. Biological dams occur in small streams where high runoff events don't remove them year to year. These are most often present within headwaters of basin streams and in mountains. Riparian plants have a broad distribution at high elevations because of shallow soils over bedrock and more frequent precipitation events during the growing season. Aerial extent of riparian zones increase where streams meander and decrease where flow is confined in straighter channels. Where water is diverted, stream channel length is increased and thus riparian plant distribution can also increase (Figure 2).

Historical change of riparian zones can now logically be related to change in water storage along stream channels. Meriwether Lewis and William Clark (Lewis and Clark 1804-1806) formally opened up the central Rocky Mountains by following the Missouri River to the headwaters of the Columbia. Their journals serve as an excellent source for describing water storage and depicting riparian zones before immigration through the Rocky Mountains to the West Coast.

Before Western Immigration - 1804-1840

Lewis writes July 12, 1804 where the Nemahaw empties itself into the Missouri from the south and is eighty yeards wide at the confluence, "From the top of the highest ground a delightful prospect presented itself...the level and extensive meadows watered by the Nemahaw, and enlivened by the few trees and shrubs skirting the borders of the river and its tributary streams...the lowland of the Missouri is covered with undulating grass, nearly five feet high, gradually rising into a second plain, where rich weeds and flowers are interspersed with copses of the Osage plum...The sand where we are encamped is covered with the two species of willow, broad and narrow leaf" (1).

On July 19, 1804 "The sandbars which we passed today are more numerous and the rolling sands more frequent and dangerous than any we have seen, these obstacles increasing as we approch the river Platte" (1).

July 21, 1804 at the mouth of the Platte River "Captain Lewis and Clark ascended the river in a perogue for about one mile and found the current very rapid, rolling over sands and divided into a number of channels, none of which are deeper than five to six feet. One of our Frenchmen who spent two winters on it says that it spreads much more at some distance from the mouth, that its depth is generally not more than five or six feet, that there are many small islands scattered through it, and that from its rapidity and the quantity of its sand it cannot be navigated by boats or perogues though the Indians pass it in small flat

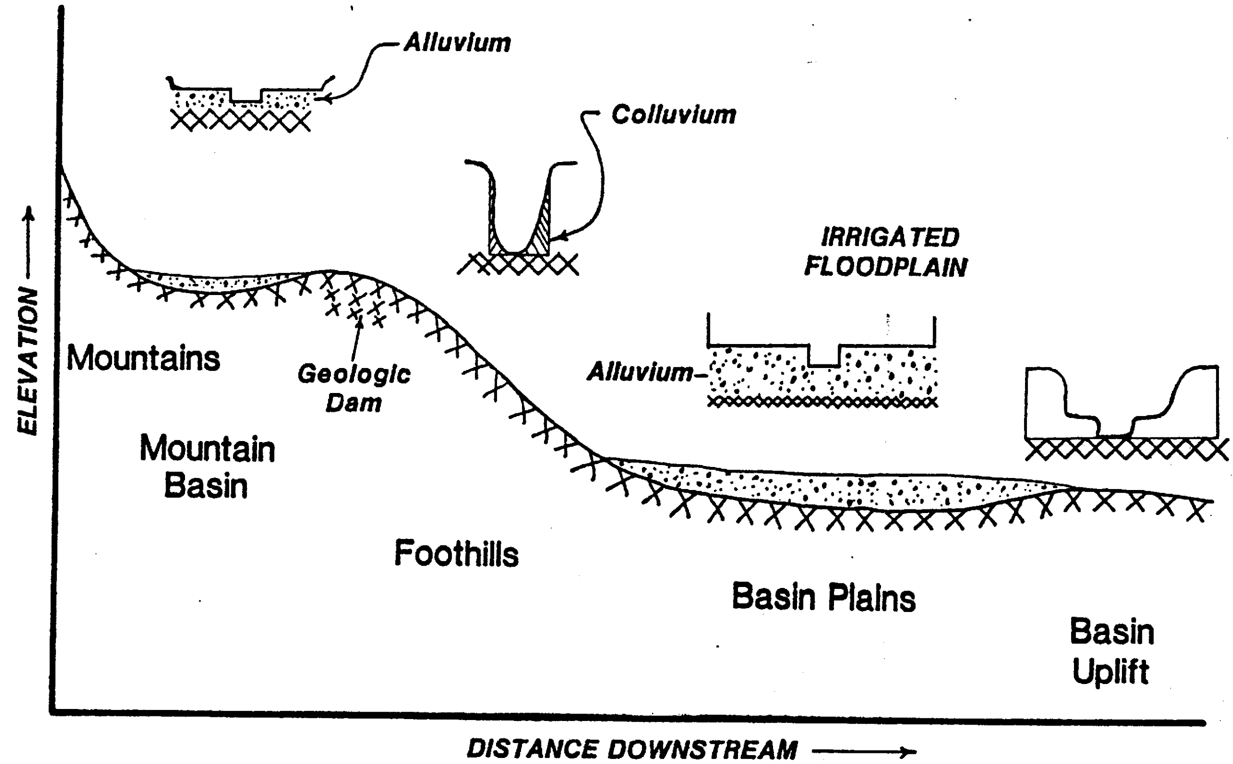

Figure 1. General natural water storage from mountains to basins in the Central Rocky Mountains.

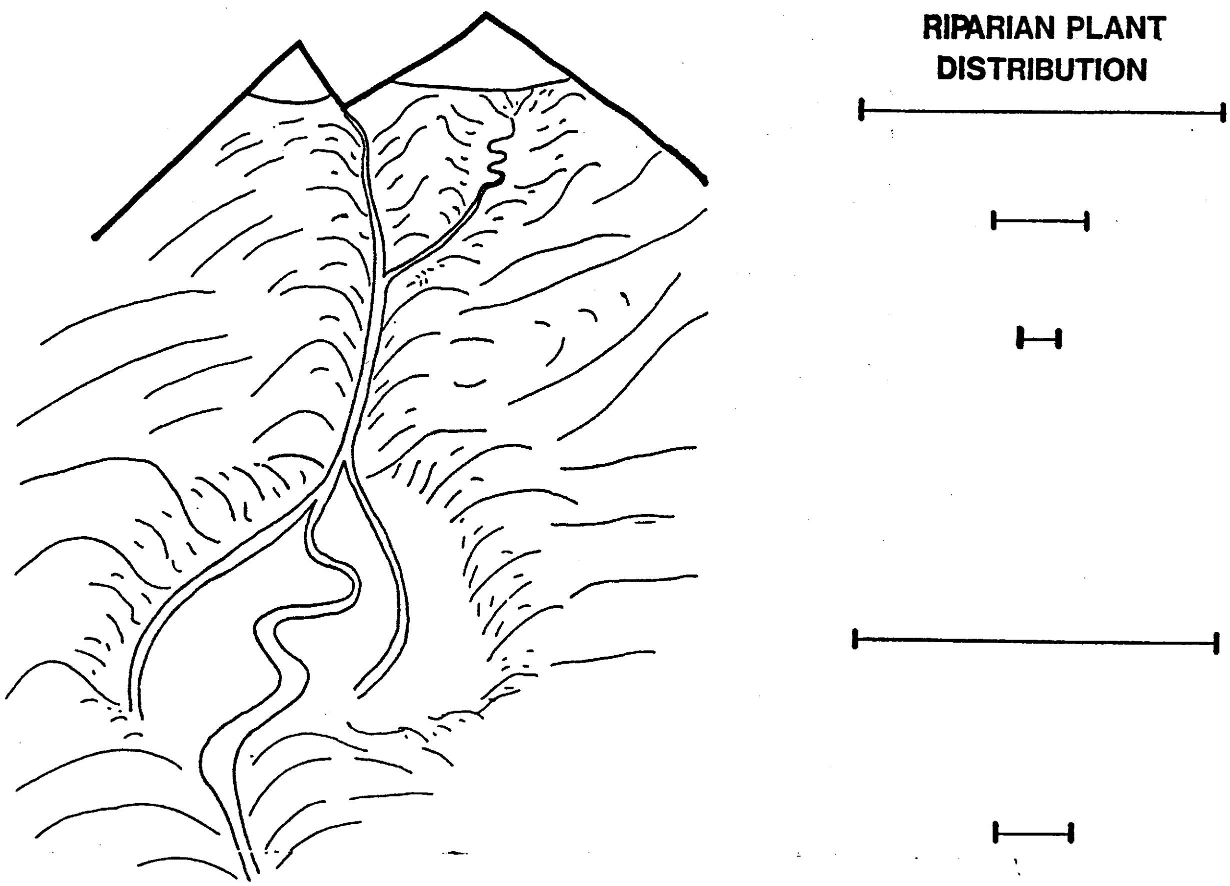

Figure 2. General riparian plant distribution from mountains to basins in the Central Rocky Mountains.

canoes made of hides...At its junction the Platte is about six hundred yards wide...With much difficulty we worked round the sandbars near the mouth" (1). They then traveled up the Missouri.

On June 27, 1843 Captain John C. Fremont talked with John Lee who tried to float the Platte during high flow from Fort Laramie. "A brief account of their fortunes will give some idea of navigation in the Nebraska. Sixty days since they had left the mouth of Laramie's fork some three hundred miles above in barges laden with furs of the American Fur Company. They started with the annual flood, and, drawing but nine inches of water, hoped to make a speedy and prosperous voyage to St. Louis, but after a lapse of forty days found themselves only one hundred and thirty miles from their point of departure. They came down rapidly as far as Scotts Bluff where difficulties began. Sometimes they came upon places where the water was spread over a great extent and here they toiled from morning until night, endeavoring to drag their boat through the sands, making only two or three miles in as many days. Sometimes they would enter an arm of the river where there appeared a fine channel, and after descending, prosperously for eight or ten miles would come suddenly upon dry sands and be compelled to return, dragging their boat for days against the rapid current and at others they came upon places where the water lay in holes, and getting out to float their boats would fall into water up to their necks, and the next moment tumble over against a sandbar. Discouraged at length, and finding the Platte growing more shallow, they discharged the principal part of their cargoes one hundred and thirty miles below Fort Laramie...after fifteen or twenty days more struggling in the sands, during which they made but one hundred forty miles, they sank their barges...Commenced the day before we encountered them, their journey on foot to St. Louis" (6).

The Platte River, with its headwaters in Wyoming and Colorado, is the first major river encountered by Lewis and Clark on their journey up the Missouri that is characteristic of having a flushing flow from melting central Rocky Mountain snowpack during spring. It is evident that the Platte was wide and aggraded with many islands and numerous channels. During high flow the water spread out over a wide sandbed and during low flow was isolated in small braided channels. Fremont generally describes timber of the Platte (most cottonwood) from Grand Island to the south fork of the Platte and then up the south fork of the Platte to the Rocky Mountains. Large islands are often well timbered. The banks were often void of timber or what was there was a fringe or consisted of clumps on meander bars.

Lewis and Clark's description of smaller streams exiting the Rocky Mountains and reaching the Missouri are not so different from the Platte. Above the Platte the Missouri riparian zone changed to more prairie plus cottonwood groves, the channel more crooked and less rapid, On August 23, 1804 Lewis wrote "The wind blew so hard from the west that we proceeded very slowly, the fine sand from the bar being driven in such clouds that we could scarcely see" (1). This is evidence the Missouri was near low flow and point bars were not wooded enough to keep sand in place. "There is, however, no timber except on the Missouri, all the wood of the Whitestone River not being sufficient to cover thickly one hundred acres" (1) Evidently the smaller rivers in this area were not well wooded. On September 14, 1804 Lewis described the mouth of the Rapid River, its headwaters in the Black Hills. The Rapid River...is one hundred and fifty-two yards wide, and four feet deep at the confluence...Captain Clark acended three miles to a beautiful plain...he found that the river widened above its mouth, and much divided by sands and islands which joined to the great rapidity of the current, makes the navigation very difficult even for small boats. Like the Platte...it throws out into the Missouri great quantities of sand...which form sandbars and shoals near its mouth" (1).

On September 15, Lewis and Clark reached the White River (Niobrara). "This river has a bed of about three hundred yards though the water is confined to one hundred and fifty. The current is regular and swift, with sandbars projecting from the points. It differs very much from the Platte...in throwing out comparatively little sand...This resemblance was confirmed by the sargent who ascended about twelve miles (7) at which distance it was about the same width as near the mouth...interrupted by islands and sandbars...at the confluence of the White River with the Missouri is an excellent position for a town...the neighborhood furnishing more timber than is usual in this country" (1).

Lewis, on October 1, 1804, described the Cheyenne River as being "...400 yards wide, the current gentle and discharging not much water and very little sand...although the river did not seem to throw out much sand, yet near and above its mouth we find a great many sandbars difficult to pass. On both sides of the Missouri, near the Cheyenne, are rich thinly timbered lowlands. As we proceeded we found that the sandbars made the river so shallow and the wind so high that we could scarcely find the channel, and at one place were forced to drag the boat over a sandbar...the ascent soon became so obstructed by sandbars and shoal water, that after attempting in vain several channels, we determined to rest for the night and...send out to examine the best channel...we found that there was no outlet practicable for...this channel...we therefore returned three miles and attempted another channel in which we were more fortunate" (1).

The Moreau, Grand, Cannonball, and Little Missouri represent other major rivers draining western range to the Missouri smaller than the Platte. Their headwaters are also in the Black Hills. Lewis describes them. "October 7, 1804 we came to the mouth of a river...Sawawkawna River (Moreau)...its current is gentle and that it does not seem to throw out much sand...and though it has now only water of twenty yards width, yet when full it occupies ninety...in the low timbered ground near the mouth of the Sawawkawna, we saw the tracks of large white bear...October 8, 1804 Wetawhoo (Grand)...its bed, which flows at the mouth over a low soft slate stone, is one hundred and twenty yards, but water is now confined within twenty yards...two miles above the Wetawhoo and on the same side, is a small river...it is twenty yards in width, but so dammed up by mud that the stream creeps through a channel of not more than an inch in diameter...October 18, 1804... Cannonball River...its channel is about one hundred and forty yards wide, though the water is now confined within forty. April 12, 1805...The Little Missouri enters the Missouri with a bold current, and is one hundred and thirty four yards wide, but its greatest depth is two feet and a half, and this joined to its rapidity and its sandbars make the navigation difficult except for canoes which may ascend it for a considerable distance...April 24, 1805...between the Little Missouri and Yellowstone River...The party are very much affected with sore eyes which we presume are occasioned by the vast quantities of sand which are driven from the sandbars in such clouds as often to hide from us the opposite bank" (1).

Evidence thus submitted again suggest streams reaching the Missouri from the Black Hills region of the Rocky Mountains were wide and during low flow, water was shallow and isolated from banks in small braided channels. Lewis and Clark did not mention evidence of or actual overbank flooding on the Missouri or tributaries during the spring of 1804, 1805, or 1806 except at the junction of the Yellowstone with the Missouri and near the Missouri headwaters where beaver could maintain dams year to year. This implies water, during high flow, (1) spread out over wide channels, (2) became deeper, and (3) seldom over flooded their banks. Consequently recharge of water to the banks of the larger rivers would only occur during spring and through only the banks themselves, but would then drain during summer. Thus riparian vegetation had to be limited to: (1) the very edge of channels in straighter reaches, (2) on meander point bars where groundwater interflow could occur from the upstream reach of the meander to the downstream reach, (3) stream junctions where surface and ground water moved from one stream to the next, and (4) islands where channel water would be available during low streamflow conditions.

Lewis states on April 26, 1805 at the junction of the Yellowstone and Missouri "The ground on the lower side of the Yellowstone near its mouth is flat and for about a mile, seems to be subject to inundation, while that at the point of junction, as well as on the opposite side of the Missouri, is at *usual height* of ten or eighteen feet above the water and therefore not overflown. There is more timber in the neighborhood of this place and on the Missouri, as far below as the Whiteearth River than on any part of the Missouri on this side of the Cheyenne. The timber consists principally of cottonwood, with some small elm, ash, and box alder. On the sandbars and along the margin of the river grows the small-leafed willow, in the low grounds adjoining are scattered rosebushes three or four feet high, the redberry, serviceberry, and redwood. The higher plains are either immediately on the river in which case they are generally timbered, and have an undergrowth like that of the low grounds, with the addition of the broad-leafed willow, gooseberry, chokecherry, purple currant, and honeysuckle, or they are between the low grounds and the hills, and for the most part, without wood or anything except large quantities of wild hysop...it is always understood that the upland is perfectly naked and that we consider the low ground well-timbered if even one fifth be covered with woods" (1).

Lewis and Clark's descriptions of streams entering the Missouri and Yellowstone Rivers which originate on basin uplands and mountain foothills show some channel response to early spring snowmelt but more so, most likely, to high intensity short duration summer thunderstorms. Examples include: May 3, 1805, Porcupine River (Poplar River) (2) from the north draining northeastern Montana and Saskatchewan. "This is a bold and beautiful stream one hundred and twelve yards wide, though the water is only forty yards at its entrance...Captain Clark ascended it several miles and passed it above where it enters the highlands, found it continued nearly of the same width and about knee deep, and as far as he could distinguish for twenty miles from the hills...there was much timber on the low grounds...the water of this river is transparent, and is the only one that is so of all those that fall into the Missouri before entering a large sandbar through which it discharges itself, its low grounds are formed of a stiff blue and black clay, and its banks, which are from eight to ten feet high and, seldom, if ever, overflow are composed of the same material (1)...May 6, 1805...We passed three streams on the south...the first...was about twenty-five yards wide, but although it contained some water in standing pools it discharges none...Little Dry Creek (Prairie Creek) (7), Big Dry Creek (Sand Creek) (7), fifty yards wide, without any water, the third...has the bed of a large river two hundred yards wide, yet without a drop of water...Big Dry River (Elk Prairie Creek) (7) like the other two, this stream ...continues its width undiminished as far as we can discern. The banks are low, the channel formed of a fine brown sand, intermixed with a small proportion of little pebbles of various colors and the country around flat and without trees...They had recently discharged their waters and from their appearance and the nature of the country through which they pass, we concluded that they rose in the Black Mountains, or in the level low plains which are probably between this place and the mountains; that this country being nearly of the same kind and of the same latitude, the rains of spring melting the snows about the same time, conspire with them to throw at once vast quantities of water down these channels, which are then left dry during the summer, autumn, and winter, when there is very little rain...May 9, 1805...We reached the bed of a most extraordinary river which presents itself on the south. Though as wide as the Missouri itself, that is about half a mile, it does not discharge a drop of water and contains nothing but a few standing pools...it passes through a wide valley without timber...the banks are abrupt...but though they do not rise more than six or eight feet above the bed, they exhibit no appearance of being overflowed...like the dry rivers we passed before, this seemed to have discharged its waters recently, but the water mark indicated that its greatest depth had not been more than two feet" (1).

Riparian zones along these basin streams which had all but gone dry by early May did not support extensive riparian zones marked by the presence of cottonwood trees. However, the Poplar River must have supported perennial flow to be wooded as described by Lewis.

On May 20, 1805, Lewis and Clark reached the Musselshell River joining the Missouri on the south shore. "This stream...is one hundred and ten yards wide and contains more water than streams of that size do in this country; its current is by no means rapid...its bed is chiefly formed of coarse sand and gravel, with an occasional mixture of black mud, the banks abrupt and nearly twelve feet high, so that they are secure from being overflowed. The water is of greenish-yellow cast and much more transparent than that of the Missouri, which itself, though clearer than below, still retains its whitish hue and a portion of its sediment. Opposite to the point of junction the current of the Missouri is gentle and two hundred and twenty two yards in width, the bed principally mud (the little sand remaining being wholly confined to the points) and still too deep to use the setting pole ...our Indian information is, that it rises in the first chain of the Rocky Mountains not far from the sources of the Yellowstone. The party who explored it for eight miles represented low grounds on the river as well supplied with cottonwood of a tolerable size" (1). Also on May 29, Lewis describes the Judith River along the same bank. "It rises in the Rocky Mountains in about the same place with the Musselshell and near the Yellowstone River. Its entrance is one hundred yards wide...the water occupying about seventy-five yards, and in greater quantity than the Musselshell River...no stones or rocks in the bed, which is composed entirely of gravel and mud with some sand, the water is clearer than any which we have yet seen and the low grounds as far as we could discern, wider and more woody than those of the Missouri. Along its banks we observed some box alder intermixed with the cottonwood and the willow, the undergrowth consisting of rosebushes, honeysuckle, and a little red willow" (1).

These rivers from the Rocky Mountains have cleaner water and transport little mud. They don't overflow their banks but support riparian zones because of perennial flow. Examples of their low flow channel conditions as they exit the mountains below and above the three forks of the Missouri in July 1805 are: July 22..."We set out at an early hour. The river being divided into so many channels by both large and small islands, that it was impossible to lay it down accurately by following in a canoe any single channel, Captain Lewis walked on shore, took the general courses of the river and from the rising grounds laid down the situation of the islands and channels, which he was enabled to do with perfect accuracy, the view not being obstructed by much timber...July 23...during the whole day the river is divided by a number of islands which spread it out sometimes to the distance of three miles, the current is very rapid and has many ripples and the bed formed of gravel and smooth stones. The low grounds are wide and have very little timber but a thick underbrush of willow and rose and current bushes...our journey today was twenty two and a quarter miles, the greater part of which was made by means of our poles and cords...July 24...the current of the river was strong and obstructed as indeed it has been for some days by small rapids or ripples which descend from one to three feet in the course of one hundred and fifty yards, but they are rarely incommoded by any fixed rocks, and therefore, though the water is rapid, the passage is not attended with danger...beaver seem to contribute very much to the number of islands and the widening of the river. They begin by damming up the small channels of about twenty yards between the islands, this obliges the river to seek another outlet and as soon as this is effected, the channel stopped by the beaver becomes filled with mud and sand. The industrious animal is then driven to another channel which soon shares the same fate, till the river spreads on all sides and cuts the projecting points of land into islands" (1).

The three rivers making up the three forks of the Missouri were described by Lewis as "all being about ninety yards wide and run with great velocity and throw out large bodies of water. The Gallatin River is, however, the most rapid of the three. The Madison River though much less rapid than the Gallatin, is somewhat more rapid than the Jefferson, the beds of all of them are formed of smooth pebble and gravel, and the waters are perfectly transparent. The low grounds, although not more than eight or nine feet above the water seem never to be overflowed except where bayous were formed by beaver, where rushes as high as a man's chest grew" (1).

Above the three forks on the Jefferson..."As we proceeded, the low grounds were covered with cottonwood and a thick underbrush, and on both sides of the river, except where hills prevented it the ground was divided by bayous, which are dammed up by the beaver...Captain Lewis proceeded after dinner through the extensive low ground of timber and meadow land intermixed; but the bayous were so obstructed by beaver dams, that in order to avoid them he directed his course towards the high plain...when he desired to rejoin the canoes he found the underbrush so thick and the river so crooked that this joined to the difficulty of passing over the beaver dams, induced him to intercept the river at some point where it might be more collected into one channel...July 31, 1805...the Jefferson continues as yesterday, shoaly and rapid, but as the islands though numerous are small, it is, however, more collected into one current than it was below and is from ninety to one hundred and twenty yards in width. The low ground...contains a considerable quantity of timber with the bullrush and cattail flag very abundant in the moist spots, while the drier situations are covered with fine grass, tansy, thistle, onions, and flax. The uplands are barren and without timber...and the only produce is the pricklypear, the sedge, and the bearded grass, which is as dry and inflammable as tinder." Higher up the Jefferson August 3rd..."In the level parts of the plains and the river bottoms there is no timber except small cottonwoods near the margin, and an undergrowth of narrow-leafed willow, some honeysuckle, rosebushes, currants, serviceberry and gooseberry, and a little birch" (1).

August 8th on the middle fork of the Jefferson 30-35 yards wide..."The bottom is rich, with some small timber on the islands and along the river, which consists rather of underbrush, and a few cottonwoods, birch, and willow trees...through the valleys are scattered bogs. On all of the three branches of the Jefferson River are immense quantities of beaver, otter, and muskrat. At our camp there was an abundance of rosebushes and briars but so little timber that we were obliged to use willow bush for fuel...the river increases in rapidity as we advance (August 9th) and is so crooked that the eleven miles, which cost us so much labor, only bring us four miles in a direct line...August 10th the river, which before it enters the mountains was rapid, rocky, very crooked, much divided by islands and shallow, now becomes more direct in its course as it is hemmed in by the hills, and has not so many bends nor islands, but becomes more rapid and rocky and continuous as shallow" (1).

The last valley before the continental divide, August 10, 1805, "...a beautiful and extensive plain about 10 miles long and five or six in width. At this place they halted for the night...and having lighted a fire of dry willow bush, the only fuel which the country affords, supped on deer...the river not so rapid as yesterday, though more narrow and still very crooked, and so shallow that we were obliged to drag the canoes over many ripples in the course of the day (12 yards wide)...these low grounds are very much intersected by bayous and bogs covered with tall grass...we saw a number of geese, ducks, beaver, otter, deer, and antelope, all of which one beaver was killed with a pole from the boat, three others with a tomahawk and the hunters brought in three deer and an antelope" (1).

All River Lewis and Clark. Your dedicated description of rivers exiting the central Rocky Mountains confirm: (1) channels in low gradient river reaches were wide with high banks, (2) aggraded with gravel and cobble, (3) during low flow conditions were braided with islands thus the rivers were split into more than one channel, and (4) during high flow did not often overflow their banks except where beaver were able to dam up smaller channels along the sides of larger main flow routes. Near the head waters of these mountain streams, in low gradient reaches, beaver dams caused spreading of water as over bank flooding thus creating bog-wet meadows laced with willow and few trees.

Indians and Buffalo, 1804-1840

The presence of riparian vegetation, particularly marked by cottonwood trees, was not extensive along entire river corridors. Indians and buffalo were confined to these zones because of the need for water and shelter. Osborne Russell (1834-1843) writes about buffalo, "In summer they go to water and drink once in 24 hours, but in the winter they seldom get water at all" (3).

Examples of numbers of buffalo using limited riparian zones are further described.

Captain Lewis' July 11, 1806,..."The hunters were sent down the Medicine River (Montana) to hunt elk...they had seen elk; but in this neighborhood the buffalo are in such numbers that on a moderate computation there could not have been fewer than ten thousand within a circuit of two miles" (1). July 18, 1806 between the Maria and Tansy rivers in Montana Captain Lewis records..."reached a creek...about twenty yards wide, though with no water except in occasional pools in the bed. Down this creek we proceeded for twelve miles through thick groves of timber on its banks, pasing such immense quantities of buffalo, that the whole seemed to be a single herd." Captain Clark describes buffalo crossing the Yellowstone August 1, 1806..."A herd happened to be on their way across the river. Such was the multitude of these animals that although the river, including an island over which they passed was a mile in length, the herd stretched as thick as they could swim, completely from one side to the other, and the party was obliged to stop for an hour...two other herds of buffalo as numerous as the first soon after crossed the river" (1).

Washington Irving's "Astoria" of Wilson P. Hunt's crossing of the plains east of the Rocky Mountains in 1811 on the Missouri writes, "Boundless wastes kept extending to the eye, more and more animated by herds of buffalo. Sometimes these unwieldy animals were seen moving in long procession across the silent landscape, at other times they were scattered about singly or in groups on the broad, enameled prairies and green acclivities, some cropping the rich pasturage, others reclining amidst the flowery herbage, the whole scene realizing in a manner the old scriptural descriptions of the vast pastorial countries of the Orient, with "cattle upon a thousand hills." At one place the shores seemed absolutely lined with buffaloes, many were making their way across the stream...at another place a number were described on the beach of a small island, under the shade of trees, or standing in the water, like cattle, to avoid the flies and the heat of the day" (4).

Washington Irving writes about Captain B.L.E. Bonneville's view of buffalo in his trip of 1832 between the South and North Forks of the Platte Rivers. "They had reached also a great buffalo range, Captain Bonneville ascended a high bluff, commanding an extensive view of the surrounding plains. As far as his eye could reach, the country seemed absolutely blackened by innumerable herds. No language, he says, could convey an adequate idea of the vast living mass thus presented to his eyes" (5).

Captain Fremont on the South Fork of the Platte River July 4, 1842..."Column after column of buffalo came galloping down directly to the river. By the time the leading herds had reached the water, the prairie was darkened with the masses. Immediately before us, when the bands first came down the valley, stretched an unbroken line, the head of which was lost among the river hills on the opposite side. And still they pound down the ridge on our right. From hill to hill, the prairie bottom was certainly not less than two miles wide and allowing the animals to be ten feet apart and only ten in a line, there were already eleven thousand in view. In a short time they surrounded us on every side, extending for several miles in the rear and forward as far as the eye could reach" (6).

Osborne Russell, 1834-1843, on Christmas, writes "The bottoms along the rivers are heavily timbered with sweet cottonwood and our horses and mules are very fond of the bark which we strip from the limbs and give them every night as the buffalo have entirely destroyed the grass throughout this part of the country." Near where the Clark's fork joins the Yellowstone on the Yellowstone..."The bottoms along the Powder River were crowded with buffalo insomuch that it was difficult keeping them from among the horses who were fed upon sweet cottonwood bark as the buffalo had consumed everything in the shape of grass along the river" (3) 7 February.

Indians also influenced buffalo use of riparian zones by enticing them to feed near their camps in spring. Lewis writes March 6, 1805, "The day was cloudy and smoky in consequence of the burning of the plains by the Minnetarees, they have set all the neighboring country on fire in order to obtain an early crop of grass which may answer for the consumption of their horses, and also as an inducement for buffalo and other game to visit it...March 29...every spring as the river is breaking up, the surrounding plains are set on fire, and the buffalo tempted to cross the river in search of fresh grass which immediately succeeds to the burning; on their way they are often insulated on a large cake or mass of ice which floats down the river; the Indians now select the most favorable points for attack; and as the buffalo approaches, dart with astonishing agility across the tembling ice, sometimes pressing lightly a cake of not more than two feet square; the animal is of course unsteady, and his footsteps insecure on this new element, so that he can make but little resistance, and the hunter who has given him his death wound, paddles his icy boat to the shore and secures his prey" (1).

Indians had to use trees in riparian zones for lodging, food for horses, and firewood. Captain Fremont on the North Platte River near Casper, Wyoming, July 23, 1842 reports, "We found no grass today at noon; and, in the course of our search on the Platte, came to a grove of cottonwoods where some Indian village had recently encamped. Boughs of the cottonwoods, yet green, covered the ground, which the Indians had cut down to feed their horses upon. It is only in the winter that recourse is had to this means of sustaining them; and their resort to it at this time was a striking evidence of the state of the country" (6). Forts, for trading purposes, used these streamside zones for the same purposes. Steamboats traveling the Missouri and Yellowstone used trees to fuel steam engines until coal could be developed. Although there was also trapping of beaver on the larger streams entering the Missouri during the middle seventeen hundreds, real competition for their valuable furs in the Rocky Mountains started with Wilson Hunt's expedition in 1811.

Osborne Russell wrote in November 1843, "The trappers often remarked to each other as they rode over these lonely plains that it was time for the white man to leave the mountains as beaver and game had nearly disappeared" (3). The beaver market collapsed in the late 1840s.

Beaver Harvesting to the Later 1840s

There is controversy of thought as to what effect beaver harvesting played in modifying stream channels and riparian zones during the middle 1800s after being trapped out. We know that beaver were able to dam headwater streams tributary to larger basin streams. We have read that where dams were prevalent, trees were scarce. This is a realistic picture because beaver are not conservative harvesters of structural supplies. Willows were prevalent, however, behind and below these biological dams. Perhaps once dams were in place and trees gone, willows would suffice for dam maintenance purposes in bog areas like those described by Lewis and Clark. Once beaver were eliminated, dams without maintenance were sure to fail. Collective failure of beaver dams in headwater streams would insure an increase in flushing flow to larger basin streams during spring runoff of snowmelt.

For sure, beaver dam failure would cause downcutting of stream channels supported by alluvial fill to a point controlled by bedrock or bedrock dams maintaining depression storage of alluvium. Tributaries to main stem streams would adjust to the new main stream gradient. In mountains where bedrock is near the surface, downcutting would be slight but increased flushing flow would widen the channel. In basins where bedrock control is deep, downcutting of headwaters streams could be substantial but only to a point where gradient concavity would meet large main stem channel bed profiles or resistive geologic strata. Logically, increased flushing flow would carry large sediment loads to low gradient wide stream sections or basin streams and increase channel bed aggradation as well as perhaps channel widening. This would promote backfilling of tributary streams thus lowering their channel gradient and would promote channel filling near mainstem tributary junctions of smaller streams. To further increase the rate of aggradation of basin low gradient stream reaches, summer and fall stream flow would have been reduced because of water storage loss in mountains.

Willow and wet meadow riparian vegetation would have been reduced along mountain streams. However, reduced beaver numbers and channel disturbance would have increased tree establishment. Along headwater streams in basins, if beaver had created alluvial deposits and riparian vegetation was established, these water storage zones would have been drained and willows and water loving herbaceous vegetation reduced, as trees were scarce.

Gully Erosion to the Middle 1840s

The loss of beaver because of trapping up the 1840s has been suggested as cause for accelerated erosion of upland rangeland. We see this could have happened in headwater streams in basins and foothills of mountains. However, there is evidence that accelerated erosion of uplands was caused, in part, by extensive wildlife (buffalo) impact of vegetation. These animals were obligate grazers of lands near water during summer and used stream channel areas in winter for protection from storms. Just sheer numbers of these animals alone, moving in herds of large size, were enough to cause trails, decrease vegetation cover, and compact soils; all of which are known to increase overland flow of water. Arguments that buffalo did not use riparian zones and grazed uplands more than cattle in fenced pastures do not hold up as a cause of accelerated erosion of uplands. Distance from water had to be a barrier against wildlife distribution. Pasture size and orientation would have been dictated by river and stream corridors. Accelerated erosion of uplands caused by wildlife would have partitioned contributing area thus increasing flushing flow. Perhaps gully erosion in the central Rocky Mountain region was at a peak before settlement by white man. This would mean that riparian zones were reduced to a minimum, excluding where beaver could dam streams.

Gully erosion is illustrated by Fremont's description of a tributary of the South Platte near the Rocky Mountains. July 7, 1842 "The sun was getting low and some narrow lines of timber four or five miles distant promised a pleasant camp where, with plenty of wood for fire, and comfortable shelter, and rich grass for our animals, we should find clear cool springs, instead of the warm water of the Platte. On our arrival, we found the bed of a stream fifty to one hundred feet wide, sunk some thirty feet below the level of the prairie, with perpendicular banks, bordered by a fringe of green cottonwood, but not a drop of water. There were several small forks to the stream, all in the same condition...turning off towards the river, we reached the bank in about a mile and were delighted to find an old tree, with thick foliage and spreading branches where we encamped...July 28 on the North Platte near Casper, Wyoming..."the principal obstructions are near the river where the transient waters of heavy rains have made deep ravines with steep banks, which render frequent circuits necessary" (6). Robert D. Dorn, 1985, concludes in *The Wyoming Landscape 1805-1878* "Today grass is more abundant than it was prior to white man's influence in the area...dry streambeds, in many cases, were natural prior to settlement...deep gullying and barren, washed lands were natural phenomena and not products of more modern time" (2).

During Western Immigration 1840-1870

The principal route through the Rocky Moutains to the west coast used by immigrants was the Platte and Sweetwater rivers. "An estimated 350,000 people crossed Wyoming between 1841 and 1866 primarily heading for the California gold fields or to settle in Oregon or California" (2). Other major routes to Colorado and Montana used river corridors for roadways. "One should keep in mind that the primary needs of all these travelers were grass for the animals, water for the people and animals, and fuel for the campfires" (2). Movement of people scared wildlife to distant drainage basins but grazing of roadway routes was replaced by domestic animals. Certainly trees and willows were further used for firewood.

Where beaver could reestablish on headwater streams new storage of water would have occurred to create riparian zones like those before the era of the trapper. Buffalo were reduced for food by the Indians and trappers when it could be procurred so wildlife grazing of riparian zones would have been reduced. However, along mainstream rivers, permanent white man establishments and consolidation of Indians would have used these areas more readily. Little change in stream channel conditions would have occurred because flushing flows from mountain snowpack would have not changed substantially.

During Settlement 1870-1930

Pass of traffic through the Rocky Mountains was replaced by ranches, farms, towns, and industry. The Pony Express was established to connect east with west followed by stagelines and then a railroad (1869). These links of travel again used river corridors and thus riparian zones. The railroad was the first major attempt to channelize stream flow and change the natural flow regime of basin mainstem streams. Railroad beds were placed along streams where continental elevation was low and canyons allowed access through mountain ranges. Ephemeral streams (these which only respond to individual precipitation events) may have been dammed by the rail bed and these would have decreased flushing flow to mainstem streams. Where rail beds crowded stream channels (channelized) and bedrock bottoms were not present, stream velocity during high flows and confined within narrower streams longer during summer could have deepened the main stem streams. This would have caused further downcutting of tributaries and increased contributing area gullying. Consequently, flushing flow would increase in this case. Where rail beds straightened channels to pass water beneath the bridges or culverts, increased velocity of flow would occur and channel adjustments of downcutting, filling, and widening would further result. Highways to meet the advent of the automobile had similar effects on stream channels. Riparian zones would decrease where channelization occurred and increase where roadway dams across ephemeral streams existed. Where rail and road beds were placed in flood plains growing riparian vegetation, riparian area would be eliminated.

Ranching and farms would have first placed their base operations along streams for obvious reasons. Ranches replaced grazing of rangeland by buffalo with cattle and sheep. True, livestock is blamed for causing gullying of contributing area to mainstem streams. However, we have seen in the central Rocky Mountains, that rangeland was grazed heavily by wildlife. We only replaced grazing by wildlife with livestock; first with large numbers and then by the middle 1930s reduced them. We did expand the ability of livestock to graze away from stream corridors by developing off stream water. This would have placed them where vegetation cover was less and or perhaps steeper slopes. Reduced vegetation cover, soil compaction, and trails because of livestock grazing would have increased flushing flow of lands not previously grazed because of the lack of water. Accelerated erosion from these areas would have increased aggradation of low gradient stream reaches of mainstem basin streams thus causing back filling of tributaries along the mainstem and increased gullies near the headwaters. New gullies would not support riparian zones in the headwaters and increased aggradation could have increased stream side vegetation near the backfilled tributaries along the mainstem streams. Grazing by livestock of riparian zones along the mainstem stream corridors would not have been so different than by wildlife before settlement. Results of farming of sod covered uplands during this period were evident from the dust bowl days of the late 1930s. The impact of livestock grazing on riparian zones has to be minimum compared to these farming practices. Certainly increased flushing flows occurred when native vegetation was altered to produce crops. Again gullying would occur on headwater areas and aggradation on mainstem low gradient stream reaches.

Diversions of water to sustain base ranching operations and provide water for municipalities were developed as mainstem basin streams and low gradient mountain streams were settled. Diversion of water during high flow conditions reduced the power of stream flow. Flood irrigation had the potential to store groundwater and thus return it slowly to mainstem streams later in the summer when low flow conditions exist. Reduced power of high flow conditions allowed stream bank encroachment forcing braided streams to consolidate into fewer channels. Increased sediment loads in tributaries, if present, would increase rate of channel bank building. Irrigated pastures would have provided vegetation cover and root mass to hold banks in place. Sediment deposits on building banks and controlled grazing of livestock would have induced cottonwood and willow establishment. Rate of encroachment of channel banks would have been regulated by: (1) amount and timing of flow left in channels after diversion, (2) aerial extent of watershed contributing area between diversions, and (3) the condition of contributing area itself. As more diversions were put into place, less power was available to sustain riparian vegetation as it returned to maintain late season stream flow. The overall result of this process was mainstem stream channels narrowed, became deeper, and overbank flooding occurred depending on climatic conditions and variable mountain snowpack year to year. Overbank flooding would further help increase riparian vegetation. In mountains, beaver were left to mother nature thus providing water storage for maintaining late summer flow. Increased grazing by livestock, if it occurred compared to wildlife could have increased flushing flow by trailing action and reducing vegetation cover. However, this could have been offset by any reduction in fire of mountain woodlands by providing a net increase in groundcover. Downcutting would have been minimum because of biological damming and bedrock control near the soil surface. Impact to mountain streams would be wider channels and aggradation of bottoms in low gradient reaches.

After Reservoir Storage 1930-1960

We have witnessed how important water development was to the settlement of the central Rocky Mountains region and how diversion of water could cause increases in riparian zones because of channel bank encroachment of braided streams and return flow of groundwater. Dam building and reservoir storage of water to regulate stream flow minimized overbank floods, increased available water during time of need, and increased delivery systems for irrigation of crops. Riparian zones increased because more area below dams had water longer during growing seasons by direct application and return flow of groundwater. For sure riparian zones above the dam were flooded and lost. However, this is temporary, because as dams fill with sediment, riparian vegetation can increase. Hungry water (water without sediment) released from dams can erode riparian zones until sediment supply is replaced by runoff of water from tributaries of below dam contributing areas. Perhaps, however, regulated release because of dams, to control downstream flooding of municipalities, have most generally allowed stream banks to stabilize at a given width and depth even if hungry water is released.

Small reservoir storage has, no doubt, increased riparian zones even if designed for livestock water, distribution of animals, and erosion control. Because of water development for agriculture, riparian zones exist now where none existed before.

Increased riparian zones along streams, not recent livestock grazing practices, could be a reason we see recent downcutting of headwater contributing areas of basin and foothills drainage basins without bedrock controls. Wide streams, with aggraded channel bottoms adjusted to natural flow events, became narrow when riparian zones encroached. This narrower stream would move bed material downstream causing a drop in the bed level of the mainstem channel. Tributary streams would backcut to adjust to the new channel bed level because a nick point in the tributary is present (Figure 3). On small headwater tributaries without bedrock control, downcutting would be emphasized compared to the mainstem because of: (1) steeper gradients, (2) less contributing area between tributaries, and (3) little chance of aggradation of moving sediment because of increased stream power (Figure 4).

Mountain riparian zones most likely changed very little during this period. Flushing flow would be altered because of road development for timber, fire control, and reduced grazing by livestock. Beaver numbers either increased or were managed to sustain appropriate streamside vegetation. Little dam building and diversion occurred at high elevations and if so, mountain and canyon stream gradients were maintained by the presence of bedrock. Scouring of canyon colluvium by reservoir release would alter little riparian zone habitat.

Multiple Use Management 1960-1975

Several new issues to riparian zone management surfaced during the 60s and early 70s. Public interest in the fishing industry increased. Persons interested in fishing insisted on action to mitigate the impact of stopping fish migration up and downstreams because of storage dams. Having made substantial progress on this problem, fishery biologists and enthusiastic fishermen begin to evaluate fish habitat needs. Poor fish habitat was tied to deteriorated riparian zones. This effort was complimented because the general public had increased leisure time and used it for recreation. Certainly, the recreation experience is normally perceived as being enjoyed more by the presence of water. This is especially true for one recreation activity, fishing.

Access to more remote areas of drainage basins was improved for recreationists using the four-wheel drive automobile. After World War II these vehicles were available from surplus sources. Public land agencies, ranchers, and some of the general public found them useful as replacements for horses, wagons, and 2-wheeled drive vehicles to help accomplish their livelihood. It was not long before the automobile industry capitalized on this market. New unimproved roads and off-road vehicle abuse was on the rise. This is especially true for public lands where access could not be curtailed. Increased road construction also rose because of oil and gas development in basin areas.

Increased facilities on stream reaches were developed to mitigate the public's cry for more recreation opportunities. These facilities localized larger numbers of people to small areas. Mountain home developments increased and ski areas and associated industries occupied substantial mountain valley areas. Hunting and fishing, using horses in mountains, also increased as did backpacking. Livestock grazing pressure decreased.

This increase in access and human activity in remote areas of drainage basins has increased flushing flows because of channelization of headwater areas by roads and trails. Activities in these areas remove vegetation, decrease infiltration of water into soils, and increase overland flow to streams. Riparian zones created by geological, biological, and man-made dams have decrease locally where these impacts occur. On headwaters, increased sediment and stream flow velocity of water would have been transferred downstream to low gradient reaches and basin mainstem streams.

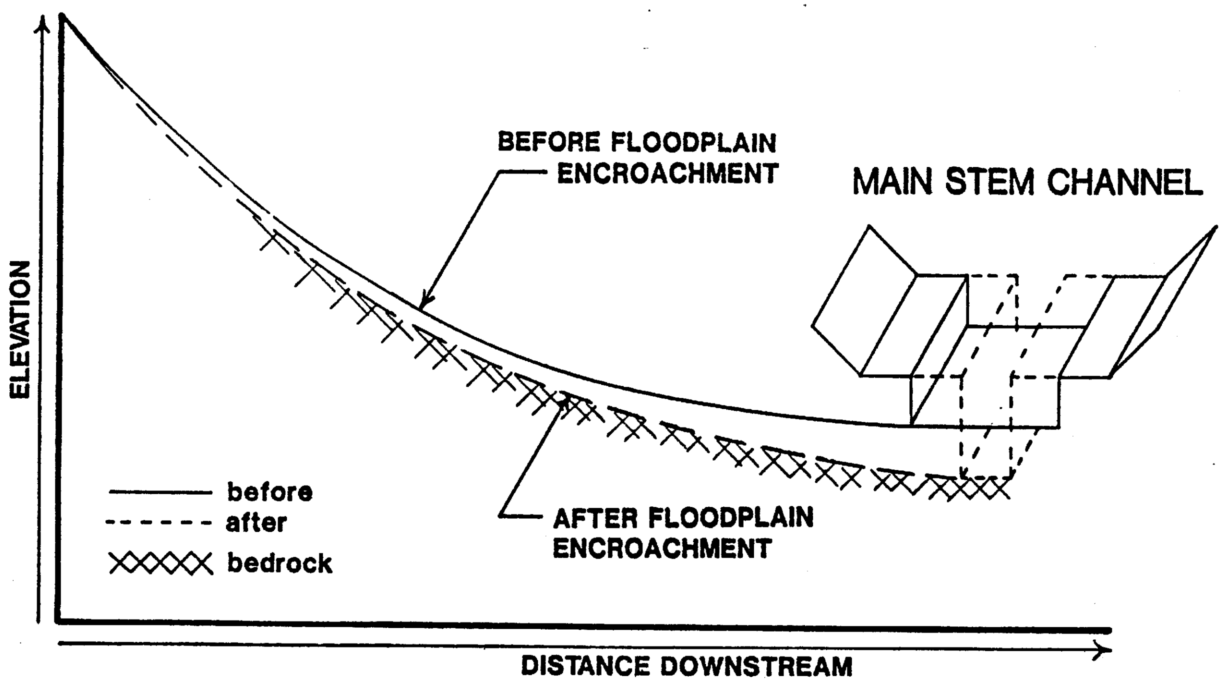

Figure 3. Stream channel encroachment and tributary backcutting caused by change in channel bed elevation.

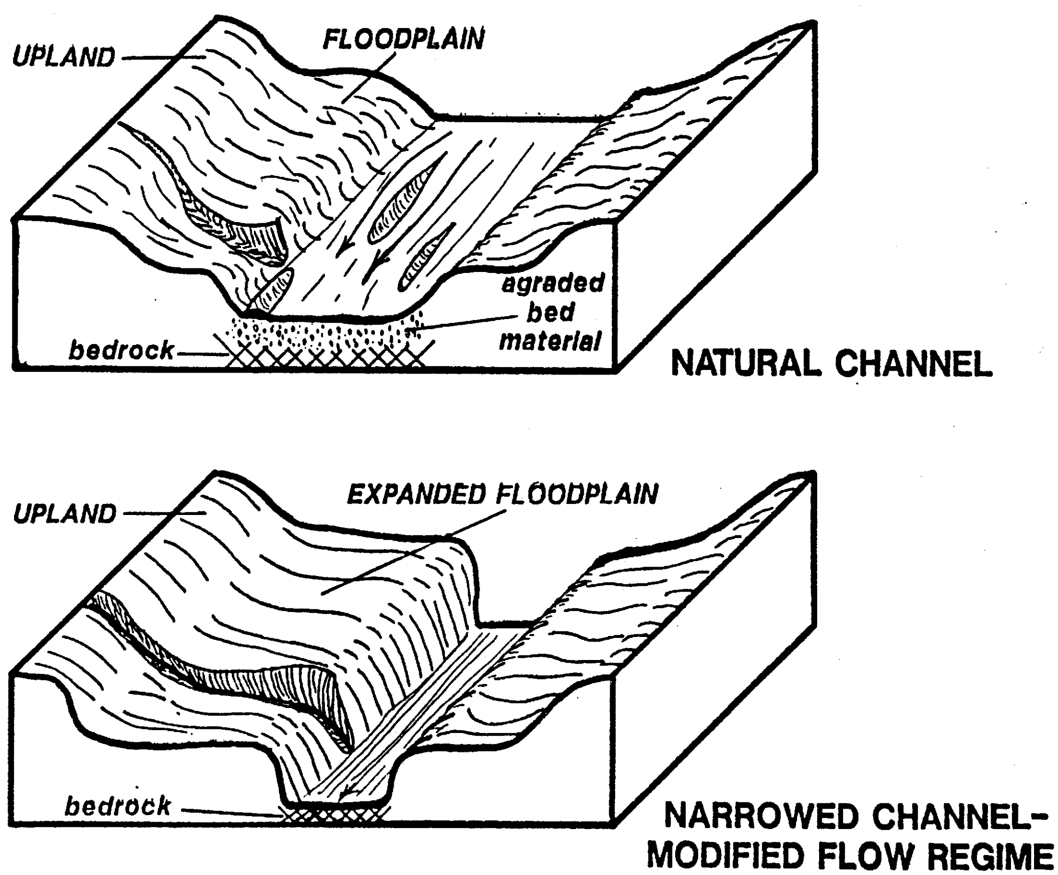

Figure 4. Downcutting of tributaries caused by lowering of mainstem channel bed elevations.

Emphasis of Riparian Zone Management 1975-1986

No less than seven national conferences have been held in the United States since 1975 to specifically address riparian zone issues. Increased knowledge of fish habitat needs, demand for recreation opportunity, emphasis placed on bird and other wildlife habitat, and decreased emphasis on water development have contributed to making streamside zones an emotional issue.

Agriculture and livestock grazing industries have taken their share of criticism for causing a decrease in riparian zones. However, this paper should help confirm Bob Dorn's conclusion about Wyoming. "Riparian vegetation may be as extensive now, if not more so, than prior to settlement" (8). G.P. William's 1978 research clearly shows the North Platte River in Nebraska has had a substantial increase in riparian zone. "The decreases in channel width are related to decreases in water discharge. Such flow reductions have resulted primarily from the regulating effects of major upstream dams and the greater use of river water by man. Much of the former river channel is now overgrown with vegetation...The changes are most pronounced in the upstream 365 km of the study reach (Minature to Overon). Within this reach, the channel in 1969 (and 1977) was only about 10-20 percent as wide as the 1865 channel. A significant part of this reduction in width has occurred since 1940" (9).

One doesn't have to give agriculture, livestock grazing, and water development a break; just give them a fair shake. There is little doubt riparian zones on private and public lands have changed from 1804 to present. Before all impact to existing riparian zones are blamed on the obvious, livestock, look behind the scenes to see what we have now compared to what we had. Without water development, basin riparian zones were marginal. Basin riparian zones are an extension of mountain watersheds. Other impacts now taking place on headwaters may change flow regimes far more than herbivory and hoof action by livestock. For instance, oil and gas development, is now occurring on headwater streams where they were not before because of technology of deep drilling. Imagine how road construction and facilities needed to provide these energy products to the United States will increase flushing flow, channelization of contributing area, and sediment downstream. This drilling activity is in addition to still increasing utilization of high elevation mountain valleys for recreation and business opportunities. We must acknowledge that riparian zones created by water development and agriculture is contributing towards holding low gradient mountain and basin river systems together as we presently know them. Irrigated vegetation has created constrictive dams, as riparian zones, which cause overbank flooding and thus decrease velocity of flow in existing channels. Other benefits include storage of water in soils and return flood and irrigation water which sustains increased aquatic habitat late in the low water seasons. If this system of using water in the western United States is disrupted, we stand the chance of losing an existing water storage capability. Can we afford to have this happen?

Dam construction is all but at a standstill because of public outcry against large reservoir storage and government permitting procedures. Reservoir storage capacity should be decreasing because of sediment deposition behind dams. As water storage decreases, more efficient use of water becomes necessary. Sando's et al. (1985) research concludes from a study on efficient irrigation of a river valley..."the primary effects of increased irrigation efficiencies are higher flows in spring months, higher peak annual discharges, and lower flow due to decrease in groundwater recharge. Large increases in spring flows can cause bank erosion (8)." Perhaps this practice of efficient irrigation is a way to return to 1804 riparian zones management. The effort of returning to 1804 type riparian zones can be partially supplemented by: (1) converting use of water for irrigation practices to be later used by industry and municipalities, (2) reducing use of livestock on public land and taking away any economic opportunity of providing ranchers a livelihood and thus, no reason for agriculture to sustain riparian zones on private lands, (3) drain water from behind geologic, biological, and constrictive riparian zones, and (4) ignore developing any additional water on the continental headwaters of the western United States where sediment is minimum and speed of runoff is maximum.

Today in Wyoming, Dorn concludes "Riparian vegetation may be as extensive now, if not more so, than prior to settlement." What do you think and what do you want? Dorn also concludes that "Today grass is more abundant than it was prior to white man's influence in the area, the prevalence today of cactus, sagebrush and other shrubs was not caused by livestock overgrazing" (2).

Please remember that, without water, riparian zones cannot exist. Distribution and extent of riparian zones change as water use changes. Perhaps we tend to focus attention on local areas meaningful to individuals' purposes instead of evaluating resources of entire drainage basins for the good of all users. Change in distribution of water for agriculture has created extensive riparian zones along basin streams. Efficient irrigation of yards, street margins, and parks; within towns and cities provide riparian zone habitat where none existed before settlement. We cannot throw rocks at water storage unless riparian zones are low priority resource needs. Entire drainage basin planning based on historial information and use is needed to move forward to meet future demands for this now desired resource. With basin planning, water utilized to meet the needs of one user can be utilized again and again to meet demands of others.

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BALANCE AND ADJUSTMENT PROCESSES IN STREAM AND RIPARIAN SYSTEMS.

Burchard H. Heede[1]

Abstract

All natural systems are dynamic and are changing regardless of man's or other influences. Natural processes within and between systems will eventually restore dynamic equilibrium after disturbances, but control measures may be desirable to speed the processes after serious disruptions. Control measures must work with rather than against, ongoing natural adjustment processes.

The Problem

Only within recent years has the importance of riparian systems been regarded for wildlife habitats and as stabilizing elements for streams. Indeed, the interaction between streams and riparian systems has since become the focus of research and management. This interaction was the missing link that in the past led to many unfounded conclusions about the present and future condition of either component. Since this research is relatively new, much has yet to be learned about possible relationships within and between these two natural systems. As a result, in many situations, we may qualify causes and expected future processes, but cannot yet quantify them. When we deal with one or both systems, we must be fully aware of this lack of knowledge, and draw a definite line between factual information and surmised perception. This is not easy for managers who are asked to deliver solutions. They, therefore, may have to resort to a value instead of a factual scale.

In the context of this report, riparian zone and stream will be discussed as individual systems, because processes operating in each are different. The report is intended to help the manager distinguish between known physical factors and relationships on one side, and conjecture on the other. Furthermore, I hope this report will help managers qualitatively project future adjustment processes where disturbance has occurred. If the direction of future processes can be evaluated realistically, many pitfalls can be avoided.

Past Work

There is ample literature available on riparian ecosystems and on streams and their channels. The riparian literature deals mainly with plant physiologic, taxonomic and ecologic problems (Irvine and West 1979, Stevens and Waring 1985, Reichenbacher 1984). Only in more recent years have interactions also between streams and their riparian zones been recognized (Platts et al. 1983a, Heede 1985a). Much of the riparian literature concerns influences of grazing on riparian communities (Platts et al. 1983b).

In contrast, the comprehensive hydraulic literature rarely mentions riparian communities and their role in channel processes. Heede (1972) considered the influence of streamside forests on the hydraulic geometry of mountain streams. Other authors, specifically in the Northwest, studied the function of large forest debris in rivers (Keller and Swanson 1979, Mosley 1981). The balance necessary for the existence of healthy natural systems was discussed by Heede (1984). Based on a 5-year experiment (Heede 1985b), and studies of mountain streams in Colorado and Arizona (Heede 1981), I concluded that this balance should exist within and between the interdependent systems. If either is disturbed, adjustment processes will be initiated that will eventually establish a new balance.

The Balance in Nature

When using the term "balance" to describe equilibrium conditions of natural systems such as forests, streams, or riparian communities, we should be aware of the term's limited applicability to nature. We all know nature is changing continuously, as we humans do. We grow older. Change is therefore the rule. Why then do we apply balance or equilibrium to this ever-changing world? We do it to contrast an orderly changing condition with severe disturbance or catastrophy. Severe disturbance prohibits orderly development from one stage to another, or in other words, from one equilibrium to a new equilibrium. In science, we refer to dynamic equilibrium, signifying a condition of balance that is not absolute, but allows for changes into a new balanced condition that, in turn, again will change into another balance with time.

Many factors or elements make up a natural system. If balance has been attained, the individual elements of a stream or riparian ecosystem are adjusted to each other. Hence the life cycle of a riparian community, for instance, can take its course from seedling to seed production into old age. If dynamic equilibrium prevails in the community, disturbances such as loss of some large trees will be healed rather quickly by increased herbaceous ground cover that absorbs the sudden increased radiation input. Other detrimental consquences will not occur, and regeneration of the riparian system is possible.

But we know also of many situations where severe disturbance may prevail for a long perod of time, during which the riparian ecosystem may seriously

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degrade. In this case, much time is required to regain a new balance within the system, because dynamic equilibrium--the ability to adjust quickly--has been lost.

We know that stream behavior is influenced by riparian systems. Riparian plants may stabilize channel banks, and riparian communities may protect flood plains from severe scour. On the other hand, streams have beneficial influences on riparian ecosystems by providing sufficient moisture for plant survival. Thus, both systems are dependent on each other. For a healthy coexistence between streams and riparian ecosystems, it is basic, therefore, that each system in itself is in a state of balance. If not, balance cannot exist between the systems, and a formerly healthy system may be thrown out of balance. I will discuss some examples later.

Adjustment Processes and Their Effect on Stream, Riparian Community, and Watershed

Thus far, I have discussed balance as a final stage of adjustment between elements or variables that make up a system. Let us consider now how adjustment within a system is achieved, if one or more variables are changed. While doing this, it will be important not only to examine the adjustment mechanism, but also the impact on the dependent system, because the adjustment processes cause changes (damage) to the system until a new balance is established. Examples will illustrate this.

Stream System Undergoes Change

A high dam with reservoir has been installed in a stream. Before dam closure, the stream gradient was sufficiently steep to create flow velocities for transport of the available sediment. After closure, most of the stream's sediment load is trapped. The water flow below the dam, rid of the sediment load it used to carry downstream, suddenly has much free energy that formerly was consumed by the load. The balance is disrupted, because waterflow, sediment, and energy are no longer in equilibrium with each other (Fig. 1). Flow velocities increase since more energy is available. The result is channel erosion, as the stream attempts to attain a flatter gradient. When it is sufficiently flat to carry relatively clear water without erosion, a new balance is attained.

If the adjustment processes are fast, as is possible when impacts are less severe than those from a high dam, balance will be regained quickly, and the impact of disturbance will be minimal.

Unfortunately, most stream processes are slow, especially those directed toward the adjustment of gradients after large sediment volumes are withdrawn. Basically, two mechanisms for lowering the gradient exist. One is lengthening of the stream course by forming meanders, the other is erosion of the streambed. Generally, the stream follows the path of least resistance. Lateral movement by meanders requires less energy expenditure than streambed erosion. But hard bank material may not allow meander formation, and the adjustment must be achieved on the existing bed; bed degradation occurs.

The relatively "hungry" stream picks up sediment load either by bank or bed erosion. During these adjustments, channel gradients and velocities of flow decrease, resulting in decreased sediment carrying capacity of the flow. Bed scour is strongest during the first one or two decades after dam closure, and then decreases considerably (Williams and Wolman 1984). In large rivers, several hundred years of adjustment may be required which may occur over a distance of several hundred miles (Hammad 1972).

During the period of adjustment toward a new balance, bank or bed erosion, and sometimes both, may have a serious impact on riparian ecosystems. Only after a new balance has been obtained in the stream system can the riparian zone begin to find its new equilibrium. We should recognize also that riparian zones of concern may be located at a long distance from the source (cause) of disturbance. In this situation, localized examinations to detect the cause of the disturbance would not be successful.

Riparian System Undergoes Change

Let us consider now a situation in which the riparian zone is disturbed, but the stream is in a healthy condition. Because of serious overgrazing or plant disease, the riparian community is dying and hence losing its ability to withstand the impact of high flows. Not only are shrubs and trees uprooted and carried away, but also lost will be the soils of banks and floodplains. As a result, the sediment load of the flow increases, but not the channel gradient nor, therefore, the sediment carrying capacity. The balance is disrupted. More sediment is available than can be transported through the stream reach. Deposition takes place. The stream has lost its balance between channel and flow. Adjustment toward a new balance begins at this point in time.

Deposition, or channel aggradation, continues until a steeper gradient has been formed which raises the sediment carrying capacity of the flow to a magnitude that makes sediment transport through the stream reach possible. When sediment input into the stream reach equals sediment output from the reach, balance exists.

The discussed considerations are theoretically correct. In reality, however, some other adjustments of hydraulic flow factors and parameters also occur. Streamflow and channel changes meet somewhere in between to allow the new balance. One must also

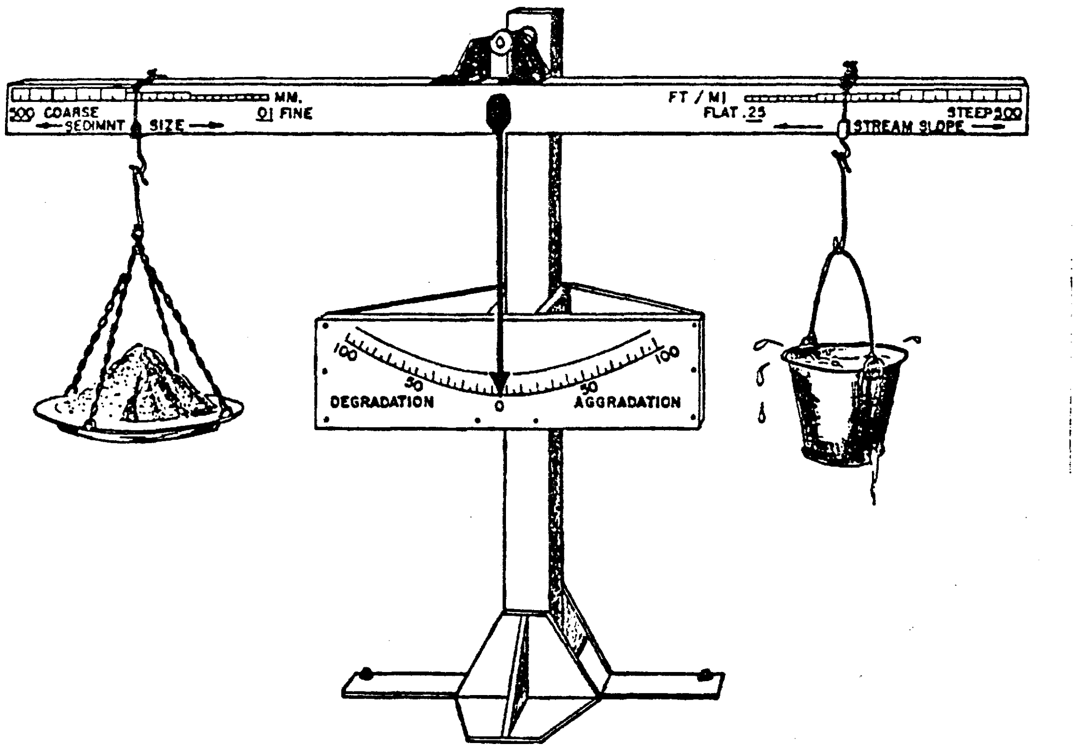

Figure 1. Lane's stable channel balance. (sediment loads times sediment size) varies as (stream slope times stream discharge).

consider that developments are not necessarily as straight forward as discussed, because sediment supply from the disturbed riparian zone may decrease, or bedrock be exposed. Hence, it is possible that the steeper channel gradient, formed during the period of aggradation, suddenly is too steep for future flows with pre-adjustment sediment levels. Then degradation ensues, and the stream is again out of balance.

Disruption of riparian and stream systems, as well as their balanced coexistence, may cover very long time periods, if the pendulum between aggradation and degradation is repeated due to geologic or other circumstances, such as grazing of an unbalanced riparian system.

In summary, while channel flooding increases during the period of aggradation, impacting the riparian zone additionally, degradation disrupts stabilizing developments at banks and floodplains.

Watershed Undergoes Change

As stated earlier, change is the role in nature. Were it not for erosion of mountainous lands, our fertile agricultural lands would not exist. Yet, developments of this geologic time scale were not one-directional. For instance, climatic changes could enhance the vegetation cover at times and at others impair it. With this, the erodibility of watershed surfaces changes also, leading to periods of strong and minor erosion. Such developments occur also within shorter time frames. A wild fire may consume the vegetation in a watershed, and it may take years before a new, effective ground cover can regrow. When regrown, the eqisode of high erosion rates (severe changes) is replaced by an episode of low erosion rates (moderate changes).

During episodes of high erosion rates on the watershed, stream channels may be filled by sediment (aggradation), because sediment delivery from the watershed may have increased more than runoff. The raising of the channel bottom leads also to widening of channel and floodplains, which favors the establishment of riparian communities. With regrowth of an effective vegetation cover on the watershed, sediment delivery to the stream decreases and the flows carry less sediment on a gradient too steep for the maintenance of balance between flow and channel. Free energies increase and transport the formerly deposited sediments downstream resulting in erosion of banks and flood plains. The new riparian zones may be destroyed. In this example, the balance, once at-tained by aggradation of the streambed, could have been disrupted by natural developments or by human interference. Regardless of the course, a third natural system, the vegetation on the watershed, was thrown out of balance and affected the stream and riparian system.

The Lesson

What are the lessons to be learned, based on our better understanding of the relationship and interdependency of riparian and stream systems? For one, we know that change of one or more elements in a system can lead to loss of balance for long time periods. If changes are not drastic, adjustments within the system may create a new balance relatively fast, say within a few years. Besides unusual external events such as earthquakes, extremely severe storms, or serious human interference, this represents the normal situation in nature. Because change is the rule in natural systems, the dynamic equilibrium condition--the ability to adjust quickly--is a desirable stage in systems development. In this situation, we don't have to interfere. Indeed, we will gain, if we simply let nature take its course. Where serious impacts exist, however, and adjustment processes require long time periods for the attainment of a new balance, we can help to speed up developments. Our help should be directed toward enhancement of the ongoing processes of adjustment. Our measures must therefore work with, and not against, the processes. This is less costly and certainly more successful. An example will illustrate how a control measure can work with the existing processes.

Let us refer to the example of high dam installation discussed earlier. The streamflow below the dam was free of its main sediment load, and the freed flow energies scoured the bed to create a more gentle bed gradient. Gradient control structures (check dams), installed at calculated spacing, can achieve the same effects as the long-lasting adjustment processes, but much more quickly. The average stream surface slope is dampened by the creation of pools behind the dam, and the flow energies are decreased by the water overfalls at the structures. The dams also reduce bed erosion because they transfer a turbulent flow into a more tranquil one. Overall, the flow is tamed as compared with the original condition after dam closure. An analysis would be required to determine whether the benefits derived from a balanced stream and a healthy riparian zone would exceed the cost of the control structures.

Before effective measures can be planned, it is imperative to establish the cause of the disruption. This requires examination of the system as a whole, because the origin of the disruption may be located far away from the site in question. Indeed, if we inspect a stream as a possible cause of riparian zone impairment, it may be necessary to examine also the master stream of which the stream is tributary. For instance, the master stream may have lowered its bed by erosion and thus forced the tributary to lower its bed by erosion. Only where hard bedrock exists, would the tributary join the main stream with a waterfall. Streambed lowering with resulting bank instability would be determined as cause for the riparian zone impairment, originating in the master stream. Stabilization within the riparian zone would therefore require that further down cutting of the main stream channel be controlled. This example illustrates the complexity of natural systems response that make easy answers a rarity.

Summary

There is always a cause for the disruption of balance within and between natural systems. Any disruption activates adjustment processes that will lead to a new balance. This balance will be achieved by mutual adjustment of the system's elements, which may include ground surfaces, channel configurations, flow velocities, and plant composition. In streams, adjustment processes are mainly recognized by erosion; in riparian zones, by rock surfaces and weak or absent plant regeneration.

If balance is lost for long periods of time, corrective measures may be desirable. If we work with the ongoing adjustment processes, the results will be better, faster, and cheaper. Where dynamic equilibrium--the ability to adjust quickly--has not been lost, we should allow nature to take its couse and not interfere, with the exception of restricting use for protection. This will enable nature to perform adjustments without interruptions that could be caused by activities such as grazing or recreation.

The complex response of natural systems. forces us to examine them very thoroughly before deciding on management actions. Due to the interactions within and between systems, we cannot focus only on impaired locations, but must include the system as an entity.

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BOULDER CREEK DRAINAGE
SHOSHONE NATIONAL FOREST

Boulder Creek is very typical of major streams in the Absaroka Range. In its upper and mid portion (reaches), the creek flows through very narrow, steep canyons that are associated with moderate to high natural soil erosion and slope stability. In its lower reaches, the creek flattens out and flows over landforms called alluvial or debris fans. Typically, in lower reaches, the stream is comprised of multiple or braided channel conditions.

The Boulder Creek drainage is approximately 11.5 miles long and has a 5,000-foot drop (average 8% gradient). Its drainage area is approximately 14,000 acres. Its two primary tributaries are Little Boulder Creek and Castle Creek. Little Boulder Creek is approximately 4.6 miles in length, with an average gradient of 20% and a drainage area of approximately 4,000 acres. Castle Creek is approximatley 5.3 miles long, with an average gradient of 11% and a drainage area of about 5,000 acres.

The confluence of Boulder Creek and Little Boulder Creek is near the break between the alluvial valley floor of the South Fork of the Shoshone River and the steep volcanic slopes of Carter Mountain. Castle Creek joins Boulder Creek 1.5 miles above its confluence with Little Boulder. All three streams orginate near the top of Carter Mountain, at elevations between 11,000 and 11,500 feet MSL.

Boulder Creek can be considered as still being in its "infancy" in terms of stream channel development. When high flows occur, large amounts of debris and sediment are moved. In the lower reaches, new channels are formed and old channels abandoned. The movement and formation of new channels causes considerable problems for adjacent property owners, public land managers, and public agencies who are responsible for roads, utilities, and other essential services.

Damaging flood flows in streams like Boulder Creek are not extraordinary events. Because of the shallow depth of the volcanic soils and associated rapid runoff, relatively minor rainstorms and "normal" spring runoff can cause channel relocation. Often times, a culvert which is working well one day is left high and dry the next, while the water runs across the road 100 feet away.

Large amounts of rainfall and/or rapid snowmelt can easily cause major changes in stream channel configuration. There is very little that landowners or public officals can do to prevent these changes and the associated resource and property damages. Their role becomes primarily that of avoiding the active floodplain zones, repairing any damage, and restoring lost services.

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'87 WYOMING WATER DEVELOPMENT AND
STREAMSIDE ZONES TOUR SCHEDULE

September 1, 1987

6:00 a.m.	Breakfast - Holiday Inn, Cody
6:50 a.m.	Load buses and leave for tour of Shoshone River, Badger Basin and Clark's Fork River areas

NARRATORS FOR THE DAY'S TOUR

-Dorse Miller, Mayor, City of Cody
-Vic Hasfurther, Wyoming Water Research Center, University of Wyoming
-Ed Norlin, Shoshone-Heart Mountain Irrigation District, Powell
-Forrest Allen, Irrigator, Cody
-Chester Blackburn, War Camp, Ralston
-Beryl Churchill, Water Development Commission and Irrigation Farmer, Powell
-Thor Stephenson, Bureau of Land Management, Cody
-Eric Greenquist, Bureau of Land Management, Cody
-Dick Kroger, Bureau of Land Managment, Worland
-Bill Sheets, District Water Commissioner, Cody
-Craig Cooper, State Engineer's Office, Riverton
-Becky Mathisen, Wyoming Water Development Commission, Cheyenne
-Alden Ingraham, Resource Conservation and Development, Thermopolis
-Ron McKnight, Wyoming Game and Fish Dept., Cody
-Fred Christenson, U.S. Bureau of Reclamation, Cody
-Quentin Skinner, Range Management, University of Wyoming

7:15 a.m.	Stop - unload buses
	Corbett Diversion Dam and Tunnel
7:45 a.m.	Load buses
7:50 a.m.	Drive through Winniger Subdivision to discuss subdivision development within an irrigation district
8:15 a.m.	Stop - unload buses
	Hydro Power Plant as part of the irrigation district
8:45 a.m.	Load buses
8:50 a.m.	Drive by concrete pipe plant

9:15 a.m.	Stop - unload buses
	Refreshments served by Powell Chamber of Commerce. Sponsored by First National Bank and Mountain Bell.
	Powell Museum - view early photos of irrigation development in the area
9:50 a.m.	Load buses
10:15 a.m.	Stop - unload buses
	Open canals and underground pipelines for delivering of irrigation water
10:45 a.m.	Load buses
11:05 a.m.	Stop - unload buses
	Reservoirs in a desert area
11:35 a.m.	Load buses
12:15 p.m.	Stop - unload buses
	Noon luncheon - served by Eastern Star, Cody
	Visit Clark's Fork Fish Hatchery on your own
1:15 p.m.	Load buses
1:40 p.m.	Stop - unload buses
	Clarks Fork River - instream flow permit and potential development of water resources.
2:30 p.m.	Load buses
2:50 p.m.	Stop - unload buses
	Clark's Fork - Badger Canal Siphon
3:15 p.m.	Load buses
4:00 p.m.	Stop - unload buses
	Newton Lakes and summary discussion of tour
4:30 p.m.	Load buses
4:45 p.m.	Arrive Holiday Inn, Cody - end of tour

SHOSHONE MUNICIPAL PIPELINE AND WATER TREATMENT PLANT

This project was initiated in May of 1981 by the Big Horn Basin Wyoming Resource Conservation and Development (RC&D) council with a meeting of the Mayors from the cities and towns of Cody, Powell, Byron, Cowley, Deaver, and Frannie to discuss future municipal water needs in the Shoshone River Drainage.

In late 1981 the Mayors decided to have Engineering Associates of Cody prepare a preliminary feasibility study of piping water from Buffalo Bill Reservoir to the seven cities and towns involved, with concepts of having a central treatment plant above Cody, the other alternative was furnishing raw water to each city and town and each treat their own water.

The "Municipal Water Development Association" was organized by the Mayors with Dorse Miller, Mayor of Cody, elected as Chairman.

During the 1983-1985 period the Wyoming Water Development Commission funded the State Level I and II studies for this proposed municipal pipeline project.

The results of the Level II study in 1985 recommended that a single new regional water treatment plant between the Buffalo Bill Reservoir and Cody be constructed at an initial capacity of 16.5 mgd (million gallons per day) and be expandable to 22.0 mgd.

During the planning process the Town of Cowley decided not to be part of this municipal water project.

The 36 inch diameter pipe from Buffalo Bill Reservoir will meet the maximum water demand to the year 2030 for these six communities. At the lower end of this 68 miles of pipeline the pipe size will be 10 inch diameter. The selected alignment allows gravity flow from a elevation of 5100 feet at the entrance to the pipeline of the treated water as the water leaves the treatment plant west of Cody to an elevation of 3855 feet in Lovell, Wyoming.

The 1987 State Legislature authorized a $15,000,000 loan from the permanent Wyoming mineral trust fund for the water treatment plant. This water treatment plant will be located between the Buffalo Bill Reservoir and the City of Cody.

At this same State Legislative session authorization was given the Joint Powers Board for the Shoshone municipal pipeline project. to receive a $27,562,500 grant and a $9,187,500 loan, both from the water development account fund.

It is planned to let the first construction contract for instalation of a portion of the 68 miles of water transmission pipeline in early 1988.

Dorse Miller earlier this year appointed Chester Blackburn with assistance from the Big Horn Wyoming Resource Conservation and Development (RC&D) to initiate action to organize the rural water users adjacent to the Shoshone Municipal pipeline into water districts. This will provide the opportunity for the rural landowners to have treated domestic water in the rural areas around and between the six cities and towns involved in the Shoshone municipal pipeline project. Alan Bair, Mayor of Byron, was elected President of the Big Horn County proposed rural water group. Bill Sheets of Cody is the Park County proposed rural water users President. Currently the two groups are jointly seeking grant and loan funds to install water systems adjacent to the Shoshone municipal pipeline for rural water users.

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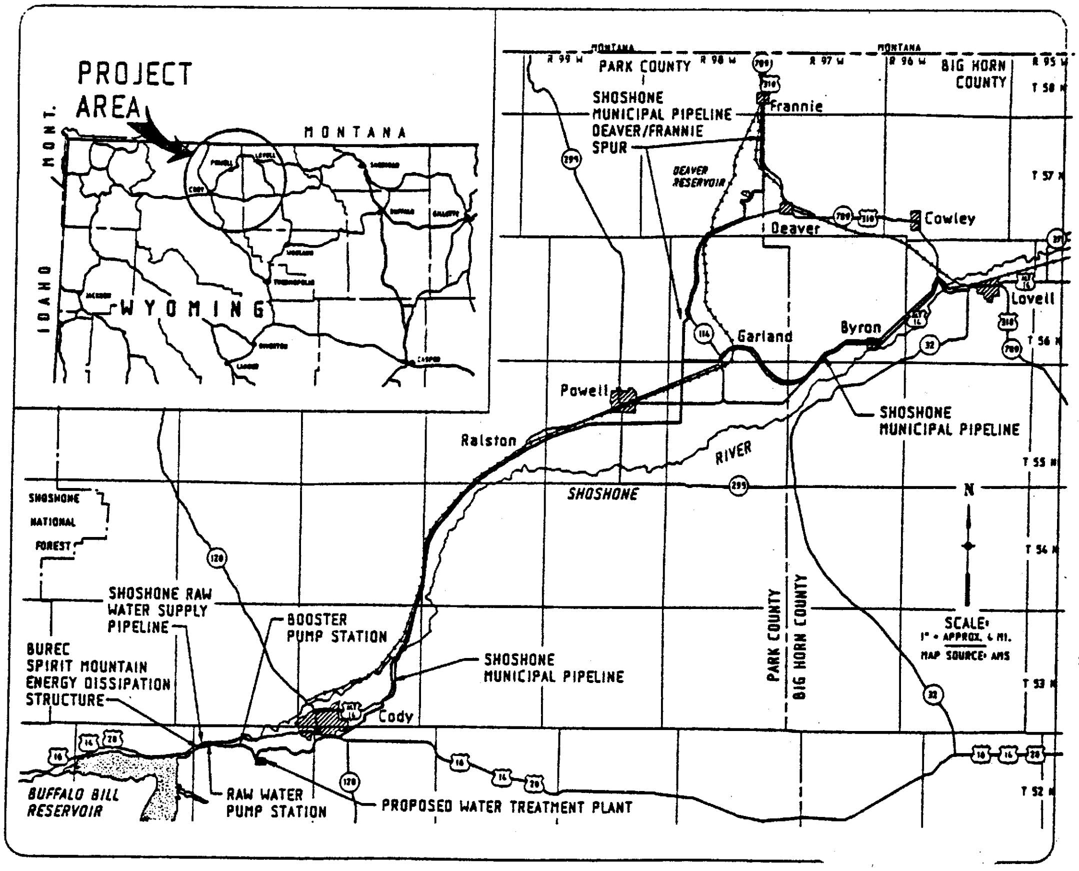

BANNER ASSOCIATES, INC. PROJECT MAP

FOUR COUNTY WATER MASTER-PLAN
BIG HORN, HOT SPRINGS, PARK & WASHAKIE

A Big Horn Basin Wyoming RC&D board member, Alden Ingraham, formally presented to the Wyoming Water Development Commission members, at their July 18 & 19, 1983 meeting in Powell, and again at their September 26, 1985 meeting in Cody, Wyoming a program asking for a water master-plan for the Big Horn River and Clark's Fork River Watersheds. The Big Horn Basin Wyoming RC&D believes this is essential to the future needs and best use of the estimated 2,000,000 acre--feet of water that is annually leaving the State of Wyoming from the Clark's Fork and Big Horn Rivers.

Senator Malcolm Wallop's cooperation to delete the Wyoming portion of the Clark's Fork River from the wild and scenic river status provides a much needed opportunity to investigate the feasibility of hydro-electric plants in conjuction with major water development structures at a sufficiently high enough elevation in the upper reaches of the Clark's Fork River to provide transfer of water by gravity flow and exchange of direct flow water rights in the Shoshone River, Greybull River, and on into the Gooseberry watershed. This also would provide the opportunity for water development in the lower Clark's Fork River Watershed in Wyoming and Montana.

On the Big Horn River, investigate the feasibility of providing water at the mouth of the Wind River Canyon at a higher elevation than the river, possibly through a canyon conduit. This would allow for hydro-electric production and gravity flow irrigation development on both the east and west sides of the Big Horn River from Thermopolis to Greybull, Wyoming.

The master water plan would determine if there is any water leaving the four counties of Big Horn, Hot Springs, Park and Washakie and the State of Wyoming in excess of future needs.

The Big Horn Basin Wyoming RC&D Council believes the water master-plan upon completion should include all possible irrigation development, municipal, industrial, and recreational uses in this four county area for the next several decades. Recreation will become much more important to the economy of this area. As the nation emerges from the present disturbed economic situation, people from the cities are going to have much more leisure time and more money to spend. It is inevitable that this area will be sought out by millions of recreational vistors. It is important that when these predictable events occur that we be ready with greatly expanded recreational opportunties. Development of these unused waters can provide much of these increased recreational opportunties throught water related recreation, enhanced fisheries, and improved wildlife habitat. The conclusion of this broad study should be basis for a water filling that will insure the water resource availability for the master-plan implementation for many many years in the future. This would permit development of the various phases of the master-plan as needs dictate and funds become available.

Goals for the development of water in the upper reaches of the Clark's Fork River should be as follows:

*Develop all or a major portion of the 425,000 acre-feet of water allocated to Wyoming.

*Provide gravity flows to as many service areas as possible including transfer of water to the Shoshone River Basin.

*Develop the high heads from the upper part of the basin to generate hydropower to help pay for the project.

The schematic layout of the proposed alternative for the use of Clark's Fork water in the four county Water Master-Plan is attached.

The Hunter Mountain site is the upper structure for the diversion of water from the Clark's Fork of the Yellowstone River. This site should be included to provide storage upstream. This would minimize tunnel diameter needed to capture water during the short runoff period and increase power revenues. Other primary project features are listed.

1. Small storage reservoir and diversions on the Clark's Fork below the confluence of Crandall Creek (near Crandall Ranger Station).

2. Tunnel 9.5 miles in length from Crandall area dam to a power plant in the Canyon to produce about 400 feet of head.

3. Incorporate Sunlight Reservoir through a penstock to above power plant on Sunlight Creek, also about 400 feet of head.

4. Canal or pipeline from Sunlight Creek to Dead Indian Creek.

5. Tunnel 6.5 miles in length from Dead Indian Creek to a power plant on Paint Creek, about 1000 feet of head.

6. Pipe or canal from Paint Creek hydropower plant to the reservoir in the area of the junction of highway 120 North and Dead Indian Pass road on Pat O'Hara Creek.

7. From Pat O'Hara Creek Reservoir through contour ditch or pipeline to Shoshone River below Willwood diversion. If pipeline, a third hydroplant below Willwood dam could have about 700 feet of head.

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SUBDIVISION IRRIGATION

With the ever increasing development of rural subdivisions comes the problem of administering water rights for these new land owners. Wyoming State Statues provide that a subdivider develop an irrigation plan and that the new land owners form a water users association to manage and deliver water within the subdivision. The law requires that the subdivider provide prospective buyers with information about existing water rights and a plan for delivery of water to the user, and return flows to the river. The quality of the system is not dictated. The extent to which these irrigation systems are developed differ considerably.

We would like to point out several well designed and installed systems for delivery of subdivision irrigation systems.

The Winniger Subdivision on the north side of the Cody-Powell Highway about 7 miles from Cody has an underground pipe delviery system. This subdivision is part of the Heart Mountain Irrigation Project and receives it's water via the Heart Mountain canal and laterals. This piped system takes in water at one point and delivers it by gravity through underground pipes to each lot. With this ideal type system there is a minimum of water loss, and no land wasted due to ditches and their associated weed problem.

Another well designed and installed system is located in the Lakeview Subdivision on the South Fork Road about eight miles from Cody. This system is made up of poured in place concrete ditches with individual taps for pump connections at each subdivision lot.

These two examples of subdivision irrigation systems represent the ideal, unforunately there are many that are not designed and installed to the same high standards. The result of many of these lower quality systems is constant management problems and frustration for the new land owner.

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GARLAND CANAL POWER PLANT

The Garland Canal Power Project located near Ralston, Wyoming is a part of the Shoshone Irrigation Project which utilizes water flows which are diverted from the Shoshone River into the Garland Canal.

The Shoshone Irrigation Project consists of a major storage reservoir and a network of downstream diversion and delivery facilities. (See Shoshone Project Map) The storage reservoir, Buffalo Bill Reservoir, is located on the Shoshone River, several miles to the southwest of the project area or about eight miles west of Cody, Wyoming. Downstream of Buffalo Bill Dam, two main diversion dams, Corbett Dam and Willwood Dam, divert water from the Shoshone River into the irrigation canals which serve the project area.

The Shoshone Project was originally constructed by the United States Department of Interior, Bureau of Reclamation. The Bureau maintained four operating divisions; Heart Mountain, Garland, Willwood, and Frannie-Deaver. When the Bureau turned the project operation over to local entities, the operating divisions become irrigation districts. The Garland Division became the Shoshone Irrigation District.

The water conveyed by the Garland Canal is diverted from the Shoshone River approximately a half-mile. The Garland Canal Power Project is located at this site.

Downstream of the Garland Canal Power Plant, the Garland Canal continues on to the northeast, delivering water to a major portion of the irrigated lands of the Shoshone Project.

The first two-thousand feet of the Ralston Chute is concrete-lined trapezoidal channel. It passes under two roads, a local county road and Highway 114, connecting Cody and Powell, Wyoming.

About four hundred feet above the chute terminus, it becomes an elevated flume which crosses over Alkali Creek. The flume discharges into a stilling basin form which the Garland Canal continues. The Garland Power Plant is located at the stilling basin near the chute terminus.

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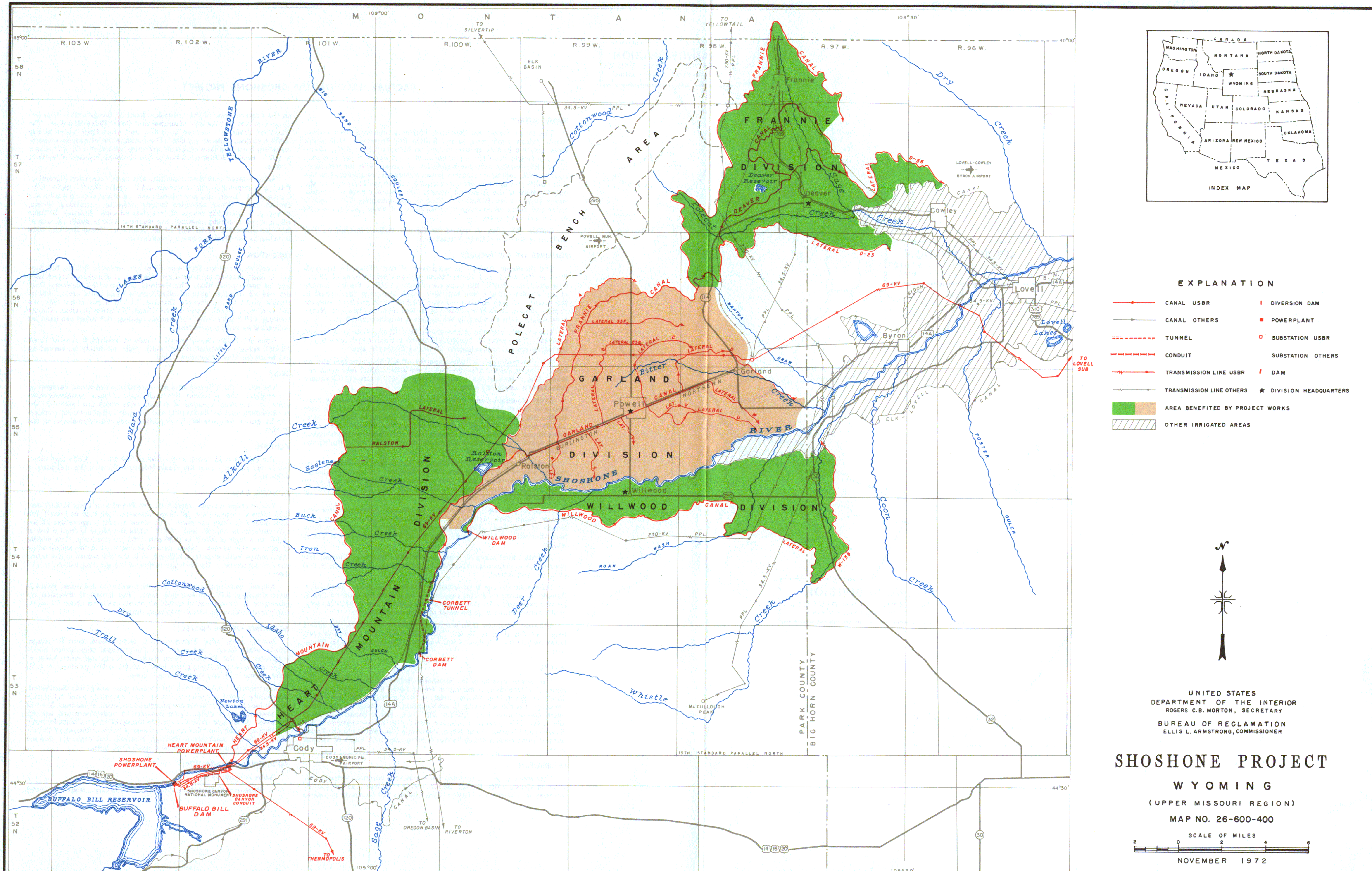

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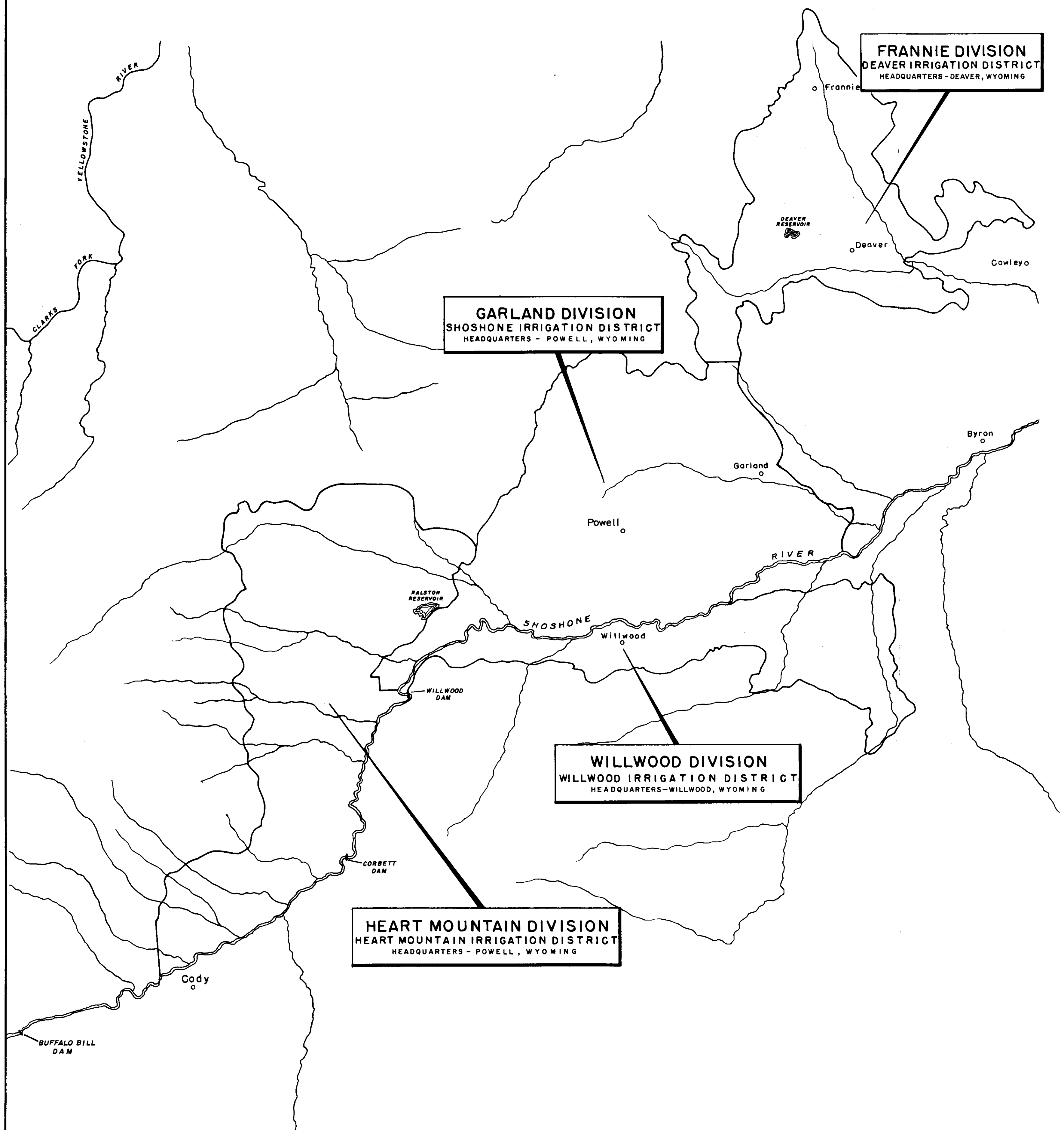

FACTUAL DATA ON THE SHOSHONE PROJECT

WATER SUPPLY

The water supply for Shoshone Project is obtained from surface runoff, mainly snow melt, above Buffalo Bill Reservoir. Buffalo Bill Dam, situated in a steep narrow canyon between Cedar Ridge Mountain and Rattlesnake Mountain, impounds flood waters of the Shoshone River and thereby provides regulation of stream flow for irrigation, flood control, sediment retention, power generation, recreation, and fish and wildlife propagation. Headwaters of the Shoshone River rise on the eastern slope of the Absaroka Range. The drainage area of the Shoshone River above Buffalo Bill Dam is approximately 1,500 square miles and yields an average of 610 acre-feet of water per square mile or 11.5 inches annually.

Buffalo Bill Dam is named for Colonel William F. (Buffalo Bill) Cody as is the town of Cody, Wyoming.

FEATURES OF THE PROJECT

The Shoshone Project is comprised of four divisions—Garland, Frannie, Willwood, and Heart Mountain—and has a total of 88,406 irrigable acres. Buffalo Bill Dam, completed in 1910, is the key feature of the Project. It is a constant radius arch dam, once the highest in the world. It was constructed with 78,576 cubic yards of concrete rubble, 108 feet thick at the base and 10 feet thick at the crest. Structural height of the dam is 328 feet and crest length is 200 feet.

The spillway consists of a rock weir, an unlined intake channel and a tunnel. The unlined horseshoe-shaped tunnel which was bored through granite is approximately 20 feet by 20 feet in size.

The reservoir has a total capacity of 491,350 acre-feet and an active capacity of 443,150 acre-feet at elevation 5,370.7 feet mean sea level. The reservoir has a surface area of 6,710 acres (10.5 square miles) and a length of 7 miles.

Heart Mountain Canal delivers water to the Heart Mountain Division and Heart Mountain Powerplant. Water is taken directly from Buffalo Bill Reservoir by means of Shoshone Canyon conduit, a tunnel 13,786 feet long through Cedar Mountain. The conduit ends at the powerplant and the canal begins with the Shoshone River siphon which spans the river below the tunnel outlet. Capacity of the siphon is 915 cubic feet per second.

Garland Canal supplies the Garland Division and the Frannie Division by way of the Frannie and Deaver Canals. The canal originates at Corbett Diversion Dam which is situated on the Shoshone River about 16 miles downstream from Buffalo Bill Dam. Initial capacity of the canal is 1,000 cubic feet per second.

Corbett Diversion Dam is reinforced concrete Ambursen weir with a short earth dike. It has a structural height of 12 feet and a crest length of 938 feet. The outlet works consist of the concrete-lined horseshoe-shaped tunnel 11′ 6″ wide by 10′9″ high and 17,335 feet in length.

Frannie Canal takes off from the Garland Canal near Ralston and extends to a point near Frannie. Initial capacity of the canal is 550 cubic feet per second.

Off-stream storage is provided by Ralston and Deaver Reservoirs. Ralston Reservoir (of limited capacity) is located off the Garland Canal. Deaver Reservoir is located on Lateral 114-F, and has a total capacity of 680 acre-feet and supplies water to the town of Deaver.

Willwood Diversion Dam is a concrete gravity structure. Structural height of the dam is 70 feet, hydraulic height is 41 feet and crest length is 320 feet. It diverts water to the Willwood Division for irrigation.

POWER

The power system of the Shoshone Project consists of two powerplants and attendant switchyards, transmission lines, and substations. Shoshone Powerplant, situated near the base of Buffalo Bill Dam, has a capacity of 5,600 kilowatts; Heart Mountain Powerplant, situated three miles downstream from Buffalo Bill Dam, has a capacity of 5,000 kilowatts. The system is interconnected with power systems of the Boysen and Riverton Units, North Platte and Kendrick Projects. Transmission lines consist of 113.6 miles of 69-kv and 57.1 miles of 34.5-kv lines.

RECREATION

Numerous activities that are associated with outdoor recreation are realized through the Buffalo Bill Reservoir. Situated at the eastern gateway to Yellowstone National Park, Buffalo Bill Reservoir is located on the eastern slope of the Absaroka Mountain Range and is bounded by spectacular Rattlesnake Mountain and Cedar Ridge Mountain. The Shoshone River has carved a narrow and precipitous gorge nearly 3,000 feet deep through granite. The combination of canyon scenery, mountain backdrop, and reservoir activities attracted 172,801 visitors in 1971. Buffalo Bill Dam is listed on the National Register of Historic Places.

Water-related activities constitute the basic recreation attraction. Fishing is popular in the reservoir and it totaled 50,203 angler days during 1971. Deer, elk, game birds, and waterfowl abound within the Project area. Other activities include camping, picnicking, hiking, riding, and observing points of historical interest. Existing facilities which enhance fishing, boating, and camping include public recreation facilities along the north side of the reservoir. These facilities were installed by the Wyoming Parks Commission.

IRRIGATION

Flood waters of the Shoshone River are stored in Buffalo Bill Reservoir and released as needed for irrigation of Shoshone Project land and for power production. The Garland Division of the Shoshone Project has an irrigable area of 35,853 acres while there are 14,600 irrigable acres in the Frannie Division, 11,530 acres in the Willwood Division, and 26,423 acres in the Heart Mountain Division. Canals totaling 140.5 miles and six tunnels totaling 6.8 miles are used for delivering water to project land.

Plans for future development include an additional area of about 19,200 acres on Polecat Bench which may ultimately be served by extending the Heart Mountain Canal.

SOILS

The soils of the irrigable area are divided into two broad categories: (1) residual soils underlain with shale and sandstone containing moderate to excessive amounts of soluble salts which are located in the northeastern part of the Project; and (2) modified alluvial soils underlain by gravel deposits which are predominant in the remainder of the Project.

ALTITUDE

The elevation at Powell on the Garland Division is 4,389 feet mean sea level. At Cody near the Heart Mountain Division the elevation is 4,984 feet.

CLIMATIC DATA

The average annual precipitation at Powell and Cody is 5.67 and 9.38 inches, respectively. Of these amounts, 0.46 inch at Powell and 1.55 inches at Cody are snow. The mean annual temperature at the two stations is 45.6°F. and 46.1°F. while the range is from a low of -46°F. to a high of 105°F. in 1936 and 1951, respectively. The middle of May is the average latest date of killing frost in the spring while the average earliest date of killing frost in the fall occurs in the latter part of September. The average length of the growing season is 147 days.

Annual consumptive use of irrigation water in the driest years is approximately 2.5 acre-feet per acre. The historical diversion requirement to meet these demands for water has been about 7.6 acre-feet per acre annually for full irrigation supply.

ECONOMY OF THE PROJECT

Beans, peas, oats, barley, wheat, sugar beets, corn for silage, alfalfa, other forage, and seeds are the principal crops grown under irrigation on the Project. Farm flocks of sheep and small herds of cattle are raised, utilizing grain, hay, pasture, and by-products of cash crops. Some lamb and steer feeding is done.

Agricultural products from the Project area are widely distributed. Dry edible beans are shipped out in large quantities after being processed locally. Sugar beets are processed in Lovell, Wyoming. Most of the seed crops are grown under contract for midwestern and eastern markets. Sheep are marketed mostly through Denver, Colorado; some are shipped to the West Coast and to markets in the Mississippi Valley. Most cattle are marketed in Billings, Montana, but some are shipped to markets in Omaha, Nebrasks, and Sioux City, Iowa.

ADDITIONAL INFORMATION

Address inquiries to:

Bureau of Reclamation, P.O. Box 2553, Billings, Montana 59103

INCREASING IRRIGATION WATER USE EFFICIENCIES AND RESULTING RETURN FLOWS

Donald J. Brosz[1]

Abstract

Improving upon irrigation water use efficiencies and adopting water conservation practices are receiving increasing attention as a solution to problems of inadequate water supplies. These methods are being pursued in lieu of more traditional methods of meeting growing water requirements through construction of more water supply facilities such as dams, conveyance facilities and wells. Since irrigated agriculture accounts for about 80 percent of all the water consumed and 50 percent of the total water diverted or withdrawn in the United States, it is assumed that by increasing irrigation water use efficiencies that substantial increases in the available water supply will result.

The Salt River Drainage Basin (Star Valley) as an agricultural watershed of 829 square miles in western Wyoming provided the opportunity for a study to determine the effects of increased irrigation efficiencies. Starting in 1971 several irrigation projects were completed that converted surface irrigation systems to sprinkler irrigation systems on approximately one-half of the irrigated acres in the valley. This conversion of irrigation systems resulted in less total water being diverted from streams for the sprinkler systems than was the case for the surface systems on the same irrigated acres.

Salt River stream flows were hydrologically analyzed and a comparison made of the flows prior to and after conversion to sprinkler systems. Significant impacts were identified. The mean monthly spring flows in the Salt River increased by 58.7 percent following the conversion to sprinkler irrigation. The study also showed substantially lower flows in the fall and early winter months. Analysis of annual flood peaks revealed that the mean annual flood peak flows increased by 47 percent.

Thus, this study shows that the primary effects of increasing irrigation efficiencies in areas where there is no storage above the irrigated area results in higher flows in the spring months, higher peak annual flow discharges and lower fall flows due to decreases in groundwater recharge. Large increases in spring flows also are causing bank erosion and damages of existing stream structures. The quantity of water available to the area essentially is unchanged but the time it is available has hanged substantially.

The study indicates that a careful analysis of resulting impacts within a watershed needs to be considered before major changes are made in the management of irrigation waters. Negative impacts upon the streamside zone land area and upon the quantity and quality of water may result.

Introduction

In parts of the semiarid West, the availability of sufficient water is one of the primary factors limiting agricultual production. For this reason, the development of irrigation systems with increased water application and conveyance efficiencies has been desirable to make better use of the limited available water. However, increases in irrigation efficiencies may affect stream flows by causing higher flows during the spring months and lower flows during the fall months (Interagency Task Force on Irrigation Efficiency, 1979). These can be undesirable effects especially to the lower portion of watersheds where no storage reservoirs are available in the upper watershed area.

Developments in the Salt River drainage basin (Star Valley) in Wyoming presented an opportunity to document some of the overall hydrologic impacts of increased irrigation efficiencies (Sando, 1985). Between 1971-1974, several irrigation projects were completed which resulted in a conversion from flood irrigation to sprinker irrigation. After the completion of these projects, approximately one-half of the 60,000 irrigated acres in Star Valley were irrigated with sprinkler systems. Those farms that converted to sprinklers increased their on-farm irrigation system efficiencies by an estimated 50 percent. The previous earthern conveyance canal systems were also replaced with underground pipelines on the sprinkler projects. The increased efficiency for delivering water to the farms thus, also increased substantially.

The Salt River has a drainage area of 829 square miles. The area is located on the west central edge of Wyoming. The Salt River flows northerly through the Star Valley for about 50 miles before flowing into the Palisades Reservoir at the lower end

[1]Associate Director, Wyoming Water Research Center, P.O. Box 3067, University Station, Laramie, Wyoming, 82071. Acknowledgements are given to Steve Sando, former University of Wyoming, Agricultural Engineering graduate research assistant who conducted this research for his masters degree thesis and to Dr. John Borrelli, advisor to Steve Sando and former University of Wyoming professor of Agricultural Engineering, now professor, Agricultural Engineering, Texas Tech. University, Lubbock, Texas.

of the watershed near Alpine Junction, Wyoming. The waters forming this river flow out of the Salt River Mountain Range on the east, the Caribou and Webster Ranges on the west, and the Gannett Hills to the south. Peak discharges in the area result from snowmelt runoff in the spring months; flooding due to thunder storms is a rare occurrence.

The Star Valley is a narrow, agricultural valley about 50 miles long and about 15 miles across at its widest point. It is one of the main dairy farming centers in Wyoming. Alfalfa hay and barley are the two main crops produced. The irrigation season typically lasts from late May to early September. Most of the soils in the valley are shallow, gravelly and well drained. Average annual precipitation is between 18-20 inches.

Many of the analyses in this study involved comparison of Salt River flows with the flows of the Greys River. The Greys River flows through a narrow drainage area 448 square miles in size immediately adjacent to Star Valley. The Greys River is essentially devoid of agricultural influence with less than 500 acres being irrigated from this river.

Analysis of Stream Flow Data

As many hydrological and statistical tests as were relevent and practical were employed in this study in an attempt to properly interpret streamflow changes on the Salt River. In all analyses, the period October, 1953 through April, 1971 was assigned to represent the pre-sprinkler period. The period May, 1971 through September, 1982 represents the sprinkler period.

Monthly Flow Comparisons

The double mass analysis was used to test the consistency of the stream flow observations on the Salt River. In this procedure, for each month, yearly accumulated streamflow values of the Salt River were plotted against those of the Greys River. A consistent record will generate a relatively straight line of constant slope. A record in which streamflow changes have occurred will yield a broken line with two or more segments of different slope. The double mass plots for the months of December-April and for the month of July yielded relatively straight lines of constant slopes, indicating little change in Salt River flows relative to Greys River flows during these months after the sprinkler systems were installed.

The double mass plots for the months of May and June showed an upward break in slope in 1971, indicated that during these months Salt River flows increased in the sprinkler period relative to those of the Greys River. The double mass plot for May (Figure1) is representative of the early season plots.

In the late season months (August-November), the double mass plots showed a downward break in slope in 1971, indicating a decline in Salt River flows in these months during the sprinkler period relative to those of the Greys River. The double mass plot for August (Figure 2) is representative of the late season plots. This test is very valuable in discerning the effect of the conversion to sprinklers upon the Salt River streamflow. The close proximity of the Greys Rivers to the Salt River provides that other factors including climatic influences are most nearly identical

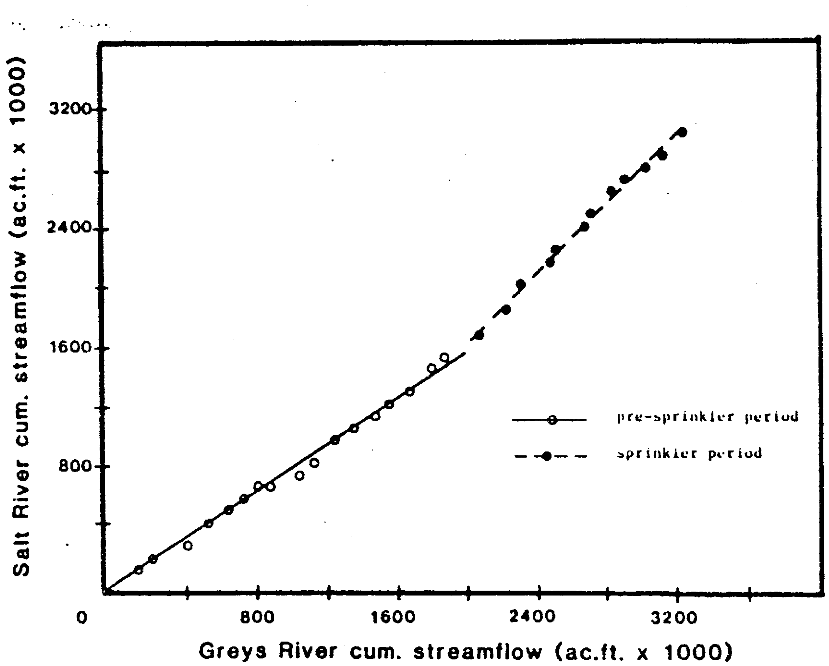

Figure 1. Double mass plot of Salt River flows versus Greys River for the month of May.

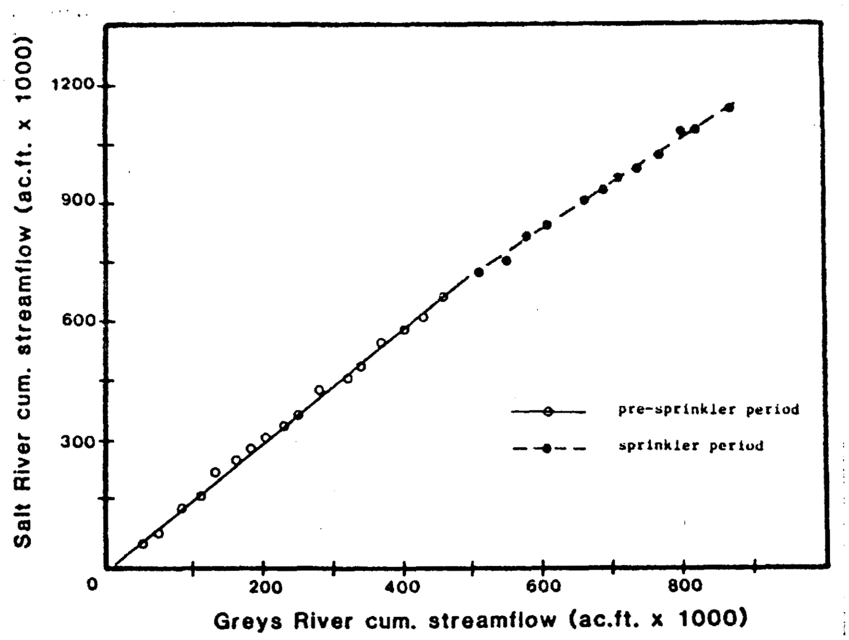

Figure 2. Double mass plot of Salt River flows versus Greys River for the month of August.

between these two drainages. Therefore, this double mass procedure tends to factor out the influence of climatic trends upon changes in the streamflow of the Salt River.

Mean Monthly Flows

The analysis of the mean monthly stream flows for the period of 1953 through 1982 show that during the months of May and June the streamflows were significantly higher since the sprinklers have been installed. The average increase for these two months was 58.7 percent.

A synthetic streamflow procedure was used to simulate what flows for the Salt River might have been in the sprinkler period if the sprinklers had not been installed. This procedural analysis substantiates the trends shown in the double mass analysis as discussed above. The synthetic procedure showed that the Salt River significantly lower in the fall months since the change to sprinkler irrigation. All other months (December-April, July) showed no significant differences.

Annual Flood Peaks

A test procedure was also used to determine whether the peak annual discharges changed significantly following the change to sprinkler irrigation. Using the pre-sprinkler flood frequency distribution, the 50 year recurrence interval flood is calculated to be 2891 cubic feet per second (cfs). This peak discharge was exceeded seven out of the twelve years during the sprinkler period. The hydrologic probability of exceeding the 50 year recurrence interval flood seven out of the twelve years is approximately one chance in 225 (4.45×10^{-3}). This is a very remote possibility which indicates that a significant change has occurred between the pre-sprinkler and sprinkler periods. Several other tests of data indicate the same change in flood peak flows.

Analysis of Other Factors

Where changes were observed in the Salt River flow between the two periods, it was necessary to consider the possibility that other factors besides the irrigation change may have contributed to those changes. Three primary influencing factors were identified and analyzed to determine their contribution to streamflow changes. These three factors were climatic trends, changes in crop water use due to increased crop production following the conversion to sprinklers, and urban construction trends.

Climatic data (mean temperature and precipitation) from Star Valley was analyzed similarly to the streamflow analyses, employing mean comparisons between the two periods and double mass analyses with data from surrounding stations. None of the tests employed revealed significant trends that would have contributed to the streamflow changes. In fact, the climatic trends that were observed tended to be opposite to those expected from the streamflow changes and therefore, the climatic trends may have served to obscure some of the effects of the sprinklers. This is especially true during the fall months where an increase in precipitation of 22.7 percent in the sprinkler period may have obscured the expected decline in streamflows during these months.

The effect of changes in crop water use was analyzed by estimating yield increases following the conversion to sprinklers and then employing a crop water function based on yield (Hill, 1983) to estimate the increase in crop water use. This increase in crop water use was then compared with the deviation in observed streamflow from the expected streamflows determined by the synthetic flows analysis. This procedure gave an estimate of the portion of reduced streamflows in the late summer and fall months that might be attributable to increases in crop water use. This analysis was performed for the months of August and September when the influence of crop water use on streamflow would be most pronounced. The results of this analysis indicated that increases in crop water use accounted for approximately 40 percent of the streamflow decline in August and approximately 30 percent of the decline in September. While these are relatively large contributions, the biggest factor contributing to the streamflow decline during these months was the reduction in groundwater inflow due to less groundwater recharge with the sprinkler systems.

The impact of urban construction trends was also considered as possibly contributing to streamflow changes. Wyoming Highway Department and Lincoln County personnel were interviewed to determine whether major increases in road or building construction occurred during the study period. The interviews revealed that no significant construction had occurred which might have contributed to the observed changes in streamflow.

Irrigation and River Basin Hydrology
(Interagency Task Force Report on Irrigation Water Use and Management, June 1979)

Basic principles of irrigation water diversions, application, and utilization need to be considered in relationship to efficient use of such water. Figure 3 shows the relationship between irrigation diversions, water use, and river basin hydrology.

To deliver a given amount of irrigation water to an irrigated crop, it is necessary to divert from the supply source (7) (numbers are located on sketch on Figure 3) in amounts of water greater than that to be consumed by the crop. This diverted water may include return flows from other areas.

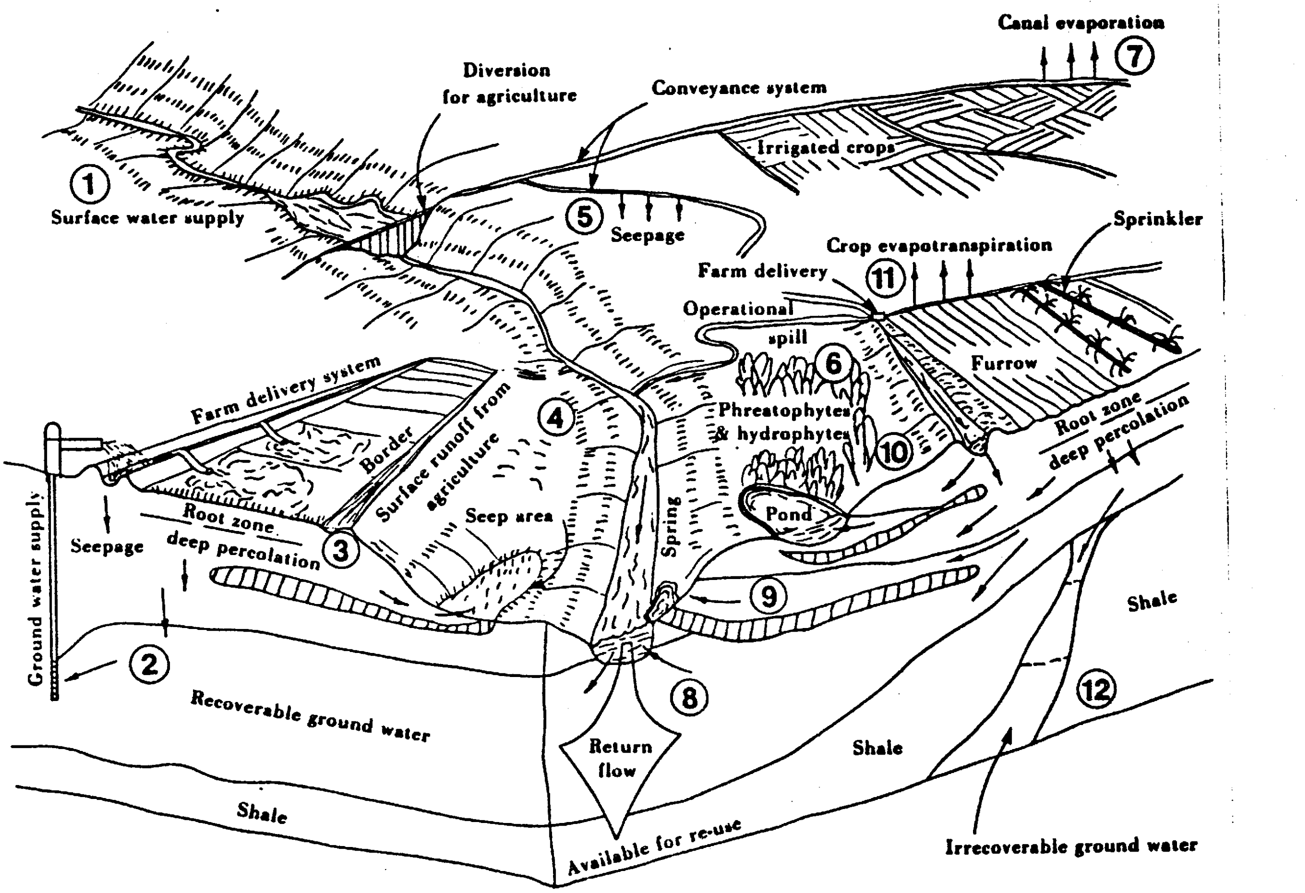

Figure 3. Schematic of Irrigated River Basin

Diverted water may leave the irrigated area as crop evapotranspiration (11), seepage (5) from the conveyance system (canals and on-farm ditches), operational spills (6), deep percolation (3), (water moving deeper into the soil than the crop roots), tailwater runoff (4) (water running off the end of the field), evaporation (7), or as phreatophyte and hydrophyte consumption (10).

Seepage varies depending on the condition of the canals and on farm ditches. Piped or lined conduits have lower seepage amounts than earthen unlined canals and ditches. Most seepage and deep percolation waters return to natural stream systems either directly via drains or indirectly through groundwater aquifers (9). Tailwater runoff, often referred to as return flows, which reach natural stream channels again become available for instream or downstream diversion (8) as do the returned seepage and percolation waters. However, the return flow water quality may be degraded. The recharge to aquifers can result due to irrigation practices which serves to maintain groundwater supplies (2).

High early-season streamflows from snowmelt are diverted near the headwater. The entire diversion, irrigation, and return flow process may take from a few hours to a few months. The delays occur when a significant amount of flow returns through the groundwater system. These returns supplement the later season low flows that normally occur. The net effect is similar to reservoir storage in the basin. Thus, large increases in system efficiencies of "upstream" irrigation projects may require additional water storage to provide the same downstream water supplies later in the season.

Operational spills (6) result from a reduction in demand for water within the system after the water has been withdrawn from the supply source. These spills usually return to the natural stream channels via wasteways and become available for instream or downstream uses.

Phyreatophyte or hydrophyte consumption (10) is noncrop vegetative transpiration of water that may occur adjacent to streams and channels, or in areas of shallow water tables. The existence of such vegetation often provides or enhances wildlife habitat.

A small quantity of deep percolation (3) (movement of water downward below crop root zone) is necessary to remove salts that would otherwise accumulate within the root zone, hampering and eventually prohibiting plant growth. This water is referred to as the leaching requirement and the quantity depends on soils, crops grown, climate, and water quality. Depending on geologic conditions, deep percolating water may slowly flow to deep aquifers or may enter stream systems through natural or manmade drainage systems. Deep percolation is often excessive as a result of poor irrigation management or nonuniform application inherent in many irrigation systems.

Filling the root zone on graded irrigation systems results in tailwater runoff (4) at the lower end of a farm field. The amount of runoff depends on soil conditions, irrigation system design, and water application methods. Some tailwater runoff may be unavoidable when graded surface irrigation systems are operated to achieve adequate infiltration and water application uniformity. Tailwater may evaporate, percolate, be consumed by phreatophytes, or reach stream channels as surface or groundwater return flow. Runoff may be collected on-farm and pumped back into the deliver systems for reuse, or may be intercepted by other users as a supplemental or primary water source.

Diverted irrigation water that recharges a groundwater aquifer (2) through seepage or deep percolation adds to the water supply available to groundwater users. Some farms and small communities depend on these replenished supplies. In some cases aquifers are used to store and distribute excess surface supplies. "Irrecoverable groundwater" (12) is groundwater resulting from seepage or deep percolation that is not recoverable or usable.

Return flows (4, 6, 9) to natural stream channels resulting from tailwater runoff, drainage flows, operational spills, or groundwater discharge may provide all or a portion of a downstream user's water supply. Return flows from irrigation sources often increase the sustained flow in smaller streams to the extent that the stream can support limited fisheries not otherwise available.

Diverting less water for irrigation would generally not change the consumptive use on the irrigation project significantly. Additional water would be available for nonconsumptive instream uses between the points of diversion and return flow. The water would be available during the time the diversion would have been made, in the absence of reservoirs to store it.

Many irrigation projects have been developed, at least in part, in consideration of return flows and reuse. The streamflow in the lower reaches of most streams does not consist of new water, but of return flows of water previously diverted from the system in the upstream reaches. Thus, the system of storage and return flow provided by current irrigation practices affects other water-related development. Any irrigation improvements which alter this system need to be carefully considered.

Additional Studies

Irrigation and return flow studies are also underway by University of Wyoming faculty on the New Fork River, a tributary of the Green River in the Pinedale, Wyoming area. The purpose of this study is to evaluate the effects of irrigation diversions and their resultant uses on the flow dynamics of the stream system. Within this content, the importance of the interaction and it attendant return flow characteristics to the stream system are being evaluated in some detail in terms of storage and release within the aquifer system. A surface water-groundwater accounting model is being developed to evaluate the irrigation practices and yearly flow of the stream system. The study is being conducted under the direction of Dr. Victor Hasfurther through the Wyoming Water Research Center located at the University of Wyoming.

Conclusions

This study has described some of the hydrologic effects of increased irrigation efficiencies. As hypothesized, the primary effects of increasing irrigation efficiencies are higher flows in the spring months, higher peak annual discharges and lower fall flows due to decreases in groundwater recharge. Large increases in spring flows can cause bank erosion and can affect structures designed according to hydraulic variables. The possibility that increased spring streamflows higher peak annual discharges and decreased fall streamflows may result from projects designed to increase irrigation efficiencies should be considered in irrigation project design. Where these effects appear likely to occur, procedures to alleviate the problems may be considered and be incorporated into the project design.

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BIG SAND COULEE SILT DETENTION RESERVOIR COMPLEX

The four reservoirs at this site were built primarily to reduce the amount of sediment entering the Clark's Fork of the Yellowstone by the way of the Big Sand Coulee drainage. The reservoirs have been effective in reducing the amounts of sediments reaching the Clark's Fork.

In addition to silt retention, the reservoir complex created significant amount of aquatic/wetland habitat, that supports numerous species of fish and wildlife. The value of the reservoir system has been further enhanced through the supply of irrigation and return flows to two of the reservoirs. These waters also pass through the reservoirs and create perennial flows in Big Sand Coulee. Maintenance of high water levels in the flow-through reservoirs has enabled year long survival of trout, that are regularly stocked by the Wyoming Game and Fish Department. These reservoirs continue to serve as intensive use areas for fisherman, picnickers, and swimmers.

Sand Coulee Reservoir, which rapidly filled with silt following construction, was inexpensively rejuvenated into a valuable marsh in 1987. Since the dam exhibited sufficient freeboard, an extension was added to the drain pipe to raise the water level. The top part of the pipe was perforated to temporarily raise the water level even higher to intermittently irrigate the vegetated fringes of the reservoir site. As a result this simple modification, more silt will be retained and the reservoir will remain a productive wetland area for many more years.

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CONVEYANCE LOSSES DUE TO RESERVOIR RELEASES

Victor R. Hasfurther and Randy A. Pahl[1]

Abstract

Three natural streams in Wyoming were studied in order to estimate incremental conveyance losses associated with incremental increases in stream flow. For each study area, all surface water inflow and outflow was measured before, during and following a significant reservoir release. With this data, conveyance losses were determined for the control period using a water budget analysis. The major losses were attributed to bank storage and a decrease in groundwater inflow. The conveyance loss results for the three study areas ranged from 0.34 to 1.66 percent per mile. Duration of release, of five times (3 days to 15 days), resulted in a decrease of the conveyance loss by over 50 percent (0.76 to 0.38 percent per mile).

Introduction

The recent growth in the areas of energy development and, to a lesser extent, agriculture and municipalities has increased pressure on available water resources throughout the U.S., and especially the Western U.S. and Wyoming with its prior appropriation doctrine (first in right, first in use). In order to satisfy these increased needs, it has become necessary to develop unappropriated water or to transfer water already appropriated for other uses. Energy development companies and municipalities have found it necessary to purchase agricultural water rights and then petition for a change in use, a change in place of use, and a change in the point of diversion of these water rights. Wyoming water law allows these changes to occur, provided the Board of Control feels that certain conditions stated in the State statutes are met. The Wyoming State Statutes, Section 41-3-104(a) declare:

> "...The change in use, or change in place of use, may be allowed, provided that the quantity of water transferred by the granting of the petition shall not exceed the amount of water historically diverted under the existing use, nor exceed the historic rate of diversion under the existing use, nor increase the historic amount consumptively used under the existing use, nor decrease the historic amount of return flow, nor in any manner injure other existing lawful appropriators..."

In order to protect downstream prior appropriators when water is transferred to a point downstream, conveyance losses need to be assigned to the transported water. However, there is a scarce amount of technical data available to aid the State Engineer and Board of Control in Wyoming in determining values of conveyance losses that would be equitable to all parties concerned. Many decisions in the past have been based on the best estimates of the people managing the stream in question. This is not unrealistic, and in many situations the only reasonable method available, but better quantification of conveyance losses would be more desirable from a technical and administratively defensible position.

Factors Affecting Conveyance Losses

When discussing conveyance losses in a stream, it is first necessary to define the term "losses." There are losses associated with the total flow in the stream that will exist year round. There are also losses associated with an incremental increase in the natural flow that will only exist when the increase exists. This increase may be the result of a reservoir release or a change in the point of diversion of an existing water right. In a case involving an incremental increase in flow due to a water transfer or reservoir release, the problem arises as to which "losses" the water user should be responsible. There are those who feel that a percentage of the total losses should be assigned to the increase, while others feel that the incremental losses associated with the increased water in the stream should be used. The amount of the increase in relation to the natural flow will partly determine which loss is the greatest. The incremental loss approach was taken in this paper due to the difficulties involved in determining total losses and the fact that if the conveyance losses associated with the increased water are completely borne by the party involved then no injury should result to any prior right appropriator of the water in the stream.

A large number of factors (> 15) affecting conveyance losses complicates the determination of the losses. M.C. Hinderlider, former Colorado State Engineer, discussed the difficulties involved in determining conveyance losses. Hinderlider states: "These factors alone, through hundreds of different combinations and changes daily imposed by the elements of nature, may produce a million different results having a direct bearing on this complicated problem....All of these factors are seriously affected from time to time by periodic changes in the hydrologic cycle, and in the

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normalcy of the rate and amount of precipitation, which have profound effects upon the underground water table of a drainage basin, and the rate and amount of return flow tributary to any natural water course" (Wright Water Engineeers, 1970).

In an effort to simplify its quantification, Colorado's administrators and engineers have split the conveyance losses that are chargeable to reservoir releases into four major components: evapotranspiration, inadvertent diversions, channel storage, and bank storage (Livingston 1973; 1978; Luckey and Livingston 1975; Wright Water Engineers 1970; 1982). In addition to these components, this paper includes a fifth component of loss which results from a decrease in groundwater inflow. These five components, to a large degree, include the effects of the many factors important to incremental losses in a perennial stream. Changes in any one of these five major components can influence the amount of the incremental conveyance losses. Several studies have been performed in an attempt to define the extent to which some of these components influence the hydrologic cycle of the stream and concurrently influence losses.

Studies on incremental conveyance losses in stream systems have resulted in loss estimates from 0.35 percent per mile to essentially zero for small incremental amounts of flow on large stream volumes on perennial streams (Livingston 1973; 1978; Luckey and Livingston 1975; Wright Water Engineers 1970; 1982). It was found that ephemeral type streams could produce much higher losses, 11.5 percent per mile (Wright Water Engineers, 1980), on the average, compared to perennial streams.

In Wyoming, very little information and essentially no detailed field studies on conveyance losses had been made in the past. In the future, it is expected that more transfers of water from upstream locations, either through building of reservoirs or transfer of water rights, will occur to downstream locations because of increased development. Since the mode of transportation will most likely be the natural stream channel, a study on incremental conveyance losses was undertaken, and the results are presented in this paper.

Study Areas

The initial studies were to test a method of analysis on reservoir releases to be conveyed to downstream owners of the reservoir storage. Three study sites were selected on perennial streams. These study sites were:

1. A portion of Piney Creek that extended from a point where Lake DeSmet discharge water enters Piney Creek to the confluence of Piney Creek and Clear Creek near Ucross, Wyoming. This stream reach traverses a total of 22 miles through a narrow valley comprised of alluvial deposits.

2. A portion of the Laramie River from Wheatland Reservoirs Nos. 2 and 3 to the confluence of the Laramie River and Sybille Creek near Wheatland, Wyoming. This stream reach is a total of 51 miles. The first ten miles of the study reach traverses through a wide valley containing alluvial deposits, and then cuts through the Laramie Mountains in a narrow precipitous canyon consisting of Precambrian rock for a distance of 27 miles. The river then exits the canyon and traverses approximately 14 miles in a narrow valley containing flood plain deposits.

3. A portion of the New Fork River near Pinedale, Wyoming, was studied from New Fork Lakes to a point approximately eight miles downstream. In this reach, the river traverses a distance of approximately one mile through glacial deposits, and then enters an narrow valley consisting of alluvial deposits.

Methodology

At each study site, a network of stream gages was established at all locations of surface water flow into and out of the main stream system. Some flows were not monitored since they remained fairly constant during the study periods and were generally small. Continuous stage recorders were installed at all flow measurement locations, and stage-discharge rating curves were developed.

With the recorders installed, the system was then monitored for a period of time to insure that the surface flows in and out of the system were relatively stable; i.e., gains into the creek from groundwater, irrigation return flows, and ungaged surface flows were constant. Once a stable condition was maintained, additional water was released from reservoir storage to provide an incremental increase in flow. This increased flow was then maintained for a period of several days (short, 3 days, to longer time periods 15 days), after which time the flow was reduced to approximately the same rate that existed prior to the reservoir release.

The hydrologic budget approach was used in the analysis of the collected streamflow data. This method required a comparison of the quantities of inflow and outflow in order to determine conveyance losses. In general terms, the water budget relationship can be written as

$$O = I - D + G \qquad (1)$$

where: O is the servace flow out of the system,
I is the surface flow into the system,
D is the surface flow diverted out of the system, and
G is the gain or loss in the flow in the entire system.

In the above equation, the 'G' term is a lumped variable which conatins the effects of groundwater flow and all sources of loss, such as surface evaporation, evapotranspiration, etc., and can be either positive or negative in sign. All of the rivers discussed in this paper were gaining at the time of the data collection, so the 'G' term was considered to be positive in the analyses. However, if a stream is losing, the approach discussed here is still applicable.

Incremental losses in the system due to the reservoir release are defined by this approach as the decrease in the gains or the increase in the losses during an increase of surface flow. The incremental loss can be calculated by manipulation of Eq. (1).

$$L = [\Delta I - \Delta D] - \Delta O \qquad (2)$$

where: L is the incremental loss due to the release,
ΔI is the increase in the surface inflow due to the release,
ΔD is the increase in diversions during the release, and
ΔO is the increase in the surface outflow due to the release.

All of the components of Eq. (2) are in the same units (i.e., cfs or acre-feet)

Eq. (2) provides a simple means for determining the losses associated with a reservoir release based solely on surface flow records. With this relationship, losses can be computed either in terms of the flow rate or the volume of the reservoir release by solving Eq. (2) in units of c.f.s. or acre-feet, respectively. Some adjustments need to be made to account for travel times. Certain limitations exist on the use of Eq. (2).

In the first place, all sources of loss are lumped together into one value. Included in this value are losses due to bank storage, channel storage, a reduction in the groundwater contribution, and an increase in surface evaporation and evapotransiration. Determination of each of these separate losses would require more field data than was collected in this study.

Secondly, use of Eq. (2) is limited to time periods when meteorological conditions are fairly consistent. Precipitation and its effect upon the surface and subsurface flows are not accounted for in this relationship. In most of the cases studied, there was negligible rainfall during the study periods; so this was not a problem.

Perhaps the most important limitation on the use of Eq. (2) pertains to the stability of the study area. Since this relationship determines the change in gains during a reservoir release, it is necessary that the flow regime in the study area is in a stable condition with relatively constant gains. This will ensure that the calculated decrease in gains is mainly due to the introduction of additional water into the stream. Any large changes in activities, such as irrigation, during the study period could affect the amount of return flows which, in turn, could affect the gains measured before, during and after the reservoir release.

The rating curve for each gage within the system was used to develop hydrographs which formed the basis for the determination of the conveyance loss. It became apparent from the measured losses that they were small enough to be affected by the degree of accuracy of the established rating curves. As a result, 95 percent confidence limits were place on rating curves in an attempt to better quantify the accuracy of the conveyance losses.

Results.

The analysis of results will be shown only for the Piney Creek study area, but all three study area results will be summarized at the end of this discussion. More details on both the methodology and results of the study areas can be found in Pahl (1985) and Hasfurther, et al. (1985).

Fig. 1 indicated the results of one of the two reservoir releases on Piney Creek. The hydrographs shown have not been adjusted for travel time. In order to make this data more understandable, the diversion hydrograph was first adjusted for travel time and was then subtracted from the inflow hydrograph, with the results indicated on Fig. 2. This plot is easier to read, and it clearly shows the relatively constant gains that existed in the system prior to the reservoir release. As discussed earlier, a stable system with constant gains is one of the prerequisites for the analysis technique used.

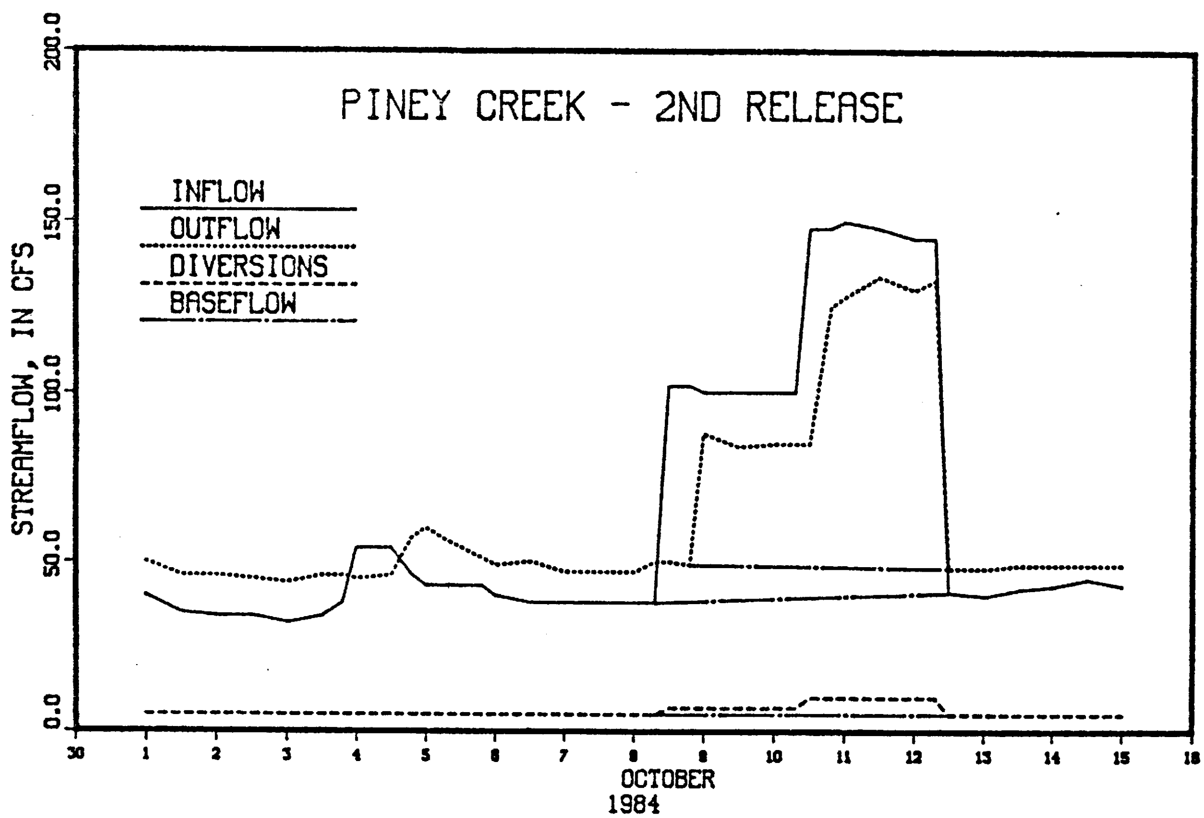

Fig. 1. Piney Creek Inflow, Outflow, and Diversions, 2nd Release.

With the stability of the system confirmed, Eq. (2) was utilized to estimate the conveyance loss associated with the release. Changes in the diversions during the release were significant; however, the amounts were not due to inadvertent diversion and, thus, the increase in the diversion term was accounted for in the analysis. It was, therefore, not included as part of the conveyance loss value. The ΔI and the ΔO terms were defined as that amount of additional flow in and out of the system, respectively, due to the reservoir release. To determine quantities for these terms, it was first necessary to estimate the base flows that would have existed had there been no release. This was accomplished using the most simple base flow separation technique which results in a straight line, on the hydrograph, connecting the flow prior to the release to the flow following the release (Fig. 1). The flow above these lines was then used to determine values for ΔI, ΔO, and ΔD. Losses were determined in terms of flow rate and volume.

Using this approach, the increase in the inflow was calculated to be an average of 84.6 c.f.s. for a period of 4 days, or a total volume of 670 acre-feet, while the average increase in the outflow was calculated to be 56.3 c.f.s. for a period of 3.66 days, or a total volume of 408 acre-feet. The average increase in the diversions was estimated to be 3.7 c.f.s. for a period of 4 days, or a total volume of 30 acre-feet.

With these values, the average conveyance loss was calculated to be 24.6 c.f.s. or 232 acre-feet. These loss figures were then converted to as percentage of the net inflow; i.e., the inflow minus the diversions. Due to the difference in the time bases of the inflow and outflow hydrographs, the volumetric loss was larger than the loss based upon the flow rate, with values of 1.66 percent per mile (volumetric) and 1.39 percent per mile (flow rate). Using volumetric values, the conveyance loss calculations were repeated with the 95 percent confidence limits placed on the hydrographs. Use of these limits resulted in a range of possible conveyance losses from 1.31 percent to 1.99 percent per mile of river. The results of these calculations are summarized in Table I, along with the other analyses made on all study areas.

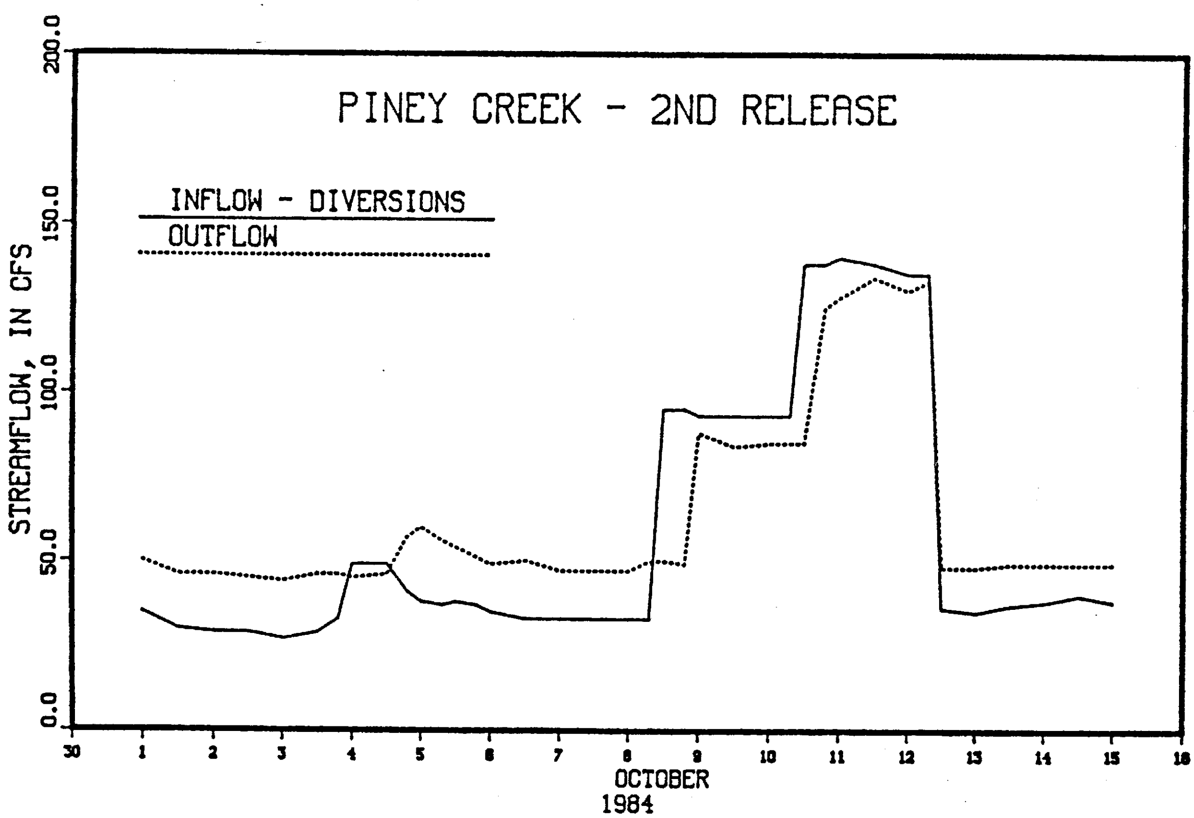

Fig. 2. Piney Creek Net Inflow and Outflow, 2nd Release.

The release shown for Piney Creek indicates that the majority of the measured loss is due to bank storage and a reduction in the groundwater inflow. During this release, the stage of the river rose an average of 0.47 feet. This increase temporarily forced water into the banks and prevented the surrounding groundwater from entering the creek. As the hydrographs on Fig. 2 show, the creek because influent during the release, losing water to the subsurface system. However, near the end of the release, the losses due to a decrease in groundwater inflow to the stream approached zero. This suggests that the stream was approaching a condition where the losses were negligible had the duration of the release been of sufficient length.

Several other releases were made on Piney Creek to try and determine the effect of time duration on the percentage of conveyance loss. Table II illustrates the results obtained when increasing the time duration from 3 days to 15 days.

This illustrates the fact that over time the groundwater system adjusts to the new flow regime and the amount of decrease in groundwater inflow and bank storage resulting from the initial increase of flow in the system is decreased with time duration as suggested by Fig. 2.

Summary

With all of the releases that were studied, it was assumed that evapotranspiration and channel storage had a minimal effect on the measured conveyance losses. This assumption agrees with the results obtained by Livingston (1973) in his study of the Arkansas River. Bank storage and reductions in the groundwater inflow were considered to be the major source of losses in the streams discussed in this paper.

The data collected for the Piney Creek study area demonstrated the high rate of loss that is typically experienced at the beginning of a reservoir release. However, in a perennial stream such as Piney Creek, the rate at which water is lost will decrease with time. As the groundwater table rises in response to the release, it is possible for the losses to continue to become smaller with time as illustrated in Table II. With this in mind, it can be stated that the longer the duration of a release in a perennial stream, the smaller will be the conveyance loss.

Table I
Summary of Conveyance Loss Results

Study Area	Average Increase of Inflow, c.f.s.	Average Increase in Stage, feet.	Loss % per mile	Upper 95% Confidence Limit, % per mile	Lower 95% Confidence Limit, % per mile
Piney Creek, 1st	41.8	0.18	0.76	1.49	0.00
Piney Creek, 2nd	84.6	0.47	1.66	1.99	1.31
Laramie River					
Lower Reach	114.6	1.02	0.34	1.0	*
Upper Reach	91.3	0.35	* *	*	
New Fork River	203.3	1.26	0.85	3.27	*

*Results showed an increase in gains

The water that was considered to be lost due to the releases in Piney Creek, the lower reach of the Laramie River, and the New Fork River was not actually lost to these systems, but was merely detained in the alluvial materials bordering these streams. In the case of Piney Creek, it was assumed that a majority of the detained water returned to the river following the recessions of the release hydrographs. However, since the hydrographs showed little evidence of this actually occurring, it was assumed that the stored water was released at a rate which was initially high (very small in comparison to total flow), but rapidly decreased with time. A similar observation was made by Livingston (1973).

The data collected in 1984 and illustrated in Table I at the three study areas resulted in loss values ranging from 0.34 to 1.66 percent per river mile. These results are rather high compared to those measured by studies indicated earlier in the paper, which ranged from zero to 0.35 percent per river mile in Colorado.

Several factors could have accounted for the differences in the results.

In the first place, the durations of the releases in previous studies were generally longer than those report in this paper even with the longer time duration illustrated in Table II on Piney Creek. As stated earlier, the longer the duration of the release, the smaller the incremental conveyance loss in terms of percentages.

Secondly, a difference in geologic conditions between the Wyoming and previous study areas could have accounted for the contrast in the results. For example, the hydraulic characteristics of the material surrounding a study reach can have a large influence on the rate at which water from the stream will enter the banks during a release.

Another reason for the dissimilarity between the results could be the fact that the previous study

Table II
Time Duration Effect on Conveyance Losses

Study Area	Change in Inflow, c.f.s	Change in Outflow c.f.s	Change in Diversions c.f.s.	Average Conveyance Loss c.f.s.	Loss % per mile
Piney Creek (3 days)	41.8	34.8	0	7.0	0.76
Piney Creek (15 days)	119.2	89.6	19.6	10.0	0.38

reaches were several times longer than the Wyoming reaches. In general, a short reach will experience a smaller total loss of water than will a long reach. Since the accuracy of many gaging stations' records is in the neighborhood of ±5 percent, any small losses in this range will be difficult to detect. The larger losses in the longer reaches will be affected to a lesser degree by uncertainties in the gaging stations' records. As such, the data collected from studies of long reaches will possiby yield more reliable results. This makes it difficult to compare the results from studies of short reaches to those of long reaches. The effect that the uncertainties in the flow records has on the conveyance loss results from short study reaches can be large, as shown with the 95 percent confidence limits listed in Table I.

Acknowledgements

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INVERTED SIPHON UNDER CLARK'S FORK RIVER

The Clark's Fork Irrigation District near Clark, Wyoming with assistance from the Powell-Clark's Fork Conservation District and technical assistance furnished by the office of the Soil Conservation Service in Powell, Wyoming, completed the Big Horn Basin Wyoming Resource Conservation and Development (RC&D) measure plan for the irrigation district's siphon project in June of 1980.

Holm and Sutherland Construction Company of Billings, Montana completed the 1254 foot irrigation pipeline under the Clark's Fork River in April, 1982. This 34 inch diameter steel pipe, an inverted siphon, under the river, replaces the 50 year-old 1200 foot siphon over the Clark's Fork River. New concrete inlet and outlet structures were poured on each end of the buried pipeline. Total cost of the project which was started in January, 1982, was $155,438.94. This pipe will deliver 72 cfs of water to 2,722 acres of irrigated land in the Clark, Wyoming area.

The Clark's Fork Irrigation District diverts water from the Clark's Fork of the Yellowstone River above Clark, Wyoming. The water is delivered through the main canal (known as the State Ditch or Badger Ditch). The Badger Ditch is about 17 miles long and serves land on both sides of the Clark's Fork River. There are 10 water users who depend on the district for delivery of their water.

The Big Horn Basin Wyoming RC&D provided cost-share assistance in the amount of fifty percent of the construction cost plus one hundred percent of the engineering costs.

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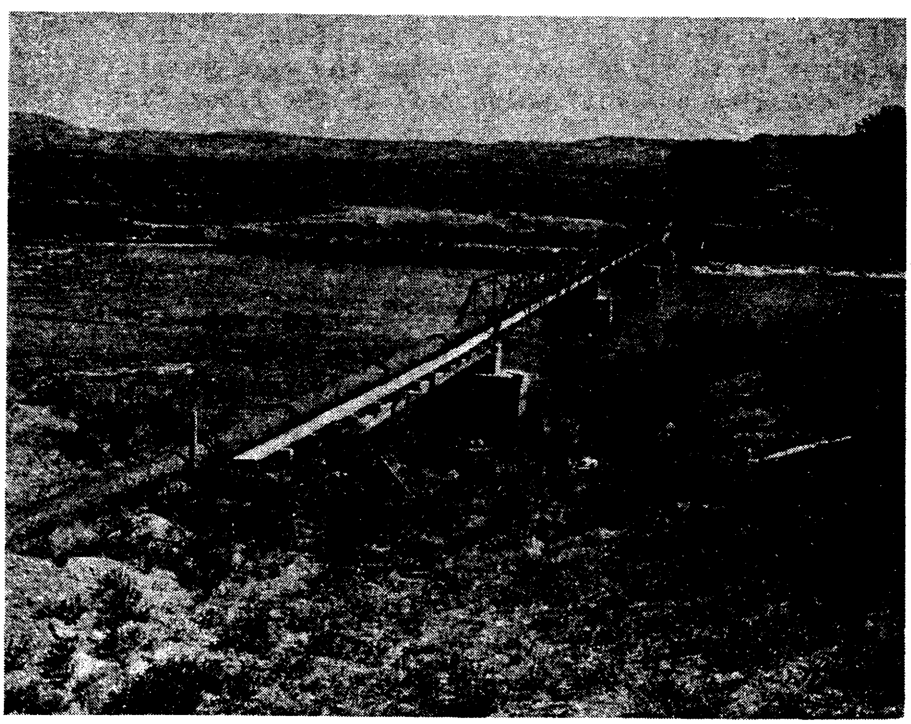

This siphon-flume transported irrigation water over the Clark's Fork River for 50 years. The 1254 feet of replacement pipe was buried under the river adjacent to the far side of this old structure.

CLARK'S FORK FISH HATCHERY

The newest of the state's eleven fisheries facilities, the Clark's Fork Hatchery, is situated on the west bank of its namesake about 35 miles north of Cody. Built in 1969-70, the hatchery began fish production March 1, 1970. To the casual observer, it might appear the facility was constructed in a strangely remote location; however, the presence of eleven natural springs supplying 50-55°F water year around made the location ideal.

A reliable source of water at a constant temperature is vital to consistent hatching and rearing results. Constant volume is also essential, since low water flows can easily kill thousands of fish within a short period of time.

The eleven natural springs at Clark's Fork provide a constant water supply of about 5.4 billion gallons of water a year or more than 10,000 gallons every minute. The water temperature at the hatchery is particularly suitable to rapid trout growth.

As a hatchery rather than a "rearing station", the Clark's Fork facility both hatches fish and cares for them after they have hatched. Rearing stations solely rear fish but do not have hatching facilities; however, both play an important part in the state's fish culture program.

As with any facility in the state, regardless of function, the story of fish rearing begins when eggs are taken and fertilized. Fisheries personnel take eggs from wild trout or from mature adults known as "brood stock" which are kept at the hatchery. Inside the building, eggs are placed in special screen trays in vertical incubators. Water flowing over the eggs and down the screen simulates stream conditions providing a constant supply of fresh water and oxygen. While in the incubator, eggs are treated with a chemical to prevent the growth of fungus.

After 18-21 days, the eye of the developing fish will become visible. At this stage, the eggs are referred to as "eyed" eggs. After the eggs have eyed, they are tranferred to "hatching baskets" which rest in the fiberglass throughs in the hatchery building.

Normally, it takes about ten days in the hatching baskets for eggs to develop into recognizable fish called "sac-fry"--so named because part of the egg yolk sac remains on the abdomen of the fish and continues to provide nourishment.

After ten days, the tiny fry will lose their egg sacs and must be put on commercial feed, which is made of a wide variety of ingredients including fish and bone meals, vitamins, minerals, and grain.

Due to their rapid growth and small stomachs at this time, fry are normally fed six times a day. Later on when they reach 1.5 inches, their ration will be cut to two times daily.

Once the eggs have hatched, they are transferred from the hatching baskets to the fiberglass throughs, with about 10,000 fry in each trough.

After eight weeks they are $1\frac{1}{2}$-2 inches, they will be transferred to the long concrete "raceways" outside until they are ready for planting. About 150,000 fish are kept in each raceway.

Since the Clark's Fork Hatchery normally does not furnish catchable-size fish for planting, nearly all of the fish are stocked when they are three-to-six inches.

With an average annual production of more than five million fish, the Clark's Fork Hatchery has a big job of planting. Due to its location, fish are transported farther than from any other station in the state. Hatchery personnel spend an average of 120 days a year planting fish and will log in about 55,000 miles using up to four trucks getting fish to the far corners of the state.

The majority of the fish planted from the Clark's Fork facility are rainbow (about 3.25 million each year), but the hatchery also plants nearly a million brown trout and close to a half-million cutthroat each year. Generally all of the fish from the Clark's Fork Hatchery are planted from April-September.

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FLUSHING · FLOW RESEARCH

T.A. Wesche, V.R. Hasfurther, W.A. Hubert and Q.D. Skinner[1]

Abstract

The effectiveness of flushing flow recommendations for the North Fork of the Little Snake River was assessed in response to sediment deposition which occurred in 1984 as a result of construction activity in the watershed. Results indicate that three spring runoff flushes meeting or exceeding the magnitude and duration of the recommended flushing flow were somewhat successful in reducing the quantity of deposited material. Quality of deposited material, in terms of trout habitat, was very low but showed an improving trend in response to the runoff hydrograph in stream areas most severely effected. Methodology for quantitatively assessing the effectiveness of flushing flows is presented as well as mitigative recommendations for 1986.

Introduction

Alteration of stream flow regime and sediment loading from water development activities can result in both short- and long-term changes in channel morphology and conveyance capacity. Subsequently, the condition of the aquatic habitat can be affected. In recent years, much research and development effort has been directed toward the determination of suitable instream flows to maintain fisheries habitat in regulated streams (Stalnaker and Arnette, 1976; Wesche and Rechard, 1980). However, there are several facets of the instream flow problem which have not been adequately investigated, one of which involves the recommendation of flushing flows to simulate the peak runoff hydrograph characteristics of most unregulated streams (Reiser et al., 1985).

Limited research has been conducted to develop methodology for determining the magnitude, timing and duration of flushing flows needed to maintain channel integrity and associated habitat characteristics through the movement of sediment deposits. Of the 15 methodologies identified by Reiser et al. (1985), a majority were not designed specifically to assess flushing flows, but rather were approaches for studying sediment transport problems. The several formal methodologies currently available (e.g. Wesche et al., 1977; Environmental Research and Technology, Inc. 1980; Rosgen, 1982) were developed in response to immediate management needs and are relatively untested in terms of accuracy and reliability.

During 1984, the Wyoming Water Research Center initiated a research project entitled, "Development of methodology to determine flushing flow requirements for channel maintenance purposes." Objectives of this project are to (1) document the rate of change of various channel characteristics resulting from aggradation/degradation processes under altered flow regimes; (2) quantify the physical and hydraulic properties needed to transport deposited sediment through natural channels; (3) test the predictive capabilities of existing sediment transport models against field data; and (4) develop methodology to predict conditions of flow needed to flush sediments to maintain given streams in prescribed hydraulic, physical and biologic conditions.

One stream selected for study in response to these objectives was the North Fork of the Little Snake River (North Fork), a steep, rough, regulated, headwater stream. Wesche et al. (1977) recommended both maintenance and flushing flow regimes for the North Fork in light of the proposed expansion of water diversion facilities in the drainage by the City of Cheyenne, Wyoming, as part of their Stage II water development program. Construction of Stage II began in 1983. During the late summer of 1984, intense rainfall in the construction area resulted in the deposition of a broad size range of sediments in that section of the North Fork where flushing recommendations had been made. At the request of the Wyoming Game and Fish Department and in cooperation with the United States Department of Agriculture, Forest Service, the authors initiated a study of the North Fork. The objectives of this paper are to (1) describe the methods used to assess the extent of the 1984 sediment deposits; (2) present preliminary results summarizing the response of the deposited sediment to the 1985 spring runoff flow regime; (3) evaluate the effectiveness of the 1977 flushing flow recommendations in relation to the 1984 sediment deposits, and (4) present mitigative flushing recommendations for 1986.

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Description of Study Area

The North Fork of the Little Snake River is a steep, rough, regulated tributary of the Little Snake River located in the Green River sub-basin of the Colorado River basin in southwest and southcentral Wyoming. The headwaters of the North Fork rise on the west slope of the Continental Divide at an elevation of 10,000 feet above mean sea level (msl) and flow southwesterly 12.4 miles to the confluence with the Little Snake River at an elevation of 6,990 feet. Average gradient is 4.6 percent. A United States Geological Survey (U.S.G.S.) streamflow gaging station (#09251800) located 1.5 miles below the study area was in operation from 1957 to 1965 and recorded a maximum discharge of 516 cubic feet per second (cfs) on June 7, 1957. Average discharge over the period of record was 25.8 cfs. Prior to initial water diversion in the mid-1960's, the North Fork hydrograph was typical of unregulated mountain streams in the central Rocky Mountain Region, with the majority of runoff occurring in the May to late-June period, as a result of the melting snowpack.

The North Fork and its tributaries support the largest known, essentially-pure, naturally-reproducing endemic population of Colorado River cutthroat trout (Salmo clarki pleuriticus Cope) (Binns, 1977). For this reason, management of the popoulation is a high priority for the Wyoming Game and Fish Department. Wesche, et al. (1977) also report the collection of mottled sculpin (Cottus bairdi Girard).

Transbasin diversion of water from the North Fork drainage has occurred since 1964 when the City of Cheyenne, Wyoming completed Stage I of its water development program. Approximately 8,000 acre-feet per year have been diverted (Banner Associates, Inc., 1976). During 1983, construction began on Stage II collection facilities. When completed in 1986, a total of 23,000 acre-feet per year will be conveyed from the upper Little Snake drainage to the east slope of the Continental Divide (U.S.D.A., Forest Service, 1981).

The study area on the North Fork is located in Section 27, Township 13 North, Range 85 West at an elevation of 8,580 feet above msl, within the boundaries of Medicine Bow National Forest, 1.5 miles below the Stage I diversion structure. Under Stage II, this structure is being modified to increase the amount of water diverted from the North Fork proper. Within the study area boundary, a stream section 0.3 miles in length, construction of a bridge and pipeline crossing was underway in the late summer of 1984 when heavy rains precipitated the sediment spill that led to the initiation of this study. Gradient through this area is 4.4 percent while the predominant natural substrate is boulders and cobbles. Wesche et al. (1977) reported a mid-July 1976 water temparature range of 55 to 63° F, a total alkalinity range of 25 to 32 ppm, a pH of 7.1, and clear water conditions for this section of the North Fork. Standing crop estimates for Colorado River cutthroat trout ranged up to 14.0 pounds per surface acre. Instream flow recommendations developed by Wesche et al. (1977) called for a minimum flow of 3.0 cfs or the natural flow, whichever is less, and a three-day annual release of 60 cfs for flushing purposes during the spring runoff period.

Methods

During the Fall of 1984, four reaches were selected for study in cooperation with personnel from the Wyoming Game and Fish Department and the U.S. Forest Service. Reach 1, the uppermost site, was located just above the confluence of Second Creek, approximately 1,300 feet upstream from the North Fork bridge and pipeline crossing. Reach 1 served as the control station above the construction area from which the sediment spill originated. Reaches 2, 3 and 4 were located in descending order below the North Fork crossing area and were within the zone of immediate deposition from the spill. Given the intensive nature of the sampling to be conducted, study reaches were kept short in length, with Reach 2 being the longest, 50 feet. Also, study reaches were located close to one another to avoid compounding the access problems involved with early spring sampling in a remote, high elevation area.

Two recording streamflow gage stations were installed within the study area in early May, 1985 to monitor the spring runoff hydrograph. One station was located at Reach 1 while the second was installed at Reach 3. As no tribuatries entered between Reaches 2, 3 and 4, this lower station served to define the hydrograph for the three downstream reaches. Each station consisted of a stilling well constructed from 12-inch diameter perforated plastic pipe, a Leopold and Stevens Type F water stage recorder, a steel platform on which the recorder was seated, and an outside staff gage for measuring stream stage. A rating curve for each gage station was developed following standard U.S.G.S procedures (Buchanan and Somers, 1969). Eight stage-discharge measurements were made at each station to determine the rating curves. The correlation coefficient (r) for each curve was 0.99. Recording thermographs to measure water temperature were installed in conjunction with each stream gage station.

Four equally spaced cross-channel transects were established during October, 1984 within each study reach. Field data collected along these transects were used to quantify changes in response to the runoff hydrograph of (1) hydraulic characteristics, including discharge, channel width, top width, water depth, cross-sectional area, wetted perimeter, hydraulic radius, mean water velocity, bottom water velocity, and intergravel permeability; (2) bedload transport; (3) suspended sediment transport; (4) quantity and distribution of deposited sediments; and (5) quality of the deposited sediments. Given the scope of this paper, analysis will focus primarily on data types 4 and 5 listed above. The hydraulic and sediment transport data collected is presently undergoing analysis and will be presented in future project papers and reports. Field sampling began in late October, 1984, was then discontinued over the winter months, and was reinitiated in early May, 1985 as spring runoff began. Sampling continued on approximately a weekly basis through early July, 1985.

The quantity of deposited sediment within each study reach was determined by the following procedure:

1. Along each transect at each sampling time, the depth of deposited material (Dd) was measured at 1.0 foot intervals to the nearest 0.05 foot by gently driving a 0.5 inch diameter round steel depth rod into the substrate until it came into contact with the underlying boulders and cobbles.

2. Mean Dd for each transect was determined by summing the individual depth measurements and dividing by the number of measurements taken along the transect (usually about 20 measurements).

3. The mean Dd for each of the four transects in a reach were then summed and divided by four to obtain the mead Dd for the reach at that sampling time.

4. Multiplying the mean reach Dd (feet) by the mean channel width (feet) and by the length of the reach (feet) yielded the volume of deposited material ($feet^3$) in the reach at that time.

5. To determine the density of the deposited material ($pounds/feet^3$), three core samples were collected along each transect in October 1984, early May 1985 and early July 1985 using a McNeil-Ahnell sample (McNeil and Ahnell, 1964). To standardize weight measurements, all core samples were oven-dried for at least 24 hours at 140 F before weighing. Volume measurements for each sample were made by water displacement technique. The mean density of each reach was calculated by dividing total weight of the 12 cores for that reach by their total volume.

6. Total weight of deposited material within each reach at each sampling time was determined by multiplying the volume of deposited material by the mean density.

7. To allow comparison of study reaches having different surface areas, the total weight was divided by reach area to obtain pounds of deposited material per square foot.

The composition and quality of the deposited material within each reach over time was assessed by the following procedure:

1. As described above, 12 core samples were taken at each study reach at each of three sampling times.

2. Particle size distribution by weight within each core sample was determined by dry-sieve analysis at the University of Wyoming's Division of Range Management Watershed Laboratory. A series of 10 sieves ranging in mesh size from 3.0 to 0.008 inches were used (Reiser and Wesche, 1977).

3. The mean particle size distribution for each reach at each sampling time was determined by averaging the results from the 12 individual core samples. Distribution plots of particle size versus percentage (by weight) finer than the given sieve sizes were then developed.

4. Quality of the deposited material by reach over time was assessed by:

a. the median particle size read from the distribution plots described above;

b. the geometric mean particle size (d_g) calculated by the equation,

$$d_g = (d_1^{w1} \times d_2^{w2} \times \ldots d_n^{wn}),$$

where d_n is the midpoint diameter of particles retained by the nth sieve and w_n is the decimal fraction by weight of particles retained on the nth sieve (Platts et al. 1983);

c. The Fredle Index (f) calculated by the equation,

$$f = \frac{d_g,}{S_o}$$

where S_o is the sorting coefficent defined as the ratio of d75 to d25 where the particle size diameters are 75 and 25 percent finer on a weight basis of the sample (Lotspeich and Everest 1981).

Results and Conclusions

Response of Sediment Deposits to 1985 Hydrograph

A summary of hydraulic characteristics for each study reach is presented in Table 1. As indicated by these data, Reach 2 had the steepest gradient, the highest water velocities, and shallowest water depths. Reach 4, the lowermost site, consisted primarily of pool habitat having the lowest gradient, deepest water and slowest velocities. Reaches 1 and 3 were similar in hydraulic characteristics and represented more moderate conditions.

Spring 1985 runoff hydrographs for the two streamflow gaging stations are presented in Figure 1. While the magnitude of the runoff was greater at the lower station due to the tributary which entered the North Fork immediately below Reach 1, timing and duration were similar. Also shown on Figure 1 is the magnitude of the flushing flow recommended by Wesche et al. (1977) for the North Fork in the vicinity of the three lower study reaches. This recommendation, 60 cfs for a duration of three days, was based upon field measurement of bankfull dishcarge and the findings of Eustis and Hillen (1954).

Three major runoff peaks occurred during 1985 which equalled or exceeded the magnitude and duration of the recommended flushing flow (Figure 1). Each peak had a maximum instantaneous discharge of 105 cfs while the maximum mean daily peaks ranged from 73 to 80 cfs. Based upon maximum instantaneous discharge, the earliest peak lasted three days (May 10 to 12), the second peak extended over eight days (May 23 to 30), and the third peak exceeded the recommended discharge on five consecutive days (June 6 to 10). A fourth peak occurred in late June during which the maximum flow approached the 60 cfs level, but only for a portion of one day.

The quantity of deposited material within each study reach at each sampling time is presented in Figure 2. Deposition was consistently lowest in Reach 1, the upstream control, and Reach 2, the uppermost study section below the construction area. Quantities in these two reaches varied from 16.1 to 31.2 pounds/feet^2. The high gradient through Reach 2 probably explains the relative lack of deposition in this area. Based upon the October 1984 and the July 1985 data, Reach 2 experienced a net export of 7.3 pounds/feet^2 through the spring runoff period. Reach 1, a moderate gradient section, realized a net gain of 5.7 pounds/feet^2 by early July 1985. As there was additional construction activity in the North Fork drainage during 1984 above Reach 1, a small increase, such as that observed, was not expected.

The quantity of deposited material sampled in Reach 3 ranged from 29.5 to 46.9 pounds/feet^2. From October 1984 to early July 1985, no net gain or loss was observed in this moderate gradient reach. The trend of the data, while greater in magnitude, did parallel that found for Reach 1, a section having similar hydraulic characteristics.

Reach 4, the lower gradient pool section, was found to have the greatest magnitude and variation of deposited material. Measurements indicated 31.6 pounds/feet^2 were present during October 1984. By early May the amount of deposition had increased to 82.1 pounds/feet^2, indicating considerable pool aggradation had occurred as a result of the first peak in the hydrograph. The effects of the three later peak runoff events on the quantity of deposited material in Reach 4 are evident from Figure 2. In total, these flushes reduced the amount of deposition from 82.1 to 50.5 pounds/feet^2. Through the entire sampling period, Reach 4 realized a net import of 18.9 pounds/feet^2.

The relative quality of deposited material in each of the study reaches over time is provided in Figure 3. As median particle size data were similar in both magnitude and variation to the geometric means, they are not presented.

The geometric mean particle size was consistently larger in Reaches 1 (range 0.39 to 0.51 inches) and 2 (range 0.39 to 0.55 inches) than in the lower two sections. Data for Reach 3 varied from 0.16 to 0.28 inches while the range for Reach 4 was 0.13 to 0.20 inches. Geometric means for both Reaches 3 and 4 increased in response to the runoff peaks.

Fredle indices for deposited material in all study reaches appear to be quite low when compared to the preliminary relationships presented by Platts et al. (1983) between index values and percent survival-to-emergence of eggs from several salmonid species. However, the trend of our data is similar to that for geometric mean particle size and indicates improvement of deposition quality in Reaches 3 and 4 in response to the spring runoff hydrograph.

Table 1. Mean hydraulic characteristics of the four North Fork study reaches at a low and a high discharge.

	Hydraulic Characteristics					
Reach	Discharge (cfs)	Top Width (ft)	Cross-Sectional Area (ft^2)	Mean Depth (ft)	Mean Velocity (ft/sec)	Water Surface Slope (percent)
#1	3.5	19.0	7.1	0.36	0.56	2.6
	39.6	21.6	21.2	0.98	1.90	–
#2	4.2	20.9	4.3	0.20	1.08	4.5
	64.7	23.6	20.5	0.89	3.18	–
#3	3.5	19.8	6.5	0.33	0.52	3.0
	74.6	24.6	26.1	1.08	2.89	–
#4	3.2	16.0	6.8	0.43	0.49	0.4
	101.1	28.1	48.1	1.74	2.23	–

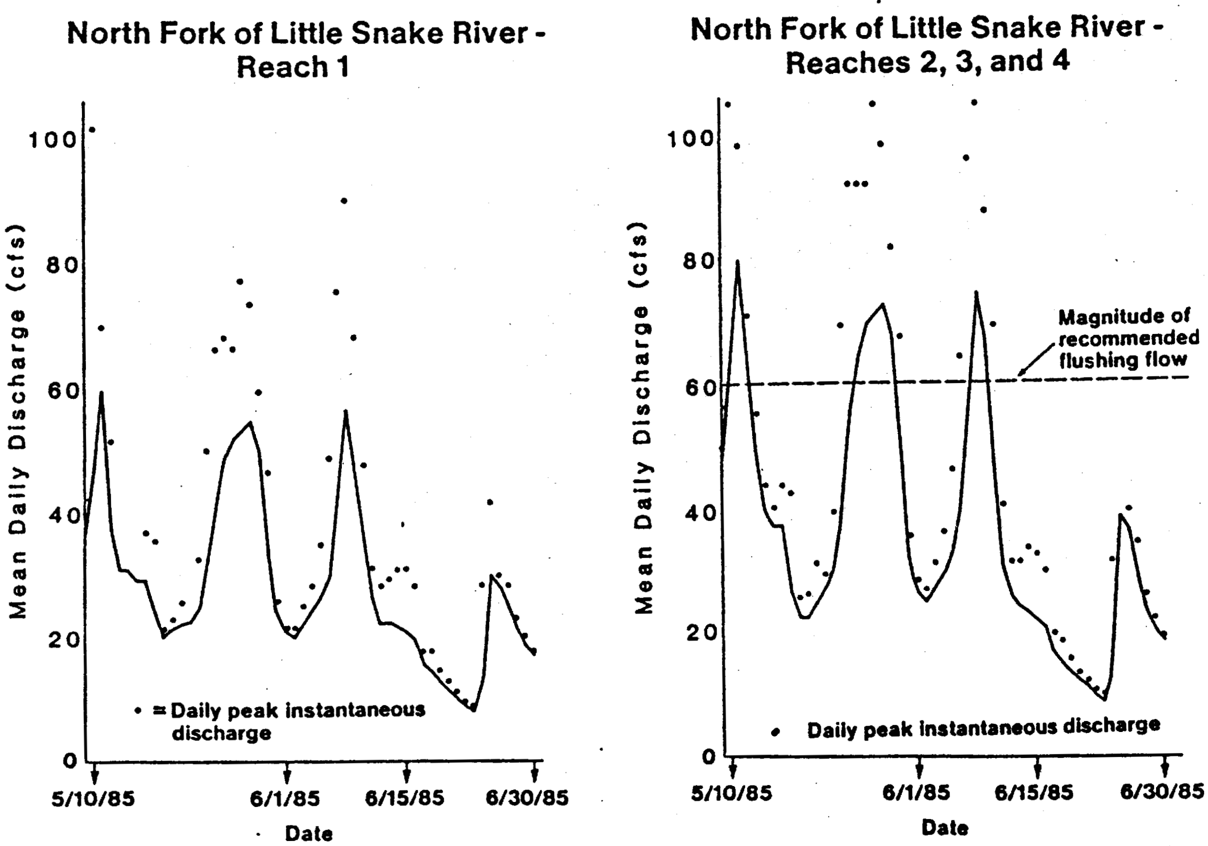

Figure 1. Spring runoff hydrographs for the two North Fork stream gage stations.

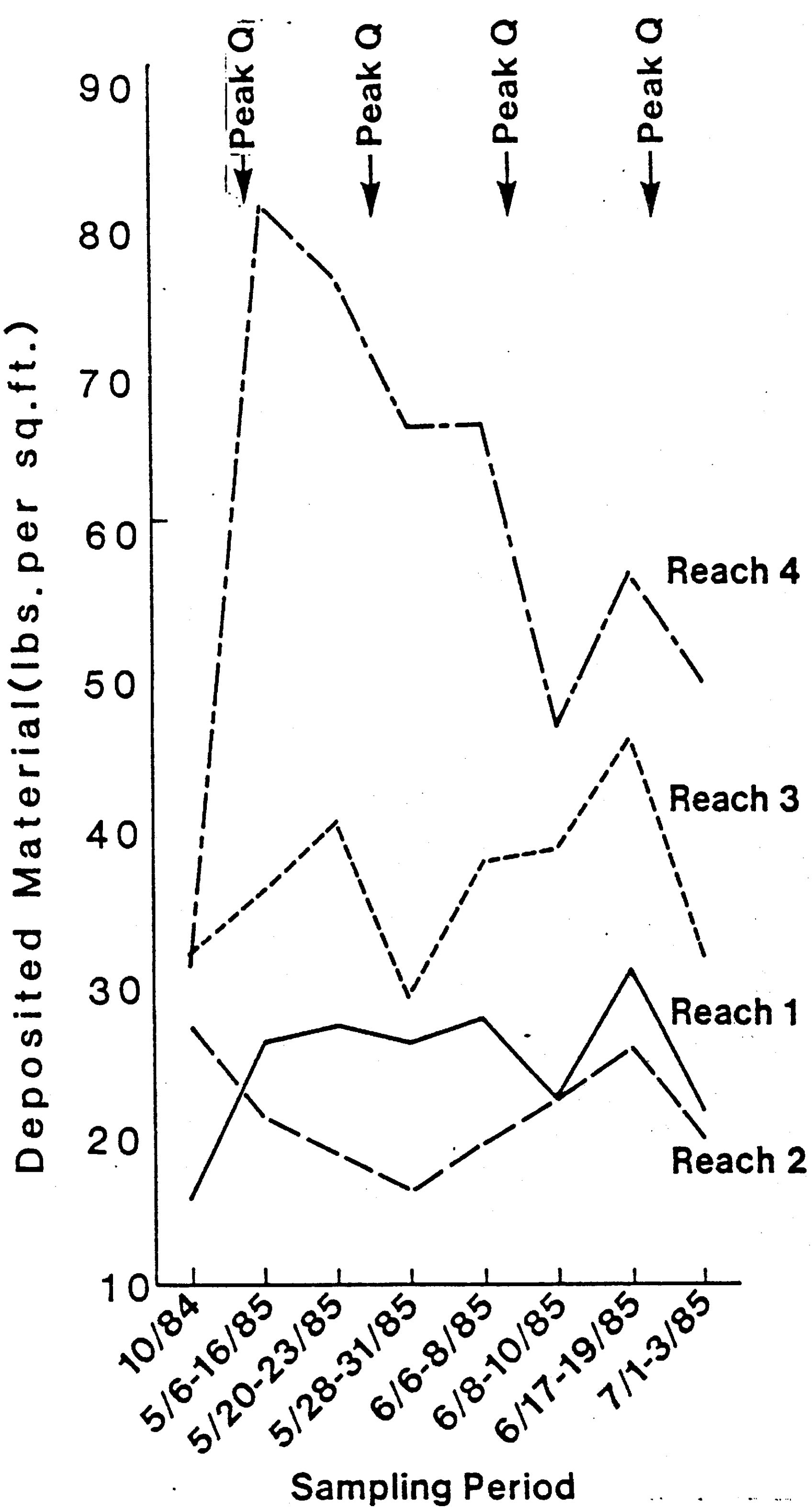

Figure 2. Comparison of deposited material in the four North Fork study reaches in relation to the spring runoff peak discharges.

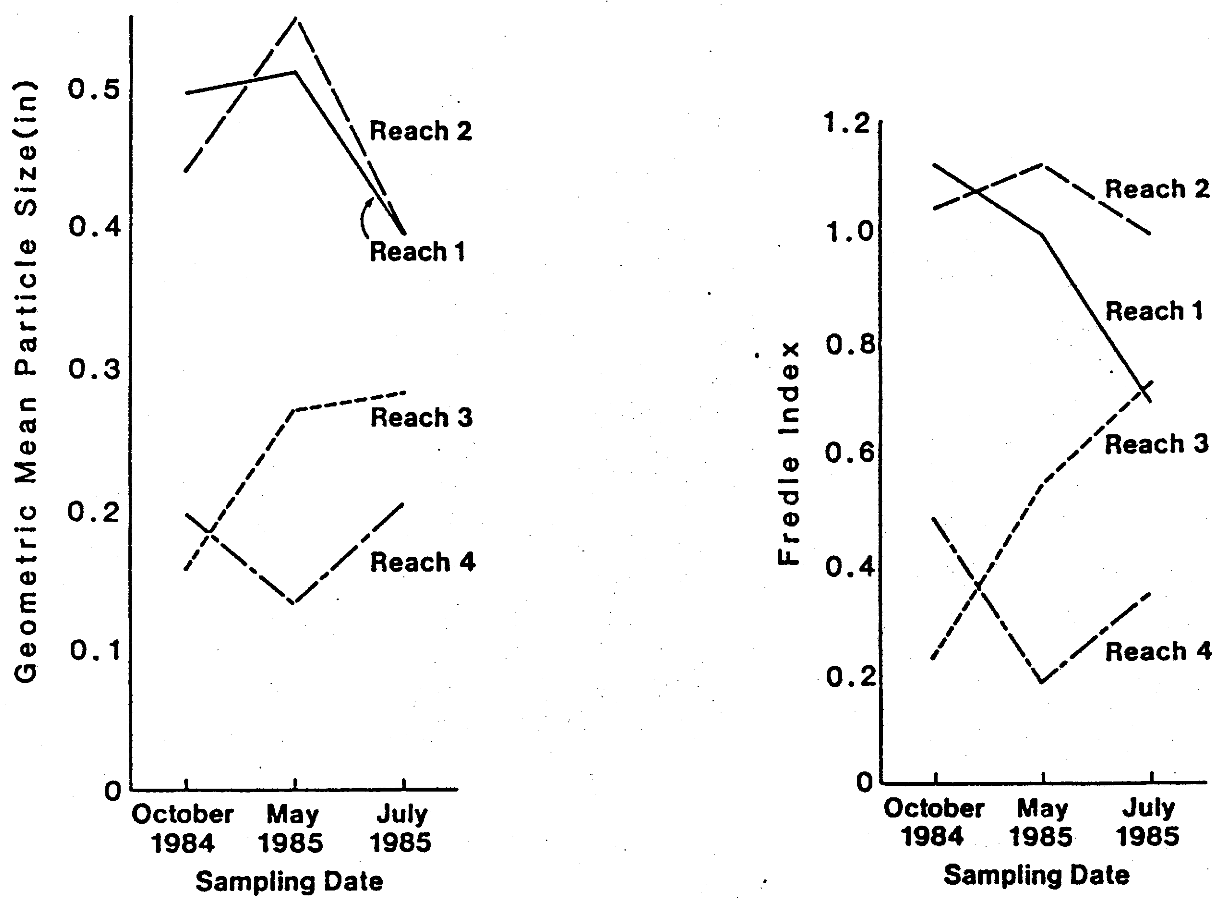

Figure 3. Quality of deposited material in the four North Fork study reaches over time.

Based upon these data, the following conclusions could be drawn regarding the response of the deposited material to the 1985 spring runoff hydrograph:

1. Three spring runoff flushes meeting or exceeding the magnitude and duration of the recommended flushing flow for this section of the North Fork of the Little Snake River were somewhat successful in reducing the quantity of deposited material.

2. Flushing was more effective in steeper gradient reaches, while results regarding duration of the individual flushes are at present inconclusive.

3. As indicated by the Fredle Index, quality of the deposited material was very low throughout the study area.

4. Quality of deposited material showed an improving trend in response to the runoff hydrograph within those study reaches having the largest quantities of deposition.

1986 Flushing Flow Recommendations

In response to a request from the Wyoming Game and Fish Department, mitigative flushing flow recommendations for the North Fork of the Little Snake River during 1986 were developed. The primary basis for these recommendations were: (1) the assumption that the maintenance of pool quantity and quality in stream sections such as Reach 4 is essential to the well-being of Colorado cutthroat trout; and (2) the relationship of the 1985 instantaneous hydrograph to the time series sediment deposition data for Reach 4 (Figure 4). Secondary information also used to justify the recommendations included: (1) flow duration curves for the four 1985 peak runoff events; (2) grain size distributions of deposited materials; (3) grain size distrubutions of sediment moving as bedload; (4) historic runoff patterns from U.S. Geological Survey records; and (5) channel cross-section plots over a range of flows. The recommendations and our justification for them will be found in Appendix A. (At the end of this paper, page 134)

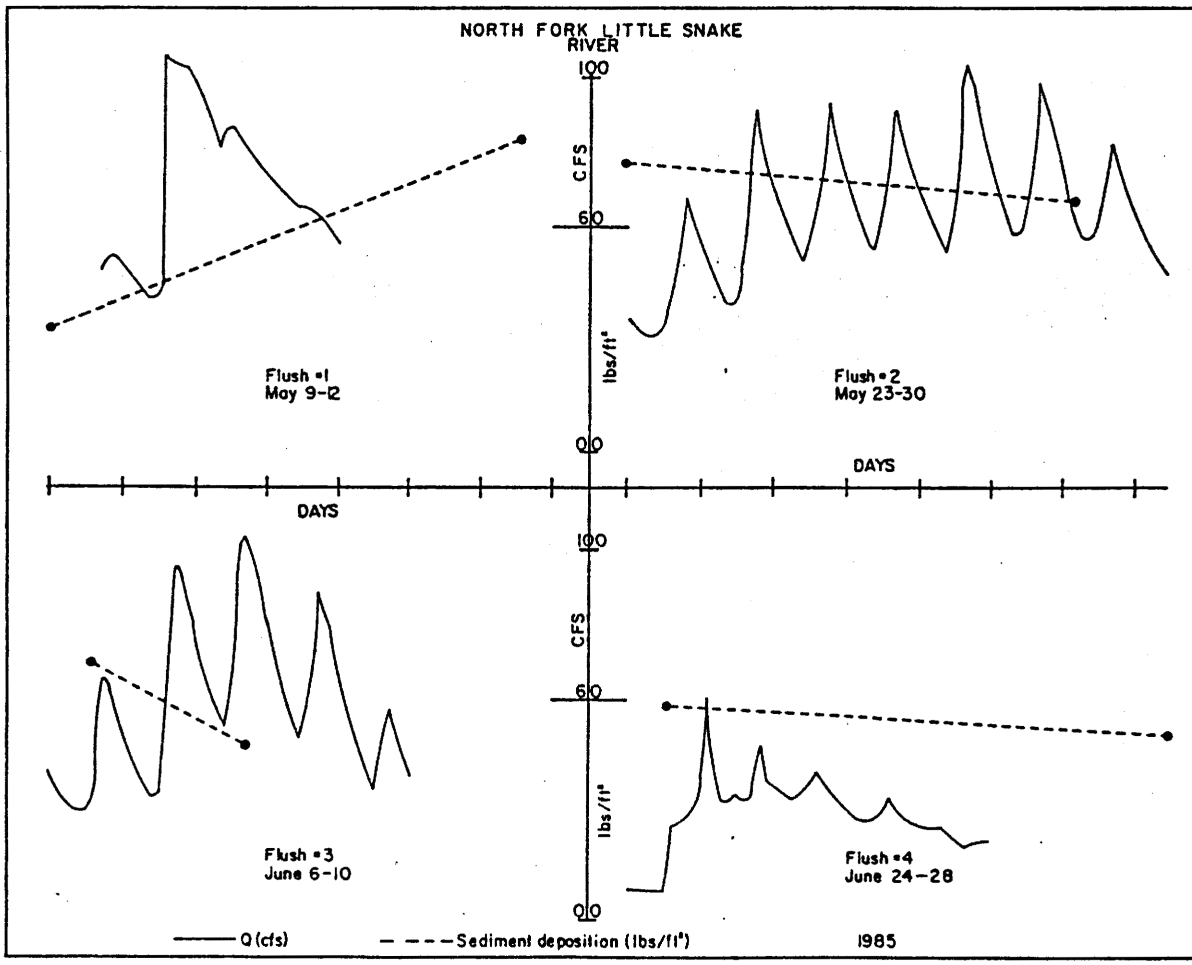

Figure 4. Relationship of 1985 instantaneous hydrograph to Reach 4 sediment deposition over the four runoff events.

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WILD AND SCENIC RIVER DESIGNATION
CLARKS FORK OF THE YELLOWSTONE RIVER
SHOSHONE NATIONAL FOREST

In 1982, a Final Environmental Statement for Legislative Action was completed by the Shoshone National Forest which recommended a 21.5 mile section of the Clarks Fork River for nomination as a Wild and Scenic River. The alternative chosen for recommendation minimized effects on the proposed Clarks Fork Reservoir, downstream from the study area. Legislation was introduced in Congress on September 13, 1982, formally nominating the river for designation. By law, the Congress had 3 years to act on the nomination.

By September 13, 1985, Congress had not acted on the proposal. Although Congress did not act, the Shoshone Forest received a letter from Sen. Alan Simpson stating that the intent of Congress was not to disapprove the nomination, but to put the nomination on hold until clear decisions could be made about several proposed water use projects affecting the Clarks Fork. He urged that the Forest continue to manage the Clarks Fork as a Wild and Scenic River until decisions were made and Congress acted on the proposal.

The Land and Resource Management Plan for the Shoshone National Forest, issued in February, 1986, contains specific language which directs that 21.5 miles of the Clarks Fork, upstream from the mouth of the Clarks Fork Canyon, be managed as if it were a Wild and Scenic River. Such direction is intended to maintain the characteristics of the River that contribute to its eligibility for inclusion in the system, until Congress acts. The Forest Service will recommend denial of leases, permits, or activities not within its discretionary authority that could affect eligibility. "Wild Rivers" are managed to be free of impoundments and are generally inaccessable except by trail, with watersheds or shorelines essentially primitive, and water unpolluted.

Some of the Standards and Guidelines from the Shoshone Plan include:

- Recognize and protect the free flowing stream character of the Clarks Fork of the Yellowstone River. Recommend denial of permits for water development that could affect that character.

- Maintain average annual minimum flows of 250 cfs at the upstream end of the segment and 390 cfs at the downstream end. Flows to be distributed through the year according to the river's normal hydrograph. (Guidelines approximating free flowing conditions.)

- Adhere to quality standards for Class I streams as prescribed in Wyoming Water Quality Rules and Regulations, Chapter I.

- Maintain or enhance the long-term productivity of soils within the riparian ecosystem.

- Recommend denial of permits for mineral activities proposed within a one-half mile corridor about the river.

- Provide for primitive and semiprimitive nonmotorized recreation in an unmodified setting.

CLARK'S FORK RIVER HABITAT IMPROVEMENT

Habitat and sport fish evaluations conducted on the Clark's Fork River in 1980-1981 revealed a relatively low density trout population dependant on inadequate bank and instream cover.

As a result, a longterm project was initiated in 1982 to improve this swift water reach lacking cover with boulder placements to create pocket pools and artificial banks. Since that date, some 1388 boulders ranging from 2.3-35.0 tons each have been placed instream throughout the public lands reach from the Canyon mouth downstream to the fish hatchery. This cooperative effort was funded and accomplished between the Park County Recreation Board, the Wyoming Game and Fish, and the Bureau of Land Management. Excellent cooperation was also given the project by various private landowners and sportsmen groups.

Subsequent evaluations through electrofishing operations and fishermen interviews document increased trout densities within the improved section. As a result of the fishery response to increased cover and over-winter holding capacity, the river stocking program continues to be adjusted relative to species, numbers, and sizes stocked.

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CLARK'S FORK RIVER INSTREAM FLOW

Based on the value of Class I(Blue-Ribbon) streams, water availability, and a non-injury water rights issue, the Wyoming Game and Fish Department filed an instream flow right application for a 5.85 mile segment of the Clark's Fork River in 1986. A direct flow right of 225 cfs was requested for the entire year to maintain existing fisheries within that reach from Sunlight Creek confluence downstream to the United States Forest Service boundary.

This reach supports a wild trout fishery and therefore all life stages (egg-adult) were considered when determining the appropriate water volume needed to pass through the section. The water right will have an 1987 priority date and will be junior to all existing rights both upstream and downstream of the segment.

Board of Control and State Engineer approval is needed in 1987 to assure that this segment will be protected from dewatering and is available to future generations for their recreational enjoyment.

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NEWTON LAKES

These highly utilized recreational outlets are located some six miles north of Cody and represent a success story in private-public cooperation.

The lakes and surrounding lands are owned by the Bureau of Reclamation. The water rights are owned by Trail Creek Ranch which also leases the USBR lands. The area is currently managed through a cooperative effort of these entities and the Park County Recreation Board and the Wyoming Game and Fish Department.

A Memorandum of Understanding is being finalized ro allow for the continued recreational use. The historic use/abuse of the area from human and livestock activity will be altered as a result of this cooperative effort. The ranch ownership has agreed to remove the livestock grazing in return for people/vehicle control to exclude use of their nearby leased and private lands. As a result, the United State Bureau of Reclamation, Wyoming Game and Fish Department and a private sportsman group have developed a fencing scheme, obtained all fencing materials and will utilize volunteer labor to direct use patterns. Vehicle and boat access will be maintained along a portion of the shoreline of both lakes to accomodate the elderly and the handicapped. The remaining shoreline will be revegetated through willow planting and natural recovery associated with elimination of trampling.

The proximity of town, easy access and high productivity levels all justify intense fisheries management efforts by the Wyoming Game and Fish Department. The West Lake is currently managed as a family fishery heavily stocked with fingerling-catchable rainbow and cutthroat trout. Stocked fish are mainly comprised of catchables ranging from 8-12 inches although brood fish are sometimes as big as seven pounds when planted. The East Lake is managed as a trophy fishery with tackle restrictions to facilitate catch and release fishing. The conservative limit of one fish also promotes the attainment of trophy sized fish. This lake is currently stocked with Golden trout and a special strain of rainbow trout to provide a unique species opportunity to the angler.

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