IN-STREAM AGGREGATE EXTRACTION AND RECLAMATION GUIDANCE DOCUMENT

Colorado Department of Natural Resources
Division of Minerals and Geology
1313 Sherman, Room 215
Denver, Colorado 80203

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IN-STREAM AGGREGATE EXTRACTION

EROSION CONTROL PHOTOGRAPHS

Prepared for:

Colorad Department of Natural Resources
Division of Minerals and Geology
1313 Sherman Street, Room 215
Denver, Colorado 80203

Prepared by:

Greystone
5231 South Quebec Street
Greenwood Village, Colorado 80111
Under Contract C188188

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ABBREVIATIONS

CDMG	Colorado Division of Minerals and Geology
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department of Public Health and the Environment
COE	Corps of Engineers
EOS	Equivalent Opening Size
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PMLU	Post Mining Land Use
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WQCD	Water Quality Control Division

INTRODUCTION

The Colorado Division on Minerals and Geology (CDMG) regulates the aggregate extraction industry in the State as provided by the Colorado Land Reclamation Act for the Extraction of Construction Materials C.R.S. 34-32.5-101 *et seq.* As part of this process, extraction operators are required to obtain permits from the CDMG and other regulatory authorities for the mining and reclamation activities. This publication provides guidance for operators to conduct in-stream aggregate extraction while minimizing environmental effects to stream channels, riparian zones, wetlands, aquatic wildlife, and the in-stream ecosystem of the mined and adjacent areas. The Board and CDMG want to emphasize that this is a guidance document only and is not a rule or regulation. The Board also wants the reader to understand that the vast majority of operators conduct their activities in compliance with the "Colorado Land Reclamation Act for the Extraction of Construction Materials." The following examples are **only illustrations of the potential impacts** that could occur with non-compliance of the Act and Regulations.

Purpose of this Publication

This publication summarizes how an understanding of stream channel geomorphology may be used to assess, predict, and manage the effects of aggregate extraction in a particular river or stream channel. It is intended to guide the planner who must determine what, if any, studies may be needed to assess the situation, and to provide guidance in the design of those investigations. The knowledge gained from reading this publication will not eliminate the need for technical assistance from a geomorphologist or hydrologist, but will provide guidance in determining the necessary information to be submitted with a permit application. Examples and suggested procedure are mainly drawn from situations encountered throughout the industry, however, the principles described generally apply to all mining operations that may be proposed in the State of Colorado.

Outline of the Publication

This publication is divided into four sections. The first provides a stream classification system that presents the geomorphology description for streams and rivers encountered throughout the State. This description provides the basis from which to evaluate potential effects of in-stream aggregate extraction. The second section provides the typical aggregate extraction methods with a description of operations and a description of potential effects from each of the various types of mining within stream channels. The third section presents a discussion of reclamation practices, including mitigation measures that should be considered to minimize potential effects of mining. The fourth section provides an outline of data that is useful for evaluating and permitting in-stream aggregate extraction operations. Conclusions and references are also provided in the text of the publication. Appendices to the publication include a Glossary of Terms (**Appendix A**), Stream Classification System Design (**Appendix B**), Estimates of Existing Stream Bedload Transport Rates (**Appendix C**), Potential Hydrologic Structures to Minimize Effects of Mining Methods (**Appendix D**), and a CDMG Inspection Checklist for In-Stream Aggregate Operations (**Appendix E**). Regulatory authorities that need to be consulted are listed in **Appendix F**.

STREAM CLASSIFICATION AND GEOMORPHOLOGY

Streams are readily classified by their geomorphic setting, slope, and channel substrate. Geomorphology is a way of characterizing land forms by their shape, geologic history and their anticipated erosional development. Streams meander, downcut, and flood in response to discharge based on the geologic formations they encounter, the types of rocks found in their upland watershed, the location of the channel within that watershed, and the slope of the stream.

Colorado has a wide diversity of geological formations and a substantial amount of topographic relief, yielding a wide variety of streams and depositional locales. For simplicity sake, this document will look at two major subsets of streams based on the seasonality of flow: perennial and ephemeral. Most streams important to long-term aggregate operations are perennial, but there are many aggregate operations in eastern Colorado that occur in ephemeral drainages. Further classification is based on a stream's potential for erosive flows. Differentiation is made between streams with a high potential for erosion, and those with a low potential for erosion. Stream reaches with low erosive capacities are not discussed since these sites are not likely for aggregate operations. Additional characterization will rely on standard geomorphic characteristics.

Rosgen (1993) has developed a stream classification system in wide use throughout the western United States. This system characterizes streams by their entrenchment or incision of the stream, the width/depth ratio of the channel, sinuosity of the stream's path, its slope, and the channel substrate. This document will refer to the basic concepts of the Rosgen classification system, but will minimize use of the associated numbering system. The terms associated with stream characterization are described briefly below, and a glossary of terms is found in **Appendix A**. **Appendix B** contains the Rosgen chart classifying streams. This section will conclude with a discussion of the aggregate carrying capabilities of streams.

Geologic Setting

Streams in Colorado occur in many geological settings, ranging from streams descending from the Continental Divide to regional rivers draining large portions of the state. The location of these streams within their watersheds influences the size of the streams and their slopes. Streams that are near the top of their watersheds are likely to be small, have steep slopes, and have a more coarse-grained, cobbly or boulder-strewn channel bottom. On the other extreme are rivers found within large watersheds, that have collected flows from many tributaries, and have slopes less than 4 percent. These channels typically have highly weathered, more fine-grained materials in their channels and in the associated well-developed floodplains. Many streams fall between the extremes and drain moderately sized watersheds, have modest channel dimensions, flow across moderate slopes, and have a variety of channel substrates. Gravel mining in Colorado typically occurs in high depositional settings or aggrading zones of perennial streams in the western half of the state, or in ephemeral, sandy channels on the eastern half of the state.

The number of channels and its migration pattern characterize a stream. Multiple channels can either be considered braided, in a high depositional setting, or have more than one channel used during high water periods. Single channel streams can be straight, meandering or sinuous. Aerial photos of different types may be observed in **Figure 1**.

The slope and the depositional and erosional history of the area influence the shape of a stream valley. A stream valley often has one or more flat, steep sided terraces along each side of the valley, that reflect previous depositional levels, below which the stream has cut (**Figure 2**). The active floodplain next to the stream may have both active perennial channel(s) and high water channels that are only used during snowmelt or flooding. The active floodplain reflects channel migrations over the last twenty-five years. The active floodplain probably represents a flood event of 2 percent annual probability, or a flood with an average recurrence interval of fifty years. The valley may have a slightly elevated area that is not a terrace shape but reflects an inactive floodplain. This may contain channels that are abandoned due to their elevation. Other abandoned channels occur in the floodplains of highly sinuous streams where a meander has been cut off and fills with fine-grained sediments during flood events.

The composition of the floor of a stream channel is dependent on the types of rock in the immediate vicinity and the types of rock in the watershed being drained. Colorado exhibits a wide variety of rock types ranging from hard igneous and metamorphic rocks formed under extreme temperature and pressure conditions, to softer sedimentary sandstones, siltstones and shales deposited in fluvial, lacustrine or marine environments hundreds of millions of years ago. The floor of a channel will also contain local stream deposits of unconsolidated materials of glacial origin and general mass wasting. These materials are less than three million years old and have been derived since the last Ice Age.

The metamorphic, igneous and sedimentary rocks are most likely to be exposed and weathering into streams in the mountainous portions of the State. Much of the eastern and far western portions of the State consist of heavily weathered, unconsolidated or semi-consolidated materials.

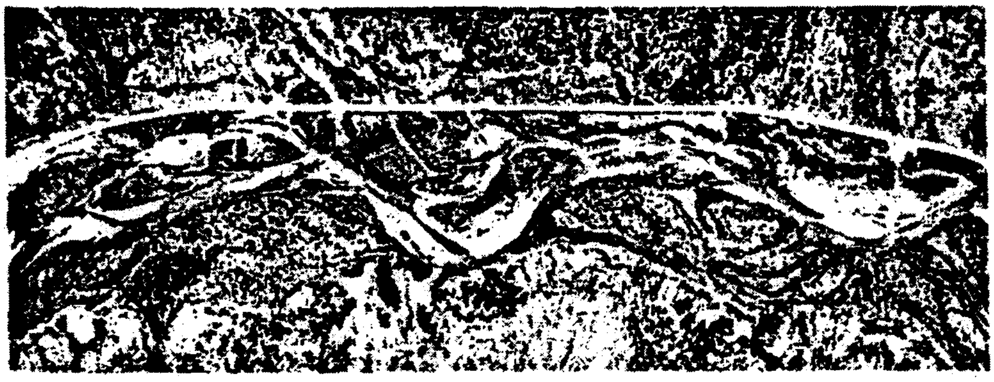
Entrenchment

Entrenchment characterizes the incision of a stream into the valley floor. Rosgen (1993) quantifies an entrenchment ratio as the ratio of the width of the flood-prone area to the bankfull width of the channel. The width of the flood -prone area is the width measured at an elevation that is twice the maximum bankfull depth. Field observations suggest that this depth typifies a flood with a recurrence interval of fifty years, or a 2 percent probability flood.

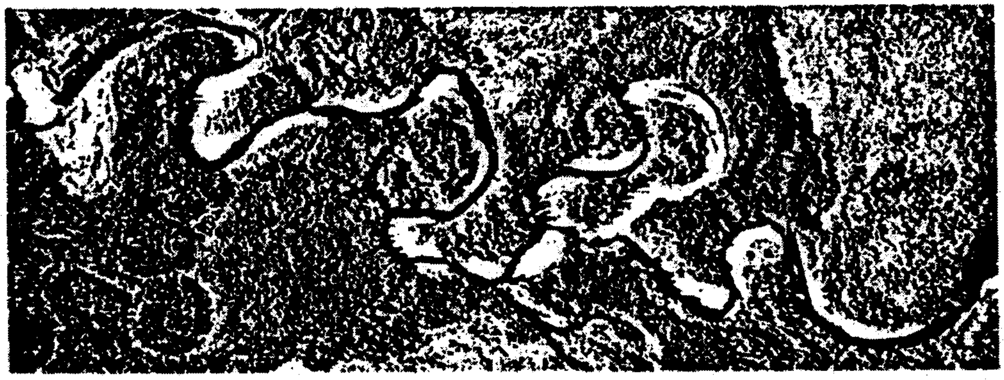
Cross-Sectional Geometry

The cross section of a stream channel is an irregular shape characterized by a bankfull width measurement combined with a number of depth measurements taken at regular intervals across the stream. The bankfull width reflects the channel width from one bank to another, and typically reflects the flow from a discharge event that occurs on average every 1.5 years for several days (Rosgen, 1993). End area averages are calculated for adjacent intervals, and a cumulative sum for the cross-sectional area of the channel is developed.

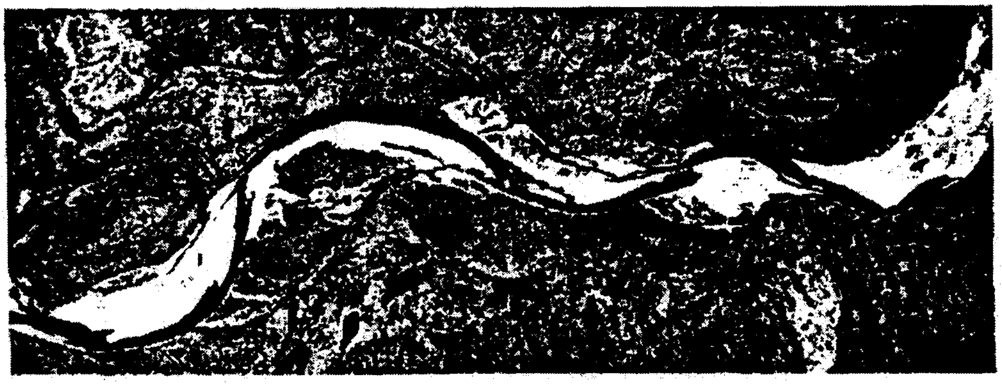
a. Braided River



b. Split Channel River



c. Meandering River



d. Sinuous River

Figure 1
Aerial Photos of Various Types of Rivers

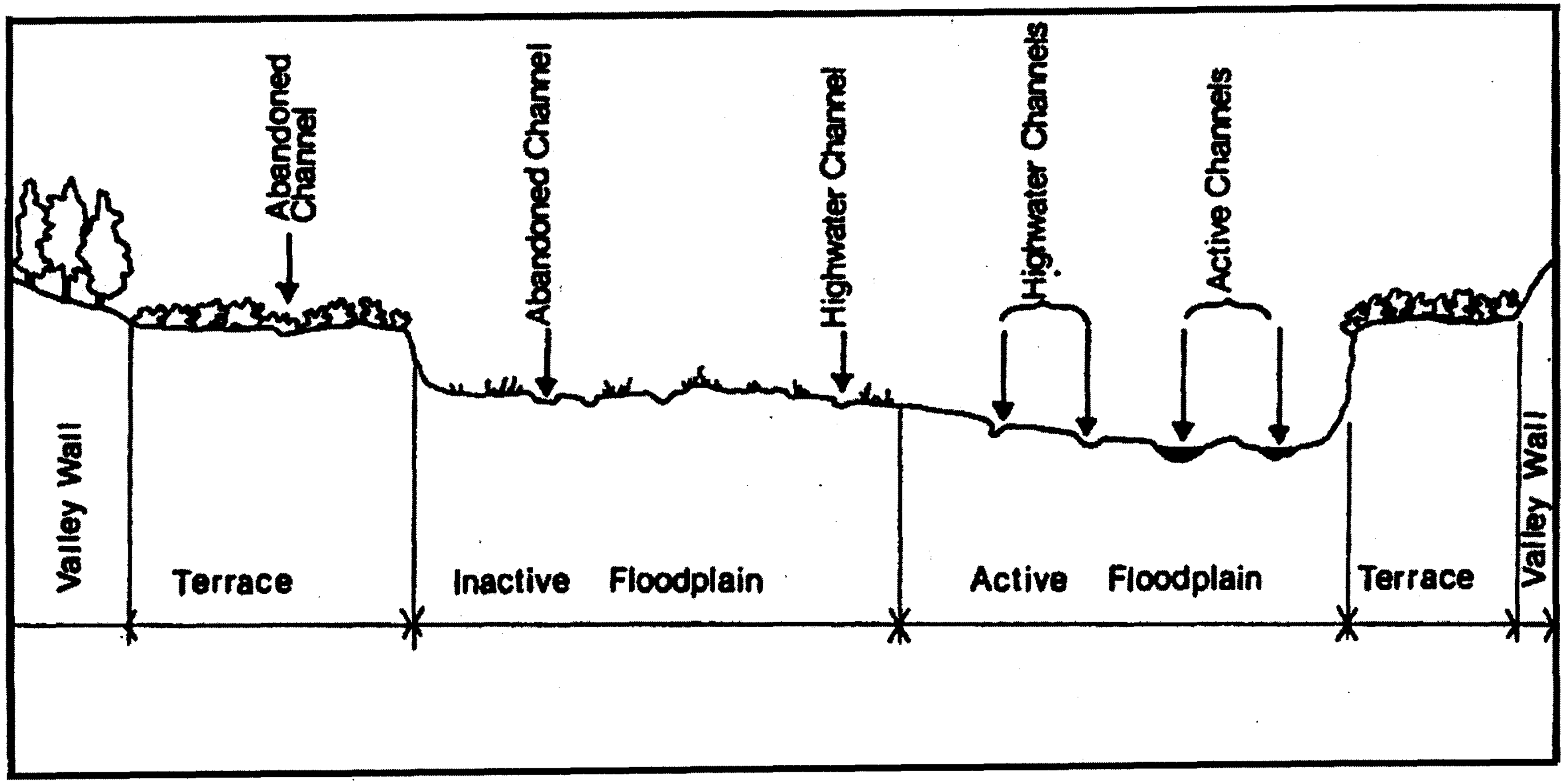


Figure 2
Floodplain Components

Width to Depth Ratio

The width to depth ratio is a measure of the dimension and shape of the stream and consists of the ratio of bankfull channel width to the maximum bankfull channel depth. This ratio indirectly reflects the energy within a channel to move sediment under various flow conditions. The maximum channel depth is found in the thalweg of the channel. A channel with high width to depth ratios, e.g., a wide, shallow channel, loses its capacity to transport sediment, tends to drop its sediment load, and evolves into an unstable channel.

Sinuosity

Sinuosity is a measure of the degree that a stream meanders. Stream sinuosity is directly related to the stream's accommodation to its valley. An example of a very sinuous stream and a more gently meandering stream may be observed in **Figure 1**. Sinuosity is typically the ratio of stream length to valley length or the ratio of valley slope to channel slope. Sinuosity may be measured using mapping from aerial photos or USGS 7-½ minute topography maps.

The average meander width is that width within the floodplain across which the channel flows (**Figure 3**). It is typically measured using a map or aerial photos. Parallel lines are drawn from the farthest outside curve on each bank using at least two full meanders. One meander length stretches from one outside curve on one bank of the stream to the next outside curve on the same bank.

Bedrock control, vegetative types, and manmade structural controls such as roads or channel confinement influence sinuosity. It also depends on channel dimensions, sediment load and discharge. In general, as gradient and particle size decrease, there is a corresponding increase in sinuosity. Increases in the bankfull width/depth ratio result in a decrease in stream length and sinuosity, resulting in an increase in local slope. This initiates a series of channel adjustments.

Grade

The grade is the slope of a channel. Steep channels are considered those greater than 4 percent. Grade may be surveyed on site using the elevations of the water surface along the reach, or may be calculated from review of a topography map. A representative sample is acquired from a minimum of twenty samples across two meander lengths. The slope is the difference in water surface elevation per unit stream length. Grade can be used to predict channel shape and bed features. Steeply sloped channels typically have cascades and frequent steps. Channels with slopes of 2 to 4 percent have rapids with infrequently spaced scour pools at bends or areas of constriction, or are gullies with step-pool channels. Most instream gravel operations are found in channels with slopes of less than 2 percent, that have alternating riffles and pools.

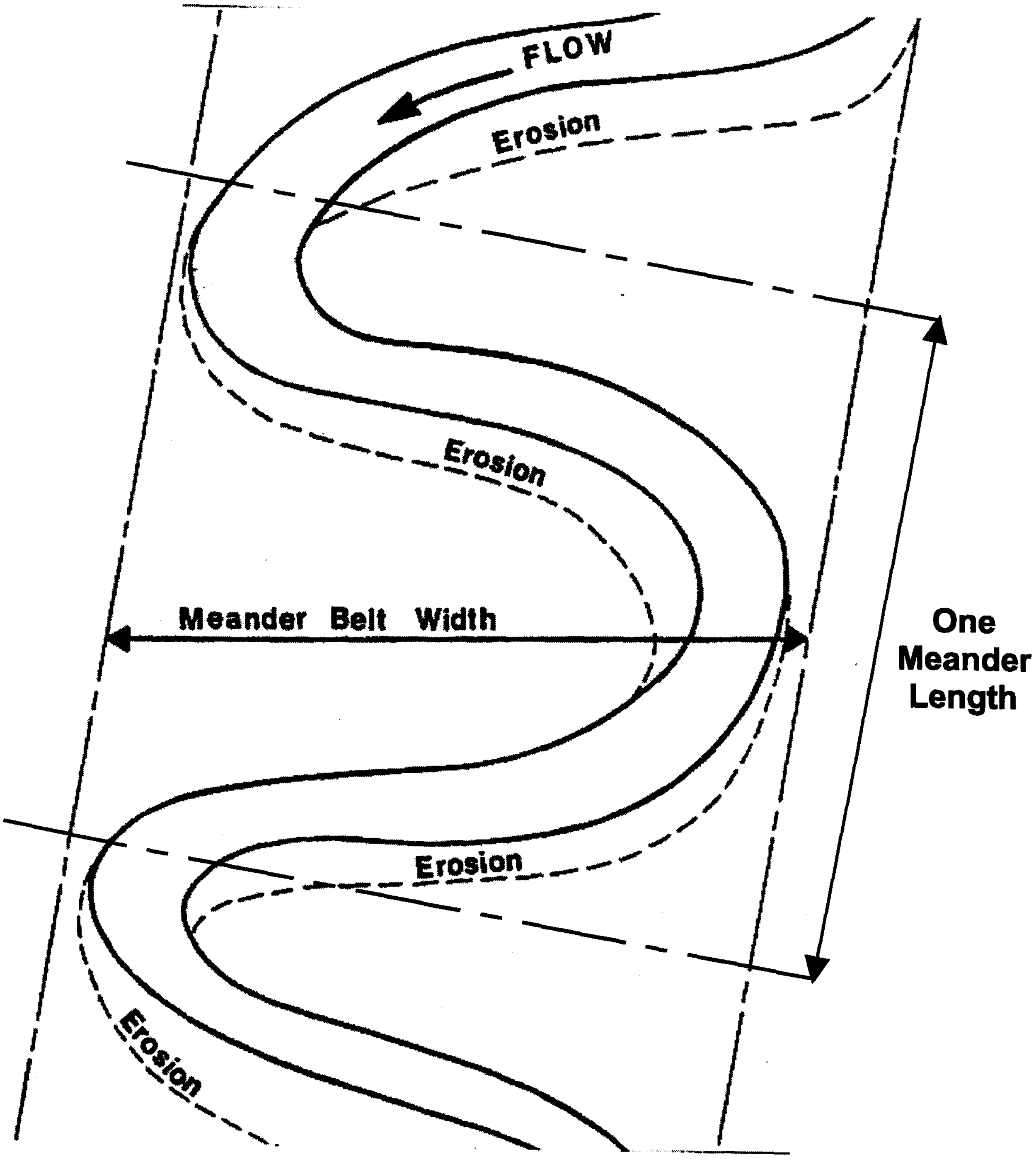


Figure 3
Schematic of a Meandering River Showing the Meander Belt Width, Meander Length, and Erosion as the River Meanders Migrate Down the Valley

Channel Substrate

The materials that make up the floor of a stream channel below the channel bed are called the channel substrate. The size and composition of these materials influence the erosion and subsequent deposition that occur in a channel under a normal range of flows. Rosgen (1993) classifies channel substrates into six categories: bedrock; boulders; cobbles; gravels; sand; and silt/clay. Boulders have a minimum diameter of 10 inches or more. Cobbles have a minimum diameter ranging between 2.5 and 10 inches. Gravels range in size from 0.08 to 2.5 inches. Sands, silts, and clays are all those particles less than 0.08 inches in diameter.

Rosgen (1993) has assigned numbers to each substrate as part of the classification system. For example, channels that run through alluvial valley floors are C channels. A C1 channel is a meandering channel on a gentle gradient with a bedrock channel substrate. A C2 channel is similar, except that more than 50 percent of the channel floor is boulder-sized. C3 through C6 channels have a median particle size that decreases from cobbles(C3) to silts and clays (C6). For additional clarification on this classification system, see **Appendix B**.

The erosional capacity of stream flow is affected by the size of the materials within the substrate and the entrained sediment in the stream and the discharge. **Table 1** from Barfield, Warner and Haan (1981) identifies erosive velocities of clear and turbid waters across various substrates. Rough substrates, with higher Manning's 'n' values can withstand higher velocities of flow than smooth substrates. Waters with a suspended load can traverse a channel with higher velocities than can clean water without eroding the banks or channel bottom. This phenomenon explains the hungry river syndrome, when a river emerges from a depositional pool and erodes the downstream reach to entrain its normal suspended load.

Channels with a coarse substrate slow waters flowing across them. This in turn, results in less erosion along the reach. Large rocks create a rougher surface than a sandy channel floor. This roughness is classified by the Manning's roughness coefficient or 'n', that typically ranges from 0.020 to 0.040, fine sand substrate to boulder substrate, respectively. Roughness may also be created by the presence of woody debris or grass-lined banks and channel floors.

Sediment Transport

Bedload/Suspended Load

Water can move solids ranging in size from large boulders to clays depending on the flow of the stream and the material available to be moved. Bedload is classified as all material greater than silt size. Bedload migration occurs during periods of high flow, and the material is transported by a combination of water and suspended material. The suspended load is that portion of the stream load moving in suspension in the stream for long distances, due to either turbulence during

Table 1
Erosive Velocities For Open Channels

Material	Mannings (n)	Clear Water Velocity fps	Water Transporting Colloidal Silts Velocity fps
Fine sand colloidal	0.020	1.50	2.50
Sandy loam noncolloidal	0.020	1.75	2.50
Silt loam noncolloidal	0.020	2.00	3.00
Alluvial silts noncolloidal	0.020	2.00	3.50
Ordinary firm loam	0.020	2.50	3.50
Volcanic ash	0.020	2.50	3.50
Stiff clay very colloidal	0.025	3.75	5.00
Alluvial silts colloidal	0.025	3.75	5.00
Shales and hardpans	0.025	6.00	6.00
Fine gravel	0.020	2.50	5.00
Graded loam to cobbles when noncolloidal	0.030	3.75	5.00
Graded silts to cobbles when colloidal	0.030	4.00	5.50
Coarse gravel noncolloidal	0.025	4.00	6.00
Cobbles and shingles	0.035	5.00	5.50

Source: Barfield, Warner, and Haan, 1981.

high flows or suspension of clay-sized particles. The suspended load particle sizes typically consist of sand, silt, and clays, or that portion less than the 0.08 inches. One measure of the suspended load is Total Suspended Solids (TSS), a parameter that looks at the weight of a water sample's sediment per unit volume (mg/l). Generally bedload is approximately 8 percent of the average suspended load each year.

Aggradation/Degradation

Aggradation consists of deposition of bedload materials in bars within a stream. Deposition occurs in several types of locations. Low velocity reaches or pools promote deposition. Slower velocities within the channel are found on the inside of channel curves and where point bars are deposited. Stream reaches where there is a decrease in slope also experience aggradation.

Degradation is a geomorphological term for erosion and weathering. Degradation occurs in high velocity portions of the channel, immediately beside the inside curve as bank weathering and over the deepest portion of the channel on the outside curve as both bank and channel weathering. Channel reaches where the slope increases substantially also tend to degrade.

Typically a stream with active deposition is steepening the channel slope, and a stream with active erosion is lowering its slope to achieve equilibrium.

Bank Erosion

Bank erosion is the weathering of the sides of a stream channel, and typically occurs in response to high localized stream velocities. Velocities vary both with position within the channel and from variations in flow rate. The highest average velocities occur over the thalweg, or deepest part of the channel. The thalweg migrates in a channel following the outside banks of a meander, and most erosion occurs on this bank of the stream. However, localized high velocities also occur from shear forces rounding the inside curves and some erosion occurs here. In addition, as flows increase, the velocity increases, resulting in an increase in bank erosion during snowmelt or flood events. Bank erosion can also be accelerated following the removal of vegetation, that can occur in response to overgrazing, or lowering of the water table.

Bar Building

Bars develop in areas of deposition, and are classified as point, lateral, or mid-channel bars (**Figure 4**). A stream builds bars with bedload materials acquired from the upstream banks along the outside curve of a stream and from channel bottom erosion. Point bars form on the inside edge of a channel in a meander bend. Lateral bars are adjacent to a channel that is not associated with a meander. Mid-channel bars occur in high depositional settings in response to mid-channel pooling and a decrease in flow, or due to deposition against a blockage of some sort, such as an in-channel bridge support.

Braided Channels

Two or more interconnecting channels of the same stream are termed as braided channels (**Figure 2**). They occur in wide, sparsely vegetated, unstable floodplains with low gradients and numerous high-water channels. A braided channel frequently exhibits a wide range in bedload grain size and a wide fluctuation in flow. Significant sediment transport from bank erosion occurs. Depositional bars of braided channels are formed of materials too coarse to be moved during anything but flood flow.

Channel Transport Characteristics

Renewal of aggregate supplies for in-stream mining operation occurs during periods of high flow, typically during short periods in the spring in association with snowmelt. Periodically, in localized areas, flash flooding will move a large bedload volume in conjunction with a summer

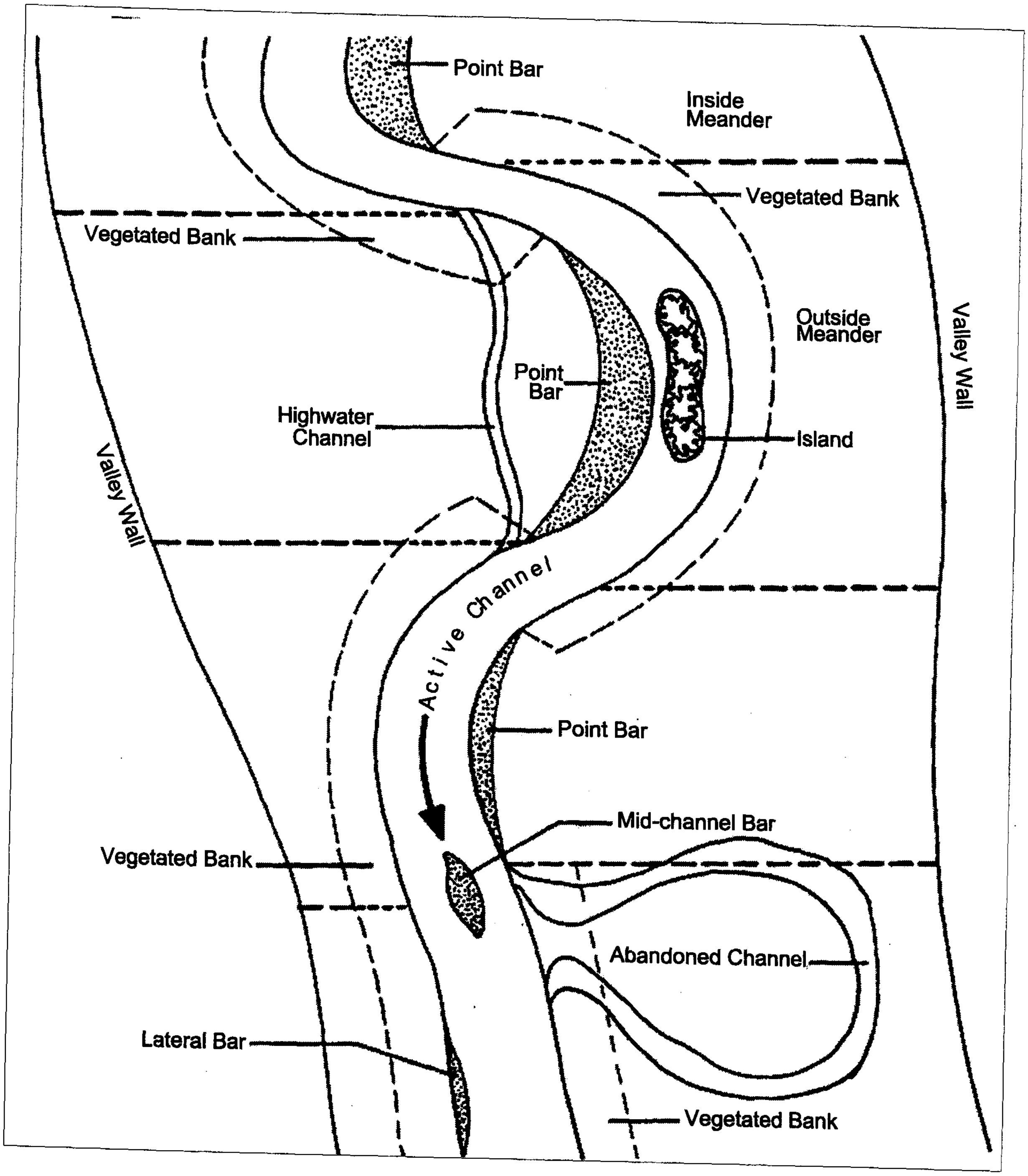


Figure 4
Aerial View of River Deposits

thunderstorm. Some channels have a higher potential for regular, annual sediment migration than others. This section groups channels by their aggregate supply, using their geomorphic settings, slopes, and channel substrate characteristics.

High Aggregate Supply

Most in-stream aggregate operations are found in fluvial settings that generate large quantities of materials. These include steeply sloped streams through mountainous areas that have high sideslope weathering. Channel weathering is active. Channel substrates range from silt and clay to cobble-sized materials. Channels on slopes greater than 10 percent are classified by Rosgen (1993) as A3a-A6a, and channels on slopes ranging from 4 to 10 percent are classified as A3-A6 (**Appendix B**).

Two other settings generally produce large quantities of aggregate: large streams with high tributary contributions of alluvial materials, and low to moderate slope areas immediately downstream from steeply sloping channels. There are four types of large sediment supply streams found on mild to moderate slopes, ranging from 0.1 to 4 percent. Rosgen D3b-D6b (moderately sloping) and D3-D6 (gently sloping, less than 2 percent) channels consist of slightly entrenched, multiple channel streams that traverse wide valley bottoms. Channel substrates vary and are less than cobble-sized. There are four, single channel type streams in the moderate slope range. Streams flowing in moderately entrenched channels through alluvial valley floors with low terraces have channel substrates ranging from clay to gravels (C4b-C6b and C4-C6). Two types of high sediment supply streams flow in entrenched, bedrock-confined settings and have channel substrates cobble-sized or smaller. They differ as one type has low width/depth ratios and moderate sinuosity (G3-G6 and G3c-G6c), while the other type includes wider streams with higher width/depth ratios and high sinuosity (F3b-F6b and F3-F6).

Moderate Aggregate Supply Settings

Five types of stream settings have potential for moderate aggregate supplies. The channels have slopes less than 4 percent: 1) entrenched, sinuous streams with boulder-filled channels and high width/depth ratios in colluvial valleys (F2 and F2b); 2) moderately sinuous streams with boulder-filled channels but low width/depth ratios in bedrock confined sites (G2 and G2c); 3) moderately entrenched streams with slopes ranging from 2 - 4 percent and channel substrates ranging from clays and silts to gravels (B4-B6 and B4c-B6c); 4) slightly entrenched, rectangular shaped channels with very low width/depth ratios, and very high sinuosity with sand or gravel channel substrates (E4b and E5b); and 5) slightly entrenched channels in alluvial valley floors with low stream terraces and cobbly channel substrates (C3b, C3, and C3c) typically have moderate aggregate supplies.

TYPES OF IN-STREAM AGGREGATE EXTRACTION

The following sections provide descriptions of typical aggregate extraction techniques used throughout the region. The descriptions are intended to be general but will provide sufficient detail to identify potential environmental effects where extraction is conducted in a worst case scenario, and associated mitigation measures that are recommended to minimize impacts. The listed environmental effects do not always occur. However, they are provided here only to alert the reader as to issues or items that may need to be considered for appropriate study and mitigation.

In-Stream Dredge Mining

Description

Dredge mining is typically accomplished with a Sauerman drag scraper, a floating suction dredge or a floating clamshell dredge. The Sauerman drag scraper consists of a dragline bucket mounted on a cable suspended between supports on both banks of the river. The bucket is lowered into the river and dragged across the channel bottom before it is raised and emptied into a bankside pile or onto a conveyor. A floating dredge typically sits on a pond surface within the floodplain of a medium to large river. A floating suction dredge with either a hydraulic cutterhead or a clamshell dredges the alluvium below, and then either vacuums or lifts the material to the dredge. The material is then transported by conveyor on floating pontoons to a screening/crushing plant. In some cases, excess sand material is returned to the other side of the pond when it cannot be sold. In some areas, a large dragline is substituted for the dredge but the essentials of the operation are the same. This method requires that the groundwater level be near the surface to allow the dredge to operate.

Operations in the active channel have the complication of altering the channel depth, width, type of bed material, etc. that may cause considerable impacts upstream and downstream.

In rivers whose flow is not controlled by reservoirs upstream, operators and regulators should consider the potential impacts from a flood event even if a significant buffer of land is used to separate the mining area from the river. History has shown that some buffers have been destroyed by flood events and the river has entered the mine area causing numerous problems requiring mitigation.

Environmental Effects

In-stream dredge mining modifies the hydraulics of the river channel, and initiates a number of physical changes in the stream. **Figure 5** shows an example of a Sauerman drag scraper dredging to the depth of the original channel. This mining method often results in a widening of the channel, and a steepening of the banks of the river in comparison to the original banks. Widening slows the stream flow through the reach, and increases deposition of more fined grained materials

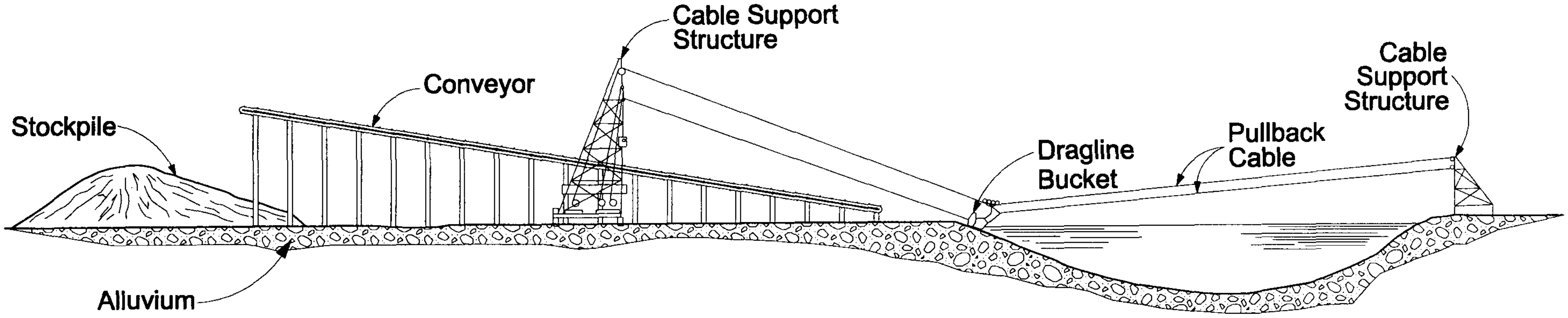


Figure 5
Sauerman Scraper In-Stream
Dredge Mining

than previously observed. This results in less bedload moving downstream and establishment of conditions promoting channel downcutting downstream to re-entrain the bedload. Steepening of the banks increases bank erosion in the area of the operation, as does removal of the riparian area beside the original channel.

These effects are increased when the dredging cuts below the original channel depth. This increases the slope of the river between the upstream reach and the mining operation. More material from upstream will move into the site of the dredging operation, as the stream seeks to reestablish its grade. In addition, there will be backwash from downstream areas up into the pit. These bedload movements may affect manmade structures in the stream at some distance from the operation, such as bridge pilings, irrigation headgates, or buried utility pipelines.

Widening of the stream channel will limit the recharge into the alluvium, since the overall depth of flow is less, and has the potential to drop the water table. The water table will increase during periods of high flow, but will result in a general lowering of the water table throughout the year. This lowering may limit sub-irrigation of fields in the floodplain, dry wetlands, and affect the viability of riparian vegetation on the banks. Bank erosion near the operation may accelerate since riparian plants, shrubs and trees typically anchor the banks in place. Riparian vegetation and wetlands may also be damaged by operation and/or access related disturbance.

Increases in the channel width, coupled with decreases in velocity will also result in an increase in evaporation. The Colorado State Engineer considers evaporation a beneficial use, for which water rights must be obtained. In-stream dredge operators may have to file an augmentation plan to ensure that there will not be a loss to water users downstream. Operators are encouraged to contact the Office of the State Engineer with regard to water rights issues.

In-stream extraction operations may increase the suspended sediment load in the stream in the area of operations and immediately downstream. Dredging suspends fine grained materials through the mechanical agitation of the streambed and banks. Farther downstream these materials are laid down on the channel floor as easily erodible deposits, resulting in a cycle of increased sediment loading each time the flow increases, at substantial distances from the mining operation. Increased sediment loading can darken the water, limiting the light available for photosynthesis of aquatic plants and plankton, and diminish the efficiency with which fish can breathe.

Of greater concern, fine grained deposits can diminish fish spawning grounds within stream riffles, resulting in decreases in the population. Many species of coldwater fish create a nest or redd of gravel cleaned of silts and aquatic plant life. The fish form the gravels into a depression with their tails to suspend and wash away the fine grained-materials, lay their eggs, and cover the nest with other cleaned gravels. The cleaned gravel allows oxygen-laden waters into the nest to remove metabolic waste. Successfully hatched fry migrate up through the gravels to emerge into the stream. A redd that has been covered with sediment after it is built may result in lower hatching rates or diminished rates of fry migration into nursery areas.

Less frequently than increased sediment generation, in-stream gravel operations may also result in water quality degradation through the mobilization of metals. Metals may pose some limitations for domestic drinking water uses or aquatic species habitat. Metals from natural mineralized zones or from previous contamination may experience accelerated weathering and dissolution during a gravel extraction operation. Alternatively, removal of all of the gravel from a channel floor may expose another geological formation that has undesirable geochemical attributes.

Similarly, mining of stream deposits may mobilize salts to increase the salinity of a water. Salts either have precipitated from irrigation return flow, that did not make it to the stream, or may reflect the presence of adjacent salt laden geological formations such as gypsum. Colorado participates in the Colorado River Basin Salinity Control Forum, and has regulations that prescribe salt loading in the Colorado River and its tributaries. For all the above surface water quality issues, the operator should contact the Colorado Department of Public Health and Environment (CDPHE), Water Quality Control Division (WQCD) for requirements of the Clean Water Act Section 401 Water Quality Certification Permit.

As discussed earlier, increased turbidity and siltation of gravel riffle areas, may diminish the fishery for some distance downstream from the operation. Should the fishery have the potential to support a fish or other aquatic species that a public agency has classified as a threatened or endangered species, the operator should contact the U.S. Fish and Wildlife Service (USFWS), and the Colorado Division of Wildlife (CDOW) for additional information concerning their proposed site and aquatic species.

Dragline or Loader Mining of Point Bars and Lateral Bars

Description

Bar mining consists of a dragline, loader or hydraulic excavator extraction of material from point bars or lateral bars in a stream channel. These locations are depositional points in the active channel and can range in size. The dragline usually operates from a point within the bar itself at a comfortable distance from the channel bank. A dragline has the advantage of a larger reach than a hydraulic excavator. Therefore, it can usually swing the excavated material directly to a stockpile area (out of the floodplain) where it can be crushed and/or screened. Typically, no barrier is used to separate the stream channel from the active mining activity.

It is normally desired that the bars have low percentage of fine material, be poorly vegetated and contain considerable volume above the low flow level during the year. It is also best that the mining operation is located on bars that are historically replenished on a regular basis.

Mining is best done when the river is at its lowest level throughout the year. Mining may occur for only a 30 to 60-day period after which the excavating machine is moved out of the channel. Subsequent year high flows restore the bars. As shown in **Figure 6**, excavation may occur above or below the low flow level in the river or stream. If it is only above, the environmental effects

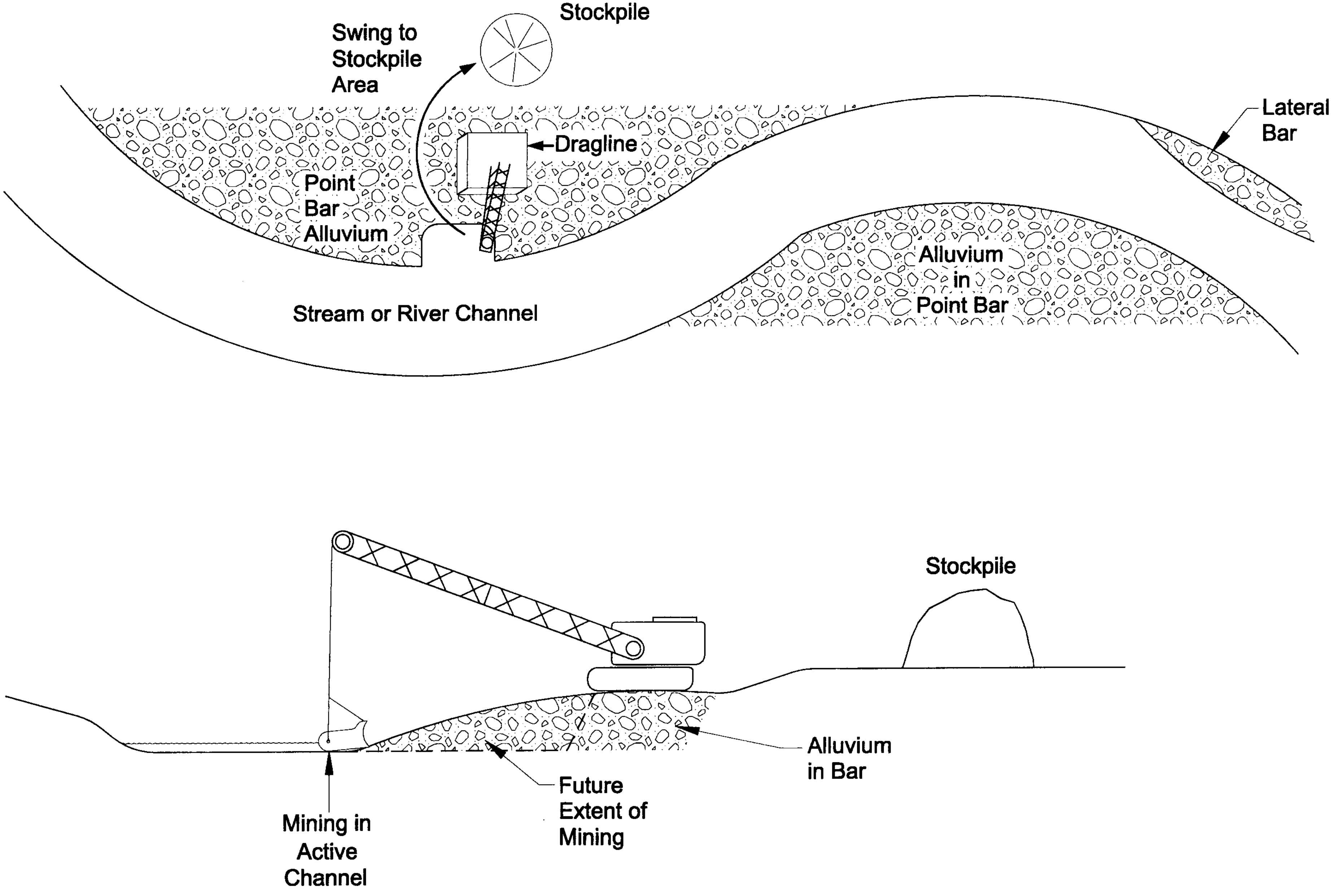


Figure 6
Dragline Mining of Point Bars and Lateral Bars

will be lessened. If it occurs below this level, the geometry of the stream changes, that may cause various environmental effects.

Environmental Effects

Point bar mining widens and slows the river or stream in the zone of operations. Pooling slows the flow in the channel, accelerating the deposition of fine-grained particles. Mining of point bars will result in straightening of the stream, that may increase the slope of the channel (**Figure 6**). While general channel widening would tend to counteract this effect, the typical effects associated with channelization may result. The stream will downcut the channel bed upstream and downstream as the stream profile attempts to restore equilibrium. Unless protected, banks will erode within the permit area, due to disturbance of the riparian community. In the event that mining of bars changes the channel substrate from gravels and cobbles to sands, silts, and clays, flows in the river will pass over a smoother surface with increased velocity during flood flows.

The operator is advised to contact the U.S. Army Corps of Engineers (COE) regarding Clean Water Act Section 404 Permits prior to beginning any action in the floodplain and river channel.

Mining directly adjacent to the stream will increase the suspension of fine-grained particles throughout the period of mining, both in the mined reach and downstream. Fine sediment deposition may decrease the availability of fishery spawning grounds, as there is a loss of natural streambed armoring in the vicinity of the operation. Mining may occur for several months out of the year during low flow periods. Coincidently, this may mobilize salts and metals that were being held in the alluvial material. The suspended and newly dissolved materials may affect water uses downstream in aquatic life and for domestic purposes. As noted in the previous section, operators should contact the WQCD concerning surface water quality issues and the Section 401 Water Quality Certification Permits.

Widening of the stream will decrease its average annual depth and decrease the level of recharge of the adjacent alluvial ground water table. This may reduce the period of saturation in adjacent wetlands and decrease sub-irrigation in the floodplain. Lowering of the water table may damage the riparian community already diminished by disturbance associated with access and mining.

Point bar removal often results in disturbance to riparian vegetation adjacent to the point bar. Ecological communities that rely on riparian vegetation will decrease during the period of operations. Operators should be aware of the designation of sensitive, threatened or endangered species in their region, and be prepared to avoid disturbance of that habitat or provide appropriate mitigation. Frequently, riparian areas are classified as supporting habitat for a species.

Mining activity in the stream may increase turbidity and subsequent deposition of silt downstream from the operations. In the event that a basin created by the mine increases deposition in the mined area, a "hungry water" situation may develop. As the stream flow re-entrains sediment, downstream scour occurs. Operators should contact the USFWS and the CDOW concerning impacts to fisheries and threatened or endangered species and their habitats.

Permanent Diversion of Existing Stream Channels

Description

In this method, mining is initially conducted in a proposed permanent diversion channel along a perennial stream. Usually, the diversion is constructed in the floodplain. A wide buffer barrier is initially left in at the upper portion of the diversion to prevent the river from entering while the diversion area is being excavated. Excavation could be done with loaders, dozers or excavators. Once the diversion is constructed and any permanent rip-rap or other lining is placed, the diversion barrier is removed and the river enters the diversion channel. A barrier preventing flow in the original channel is also installed at this time. This barrier is normally constructed of earth with pieces of concrete or large rock for armoring. The barrier should be constructed so that the river enters the new channel with no sharp turns.

After the original channel has dried, mining can commence in the channel bed and surrounding bank area as shown in **Figure 7**. This is also done with a loader, dozer or excavator. If mining occurs below the water table, a permanent pond may be left in the mining area.

A permanent diversion can extend from 100 feet to thousands of feet in length. Obviously, there are major concerns with this mining and reclamation method, particularly, the ability of the diversion to contain a flood event and the ability of the barrier protecting the mining operation to ensure that no breach occurs in the subsequent mine area. The diversion channel design must consider a number of hydrologic factors to minimize environmental effects upstream and downstream. The operator is encouraged to contact all regulatory authorities prior to beginning any activity within the 100-year floodplain or stream channel.

Environmental Effects

Installation of a permanent diversion of a stream channel can result in changes of the stream grade, depth, width, bed characteristics, lining and banks. An operator is faced with replication of the previous channel conditions or careful manipulation of many channel characteristics to minimize hydrologic effects. An increase in the channel slope will initiate downcutting upstream and downstream of the operation. An increase in fine bedding materials will result in a more erosive channel substrate. An increase in the width of the channel will decrease the velocity of water in the stream, resulting in local deposition. For further discussion of the effects associated with decreasing the dimensions of the channel from its original size, see the discussion on environmental effects from split channel mining below. An operator should consult with the COE and WQCD about all actions in the floodplain or channel.

The disturbance associated with the permanent diversion excavation and access along the banks around the mining operation will result in a loss of riparian vegetation. Vegetation removed destabilizes the banks that can result in increased erosion. Loss of riparian habitat will increase the temperature in the stream and negatively affect fisheries.

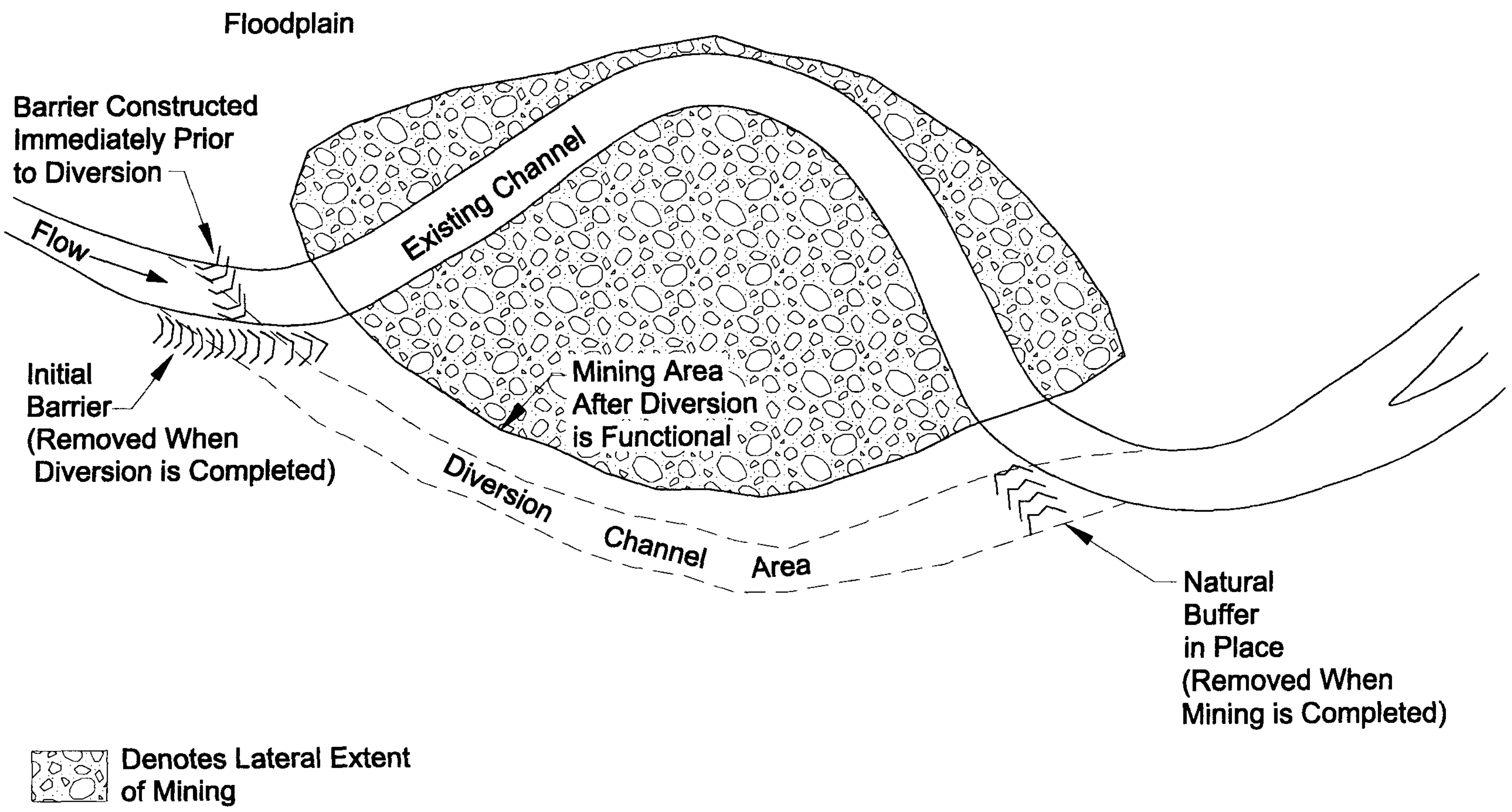


Figure 7
Permanent Diversion of Existing Stream

Utilization of a permanent diversion minimizes sediment mobilization during mining. However, if the permanent diversion material has a more fine-grained channel substrate or bank armoring than the original channel, flows will entrain more sediments until the fines have either been removed or natural depositional processes drop more gravels and cobbles. Elevated sediment mobilization along the diversion will result in more turbid waters downstream. This in turn may result in a layer of fine sediments over gravels utilized for fishery spawning grounds. Contact WQCD about specific monitoring and permitting requirements associated with water quality changes.

Rerouting the river may decrease the elevation of the water table on the bankside farthest from the permanent diversion, as there would no longer be recharge from the river. This may affect users of alluvial waters or the flows in springs. Riparian vegetation not previously impacted by the general mining disturbance may not thrive with a lowering of the water table and lack of sub-irrigation. Again, should this habitat support an identified sensitive, threatened or endangered species, the mining activity may cause unacceptable effects.

In the event that mining of the original channel drops below the original channel bed, there may be an influx of groundwater. During subsequent operations, pumping may require an NPDES permit for point source discharges. Consult with WQCD about specific monitoring and permitting requirements. Should an operator choose to allow the water to pond, either during operations or following reclamation, an augmentation plan may be required for filing with the Colorado Department of Natural Resources Water Resources Division, State Engineer's Office to accommodate the loss of water to evaporation.

Establishment of a new channel may cause short-term reduction of fishery habitat. Riparian cover may be missing. It provides shading, that cools the water temperature, and habitat for insects to fish feed. Undercut banks, that provide shelter, may not be present for some time following construction. The permanent diversion should provide alternating pool and riffle segments to accommodate different feeding and life stage requirements. Planting of riparian vegetation adjacent to the permanent diversion immediately following construction will help stabilize the banks of the new channel, and re-establish habitat for species that use the community for forage or cover.

Split Channel Mining

Channel Types

Split channel mining can occur in perennial streams that are located on mild to moderate slopes in high sediment supply settings. These typically occur at sites below steep channel reaches where there has been a major reduction in grade, or downstream from the confluence of a high sediment supply tributary with a more gently sloping main branch.

Description

This mining method utilizes the split channel stream to either harvest from alternating channels or uses one of the split channels as a natural diversion to accommodate mining of the mid-channel bar and floodplain. Initially, earth or rock barriers are constructed to contain the flows in one split channel as shown on **Figure 8.** This is normally done with a dozer during low flow conditions. Gravel is then mined from the cutoff split channel usually for a period of 30 to 60 days during the low flow period of the year (August-November). The material is excavated from the cutoff channel using loaders, dozers or excavators. The cutoff channel is reopened for the high flow season.

Once mining in one split channel is completed, cut slopes within the mined split should be reduced to approximately 3:1 (H:V), and all stockpiles and mining equipment should be removed. Any fine-grained soils exposed by mining should be removed or stabilized to prevent mobilization when the stream is reintroduced to the split. The barriers upstream and downstream are then removed (also during low flow season) and no more activity takes place until the following low flow season. During high flow season, both splits of the channel are open and are allowed to function in their normal way. During high flow, it is hoped that part of the bedload from upstream is redeposited in the mined split. During the following low-flow season, the other split is blocked off with barriers and the split that contained the flows in the previous year is now mined.

One concern with this mining method is the risk of a flood while one of the splits is blocked and the remaining split cannot handle the flow. This risk is reduced by properly designing the barriers and conducting all in-channel work in a short time during low flow season. If the island between the splits is well established and significantly higher in elevation than the low flow level, it may be that a barrier running the length of the island is not necessary. Careful study of the site specific characteristics of the permit area and the peak flow history of the stream are needed to adequately address this issue.

Environmental Effects

Diversion of all flows into one split channel with a smaller cross-sectional area than the combined channels may result in bed erosion and entrenchment of the channel (**Figure 8**). Increased velocities are responsible for the downcutting. Diversions can be classified as a form of channelization, with a decrease in the meander width of the stream. Channelization results in an increase in the slope of the river. Subsequently, channel bed erosion upstream of the operation and downstream may occur, potentially jeopardizing the stability of bridge abutments, buried utility crossings, or irrigation headgates. Entrenchment and steepening of the channel slope may also result in destabilization of the banks upstream and downstream from the operation.

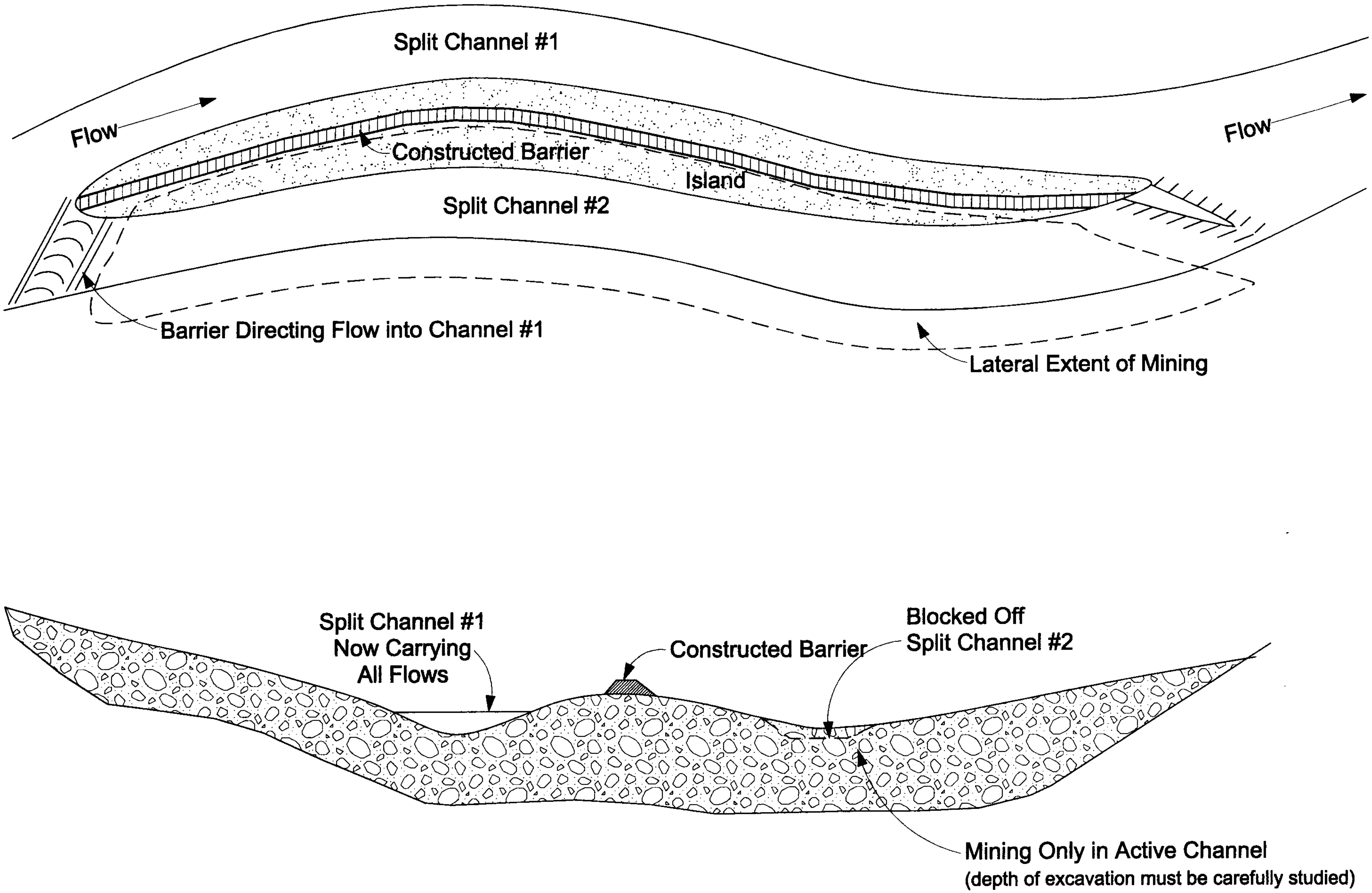


Figure 8
Split Channel Mining

This effect is heightened if the operator mines below the low flow channel level and then later chooses to mine the diversion channel. While this method promotes aggregate deposition for future mining, the effects may occur at a considerable distance upstream and downstream of the permit area, and potentially outside of the permit area. This type of bedload migration has been known to undermine the supports for bridges and to dry the inlets to irrigation headgates. An operator should consult with the COE and WQCD about all operations in the channel.

Mining below the low flow channel can result in a detrimental impact to the fishery. Suspension of sediments can cover spawning gravels downstream. Fish may become stranded during low flow in a reach where the channel bed is below the adjacent channel bed.

Barrier construction may cause localized, short-term increases in sedimentation. It is recommended that sizing be prepared by an experienced professional to ensure that the barriers will not be damaged during a 10-year, 24-hour storm event, resulting in bank erosion.

Entrenchment of the channel upstream, at the site, and downstream may cause a lowering of the water table. As described previously, this may decrease sub-irrigation, diminish wetland and riparian habitat, and affect current users of alluvial waters. In the event that mining occurs below the level of the previous year's deposition, groundwater influx may flood the channel to be mined. Operators are advised to contact the Department of Natural Resources State Engineer's Office and the WQCD to determine whether an augmentation plan or application for an NPDES permit will be required.

Riparian habitat on the mid-bar channel and on the outside banks of the stream may be disturbed by extraction operations. This may decrease bank protection, increase the temperature of the stream in the active channel and modify the fishery. Woody debris in the channel may decrease, diminishing cover and habitat. An operator should contact the USFWS and CDOW to identify any site specific concerns associated with threatened or endangered species.

Rock Vortex Weirs/Harvest Pits

Description

This method involves installing a group of durable rock boulders in the stream channel in a crescent shape as shown in **Figure 9**. The tops of these boulders are installed very close to the bed level of the stream and are called footer rock. The size depends on the particular stream or river, however, a typical size is generally 4 to 8 feet in diameter or greater.

Large durable boulders of similar size are also placed between the footer rock but much higher above the bed level, acting to slow down the flow and cause deposition behind the installation. During high flows, water moves between and above the large boulders. During low flow conditions, water flows between the boulders. The footer rocks are located directly below the drop point of the water between the boulders, thus helping to avoid scour.

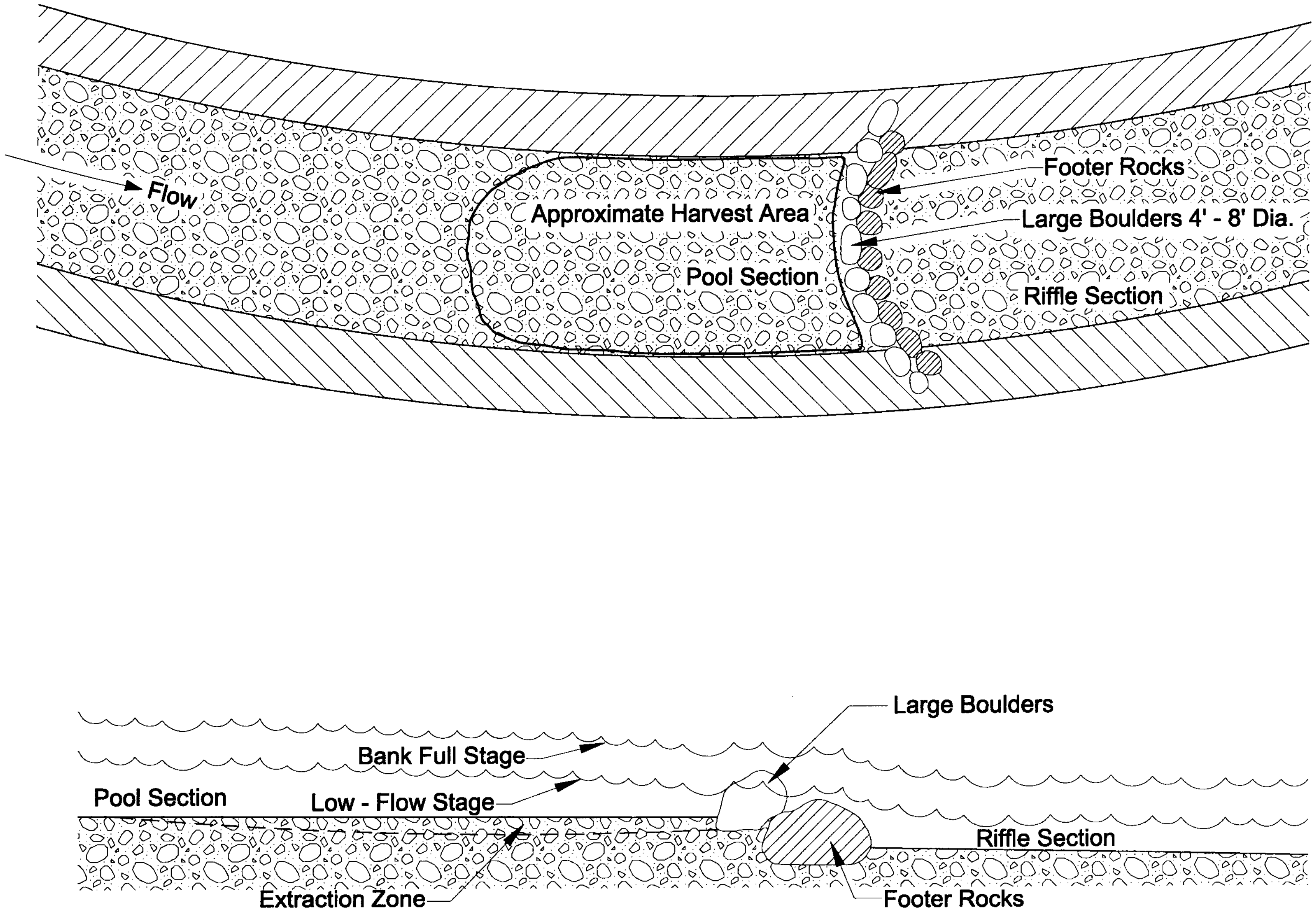


Figure 9
Rock Vortex Weirs Creating Harvest Pits

In this manner, a harvest pit is created behind the vortex weir and the area is harvested for gravel during low flow conditions with loaders, dozers or a small dragline. Variations of this method include a vortex weir installed in only part of the stream that is experiencing deposition, such as a point bar on the inside of a bend. Also, a series of vortex weirs can be installed in the same stream providing more than one harvest area.

This method is uncommon in Colorado for in-stream mining although it would apply under certain conditions. The practice of installing rock vortex weirs in the stream channel has also been used to remediate some streams that are unstable. Mining should still be restricted, as in other gravel harvesting methods, to only that material normally carried by the stream or river as bedload. The COE is aware of the potential use of this method and is also studying its merits.

Environmental Effects

The rock vortex weir is a structure that decreases the grade of the river and promotes deposition upstream. If extraction is limited to the volume of material produced in the previous year, effects minimized to the channel bed upstream will be realized (**Figure 9**). Deeper extraction may result in downcutting and bank erosion upstream. Use of the rock vortex weir promotes the deposition of fines immediately downstream of the weir, as the stream loses energy following its drop across the weir. Loss of both the bedload in the weir and the suspended load in the downstream pool may result in channel downcutting some distance downstream of the structure. These effects can be minimized through the use of a weir that only partially spans the channel. An operator should consult with the COE and WQCD about all planned activities within a channel.

Access into the harvest area may result in bank erosion, and efforts should be made to minimize this associated disturbance. Bank destabilization may migrate upstream from the site, and result in the entrainment of bank materials during both high and low flow conditions.

Sediment loading may occur during the initial installation of the weir and during the brief period when the gravel is extracted from perennial streams. Deposition of the newly suspended fines will occur immediately downstream in the pool below the weir.

There are not likely to be any effects from lowering the water table unless extraction occurs below the depth of annual deposition. Should this occur, the previously described effects of riparian vegetation and wetland loss, a drop in the depth available for sub-irrigation, and potential loss of water to users of alluvial water may occur.

The fishery may be reduced by the slowing of flows upstream and downstream of the weir, additional deposition of fines downstream of the weir, and mechanical disturbance of the harvest pit. Loss of riparian habitat will indirectly influence the temperature of the water, the presence of woody debris in the stream, and the habitat for insects.

Mining of Bars and Minor Islands above Low Water Level

Channel Types

This type of mining occurs in medium to large, slightly entrenched, braided or meandering perennial streams (D3b) (**Figure 1**). These settings occur in wide valleys with high depositional zones at slopes ranging from 0.5 to 4 percent. The potential for deposition is high as there is either a substantial reduction in the slope of the stream channel or large flows from large contributing watersheds full of heavily weatherable deposits.

Description

This method is best suited for braided streams (heavy depositional reaches) but can also be used on point bars and lateral bars. The method simply involves mining the bars/islands above the water level during low flow periods as shown in **Figure 10**. Temporary access culverts may be placed in the stream to allow the loader to reach certain areas and trucks are then loaded directly by the loader.

The critical item in this mining method is the depth of extraction within the bars/islands. If an engineered separation height is required between the low flow level and the maximum extraction depth, environmental effects are minimized, but in many cases no appreciable amount of gravel is available for mining. On the other hand, if mining is allowed at or below stream level, the stream geohydrology is altered and environmental effects can increase significantly.

Environmental Effects

Mining of bars above the low flow channel elevations within a braided stream does not modify the channel slope or length. However, the channel substrate may change, and the cross section of the channel will increase during high flows. In addition, the velocity of flow in the channel may increase with the loss of vegetation as energy dissipators. Channel and bed erosion may be slightly accelerated.

Mining bars below the channel floor may result in more extensive geomorphic changes. Gravel bar skimming can eliminate confinement of the low flow channel, resulting in a thin sheet of water at base flow that could detrimentally affect the fishery. Initially, gravel removal at depth may increase the slope, causing additional migration of bedload from upstream. The formation of a deeper area in the channel may result in ponding, or substantial slowing of the stream and an increase in deposition in the area. The stream may scour additional bedload downstream, resulting in channel downcutting. An operator should discuss their mining plans with the COE and WQCD prior to proceeding.

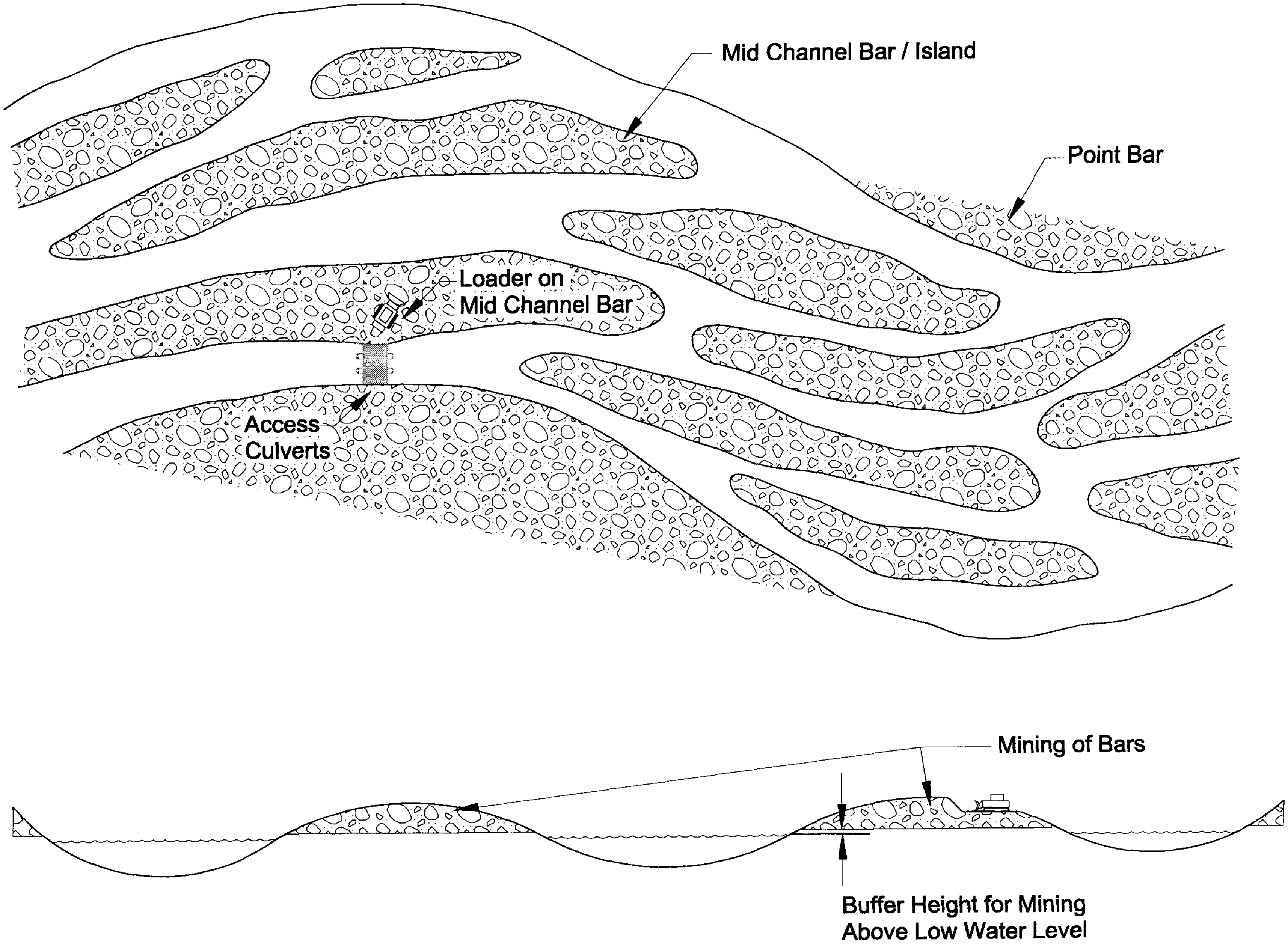


Figure 10
Mining of Bars and Minor Islands Above Low Water Level

The suspension of fine grained materials may increase in the immediate vicinity of the mining operation, due to loss of pushed material at the edges of the bars. This may diminish downstream spawning grounds if there is a high proportion of sand and silt-sized particles or increase turbidity of the stream, if there is a large proportion of clay-sized particles.

Mining of bars and minor islands in a braided stream may damage any established riparian or wetland vegetation. Loss of vegetation to mining disturbance on the bars may accelerate the destabilization of the bars due to loss of root mass. Elimination of riparian areas may indirectly affect the fishery by removing shade, increasing water temperatures, and destroying vegetation-based insect habitat. Sensitive, threatened or endangered species that depend on riparian habitat will also be affected by the mining of bars and minor islands above the low water level. An operator is encouraged to initiate discussions with the USFWS and CDOW to ascertain the status of classified species.

Dry Ephemeral Channels

Channel Types

Eastern Colorado has a number of aggregate operations occurring in dry ephemeral channels. These channels have ephemeral or intermittent flow in response to storm events, and occur in gently to moderately sloping watersheds in areas of limited precipitation.

Description

This method is generally employed in ephemeral channels such as many minor washes in eastern Colorado. These washes have a very mild grade and only flow in response to spring thaw and summer thundershower events. During late summer, the channels can be very dry and the channel itself can be mined with a front end loader to a shallow depth without causing significant effects to the surrounding area (**Figure 11**).

Normally, the bed of these ephemeral channels is sandy and without vegetation, although certain valuable habitats such as cottonwood groves can also exist in the major washes.

The sand from the channel is normally mined to a depth of 2 to 6 feet over an area of a few acres. It is typical for operations of this type to have very low reclamation bond amounts since the disturbed area is normally without vegetation. Once the channel is harvested, the material is placed out of the channel floodplain and is used on an as-needed basis. From subsequent storms, the channel bed is allowed to restore itself to its pre-mining level, that may take two or three years. In many areas of Colorado, this method is the only way that construction material can be easily provided.

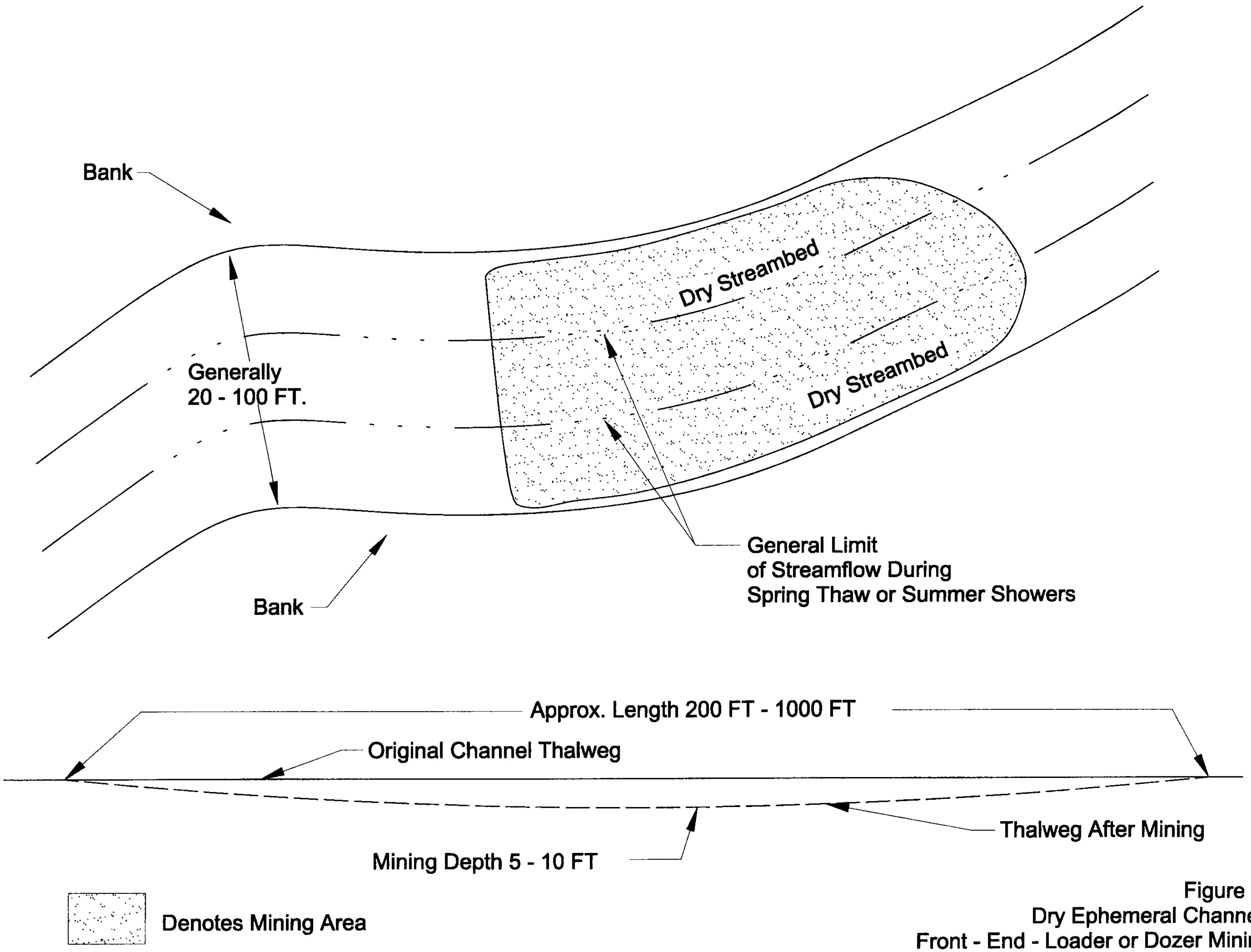


Figure 11
Dry Ephemeral Channels
Front - End - Loader or Dozer Mining

Environmental Effects

Mining of dry, ephemeral washes results in fewer water-related environmental effects than other in-stream operations, but may exhibit the same effects to channels, as presented earlier in the descriptions of mining methods. Effects to the channel are based on the depth of extraction, the width of extraction, and the frequency and amount of flow. Substantial increases in the depth of extraction that exceed the volume of the annual depositional supply, will increase the slope of the channel, causing channel downcutting upstream and downstream of the extraction area. This entrenchment will tend to destabilize channel banks and accelerate widening of the channel. Deep extractions will result in ponding immediately following operations, that may diminish the amount of water available to downstream users. Increasing the width of the low flow channel may result in shallower flows through the area and increased deposition of bedload. This deposition may also accelerate downstream channel bed erosion, as the river attempts to regain its bedload. Mining may also change the channel substrate. A change to a smaller average particle size will result in increased velocities of the stream. However, such effects may be of little or no environmental consequences, given the remote nature of many of these sites.

There should be no effects to water quality during the extraction of the resource. In the event that the mining produces additional downcutting or bank erosion, the stream may have a higher sediment load. Mobilization of previously precipitated metals or salts is not likely to occur when mining in a dry setting.

Dry ephemeral streams are not likely to have a water table near the zone of extraction of annual deposition. However, deeper extraction may result in an influx of water into the extraction area. In addition to changing the nature of the mining operation, this could require an augmentation plan from the State Engineer to account for evaporation, and would increase the mobility of fine grained sediments, salts and metals.

Wetlands and riparian zones are unusual adjacent to ephemeral streams, and their ecological importance is subsequently elevated. Furthermore, the presence of such vegetation implies a shallow water table, that may change extraction techniques.

MINING METHODS AND RECLAMATION PLANNING

The Colorado Mined Land Reclamation Board has defined "Reclamation" as "the employment during and after a mining operation of procedures reasonably designed to minimize, as much as practicable, the disruption of the mining operation and to provide for the establishment of plant cover, stabilization of soil, the protection of water resources, or other measures appropriate to the subsequent beneficial use of such affected lands." In order to plan and implement reclamation activities, an intended Post Mining Land Use (PMLU) is necessary. PMLUs generally follow the pre-existing mine land use, but are joint decisions of the landowner, operator and regulatory authorities including the local land use planning agency. Regulatory authorities which should be consulted are included in **Appendix F**.

Post Mining Land Uses

Typically, project proponents propose a PMLU that is compatible/similar to the existing and surrounding land use(s). Another critical element of PMLU selection is determined following/in conjunction with environmental baseline development. Combinations of proposed PMLUs are common and encouraged to offer diversity and opportunity for multiple uses. The reader is referred to the Act and Rules and Regulations that provide the performance standards for the classified post mining land uses.

Of special interest in this document are areas managed for wildlife, industrial/residential zoning and recreational uses. Wildlife PLMUs associated with in-stream gravel operations typically include wetland and riparian zones and fisheries. PMLUs for industrial, residential and recreational uses have special considerations associated with long-term stability and areas of mixed zoning.

Wildlife PMLU

Wetland-Riparian areas are among the most productive and important ecosystems nature has to offer. Characteristically, these areas display a greater diversity of plant and animal life than adjoining ecosystems. Plants occur at multiple heights providing a variety of habitats. Healthy wetland-riparian systems filter and purify water as it moves through the zone, reduce sediment loads and enhance soil stability, and provide microclimate moderation when contrasted with extremes in adjacent areas.

Riparian areas are located in areas adjacent to and influenced by streams (whether waters are surface, subsurface, or intermittent), springs, lake shores, marshes, potholes, swamps, muskegs, lake bogs, wet meadows, and estuarine areas. Wetlands are a form of riparian areas transitioning between permanently saturated wetlands and upland areas. They include the vegetative zones along the banks of natural "wet areas."

The development of wildlife habitat involves maximizing vegetation cover, production and diversity; encouraging soil development; and maximizing infiltration and minimizing runoff. Vegetative diversity is also important and not only refers to species diversity, but reflects a range of life forms including trees, shrubs, and grasses. If the operator desires to target specific types of wildlife, it is worthwhile to discuss the vegetation plan with CDOW or a local county extension agent, to ascertain the species' appropriate requirements, and to identify any seasonal variations in forage required by the species. Wildlife is attracted to water sources that have shelter and cover from predators as well as open spaces.

Wetlands

An operator may desire to reclaim a portion or all of the site to wetlands. Wetlands supplement vegetative diversity of the site, improve the water quality within the watershed, and regulate flows and provide storage for flood control following storms. Wetlands decrease sediment loading, and may beneficially decrease nutrient loading, metals concentrations, and acidity problems, depending on their design. An operator may be able to reduce reclamation costs by entering into a relationship with an entity that is required to mitigate for wetland losses in another location. Alternatively, a gravel pit near a municipal water treatment plant may be able to incorporate wetlands into their treatment process.

Wetland construction is most effective when water has a high residence time to accommodate settling and biological transformations that improve water quality. The inlet to the wetland, or the first pond should act as a sediment settling basin. The lifetime of the wetland will be increased if this is eight-to-ten feet deep. Residence time should be at least 24 hours, and this may be achieved by having a length to width ratio of 2.5 to 3, or through the installation of baffles. The balance of the 1.5 - 3 feet deep wetland should also have a high length to width ratio, that may either be accomplished by having a long, narrow site, or more typically by routing water through the use of gravel dikes or baffles throughout the site. The use of straw bales or logs for baffles is discouraged, as they cannot act as a substrate for wetland plants, and they degrade over time resulting in short-circuiting within the wetland. The wetland should be planted with a combination of wetland species such as sedges (*Carex*), spikerushes, (*Eleocharis*), and bulrush (*Scirpus*). Cottonwood (*Populus*) and willows (*Salix*) should be planted around the edges of the wetland. These plants may be harvested from existing wetlands or may be acquired from a nursery. Contact CDPHE and the Corps of Engineers for applicable regulations associated with wetland development.

Fisheries

Establishment of a fishery requires minimization of sources of sedimentation and development of habitat. Grading should be directed toward laying back the banks, and stabilizing them with rip-rap or vegetation. Understanding the pre-mining fishery habitat characteristics will promote success in achieving this PMLU. The goals of fisheries are to emphasize diversity of habitat through variation in stream morphology (i.e., gradient, sinuosity).

A typical fishery consists of alternating pools and riffles; the pools are deeper, low velocity, fine-grained reaches, while the riffles have relatively shallow depths, higher than average velocity and coarse substrate. The pools provide resting locations, while the riffles function as food production and spawning areas. Aquatic invertebrates decrease in number and diversity as the substrate varies from rubble to sand. Riffles are more highly oxygenated zones, enhancing respiration and promoting food acquisition. Variations in substrates can be developed through the use of jetties (**Appendix D**), rock vortex weirs, and placement of boulder or timber barriers. These create variations in the velocity depth regime within the stream and create spawning areas upstream of structures and point bars downstream.

The placement of large boulders or woody debris provides cover for fish and lee side surfaces where invertebrates can anchor. Single or multiple boulders placed in a diamond or triangular pattern and ranging from two to five feet in diameter have been successfully used. Boulders should be anchored in the stream bed and located toward the middle of a stream. Large trees may need to be anchored in place perpendicular to the direction of flow using cables. Optimal velocities and depths to maximize stream productivity range from 0.5 to 3 feet per second and 0.5 to 3 feet, respectively (Hansen, 1996).

Retention of deeper areas as channel pools may be less desirable than allowing scour pools to develop. Pools within a permanent diversion allow aquatic species habitat during periods of drought. However, these same depressions may pose a migration barrier to fish, trapping them during periods of low flow. In addition, these basins may fill with sediment if the volume of periodic storm runoff is not sufficient to provide scouring flows.

The stream adjacent to the riparian zone supports an aquatic community that relies on diverse habitats. Adjacent woody riparian zones provide shade that cools the water and generates a type of cover formed by variations in light. A fishery requires cover in the form of overstory, shrubby, and wet riparian vegetation on the banks. The plants should be tolerant of fluctuating water levels that may result in saturation at times. The adjacent floodplain will be flooded during large storm events.

Industrial/Commercial/Residential PMLUs

An instream sand and gravel operation that is being converted to industrial, commercial, or residential use will require filling of the pit with inert materials. Typically, a permanent diversion is routed around the pit, and the fill is installed in lifts, to minimize long-term settling. It is appropriate to discuss such plans with the County and the CDPHE Solid Waste Division to understand the zoning and special use limits and regulatory requirements of such activities. Commercial and industrial activities within floodplains may face recurrent operating costs associated with large storm events.

In those instances where the operator's choice of PMLU is for the development of the affected land for homesite or industrial uses, the basic minimum requirements necessary to obtain bond release must be established in the permit. If the proposed PMLU is for industrial, residential, or commercial purposes and such use is not reasonably assured, an alternative plan for establishment of a beneficial PMLU may be required. These alternative plans usually involve the establishment of vegetation to stabilize the ground pending eventual development and to provide an interim beneficial use such as rangeland or wildlife habitat.

Recreation PMLU

Reclamation of the in-stream mining operation and the surrounding floodplain to a recreation PMLU can encompass a number of uses. Water-based activities range from fishing, hunting, motorized and non-motorized boating, and swimming, while open space within the floodplain activities range from hiking, walking, and nature study. Issues that need to be addressed for such a PMLU concern long-term right-of-entry, management of the land and the potentially competing users, long-term maintenance of the site, and the establishment of facilities such as parking lots, trails and bathrooms.

Mining Methods

The Mining and Operations plan should include details of the extraction operation and a demonstration of how the mining rate was selected to minimally impact the stream environment. There are basically three mining strategies, or best management practices to minimize impacts from an instream mining operation: specification of a maximum depth of mining; limiting extraction to the depth of the existing thalweg; and harvesting only the annual bedload yield of the river (**Appendix C**). For certain operations, it is recommended that a maximum depth of extraction be defined by the operator. This will avoid the cases where an operation is planned to take out the "normal, annual" bedload transport rate from upstream, but a two or more year period occurs where no normal flood event on the stream occurs, so that the stream never delivered the average annual bedload transport rate from upstream. Mining a fixed rate could cause depth changes in the stream that could result in a wide range of problems. Limiting extraction to the pre-mining depth of the channel's deepest point minimizes slope changes along the river, and prevents channel and bank erosion. This technique also retains the existing natural armoring of the channel substrate, thereby minimizing channel erosion.

Riparian habitat and streamside wetlands may be affected by disturbances associated with access. Minimization of this disturbance to a limited area on one bank will reduce the efforts required for reclamation. Reduction in the bank slope and armoring with rip-rap at the access points will also assist in minimizing this effect.

Minimization of disturbances will reduce the efforts required for reclamation and limit the potential effects to sensitive, threatened and endangered species utilizing these zones for habitat. Avoidance may be the mitigation means of choice to eliminate effects to wetlands, threatened or endangered species or cultural resources. Minimization of disturbance to valuable riparian zones is also considered mitigation. For example, a miner of ephemeral drainages may choose to mine around a cottonwood grove, to maintain the site's values to wildlife, and to maintain the bank's stability at that site.

Reclamation strategies should consider the PMLU. It may be helpful to plan for a variety of post-mining land uses, to accommodate the different needs in the area, as well as the revised geomorphology of the site. An operator may want to consider the development of wetlands for flood water retention and water quality improvement.

Concurrent/Interim Reclamation

Concurrent/interim reclamation in the in-stream aggregate extraction industry can almost always be considered due to the way that mining follows the typical lateral sediment deposits. This contributes to minimizing impacts and allows a head start on the reclamation and closure of a facility. It also reduces the financial exposure of having to fund and perform reclamation over the whole project. This, in turn, may offer ways of reducing bonding obligations for the project.

Concurrent/interim reclamation on affected lands is advisable if no further disturbance is scheduled, or if there will be no other activity in the affected area for a minimum of two years. Concurrent/interim reclamation also reduces the homogeneous appearance of reclamation and offers the diversity of different aged revegetation species. It also minimizes the cumulative environmental effects of having a complete project area exposed at any one time and susceptible to move extensive erosion and geologic instability.

General Requirements for All Reclamation Post-Mining Land Uses

All mining operations must comply with certain general requirements. These include:

- The rehabilitation of affected land to a condition that achieves the selected PMLU;
- All reclamation activities subject to concurrent, interim, and final reclamation requirements outlined in the proposed plan or regulatory performance standards; and
- All reclamation required by the approved reclamation plan completed to obtain release of liability and reclamation surety.

Other specific reclamation recommendations are provided below.

Backfilling and Grading

Grading, backfilling, and other topographic reconstruction methods must be included in reclamation plans to achieve functionally compatible contours. For example, the original drainage must be preserved as much as possible. Alternative drainage can be used if it is functionally compatible with, and maintains, the prevailing hydrologic balance of the area.

The following general criteria apply to grading, backfilling, and other topographic reconstruction methods. Grading should be suitable for the PMLU. In other words, if the PMLU is a fishery, then an alternating pool-riffle sequence should be designed for implementation.

Grading and backfilling must control erosion and sedimentation, protect areas outside the affected area, and minimize the need for long-term maintenance. Erosion control measures must be implemented during all phases of construction, operation, and reclamation. Detailed plans indicating the dimensions, location spacing, and design of the grading plan are needed. In order to minimize the production of excess sediment, it is recommended that grading, backfilling, and topographic reconstruction should be completed as soon as feasible after mining ceases.

Slopes should be structurally stable. Channel slopes should be graded to 3:1 (H:V) or gentler. Channel slopes should be protected with armoring or revegetation. The inside curves should be armored either all the way to the top of the channel, or to the top of the average water line, and then erosion mats used to protect plantings of riparian vegetation. Revegetation mats can be used to promote revegetation on straight banks or outside curves.

Hydrologic Balance

The Act and Rules and Regulations discuss minimization of disturbances to the prevailing hydrologic balance. This means that the site should not cause effects outside of the permit area to flows, channel shapes or water quality in a manner that would be contrary to all applicable laws, whether they concern water use adjudication with the Department of Natural Resources State Engineer's Office, wetland and channel policies of the U.S. Army COE, or water quality concerns with CDPHE WQCD.

In addition, an operation should manage water to minimize changes in flow or quality during operations through the use of surface runoff diversions. Unchannelized surface water from the upland watershed may need to be diverted around the operation to minimize pollution and erosion and to protect the operation and downstream users.

The 10-year 24-hour storm/precipitation event is recommended for diversion design. In soils or other unconsolidated material, the sides of the surface runoff diversion should be no steeper than two horizontal to one vertical (2:1). The sides and, in the ditches carrying intermittent discharges, the bottom must be stabilized by seeding with grasses or other methods specified in the reclamation plan. Rock rip-rap, concrete, geosynthetic liners, filter media, soil cement, or other methods also may be used for channel stabilization. Diversion ditches must not discharge onto topsoil stockpile areas, other unconsolidated material, or steep, erodible settings. Consideration should be given to culverts and bridges that may need to be installed for access.

Reclamation should return the site to at least a similar hydrogeologic balance. Temporary sedimentation, erosion, or drainage control structures must be removed after affected lands have been reclaimed and stabilized. Permanent diversion structures must be designed not to erode during the passage of the approved flow or designed precipitation event.

Diversions of Intermittent and Perennial Streams

Reclamation within stream channels and construction or reconstruction of stream channels should consider the potential for upstream and downstream impacts to channel stability and should incorporate restoration of aquatic life habitat elements such as instream roughness elements, particularly large woody debris, and restoration of channel substrate to provide spawning gravels. This may require the preparation of flood frequency analyses that can be developed from data acquired at U.S. Geological Survey (USGS) gages in the vicinity or through computer modeling of the upland contributing watershed. Modeling will require information on soils, vegetative cover, land uses, and slopes in the watershed upstream from the operation.

Permanent diversion of a stream channel to facilitate mining requires considerable planning to maintain the stream grade, depth, width, bed characteristics, lining and banks. An operator is faced with replication of the previous channel conditions or careful manipulation of many channel characteristics to minimize hydrologic impacts. Cross-sections and other hydrologic data for the existing stream above, below, and within the diversion are necessary to determine the flow capabilities, channel configuration, and shape of the diversion. Maintenance of the original channel's slope throughout the same length of channel will minimize downcutting upstream and downstream of the operation. Retention of the same slope, channel width, and bedding materials will conserve the flood capacity of the channel. It may be necessary to increase the length of the channel and form a meander to replicate the steam slope. In contrast, changes in the width of the channel will modify the velocity of water in the stream, resulting in changes in erosion or deposition.

The banks of a diverted intermittent or perennial stream need to be stabilized as soon as practicable. The banks and channel of a diverted intermittent or perennial stream should be protected where necessary by rock, geosynthetic liners, filter media, rip-rap, or similar measures to minimize erosion and degradation of water quality. Permanent diversions should be designed and constructed to prevent erosion and to carry flow consistent with the flow produced by the stream's original width, depth, shape, and gradient.

Stream beds within permanent diversions are normally composed of a series of layers. Ideally these layers include a gravel base, a fine sediment-gravel seal, a gravel scour protection layer, and an armor layer to facilitate stream bed stabilization. The bottom three layers may be replaced by a single layer consisting of a mixture of silt, sands, and small gravel placed in a series of shallow lifts. The upper armor layer stabilizes the channel bottom and provides the predominant substrate for habitat.

Spoil, topsoil, or other unconsolidated material should not be pushed into, or placed within, approximately 10 feet of the banks of a perennial or intermittent stream, or in a location that may subject them to bankfull flooding, except during construction of the diversion in accordance with an approved permit(s).

Specific Mining Recommendations for In-Stream Mining Activities

Specific recommendations for reclamation and mitigation measures for mining operations are contained in the following sections. Additional details and photographs of erosion control strategies are contained in **Appendix D**. Operators will be required to maintain reclamation structures and revegetated areas until the bond has been released. Permanent structures must be designed for long-term stability following bond release.

In-Stream Dredge Mining

Permanent Impoundments

An operator may want to consider as a PMLU the use of a dredged pit as an impoundment for water supply storage in association with a local water district. Alternatively, a water supplier may be interested in using the site for recharge into the alluvial aquifer. Most commonly, a pit is reclaimed with a recreation or fish and wildlife PMLU as an objective.

The design of the impoundment should incorporate aspects compatible with its anticipated uses. A stock watering impoundment will have different characteristics than one intended for wildlife and fish habitat, and recreation. The operator should consider if the PMLU can tolerate the anticipated water level fluctuations. The water quality should be compatible with the proposed use and should not result in water quality changes that would adversely impact to downstream users. An adequate, appropriated water supply available to sustain the associated evaporation and proposed use should be encouraged. The Natural Resources Conservation Service (NRCS) should have copies of a technical guide produced by the Soil Conservation Service (SCS) in 1989 entitled "Ponds", SCS Public Standard Publication No. 378, that provides direction for embankment and outlet works sizing. Embankment and spillway design should be consistent with the size, risk of failure and appropriate jurisdictional agency. Consultation with the State Engineer's Office is recommended to discuss dam stability and water rights issues.

Permanent impoundments for fish and wildlife uses should have undulating shorelines that may include peninsulas. Islands provide nesting habitat for waterfowl that require isolation from predators and general traffic. These should be one-to-four feet higher than the high water line, and 200 feet from the high water line perimeter if possible. Retention of a pond floor with varying elevations also promotes habitat diversity. In a pond with no substantial water flow 25 percent of the total pond area should be at least 12 feet deep to provide adequate space for overwintering species (Hansen, 1996). If there is good water flow, 25 percent of the pond needs to only be 8 feet deep. Side slopes should be 5:1 (H:V) or less to accommodate access, and prevent accidents. Kondolf (1998) recommends slope pit margins of 7 percent or less at least 65 feet out from the perimeter. Alternatively, the inclusion of several ramps with more gentle slopes can provide egress for animals that have lost their footing (Hansen, 1996). Another possibility is to establish multiple tiered benches along pit margins to provide both shallow aquatic habitat and exposed surfaces for the establishment of riparian vegetation.

Areas that see moving water, spillways, outlet channels, inlet channels, downwind shorelines, embankments and mechanical outlet works, should be stabilized with vegetation before they are needed. Steeper sections will require rip-rap, while more gentle stretches can be vegetated with riparian trees, shrubs or grasses. In general, trees should not be planted in dam embankments, as their root systems may result in failure of the dam. The surrounding disturbed areas may require a zoned planting mixture of wetland, riparian, and rangeland species for fish and wildlife uses and range.

Grade Control Structures

The depth of mining should be controlled in the harvest pit, depending upon the site specific hydrology of the permit area and the potential for upstream and downstream effects. Drop structures and weirs are exceptional for developing a fishery PMLU as their design results in alternating riffles and pools. **Appendix D** provides details for installation of these structures. The main reclamation concerns are stabilizing the disturbed bank and re-establishing bank cover. There are a variety of methods and commercial products available to retain and/or mulch a freshly seeded bank.

Bank Protection

Bank protection measures should be implemented to control erosion during and following mining activities. Several measures are available and can be used individually or in combination. These measures include bank armoring, biorevetements, vegetation stabilization, gabion baskets, and jetties. As durable rock is available from most mining operations, use of bank armoring, gabion baskets, and jetties are cost effective methods for controlling erosion. Vegetative plantings should also be used to further stabilize stream banks within and adjacent to mining operations. Design and installation details are included in **Appendix D**.

Split Channel Mining

The earthen or rock dikes used as barriers on the split channel mining should be sized to handle the 10-year 24-hour storm event. It is highly recommended that excavation only occur to a predetermined level. This level should take into account the average bedload delivered to the split channel. If the mining only excavates the material to a level that is replenished in a normal flow year, effects upstream and downstream can be minimized.

Mining of Braided Channels

The mining rate should be based on the previous year's deposition of material. The CDMG recommends that the operator commit to mine only to a certain level above the low flow level, to minimize effects. Mining of bars may not be accommodated by a constant supply of material from one year to the next. In a drought year, adequate volumes of material may not be available.

In any case, activity in this method should only take place during brief periods within the low flow period. The temporary culverts for access should be removed when mining/harvesting stops during the low flow season. Peak flows are then allowed to restore the bars and islands in the subsequent season.

Braided sites have a high potential for reclamation success since they are dynamic and channel shifting is frequent in floodplain. Rosgen (1993) suggests that vegetation presents a very high stabilization influence. Planting of willow stakes, and wetland sedges and grasses should be done the spring following mining.

Dry Ephemeral Channels

Dry ephemeral channels typically occur on mild slopes. Rosgen (1993) notes that vegetation exhibits a controlling influence against erosion for these sites. Banks should be stabilized using revegetation mats, and a combination of native and introduced species with deep rooting habits to produce a stable long-term vegetative community adapted to the area. An operator may want to include sterile winter wheat or rye for quick temporary stabilization and to act as a living mulch while the native species grow in.

OUTLINE OF DATA DESIRED FOR EVALUATION OF IN-STREAM MINING PERMITS

In the case of in-stream mining, it is particularly important, both for the operator and the regulatory agency, that good baseline information be provided for a permit application. In-stream mining receives special scrutiny from nearby landowners, environmental groups, other state and federal agencies, and county officials. Consultation with the regulatory authorities discussed throughout this document (listed in **Appendix F**) should provide the planning necessary for collection of appropriate baseline information. Some in-stream operations have resulted in complaints that are, at times, difficult to resolve due to the lack of good historical data on the geomorphology of the stream.

Environmental baseline development is an essential permitting requirement for most mining projects. This information is very helpful in the development of mine plans and choosing a PMLU. In addition, environmental baselines serve as excellent tools in assessing the success or lack of success of completed reclamation. In general, baseline data for in-stream operations may utilize any of the following:

<u>Aerial Photographs and Site Mapping</u> - Aerial photographs are usually obtained from the county, NRCS (formerly SCS), USGS, Forest Service, Bureau of Land Management, or other sources. Photos taken at different times are particularly valuable for planning of operations. Topographic maps along with aerial photos should provide the basis for mapping of resources and presentation of mine plans.

<u>Climate</u> - Meteorological data will help in the selection of reclamation species that are adapted to precipitation zones. Wind speed and wind direction may assist in determining of where to plant trees and shrubs in optimum locations to minimize dust from disturbed areas.

<u>Vegetation</u> - Inventories of baseline communities prior to mining are an excellent starting point for determining what will grow during operations (interim), and after reclamation (final). Collection of seed from nearby areas provides an excellent opportunity for propagation success. If diversity of species is important to the overall reclamation goal(s), then knowing what may be compatible is important.

<u>Wildlife</u> - Determining the species that inhabit the area (year around or seasonal) is important in planning reclamation. Knowing and determining cover, browse, and edge opportunities will play an important role in reclamation planning. Such information may be available from local CDOW or NRCS offices.

<u>Water Resources</u> - Information such as the drainage area in square miles, typical land uses, slopes and seasonal changes in the watershed should be secured. Locations and descriptions of upstream dams, irrigation structures, and bridges should also be provided. Estimates and/or data of the historic patterns of stream movement within the floodplain, grade mapping for the permit area and

one mile upstream and downstream, stream classification, bed description to include size consistency of the material, thickness, and characterizations of the substrate below the bed to be mined or harvested. Modeling may be used to characterize the geomorphological impacts associated with the proposed operation. This could support an operator's contention that the in-stream gravel operation would have minimal impacts. Two computer models that may be helpful are Boss SMS and MIKE 11 developed by Boss International and the Danish Hydraulic Institute.

Contact with CDMG and/or hydrological consultants should be considered early in your project planning. Cross-sections should be provided at intervals adequate to define the pre-existing condition of the stream in the permit area and above and below the permit area. The cross-sections are important so that documentation is available showing any change in the stream channel. This can also protect the operator from false accusations of altering the stream. Flow rates throughout the year are important (large streams usually have USGS gages). Estimates may also be made for the stream aggradation or degradation rate in the permit area. A hydrologic analysis may be provided to describe the current channel's tendency to erode banks, develop meanders, braids and bars. Historic flood data may also be helpful.

In terms of addressing WQCD water quality issues, that agency should be contacted for recommendations. Any springs or wells within an area that could be affected by the operation should be located, mapped, and tested. Historic minimum and maximum flows should be reported. Seasonal variations in the water table elevation in the alluvium should be provided for at least two sites within the permit area for all operations unless it is demonstrated that the level is well below the excavation area (in the case of mining sand in some dry ephemeral channels) and will not be affected by mining.

This baseline data offer an excellent basis for assessing interim and final reclamation successes. It also serves as a mechanism for determining if additional or alternative reclamation practices are warranted. Even though surface water quality is the responsibility of the WQCD, the water quality baseline information can also assist in selection of an appropriate PMLU (i.e., can the water quality support fisheries, aquatic, and/or wildlife habitat?). One can also assess whether the water quality can support irrigation practices (Agricultural PMLU).

Aquatic Resources - Questions regarding impacts to aquatic resources, and baseline information needs should be directed to the CDOW, and USFWS. The information should then be included in the operator's permit application. Similar to the water quality baseline listed above, aquatic, macroinvertebrate, and fisheries baselines may be used to determine the condition of a stream or river. If certain species are needing improved or increased habitat, this can guide proposed reclamation practices. Success of reclamation can be assessed by subsequently evaluating quality and quantity of species. Pre-mine aquatic life habitat condition should also be rigorously evaluated.

Soils and Geology - These baselines provide excellent information on reclamation potential of the material that may be available for use in reclamation. Quantities and quality of topsoil will help determine if the intended PMLU can be met, or if additional material is needed. Determining quality of material can tell a project proponent or regulator what amendments are necessary to promote revegetation, or what kind of vegetation is appropriate for the specifics of the area. Contact with the local NRCS is recommended for help in this area.

Monitoring Plan - A permit should include a plan to monitor the operation. Minimum monitoring should include periodic channel shape characterization, with cross-sections upstream and downstream, channel slopes along the mined reach, photo documentation, and water quality analyses. CDMG recommends a survey of designated cross-sections and photo/documentation of the banks once per year following peak flow. Annual aerial photos of the site and areas two miles upstream and downstream are encouraged but not required. Streambed conditions below the operation may require monitoring to assess potential siltation of spawning gravels. Other site-specific resources such as wildlife, fish, or threatened and endangered species should also be monitored as necessary for a given area, as required by the CDOW and USFWS. Surface water monitoring may be required by CDPHE through their NPDES or stormwater management program.

Typically, groundwater quality is not an issue at instream gravel mining operations. However, groundwater quantity or elevation is likely to be an issue. Groundwater elevation or quantity should be monitored near the upstream and downstream boundaries of the operation. There should also be several monitoring points established perpendicular to the river and across the width of the floodplain at the downstream location to identify impacts at a distance from the stream. If groundwater wells for monitoring are installed, the wells should be installed in accordance with well construction rules issued by the State Engineer's Office. Existing wells may be substituted for new monitoring points if completion information about the depth and perforated interval are available. Groundwater level monitoring should occur quarterly. Please contact CDMG concerning groundwater monitoring appropriate to your site.

The results of the above referenced investigations and studies will provide the basis for determining the PMLU(s) of a project. The baseline studies should not be analyzed independently of one another but should be collected and evaluated by the applicant to determine the most appropriate PMLU that offers the greatest opportunity for success. In addition, the collected baseline information and analysis should be submitted to the appropriate agencies as documentation of site conditions prior to mining.

SUMMARY

In many different mining scenarios presented in this publication, the recommended extraction rate for an in-stream operation is the bedload transport rate. In this way, channel effects such as head cutting, channel incision, bank erosion, harm to structures, etc. can be minimized. This, however, does not mean that all effects off the property can be totally avoided. If a natural stream is accustomed to moving 20,000 tons of bedload per year at a certain area and an operation is started to extract this transport rate, the downstream reaches are no longer receiving their 20,000 tons per year. Since the water downstream of the operation is now free of bedload, the stream will pick up bedload to replace what is being removed. One should also expect a deviation from the average annual bedload transportation.

Detailed analysis of ecological or structural effects of aggregate extraction is beyond the scope of this publication. However, the discussion illustrates how analysis and understanding of the physical effects are necessary to evaluate ecological effects. Examples are provided in the studies of how ecological effects can result from physical changes such as the scouring of bed gravels and exposure of underlying substrates not suitable as habitat, and the destruction of pool and riffle structure, that are important for habitat.

Few streams or river basins have had historic or projected future effects of aggregate extraction determined. It is the intent that the presentation of the information contained in this publication will promote creative planning, mitigation, and reclamation. Discussions with and permit approval by CDMG and other regulatory authorities mentioned in this document should accomplish this goal. Implementation of these plans should adequately minimize potential effects of in-stream aggregate extraction.

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APPENDIX A
GLOSSARY AND ABBREVIATIONS

GLOSSARY

abandoned channel - A channel that was once an active or high-water channel, but currently flows only during infrequent floods.

active channel - A channel that contains flowing water during the ice-free season.

active floodplain - The portion of a floodplain that is flooded frequently; it contains flowing channels, high-water channels, and adjacent bars, usually containing little or no vegetation.

aggradation - Deposition of gravelly materials.

alluvial river - A river that has formed its channel by the process of deposition, and the sediment that it carries (except for the wash load) is similar to that in the bed.

armor layer - A layer of sediment that is coarse relative to the material underlying it and is erosion resistant to frequently occurring floods; it may form naturally by the erosion of finer sediment, leaving coarser sediment in place or it may be placed by man to prevent erosion.

backwater analysis - A hydraulic analysis, the purpose of which is to compute the water surface profile in a reach of channel with varying bed slope or cross-sectional shape, or both.

bank - A comparatively steep side of a channel or floodplain formed by an erosional process; its top is often vegetated.

bankfull discharge - Discharge corresponding to the stage that the overflow plain begins to be flooded.

bar - An alluvial deposit or bank of sand, gravel, or other material, at the mouth of a stream or at any point in the stream flow.

beaded stream - A small stream containing a series of deep pools interconnected by very small channels, located in areas underlain by permafrost.

bed - The bottom of a watercourse.

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

bedload material - That part of the sediment load of a stream that is composed of particle sizes found in appreciable quantities in the shifting portions of the stream bed.

bed, movable - A stream bed made up of materials readily transportable by the stream flow.

bed, stream - The bottom of a stream below the summer flow.

berms - Areas of native material or fill material separating a river or stream from the overbank gravel pits or one overbank gravel pit from another overbank gravel pit.

braided river - A river containing two or more interconnecting channels separated by unvegetated gravel bars, sparsely vegetated islands, and occasionally, heavily vegetated islands. Its floodplain is typically wide and sparsely vegetated, and contains numerous high-water channels. The lateral stability of these systems is quite low within the boundaries of the active floodplain.

carrying capacity, discharge - The maximum rate of flow that a channel is capable of passing.

channel - A natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. It has a definite bed and banks that serve to confine the water.

configuration - The pattern of a river channel(s) as it would appear by looking vertically down at the water.

contour - A line of equal elevation above a specified datum.

cover, bank - Areas associated with or adjacent to a stream or river that provide resting, shelter, and protection from predators - e.g., undercut banks, overhanging vegetation, accumulated debris, and others.

cross section area - The area of a stream, channel, or waterway opening, usually taken perpendicular to the stream centerline.

current - The flowing of water, or other fluid. That portion of a stream of water that is moving with a velocity much greater than the average or in which the progress of the water is principally concentrated (not to be confused with a unit of measure, see velocity).

D_{50} - The median diameter of rip-rap. Half of the particles sizes are greater than the D_{50} and half are smaller.

datum - Any numerical or geometrical quantity or set of such quantities that may serve as a reference or base for other quantities. An agreed standard point or plane of stated elevation, noted by permanent benchmarks on some solid immovable structure, from which elevations are measured, or to which they are referred.

dewater - The draining or removal of water form an enclosure or channel.

discharge - The volume of water flowing in a given stream at a given place and within a given period of time, expressed as cubic feet per second (cfs).

drainage area - The entire area drained by a river or a system of connecting streams such that all stream flow originating in the area is discharged through a single outlet.

dredge - Any method of removing gravel from active channels.

drift, invertebrate - The aquatic or terrestrial invertebrates that have been released from (behavioral drift), or have been swept from (catastrophic drift) the substrate, or have fallen into the stream and move or float with the current.

duration curve - A curve that expresses the relation of all the units of some item such as head and flow, arranged in order of magnitude along the ordinate, and time, frequently expressed in percentage, along the abscissa; a graphical representation of the number of times given quantities are equaled or exceeded during a certain period of record.

endangered Species - Any species of animal or plant that is in danger of extinction throughout all or significant portions of its range and has been designated "endangered" in the Federal Register by the Secretary of the Interior. Disturbance of the habitat of endangered species is prohibited by the Endangered Species Act of 1973, as amended.

erosion, stream bed - The scouring of material from the water channel and the cutting of the banks by running water. The cutting of the banks is also known as stream bank erosion.

FHAD - A Flood Hazard Area Delineation report prepared by an Urban Drainage & Flood Control District.

fines - The finer grained particles of mass of soil, sand, or gravel. The material, in hydraulic sluicing, that settles last to the bottom of a mass of water.

flood - Any flow that exceeds the bankfull capacity of a stream or channel and flows out of the floodplain; greater than bankfull discharge.

floodplain - The relatively level land composed of primarily unconsolidated river deposits that is located adjacent to a river and is subject to flooding; it contains an active floodplain and sometimes contains an inactive floodplain or terrace(s), or both. Land adjacent to a watercourse that is subject to flooding as a result of the occurrence of the 100-year or 1 percent frequency flood watercourse.

flood probability - The probability of a flood of a given size being evaluated or exceeded in a given period; a probability of 1 percent would be a 100-year flood, a probability of 10 percent would be a 10-year flood.

flood profile - A graph or longitudinal profile showing the relationship of the water surface elevation of a flood event to location along a stream or river.

floodway - That area of the floodplain required for a reasonable passage or conveyance of the 100-year flood and that will convey the flood flows with not more than 0.5 foot rise in the water surface elevation based on the assumption that there will be an equal degree of encroachment onto the overbank conveyances on both sides of the floodplain.

flow - The movement of a stream of water or other mobile substances, or both, from place to place; discharge; it comprises the total quantity carried by a stream.

flow, base - That portion of the stream discharge that is derived from natural storage - i.e., groundwater outflow and the draining of large lakes and swamps or other sources outside the net rainfall that creates the surface runoff; discharge sustained in a stream channel, not a result of direct runoff and without the effects of regulation, diversion, or other works of man. Also called sustaining flow.

flow, laminar - That type of flow in a stream of water that each particle moves in a direction parallel to every other particle.

flow, low - The lowest discharge recorded over a specified period of time.

flow, low summer - The lowest flow during a typical year.

flow, uniform - A flow in which the velocities are the same in both magnitude and direction from point to point. Uniform flow is possible only in a channel of constant cross section.

flow, varied - Flow occurring in streams having a variable cross section or slope. When the discharge is constant, the velocity changes with each change of cross section and slope.

frequency curve - A graph documenting the frequency of flow. The event that occurs most frequently is termed the mode.

gage - A device for indicating or registering magnitude or position in the specific units, e.g., the elevation of a water surface or the velocity of flowing water. A staff graduated to indicate the elevation of a water surface.

geomorphology - The study of the form and development of landscape features.

habitat - The place where a population of animals lives and it surroundings, both living and nonliving; includes the provision of life requirements such as food and shelter.

high-water channel - A channel that is dry most of the ice-free season, but contains flowing water during floods.

high water line - The elevation used to determine the volume of overbank gravel pits. The high water line elevation shall be the spillway elevation when only one spillway is used or the average of both spillways when two are used.

Hungry River - A river that has dropped its bedload in a depositional basin and is in the process of acquiring it downstream.

hydraulic radius - The area of flow divided by the length of the section or channel perimeter exposed to water.

hydraulics - The science of dealing with the mechanical properties of fluids and their application to engineering; river hydraulics deals with mechanics of the conveyance of water in a natural watercourse.

hydraulic depth - The average depth of water in a stream channel. It is equal to the cross-sectional area divided by the surface width.

hydraulic geometry - Those measures of channel configuration, including depth, width, velocity, discharge, slope, and others.

hydraulic radius - The cross-sectional area of a stream of water divided by the length of that part of its periphery in contact with its containing channel; the ratio of area to wetted perimeter.

hydrograph - A graph showing, for a given point on a stream, the discharge, stage, velocity, or another property of water with respect to time.

hydrology - The study of the origin, distribution, and properties of water on or near the surface of the earth.

impervious - A term applied to a material that water cannot pass through or that water passes with great difficulty.

inactive floodplain - The portion of a floodplain that is flooded infrequently; it may contain high-water and abandoned channels and is usually lightly to heavily vegetated.

in-stream mining - Mines located in the channel of a river or any of its tributaries, or gravel mines that were originally out of the channel if it is proposed to relocate the river or stream through those gravel mines in the future.

interior banks - Banks that face the interior portion of gravel pits.

invert - The lowest point or elevation in the river or stream channel.

island - A heavily vegetated sediment deposit located between two channels.

jetties (groins) - Bank stabilization technique involving the placement of strips of stabilized fill projecting into the river channel from the banks.

lateral bar - An unvegetated or lightly vegetated sediment deposit located adjacent to a channel that is not associated with a meander.

lateral berms - Berms constructed or left in place between pits that are perpendicular to the general direction of flow of a river or a stream.

low flow channel - That portion of the channel that is subjected to continuous flow or frequent flows and where the flows are concentrated.

Manning's equation - In current usage, an empirical formula for the calculation of discharge in a channel. The formula is usually written

$$Q = \frac{1.49}{n} R^{2/3} S^{1/2} A$$

where Q is discharge, n is the Manning's n roughness coefficient, R is the hydraulic radius of the channel (feet), S is the slope (ft/ft) and A is the cross-sectional area of the channel flow.

mean flow - The average discharge at a given stream location computed for the period of record by dividing the total volume of flow by the number of days, months, or years in the specified period.

mean water velocity - The average velocity of water in a stream channel, that is equal to the discharge in cubic feet per second divided by the cross-sectional area in square feet. For a specific point location, it is the velocity measured at 0.6 of the depth of the average of the velocities as measured at 0.2 and 0.8 of the depth.

meander wave length - The average down valley distance of two meanders.

meandering river - A river winding back and forth within the floodplain. The meandering channel shifts down valley by a regular pattern of erosion and deposition. Few islands are found in this type of river and gravel deposits typically are found on the point bars at the insides of meanders.

microhabitat - Localized and more specialized areas within a community or habitat type, utilized by organisms for specific purposes or events, or both. Expresses the more specific and functional aspects of habitat and cover that allows the effective use of larger areas (aquatic and terrestrial) in maximizing the productive capacity of the habitat. (See cover types, habitat.)

mid-channel bar - An unvegetated or lightly vegetated sediment deposit located between two channels.

parameter - A variable in a mathematical function that, for each of its particular values, defines other variable sin the function.

permafrost - Perennially frozen ground.

pit excavation - A method of removing gravel, frequently from below overburden, in a manner that results in a permanently flooded area. Gravels are usually extracted using draglines or backhoes.

pitside banks - The interior bank of a gravel pit located adjacent to a river or a stream.

point bar - An unvegetated sediment deposit located adjacent to the inside edge of a channel in a meander bend.

pool - A body of water or portion of a stream that is deep and quiet relative to the main current.

pool, plunge - A pool, basin, or hole scoured out by falling water at the base of a waterfall.

profile - In open channel hydraulics, it is the water or bed surface elevation graphed against channel distance.

reach - A comparatively short length of a stream, channel, or shore. A hydraulic engineering term to describe longitudinal segments of a stream or river.

regional analysis - A hydrologic analysis, the purpose of which is to estimate hydrologic parameters of a river by use of measured values of the same parameters at other rivers within a selected region.

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

riparian - Pertaining to anything connected with or adjacent to the banks of a stream or other body of water.

riparian vegetation - Vegetation bordering floodplains and occurring within floodplains.

rip-rap - Large sediments or angular rock used as an artificial armor layer. Broken stone or boulders placed compactly or irregularly on earth or gravel surfaces to protect against the erosive action of water.

river banks - The banks of a river or a stream.

river regime - A state of equilibrium attained by a river in response to the average water and sediment loads it receives.

riverside berms - Berms immediately adjacent to a river or a stream (see berms).

rubble - Inert materials such as concrete blocks, broken concrete, or concrete pavement with a specific gravity of 2.3 or greater that can be used in lieu of rock rip-rap for erosion protection.

run - A stretch of relatively deep fast flowing water, with the surface essentially non-turbulent.

safety factor - The ratio of forces resisting movement to those attempting to initiate movement (abbreviated SF).

scour - The removal of sediments by running water, usually associated with removal from the channel bed or floodplain surface.

scrape - A method of removing floodplain gravels from surface deposits using tractors or scrapers.

sediment discharge - The volumetric rate of sediment transfer past a specific river cross section.

setback - The distance between any property line and the wall or support of structure. Setbacks are not applicable to fences except where specifically indicated. It may also refer to the distance between the top of the streambank and land proposed to be affected by the mining activities.

sinuous river - Sinuous channels are similar to meandering channels with a less pronounced winding pattern. The channel may contain smaller point bars and have less tendency for down valley shifting. The channels are more stable with respect to lateral shifting.

sinuosity - A measure of the amount of winding of a river within its floodplain; expressed as a ratio of the river channel length to the corresponding valley length.

slope - The inclination or gradient from the horizontal of a line or surface. The degree of inclination is usually expressed as a ratio, such as 25:1 (H:V), indicating 25 units of horizontal distance per one unit vertical rise.

split river - A river having numerous islands dividing the flow into to channels. The islands and banks are usually heavily vegetated and stable. The channels tend to be narrower and deeper and the floodplain narrower than for a braided system.

stage - The elevation of a water surface above or below an established datum or reference.

straight river - The thalweg of a straight river typically winds back and forth within the channel. Gravel bars form opposite where the thalweg approaches the side of the channel. These gravel bars may not be exposed during low flow. Banks of straight systems typically are stable and floodplains are usually narrow. These river systems are considered to be an unusual configuration in transition to some other configuration.

subarctic - The boreal forest region.

suspended load - The portion of stream load moving in suspension and made up of particles having such density of grain size as to permit movement far above and for a long distance out of contact with the stream bed. The particles are held in suspension by the upward components of turbulent currents or by colloidal suspension.

terrace - An abandoned floodplain formed as a result of stream degradation and that is expected to be inundated only by infrequent flood events.

thalweg - The line following the lowest part of a valley, whether under water or not; also usually the line following the deepest part or middle of the bed or channel of a river or stream. The lowest portion of a river or stream channel.

threatened Species - Any species of animal or plant that is likely to become endangered within the foreseeable future throughout all or significant portions of its range. It has been designated in the Federal Register by the Secretary of the Interior as a threatened species. Disturbance of the habitat of threatened species is prohibited by the Endangered Species Act of 1973, as amended.

top width - The width of the effective area of flow across a stream channel.

velocity - Speed or rate; the distance traveled divided by the time required to travel that distance.

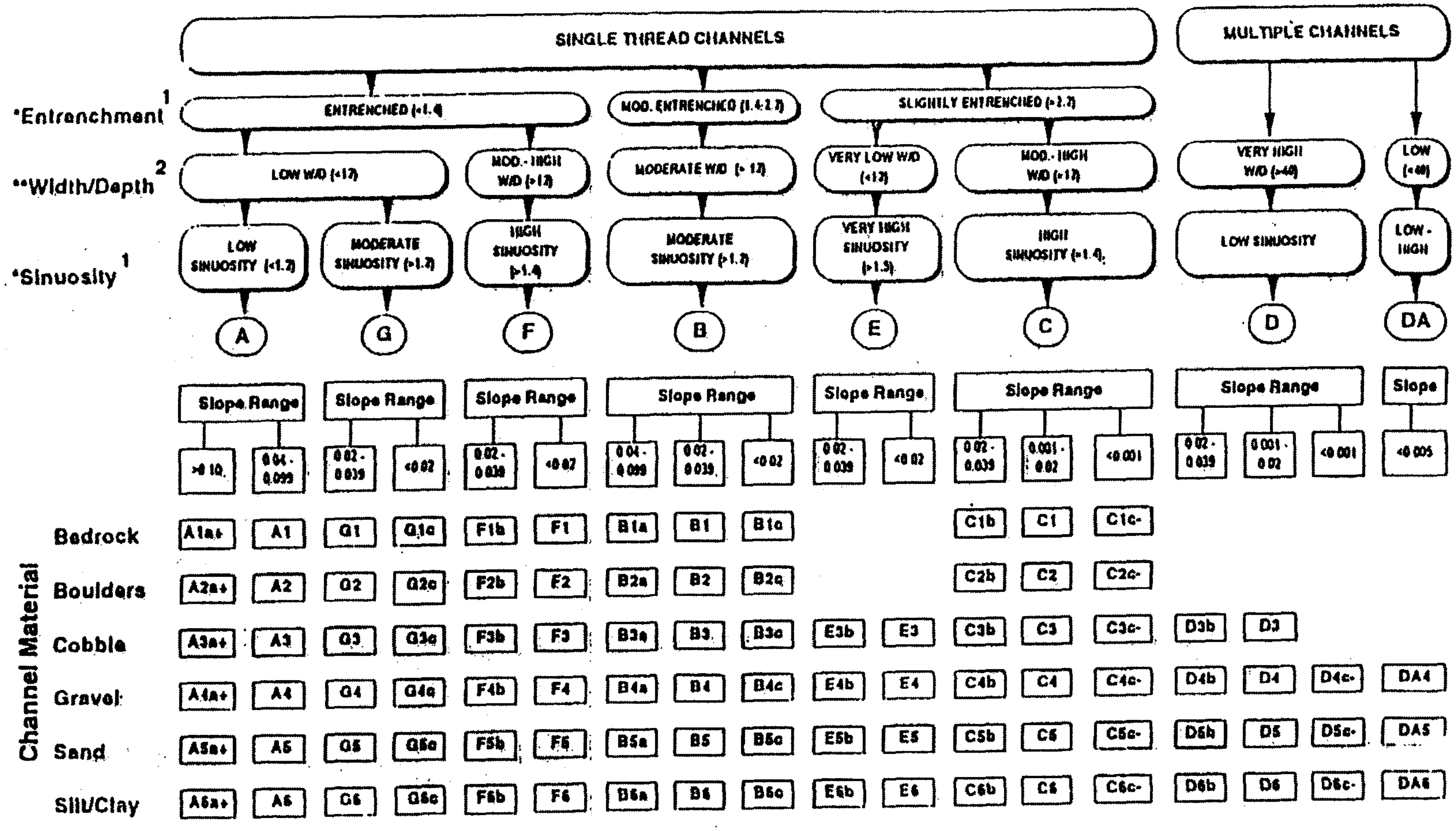
wash load - In a stream system, the relative fine material in near-permanent suspension, that is transported entirely through the system, without deposition. That part of the sediment load of a stream that is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of the stream bed.

water quality - A term used to describe the chemical, physical, and biological characteristics of water in reference to its suitability for a particular use.

wetted perimeter - The length of the wetted contact between the stream of flowing water and its containing channel, measured in a plane at right angles to the direction of flow.

wildlife - All living things that are neither human nor domesticated; most often restricted to wildlife species other than fish and invertebrates.

APPENDIX B
ROSGEN CLASSIFICATION SYSTEM



[1] Values can vary by ± 0.2 units as a function of the continuum of physical variables within stream reaches.

[2] Values can vary by ± 2.0 units as a function of the continuum of physical variables within stream reaches.

Figure B-1
Key to Classification of Natural Rivers

APPENDIX C
ESTIMATES OF EXISTING STREAM BEDLOAD TRANSPORT RATES

ESTIMATES OF EXISTING STREAM BEDLOAD TRANSPORT RATES

It is very valuable for the operator and regulatory agency to make some estimate of the normal aggradation or degradation rate of the stream channel segment in the area around a particular mining operation. In almost all cases, the stream segment should be aggrading, since these areas provide the best opportunity for harvesting material.

Sediment in a stream is made up of bedload and suspended load. One method of measuring bedload is defined as that portion of the load that enters a 3-inch high square orifice resting on the stream bed (Emmett, 1981). Larger particles are also considered bedload. All other sediment moving above this point is considered suspended load.

A number of factors make measuring bedload a very difficult task:

1. In most ephemeral and perennial streams in the western U.S., the entire bedload for a year period may be due to large runoff events that only occur a few days a year.

2. An event that may occur once in ten years may move more sediment in a 24-hour period than a combination of several previous years. As the total sediment and bedload increases, the specific gravity of the flow becomes greater, making it easier to lift and carry larger particles, and resulting in an exponential effect on the carrying capacity of the stream. The extreme case of this phenomena is a debris flow that is the result of an unusually large runoff event that can carry large boulders downstream for considerable distances.

3. Many factors can change the bedload of a stream such as changes in land use in the watershed, irrigation ditches, development in the floodplain, stock ponds, reservoir development, etc. In many cases, landowners have armored banks in the natural stream to protect their land and many vegetated bars have been converted to agriculture, preventing the stream from moving within the floodplain in its natural way.

4. The measuring equipment is expensive and must be utilized over a few year period to produce any meaningful results.

METHOD #1 - DIRECT SAMPLING

A standard method of sampling involves the use of the Helley-Smith bedload sampler. This streamlined weighted collection device is lowered into the stream during a flow event at various points along a channel cross-section. The sampler collects bedload for a prescribed period of time at each location. Volume of the discharge is also measured during sampling. After a number of events are recorded in this manner, a log-log graph relationship is built between the rate of discharge and the amount of bedload measured. From this relationship, bedload can be theoretically predicted for other water discharges not sampled.

Data should also be collected from various seasons throughout the year. Large events should obviously not be missed since they will contain the most bedload.

In order to predict an average annual bedload, estimates of the average daily flows should be made for the entire year. Daily flow data are published by the U.S. Geological Survey for all gaging stations, that are located on most major streams and rivers. Average daily flows should be made by averaging at least 10 years of data.

This method has the drawbacks of expensive sampling and data reduction to produce an estimate that could be significantly inaccurate if no large events were measured during the sampling period.

METHOD #2 - BEDLOAD TRANSPORT FORMULA

A number of formulae for bedload transport have been developed and care must be taken to use a particular formula within the limits that it was determined. It may prove difficult to evaluate certain streams by the formulae, particularly extremely steep rivers with very coarse bed material.

The formulae produce a relationship between instantaneous water discharge (usually cfs) and bedload transfer (usually tons/day) similar to that produced from the Helley-Smith sampler described in Method #1. This relationship is converted to an annual bedload transport using USGS gage data or other information as described above in Method #1.

The bedload transport formulae are useful for approximate estimates of annual movement at a fixed point in the stream. Most formulae have been designed for sand-bedded alluvial channels and are based on the following assumptions (Reid and Dunne, 1996):

- discharge remains constant for long periods;
- downstream variations of depth and velocity are minor; and
- there is an infinite supply of sediment of grain sizes represented by some component of the bed material.

These conditions are not well-met in many mountain channels. Also, the hydraulics of steeper, gravelly-bedded channels is complex and not as well-understood as the sand-bedded channels. Nevertheless, the formulae present a relatively easy way to estimate bedload transport and some equations do address gravelly-bedded streams.

The use of bedload transport formulae requires estimation of the following parameters:

- grain-size distribution of the bed material in the stream;
- accurate cross sections in the area of question;
- average longitudinal surface slope of the water; and
- relationship between depth of the stream and discharge (Manning's formula).

A list of bedload equations with average sediment size and grain size mixtures are shown in **Table C-1** (Reid and Dunne, 1996).

Table C-1 - Sediment Transport Equations

A. BEDLOAD

Equation	Code	Sediment D_{50}(mm)	Grain-Size Mixture	Data*		Reference
				fl	ch	
Bagnold 1956	B56					
Bagnold 1980	B80	1.1?	uniform	x		Bagnold 1956
Diplas	Di	54	mixture	x		Bagnold 1980**
du Boys/Straub	Du	0.1-4?	uniform?	x		Diplas 1987
Einstein, bedload	Eb	0.3-29	uniform?	x		Vanoni 1975, Brown 1950
Einstein/Brown	EB	0.3-29	uniform?	x		Vanoni 1975, Einstein 1950
Engelund/Fredsoe	EF					Nakato 1990**
Kalinske	Ka					Graf 1971, Kalinske 1947
Meyer-Peter	MP	3-29	uniform	x		Vanoni 1975
Meyer-Peter/Muller	MM	0.4-29	mixture	x		Vanoni 1975
Parker 1982	P82	54	mixture	x		Gomez and Church 1989, Parker et al. 1982
Rijn, bedload	Rb	0.2-2	mixture?	x		Rijn 1984a
Rottner	Ro					Rottner 1959
Schoklitsch 1934	S3	0.3-5	mixture?	x		Vanoni 1975, Graf 1971
Schoklitsch 1943	S4	sand?	mixture	x	x	Gomez and Church 1989, Graf 1971
Shields	Sh	1.6-2.5	uniform	x		Vanoni 1975, Graf 1971
Toffaleti	To	sand	mixture	x	x	Vanoni 1975, Toffaleti 1969
Yalin 1963	Ya	0.3-29	mixture	x		Gomez and Church 1989
Yang 1984	Y84	2-7?	uniform	x		Yang 1984

* Primary source of data used to develop equation: fl+ flume, Ch=Channel.

** Reference corrects earlier version of equation.

Where possible, references are given that discuss or illustrate the use of the equations. Where these are not available, only the primary source is given.

Table C-2 shows how various formulae performed when tested on actual streams within the design range. This table shows results for different stream types, ranging from gravel-bedded medium to sand-bedded large. The **Equation Type** column shows whether bedload or total load is being tested. It is seen that very few bedload formulae have been tested in actual streams.

Table C-2 - Potentially Useful Sediment Transport Equations for Channels of Various Types *(Explanation of symbols and headings is shown below)* (Reid and Dunne, 1996)

	Equation type	Modal ratio	Rivers	Independent tests/total	Rank
Gravel-bedded, medium					
Bagnold 1980	b	0.20	4	2/6	B
Gravel-bedded, braided					
Meyer-Peter/Muller	b	0.00	3	3/3	A
Sand-bedded, small					
Ackers/White	t	0.11	6	6/9	B
Laursen	t	0.24	3	3/5	B
Shen/Hung 1972	t	0.20	2	2/2	C
Yang 1973	t	0.20	2	½	E
Toffaleti, total	t	0.40	3	3/3	E
Meyer-Peter/Muller	b	0.42	4	10/10	E
Schoklitsch 1934	b	0.45	3	5/5	E
Sand-bedded, medium					
Shen/Hung 1972	t	0	3	3/5	A
Einstein, modified	t	0	3	3/4	A
Ackers/White	t	0.05	3	5/7	A
Maddock	t	0.06	3	3/6	A
Blench	t	0.07	3	5/5	A
Yang 1973	t	0.07	3	2/5	B
Rottner	b	0.00	2	3/3	C
Einstein, total	t	0.40	2	5/5	D
Colby 1964	t	0.13	5	5/6	D
Toffaleti, total	t	0.22	4	6/9	D
Bishop et al.	t	0.22	4	2/6	D
Kalinske	b	0.46	2	5/5	D
Bagnold 1966	t	0.14	6	2/6	E
Schoklitsch 1934	b	0.22	3	5/5	E
Einstein, bedload	b	0.33	3	6/6	E
Sand-bedded, large					
Toffaleti, total	t	0.08	6	5/10	A
Einstein, modified	t	0	5	6/6	A
Colby 1964	t	0.20	2	3/4	C
Ackers/White	t	0.24	5	2/6	D
Bagnold 1956	b	0.38	3	3/3	E

Equation type: t = total-load equation, b = bedload equation.

Modal ratio: Percent of tests outside a factor of 2.

Rivers: number of rivers tested within the river category.

Independent tests/total: number of comparisons by independent users for river class/total number of comparisons.

Table C-2, Continued

Rank: listed from A (high) to E (low) according to the following criteria:

A Three or more channels tested.
Modes for each river tested within a factor of 2 of measured values for all (sediment loading comparison).
Fewer than 10% of test quarterlies off by more than a factor of 2 for all tests (sediment transport comparison).
Three or more independent tests.

B Three or more channels tested.
Modes for each river within a factor of 2 of measured values for all tests (sediment loading comparison).
Fewer than 25% of test quarterlies off by more than 2x for all tests (sediment transport comparison).
Two or more independent tests.

C Two or more channels tested.
Modes within a factor of 2 for all tested.
Fewer than 25% of test quarterlies off by more than 2x for all tests (sediment transport comparison).
Two or more independent tests.

D Two or more channels tested.
Modes for each river within a factor of 2 of measured values for at least 75% of tests.
Fewer than 50% of test quarterlies off by more than 2x for all tests (sediment transport comparison).
At least one independent test.

E Two or more channels tested.
Modes within a factor of 2 for more than 50% of all tested.
Fewer than 50% of test quarterlies off by more than 2x for all tests (sediment transport comparison).
At least one independent test.

From the results, it is seen that the Bagnold, 1980 formulae is good for gravel-bedded medium streams. Braided streams and sand-bedded small streams should use the Meyer-Peter/Mueller formula. Sand-bedded medium streams should use the Rottner formula and sand-bedded large streams should use the Bagnold, 1956 formula, although its testing performance was somewhat disappointing. More than one formula should be used and then compared for greater accuracy. Overall, however, this method is acceptable as a method for determining bedload transport. Actual demonstrations of each of these formulae is beyond the scope of this publication, however, references are provided for the formulae recommended.

METHOD #3 - ESTIMATION OF BEDLOAD FROM SUSPENDED LOAD

Very little bedload data exists for many rivers and streams in the United States. However, it is common that considerable data is available for suspended load from a variety of sources such as the USGS, State and County Health Departments, EPA, existing water reports and environmental reports, etc.

A reasonably accurate estimation of bedload can be made directly from the suspended load:

a. For streams in mountainous areas, the bedload is normally 8-16% of the suspended load;

b. For moderately sloped streams, the bedload is normally 4-10% of the suspended load; and

c. For mildly sloped rivers in lowlands, the bedload is typically 2-6% of the suspended load.

In arriving at a particular percentage for a given location in a river, investigation should be done to see if any bedload and suspended load data is available for similar streams in the region to provide a comparison.

Care must be taken in interpreting the suspended load data before making the prediction of bedload. If daily suspended load is available along with daily flows, a reasonable estimate of annual bedload can be made directly. A few measurements of suspended load during large flow events cannot be solely used to predict the suspended load throughout the year. Average annual flow and annual average suspended load can also be used, if available.

This method is by far the easiest and in many cases yields equally acceptable results to more expensive and time-consuming investigations.

METHOD #4 - ESTIMATING BEDLOAD FROM BAR ACCRETION OR BANK EROSION

In many sinuous or meandering streams, it may be possible to measure the amount of bedload transported within a given interval of time by examining aerial photographs and estimating the movement of bars. This is done by first developing a projected scaled image of the photographs and then applying a grid to the photographs (**Figure C-1**). A volume of material moved is then computed by counting the grid squares of bars in a particular reach of stream that have moved. An average height is assigned to the bar movement that is best done by visual observation in the stream itself. The result is a very rough estimate of the bedload transport.

This method is best applied to streams that are heavily aggrading, since bedload movement in these streams usually occurs over a shorter distance than other types of streams. This method obviously does not measure any bedload that is carried further downstream, tending to make the estimate somewhat conservative.

METHOD #5 - BEDLOAD ESTIMATION FROM RESERVOIR DEPOSITION

Bedload transport in a particular stream or river with no data can be estimated by reservoir deposition measurements over time in similar streams or rivers. Care must be taken to compare the drainage area, geology, land use and presence of other reservoirs of the rivers in question to draw reasonable conclusions.

The material deposited in rivers includes bedload and part of the suspended load. This suspended load must be subtracted to determine bedload. This is done by determining the total suspended load from USGS or other data and then determining the amount of suspended load that is leaving the reservoir. A mathematical procedure for this exercise is presented in Graf, 1984.

SUMMARY

To provide reasonable accuracy in determining bedload transport rates, it is advisable to determine the rate using a few methods and then compare them, wherever possible, since the possibility for error in any of these methods is significant. Also, the degree that a particular operation could seriously affect nearby environmental resources or personal property should determine what level of importance is placed on the estimation of bedload transport. If a 2.0 acre operation is planned to mine sand in a dry wash with no wetlands, subirrigated land or riparian habitat nearby and it is unlikely that the operation could affect nearby property owners, it is probably not necessary to investigate the bedload transport in the same detail as an operation near a populated region or in an area with irrigation inlets, springs and manmade structures such as bridges and roads.

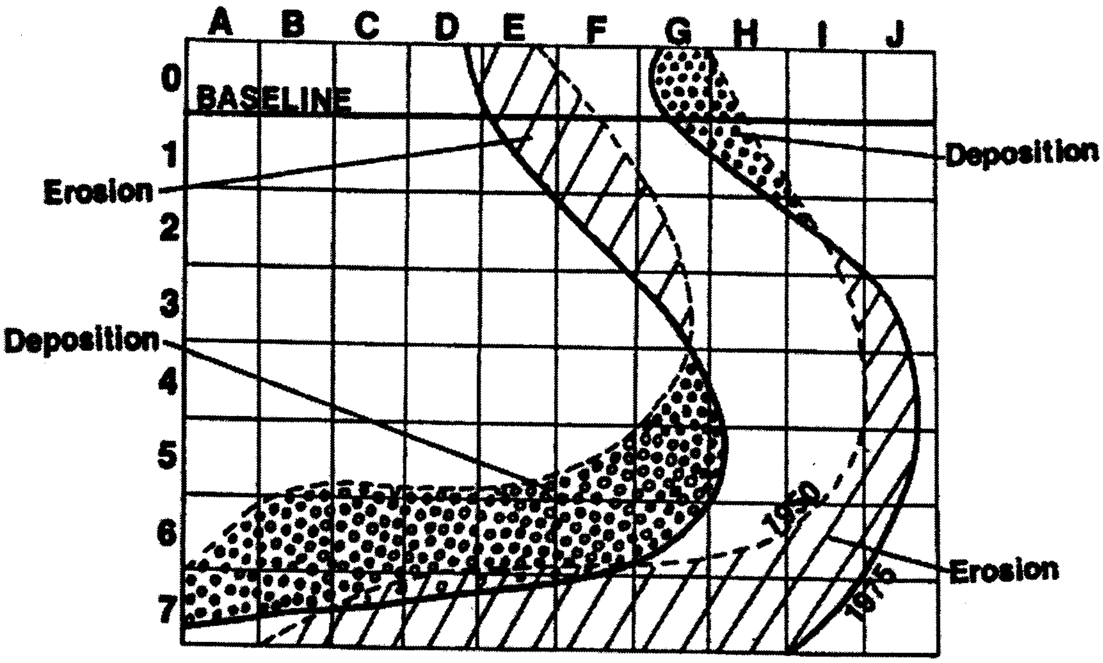


Figure C-1
Completed Schematic Showing Bank Lines and Zones of Erosion and Deposition from which Rates of Erosion can be Measured

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APPENDIX D
POTENTIAL HYDROLOGIC STRUCTURES TO MINIMIZE EFFECTS OF MINING METHODS

POTENTIAL HYDROLOGIC STRUCTURES TO MINIMIZE EFFECTS OF MINING METHODS

There are a number of measures that can be applied to areas where in-stream aggregate extraction is being conducted that will minimize potential effects. The following sections describe some of the measures that can be used by themselves or in combination.

BUFFER ZONES

Low flow buffers may be established to protect the integrity of the channel shape, and to reduce effects of mining on aquatic habitats. **Figure D-1** shows a schematic of a low-flow buffer, and **Figure D-2** provides a plan view with sizing specifications. The upper limit of a low flow buffer is the lesser of an elevation of one to two feet above the low summer flow elevation, or, the elevation intersected by half the channel width from the low summer flow elevation at bankfull conditions.

Undisturbed buffer zones can be established between the active channel and the material processing and stockpile site to provide protection for the extracted resource during floods (**Figure D-3**). This distance should take into consideration historic migration patterns while continuing to provide the desired buffer. Operators can determine migration patterns from a review of annual flows through the site and a comparison of aerial photos acquired over several decades. The elevation of the material storage area should take into account the flood risk an operator is willing to assume. The mining method, size of the river, channel configuration, type of vegetation, and soil composition will influence the buffer width.

The CDMG recommends that dredging operations protect their stockpiles by locating them at a minimum floodplain elevation above that of a 25-year 24-hour storm (a storm with a 4 percent annual probability of occurrence). This will result in minimum horizontal distances from the bank of 500 to 800 feet depending on the size of the river. Scraper operations should consider placement of material stockpiles at an elevation equivalent to the 5-year 24-hour flood (a storm with a 20 percent annual probability of occurrence), and buffer widths ranging from 100 to 150 feet. Lower elevations or smaller buffer widths should plan for stockpile armoring or temporary diking for flood stabilization (**Figure D-4**).

Braided rivers exhibit maximum lateral migration on an annual and seasonal basis. Lateral stability improves when progressing through an evaluation of split channel rivers, meandering rivers, and sinuous rivers. Not unexpectedly, straight rivers display the least lateral migration.

Vegetation can provide substantial protection from lateral migration within a buffer zone. Deeply rooted plants, or dense ground cover can reduce the potential for erosion in the buffer zone. Soil composition also influences the erosion rate. Fine-grained materials such as clays and sands are more erosive than coarse-grained gravels or cobbles. If the vegetation or soils vary within the proposed buffer zone, the width of the buffer should change correspondingly.

BANK PROTECTION

Bank protection may be required during operations, following reclamation, or both. Typically, armoring is performed to reduce bank erosion, but may be used to protect an operation's facilities or materials. Armoring of the mid-channel bar was identified in split channel mining on **Figure 8**.

Bank Armoring

Armoring of a bank is generally installed through a zone that is likely to experience lateral migration, typically, the outside bank of a curve. Bank protection is a form of channelization and should be undertaken only when absolutely necessary. Frequently the impacts from such stabilization will create scour and erosion at other points in the river system.

The design of dikes or revetements should take into consideration the design flood event for which protection is needed, end protection of the dike, toe protection of the dike, and the material available for construction. Engineered designs are based on site-specific information, but the armoring is only as good as its installation. The failure to follow the design or the use of inappropriate or undersized materials will result in only temporary bank protection.

Operators can install armoring with rip-rap, a combination of vegetation and rip-rap, soil cement, or wired gabion baskets. Rip-rap is a layer of angular, durable rock for which the median diameter and a size gradation have been specified. The median diameter of rip-rap is its D_{50}, 50 percent of the rip-rap is larger and 50 percent is smaller. Rip-rap ranges in size from 0.2 x D_{50} to 2 x D_{50}. Standard rip-rap classification types are described in **Table D-1**. The thickness of the installation ranges from 1.5 x D_{50} to 1.75 x D_{50}. Rip-rap requires placement on a graded earthen material filter blanket or geotextile to prevent the loss of fine-grained bank material. Side slopes for rip-rapped banks, should be no steeper than 2.5:1 (H:V).

General specifications can be reviewed on **Figures D-5** and **D-6**. End protection can be achieved by extending the armoring into a non-erosive area within the floodplain or by doubling the thickness of the armoring at each end (**Figure D-7**). Similarly, toe protection can be achieved by burial of the toe of the rip-rap at least five feet, or through the extension of thicker rip-rap into the channel bed (**Figure D-8**.) Photographic examples of bank armoring are shown in **Figure D-9**. Several of the photographs are from non-mining applications.

Biorevetements

Geotextiles in fluvial settings provide temporary protection prior to the establishment of vegetation. Geotextiles are woven or non-woven fabrics that promote bank stabilization through a mulching capacity or as a strengthener. These synthetic fabrics may be a coarse netted fabric sandwiching a straw, coconut hull, or synthetic blanket that are used as mulches. Synthetic, non-woven or finely woven fabrics can be employed as replacements for graded gravel filter blankets below rip-rap. The use of geotextiles is considered a biorevetement when seeding is incorporated

Table D-1
Classification and Gradation of Ordinary Rip-rap

Rip-rap Designation	% Smaller Than Given Size by Weight	Intermediate Rock Dimension (inches)	D_{50}* (inches)
Type M	70-100	21	
	50-70	18	
	35-50	12	12
	2-10	4	
Type H	100	30	
	50-70	24	
	35-50	18	18
	2-10	6	
Type VH	100	42	
	50-70	33	
	35-50	24	24
	2-10	9	

* D_{50} = Mean particle size

into the installation, with the final objective being a vegetated channel. When a mulching geotextile is used, seed is placed on the bank prior to placement of the fabric. Zoned bank protection can be provided when the banks are rip-rapped up to the average water level, and grasses and woody species are planted above the rock armoring along the banks using a mulching geotextile.

Geotextile fabrics used below rip-rap should prevent movement and piping of fine particles while allowing liquid to flow into the rip-rap. Finer filter blankets are required for clay-sized particles; looser, larger opening sizes may be used with coarse-grained particles. The installation should be perpendicular to the direction of flow, with sheets shingled in the direction of flow. Anchor at the top of the bank at least 1-foot above the high water line.

Contact with a manufacturer's representative to obtain specifics on the appropriate fabric for the situation should be conducted. Be prepared to specify the side slopes and bottom slopes of the channel, the type of soil, whether there are elevated sodium concentrations or other conditions that make the soil highly dispersive, how plastic the soil is, the percentage of gravel and the grading of the gravels. The representative will determine the equivalent opening size (EOS) of the woven fabric based on the soil type and the average diameter of the rip-rap.

Frequently a biorevetement will include willow plantings. These consist of willow stakes or fascines, that are approximately 5 to 8 foot wands of dormant willows cut in the spring before they have leafed out. Store in water with a root promotion solution until planted. Do not allow them to dry out. Fascines are bundles of willows that have been planted horizontally in shallow trenches at benched heights ranging from several inches to 2 to 3 feet above the low flow water surface elevation. Willow plantings are most successful when planted in sites with adequate moisture in well-drained conditions such as silty sand. They should not be planted below the perennial waterline (base flow elevation of stream), or success will be tempered.

Gabion Baskets

Gabion baskets are sized rock enclosed in a wire mesh basket. It is recommended that a type of galvanized wire be used to promote a longer life of the installation. Size of the basket and rock can vary with the type of installation and the objectives of the control measure. Gabion baskets provide a durable and long-lasting erosion control measure and rock materials are usually available at the mining site. **Figure D-10** shows photographs of two types of gabion baskets.

Jetties

Jetties consist of dike-type structures that may be used for bank protection (**Figure D-11**). Jetties project from the toe of a graded 4:1(H:V) channel bank to no more than one-third the stream's width, and optimally 15 to 25 feet. Jetties are installed in a series along a straight reach or outside bank. Their orientation should be either perpendicular to a stream's centerline or at a 45 degree angle downstream. Jetty spacing should be placed at a ratio of centerline spacing to jetty projection less than or equal to three. Thus, if the jetty extends 25 feet from the toe of the bank, jetty installation should occur every 75 feet or less. Jetties should be toed in at least 5 feet deep, and wing walls should extend at least 25 feet. Jetties should be constructed of Type H rip-rap. The core of the jetties may be constructed with a mixture of concrete rubble. Banks between jetties should be stabilized with vegetation. **Figure D-12** contains photographs of jetties installed in river channels.

Vegetation Stabilization

Vegetation is often used in a variety of methods to stabilize and protect stream banks from erosion. A combination of species are used, including willows and grasses. Vegetation is often used in conjunction with other stabilization methods such as rock armoring, biorevetements, and vegetated zones between jetties. **Figure D-13** shows revegetated stream banks following mining operations.

GRADE CONTROL STRUCTURES

In-stream grade control structures, if used, should be installed on the upstream end of the in-stream pit. Examples of these structures are described below.

Drop Structures and Weirs

A variety of drop structures and weirs can be placed in the channel to prevent head cutting upstream and downstream of a mining operation. The invert elevation should be no lower than the pre-mining channel invert elevation. Type VH rock is trenched 5 feet deep into the channel for at least 20 feet from the bottom of a 10:1 (H:V) side slope (**Figure D-14**.) This structure is anchored with a double row of sheet piling spaced 5 feet apart and driven to refusal. The wingwalls should extend across the width of the floodplain. Photographs of drop structures and vortex and W-shaped weirs are provided in **Figure D-15**. Several of the photographs are from non-mining applications. These structures must also be anchored into the stream bed to prevent undercutting and erosion.

Berm Stabilization

Spillways minimize the potential for failure of the berms during flood events. Spillways should be installed on berms protecting the active pit in split channel mining or along lateral berms running between a stream and a floodplain pit. The invert elevation of the spillway crest should be one-foot above the 2-year 24-hour flow elevation. The side slopes should be 10:1 (H:V) and the channel should be stable during a 25-year 24-hour flow event.

In the event that an in-stream mining operation includes a pit within the adjacent floodplain, berms between the river and the pit should be at least 100 feet wide, and should have reinforced side slopes between the stream and the pit. Rip-rap, concrete or soil cement can be used for stabilization. General specifications are shown in **Figure D-16**. The minimum top width of the berm increases to 400 feet if no armoring is used.

SUMMARY

There are a number of techniques that may be used by themselves or in combination to stabilize a channel utilized for an in-stream aggregate operation. These include armoring with rock or vegetation, installation of jetties, and placement of grade control structures. A hypothetical plan view of a river that combines the use of these structures may be reviewed in **Figure D-17**. Pre-project planning may also identify the benefits of designation of an undisturbed vegetated buffer zone between the stream and the operations area. Buffer zones are also identified in **Figure D-17**.

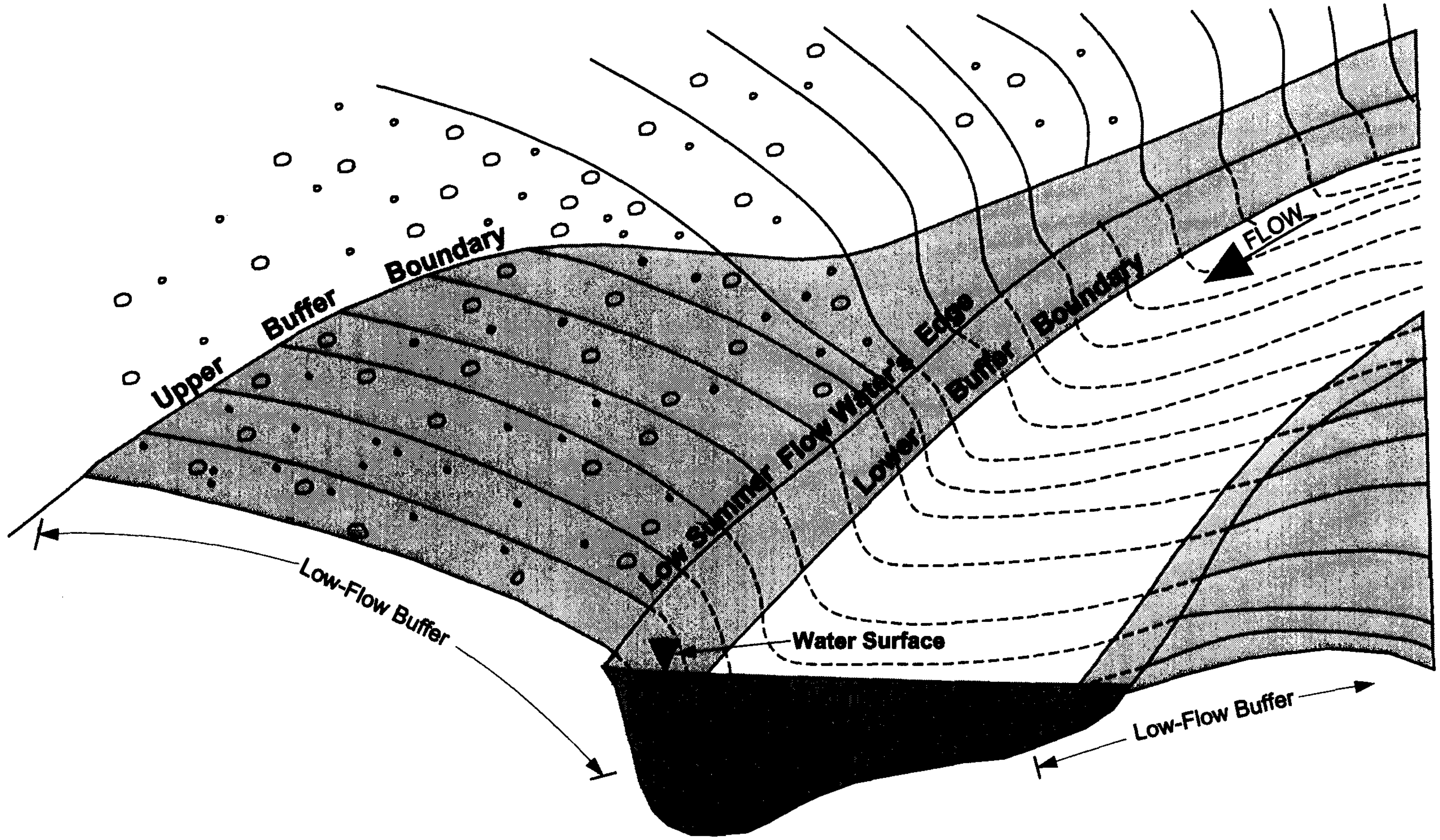


Figure D-1
Schematic Diagram of the Low-Flow Buffer

Source: USDI, FWS, 1980.

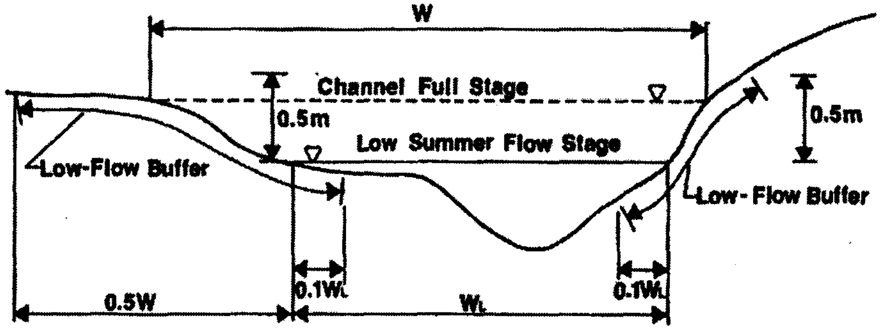


Figure D-2
Cross-Section Diagram Showing Low-Flow Buffer Boundaries

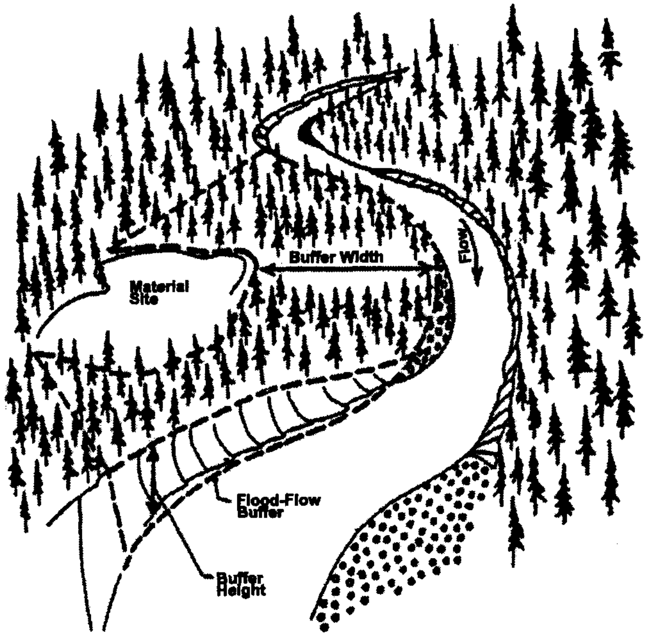
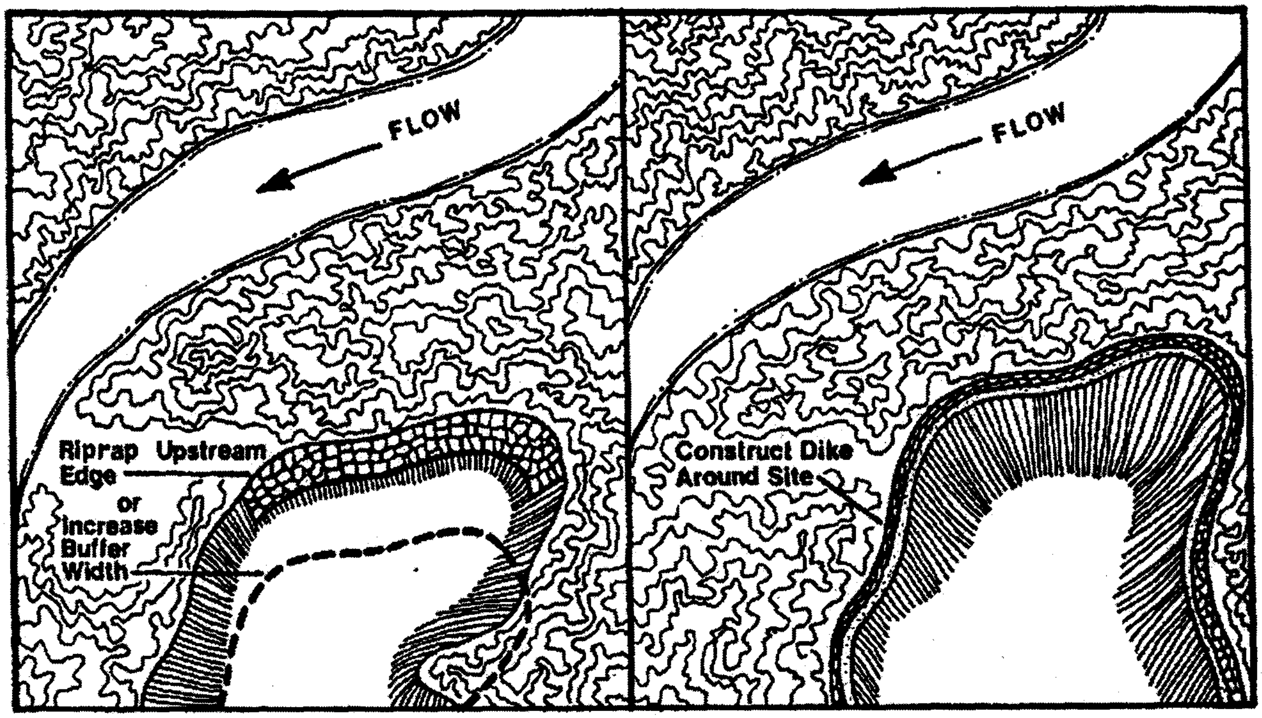


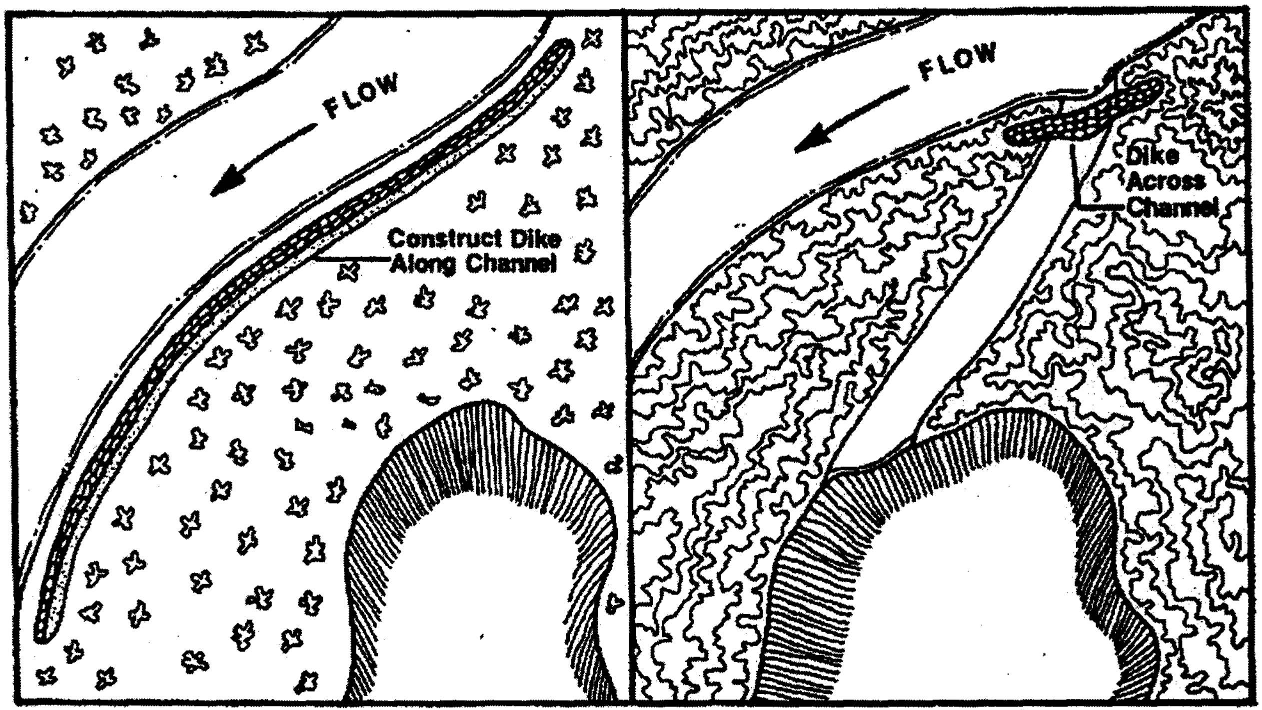
Figure D-3
Aerial View of the Flood-Flow Buffer

Source: USDI, FWS, 1980.



a. Heavily vegetated buffer and flow through the site is acceptable.

b. Heavily vegetated buffer and flow through the site is acceptable.



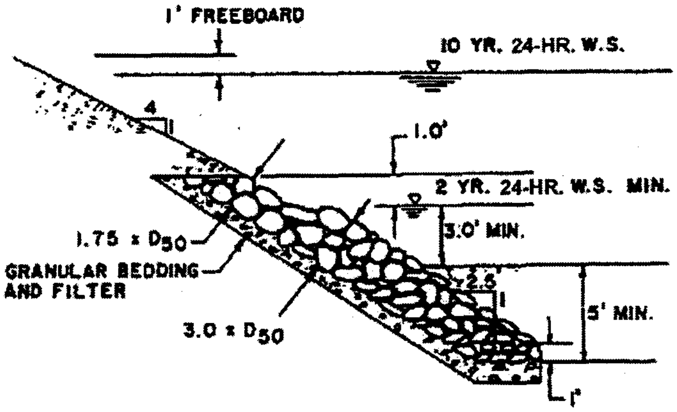
c. Lightly vegetated buffer and flow through site is acceptable.

d. Highwater or abandoned channel through heavily vegetated buffer and flow through site is acceptable.

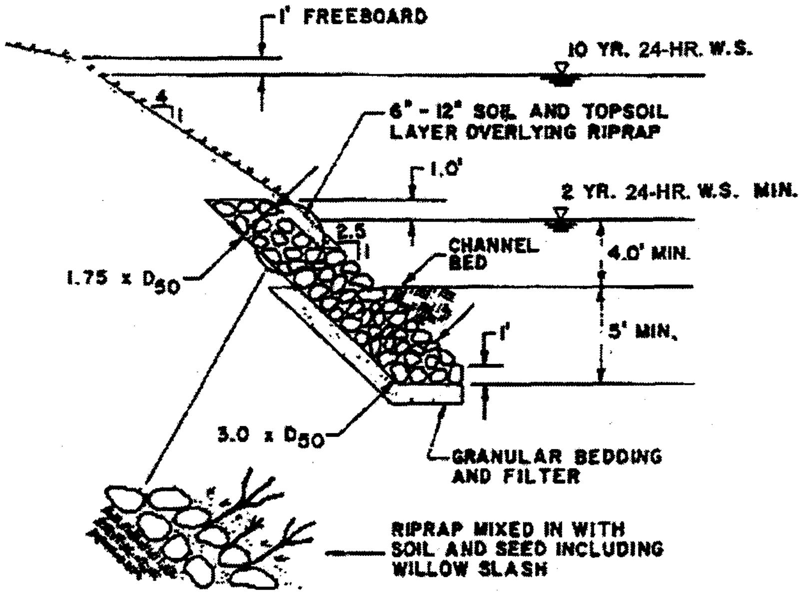
Figure D-4
Schematic of Alternatives if the Probability of Flow Through the Site is High

Source: USDI, FWS, 1980.

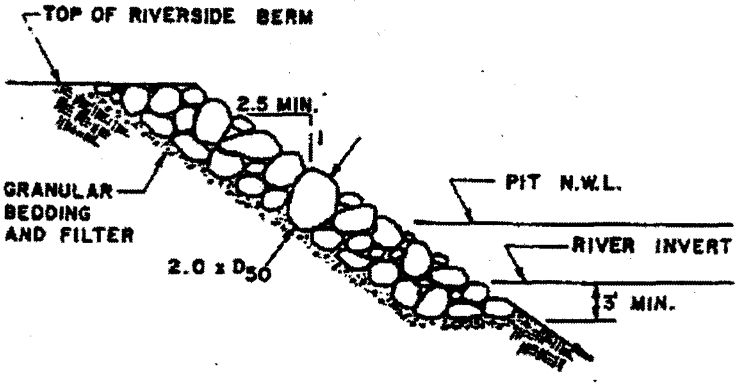
a) TYPICAL CHANNEL RIPRAP SLOPE PROTECTION



b) TYPICAL RIPRAP AND VEGETATION SLOPE PROTECTION



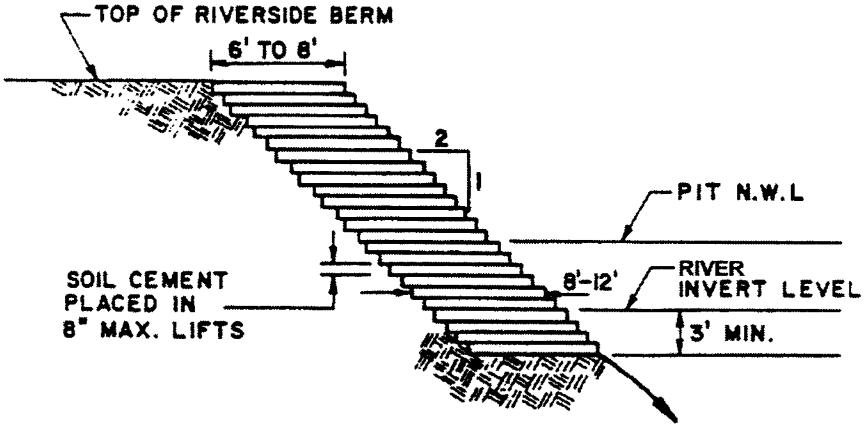
c) TYPICAL PITSIDE RIPRAP SLOPE PROTECTION



W.S.-Water Surface
N.W.L.-Natural Water Level

Figure D-5
Rip-Rap Slope Protection

Source: UDFCD, 1987.



N.W.L.- Natural Water Level

Source: UDFCD, 1987.

Figure D-6
Typical Soil Cement Slope Protection

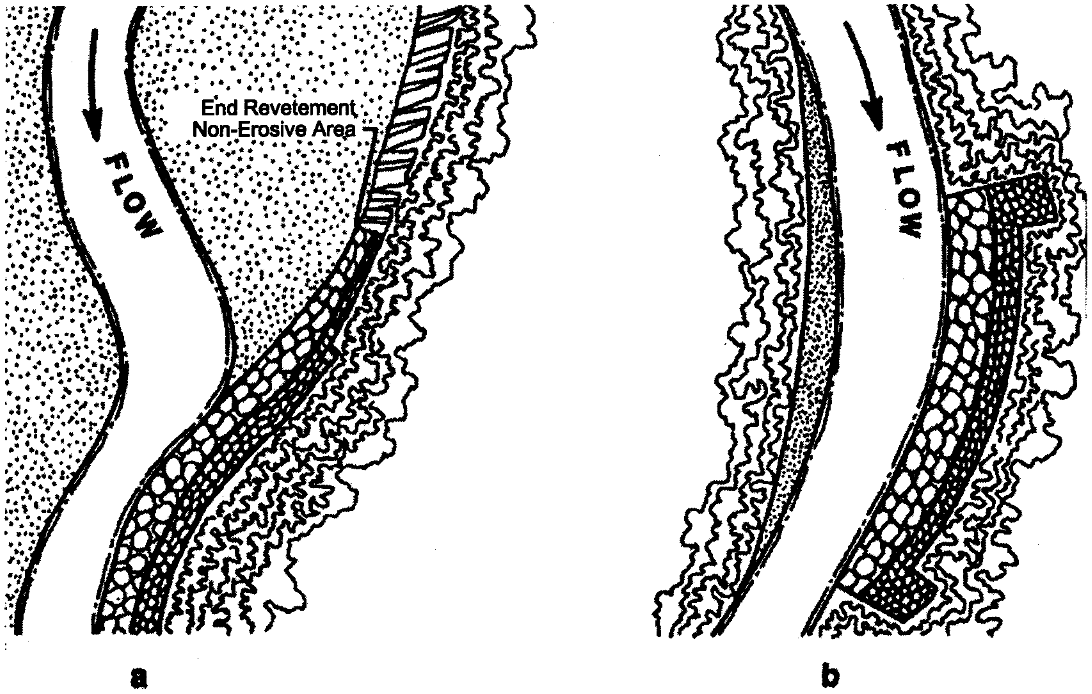


Figure D-7
Plan Views of End Protection Configurations:
a) Extension Out of the Zone of Erosion with a Potential Reduction in Thickness,
and b) an Increase in the Thickness at the Ends of the Revetement

Source: USDI, FWS, 1980.

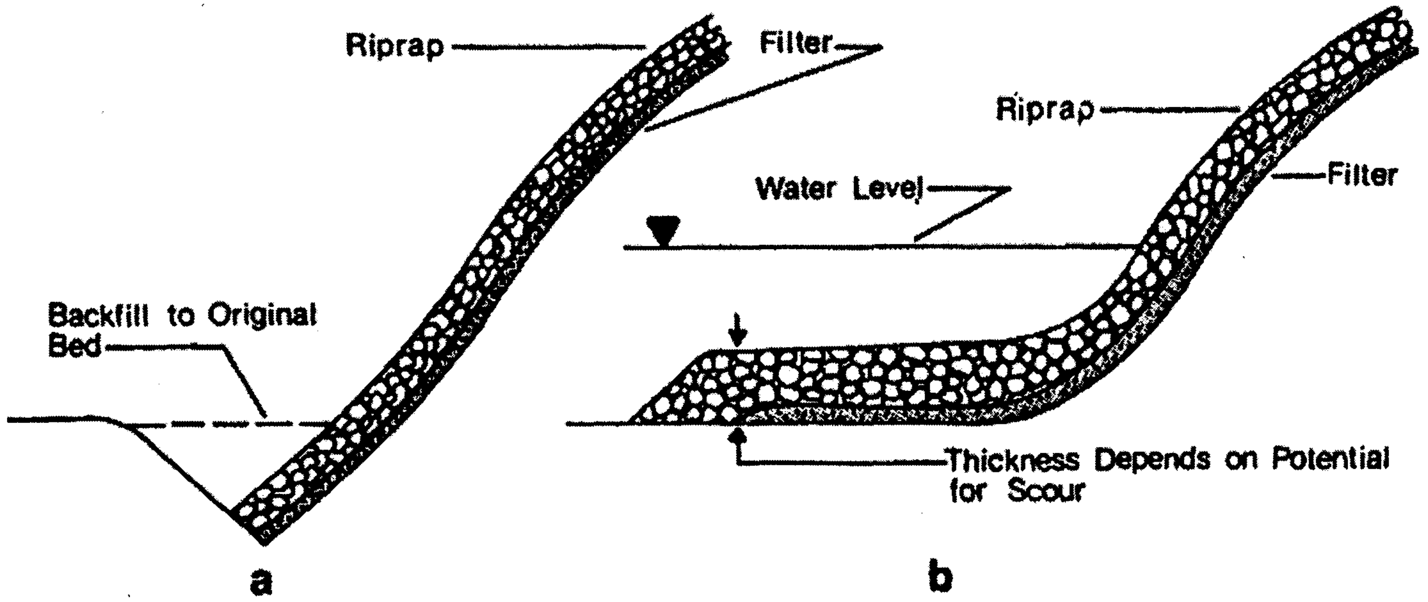
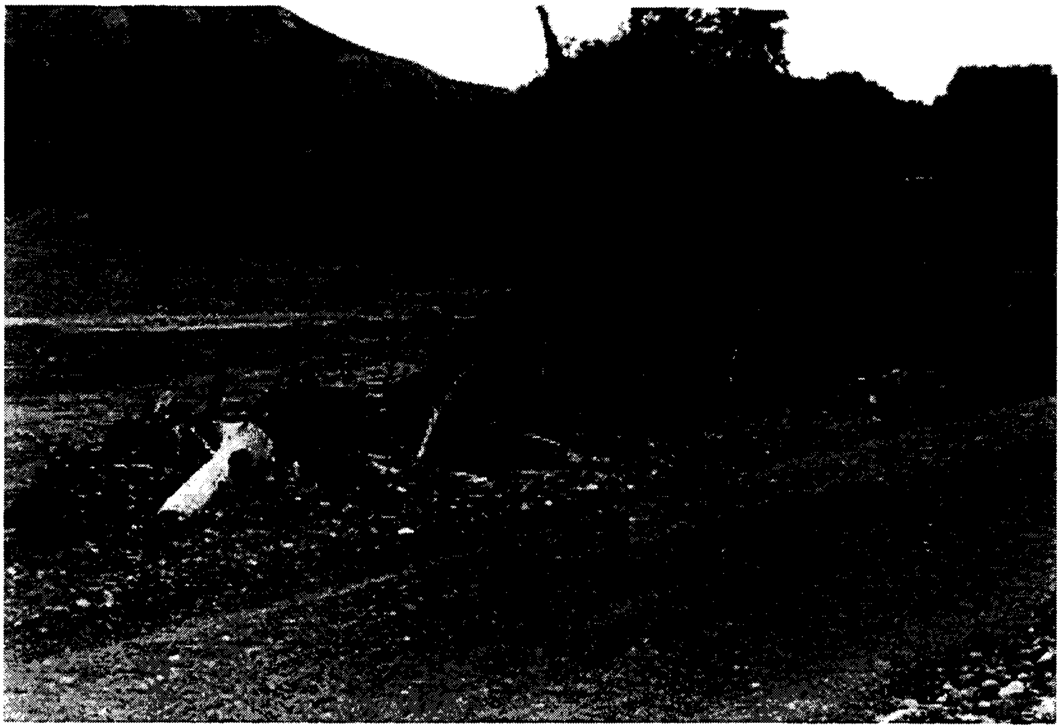


Figure D-8
Cross-Sections of Toe Protection Configurations:
a) Extension of the Riprap Below the Dry Bed and Backfilling, and
b) Placement of Extra Material Along the Bed to Launch Itself into Developing Scour Holes

Source: USDI, FWS, 1980.

Bank Armoring Photographs



Shows an example of an outside river bend without any bank protection. The bank is severely eroded and is undercutting trees on the top of the bank. Debris has washed into the base of the bank which is providing some protection.

Shows broken concrete foundation material and tree trunks placed on the outside bend of a river to protect against bank erosion. The slabs were end-dumped from a truck at the top of the bank and do not serve to protect the bank bottom against erosion. As erosion occurs, the slab material will fall lower but it will occur haphazardly and may leave gaps of unprotected areas.

Figure D-9

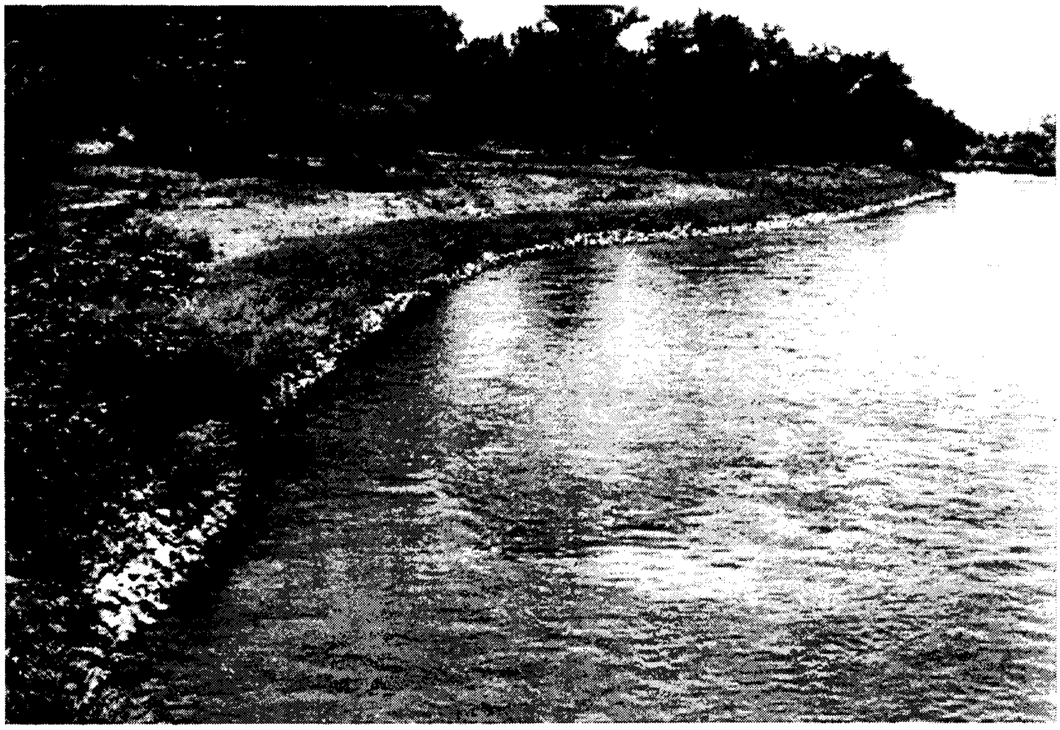
Bank Armoring Photographs

This photo shows a 25 feet wide trench dug parallel to the River. The River is immediately to the left of the photo. The trench is then filled with durable rock or broken concrete of 2' diameter to a height of 7' or more and then backfilled with fill and then soil. The trench then provides long-term bank protection between the River and the mined out gravel pits in the floodplain immediately to the right of the photo.

This durable granitic type rip-rap has a D50 of approximately 14-18" and is angular to provide better resistance to slumping. It was installed to a thickness of 2 x D50 and is as seen from the photograph, care was taken in the placement of the material. This placement should handle high flow events.

Figure D-9

Bank Armoring Photographs



This bank protection includes a layer of 6" rounded rip-rap placed in a layer 24-36" thick extending 5 feet below the low flow water level and 4' above the water level on a 2.5H:1V slope. Above 4' in height, the rock is extended laterally for a distance of 15-20 feet and covered with soul and planted. Willow bunches are also used on the slope. This bank protection is only adequate up to a 3 to 4 year event.

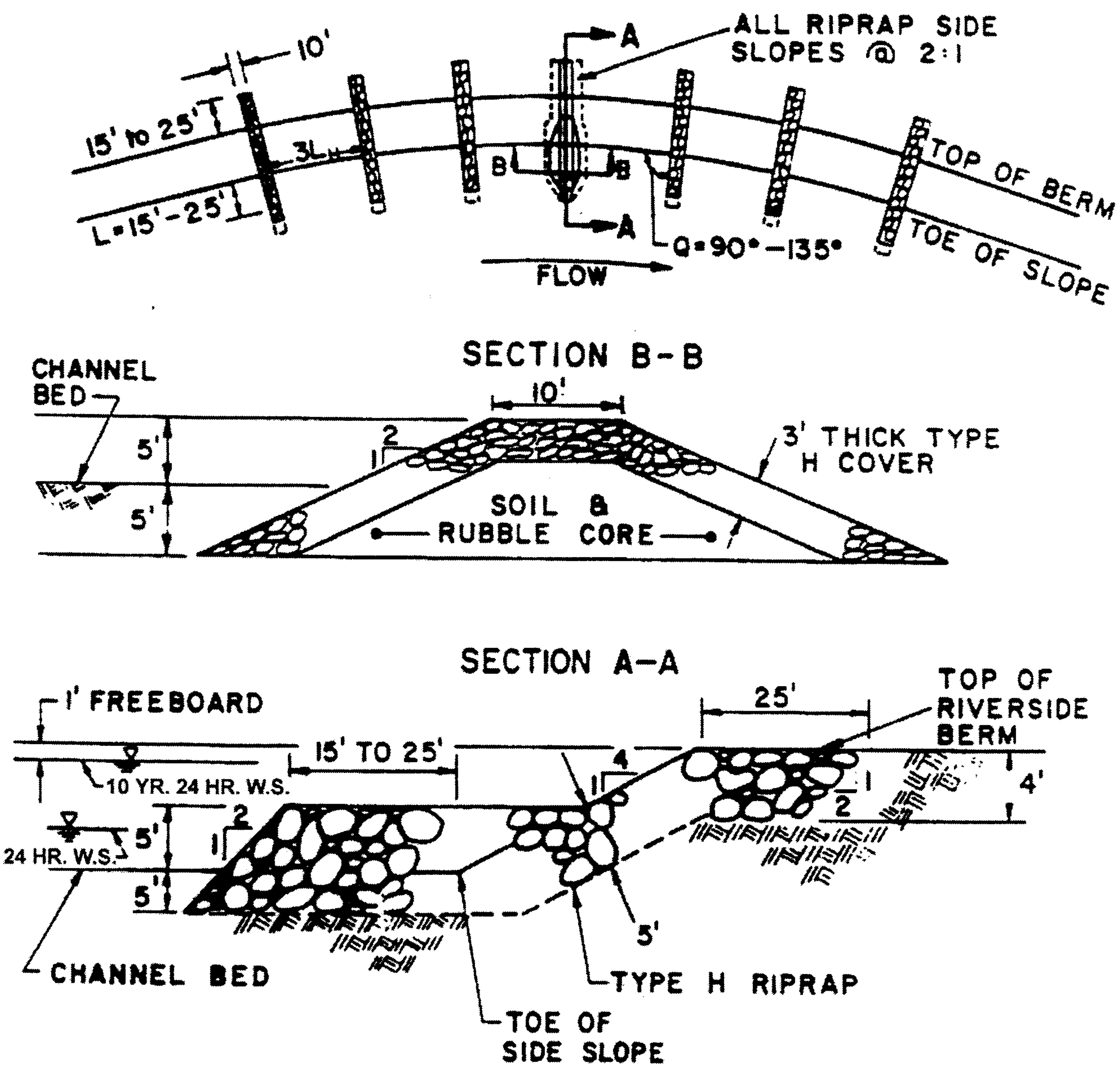
Figure D-9

Gabion Basket Photographs

Shows gabion baskets with small openings filled with small durable rock for bank protection. Opening size is approximately 3" while the rock size is 5". As shown in the photo, two tiers are used. Each tier is 6 feet high. This should provide bank protection for any event up to the height of the second tier. This is effective and provides excellent bank protection.

Shows a gabion basket of relatively small rip-rap with D50 of 8" covered by a wire mesh that greatly increases its ability to provide bank protection from flood events. In areas where large rock is not available, this is a viable alternative.

Figure D-10

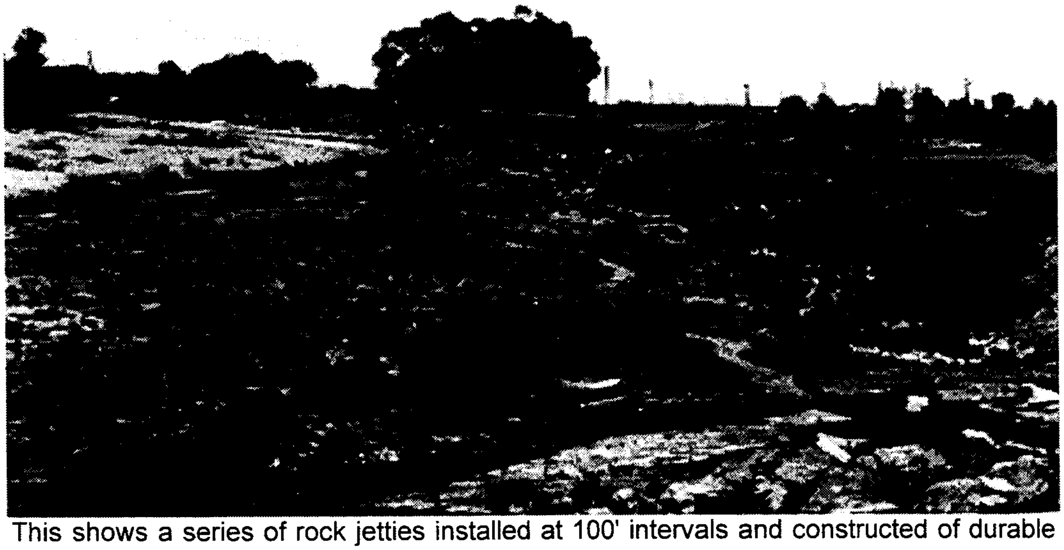


Source: UDFCD, 1987.

Figure D-11
Jetty Slope Protection

Jetty Photographs

Shows rock jetties constructed of gabion baskets of 6' x 2.5' x 2.5'. First, a 2 foot cut was placed in the bank. The first tier of gabion baskets was placed and filled with durable rounded rock (granite) of D50 of 6". A second tier of baskets was then placed and filled extending out to the river a distance of approximately 10 feet. The baskets are very useful because they greatly increase the flow event that the rock could handle alone and rounded rock can also be used without problems. The baskets can be constructed to any size and are not very expensive.

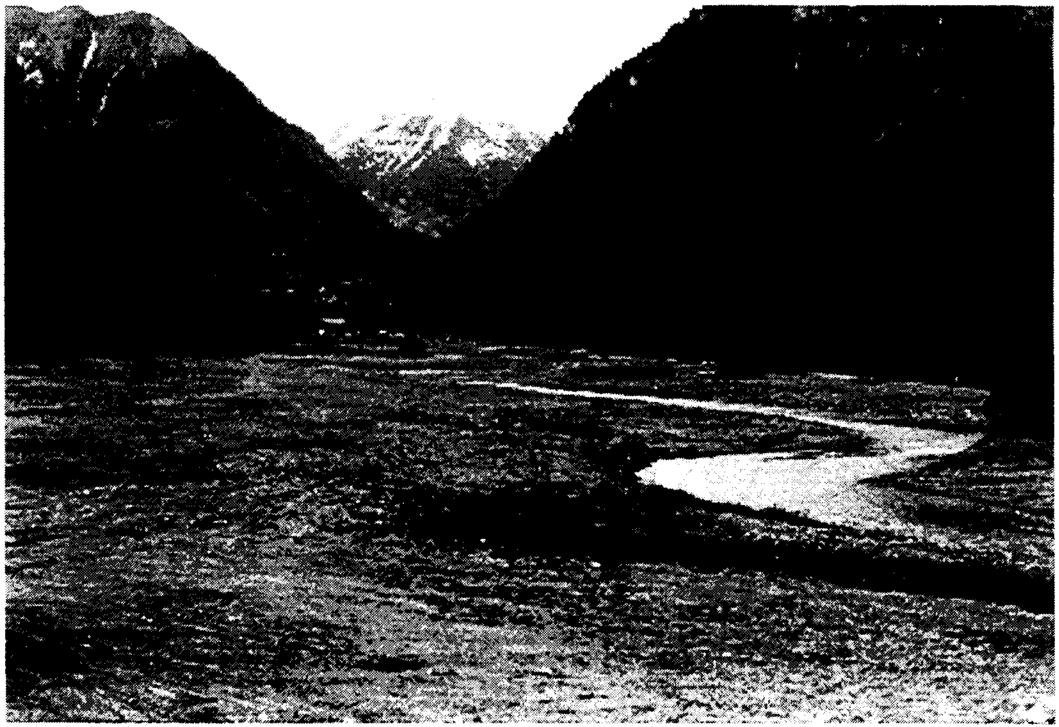


This shows a series of rock jetties installed at 100' intervals and constructed of durable angular rock of D50 of 18"-20". The jetties were installed to protect against bank erosion during high flow events. The jetties are approximately 16 feet long and 7 feet high. They are most helpful on the outside bend of the channel (as shown in the picture).

Figure D-12

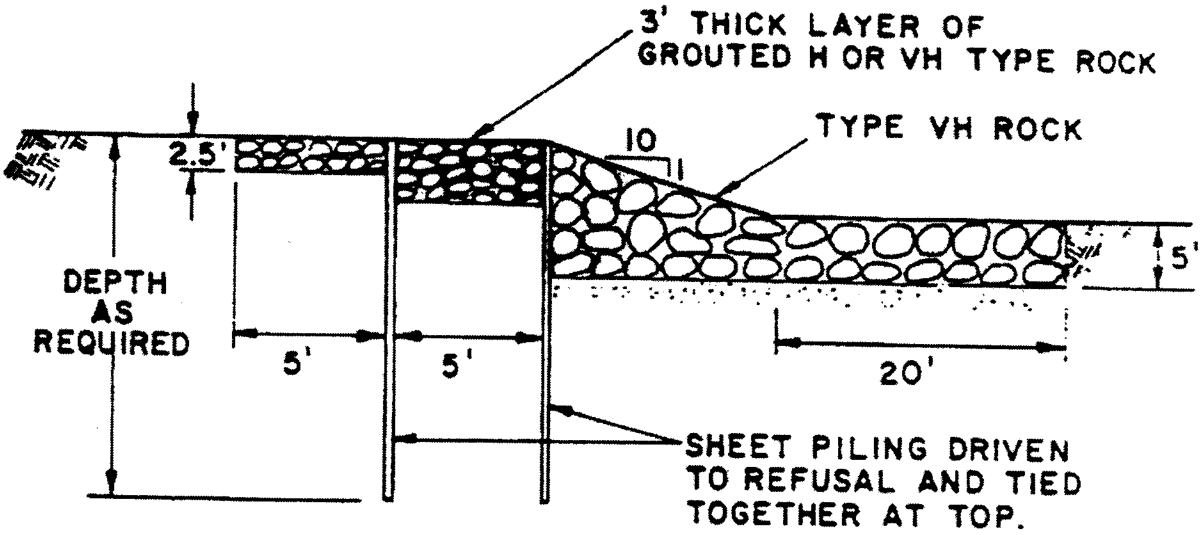
Vegetation Stabilization Photographs

Shows a berm of approximately 20 feet top width, well-vegetated 2.5:1 slopes on both sides between a river (on the left) and a mined-out lake on the right. The berm is stable and the thick vegetation should provide protection against high flow events.



Shows a reclaimed gravel operation where a wide shallow floodplain has been left to allow future deposition and movement of the flow channel with the floodplain. In areas where rivers leave mountain ranges and enter wider shallow grade floodplains, high deposition occurs and any mining and reclamation of these reaches should account for these conditions.

Figure D-13

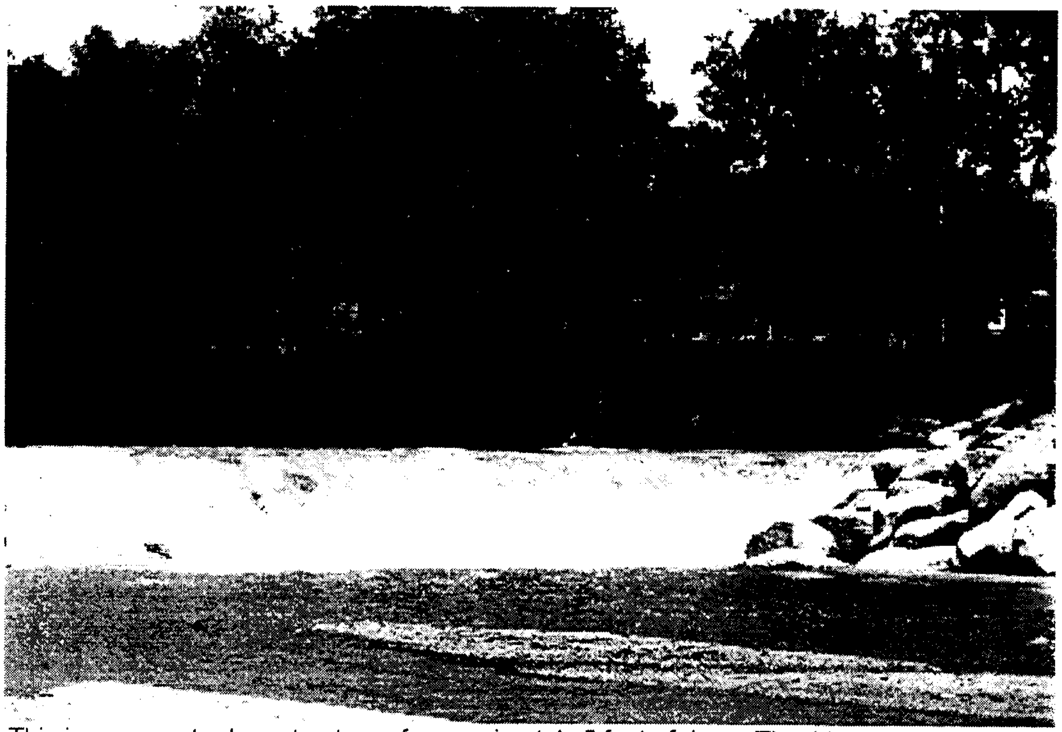


DEPTH OF SHEET PILING, GAUGE OF PILING, SIZE OF ROCK, AND ROCK AND FILTER GRADATIONS ARE TO BE DETERMINED BY A REGISTERED PROFESSIONAL ENGINEER ON A SITE SPECIFIC BASIS. PROVIDE AN OPENING FOR LOW FLOWS, SAFE PASSAGE OF BOATERS AND FISH MIGRATION. THE LOW FLOW OPENING SHALL BE DESIGNED IN STEPS OF POOLS AND CHUTES WITH THE LAST CREST OF THE DOWNSTREAM CHUTE BEING AT THE PROJECTED TAILWATER WHEN ALL GRAVEL IS REMOVED FROM THE PIT. THE VERTICAL DISTANCE BETWEEN SUCCESSIVE CRESTS SHALL NOT EXCEED 18 INCHES.

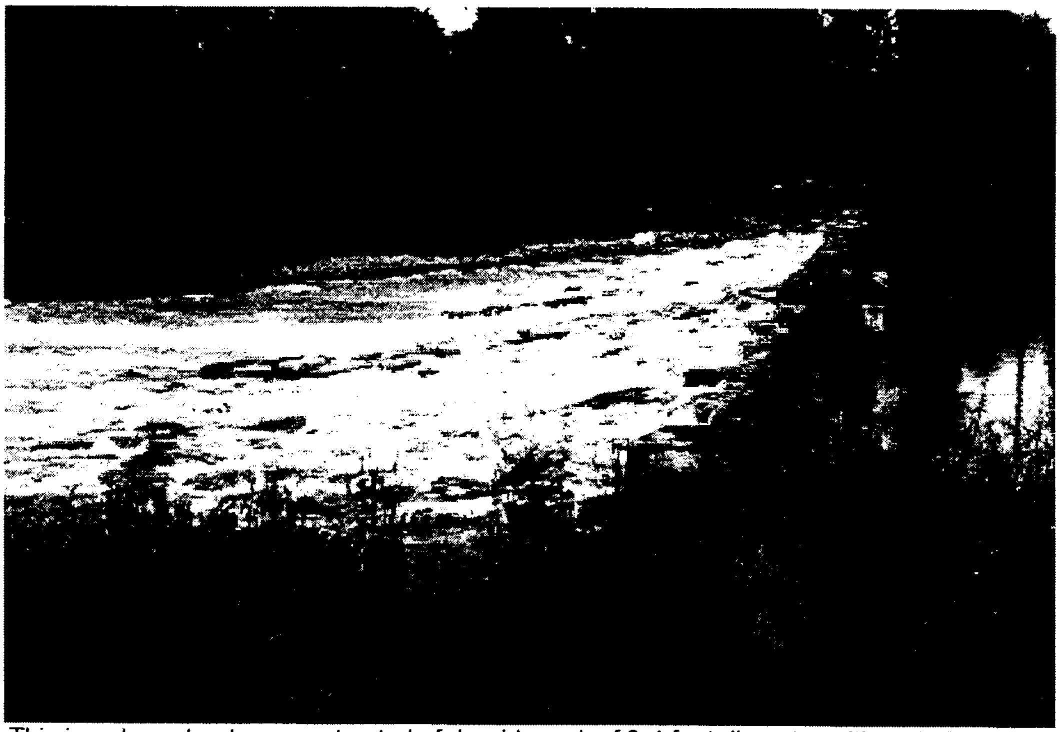
Source: UDFCD, 1987.

Figure D-14
Typical Instream Headcutting Control Structure

Drop Structures and Weirs



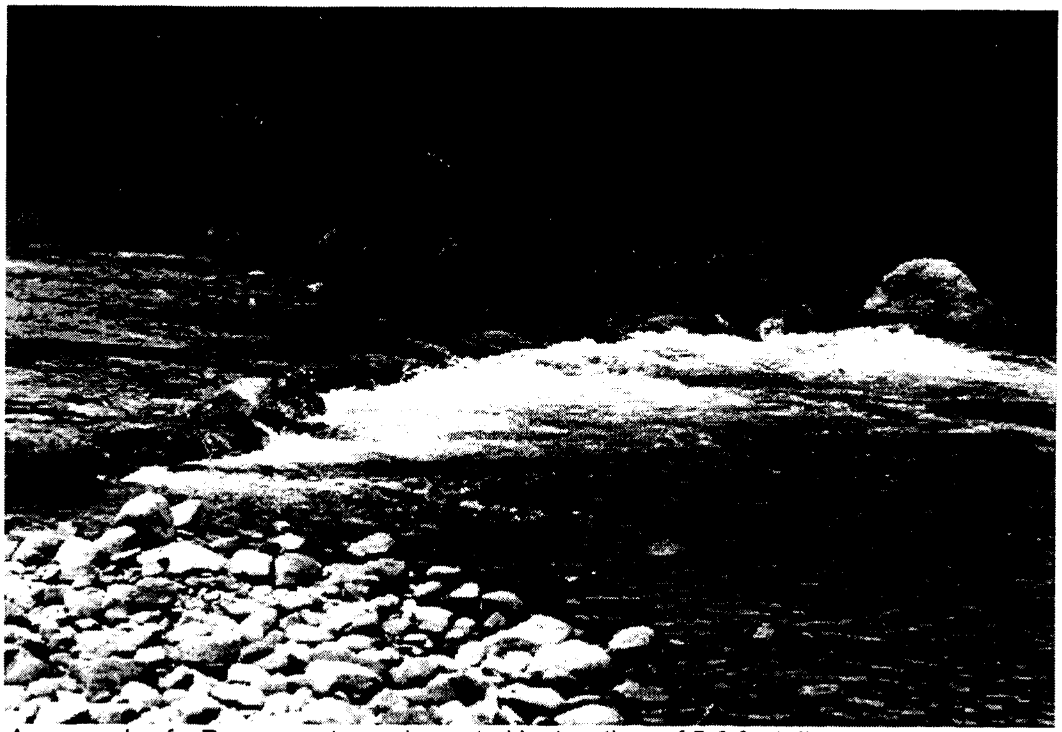
This is a concrete drop structure of approximately 5 feet of drop. The thickness is unknown but the concrete extends 2 feet upstream from the top crest of the drop to two feet downstream of the bottom to prevent scouring. The purpose of the structure was to provide drop in a safe way to eliminate cutting upstream and downstream.



This is a drop structure constructed of durable rock of 3-4 foot diameter with a shallow drop on the downstream side to improve stability. The total drop is approximately 4 feet. Although difficult to see in this photo, the central area of the structure was made deeper to allow rafts, kayaks, etc. to easily pass through the structure.

Figure D-15

Drop Structures and Weirs

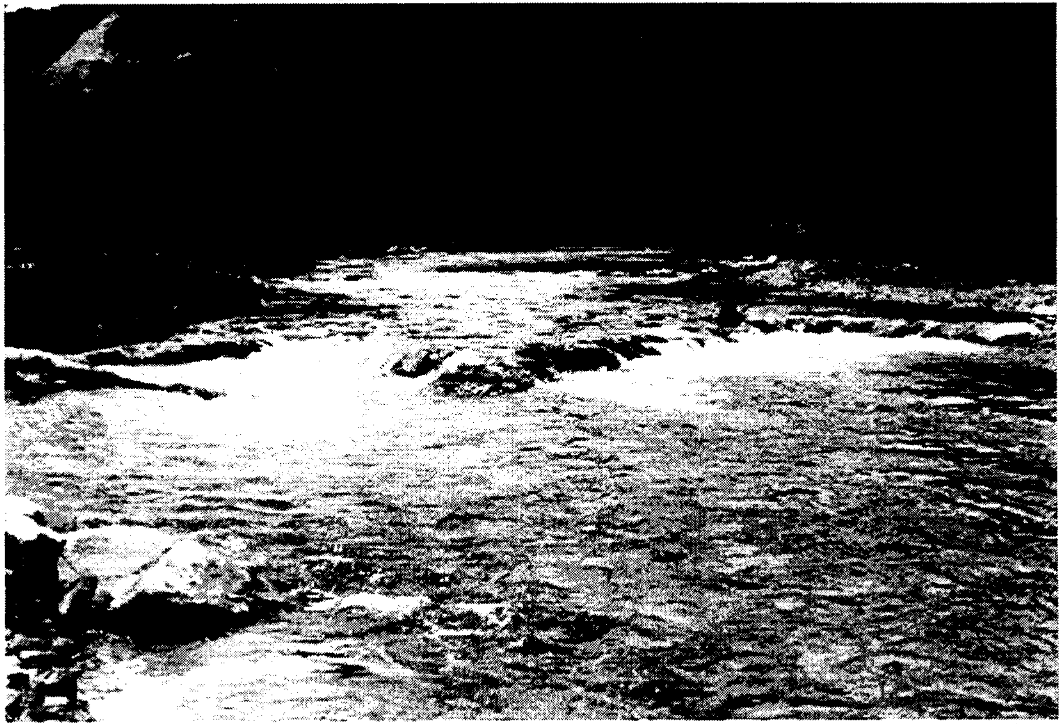


An example of a Rosgen vortex weir created by two tiers of 5-6 foot diameter rock with the lower tier below the water surface. Gaps between the upper tier of rock allow water passage. The weir is constructed in an arc shape with the center pointing upstream. The weir serves to provide drop without erosion while providing some depth during the low flow periods to improve fish habitat.

This is a "double vee" weir placed directly in the channel created by durable rock of 4-6 feet in diameter placed in two tiers. The first tier is below water level. The structure reduces bank erosion, slows velocity, and deeps greater depth between both sections during low flow conditions.

Figure D-15

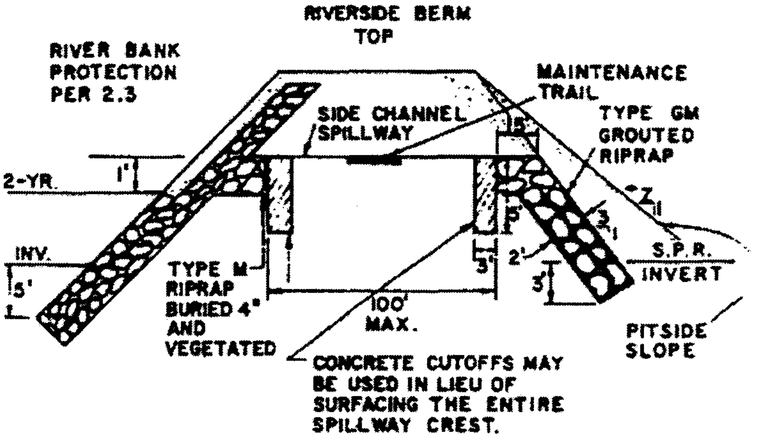
Drop Structures and Weirs



This is a “w” shaped weir employed by Rosgen. It was created by two tiers of 5-6 foot diameter rock with the lower tier below the water surface. Gaps between the upper tier of rock allow water passage. The weir serves to provide drop without erosion while providing some depth during low flow periods to improve fish habitat.

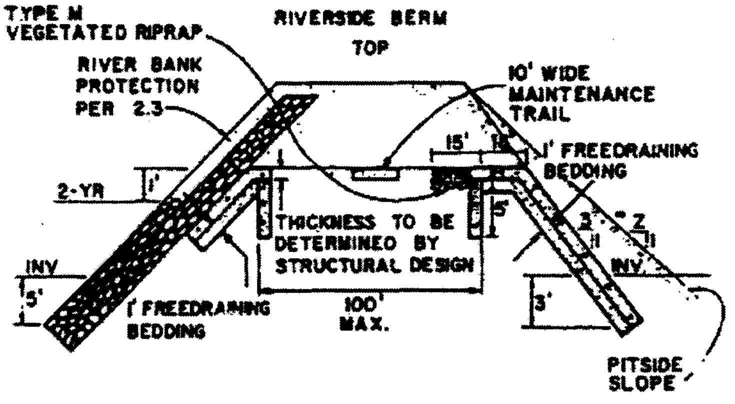
Figure D-15

RIPRAP



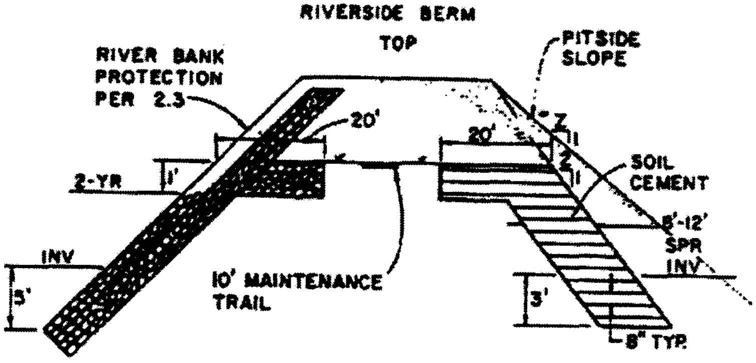
* Z VARIES WITH RECLAIMED USE

CONCRETE



* Z VARIES WITH RECLAIMED USE

SOIL CEMENT



* Z VARIES WITH RECLAIMED USE

Figure D-16
Berm Stabilization Alternatives:
Riprap, Concrete and Soil Cement

Source: UDFCD, 1987.

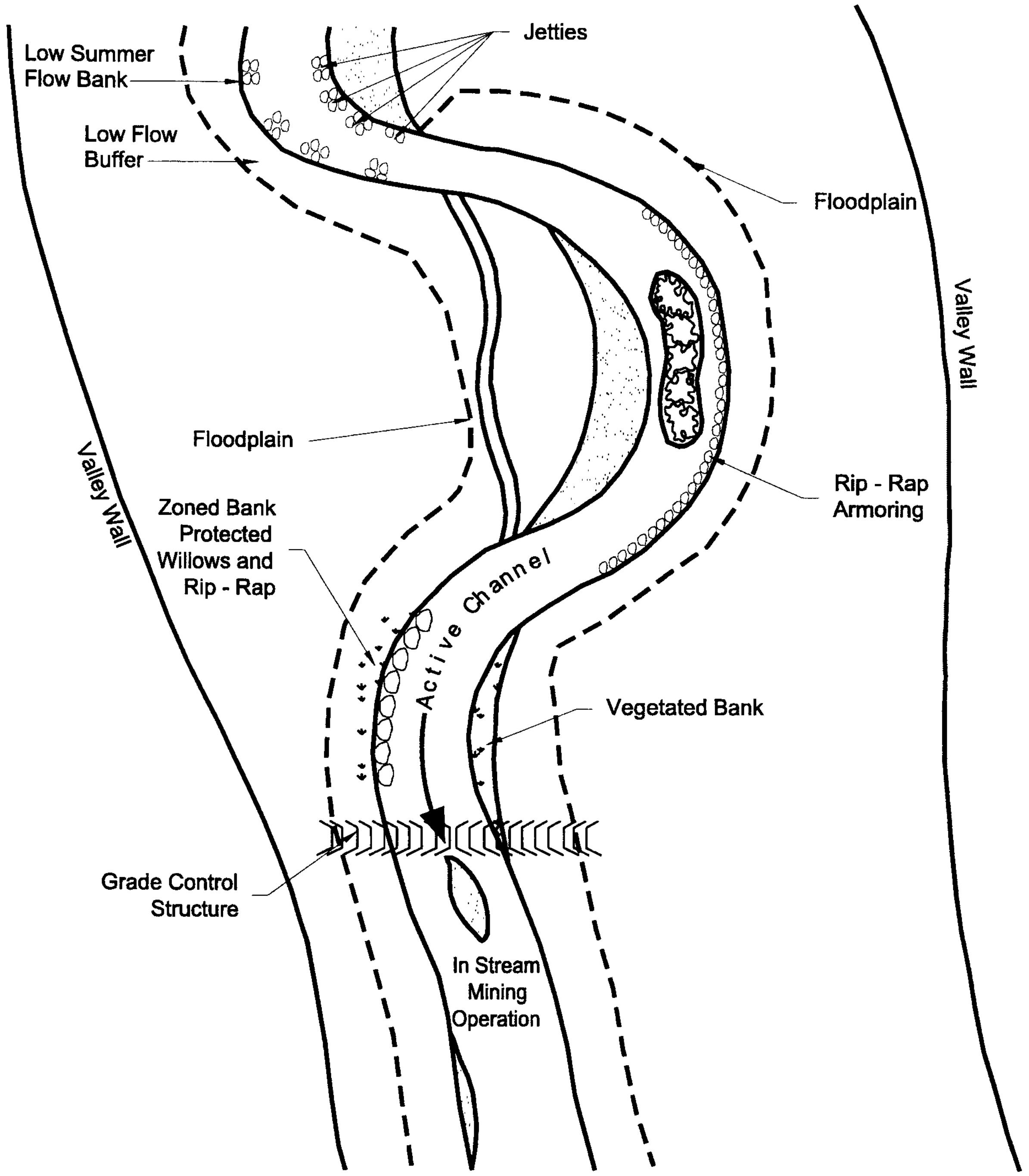


Figure D-17
Use of Hydrologic Structures

APPENDIX E
CDMG INSPECTION CHECKLIST, IN-STREAM AGGREGATE OPERATIONS

CDMG INSPECTION CHECKLIST, IN-STREAM AGGREGATE OPERATIONS

Since many operations only mine for short periods during low flow conditions, attempt should be made to inspect during active mining.

- Evidence of channel cutting or entrenchment within the permit area? Is the channel bed deeper than previous inspections? If so, is it within the parameters of the permit?
- Is there evidence of bank erosion, banks sloughing off, etc?
- Check for any sensitive habitat, vegetation species drying up and dying along the banks and within some distance of the stream, especially if there is evidence of stream cutting.
- If there is down cutting within the permit area, the inspector should check upstream and downstream to notice evidence of cutting and potential damage to the structures off the permit area.
- Inspect channel bottom downstream from the operation for evidence of unusual siltation of spawning gravels.
- Compare most recently submitted cross-sections with observations on-site.
- Check alluvial water level data and quality information.
- Disturbed area limits versus permit area.
- Are undisturbed buffer areas being maintained?
- Any barriers, berms, or stream protection installations should be checked for problems such as breaches, unequal settling, inadequate width, destabilization, undercutting or piping.
- Sediment control system for the stockpile/plant area.
- If the operation has a prescribed mining depth limit, this should be checked.

APPENDIX F
POTENTIAL REGULATORY AUTHORITIES

The following are regulatory authorities that may have permit or approval processes that would need to be obtained prior to beginning an in-stream aggregate extraction operation. This list may or may not contain all of the approvals necessary, and it is the operator's responsibility to determine and acquire all of the necessary approvals prior to beginning operations

- Colorado Division of Minerals and Geology
- U.S. Army Corps of Engineers
- Natural Resources Conservation Service, Soil Conservation District
- U.S. Fish and Wildlife Service
- Colorado Division of Wildlife
- Colorado Department of Public Health and Environment
    - Water Quality Control Division
    - Air Pollution Control Division
    - Hazardous Materials and Waste Management Division
- Colorado Division of Water Resources, State Engineer
- County Planning and Zoning Commission
- Local Special Use Districts