IMPACT OF SURFACE MINING SEDIMENT CONTROL REGULATIONS ON THE HYDROLOGIC BALANCE OF DRYLAND STREAMS[1]

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Abstract. Sediment effluent standards developed in Appalachia, where low background concentrations are the norm, are being applied to western dryland streams where relatively high suspended sediment levels are present. Generally accepted hydrologic and geomorphic principles indicate that this will eventually lead to significant impacts on the hydrologic balance.

INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) is intended to mitigate the impacts of resource extraction. The Act mandates enforcement by the U.S. Department of Interior's, Office of Surface Mining and Reclamation Enforcement (OSM) and requires, among other things, that mining be conducted in such a manner as to, "...minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and ground water systems both during and after surface coal mining operations and during reclamation..." Further stipulations of the Act allude to the prevention of "additional contributions of suspended solids to streamflow, or runoff outside the permit area" and state that, "in no event shall contributions be in excess of requirements set by applicable State or Federal law." Another goal is the avoidance of channel deepening or enlargement by water discharged from mines.

Implementation of the Act utilizes sedimentation ponds to prevent "additional contributions of suspended solids from streamflow..." These structures were found to be effective in the Eastern U.S. and their use is considered the "best technology currently available." Effluent limitations (70 mg/l maximum daily and 35 mg/l maximum 30-day averages for suspended solids) were acquired from the U.S. Environmental Protection Agency (EPA). They had been established based on studies performed in Appalachia where sediment concentrations of mine discharge are typically greater than that of natural streamflow. Publication of the proposed OSM regulations drew protests from western mine operators who questioned the applicability of these sediment effluent criteria to the more arid West. The comments noted that dryland streams are adjusted to high sediment concentrations and suggested that detention of essentially all sediment might trigger damaging downstream channel changes. The purpose of this study is to assess the impact of these sediment control regulations on the hydrologic balance of dryland streams.

DRYLAND ENVIRONMENTS AND GEOMORPHIC PROCESSES

Owing to the numerous, sometimes contradictory and ambiguous, definitions of "arid" and "semi-arid", we have elected to use the term "dryland" to characterize the region of concern. With the exception of areas adjacent to the Pacific Coast and high mountain terrains, the term is used here to describe desert and prairie lands west of the 100th Meridian in the U.S. These landscapes are quite different from those found in more humid regions. Topography is more abrupt, soils are thinner, relatively more bedrock is exposed and most streams are intermittent or ephemeral. Vegetation in these areas is typified by xerophytes with phreatophytes generally occurring along floodplains. Unlike more humid areas, a continuous vegetal mat is rarely present and scattered plants consist mainly of drought resistant, salt-tolerant types. Mechanical weathering tends to dominate over chemical weathering to produce thin, immature, azonal, saline soils.

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Dryland hydrology derives its character from the prevalence of precipitation from small storm cells that produce high intensity events over relatively small areas. This type of storm produces "flashy" runoff (i.e., storm hydrographs have a steep rising limb) with a pronounced capacity for erosion and transportation of sediment. Many dryland streams flow only during the spring runoff season and immediately following major storms. Leopold et al. (1966) found that arroyos near Santa Fe, New Mexico flow only about three times a year. As a consequence, dryland stream morphology is adjusted to these sporadic events and hence, differs from that of the humid-zone streams.

Regardless of climatic zone, streams comprise the means by which both water and sediment cross the earth's surface. According to Schumm (1977) a stream basin is a process-response system, divisible into three parts that include, the drainage basin or source of water and sediment; the channel of transfer zone; and the area of deposition or ultimate destination for water and sediment. Within a moderate span of time, sometimes called "graded time", physical factors such as lithology, structure, relief, history, valley dimensions, climate and vegetation tend to be more or less constant and provide an environment to which other variables adjust. Within a very short time frame, sometimes known as "steady time", only variables such as water and sediment discharge along with stream hydraulic parameters may vary. Because all other variables remain relatively constant, the fluvial system approaches a steady state. Despite continuous fluctuation of at-a-point discharge conditions and channel form, streams tend to move toward an equilibrium state that optimizes the combination of water and sediment discharge, stream gradient and total energy in the system. The convergence of conditions toward equilibrium may occur as continuous, progressive change, or it may occur as episodic movement from one metastable state to another. In the latter, sudden periods of rapid change in channel form, usually coincident with the exceedance of a physical threshold, punctuate long periods of relative stability.

Attainment of equilibrium produces a "graded stream". Mackin (1948) describes such a condition as one, "in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of load from the drainage basin." While equilibrium is a useful concept in understanding stream processes, few streams ever attain equilibrium but all move in the direction of balance. Dryland streams, particularly ephermeral channels, display extreme non-equilibrium behavior and most workers in drylands comment on the "violently non-uniform, unsteady behavior of these channels..." (Thornes, 1977).

The well-known "arroyo problem" in the America Southwest is an excellent example of non-equilibrium behavior of dryland streams. At the time of U.S. occupation in the mid-nineteenth century, most southwestern drainageways were broad, open valleys carrying intermittent or perennial flow. Starting about 1870 to 1880, many of the streams began to rapidly downcut to form deep, steep-sided channels commonly called arroyos. The trenching also produced a change from intermittent to ephemeral flow and is responsible for a decline in water tables and a reduction of vegetation density on floodplains. The Rio Puerco in central New Mexico, a tributary of the Rio Grande, is a superb example of the change. By the mid-twentieth century there were old settlers alive who could remember a quiet, shallow stream flowing through a wide valley. By 1937, however, the Rio Puerco was deeply entrenched along more than 160 km of its course. At that time, scientists with the Soil Conservation Service estimated that 555,000,000 cubic meters of sediment had been eroded and transported by the stream (Peterson and Hadley, 1960). The cause of the arroyo cutting is commonly attributed to changes in land use coupled with poor conservation practices and/or to subtle changes in climate. Although there is not complete agreement on the cause of the arroyo cutting, there is little disagreement that the streams are today in a metastable condition and that they tend to carry extremely high sediment loads.

SEDIMENT TRANSPORT AND CONTROL

Working mainly with data from the U.S., Langbein and Schumm (1958) developed a family of curves that express general trends in annual sediment yield as a function of mean annual rainfall. Their data indicate that peak sediment yields occur in semi-arid, desert and prarie environments where sparse vegetation and high intensity precipitation produce optimal conditions for denudation. Vegetative cover is not the only important factor as soil type, degree of development and soil moisture are also critical factors. Nevertheless, plant cover does serve as a useful index of erosion susceptibility.

Suspended sediment concentration is the important parameter used in assessing water quality. Morris and Doehring (1980) cite 58 published suspended sediment concentrations for dryland streams. They range in value from 5 to 1,300,000 mg/l and have a mean concentration of 109,000 mg/l.

Figure 1 is a map of the United States showing suspended sediment concentrations as well as isohyets. Dryland concentrations generally exceed 2,000 mg/l and in one area that includes parts of the Colorado Plateau an Basin and Range Provinces concentrations excee 30,900 mg/l. Beverage and Culbertson (1964)

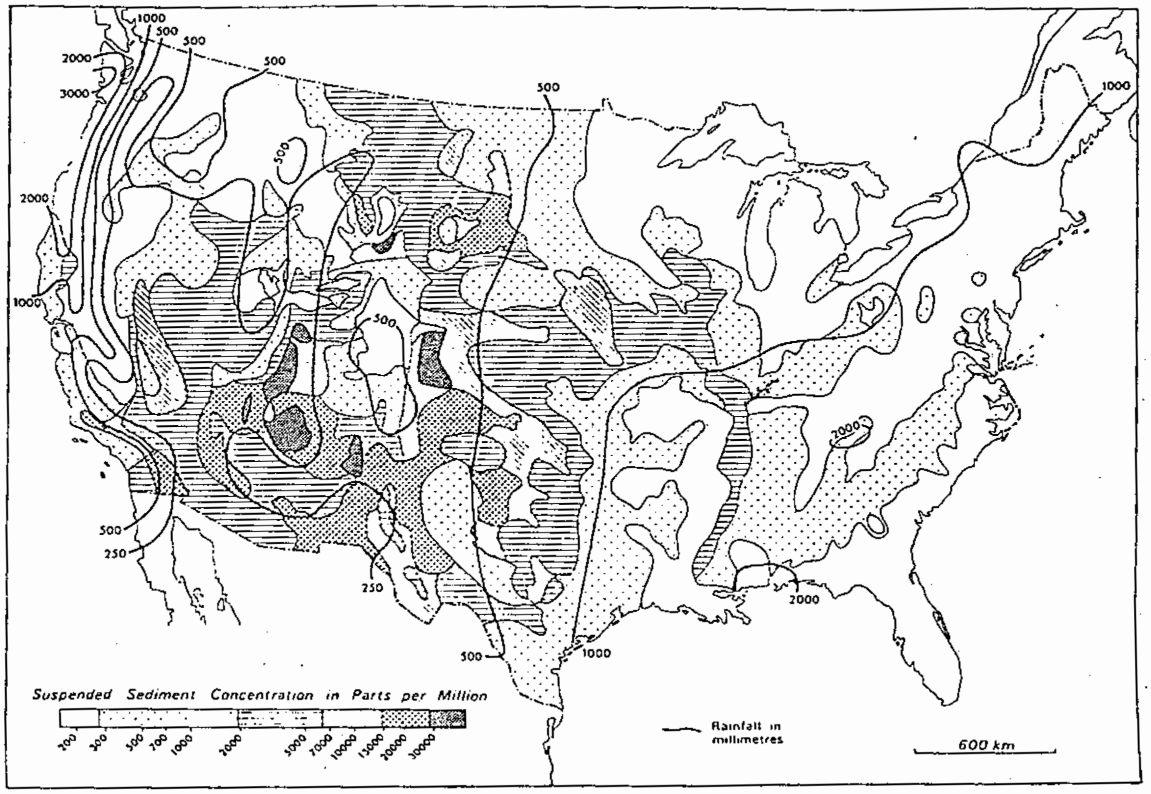

Figure 1. Suspended Sediment Concentrations in the United States (from Gregory and Walling, 1973).

report maximum concentrations in excess of 1,040,000 mg/l for the Paria and Little Colorado Rivers in Arizona. It is apparent from Figure 1 that Appalachia is not typical of the U.S. with regard to suspended sediment concentrations.

At first glance, SMCRA appears to require the removal of sufficient sediment so that mine runoff will equal or exceed the quality of the receiving stream. However, the Act also provides that State and Federal water quality limits may not be exceeded. Consequently, EPA administers surface coal mines as water pollution point sources under the authority of the Federal Water Pollution Control Act and the Clean Water Act. Under these statutes, acceptable levels of pollutants are defined not on the basis of their characteristic or natural background levels, but solely on the basis of man's ability to remove those pollutants from water. This is the meaning of "best technology currently available" and the basis for the EPA effluent limitations of 35 and 70 mg/l maximum daily and 30-day mean concentrations respectively (U.S. Environmental Protection Agency, 1976; 42 CFR 434). Although EPA discharge limitations do not specify the required control technology, OSM specifically defines sediment ponds as constituting the "best technology currently available" (30 CFR 816.42) and sets forth detailed specifications for their construction, maintenance and removal (30 CFR 816.46). As a consequence of these regulations, mines in drylands typically detain all surface flows less than the 10 year, 24-hour storm in sediment ponds.

IMPACT OF SEDIMENT PONDS ON DRYLAND STREAMS

Despite our limited experience with sediment ponds in drylands, there are a number of useful studies that deal with the impact of analogous structures. Many of these studies are summarized by Morris and Doehring (1980). Channel changes induced by man usually result from changes in sediment load relative to flow parameters. Strahler (1956) conciaely states the relationships as follows.

> "What is of prime importance is therefore the ratio between (sediment) load and (water) discharge. In general, an excessively high load-to-discharge ratio will be met with aggradation and steepening of slope; a low ratio, with scour of the bed and lowering of the slope."

Perhaps the most relevant study of channel changes on ephemeral dryland streams is that of Akerbergs (1976). He examined channel responses to stockpond construction in the

Powder River Basin of Wyoming. Working with a sample of 23 small reservoirs from which construction information was available, he identified the following six types of changes.

1. Gullying in the spillway-discharge route.
2. Enlargement of the channel downstream from the reservoir.
3. Gullying in the main channel upstream from the reservoir.
4. Decrease in cross sectional area of the channel downstream from the reservoir.
5. Obliteration of channel features downstream from the reservoir.
6. Sedimentation in the reservoir and extending upstream.

The second, fourth and fifth of these concern changes in downstream channel morphology. Changes four and five involve aggradation along banks with change five occurring immediately below reservoirs and change four farther downstream. Both involve the adjustment of channel geometry to accommodate a new dominant discharge, however, channels immediately below reservoirs may receive little or no discharge and mass wasting of the banks eventually obliterates the former active channel. When the basin is large enough to produce more-or-less regular flows, a small inner channel forms within the pre-reservoir channel. Change two (i.e., channel widening) occurs below reservoirs that display spillway gullying. This suggests that a significant flood has occurred since dam construction. Apparently, the flood flows produced intense bank erosion in channels that had been previously constricted by mass wasting of the banks.

Ackerbergs´ (1976) work provides some fairly definite confirmation to the evidence of other case studies that damming, with its consequent hydrograph modification and sediment withdrawal, can and does produce significant channel changes in dryland ephemeral and intermittent streams. In his concluding chapter, he states that the downstream effects, "...are unavoidable changes which occur as a result of impoundment of water. The only way to prevent them is to avoid building any reservoirs..."

CONCLUSIONS

The installation of a sediment pond meeting OSM standards on a dryland stream will have several important hydrologic impacts. It will produce major changes in storm and annual hydrographs by attenuating stage and increasing the time base. At times of normal flow, it will intercept and detain virtually all waterborne sediment, including both the "natural" and the mining-generated components. It is likely to change ground water hydrology by changing evapotranspiration rates as well as the spatial pattern of recharge.

By depriving the downstream channels of small but relatively frequent flows, channel geometry will not be maintained. The less active channels will be modified by processes of mass wasting; banks will cave and slope processes will tend to obliterate the channels thus eliminating their ability to convey flows of sediment and water. If some flow is maintained, a small, "underfit" inner channel will be produced. When substantial flows return, either due to a high yield storm or due to removal of the sediment pond, accelerated erosion and flooding should be expected. Overall, the impact of sedimentation ponds on dryland streams appears to be the initiation of an accelerated arroyo cycle. The magnitude and significance of the cycle will be a function of the total amount and distribution of land disturbed by mining and the total time period of sediment control on those lands. While sedimentation ponds are quite capable of achieving the sediment concentration reductions necessary to meet EPA discharge limitations, the net effect of achieving those reductions will be the triggering of large bursts of sediment produced by channel adjustments. Whether this effect is good or bad depends somewhat on one´s point of view. However, there is little doubt that such an application of "best technology currently available" to sediment in dryland streams represents, in itself, a major disruption of the "hydrologic balance" that may rival, if not exceed, the impact of the mining operation.

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