

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

April 2007

A Geomorphic Perspective on Things to Think About Before Starting a Gravel Augmentation Project

by Kristin Bunte, John P. Potyondy, and Daniel A. Cenderelli

Gravel augmentation for the purpose of spawning habitat improvement has been carried out episodically by various government agencies since the 1960's, and renewed interest in gravel augmentation was generated during the relicensing of numerous hydroelectric projects in the 1990's. From a scientific and engineering perspective, not much was known about gravel augmentation and consequently, a trial and error approach was often used with varied success.

The report, *State of the Science Review, Gravel Mitigation and Augmentation Below Hydroelectric Dams: A Geomorphological Assessment* (Bunte, 2004) provides a comprehensive review of the different approaches to gravel augmentation, the tools used in gravel augmentation projects, and the analyses needed to arrive at a final gravel augmentation plan. Written from a geomorphological perspective, the review places much of its focus on gravel augmentation projects that emphasize the link between the geomorphic and biological functioning of the stream. Many of the technologies and

concepts presently used in gravel augmentation are still in the process of vigorous development. Most will be modified over time as more is learned about the geomorphic and biological responses of streams to augmentation. The full report is available from the U.S. Department of Agriculture, Forest Service, Stream Systems Technology Center, Fort Collins, Colorado.

Here we summarize the major approaches to gravel augmentation discussed in Bunte (2004), the strengths and limitations of those approaches, and the data that need to be analyzed to successfully implement a gravel augmentation project.

Approaches to Gravel Augmentation

Many different approaches to spawning habitat augmentation have been applied that vary widely in temporal and spatial scales. Successful approaches tend to emphasize "working with the stream." Gravel augmentation is a complex and geomorphologically and biologically challenging

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

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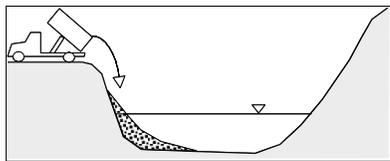
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undertaking, with a high degree of uncertainty regarding the volume of gravel needed and whether the created spawning habitat will have any long-lasting beneficial effect. Tackling gravel augmentation in an interdisciplinary way is essential for the best chance of achieving the desired outcome.



Gravel augmentation approaches, from the simple to the more complex, can be categorized as:

- 1) Local, indirect, or passive gravel additions,
- 2) Direct placement of gravel based on hydraulic and sediment modeling, and
- 3) Comprehensive restoration of geomorphic and biological function.

Approach 1: Local, indirect, or passive gravel additions

Indirect or passive gravel augmentation supplies spawning gravel to a logistically convenient stream location at which the gravel is likely to be entrained and transported downstream by relatively frequent high flow events. Natural downstream deposits of the introduced gravel can provide spawning habitat if the deposits are large enough and contain the preferred sized gravel for the fish species of interest. The volume must be sufficient to deposit the necessary patch sizes used by the target species. However, spawning habitat created this way may be subject to destruction or deterioration if moderate or large floods scour the gravel or if the gravel is stable during smaller floods and not moved sufficiently to wash out potential infiltration of fines.

This method is the cheapest approach to gravel augmentation, because the amount of pre-project computation is typically small and implementation is easy (e.g., dumping gravel from a truck, close to a gravel source, whenever gravel becomes available). To have a long-term beneficial effect, the stream must have gravel conveyance such that the passively supplied gravel can be transported downstream over time and provide spawning habitat along the way. Flows with a competence to

entrain these gravels from the augmentation site and to transport them further downstream must also occur frequently enough to be geomorphically and biologically effective.

Approach 2: Direct placement of gravel based on hydraulic and sediment modeling

These designs rely heavily on hydraulic and sediment transport modeling. Design outcomes are still faced with relatively high uncertainty because knowledge of actual pre- and post-restoration bedload transport rates is limited. The approach requires expertise in stream restoration and hydraulic/sediment transport modeling.

The first step in hydraulic and sediment modeling is identifying the major objectives for the site. The objective may be to create large amounts of high quality spawning habitat, provide for beneficial intra-gravel conditions, provide for geomorphic sustainability, or to efficiently use the amount of gravel within economic constraints.

A hydraulic model calibrated to the site is used to predict hydraulic conditions for the entire reach. Design scenarios are evaluated for factors such as the amount of spawning habitat of different quality created within the reach, whether critical flow for entrainment will be reached or exceeded at various flows, habitat variability downstream of hydraulic controls, or the amount of gravel needed to implement the design.

This highly computational approach to gravel augmentation is based on detailed field measurements (topographic surveys, flow hydraulics, bed material size, intra-gravel flow conditions, and redd counts) and expertise in salmon spawning habitat requirements. It also requires expertise in hydraulic modeling, involves significant survey and modeling efforts, and is limited to those channel types that can be adequately modeled. Successfully applied, it optimizes the chances of creating suitable and long-lasting spawning habitat.

Approach 3: Comprehensive restoration of geomorphic and biological function

The foremost goal of a comprehensive approach to gravel augmentation is restoration of the

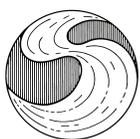


Table 1. Overview of parameters for which information may be required in gravel augmentation projects.

	Unknown parameter or interaction	What to measure and compute	Methods used
Streambed Topography	Current cross-sectional shape for pre-project condition and its change over time	x-y coordinates of cross-section at geomorphologically active locations, repeated over time	Topographical Survey
	Stream gradient	x-y coordinates of longitudinal profile	
Sediment supply	Status of sediment supply: is the stream aggrading or degrading?	Areal extent of stream-bed covered by different geomorphological units and facies units	Topographical survey; Mapping geomorphological units and facies units, digitization, and spatial analysis
Bedload transport	Bed mobility, critical flow for gravel entrainment, pre-and post-project	Bed surface particle-size distribution	Pebble count
		Post-flood displacement distance of seeded D_{84} , D_{50} and D_{31} particles at different flows	Tracer study
	Depth of scour and re-deposition	Pre- and post flood x-y coordinates of top and bottom of scour core	Topographical survey of scour cores
	Current bedload transport rates, annual load, amount of gravel to be supplied	Bedload transport rates during flood events, annual load	Bedload sampling, annual load computation
	Amount of gravel to be supplied	Stream-bed elevation before and after flood events, prior to which gravel was applied; scour depth	Topographic survey, topographic differencing; scour cores
Spawning gravel	Current quantity of spawning gravel	Area suitable for spawning based on appropriate flow depth, velocity, and bed material size; redd counts	Stream mapping, digitization and spatial analysis
	Quality of spawning gravel	Particle-size distribution; intra-gravel flow, temp., turbidity, dissolved oxygen	Unstratified bulk samples; Piezometer water samples, egg/alevin counts
	Sources and sinks for fines	Amount of fines in pools and other deposits, veneer thickness, bulk density, total amount of fines per stream segment; tributary supply of fines	Visual assessment, stream mapping, digitization, spatial analysis; geomorphic analysis at confluence; bedload sampling
Modeling complex interactions	Stream-bed topography	x-y coordinates of stream bed within project reach	Topographic modeling, DEM
	Interaction of water depth, velocity, total flow volume, and surface gradient in pre- and post-project channel shape	Current flow hydraulics for model validation; Flow dynamics for specified flow and channel shape	Hydraulic modeling, 1-D or 2-D
	Critical flow for incipient motion	Ratio of actual flow to an assumed critical flow	Based on output of hydraulic model and critical flow equation
	Sediment transport and channel change for specified flows in pre- and post-project channel	Current bedload transport rates for model validation; Transport rates for specified flow & channel shape	Bedload transport modeling, based on output of 1-D hydraulic model and bedload equation

geomorphic functionality of an entire stream or multiple stream reaches, based on the understanding that if the pool-riffle or alternate bar morphology is restored within the context of the existing altered flow regime, fish habitat will

develop as a natural process, fulfilling various biological functions at different stream locations. Measures to restore geomorphic functionality may include: (1) shaping the channel by adding or removing gravel to ensure that the post-dam 1.5-



year recurrence interval flow fills the channel to its morphological bankfull stage, (2) adding bed material that can be partially mobilized at bankfull flow, and (3) continuing gravel additions that match post-restoration transport capacity as a long-term measure. As these projects incorporate the concept of mobile gravel, unimpeded downstream gravel conveyance, and overall stream and habitat restoration, the spatial project scale may extend over stream segments several tens of miles long or multiple reaches, while the temporal scale typically covers multi-year and decade long periods.

This approach provides for a long-term solution that, once a geomorphologically and biologically functioning stream is established, requires little maintenance apart from episodic or regular passive gravel additions for replenishing insufficient upstream gravel supply. Complete river restoration requires expertise in fluvial geomorphology and bedload transport processes, as well as in conducting field measurements and habitat assessments. All of the tools and skills necessary for detailed hydraulic and sediment transport modeling and evaluation are typically employed. In spite of the extensive expertise required in the biological and engineering sciences, project outcomes are still highly uncertain because no such project has been fully implemented, monitored, and evaluated to date. These efforts, however, provide great opportunities to expand our knowledge of morphological processes in gravel-bed rivers and how these processes create aquatic habitat.

Data Needed for Analysis

The outcome of gravel augmentation projects is difficult to predict with a high degree of certainty. In order to go forward with gravel augmentation projects, while still lacking complete scientific understanding, adaptive management is generally recommended as a project strategy. Under this strategy, a project is treated as a scientific experiment with potentially unknown outcome and the project is modified over time based on data from monitoring and evaluation.

Table 1 provides an overview of the information that may be required for a specific project. The table is intended to illustrate the complexity of the issues likely to be encountered in a typical project

and reinforce the need for an interdisciplinary and adaptive management approach.

Conclusions

In summary, gravel augmentation is a difficult and complex endeavor challenging the biological, geomorphic, and engineering sciences. Successful projects require extensive geomorphic and biological understanding and experience and are hampered by our current poor understanding of gravel transport processes coupled with a high degree of uncertainty associated with existing computational models.

Because gravel augmentation can exert a large influence on stream processes and channel response, engaging in this undertaking requires a deep understanding of geomorphic and biological processes as well as experience in gravel augmentation projects. The larger the spatial and temporal scale of the project, the wider the range of factors that influence the project outcome and are influenced by it. This implies that large-scale projects have a particularly pressing need for an interdisciplinary approach including fluvial geomorphology, fisheries biology, watershed sciences, and riparian ecology.

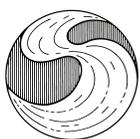
References

Bunte, K. 2004. State of the Science Review, Gravel Mitigation and Augmentation Below Hydroelectric Dams: A Geomorphological Perspective. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Report submitted to the Stream Systems Technology Center, Fort Collins, CO. 234 p. Available: <http://www.stream.fs.fed.us/publications/PDFs/Gravel Augmentation Report.pdf>.

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Impacts of ATV Traffic on Undesignated Trails

by Randy B. Foltz and Dexter L. Meadows

The U.S. Department of Agriculture, Forest Service reports that driving motor vehicles off-road has become one of the fastest growing activities on national forest lands. The continued growth and use of all-terrain vehicles (ATVs) has created a demand upon many existing trail systems that were not designed for this level of use. This has challenged the capacity of trails and the ability of recreation managers to schedule and perform basic trail assessments and regular maintenance.

Although the Forest Service is committed to providing public access to recreational opportunities on national forests and grasslands, the ever-increasing ATV-management challenge is to provide public access to roads and trails that can be sustainable without compromising the aesthetic beauty and integrity of natural resources and ecological processes. The Forest Service has responded to this challenge by establishing Travel Management Regulations in 2005, often referred to as “the Off-Highway Vehicle Rule”, that ensured the access to and protection of the natural resources on national forests and grasslands. The Forest Service also performed a study to determine the effects of ATVs on national forest resources. This article provides a brief summary of the study.

The objective of the study was to determine if ATVs had an effect on the natural resources and if so, which ATV types and tire treads created the impact. All phases of the study were performed at six locations across the country within representative ecoregions: Tonto NF, Arizona; Land Between the Lakes National Recreation Area, Kentucky; Kisatchie NF, Louisiana; Superior NF, Minnesota; Beaverhead-Deerlodge NF, Montana; and Wenatchee NF, Washington. Only the ATV traffic portion was performed on the Mark Twain NF, Missouri and is not discussed here.

Methods

The experimental approach was to make repeated passes over the same piece of the landscape and measure the effects on the natural resources. At each location four new loop trails characterized by

uphill climbs, downhill descents, turns, and straight sections were setup for the study (fig. 1). Two ATV types (sport and utility) and two tire tread types (original equipment manufacturer and a more aggressive aftermarket tire) were selected for this study. The machines selected represent the most popular ATVs found across the country at the time of the study. The original equipment manufacturer general-purpose tire had a lug height not to exceed 0.5 inches and lug width not to exceed 1.5 inches. The aggressive-tread aftermarket tire for each location was the one most often used by local riders and accepted by the local regulatory authorities. None of the aftermarket tires had lug heights exceeding 0.75 inches.

Rather than attempt to measure each structural characteristic of the natural environment along the continuum of no disturbance to unacceptable disturbance, three disturbance classes (low, medium, and high) were developed. The three indicators that determined the disturbance classes were litter and vegetation, trail width, and ATV rut depth (table 1). To use the disturbance class matrix an observer walked along a trail section and chose the descriptor in each of the three indicators that best represented that section of trail, and circled it on the rating sheet. After all the indicators had been rated, the number of choices in each disturbance class was totaled. The disturbance class with the highest total was the condition of that trail section. Ties between low and medium or between medium



Figure 1. An ATV rider on the loop trail at the Superior National Forest, Minnesota.



Table 1. The trail disturbance class matrix used in the field to identify the disturbance level from ATV use.

Disturbance Indicator	Low Disturbance	Medium Disturbance	High Disturbance
Litter and vegetation	0- to 30-percent loss of ground cover, small roots exposed, rocks no more exposed than natural conditions.	30- to 60-percent loss of ground cover, small roots exposed and broken, rocks exposed and fractured.	Greater than 60-percent loss of ground cover, large roots exposed and damaged, large rocks worn around or displaced.
Trail width (both tread and displaced material)	54 inches or less.	Between 54 and 72 inches. Some trail braiding. Evidence of width increasing.	72 inches or greater. Braided trails evident. Trail width is growing.
ATV rut depth	Ruts less than 3 inches deep.	Ruts 3 to 6 inches deep.	Ruts greater than 6 inches deep.

and high were rounded down. Any observation of a high condition resulted in a condition classification of at least medium.

Removal of litter and vegetation causes both visual impacts and allows increased soil erosion. Visually, the reduction of cover distinguishes an ATV trail from the undisturbed forest. Continued ATV use also inhibits plant re-growth in much the same manner as vehicle traffic inhibits plant re-growth on unpaved forest roads. Trail width was a key indicator of trail conditions. Increasing trail width results in more area disturbed. ATV rut depth was the final indicator of trail conditions. Deeper ruts allow channeling of water on the trail and concomitant concentrated flow erosion.

The experimental design for the ATV traffic was one loop for each combination of vehicle and tire type for a total of four loops at each site. Each loop had four trail features (uphill climbs, downhill descents, turns, straight sections) and each feature was rated with the condition class matrix after approximately every 40 passes. While this results in a large number of observations, there are no replications in the experimental design. Further, the number of ATV passes was not the same on each loop and the goal of reaching the high disturbance condition was not achieved at all locations.

Rainfall simulation was used to determine soil erosion characteristics of infiltration and raindrop splash parameters for each combination of location and vehicle-tire combination. Differences in soil moisture, slope, and ground cover at each location made direct comparison of runoff and sediment loss inappropriate. To account for these differences, the Water Erosion Prediction Project (WEPP) model was used to determine the infiltration and erosion characteristics. The WEPP model (Flanagan and Livingston, 1995) is a physically based soil erosion model that provides

estimates of runoff, infiltration, soil erosion, and sediment yield considering the specific soil, climate, ground cover, and topographic conditions.

Results

Some portion of the trail transitioned from low to medium disturbance class in 20 to 40 passes. This level of ATV traffic could be achieved in one weekend from a moderate sized ATV group. Similarly, all six locations had some portion of the trail transition from the medium to high disturbance class in 40 to 120 passes. This level of ATV traffic could be achieved in less than a month. Changes in ground cover, one of the components of the condition class matrix, are shown in figure 2. Noteworthy were the decrease in cover from undisturbed to low and the continuing decrease in cover from low through high. A high disturbance condition class was not achieved at the Minnesota, Montana, or Washington sites. At the Arizona site, a medium condition class was not observed.

Erosion parameters of hydraulic conductivity and interrill erosion were determined using the WEPP model for each set of rainfall simulation tests.

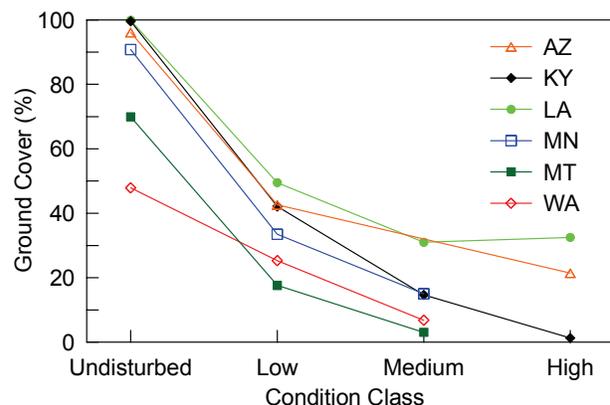
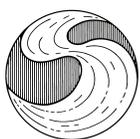


Figure 1. Percent ground cover each disturbance class at each site. The lack of a point for a given disturbance class indicates no data were available or obtained for that site.



Investigation of changes in both runoff and raindrop erosion can indicate how sediment loss changes due to ATV traffic. It is possible for runoff and raindrop splash erosion to independently increase, decrease, or remain the same. In this ATV study there were only four combinations of changes in runoff and raindrop splash erosion.

The locations with the largest potential increase in sediment loss were the loamy sand soil texture locations of Louisiana and Washington where runoff increased and raindrop splash erosion increased. At these locations, ATV traffic caused an increase in runoff and an increase in sediment loss in excess of that due to the increased runoff alone. At both of these locations, runoff was approximately doubled after traffic and raindrop splash was approximately doubled after traffic. These locations and ones with similar loamy sand soils will likely have increased runoff combined with sediment loss in excess of that due to the increased runoff alone.

Runoff increased and raindrop splash erosion remained unchanged at the gravelly sandy loam soil texture sites of Minnesota and Kentucky. Runoff increased due to impacts of ATV traffic by 3 to 40 times the undisturbed values. Both locations will likely have large increases in runoff from ATV trails. The increased runoff has the potential to make a proportionate increase in soil loss.

At the gravelly sand locations of Arizona and Montana runoff was unchanged and raindrop splash erosion increased. The gravelly sand did not compact during ATV traffic resulting in no change in infiltration. Soil erodibility at Arizona doubled, while at Montana, it tripled. These locations and ones with similar gravelly sand soils will likely have increased sediment loss with no increase in runoff when compared to undisturbed areas.

All of the vehicles tested had an impact on site conditions regardless of the combination of ATV type or tire tread. Sport model vehicles (lighter weight ATVs) caused as much disturbance as the heavier utility model vehicles. The heavier more powerful utility vehicles reached the targeted disturbance levels in fewer passes than the sports two wheel drive models, but when the number of passes was the same, the levels of disturbance were

the same from each vehicle type. The study found no differences between the two tire types tested.

Conclusions, Management Implications

The study concludes that ATV traffic adversely affects natural resources. The study further concludes that all of the vehicles tested contribute to those effects regardless of the type of ATV or tire type. The effects are considered adverse because the natural resources (soil, water, air, and vegetation) have been reduced or changed in a manner that prevents them from maintaining and performing their naturally prescribed functions. The ramifications of the effects are manifested in the removal or destruction of vegetation including forest floor litter, the exposure and destruction of plant root networks, the exposure of bare soil, and soil erosion as a result of bare soil exposure.

The data also implies that straight sections of trail will require less maintenance especially if these sections are located away from weaker soils. This will be an important distinction to management as forests involve and work with volunteer groups in an effort to make their contributions meaningful and effective.

The study also suggests that to simply limit ATV traffic to trails is not enough to protect the natural resources. Trail planning and design, particularly trail location, are key considerations for limiting disturbances to natural resources. The design phase should identify destinations as well as areas to avoid such as soils that are easily disturbed, wet areas (riparian zones), and sensitive wildlife habitats and archeological sites.

References

Flanagan, D.C. and Livingston, S.J., eds. 1995. *WEPP User Summary*. NSERL Report No. 11. W. Lafayette, IN: National Soil Erosion Laboratory. 131 p.

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