Physically-based model of downstream fining in bedrock streams
with side input: Part II; field applications

Eric Lajeunesse\textsuperscript{1}, Phairot Chatanantavit\textsuperscript{2,3}, Luce Malverti\textsuperscript{1}, Patrick Meunier\textsuperscript{4}, and Gary Parker\textsuperscript{5}

\textsuperscript{1}Laboratoire de Dynamique des Fluides Géologiques, Institut de Physique du Globe de Paris, France

\textsuperscript{2}St Anthony Falls Laboratory, Civil Engineering, University of Minnesota,

Minneapolis, MN, 55414 USA

\textsuperscript{3}Now at Philip Williams & Associates, Ltd., San Francisco, California, 94108 USA

\textsuperscript{4}Dept. of Earth Sciences, University of Cambridge, Cambridge, UK

\textsuperscript{5}Dept. of Civil and Environmental Engineering & Dept. of Geology, University of Illinois,

Urbana, IL, 61801 USA

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Corresponding Author:

Phairot Chatanantavit
Philip Williams & Associates, Ltd.
550 Kearny Street, Suite 900
San Francisco, CA 94108
USA

Tel: 763-350-5226
Email: p.chatanantavit@pwa-ltd.com
ABSTRACT

This paper focuses on downstream fining in a bedrock stream with a partial cover of gravel (gravel and coarser material, here lumped together as “gravel” for simplicity). The supply of gravel particles from hillslopes in bedrock rivers may result in a bed and bedload in which characteristic grain size declines downstream due to abrasion, and/or selective sorting. In a companion paper, we included both processes in the development of a physically-based model of downstream fining in bedrock streams with side input. The model is here tested against field data from Vieux-Habitants River in Guadeloupe Island, which is located in the Caribbean Sea. The river shows clear downstream fining, and this pattern is captured reasonably well by the model. The model results indicate that abrasion (including fracturing) is solely responsible for the downstream fining pattern for most of the study reach of the Vieux-Habitants River. The results also suggest that in general, selective sorting by differential transport can play a role in downstream fining only in cases of streams with relatively fine gravel sizes and lower slopes.

Key Words:
downstream fining, bedrock river, abrasion, selective sorting, bedload transport

1. Introduction

A well-known characteristic of many rivers is a tendency for decrease in the characteristic grain diameter of the bed (e.g. the median bed surface size $D_{50}$) in the downstream direction. This tendency, which is often termed downstream fining, is usually accompanied by a downstream decrease in bed slope, i.e. a concave-upward longitudinal profile. These characteristics are well documented in the literature [e.g. Sternberg, 1875; Kodama, 1994a; Hoey and Ferguson, 1994]
and have been the focus of several numerical modeling efforts, such as Parker [1991a,b], Hoey and Ferguson [1994], Pizzuto [1995], and Cui et al. [1996]. All of these studies address the case of alluvial rivers rather than bedrock streams. In aggregate, they include the effects of selective bedload transport, abrasion, tributary inputs, and tectonic subsidence on downstream fining.

By comparison, only few authors have addressed the problem of downstream fining (or its absence) in bedrock rivers. This is rather surprising if one thinks of downstream fining as a tool to probe important geomorphic processes such as abrasion by bedload or long term fluvial incision into bedrock. Sklar et al. [2006] were probably the first to study downstream fining in bedrock streams with side input. However, only abrasion (wear) processes were considered in their work. For the case of spatially uniform supply of poorly-sorted hillslope materials, they found little or no downstream fining of bed and bedload material, because local re-supply offsets the size reduction due to abrasion. They then suggested that downstream fining in bedrock rivers must be due mainly to spatial gradients in hillslope, sediment production and transport features.

In the companion paper, Chatanantavet et al. [submitted], a formulation is presented for modeling the downstream variation in bed sediment characteristics of bedrock rivers with side input by incorporating both abrasion and sorting by differential transport. In this paper, the model is applied to a fairly typical steep bedrock stream flowing into the ocean.

More specifically, the model is tested against field data in Vieux-Habitants River, an andesitic bedrock river flowing on the tropical volcanic Basse-Terre Island, which is a part of Guadeloupe Island (Guadeloupe archipelago, Lesser Antilles Arc). Our field observations indicate that the material input from the hillslopes is nearly spatially invariant from upstream to downstream. This notwithstanding, Vieux-Habitants River exhibits downstream fining, in
contradiction to the conclusion of Sklar et al. [2006]. Thus particle abrasion and/or fracturing must prevail, as confirmed by our observations of rock fracturing and crushing along the stream.

A secondary purpose of the present investigation is to test whether granulometric measurements of downstream fining along bedrock streams can be used to quantify long term bedload transport. Indeed, bedload transport in rivers on Basse-Terre Island appears to be driven by flashfloods triggered by episodic intense rainfalls during the rainy season. Direct measurement of bedload transport during these events is not possible, and their impact on long term denudation rates has not yet been quantified. A physically-based model of downstream fining constrained with both granulometric and hydrologic data could therefore provide indirect estimate of bedload transport associated with intense flow rates. The paper starts with a description of the field site and the procedure for data acquisition. The model application to the field data is then outlined, and the results are evaluated and discussed.

2. Field description: Guadeloupe Island

Basse-Terre Island belongs to the archipelago of Guadeloupe, and is in fact a part of Guadeloupe Island. Guadeloupe Island consists of Basse-Terre Island and Grand-Terrre Island, which are connected by a narrow isthmus. It is located in the volcanic arc of the Lesser Antilles, which was created by subduction of the Atlantic Ocean lithosphere beneath the Caribbean plate. Basse-Terre Island consists of 7 main eruptive fields [Komorowski et al., 2005]. Age determination by Blanc [1983], Carlut et al. [2000], Carlut and Quidelleur [2000], and Samper [2007] have constrained the timing of volcanism. Basse-Terre Island is characterized by a quite uniform andesitic lithology: the terrain is composed of lava flows and eroded volcanic edifices dated between 2.79 Myr in the north of Basse-Terre (Basal Complex and Septentrional Chain) to 0 My
for the present day active Grande Découverte-La Soufrière volcanic complex in the South. Volcanic massifs ages are correlated with their maximum elevations. The youngest massif (Grande Découverte) culminates at 1437 m. Toward the North, maximum elevations decrease progressively to 1000 m for the axial chain, 700 m for the Septentrional chain and 400 m for the Basal Complex. A recent investigation of tectonics [Feuillet, 2001; Feuillet, 2004] has revealed that Basse-Terre Island is affected by east-west conjugated normal faults which delineate a complex 20 km wide graben. The southern fault marks the limit between the Caraïbes massif and the Grande Découverte massif. The northern fault crosscuts the axial chain from Bouillante to Sainte Marie.

The climate of Basse-Terre is tropical, with high temperatures (24 - 28°C) and high precipitation rates. Averaged annual runoff ranges from 2700 mm/yr on the west (leeward) coast to 3100 mm/yr on the east (windward) coast. The hydrologic regime is torrential: tropical storms and hurricanes are frequent, particularly during the rainy season which spans the period from June to January. Vegetation is dense and tropical, and soils are very thick. The landscape is controlled by the competition between effusive volcanism and tectonic uplift on the one hand and weathering and erosion processes on the other. These are qualitatively similar to those at work in many active mountain belts. Rivers and debris flows cut the bedrock, while landslides limit the relief of interfluves. Topography is characterized by a high relief ridge-and-valley landscape, with straight, steep hillslopes and a well connected channel network, which evacuates erosion products over the long term. Episodic intense rainfalls trigger landslides and flashfloods, and cause significant transport of dissolved and solid materials in rivers in the form of alluvial river flows, as well as mud or debris flows. The impact of these events on the long term denudation rate is yet unquantified.
We conducted a data collection campaign on the Vieux-Habitants River in February of 2007. This river, located in the south-west of Basse-Terre Island and draining into the leeward coast, has a length of ~ 19 km (Figure 1). Its bed elevation varies from 1100 m at its most upstream end to 0 m at the Vieux-Habitants village, where it reaches the sea. It is characterized by a concave-upward profile of bed elevation, and high slopes of approximately 8% upstream to 2% downstream (Figure 2a). Most of the river catchment is located within a national park, so that anthropogenic forcing is expected to be weak. Vegetation is very dense and the lithology is relatively uniformly andesitic.

The denudation rate of the Vieux-Habitants catchment has been estimated to be about 610 mm/kyr, by means of a geochemical mass balance method [Rad et al., 2006]. This erosion rate has recently been confirmed by Lajeunesse et al. [submitted], in which a Digital Elevation Model (DEM) was used to estimate the total volume removed by erosion. Based on the measurements of Samper et al. [2007], they deduced the basin averaged denudation rate to be near 390 mm/kyr, and the river incision rate to be near 800 mm/kyr.

Upstream of the Barthole site, which is ~ 7 km upstream of the river mouth (Figures 1 and 2a), Vieux-Habitants River flows on an andesitic bedrock channel and incises a rather narrow V-shaped valley. Its bed is partially mantled by a thin alluvial cover whose thickness can increase locally, most likely when overwhelmed by an episodic sediment supply from adjacent hillslopes, gullies or tributaries. Not far downstream of the Barthole site, the bed of the Vieux-Habitants changes from bedrock to alluvial (Figures 1 and 2a), and the valley widens.

Several field trips along the river allowed us to directly measure the river width up to a distance of 11 km from the sea, by means of a laser-distance meter. We were not able to walk farther upstream because the rain forest becomes very dense. In the bedrock part, the width of the
river is on the order of 15 to 20m (Figure 2b). Downstream of the bedrock-alluvial transition, width increases from 30 m near Barthole to 40 m at the sea.

The water discharge of the Vieux-Habitants River is monitored by the Direction Regionale de l’Environnement (DIREN). A gauging station located at the Barthole site has been recording water flow depth every 15 minutes by means of a pressure sensor since 1980. Hourly discharge data extending from 1951 to 1988 are also available from another gauging station, Pont du Bourg, which is at a distance from the sea of 1.3 km. This station is no longer in use. Despite some gaps, this set of data covers a period long enough to characterize the hydrologic regime of the river. The discharge of the Vieux-Habitants River is highly variable. Instantaneous flow rates recorded at the Barthole station between 1980 and 1993 vary between 0.4 and 250 \( \text{m}^3\text{s}^{-1} \). At the Pont du Bourg station, located farther downstream, water flow rates as high as 410 \( \text{m}^3\text{s}^{-1} \) have been recorded. These peaks of water flow rates correspond to flash floods caused by tropical storms and hurricanes. These are rather frequent during the rainy season, which spans from June to January. They are responsible for most of the bedload transport in the river.

Typical bedrock reach in the upstream part of the Vieux-Habitants River (e.g. upstream of the Barthole gauging station) and typical alluvial reach in the downstream part where bedrock exposure is no longer observed are shown in Figures 3a and 3b, respectively. We used the Wolman [1954] method with a sampling interval of 1 m to determine the grain size distribution for 16 sites along the river (see Figures 1 and 2a). For each site, about 200 samples were recorded along bars (Figure 3c), based on the assumption that these characterize the alluvial material of the bed. The median diameter decreases from about 200 mm at 10.3km from the sea to 48 mm at the sea. The channel bed is characterized by the presence of numerous boulder blocks of meter size (Figure 3b) as indicated by the \( D_{90} \) which varies from 1660 mm at 10.3 km
from the sea to 160 mm at the sea. The Wolman method was also applied to characterize the granulometric distribution of a landslide deposit along the river bank (Figure 4a). The resulting distribution, shown in Figure 4b, gives an idea of the size of the sediments feeding the river. Note that material finer than 2 mm has been excluded from the grain size distributions, as this material is assumed to move as washload during floods.

3. Model application and results

In this section, the numerical model developed in the companion paper is applied to the field data from the Vieux-Habitants River in Guadeloupe Island. Several power relations are used as follows in order to simulate the field data and input into the numerical model. Figure 5a shows the field data for drainage area $A$ as a function of downstream distance $x$ in the Vieux-Habitants River as deduced from the previously-described DEM, as well as a power-law fit corresponding to the form of Hack's law [1957]. For the most part in the upstream reach, the coefficient is the same as the value given by Hack [1957], but the exponent has been adjusted downward from 1.7 to 1.6, using the length unit of meter. In the 6-km portion of the reach farthest downstream, however, the drainage area increases toward downstream relatively slower due to the drainage shape (Figure 1) and can be fitted by another adapted power law as shown in Figure 5a. Figure 5b shows the collected field data for channel width $B$ versus $A$, as well as a power-law approximation relating the two. The coefficient and exponent, which take the values of 0.03 and 0.4 using the length unit of meter, were adapted from the form of the width-area relation for mountain streams given by Montgomery and Gran [2001]. Finally, Figure 5c shows the field data for bed slope $S$ versus distance $x$ for the river, along with an exponential fit of the form:

$$S = S_0 e^{-c(x-x_0)}$$

(1)
\[ c = \frac{\ln(S_u / S_d)}{L} \]  

where \( S_u \) is bed slope at the upstream boundary of the study reach, \( x_u \) is distance from the upstream divide to the upstream boundary of the study reach, \( S_d \) is bed slope at the downstream boundary of the study reach, and \( L \) is the total down-channel length of the study reach. The values of \( L, S_u, S_d, \) and \( x_u \) are used as inputs to the model.

Table 1 below summarizes the input parameters used in this section to simulate downstream change in grain size in the Vieux Habitants River. The effective rainfall rate and flood intermittency are deduced from the flow discharge record collected from 1951 to 1988 by DIREN. The basin-wide denudation rate \( v_d \) of the Vieux-Habitants drainage has been estimated to be about 0.4 mm/yr using DEM to estimate the total volume removed by erosion [Lajeunesse et al., submitted]. The abrasion coefficient (\( \beta \)) or volume fraction of grain lost per unit distance traveled is estimated for andesitic rock, which is the most common lithology in the river, based on information in Kodama [1994b], Sklar and Dietrich [2001, 2004], and Chatanantavet and Parker [submitted].

The numerical model outputs shown here consist of plots of the downstream variation of surface geometric mean grain size \( D_{gs} \), gravel transport rate, areal fraction of alluvial coverage during floods and low flows, and grain size distributions of the gravel part of the bedload and bed surface material along the stream. Figure 6 shows a comparison of the downstream variation of gravel surface geometric mean grain size as measured in the field and predicted by the model.

For the most part, the numerical model results are in good agreement with the field data except the most downstream 1.5-km portion in which the selective entrainment, such that smaller sizes predominate in the load during the lower flows but the largest sizes are only moved near the peak flow, appears to characterize. Figure 7 shows the numerical model results for the downstream...
variations of sediment transport rates. Note that the model produces a large amount of sand and silt (< 2 mm) partly due to the exclusion of particle fracturing processes in the model (see the companion paper). It is interesting to note, however, that sand-sized particles were observed in the field to be increasingly more common from upstream to downstream, and the river was observed to be sand-bed right at its mouth.

Figure 8 illustrates the numerical model results for the downstream variation in the areal fraction of alluvial coverage during floods and low flows for the Vieux Habitants River. The coverage at low flow was estimated by precipitating the wash load (sand and silt) during floods onto the bed of the stream, and combining it with the gravel. The results are consistent with our field observations that in the upstream part of the stream (e.g. upstream of the Barthole water gauging station) bedrock exposures were found to be ubiquitous, whereas in the seven kilometers corresponding to the farthest downstream part of the reach bedrock exposures are absent at low flow. As discussed in the companion paper, the results during low flows are more proper values to use even in replacement of the values during the high-flow events since the results during floods underestimate the gravel-bedload sediment transport and alluvial bed coverage. In this model the neglecting of rock splitting processes, which is implicitly built-in the abrasion coefficient, results in the overproduction of silt and sand (suspended load) rather than breaking-up into smaller sizes of cobble/gravel.

Figures 9a and 9b show the model results for the grain size distributions of the gravel portions of the bed surface and bedload material, respectively, along the study reach of the Vieux Habitants River. Unlike the results for the grain size distributions of surface and bedload materials in the companion paper, Chatanantavet et al. [submitted], where smaller grain sizes and lower slopes were used, the results for the Vieux-Habitants River show virtually no surface
coarsening or armoring. The size distributions of both surface and bedload material within the channel are mostly finer than the landslide material because of the effect of downstream fining. It is shown below that this downstream fining feature is solely due to abrasion.

4. Discussion

In this study, we provide evidence that the physically-based model of downstream fining in bedrock streams with side input developed in the companion paper, Chatanantavet et al. [submitted], is able to simulate the downstream variation in grain size characteristics of surface material along a natural bedrock river. The model provides numerical results for the downstream variations of surface geometric mean size $D_{sg}$ and surface $D_{90}$ (such that 90% by weight of a sample is finer), gravel transport rates during floods, areal fraction of alluvial coverage, transport capacity, and grain size distributions of gravel bedload and the gravel part of the bed surface material.

The plot of areal fraction of alluvial coverage, which shows high bedrock exposure (i.e. low values of the fraction of alluvial coverage) in the upstream part and zero bedrock exposure in the downstream part (Figure 8), is within a reasonable range consistent with the field observations. The resulting plots of grain size characteristics along the stream are also consistent with the field data.

The model results for surface geometric mean size seem to match the field data reasonably well except in 1.5-km region representing the farthest downstream portion of the study reach, where the model overpredicts (Figure 6). This abrupt change in grain size is probably due to another type of selective sorting, of which smaller sizes predominate in the load during the lower flows but the largest sizes are only moved near the peak flow (so called
selective entrainment). This type of selective sorting is not considered in the present study. This abrupt change in grain sizes in the Vieux-Habitants River, was recorded but not documented photographically. A very similar abrupt change in grain sizes was also observed in a nearby smaller bedrock stream in the Guadeloupe Island, the Capesterre River (Figure 10). In Figure 10, boulder-sized clasts were found to be very common in the channel immediately upstream of the point at which the picture was taken, yet immediately downstream the surface material was found to abruptly change to finer gravel and cobble sizes. Material in this latter size range was continuously observed in this river from the location of Figure 10 to the river mouth, which is approximately 1 km downstream. A large amount of sand was observed in the bed material right at the mouth.

The model can be used to quantify the relative roles of abrasion and selective sorting in downstream fining in the Vieux Habitants River. Figure 11 shows a comparison of the model results for surface geometric mean size along the channel, with a comparison between a case in which abrasion is turned off (by setting $\beta = 0$) and one in which abrasion is included (with $\beta = 0.00015 \text{ m}^{-1}$). In the former case, the results produce essentially no grain size reduction. This suggests that sorting by differential transport may not contribute to downstream fining in this case, unlike the sample results presented in the companion paper, Chatanantavet et al. [submitted]. This is most likely due to the fact that the test run in the companion paper uses smaller grain sizes and milder slopes.

The model has a number of limitations. The application of a gravel transport relation directly to a stream in which boulders are common is unlikely to be correct in general. This is particularly true when the boulders are never inundated, even during the largest floods. Yager et al. [2007] have recently presented a methodology that could address this question. It is of
interest to note that the bedload transport equation that they recommend in their calculations is
\cite{Parker1982}, which is a relative of the relation used here, i.e. that of \cite{Parker1990}.

The model could be further improved by including fracturing (comminution) into the
description of downstream fining. The model as it stands produces only sand and silt from
abrasion. The incorporation of fracturing would allow the breakup of coarser stones to produce
finer stones as well as sand and silt. \cite{Parker2008} have presented a framework for a
comminution mode that can be applied to rivers.

The model in its present form tracks sand and silt through the system by treating it as
wash load during floods, but precipitating it out on the bed during low flows. A more advanced
treatment of sand-silt transport through a bedrock, gravel-bed stream would allow for a better
representation of this aspect of the modeling.

\section*{5. Conclusion}

The physically-based model of downstream fining (or its absence) in bedrock streams with side
input from hillslopes of the companion paper, \cite{Chatanantavet2020}, was developed to
provide a model framework that includes both abrasion and selective sorting by differential
transport. In this paper, the model has been applied to the Vieux-Habitants River in the
Guadeloupe Island. Using data input specifically fitted to the river, as well as reasonable
estimates of other input parameters, the model is found to represent the field data fairly well.
The only region where the model predictions do not fit the data is a 1.5 km reach ending at the
river mouth. Within this reach, the channel slope is considerably mild such that another type of
selective sorting, of which smaller sizes predominate in the load during the lower flows but the
largest sizes are only moved near the peak flow (so called selective entrainment), prevails.
The results suggest that the model represents an advance in the study of downstream fining in bedrock streams with side input from hillslopes. The results further indicate that abrasion (including fracturing) is solely responsible for the downstream fining pattern over most of the study reach of the Vieux-Habitants River (in which boulders are common). Selective sorting associated with flood hydrographs, or selective entrainment, such that smaller sizes predominate in the load during the lower flows but the largest sizes are only moved near the peak flow, appears to characterize the 1.5-km portion of the reach farthest downstream. The model results also suggest that selective sorting by differential transport is most likely to play a role in downstream fining in bedrock streams only in cases of streams with relatively small gravel sizes and lower slopes.

**Definition of symbols**

- $A$: drainage area
- $B$: channel width
- $D_{50}$: grain size such that 50 percent by volume of grains are finer
- $D_{90}$: grain size such that 90 percent by volume of grains are finer
- $D_{s90}$: grain size in the bed surface such that 90 percent by volume of grains are finer
- $D_{sg}$: surface geometric mean size
- $dx$: spatial step length
- $i$: effective rainfall rate
- $I$: flood intermittency
- $K_h$: coefficient in Hack’s law
- $L$: total length of the study reach
- $n_b$: exponent in width-area relation
- $n_h$: exponent in Hack’s law
- $n_k$: coefficient characterizing surface roughness ($\sim 1.5$ to $3$)
- $p_i$: volume probability density that a bedload particle is size $\psi_i$
- $p_{i,u}$: volume probability density that a bedload particle is size $\psi_i$ at upstream end
- $p_{Li}$: volume probability density of sediment in landslide material derived from adjacent hillslopes for the $i^{th}$ grain size range
- $P_c$: fraction of bedrock surface that is covered by alluvium
- $q_{bT,u}$: total volume bedload transport rate per unit width summed over all grain sizes at upstream end
- $q_{tot,u}$: volume total transport rate per unit width at the upstream end
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\( R \)  
gravel submerged specific gravity

\( S \)  
channel slope

\( S_d \)  
bed slope at the downstream boundary of the study reach

\( S_u \)  
bed slope at the upstream boundary of the study reach

\( v_d \)  
an estimate of the denudation rate of the hillslopes

\( x \)  
down-channel distance

\( x_u \)  
distance from the upstream divide to the upstream boundary of the study reach

\( \alpha_b \)  
coefficient in width-area relation

\( \alpha_p \)  
constant in gravel transport relation of Parker [1990]

\( \alpha_r \)  
coefficient in the Manning-Strickler resistance relation

\( \beta \)  
abrasion coefficient characterizing the fraction volume of a grain that is lost per unit distance traveled

\( \eta \)  
bed elevation

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References

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### Table 1. Input parameters for the Vieux-Habitants River.

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>Values</th>
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<th>Values</th>
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<tr>
<td>Size distribution of bedload at upstream end ($p_{i,u}$)</td>
<td>See Figure 4b</td>
<td>Coefficient in Manning-Strickler resistance formulation ($\alpha_r$)</td>
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<tr>
<td>Size distribution of landslide materials ($p_{Li}$)</td>
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<td>Reach length ($L$)</td>
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<td>Spatial step length ($dx$)</td>
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<td>Channel slope at downstream end ($S_d$)</td>
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<td>Exponent in <em>Hack’s Law</em> ($n_h$)</td>
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<td>Volume total transport rate per unit width at the upstream end ($q_{tot,u}$)</td>
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<td>Volume fraction of grain lost per unit distance traveled ($\beta$)</td>
<td>0.00015 m$^{-1}$</td>
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Figure captions

Figure 1. Map of the Vieux-Habitants catchment, in the south-west of Basse-Terre Island. The catchment divide and the river channel are drawn in white. Circles indicate the position of the sites where granulometric measurements were performed.

Figure 2. (a) Elevation $\eta$ (left axis) and drainage area $A$ (right axis) of Vieux-Habitants river as a function of downstream distance $x$ ($x = 0$ at the drainage divide). Circles indicate the position of the granulometric sampling sites. (b) River width $B$ as a function of downstream distance $x$.

Figure 3. (a) Typical bedrock reach in the upstream part of the Vieux-Habitants River (e.g. upstream of Barthole gauging station). Note a small alluvial patch in the top part; (b) Typical alluvial reach in the downstream part of the Vieux-Habitants River where bedrock exposure is no longer observed; and (c) Granulometric sampling of a river bed.

Figure 4. (a) Fresh blocky material from a landslide on the hillslope of the Vieux—Habitants River. (b) Grain size distributions of the gravel part of landslide materials and of the gravel part of the bed material at the upstream boundary of the study reach, collected from the field.

Figure 5. (a) Power approximation relating drainage area and down-channel distance for the Vieux-Habitants River (coefficients adapted from Hack’s law); (b) power approximation relating bedrock channel width and drainage area for the Vieux-Habitants River (coefficients adapted
from Montgomery and Gran, 2001); and (c) exponential approximation of channel slope along the Vieux-Habitants River.

Figure 6. Comparison of the observed downstream variations of surface geometric mean grain size in the Vieux-Habitants River (dots) and numerical model results (line).

Figure 7. Numerical model results for the downstream variation of sediment transport rates predicted by the model for the Vieux Habitsants River. Note that the model produces a large amount of sand and silt (< 2 mm) partly due to the exclusion of particle fracturing processes in the model.

Figure 8. Numerical model results for the downstream variation of the areal fraction of alluvial coverage during floods and of low flows for the Vieux Habitsants River.

Figure 9. (a) Numerical model results for grain size distributions of surface material along the Vieux-Habitants River at various points downstream. (b) Corresponding numerical model results for grain size distributions of bedload material along the Vieux-Habitants River. Note that the value next to each line in the legend indicates the longitudinal distance (m) from upstream drainage divide.

Figure 10. Abrupt change in grain sizes in Capesterre River, a nearby smaller river on Guadeloupe Island. Both pictures were taken at the same location, but are different views; (a)
looking upstream (notice the big boulders in the background) and (b) looking downstream. Note the drastic contrast in grain sizes. The site is at about 1 km from the river mouth.

**Figure 11.** Model results for surface geometric mean size along the Vieux-Habitants River when abrasion process is turned off ($\beta = 0$) and when abrasion process is included ($\beta = 0.00015 \text{ m}^{-1}$). In the former case, the results produce no downstream fining. This means that selective sorting by differential transport may not contribute to downstream fining in this river.
Figure 1.
Map of the Vieux-Habitants catchment, in the south-west of Basse-Terre Island. The catchment divide and the river channel are drawn in white. Circles indicate the position of the sites where granulometric measurements were performed.
Figure 2.
(a) Elevation $\eta$ (left axis) and drainage area $A$ (right axis) of Vieux-Habitants river as a function of downstream distance $x$ ($x = 0$ at the drainage divide). Circles indicate the position of the granulometric sampling sites. (b) River width $B$ as a function of downstream distance $x$. 
Figure 3.
(a) Typical bedrock reach in the upstream part of the Vieux-Habitants River (e.g. upstream of Barthole gauging station). Note a small alluvial patch in the top part; (b) Typical alluvial reach in the downstream part of the Vieux-Habitants River where bedrock exposure is no longer observed; and (c) Granulometric sampling of a river bed.
Figure 4.
(a) Fresh blocky material from a landslide on the hillslope of the Vieux–Habitants River.
(b) Grain size distributions of the gravel part of landslide materials and of the gravel part of the bed material at the upstream boundary of the study reach, collected from the field.
Figure 5.
(a) Power approximation relating drainage area and down-channel distance for the Vieux-Habitants River (coefficients adapted from Hack’s law); (b) power approximation relating bedrock channel width and drainage area for the Vieux-Habitants River (coefficients adapted from Montgomery and Gran, 2001); and (c) exponential approximation of channel slope along the Vieux-Habitants River.
Figure 6.
Comparison of the observed downstream variations of surface geometric mean grain size in the Vieux-Habitants River (dots) and numerical model results (line).
Figure 7.
Numerical model results for the downstream variation of sediment transport rates predicted by the model for the Vieux Habitants River. Note that the model produces a large amount of sand and silt (< 2 mm) partly due to the exclusion of particle fracturing processes in the model.
Figure 8.
Numerical model results for the downstream variation of the areal fraction of alluvial coverage during floods and of low flows for the Vieux Habitants River.
Figure 9.
(a) Numerical model results for grain size distributions of surface material along the Vieux-Habitants River at various points downstream. (b) Corresponding numerical model results for grain size distributions of bedload material along the Vieux Habitants River. Note that the value next to each line in the legend indicates the longitudinal distance (m) from upstream drainage divide.
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Abrupt change in grain sizes in Capesterre River, a nearby smaller river on Guadeloupe Island. Both pictures were taken at the same location, but are different views; (a) looking upstream (notice the big boulders in the background) and (b) looking downstream. Note the drastic contrast in grain sizes. The site is at about 1 km from the river mouth.
Figure 11.
Model results for surface geometric mean size along the river when abrasion process is turned off ($\beta = 0$) and when abrasion process is included ($\beta = 0.00015$ m$^{-1}$). In the former case, the results produce no downstream fining. This means that selective sorting by differential transport may not contribute to downstream fining in this river.