Environmental Science & Policy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

Short communication

The legacy of surface mining: Remediation, restoration, reclamation and rehabilitation

Ana T. Lima[a,*], Kristen Mitchell[a], David W. O'Connell[a], Jos Verhoeven[b], Philippe Van Cappellen[a]

[a] Ecohydrology Research Group, Department of Earth and Environmental Sciences and Water Institute, University of Waterloo, Waterloo, N2 L 3G1, Canada
[b] Institute of Environmental Biology, Utrecht University, P.O. Box 80084, 3508 TB Utrecht, The Netherlands, The Netherlands

ARTICLE INFO

Article history:
Received 21 August 2015
Received in revised form 4 April 2016
Accepted 23 July 2016
Available online xxx

Keywords:
Surface mining
Remediation
Reclamation
Restoration
Rehabilitation
Resource extraction

ABSTRACT

Surface mining is a global phenomenon. When dealing with the land disturbances caused by surface mining operations, the terms remediation, reclamation, restoration and rehabilitation (R4) are commonly used interchangeably or otherwise vaguely defined. Expectations associated with these terms may differ significantly from one stakeholder to another, however. Regulators, industry, environmental practitioners, local communities and the general public therefore stand to benefit from a precise terminology based on agreed-upon end-goals. The latter range from the avoidance of exposure to pollutants (remediation) to the full recovery of the original ecosystem (restoration). Although frequently claimed as the end-goal, restoration may often not be unachievable, because of altered hydrology, habitat fragmentation, contamination, climate change, prohibitive costs and other environmental and socio-economic boundary conditions. Mostly, the definitions of reclamation and rehabilitation may overlap in their definitions and approaches. Here we attempt the creation of a road-map that can clearly translate end-goals for each of the R4 terms. According to the definitions encountered and exposed here, reclamation, which aims to recover key ecosystem services and biogeochemical functions within a replacement ecosystem or rehabilitation, which implies a repurposing of the landscape, may be the best approaches to deal with surface mining legacies.

1. Introduction

In surface mining, soil and rock overlying or hosting a shallow ore deposit is physically removed to access the resource. Surface mining comprises different practices – strip mining, open-pit mining and mountaintop-removal mining – and accounts for more than 80% of ore mined each year (Ramani, 2012). Surface mining disturbs the landscape and impacts habitat integrity, environmental flows and ecosystem functions; it raises concerns about water (Miller and Zégre, 2014), air and soil quality (Mummey et al., 2002), and often also public health. Legacies of surface mining may include loss of soil structure and fertility, altered hydrology, and long-term leaching of contaminants from tailings and end-pit lakes (Isosaari and Sillanpää, 2010; Li, 2006; Ramani, 2012). Very large-scale surface mining activities may cause ecosystem fragmentation and affect regional biodiversity (Rooney et al., 2012a, 2012b).

Long-term legacies whose environmental effects extend far beyond the lifetime of the mining operations represent some of the more difficult issues facing regulators and industry (Bernhardt et al., 2012; Bullock et al., 2012; Rooney et al., 2012a, 2012b). Existing environmental management guidelines and policies invariably refer to the need to remediate, reclaim, rehabilitate, restore, or some combination thereof, of the mining site after closure. Remediation, reclamation, rehabilitation and restoration (hereafter referred to as R4), however, are used interchangeably in the scientific literature or in government reports and policy documents (Hüttl and Weber, 2001; Li, 2006). For example, one may find reclamation defined as "restoring the top-soil" (Mitchell and Casman, 2011), or directives that aim for the "land to be cleared" and the "soil handled" (Alberta Environment, 2010). Existing policies for coping with surface mining legacies have therefore been criticized for their lack of clarity (Bernhardt et al., 2012) and for setting ill-defined or unrealistic goals (Bullock et al., 2012; Rooney et al., 2012a, 2012b).

The chosen case-studies consist of carbon extraction of different surface mining scales. Throughout the years, Mankind

* Corresponding author.
E-mail address: atlima@uwaterloo.ca (P. Van Cappellen).

http://dx.doi.org/10.1016/j.envsci.2016.07.011
1462-9011/

has explored nature for fuel: first trees and peat, then coal and lastly oil. Although there are other examples of surface mining impacts, here we compare three examples of still active exploitation: peat extraction in Ireland, coal mining in Appalachia (United States) and oil sands exploitation in Alberta (Canada). We revisit the R4 terminology in the context of surface mining and propose a decision tree to help identify the appropriate R4 strategy based on the desired end-point for the post-mining site. A discussion is followed regarding the actions taken at each case-study and whether they achieved the envisioned R4 end-point.

2. R4 terminology revisited

Classic ecological terminology note rehabilitation, reclamation and restoration as terms with similar goals (Society for Ecological Restoration International Science and Policy Working Group, 2004), where rehabilitation has been identified with managerial urban and agricultural usages (Box, 1974; Haigh, 2007; Wali, 1996). The most frequent R4 terms in scientific literature are restoration and remediation (Fig. S1). To avoid further confusion on the topic, we chose to define rehabilitation as more managerial and reclamation as the more ecological term (see Table 1).

The call for more uniformity and consistency in R4 terminology is not new (Wali, 1996). Clear definitions of the R4 terms may be key to the participatory planning and communication of long-term solutions for surface mining legacies. But more important than redefining these R4 terms is to clarify objectives for site end-use and expectations each involved part has regarding post-mining land-use. In lights of previous idiosyncratic literature e.g. (Society for Ecological Restoration International Science and Policy Working Group, 2004), definitions have been established vaguely to encompass a wide variety of R4 practices. However, the goals and end-points of R4 programs should be established at the earliest possible time, preferably even before mining operations begin (Fig. 1) to avoid post-mining adversities. Fig. 1 was developed based on Table 1 definitions and consists of an attempt to simplify R4 by defining specific *targets* and *end-goals*. Targets are explicit environmental compartments, functions or services passive of improvement after impacted by resource exploitation. End-point is the site state or condition after accomplishing a given R4 measure. Below we explore each R4 and exemplify the definitions.

Contamination control, i.e. **remediation,** needs to occur before re-establishing a land-use. Therefore, remediation targets a specific *target* – being it soil, water, human health – and proposes remedial actions to solve it, aiming at a decontaminated or contaminant-free site (*end-goal*) (Fig. 1). **Restoration** proposes to bring back the pre-existing ecosystem. This definition aims to classically (re)establish the whole ecosystem function (*target*) and therefore bring back the exact pre-existing ecosystem before resource exploitation impacted the site (*end-point*). This end-point

Table 1
Summary of the main characteristics of remediation, rehabilitation, reclamation and restoration. Note that remediation refers to soil remediation, not groundwater or other environmental compartments.

	Remediation	Reclamation[a]	Rehabilitation[a]	Restoration
Target	Soil	Land, site	Land, site	Ecological/Ecosystem
General definition	A physical, chemical or biological action to remove contaminants with the goals to reduce and manage the risks to human beings posed by contaminated sites (Beames et al., 2014). Remediation includes rehabilitation actions aimed specifically at treating or otherwise removing pollution or contamination	Geotechnical stabilisation of land via a series of integrated operations (Saperstein, 1990; Adriano et al., 2004), implying a final step where repopulation occurs with original species or other related ones (Wali, 1996). This definition of reclamation is the same as rehabilitation of other authors (Haigh, 2007; Society for Ecological Restoration International Science and Policy Working Group, 2004).	A managerial wide term that measures costs and benefits of maintaining environmental quality and optimize local land management capacity (Haigh, 2007). However, according to other authors rehabilitation shares with restoration a fundamental focus on historical or pre-existing ecosystems as models or references (Society for Ecological Restoration International Science and Policy Working Group, 2004).	Original concept of restoration stems from classical ecology, it aims at describing the act of assisting the recovery of an ecosystem to the point where flows of natural goods and the provision of cultural values are restored (Box, 1974; Clewell and Aronson, 2008). It is loosely defined to encompass a large variety of practices (Society for Ecological Restoration International Science and Policy Working Group, 2004)).
End goals	(Haigh, 2007) defines the term as "soil rehabilitation". The end-point of this action results in a decontaminated site.	Depends on the definition. Other documents establish reclamation as ecosystem full recovery	According to (Haigh, 2007; Wali 1996; Box 1974), the site is either returned to nature or to more human-use.	attempts to replicate the original fauna and flora of an ecosystem (Wali, 1996; Powter et al., 2012).
Approach	Soil "clean-up" Physical-chemical techniques to remove a part or the total of contaminants – including replacing soil	Bio-remediation, phytoremediation – Species are planted with the aim of aiding remediation, sometimes replacing the step "remediation" of soil	Dichotomy decision tool to define the operational steps to achieve the end-goal.	Define ecosystems species composition, community structure, ecological function, suitability of the physical environment to support the biota and connectivity with the surrounding landscape (Clewell and Aronson, 2008)
Price tag	35 Euro per capita per year in soil clean-up efforts – in the EU (Rodrigues et al., 2009)	250–400 Euro per m^2 e.g. (Consulting, 2006; Schaart, 2008)	Depends on end-goal	0.32-2.5 Euro per m^2 e.g. (Perrow, 2016; Olsen and Shannon, 2010)
Time scale	Depending on the technique, it may vary from a couple of months to a couple of decades (natural attenuation)	Slow process needing a speedy assisted remediation to avoid the leaching of contaminants (Burgos et al., 2013), with only long-term results (Wang et al., 2013)	Depends on end-goal	Long-term commitment of land and resources; time consuming (Wali, 1996)
Legacy	Often destroys the soil structure; remediated land is reused as industry or urban districts, changing the geomorphology	Geotechnical stability is a main concern. It differs from rehabilitation in the sense that decision wise, there is not so much freedom. The end-use is to repopulate with original-like species.	A major proportion of land reclaimed or rehabilitated for human use does not remain in a good quality condition (Haigh, 2007)	The initial land-use gets restored, regarding ecosystem functionality. Geotechnical issues are often overlooked.

[a] This table tries to highlight the difficulties encountered in defining R4 terms, especially reclamation and rehabilitation.

Please cite this article in press as: A.T. Lima, et al., The legacy of surface mining: Remediation, restoration, reclamation and rehabilitation, Environ. Sci. Policy (2016), http://dx.doi.org/10.1016/j.envsci.2016.07.011