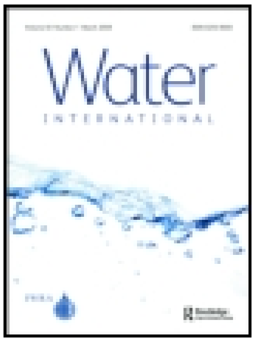

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Lessons from Yanacocha: assessing mining impacts on hydrological systems and water distribution in the Cajamarca region, Peru

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ABSTRACT
A major concern of mining activities is their influence on hydrological systems. This article highlights impacts on water flows and distribution in the Mashcon catchment in Cajamarca, Peru, one of those most affected by the Yanacocha mining project. Some important concerns are identified regarding changes in water flows, lowering of water tables, and decrease of base flows. These considerations indicate deficiencies in distributing actual water uses in relation to the allocation of water rights. Finally, the article discusses challenges for regulation of mining, including democratic processes for water management that require clear accountability in the context of local social needs.

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Introduction

Water is arguably the most common receptor of environmental impacts, and the use of this rival resource creates a complex competition among multiple land uses (Bebbington, Bebbington, & Bury, 2010; Bebbington & Williams, 2008; Bridge, 2004). Mining activity is one such land use whose water demand impacts other uses in society. In regions where water is conceived as a valuable and scarce resource, conflicts emerge as a consequence of the disruption of traditional water uses. The Yanacocha gold mine, in the Cajamarca district of Peru, is a clear example of high levels of contestation related to multiple water uses. The Yanacocha mine has become one of the largest gold extraction projects in the world. The scale of its operations is defined by not only the amount of material extracted but also the associated volumes of water harnessed in the process. The project is located in the headwaters of the *jalca* highland ecosystem, which regulates water in the region by recharging and storing water in the soil and maintaining a supply downstream (Buytaert et al., 2006). Mining activities in this sensitive ecosystem have caused rapid alteration of hydrological regimes and several restrictions in the access to water for other legitimate users, resulting in multiple claims of water shortages (Rojas, 2010; Yacoub, 2013).

Multiple studies have analyzed the environmental impacts of the Yanacocha mine. These studies have focused on contested claims of water contamination (Yacoub, 2013),

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conflicts over water use, water management institutions, and accountability (Bebbington et al., 2010; Bebbington & Williams, 2008; Bury, 2004, 2005; Sosa & Zwarteveen, 2014). However, scant research has been devoted to understanding the impacts on the quantity of water resulting from competing water uses across the whole catchment. Although the identification of impacts is complex, estimation of the effect of mining on water flows represents a significant advance in the discussion of water access and distribution in Cajamarca. Thus, this article analyzes, first, how the use and manipulation of water by mining activities has potentially altered the quantity of water in the catchment; secondly, it addresses the implications for distribution among different water users. These inquiries are important for developing mechanisms of accountability to maintain water resources, regulate mine sites, and secure access to water that aligns with social preferences.

Competition over the limited water resource represents a substantial liability to users, especially in the dry season. The three main water users in the district of Cajamarca are small farmers, the urban population and the Yanacocha mining company. Small farmers are the largest group of water users in the region, representing 67% of the population (INEI, 2007). Traditionally, these rural communities depend heavily on water-intensive agriculture and livestock activities to survive (Garcia & Gomez, 2006). The second-largest group of water users is the growing urban population in the downstream city of Cajamarca, which depends primarily on water supply influenced by the Yanacocha project. Finally, the Yanacocha mine itself is considered the third-most influential user due to the sheer volume of water managed for operations. Accordingly, the distribution of water among several users requires an open discussion to define priorities based on social understandings of collective well-being, as the allocation of a rival resource might not necessarily satisfy all water users (Falkenmark, Lindh, de Mare, & Widstrand, 1980).

In the next section, the main quantitative alterations of water are described as well as managerial changes in the distribution of water occurring in Cajamarca over the past 20 years. The third and fourth sections present the case study and the methods used for analysis. The results presented in the fifth section indicate that alteration of the hydrological regime is occurring as a result of large-scale water mobilization by the mining company. The reduction of water flows is highlighted, which affects water supply for irrigation purposes as well as future hazards for domestic water supply. Finally, the complexity of physical processes associated with mining is discussed, which renders the determination of precise impacts on water flows a challenging yet non-inconsequential process, requiring increased scrutiny and democratic mechanisms for sound accountability.

Mining activities, water impacts and distribution

Physical alterations of water resources

Large-scale mining operations alter the hydrological regime by transforming the landscape and affecting the quality and quantity of water resources throughout the catchment (Bridge, 2004; Younger & Wolkersdorfer, 2004). The impacts are intensified as mineral reserves are often located in vulnerable glacial or headwater areas of drainage basins that serve as supply for downstream populations. In Peru, for example, historical records of observed environmental impacts have contributed to the reputation of large extractive activities as responsible for affecting water resources (Scurrah, 2008).

In mining activities, water is mainly used as an inflow for ore separation procedures, machinery washing and dust control, with gold mining using the most water per unit of material produced (Mudd, 2007). According to Mudd (2007), between 1991 and 2006, the global estimated average water flow for gold mining was 691 m^3 per kilogramme of gold. However, the total amount of water harnessed by a mining project is greater than the water consumed in these operations; mining companies also extract groundwater to discharge excess from the mine site. Open-pit extraction requires dewatering, a process in which groundwater is pumped out of the surrounding aquifers to lower the water table below the base-floor of the pit. Dewatering is done to reduce risk of landslide and acid drainage (Sperling, Freeze, Massmann, Smith, & James, 1992). This transfer of water further alters the hydrological regime of the catchment by increasing surface runoff and decreasing base flows in streams.

Mining activities also prevent aquifer recharge by altering the natural upstream drainage system. For instance, deviation canals and sinks are built around open pits to intercept precipitation and prevent the water table from rising (Sperling et al., 1992). Aquifers, however, play an important role by maintaining the hydrological regulative process of the watershed, which requires rainfall recharge, as well as sustaining the base flows of streams during the dry season (Todd & Mays, 2005). The alterations to the drainage system caused by mining present a risk of post-mining flooding, uncontrolled discharge of stored water, and drought (Younger & Wolkersdorfer, 2004).

Hydrological analysis thus permits the assessment of the state of the resource and depicts how critical dynamics of access and use are influenced by mining activities. As Kemp, Bond, Franks, and Cote (2010) discuss, apart from the work on technical frameworks for water use, quantification and accountability within the mining sector (see Cote, Moran, Cummings, & Ringwood, 2009, for more details), there should also be integration with studies of the implications of mining water use for water distribution and management.

Socio-political alterations of water access and distribution

Along with physical alterations, hydrological processes are constantly shaped by social changes (Budds, 2009). New development projects, extractive industries, and water policies modify previous forms of water resources management and subsequently the distribution of water among users (Bebbington, 2013; Budds & Hinojosa-Valencia, 2012). Specifically, the involvement of the private sector alters previous forms of water governance through the appropriation of water resources. Although the state exercises control over the allocation of water rights in Peru, these rights are re-allocated by illegitimate transactions between the private mining company and irrigation-water users, resulting in unaccountable environmental governance. Such actions are often supported by neoliberal extractive policies, accommodating water authorities and the exclusion of community demands (Achterhuis, Boelens, & Zwarteveen, 2010; Budds & Hinojosa-Valencia, 2012; Bury, 2005).

In Cajamarca, for instance, there have been cases in which irrigation-water users in the area of influence of Yanacocha have been dispossessed of their water rights through direct negotiations, bribery and economic compensation, without oversight or intervention by the state. In this process, irrigation water users renounce their water rights and transfer them to the mining company, with minimal accountability (Sosa & Zwarteveen, 2012, 2014). Thus, water rights are shifted from traditional users to the mining company, and the Yanacocha mining company assumes de facto control over the resources, thus inciting social tensions among local people (2012, 2014). Such re-allocations affect livelihoods and appropriate the means of subsistence of rural people (Bebbington, 2007; Bebbington, Hinojosa, Bebbington, Burneo, & Warnaars, 2008; Bury, 2004, 2005). Accordingly, water management requires accounting for the impacts on water resources, which in turn have profound implications for the creation of conflicts over the distribution of water between different users in the catchment (Bebbington & Williams, 2008). In the following section, the case study is contextualized in order to present findings on water use and distribution in Cajamarca.

Case study

The Yanacocha project in Cajamarca, Peru, is one of the largest gold mines in Latin America, with gold production of 498,000 troy ounces in 2014 (Newmont, n.d.). The mine concession encompasses 172,500 ha, and operations cover approximately 15,500 ha (MYSRL, 2006). This project started in 1993 under the administration of Minera Yanacocha (MYSRL), a consortium between Newmont Mining Corporations, Buenaventura, and the World Bank's International Finance Corporation. The Yanacocha complex consists of 13 open-pit mines, nine rock residue heaps and four lixiviation piles in six main zones: Carachugo and Maqui Maqui (already closed), San José and Cerro Negro (already mined), and Yanacocha and La Quinua–El Tapado (in operation).

The mine site is at the peak of the Yanacocha Mountain, in the north Andean highlands, at an elevation of nearly 4000 m. Operations are positioned on headwaters of four important catchments in this area: Chonta, Mashcon, Rejo, and Honda. For this study, the Mashcon catchment was chosen for analysis because mining operations are primarily located in the upstream portion of this catchment and it is the most densely populated in the area of influence of the mine (MYSRL, 2006, 2007). The Mashcon catchment is to the south and south-east of the Yanacocha mine, as illustrated in Figure 1. The catchment is approximately 15,820 ha in area, ranges from 2700 to 4100 m in altitude, and is formed of two sub-catchments, for the Grande and the Porcon Rivers, which join downstream to form the Mashcon River before reaching the city of Cajamarca. Around 6500 people directly depend on the catchment as its main rivers and streams provide water to small rural communities and to the majority of the population in the city of Cajamarca (Rojas, 2010).

Cajamarca is currently experiencing social unrest due to environmental impacts connected to MYSRL. Since 2000, the Observatory of Mining Conflicts in Peru (Observatory of Mining Conflicts in Peru, n.d.) has reported water-related conflicts associated with the destruction of irrigation canals, reduction of flows, and water contamination, which have resulted in multiple protests against MYSRL. For its part,

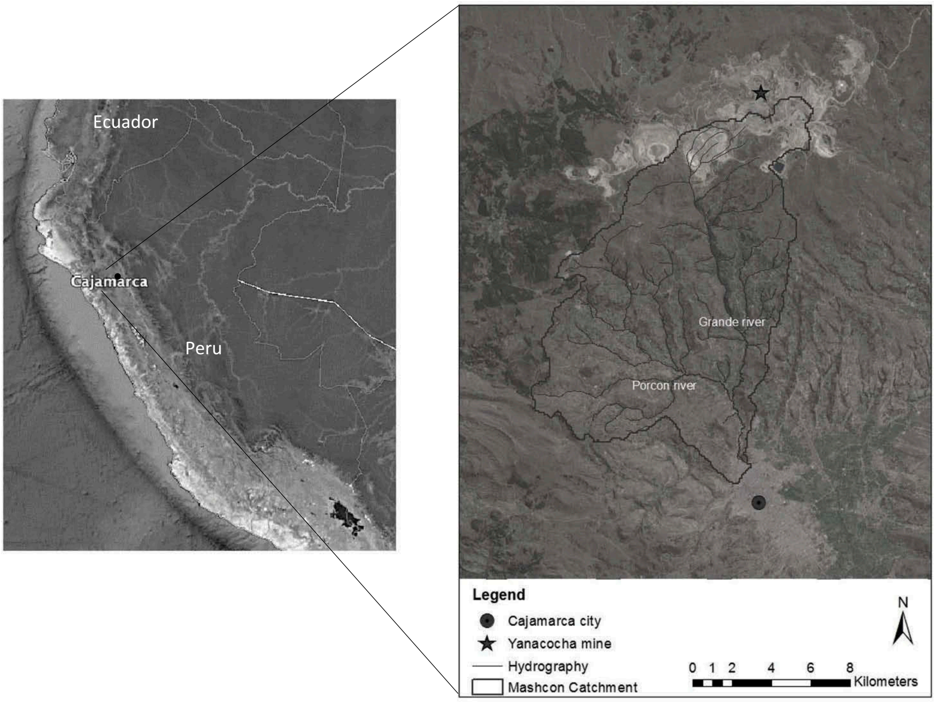

Figure 1. Location of the Mashcon catchment in the Cajamarca District, Peru.

the company argues that sophisticated technological processes to avoid water impacts are being employed to prevent mining activities from affecting other land practices (MYSRL, 2011a). MYSRL stresses that mitigation plans and monitoring ensure that the water supply is not being reduced downstream during the dry season. Conflicts are likely to be exacerbated due to growing population and demands for just access to resources, as well as dynamic environmental conditions such as climate change and the presence of recurrent droughts.

Methods

The analysis of hydrological changes and water distribution in the Mashcon catchment is based on secondary information provided by multiple organizations involved in water management, monitoring and planning in the Cajamarca district. Information was collected from the databases of local and regional authorities and water user associations, as well as from literature reviews of independent studies, environmental impacts assessments, and MYSRL reports. Table 1 details the sources of data used in this study. Information was processed to identify alterations of the hydrological regime due to mining activities, with definitions of different water uses and the distribution of water based upon use and established water rights. Descriptive statistics were conducted where possible to determine percentages of water flow changes in the river, proportion

Table 1. Sources of hydrological data collection, water rights and water used by different sectors.

Water flows of the Grande River	Reports: 'Optimized Master Plan SEDACAJ 2012–2017' (SEDACAJ, 2012) 'Inventory of sources of surface water for the Mashcon catchment' (Benavides et al., 2007) 'Evaluation of hydrological characteristics of the Porcon and Grande Rivers in the Province of Cajamarca. Hydrological year 2010–2011' (SENAMHI, 2011) 'Supplemental environmental impact assessment Yanacocha Oeste' (MYSRL, 2006) Raw data: River flow of the Grande River, provided by the Local Water Authority in Cajamarca
Information on streams and springs	Report: 'Inventory of sources of surface water for the Mashcón catchment' (Benavides et al., 2007) Raw data: Database discharges on MYSRL's discharge outlets and receptor water bodies, provided by the Group for Capacity Building and Intervention towards Sustainable Development, GRUFIDES
Groundwater information	Report: 'Supplemental environmental impact assessment Yanacocha Oeste' (MYSRL, 2006) 'Environmental impact assessment: exploration project Maqui Maqui' (MYSRL, 2010b)
Meteorological information	Precipitation values: database provided by the National Service of Meteorology and Hydrology of Peru, SENAMHI.
Water rights distribution	Raw data: Database of water rights of the Cajamarca district from 1985 to December 2013 (Autoridad Local del Agua Cajamarca [ALA-C], 2013)
Mining water use	Reports: MYSRL's sustainability reports from 2008 to 2013 (MYSRL, 2008, 2009, 2010a, 2011b, 2012, 2013, 2014)
Domestic water use	Reports: 'Optimized Master Plan SEDACAJ 2012-2017' (SEDACAJ, 2012). 'Inventory of sources of surface water for the Mashcón catchment' (Benavides et al., 2007)
Irrigation water use	Report: 'Supplemental environmental impact assessment Yanacocha Oeste' (MYSRL, 2006) Raw data: Database of irrigation canal network by the Association of Water Users of the Mashcon catchment Database of discharge water flows of irrigation canals by the Monitoring Commission of Irrigation Canals in Cajamarca, COMOCA

of streams and springs affected, lowering of water tables and distribution of water rights among users.

For the discharge of water in the monitored irrigation canals, a time series analysis was carried out to test temporal trends in water flows. The non-parametric Mann-Kendall test (Mann, 1945) was used since data exhibited a non-normal distribution. The Mann-Kendall test is a monotonic trend regression analysis that shows increasing or decreasing trends over time when there is a consistent change that is not necessarily linear. This test replaces a parametric linear regression analysis when the data are not normally distributed. The Mann-Kendall test assumes that all values are independent and that the distribution of values is constant and sufficiently large that no correlation exists across different time periods. The test was conducted using information for the dry season (June–October) for the past 14 years. Despite the dry season's extending from May to September in Cajamarca, for this analysis, a delay in measuring base flows more realistically assesses groundwater following a reduction in precipitation.

Finally, the biggest challenge in making clear estimations of impacts on hydrological regimes and water availability is access to information. Most hydrological data for the upstream catchment area are limited and managed exclusively by MYSRL. However, the available information provides guidance for valid estimates of the effects of mining in the catchment and legitimate concerns regarding the implication of these effects on the availability of water for other uses.

Quantitative changes in water resources in the Mashcon catchment

The headwaters of the Mashcon catchment are subject to heavy environmental impacts due to mining extraction (Benavides, Ángeles, Salazar, & Abásolo, 2007; MYSRL, 2006). The sections below detail how landscape transformations have severely altered the water tables and the flow of rivers, streams and springs in the Mashcon catchment.

Impacts on groundwater

Mining activities affect groundwater hydrology by dewatering the area below the pit for depressurization. Precipitation falling to the surface of the mine site is rerouted from its natural drainage system, preventing rainfall infiltration. Instead, water is captured, treated, stored in artificial reservoirs and eventually drained to other outlets, irrespective of the original water bodies. Impermeability of the mining area, which prevents aquifer recharge, and permanent dewatering are direct causes of the lowering of water tables. In turn, the lowering of water tables below the depth of the spring outlet or streambed prevents groundwater discharge and reduces river base flows (Younger & Wolkersdorfer, 2004). Although MYSRL permanently monitors the water table at different gauging points along its installations, information on the influence of dewatering on the water tables is kept confidential. There is no clear identification of water tables, though according to MYSRL (2006), they have suffered a permanent decrease. Most of the open pits reach a depth of around 300 m beneath the natural topography, and in some cases reach a maximum of 500 m (MYSRL, 2010b). Since the water table must be below the base level of the pits, water tables in the aquifers need to be lowered dramatically. Table 2 shows that the water tables of the La Quinua, Yanacocha and Carachugo projects have fallen more than 100 m in less than a decade. To the authors' knowledge, more recent data are not available.

MYSRL has developed a mitigation programme for the reduction of groundwater in the Mashcon catchment. This programme includes collecting water and discharging it at specific points in the drainage system to restore lost flow in streams and irrigation canals (MYSRL, 2006). Despite the objectives of the mitigation programme, groundwater is continuously pumped and transferred to the surface at a rate much higher than the natural discharge rate, a process that generates a loss of hydrological balance in the catchment boundaries. However, MYSRL's reports do not mention any measures to remediate the loss of groundwater and restore the infiltration capacity of the soil.

Impacts on the Grande River

The greatest mining impacts are occurring in the Grande River subcatchment of the Mashcon catchment, since most of the upstream area is being obstructed by the mine

Table 2. Lowering of water tables of aquifers.

Project	Start of operations	Closure of operations	Average initial water table height (m)	Average latest water table height (m)	Change in height (m)
Cerro Negro	2003	2005	3678 (2001)	3590.3 (2004)	−87.5
La Quinua	2001	2007	3798 (1999)	3664.4 (2005)	−133.57
El Tapado	2007	2010	3545	3460 (n.a.)	−85
Corimayo	2011	2014	3554 (2001)	3543.8 (2005)	−9.9
Yanacocha Norte	1997	2009	4024 (1996)	n.a.	−65 m between 2000 and 2004
Yanacocha Sur y Oeste	1997	2009	4006 (2001)	3905.95 (2005)	−100.31
Carachugo	1993	2002	3934 (1998)	3828.5 (2004)	−105
Chaquicocha[a]			4037 (2001)	3956.84 (2002)	−80.3

Note: [a]Years of starting and closure of operations are not known.
Source: Information was taken from available data provided in the Yanacocha West Environmental Impact Assessment and annexes (MYSRL, 2006).

installations (MYSRL, 2006). The available river flow data for the Grande River are shown in Table 3. Due to scarcity of data and multiple locations for measuring flow, conclusive results are not possible; however, some concerns can be identified. The two periods with the most flow data are 2002 and 2013–2014. A simple comparison between these two monitored events shows an increase in flow of 35–70% during the rainy season. This increase in flow might be a result of increased surface water runoff from higher dewatering rates and denuded surfaces. A time series regression analysis suggests that precipitation is not a factor in the increase in flow in the Grande River as precipitation values do not differ significantly between 2002 and 2013 (p = 0.2486). The increase in water flow might represent a change in the natural hydrological regime of the catchment, which renders the area more vulnerable to floods and represents a potential risk for uncontrolled discharge of stored groundwater.

Due to alterations in the drainage system that affected the supply of water in the Grande River during the dry season, MYSRL and the local water authority in Cajamarca (ALA-C) agreed in 2005 on a minimum flow discharge rule of 0.50 m^3/s from a reservoir managed by MYSRL (Kuijk, 2015). Table 3 indicates that the minimum discharge of 0.50 m^3/s agreed by Yanacocha was not met in June and October 2014, two critical months in the dry season when water is needed for irrigation and domestic

Table 3. Available monitored records of flow (m^3/s) in the Grande River.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	0.74	0.96	1.20	0.92	0.66	0.41	0.31	0.29	0.32	0.49	0.44	0.69
2007							1.23					
2010										0.67	0.87	0.98
2011	2.10	2.41	1.24	1.49								
2013				2.63	1.87	1.05	0.75	0.79	0.62	0.70	0.63	1.42
2014	1.55	2.14	2.88	1.30	1.30	0.46				0.29		
2014*			1.63	1.05				0.89				
2015		2.71										

* The two rows for 2014 represent the measurements of water flow from two different organizations: the first from ALA-C, the second from SENAMHI.
Source: Information was obtained from Autoridad Local del Agua Cajamarca – ALA-C (2013); SEDACAJ (2012); Servicio Nacional de Meteorología e Hidrología del Perú – SENAMHI (2011); and Benavides et al. (2007). The table presents only the data that have been made publicly available.

consumption. It is necessary to emphasize however that the lack of data for other years precludes confidence in compliance with the agreement on minimum discharge.

Impacts on streams and springs

A detailed inventory of the streams contributing to the Porcon and Grande Rivers was conducted by Benavides et al. (2007). Figure 2 is a map of the main streams in the Mashcon catchment based on the inventory. The two most impacted streams are the Encajon and the Callejon, which in turn are the main tributaries of the Grande River

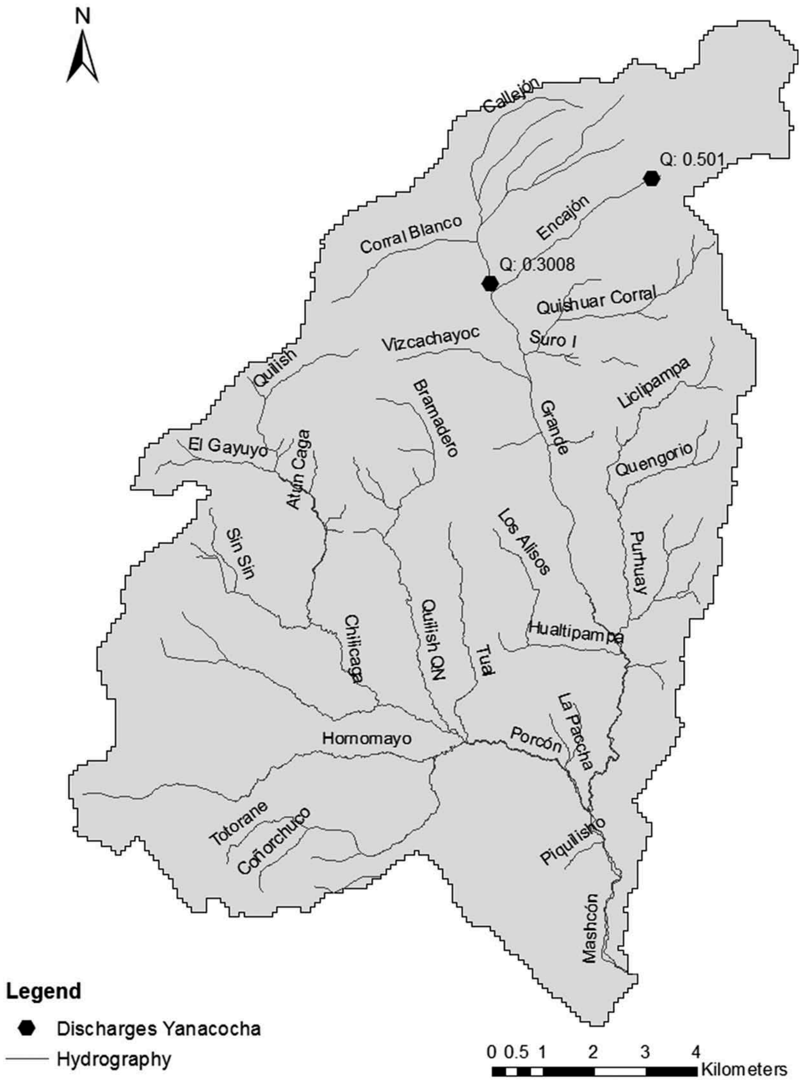

Figure 2. Hydrography of the Mashcon catchment identifying main streams. Additionally, two discharge points indicate the volume of water discharged (m^3/s) to the Callejon and Encajon streams by MYSRL.

upstream. The Encajon stream contributes to the Grande River with 60% of the flow in the dry season, while information on the contribution of the Callejon stream is not available (2006). Both streams have been disturbed by mining activities since 1994 as a result of operations in their drainage area. As a compensatory measure for the impact on natural drainage patterns of the streams, MYSRL agreed to discharge water from a reservoir to the Encajon and Callejon streams. Information provided by the Group for Capacity Building and Intervention towards Sustainable Development (GRUFIDES) on MYSRL's outlets and receptor water bodies between 2010 and 2012 indicates that the Encajon and Callejon streams receive a much higher discharge from the mine than the mean average yearly flow. For example, the mean average yearly flow of the Encajon stream is 0.0186 m^3/s, while the MYSRL's average discharge is 0.5013 m^3/s. Similarly, the Callejon stream has a mean average yearly flow of 0.127 m^3/s, while the MYSRL's average discharge is 0.3008 m^3/s. Although these flows represent average yearly values and will logically be much lower in the dry season, the increase of volume in the main streams changes the flow regime of the catchment, which is otherwise highly dependent on seasonality. Moreover, only the main streams that receive the discharge of the operation can supply water to the Grande River downstream, while small streams tend to dry up due to the overall falling water tables.

Benavides et al. (2007) also inventoried springs in the Mashcon catchment. Most of the springs in the Grande River subcatchment are in the mid-to-upstream catchment, with 93% of them having a water flow of less than 0.001 m^3/s. These two conditions make springs highly vulnerable to lowered water tables since they will no longer receive supply from aquifers.

In sum, although the results presented here cannot firmly quantify the impacts of mining on water nor assess the available water in the catchment, disturbances in the hydrological regime are evident. There are thus some critical interpretations that can be inferred here. These results on the hydrological impacts in the Mashcon catchment indicate sudden changes in water flow in the Grande River, a dramatic lowering of water table levels, and alteration of water flow in springs and streams. Moreover, upstream water networks directly influenced by mining activities are at the greatest risk of damage due to direct influence by the mining operation.

In 2000, MYSRL more strictly defined regulations for water management as a result of increasing local demands on the declining water resources. This resulted in a public demand for an environmental impact assessment prioritizing regional hydrology and the establishment of minimum discharge agreements from MYSRL (Kuijk, 2015). Nevertheless, such assessments have been insufficient to assess the complexity of mining effects on water. Several academic and research reports have shown that the hydrogeological component of environmental impact assessments tends to be generalized and minimizes emphasis on impacts on water (Moran, 2003; Rojas, 2010). These assessments lack sufficient information and analytical depth, which results in imprecise evaluations to diagnose the temporal and long-term hydrological effects of cumulative impacts of mining operations (Bridge, 2004). Li (2009) argues that the environmental impact assessments of MYSRL are conceived as mechanisms to legitimize the actions of the company rather than to hold the company accountable for the possible impacts of the operation. This is because the company itself defines the content of the document and identifies risks that are technically manageable. A critical liability is that each project in Yanacocha has its own environmental impact assessment that focuses on specific impacts related to individual projects to mitigate or compensate but does not account for the cumulative impacts on water, making it impossible to identify reinforcing feedback loops and synergies between different processes.

Finally, it should be highlighted that the MYSRL impacts on water are related not only to the reduction of water flow but also to the reallocation of water resources and disruption of the baseline hydrology. For instance, the soil removal from open pits where headwaters are located, alteration of the draining system, dewatering, and the development of reservoirs create a new hydrological regime shaped to meet the priorities of MYSRL. These impacts are the results of permissive regulations, nonexistence of public information, and permissive water authorities that have not been able to render MYSRL accountable.

Water distribution and users in the Mashcon catchment

Disturbances in water supply not only reflect the alterations in the hydrological regime but also highlight changes in water distribution. Water consumption in the Cajamarca district is divided among small farmers, the urban population, and MYSRL.[1] However, water is unequally distributed among these users. The distribution of water rights in the Mashcon catchment is presented in Table 4. The water rights granted to the three main users are an indicator of current imbalances in the distribution of water according to the social priorities for water supply.

The Peruvian Water Law establishes that the use of water must be prioritized for the satisfaction of social and environmental functions. However, precise operationalization of water distribution according to defined demands and availability remains uncertain. In practice, water is diverted to prioritize economic interests for mining; the Yanacocha mine uses 34.2% of the water demand in the Mashcon catchment (Table 4). This includes water consumed by the operations but also water transferred from aquifers to surface runoff. According to the licence for use of groundwater, MYSRL is authorized to pump 0.574 m^3/s of groundwater and use 0.060 m^3/s of surface water, for a total of 0.634 m^3/s. This volume extracted by MYSRL is more than 1.5 times the volume of water granted annually to the Cajamarca drinking water plant, which supplies water for 70% of the population of the city of Cajamarca (SEDACAJ, 2012). Although the dominant water use has been irrigation, representing 41.2% of the demand, the volume

Table 4. Multisectoral water rights based on licenses granted by the Autoridad Local del Agua Cajamarca in the Mashcon catchment. Estimates of the number of users and the area of irrigation and mining use were based on records of water rights until December 2013.

Use	No. of users	Area (ha)	Granted flow (m^3/s)	Percentage of demand
Irrigation use	7,869	1,669	0.7656	41.2
Domestic use	89,296*	n/a	0.4558**	24.6
Mining use	1	16,000	0.6344	34.2

* Based on the records of water rights granted upstream and estimated beneficiaries in the city of Cajamarca according to the estimated population in 2010 (127,363).

**The water licence of domestic use in the city of Cajamarca constitutes 0.200 m^3/s. Other values represent water rights in the catchment for multiple uses, of which domestic consumption is the main use.

of water granted for mining operations is much higher when considering a per user analysis since the water rights granted for irrigation are only 9.729×10^{-5} m^3/s per user.

MYSRL and its water use

MYSRL has been one of the most influential water users in Cajamarca. Given the economic priority that the Peruvian government has afforded to the mineral industry, MYSRL has been able to avoid critical accountability and closure of operations stemming from the socio-environmental repercussions occurring in the area. However, as specified, MYSRL has generated legitimate concerns for other water users. These concerns relate to the reduction of groundwater, scarcity of water in springs and streams in upstream areas, uncontrolled discharge of water by the Yanacocha mine to the Grande River and destruction of the natural hydrological regime.

In terms of the water used by MYRSL, the mine requires a constant supply of water. Table 5 shows the annual amounts of water managed in the mining installations since data was reported in 2008. The volume of total water consumption for all years is higher than the total water harnessed, indicating that the volume of water recycled in the installations is much larger than the yearly water inputs reflected in net water consumption. MYSRL argues that the company consumes approximately 2 million cubic metres (MCM), representing only 1% of the total water consumed in the region, in contrast to the amount of water used for agriculture, which is approximately 68 MCM (MYSRL, 2011a). However, MYRSL's total water consumption (Table 5) suggests a highly water-intensive process, which in most years uses almost double the quantity consumed by agriculture. Moreover, there is a progressive increase of total water harnessed, even though the last two years reported showed a reduction of the net water consumption.

Nearly all the water harnessed comes from groundwater. While the granting of water rights allows the company to pump 18.10 MCM per year (0.574 m^3/s) (Autoridad Local del Agua Cajamarca – ALA-C, 2013), the amount of water drained from aquifers since 2010 is greater than this. In the 2013 report, groundwater drainage surpasses the

Table 5. Reported water use in the Yanacocha mine, obtained from company sustainability reports (MYSRL, 2008, 2009, 2010a, 2011b, 2012, 2013, 2014). All figures in million cubic metres.

Year	Total water harnessed*	Surface drainage	Groundwater drainage	Precipitation	Total water consumption**	Net water consumption***	Water discharged
2008	29.69	7.90	11	10.79	n/a	0.36	29.34
2009	33.79	7. 95	13.47	12.36	125.10	5.60	31.44
2010	32.29	4. 90	18.29	9.10	126.97	2.14	34.48
2011	40.77	4. 14	27.05	9.58	128.64	n/a	46.37
2012	49.07	4. 22	32.40	12.45	89.92	4.12	44.96
2013	53.07	15.50	37.58	Included in surface drainage	62.27	3.30	49.78
2014	44.57	15.33	29.24	Included in surface drainage	47.82	2.67	41.89

* Comprises volumes from surface drainage, groundwater drainage, and precipitation.
** Includes volumes for recycled water used in the mining installations.
*** Values for 2008, 2012, 2013 and 2014 were calculated as the difference between the total water harnessed and the water discharged. For 2009 and 2010, net consumption was reported. Net consumption for 2011 was not calculated, as the value for water discharged was larger than the value for water harnessed.

company's water rights by more than twice the volume granted. These findings suggest that MYSRL greatly exceeds the permitted rights of water extraction, which might jeopardize access to water for other users that depend on flows upstream in the Mashcon catchment.

Domestic use for rural and urban populations

In 2012, only 68% of people in Cajamarca had access to permanent clean water, a problem mainly affecting rural populations (Instituto Nacional de Estadística e Informática – INEI, 2012). Around 9330 families live in the influence area of the mine and use water from streams and springs for domestic purposes (Sosa & Zwarteveen, 2012). However, the quality of water consumed by the rural population has been contested due to several claims of acid drainage and chemical discharges from the Yanacocha mine to the streams (Observatory of Mining Conflicts in Peru, n.d.). Descriptive statistics for the Mashcon catchment (Benavides et al., 2007) suggest that springs with a flow of less than 0.001 m^3/s are estimated to serve just one household; however, 204 springs with less than the previously stated volume provide water for more than one family. For example, the Chicos-Chicos spring has a hydrological yield of 0.0016 m^3/s and provides water to 103 families for domestic and agricultural use. Considering that 92% of the springs in the Mashcon catchment are traditionally used without official authorization and have not been registered, this might represent a problem for rural communities, as the loss of water flow in springs cannot be formally reclaimed. Although water supply is theoretically allocated according to defined water rights, this does not necessarily reflect actual demand. For example, upstream water for rural populations was neither documented nor clearly regulated, while water flows remain affected, possibly jeopardizing the livelihoods of rural populations of the Cajamarca district.

Due to the proximity of the mining operations to the city of Cajamarca, impacts also extend to the urban population. The water downstream is mainly directed to the city of Cajamarca and its 150,197 inhabitants (INEI, 2007). This population has been growing by 4%, a higher rate than in Peru's capital, Lima. The introduction of the Yanacocha project in 1993 is considered a major driver of rapid growth in the city, especially through the influx of new workers for the mine (Steel, 2013). As a consequence of this growth, the city has not been able to accommodate demands for water access. In addition, water shortages occurred regularly in 2011 and 2012, resulting in the MYSRL being accused of desiccation of the Grande River (Prado, 2012).

The population of the city of Cajamarca uses water provided by SEDACAJ, a company responsible for managing drinking water in the city. The SEDACAJ (2012) report identifies the Grande River as the main source of water for SEDACAJ, providing a supply representing approximately 75% of the river minimum flow (2012).[2] Since 1999, SEDACAJ's licence has been for 0.380 m^3/s; yet, domestic demand has increased due to population growth. In 2012, the SEDACAJ treatment plant had a supply flow of 0.250 m^3/s. Demand however, corresponded to 0.266 m^3/s, generating a deficit of 0.016 m^3/s. The water demand for the city of Cajamarca is predicted to grow from 0.266 m^3/s in 2011 to 0.646 m^3/s in 2035 (2012), a volume difficult to supply with current water sources. In fact, there is a paucity of alternatives for the expansion of supply sources for drinking water. Alternative sources for the future water supply for the city of Cajamarca are invariably influenced by MYSRL (SEDACAJ, 2012). Moreover, the mitigation plan of MYSRL for using discharge water from the mine would result in increased treatment costs for drinking water, a cost that will ultimately be shifted to the population of Cajamarca.

Small farmers' claims and water use

Small farmers in the region have traditionally been milk producers and cultivate small pastures and dairy cattle as their main agricultural activities. The historical use of surface water in the region is irrigation deriving from regulated canals in the catchment, which are managed by committees of water users. The distribution of water between different water associations is embedded in collective institutions for regulating the use and operations and maintaining the canal infrastructure. After persistent complaints from the upstream user committees regarding the reduction of their water flows in the canals, it was clear that MYSRL incited substantial competition over water.

Irrigation committees upstream of the Grande River depend on water diverted from most springs and streams. During the expansion of the La Quinua and Yanacocha mining projects, five canals in the subcatchment of the Grande River were impacted: the Encajon-Collotan, Yanacocha-Llagamarca, La Shacsha, Quishuar, and San Martín–Tupac Amaru–Río Colorado. The mining company agreed to supply 0.163 m^3/s of water from a mining reservoir to the affected canals to mitigate the effects of reduced base flows (MYSRL, 2006). However, this value does not represent a constant annual supply. In fact, water to the Quishuar and Encajon-Collotan canals was supplied for the 8.5 months of reduced precipitation (2006). Figure 3 shows the main canals in the Mashcon catchment together with the four discharge points for the Encajon-Collotan (0.042 m^3/s), Quishuar (0.056 m^3/s), Yanacocha-Llagamarca (0.025 m^3/s) and San Martín–Tupac Amaru–Río Colorado (0.040 m^3/s) canals (2006).

In return for the agreement made with MYSRL for a minimum water discharge in the canals, the irrigation committees gave up their water rights and accepted the company's conditions for supervision, provision and distribution of the water from the reservoir (Kuijk, 2015). These negotiations between water committees and MYSRL were carried out without involvement of the water authority (Sosa & Zwarteveen, 2012).

In order to ensure constant monitoring of the canals that could be affected by mining in the Mashcon catchment, a commission for the monitoring of irrigation canals (COMOCA) was created. Using COMOCA's monthly data on water flows of the canals, an historical trend analysis was conducted by using the Mann-Kendall test on the water flow supply. Results are summarized in Table 6. An increasing trend can be seen in the major upstream canals of Encajon Collotan, La Shacsha, and Quishuar, each located in the mining proximities of the Grande River subcatchment (see Figure 3). These upward trends could be the result of large volumes of water discharged from the mining operations as established in the mitigation agreement between MYSRL and the respective water associations. In contrast, four canals (Atunmayo, Carhuaquero

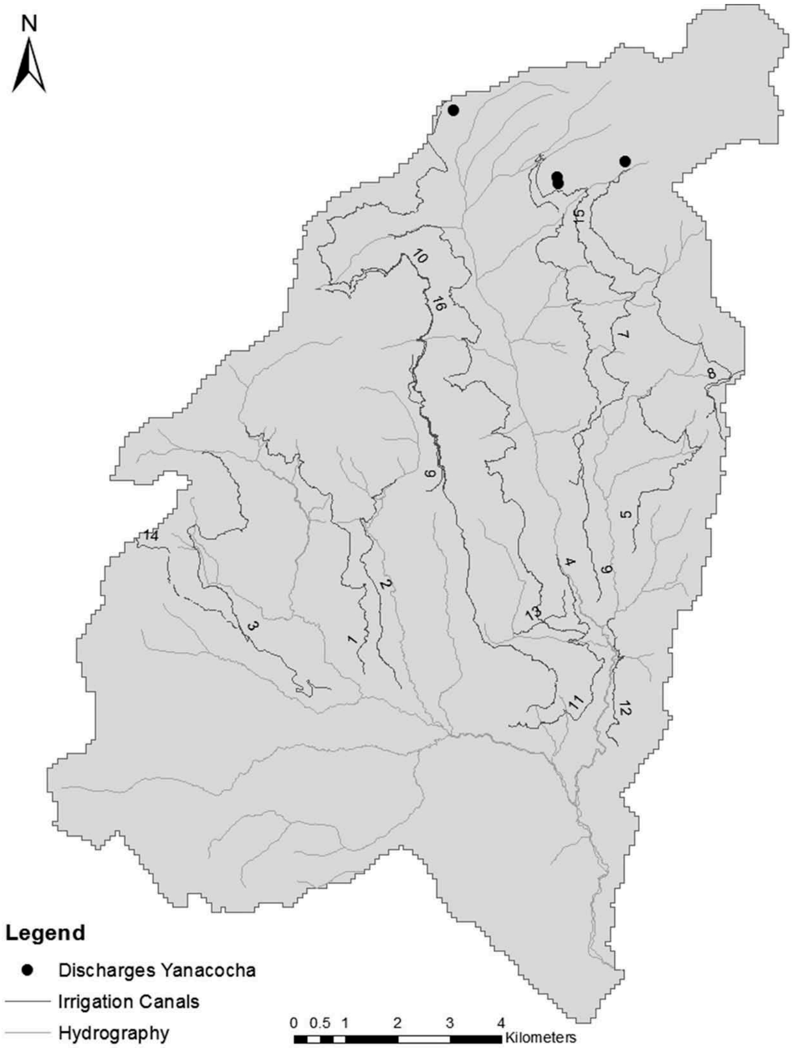

Figure 3. Primary irrigation canals in the Mashcon catchment. The canal numbers correspond to the reference numbers in Table 6.

Yacushilla, San Martín–Tupac Amaru–Río Colorado and San Salvador José de Coremayo) have a decreasing flow trend over the time period analyzed. Since each irrigation canal initially received water from streams, it is possible to deduce that the mining operations have affected the latter canals, which are dependent on water flows deriving from a series of networks of major upstream irrigation canals. Finally, the Cince Las Vizcachas, La Collpa and Quillish Porcon Bajo canals, in the less impacted Porcon River subcatchment, do not show a significant trend, suggesting that flow in those canals has not been affected. No information was available to analyze the flow trend for one of the main canals, the Yanacocha-Llagamarca.

Table 6. Irrigation canals within the influence area of the Yanacocha project in the Mashcon catchment. Results show a trend analysis on discharge water flows of the irrigation canals monitored by COMOCA.

Ref. no.	Irrigation canal	Water use right (m^3/s)	Minimum flow (m^3/s)	Maximum flow (m^3/s)	Time series	Measuring point	*p*-value from trend analysis
1	Hermanos Cueva	0.0173	0.0012	0.12	2001–2014	CHCD-1	(–) 0.013*
						CHCI-1	(+) 0.00029***
						CHC	(–) 0.223
2	La Collpa	0.017	0.02	0.098	2001–2014	CCOL-1	(–) 0.395
3	Quilish Porcon Bajo	0.010	0.0015	0.151	2001–2014	CQUI-1	(+) 0.275
						CQUI-2	(–) 0.630
4	Atunmayo	0.020	0.0025	0.088	2003–2014	CAM-1	(–) 0.034*
5	Carhuaquero Yacushilla	0.0116	0.00058	0.150	2001–2014	CCY-1	(–) 0.00017***
6	Cince las Vizcachas	0.0014	0.0012	0.045	2004–2014	CCV-1	(–) 0.438
7	Encajón Collotan	0.0633	0.0068	0.071	2001–2014	CEC-1	(+) 2.22e-16***
						CEC-2	(+) 2.22e-16***
8	La Sacsha	0.00923	0.004	0.222	2001–2014	CSH-1	(+) 1.668e-06***
9	Quishuar	0.0848	0.003	0.150	2001–2014	CQ-1	(+) 1.192e-05 ***
						CQ-2	(+) 0.00496*
10	San Martin-Tupac Amaru-Río Colorado	0.163	0.001	0.563	2001–2014	CTU-1	(–) 1.500e-06***
						CTU-2	(–) 0.053
						CTU-2A	(–) 0.155
						CTU3	(–) 0.230
11	San Salvador José de Coremayo	0.068	0.0005	0.089	2004–2014	CSC-1	(–) 0.00045***

Note. Two-sided *p*-values indicated with *** for $p < .001$, ** for $p < .01$, and * for $p < .05$. Increasing and decreasing trends indicated by (+) and (–). Data from COMOCA 2001–2014, Autoridad Local del Agua Cajamarca – ALA-C (2013).

A decreasing trend in water flows in some irrigation canals during the dry season is of critical concern since optimal production of crops and pastures in the region depends on water throughout the year. Although mining has been shown to have an impact on the reduction of flow, the lack of adequate infrastructure, and inefficient irrigation methods, are also to blame (Bernet, Hervé, Lehmann, & Walker, 2002). For efficient irrigation technology to be implemented, it is necessary that greater investments in planning be made. Such burdens fall on poor farmers who are strongly dependent on agriculture for subsistence. Although current water policies in Peru favour so-called advanced water use technologies, more efficient infrastructure and stronger controls among water user associations to mitigate water reduction, these arguments divert the discussion from accountability for water impacts and shift liability to irrigation-water users.

Lessons learnt

Despite the critical importance of hydrological analysis to inform decision making, this field is hindered by an acute scarcity of data, which jeopardizes formulation of adaptive measures for water management (Buytaert et al., 2014). A critical factor that limits drawing conclusive results on the impacts on water of the Yanacocha mine is the lack of a baseline study of the region's natural hydrology, historical records of water flows and changes in the water tables of aquifers in the Mashcon catchment. This challenge has been confirmed by other authors (Kuijk, 2015; Yacoub & Cortina, 2007). However, the urgency of implementing regulations on the use and distribution of water also provides the opportunity to generate citizen mechanisms to define restrictions on the use of water in intensive land-transformation activities (2014).

The Yanacocha project will soon begin its overall closure stage; however, the post-mining phase is equally critical to secure water provisioning for wider demands from the catchment. As a result of the constant threat of water reduction, proposed policies are being crafted in favour of the efficient use of water (Boelens & Vos, 2012). These alternatives focus mainly on technological solutions such as the construction of reservoirs and dams that will supply water to different users (MYSRL, 2013). Construction of reservoirs and dams aims to mitigate the reduction of base flows but does not aim to regenerate water flows, thereby threatening the sustainability of the hydrological regime in the future (Fonseca, McAllister, & Fitzpatrick, 2013).

Management of water resources in Yanacocha is associated not only with physical changes, but also with poor management systems, the granting of water rights without adequate planning, and the lack of monitoring mechanisms to control actual use. Thus, changes in water distribution require more than new mechanisms for coping with the reduction of water; a thorough analysis of water sources, clear accountability of water use by multiple stakeholders, socially just distribution of water rights, and assumed responsibilities for water loss are also required.

The regulatory role of state institutions also requires further strengthening. Although the role of the state in managing water resources is essential, overly top-down water policies have a history of disciplining users and undermining diverse local systems of water management in several Andean countries (Boelens, 2009; Gelles & Boelens, 2003). Instead, recognition of 'legal pluralism' can serve to build stronger mechanisms of management, control and accountability for water resources. A broader regulatory context based on strengthening customary water rights should recognize diverse institutionally contingent arrangements (Vos, Boelens, & Bustamante, 2006). Moreover, the interplay of plural institutional mechanisms depends critically on deliberative processes allowing democratic decision making and incorporating the discussion of just distribution of water according to water availability and social priorities. A balanced decision-making system between technical analyses and recognition of a just and equitable system for allocation of water should set appropriate limits on water use and form the benchmark for monitoring compliance (Perreault, 2014; Zwarteveen & Boelens, 2014). There is thus an urgent need to *collectively* define, based on environmental criteria and population requirements, whether mining activities are appropriate and where they should not be permitted.

The Yanacocha project is reaching its final years of production, and the company is currently targeting a new project known as Conga. This project is an extension of MYSRL, 25 km north-east of the current mining district. Given a similar climate and ecological conditions, as well as historical records in terms of water management, it is necessary to develop a sound baseline in the catchments around the planned Conga project. Lastly, ethical questions should also be deliberated upon regarding water rights allocation and priorities for environmental conservation and livelihoods in the region of Cajamarca.

Conclusions

The cause-and-effect relationship between mining activities, impacts on water, and subsequent land uses is not straightforward and suggests the need for a more comprehensive understanding of the specific biophysical conditions and land use practices that affect the provisioning of water. The lack of baseline information and monitoring represents a challenge for the definition of a hydrological budget between water availability and demand in the Mashcon catchment. However, this lack of complete information regarding the modifications of water flows should not be a reason for the failure to identify salient and proactive policy solutions associated with mining extraction. We have argued that water reduction, and the lack of regulation in the use and distribution of water rights, are serious barriers to water sustainability in Cajamarca. Regulatory mechanisms to cope with water scarcity should be based on the recognition that water resource allocation is conditioned by both availability and a contestation of social priorities. The policy relevance lies in whether it is sustainable to assign water rights without hydrological planning and clear knowledge of the availability of water resources. A more comprehensive and socially just distribution of water requires critical modifications to ensure that local and regional development is not restricted to the success of mining activities, but can be a reality for the totality of the population in Cajamarca.

Notes

1. Additional water users relate to energy production and other industrial uses; however, they are not considered here, as they do not represent a significant value in terms of volume of water used or number of users.
2. Other small sources of water for SEDACAJ come from the Ronquillo River, which provides an additional flow of 0.060 m^3/s. In the peripheral zone of the city water is provided by small aquifers.

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