Journal of Environmental Management 100 (2012) 52–58

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

Costs of abandoned coal mine reclamation and associated recreation benefits in Ohio

Shruti K. Mishra[a,*], Frederick J. Hitzhusen[a], Brent L. Sohngen[a], Jean-Michel Guldmann[b]

[a] Department of Agricultural, Environmental, and Development Economics, The Ohio State University, Columbus, Ohio, 2120 Fyffe Road, Columbus, OH 43210, USA
[b] Department of City and Regional Planning, The Ohio State University, Columbus, Ohio, 275 West Woodruff Avenue, Columbus, OH 43210, USA

ARTICLE INFO

Article history:
Received 24 April 2011
Received in revised form
7 January 2012
Accepted 16 January 2012
Available online 22 February 2012

Keywords:
Externalities
Water quality
Coal mining
Ecosystem services
Recreational value
Coal mine reclamation
Policy

ABSTRACT

Two hundred years of coal mining in Ohio have degraded land and water resources, imposing social costs on its citizens. An interdisciplinary approach employing hydrology, geographic information systems, and a recreation visitation function model, is used to estimate the damages from upstream coal mining to lakes in Ohio. The estimated recreational damages to five of the coal-mining-impacted lakes, using dissolved sulfate as coal-mining-impact indicator, amount to $21 Million per year. Post-reclamation recreational benefits from reducing sulfate concentrations by 6.5% and 15% in the five impacted lakes were estimated to range from $1.89 to $4.92 Million per year, with a net present value ranging from $14.56 Million to $37.79 Million. A benefit costs analysis (BCA) of recreational benefits and coal mine reclamation costs provides some evidence for potential Pareto improvement by investing limited resources in reclamation projects.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Two hundred years of coal mining in Ohio have degraded land and water resources, imposing social costs on Ohioans. The federal and state governments have reclamation programs for coal mines abandoned before 1977, and regulations to prevent pollution from mines after 1977. The Surface Mine Control and Reclamation Act (SMCRA) of 1977 mandates mining companies to return the land to its approximate original contour and minimize disturbances to nearby hydrologic systems. The reclamation of the abandoned mines is funded by federal and state taxes on current coal-mining companies (Ohio Department of Natural Resources, ODNR). However, the long-lasting nature of these impacts, along with insufficient funding for the reclamation of abandoned mines, perpetuates the problem. Government is lagging behind by 135,650 abandoned mine reclamation units (ODNR), which continue to incur societal losses through deteriorated ecosystem services. Their reclamation is expected to cost $814 Million (2006 dollars).

A limited budget is allocated for reclaiming mines classified by three priority levels. Mines posing health and safety risks are in priority 1 and 2, and those posing environmental problems are in priority-3. Better estimates of the social losses from these unreclaimed mine sites and the potential post-reclamation benefits are needed to evaluate the efficiency of current reclamation efforts. A full evaluation of the damages associated with coal mining (Fig.1) and benefits of restoration would provide a sound basis for efficient reclamation decisions. We evaluate here a major component of social losses, the effect of acid mine drainage (AMD) on downstream recreation. We expect that this component is significant because the recreational returns from air and water quality improvements have been found in the past to constitute a significant share of the total benefits from restoration [50% according to Freeman (1979); 95% according to Federal Water Pollution Control Report (1966)].

Because the recreational benefits of improved environmental quality are not completely observable as market transactions, non-market valuation methods are needed to fully evaluate these benefits. Earlier studies have estimated the non-market benefits from reclaiming damaged ecosystems, using environmental valuation techniques such as conjoint analysis, contingent valuation, travel cost method, and hedonic pricing methods. Farber and Grinner (2000) estimate coal-mining damages to both the use

* Corresponding author. US Geological Survey, 345 Middle Field Road, Menlo Park, CA 94025, USA. Tel.: +1 650 329 4346.
E-mail address: saishruti@gmail.com (S.K. Mishra).

0301-4797/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2012.01.021

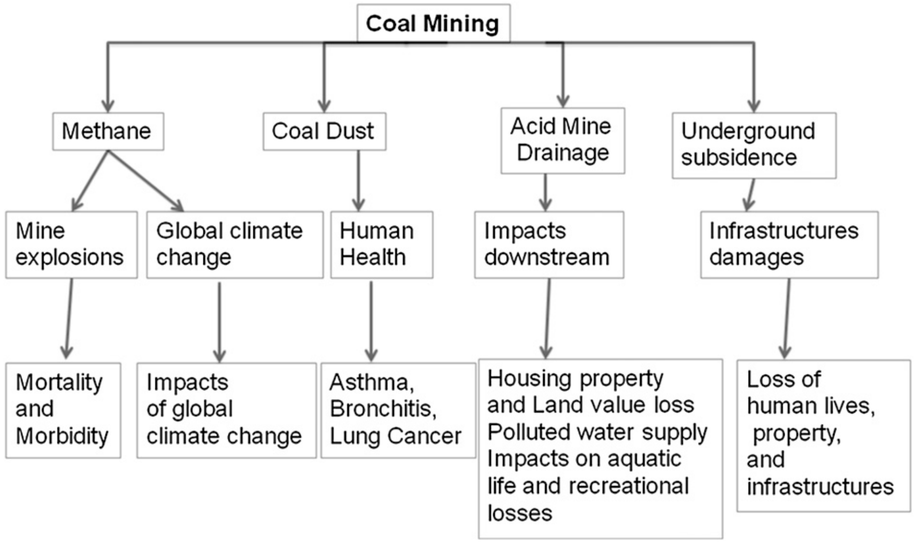

Fig 1. Coal mining externalities.

and non-use value of a stream, while other studies focus only on stream-use value. Randall et al. (1978) evaluate the damage from coal mining in terms of water treatment costs, recreation restoration costs, damages to land and buildings, and the value of damages to the aesthetics of the area. Sommer and Sohngen (2007) focus on recreational damages, using the travel cost method. Hitzhusen et al. (1997) evaluate losses of housing property value and recreational losses, while Williamson et al. (2008) estimates the AMD damages to housing property values. These foregoing analyses involve the estimation of the recreational damage in a stream/river or lake in a single watershed. In contrast, our Eastern Ohio study area includes multiple watersheds in the coal bearing counties of the state, and therefore is of major significance to state regulators.

In this research, we estimate the value of water quality change in lakes in Eastern Ohio. People respond to change in environmental quality by increasing or reducing the use of the resource. The value of lost recreation due to water quality change is a good measure of damages to lakes from coal mines. The incremental recreation value of post-restoration water quality improvement is the measure of restoration benefits.

We face some limitations in the empirical estimations. In order to estimate the revealed preference for water quality, the best method would be to take a survey on trips taken and to estimate a recreation demand model to derive the trade-off between water quality and trips taken. Given the regional extent of the analysis, primary data collection would have been time and budget intensive, and was not feasible. Our estimation approach is therefore based on secondary data collected by government agencies, GIS-derived variables, and data available in the literature. Given these data limitations, a visitation function is estimated to measure the damages to ecosystem services from coal mining and the benefits of restoration, and is believed to provide robust estimates than other non-market valuation techniques.

The visitation function method is used to estimate the changes in the number of visits to a lake as a result of changes in water quality. We also use the benefit transfer method and metrics, when reliable. Our aim here is to quantify (1) coal-mining damages to lakes at the regional scale, and (2) post-reclamation welfare gains from improved water quality in the region. As components of a benefit cost analysis (BCA), the reclamation costs for the coal mines located in the watersheds of the lakes are estimated and compared to the benefits attributed to the reclamation efforts.

2. Methodology

The Eastern Ohio counties housing abandoned coal mines are the site of this study (Fig 2). This section first examines the relationship between coal mining and lake water quality, using a Geographic Information System (GIS), hydrology, and water chemistry. Next, the visitation function model is developed and used to estimate damages and post-reclamation benefits. Reclamation costs are then estimated. Finally, a BCA of coal mines reclamation and improved ecosystem services from the lakes is discussed for prioritizing coal mine reclamation projects.

2.1. Identification of coal-mine-impacted lakes

2.1.1. Geographic information system analysis

GIS analysis is used to identify the spatial distribution of ongoing coal mining areas, reclaimed coal mines, and unreclaimed abandoned underground and surface coal mines located in Eastern Ohio (Fig. 2). A Digital Elevation Model (DEM) (USGS, 2009a), a watershed map (Natural Resources Conservation Services, 2009), a streams map and a lakes map (USGS, 2009b), and slope and flow accumulation maps derived from the DEM using the Spatial Analyst function of ArcGIS 9.3 (ESRI, Redlands, CA) are used to identify the lakes and streams impacted by coal mines. Thirteen lakes are identified as receiving runoff from the abandoned mines (Table 1), and therefore could potentially be impacted by these mines. The lake chemistry of these thirteen lakes is further investigated to quantify coal-mine-specific impacts.

2.1.2. Lake chemistry: coal-mining-impact indicators

Coal mines deteriorate downstream water quality with heavy metals, acid mine drainage, sulfur and other chemicals. The literature on the chemical conditions of lakes has been reviewed to find an appropriate variable representing coal-mine impacts. Physical, chemical, and biological measures, such as the Integrated Biotic Indices (IBI), Lake Condition Index (LCI), color, turbidity, chemical indices, pH, alkalinity, oxygen indices, and Coliform bacterial count, have been used in previous studies to evaluate water quality impacts on water-based recreation demand. The Ohio Environmental Protection Agency (OEPA) developed the Ohio LCI, based on 14 parameters, ranging from 10 to 100, where 100 is most impaired. This index is used to assess the overall lake ecosystem (Davic et al., 1997). The LCI measures overall nonpoint source pollution but not

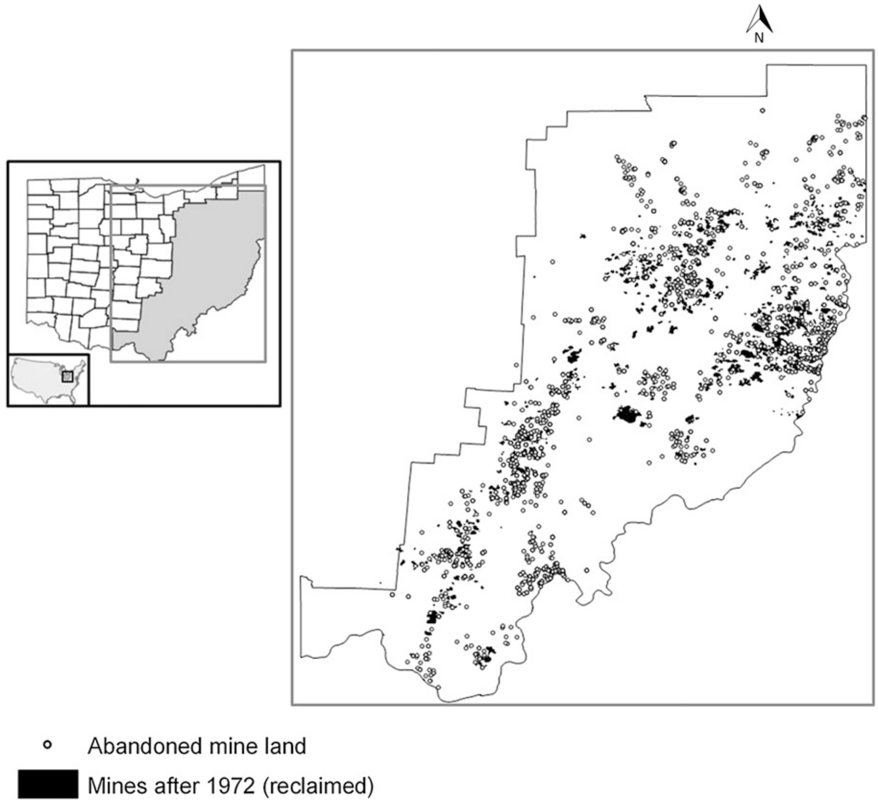

Fig 2. Location of coal mines in eastern Ohio.

coal-mine-specific impacts, and therefore could be misleading. Sulfate (SO_4) content and the specific conductivity (SC) of lake water are appropriate measures of coal-mine-specific impacts (Rikard and Kunkle, 1990). A lake identified as coal-mine-impacted has a higher level of SO_4 than a non-impacted one (US Army Corps of Engineers, USACE, 2009–10). Leesville, a non-impacted lake, has the lowest SO_4 level (26 mg/l), while impacted Piedmont Lake has the highest level (840 mg/l), suggesting that SO_4 can be used as coal-mine-impact variable.

In contrast to other water quality measures such as turbidity, the SO_4 or SC levels are not visible to visitors. IBI is negatively correlated with SO_4 [US Environmental Protection Agency (USEPA), 2002] and with SC [US Geological Survey (USGS), 2006], indicating that higher SO_4 or SC levels do not support aquatic life. USEPA (1997) found that SC in the range of 150–500 μmhos/cm can support well-mixed fisheries. Negative relationships between SC and the mean length of fish (Rogowski, 2006) and between SC and fish population (Kimmel and Argent, 2009) suggest that higher SC or SO_4 will affect anglers. However, boaters and skiers might not be directly affected by SC or SO_4. Drinking high SO_4 concentration water causes diarrhea (Delaware Health and Social Services, Division of Public Health, Delaware, 2008), posing risks to swimmers. For the above reasons, SO_4 and SC are the water quality parameters selected in the visitation model estimation.

Table 1
Coal-mine-impacted lakes.

AML[a]-surface	AML-underground
Atwood	Wills Creek
Evans	Tappan
Piedmont	Wolf Run
Senecaville	Dow
Snowden	Rupert
Jackson	
Vesuvius	
Rupert	

[a] AML Abandoned Mined Land.

2.2. Recreational visitation to lakes

2.2.1. Visitation function model

The number of visitors (visitation) to a recreational site is determined by the characteristics of the site, entry and other fees, vicinity to population centers, substitute or complementary recreation sites in the vicinity, and the demographics of the population of potential users around the site (Macgregor, 1988; Hanink and White, 1999; Weiler et al., 2003; Loomis, 2004; Neuvonen et al., 2010). Visitation to a lake is modeled as follows:

$$V = f(\mathbf{L}, TC, \mathbf{P}, \mathbf{S}) \tag{1}$$

where V is the total annual number of visitors to the lake, **L** a vector of lake characteristics, TC the travel cost, **P** a vector of demographic characteristics of the population in the lake vicinity, and **S** a vector of substitute or complementary sites. The annual number of visitors to a lake for specific recreational activities is recorded by the USACE for the year 2006 for the lakes in Ohio.

The total population in the urban centers close to a lake can be expected to add to lake visitors. Similarly, the higher the income levels of the prospective visitors the larger the visitation. The travel cost associated with recreation at a given site is another important determinant of visitation. The farther the lake from the cities, the higher the travel cost, which in turn negatively affects visitation. Therefore, distance from a population center to a lake is used as a proxy for travel cost. To account for the trade-off between population size and distance to a lake from the cities potentially supplying visitors, a gravity variable is formulated as:

$$PD = \sum_{k=1}^{n} P_k/(D_k + HD_k) \quad (2)$$

where P_k is the population of city k, D_k the distance from city k to a highway location closest to the lake,[1] and HD_k the distance from that highway location to the lake.

Lake characteristics include physical properties, such as total surface area, depth, age, and water quality parameters. Larger lakes, lakes where higher horsepower (HP) boats are allowed, and deeper lakes attract more visitors. The better the water quality, the higher the number of visitors. Recreational and accessory facilities include camping,[2] lodging, showers, boat ramps, marina, gas, picnic area/shelter, playground, swimming area,[3] fishing facilities,[4] trails,[5] golf courses, amphitheater, grocery and snack bar, and HP allowed for boating. Lakes providing more and better facilities attract more visitors. A lake facility index (F_i) is created, based on the facilities available at a lake site, with:

$$F_i = \frac{N_{mi}}{N_m} + \frac{N_{Bi}}{N_B} + \frac{M_{si}}{M_s} + \frac{N_{si}}{N_s} + \frac{N_{Fi}}{N_F} \quad (3)$$

where N_{mi} is the number of marinas, N_{Bi} the number of boat ramps, M_{si} the number of marina slips, N_{si} the number of swimming areas, and N_{Fi} the number of fishing ramps at lake i. The denominators are the average values of the respective variables across all the lakes.

The visitation function is expressed as:

$$V_i = \beta_0 + \beta_1 A_i + \beta_2 F_i + \beta_3 WQ_i + \beta_4 S_i + \beta_5 HP_i + \beta_6 I_i + \beta_7 PD_i + \varepsilon_i \quad (4)$$

where V_i is the annual number of water-based recreation visitors to lake i, as recorded by the USACE for specific activities such as swimming, boating, and fishing. Water-based recreation visits were calculated while taking into account possible participation in more than one activity. A_i is the lake surface area (acres), F_i the facility index, WQ_i the water quality parameter (SC for all lakes or SO_4 for all lakes), S_i the sum of the areas of substitute lakes within a 30 miles distance from lake i, HP_i the horsepower allowed in the lake, I_i the income of the population in the cities in the vicinity of the lake, and PD_i the gravity variable. Lake characteristics data and water quality data (SO_4 concentration and SC) were collected from the USACE. Sulfate trends were verified with OEPA and USGS data. Mines data were collected from ODNR. GIS analyses were used to prepare the data for some of the variables used in the regression analysis. The assumption was made that visitors would travel to another cleaner lake within about an hour of driving distance over small secondary roads (an incremental drive of 30 miles). Lakes within that distance were identified, using GIS analysis, as substitute sites and their surface areas were summed up and used as the substitute lake variable. Distances from lakes to nearest highway and to cities were estimated using MapQuest. Population and income data were drawn from the Census. Descriptive statistics for these variables are presented in Table 2.

Table 2
Descriptive statistics for visitation function variables.

Variable	Mean	Standard deviation	Minimum	Maximum
Water-based recreation visits	396,864	389,583	7,270	1,295,869
Household income ($)	36,504	11,530	27,280	71,414
Gravity index	8287	7737	1059	30,290
Lake surface area (acres)	2083	1561	154	7580
Water quality (sulfate mg/l)	171	267	23	840
Substitute lakes area (acres)	3242	2330	0	7504
Facility index	0.71	0.40	0	1.56

2.2.2. Monetizing recreational damages and post-reclamation benefits

Monetization of the change in lake water quality must account for (1) the change in the number of visits, and (2) the change in the value per visit because of the change in water quality.

The economic surplus ES_i for each lake i is estimated as:

$$ES_i = VN_i * VV_i \quad (5)$$

where VN_i is the total number of visitors to lake i, and VV_i is the daily-use value per visit.

The daily-use values per visit were determined using the benefit transfer method and metrics, following Walsh et al. (1992) and Smith et al. (2002). This method involves transferring the value of the environmental goods from study site to policy site. This method provides better estimates if the study site and policy site have similar characteristics. Otherwise, the results from the study site need to be adjusted before using them in the policy site. Studies in Eastern Ohio are thus most relevant in estimating the value per trip. Rosenberger and Loomis (2001) and Bhat et al. (1998) estimate daily-use values for recreation for large ecological regions that include Ohio. Sommer and Sohngen (2007) estimate the consumer surplus per boating and angling trip in the Hocking River valley, Ohio, at $23.55, and estimate the increase in consumer surplus at $4.88 and $5.13, for water quality improvements in the Hocking River valley from poor to good and from poor to excellent quality, respectively. Since this study was conducted in Eastern Ohio, where water quality deterioration is attributed to coal mining, a direct benefit transfer is proposed to estimate the value per trip and the incremental value of a trip.

Coal-mine damage is measured as the difference in visitation value, using the non-impacted reference lake of Leesville, which has characteristics similar to those of the impacted lakes in the region, but has comparatively lower sulfate levels, with no coal-mining impacts. Had there been no upstream coal mining, the sulfate levels in the impacted lakes would be similar to those in Leesville. Therefore, the sulfate level in Leesville is taken as the reference sulfate level. Total damage D is estimated using both the numbers of visits and the values per visit under the current impacted water quality and under the undeteriorated water quality (sulfate level) in the reference lake, with:

$$D = \sum_{i=1}^{n} \{(VN_i * VV_i) - (VN_{is} * VV_{is})\} \quad (6)$$

where VV_{is} is the value per trip under reference lake water quality condition for lake i, VN_{is} is the number of visitors under such reference condition, VV_i is the value per trip under current water quality condition, and VN_i is the current number of visitors.

In order to estimate the potential post-reclamation recreational benefits, both the increase in visitation due to improving water quality and the increased value per trip attributed to water quality improvement are considered. Water quality improvement (sulfate reduction) is achieved by restoring abandoned mine land (AML). A

[1] The major Ohio cities included in the gravity variable are Ashland, Cambridge, Canfield, Canton, Centerville, Chillicothe, Cincinnati, Columbus, Coshocton, Covington, Dayton, Dublin, Franklin, Fredericktown, Greenfield, Grove city, Hilliard, Hillsboro, Kent, Kettering, London, Louisville, Mansfield, Marion, Marysville, Massillon, Middletown, Mt Vernon, New Carlisle, New Philadelphia, Newark, Niles, Powel, Ravenna, Salem, Springfield, Strasburg, Tallmadge, Uhrichsville, Warren, Washington Courthouse, Wooster, Worthington, Youngstown, and Zanesville.

[2] Electric campsites, nonelectric campsites, pull through campsites, group camping, and dump station.

[3] Beach, swimming pool.

[4] Fish cleaning stations, fishing docks.

[5] Bike trails, equestrian trails, hiking trails, off road vehicle trails.

separate study on the impacts of upstream mine reclamation on chemical concentrations and overall ecological health of downstream water bodies would be required for accurately quantifying reductions in sulfate level. This was dealt with by using earlier research in Ohio on SO_4 level reductions as a result of upstream reclamation in order to derive possible SO_4 reduction scenarios. According to Hren et al. (1984), the difference in SO_4 levels in lakes downstream from abandoned mines after reclamation was 7.25% over 7 years. For the purpose of this research, a sensitivity analysis was conducted using a 12.5% reduction based on Hren et al. estimates over a 12-year reclamation time frame, and 15% and 6.5% reductions under accelerated and slowed-down reclamation. The incremental value per trip from poor to good water quality in Sommer and Sohngen (2007) was used for the case of 6.5% SO_4 reduction, and the value per trip corresponding to an improvement to excellent water quality was used in the case of a 15% reduction in SO_4 level. Increase in visitation was estimated using the mean parameter values of the visitation function model.

The net present value (NPV) of the recreational benefit stream is estimated as:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{\mathrm{RB_t}}{(1+r)^t} \tag{7}$$

where RB_t is the reclamation benefit in year t, r the discount rate, and T the number of years of benefit flows. An annual discount rate of 7% (Office of Management and Budget, Circular Number A-94, 1992) is used to estimate NPV. It is further assumed that the designated percentage of sulfate reduction is achieved after 12 years of reclamation and that the benefit stream attributed to water quality will continue to be incurred over 20 years after completing reclamation.

2.3. Reclamation costs estimation

Reclamation costs were estimated using the database on AML obtained from ODNR. The AMLs were categorized according to the type of AML problems and their assigned priorities. Coal mining problems are designated as priority P-1,[6] P-2,[7] or P-3. P-3 problems meet the conditions under Section 403(a)(3) [coal] or 411(c)(3) [non-coal] of the SMCRA concerning the restoration of land, water resources and the environment previously degraded by the adverse effects of mining practices or a condition that is causing degradation of soil, water, woodland, fish, wildlife, recreational resources, or agricultural productivity.

Reclamation costs were estimated for each AML problem type, using the per unit (number, acreage, feet, or miles) reclamation costs derived from the database, with:

$$\mathrm{RC} = \sum_{w=1}^{W} \mathrm{CU_w} {*} \mathrm{U_w} {*} \mathrm{I} \tag{8}$$

where RC is the total reclamation cost, CU_w the per unit reclamation cost for reclamation category w, U_w the number of AML units of type w, I the inflation factor to convert dollars to 2006 dollars, and W the number of reclamation categories. Details on the estimation of reclamation costs are available in Mishra (2009). The Office of Surface Mining Reclamation and Enforcement at ODNR has a budget allocation for AML reclamation until year 2021. Therefore, the discounted present value of the reclamation costs was distributed over the period extending to the year 2021.

[6] P-1: Problems related to protection of public health, safety, general welfare, and property from extreme danger due to adverse effects of mining practices or a condition that could reasonably be expected to cause substantial physical harm to persons or property.

[7] P-2: Problems similar to P-1 but do not create an extreme danger.

Table 3
Visitation function regression results.

Variable	Coefficients (T-stat)
Lake surface area (acres)	0.823 (2.45)**
Water quality (sulfate, mg/l)	−0.462 (2.78)***
Facility index	1.269 (2.31)**
Gravity index	0.286 (1.79)**
Constant	4.31
R^2	0.7523

Note: ***1 % significance, **5% significance.

3. Results and discussion

3.1. Recreational damages

Damages to recreational activities were evaluated using the visitation function estimated with data for most of the USACE lakes (n = 20) in Ohio (dry dams excluded). The best fit log-log model is presented in Table 3. The coefficients for the lake surface area, facility index, and gravity variables have positive signs as expected. The income variable was not significant, probably because there is not enough variation in income levels in Eastern Ohio, and is not included in the final regression. The HP variable is one of the facility characteristics, which may explain why including both HP and the facility index as variables in the visitation function made both variables insignificant (multicollinearity). Since the facility index variable is a stronger explanatory variable than HP, which only explains boating visits, the later was dropped from the equation. The water quality variable (SO_4) has a negative sign, confirming a negative relationship between number of visits and sulfate level. Regression results using SC as the water quality variable are not reported because SC was not significant. All the reported coefficients are significantly different from zero.

The numbers of visits corresponding to reference water quality condition are estimated with the mean parameter values of the visitation function. The difference between the number of visits under existing water quality and reference water quality is the loss in visitation as a result of water quality deterioration. The monetary value of the loss in visitation is calculated using the value per trip discussed in Section 2.2.2. The loss of visitors ranges from 30,365 to 284,242 per lake per year, as illustrated in Table 4 for five of the coal-mining-impacted lakes. The estimated recreation loss ranges from $0.92 Million to $ 8.37 Million, with a total of $21.00 Million.

The estimated total damage is a lower bound for Eastern Ohio, because there are other coal-mine-impacted lakes with no visitation and water quality data. Damages to these lakes are not accounted for in this research. In addition, there are also several rivers and streams impacted by coal mining that are not accounted for.

3.2. Benefit cost analysis: coal mine reclamation and recreational benefits

Coal-mined lands are located throughout Eastern and Southeastern Ohio. Although it may be important to reclaim all these

Table 4
Annual recreational damages ($ 2006).

Lakes	Visit reduction	Damage ($ Million)
Clendening	186,899	5.51
Piedmont	89,779	2.63
Senecaville	77,869	3.57
Wills Creek	30,984	0.92
Tappan	284,242	8.37
Total	669,773.00	21.00

Table 5
Annual recreation benefits from increased reclamation ($ million).

Lake	Sulfate reduction	
	6.5%	15%
Piedmont	0.14	0.38
Senecaville	0.91	2.28
Clendening	0.31	0.84
Tappan	0.48	1.27
Wills creek lake	0.06	0.15
Total	**1.89**	**4.92**

lands, budget constraints require prioritizing their reclamation. A way to set reclamation priorities is by using reclamation BCA. Mined lands associated with the highest net reclamation benefits should be given the highest priority. This BCA is applied to the five impacted lakes (Table 4).

Lake-based recreational benefits attributable to upstream reclamation range from $1.89Million to $4.92 Million per year for the five lakes (Table 5). As other benefits (e.g., esthetic benefits, increases in property value etc.) are not accounted for, these benefit estimates are conservative. Given the long-run uncertainty associated with water quality improvement, the net present value (NPV) of the benefit stream of these five lakes is therefore estimated over 12 years of reclamation and 20 years after completion of reclamation, ranging from $14.56 Million to $37.79 Million (6.5% and 15% reduction in SO_4 level). Detailed NPV estimates are presented in Table 6.

The total reclamation cost for all the AMLs in the region is estimated at $689.61 Million, using Eq. (8), and including $444.4 Million for P-1 and P-2 problems and $245.2 Million for P-3 problems. Priority-3 problems, focused on environmental control, make up 35.6% of all reclamation costs. Coal mine reclamation costs for P-3 problems are estimated at $293,120 for Wills Creek Lake, 3.5 Million for Seneca Lake and $25.75 Million for Piedmont Lake. Similar reclamation costs for the other lakes could not be estimated due to lack of information. Piedmont Lake has many AML sites within its watershed, and their reclamation costs largely exceed the lake incremental recreational benefits. For Seneca and Wills Creek lakes, the estimated post-reclamation recreation benefits (Table 6) exceed the reclamation costs. The recreation benefits for Seneca and Wills Creek lakes range from $6.98 to $17.56 Million and from $0.43 and $1.13 Million, respectively. A review of the NPV of the costs and benefits for the lakes included in this study shows that it is most beneficial to reclaim abandoned coal mines within the watersheds of Seneca and Wills Creek lakes.

Table 6
Net present value (NPV) of recreation benefits ($ million).

Period	Lake	Sulfate Reduction	
		6.5%	15%
12 Years Reclamation period	Clendening	0.98	2.60
	Piedmont	0.43	1.16
	Seneca	2.81	7.08
	Tappan	1.47	3.93
	Wills Creek	0.17	0.46
	Total	**5.87**	**15.23**
12 years reclamation period plus 20 additional years	Clendening	2.42	6.46
	Piedmont	1.08	2.89
	Seneca	6.98	17.56
	Tappan	3.66	9.76
	Wills Creek	0.43	1.13
	Total	**14.56**	**37.79**

4. Conclusions

Eastern Ohio includes the coal mines of the state and has a long history of water quality problems, despite continuous efforts by governments and residents to mitigate them. The evaluations of coal-mining damages, the costs to reduce these damages by reclaiming coal mines, and the benefits from reclamation, are all crucial in policy decisions, such as mine reclamation choices, coal taxation, and electricity portfolio decisions.

To the best of our knowledge, this paper reports the first interdisciplinary approach in estimating regional coal-mining damages, specifically using coal-mines-specific water quality indicators in an environmental valuation framework. Coal-mining impacts on lakes in Eastern Ohio have been identified using hydrology, GIS, and lake chemistry. Damages to the impacted lakes have been estimated with a visitation function and benefit transfer methods.

Reclamation efforts enhance the recreational and other ecological services provided by the affected land and water. Based upon the estimated recreational benefits for five of the impacted lakes, a potential Pareto improvement (PPI) cannot be demonstrated for reclaiming all P-1, P-2, and P-3 coal-mined lands in Eastern Ohio. Including several other benefits from mine reclamation might possibly lead to the designation of many other mine sites as PPI sites. Estimation of the benefits related to increased house and land values, esthetic improvements, water treatment costs, mine subsidence, recreation on all impacted streams and lakes, and improved wildlife habitat attributed to reclamation efforts, would provide a clearer picture as to whether it is socially desirable to address the other coal-mined land problems not assessed by this research.

However, this research demonstrates that the reclamation of coal mines in the watersheds of some of the lakes is a PPI or socially beneficial project. Reclamation of P-3 coal mines contribute to the recreational benefits measured with the visitation function. Reclamation of P-1 and P-2 mines is associated with safety issues, which are outside the scope of this study. A BCA of P-3 AML reclamation and recreational benefits demonstrates a PPI for two of the three lakes for which the BCA was completed, indicating that it is most beneficial to reclaim the abandoned coal mines in the watershed of Seneca Lake. The NPV of the total recreational benefits for five lakes ranges from $14.56 Million to $37.79 Million, while the total reclamation costs of coal-mined land in their watersheds is $31.5 Million. The recreation benefits for Seneca and Wills Creek lakes range from $6.98 to $17.56 Million and $0.43 and $1.13 Million, respectively, while the estimated reclamation costs are $293,120 for Wills Creek Lake and 3.5 Million for Seneca Lake. The methodology can be used to quantify the damages to other coal-mine-impacted lakes in Ohio and other places, and the corresponding costs to reduce such impacts by reclaiming the coal mines in their watersheds. One obvious implication is the development of more comprehensive estimates of the full societal costs of coal-based electric generation, particularly when compared to wind, solar and biomass energy options.

Acknowledgment

The authors are grateful to two reviewers and the Associate Editor for comments and suggestions that have led to a significant improvement of this manuscript.

References

Bhat, G., Bergstrom, J.R., Teaseley, J.J., Bowker, J.M., Cordel, H.K., 1998. An ecoregional approach to the economic valuation of land water-based recreation in the United States. Environ. Manage. 22 (1), 69–77.

Delaware Health and Social Services, Division of Public Health, 2008. http://www.dhss.delaware.gov/dhss/dph/files/sulfatefaq.pdf (accessed 04.03.10).

Davic, R.D., Eicher, D., DeShon, J., 1997. Ohio's Public Lakes, Ponds, & Reservoirs. In: 1996 Ohio Water Resource Inventory, vo. 3. http://www.epa.state.oh.us/portals/35/documents/96vol3.pdf.

Farber, S., Grinner, B., 2000. Valuing watershed quality improvements using conjoint analysis. Ecol. Econ. 34, 63–76.

Federal Water Pollution Control, 1966. Delaware Estuary Comprehensive Study' Preliminary Report and Findings, Technical Report, Dep. of Inter., Philadelphia, Pa.

Freeman, A.M., 1979. The Benefits of Air and Water Pollution Control: A Review and Synthesis of Recent Estimates. Technical Report prepared for the Council on Environmental Quality, Washington, D.C.

Hanink, D., White, K., 1999. Distance-effects in the demand for wild land recreational services: the case of national parks in the United States. Environ. Plann. A 31, 447–492.

Hitzhusen, F.J., Friedman, L., Silva, K., Hite, D., 1997. Hedonic Price and Travel Cost Estimation of Strip-mine Impacts on Lake Based Property and Recreation Values. ESO 2376.

Hren, J., Wilson, K.S., Helsel, D.R., 1984. A Statistical Approach to Evaluate the Relation of Coal Mining, Land Reclamation, and Surface Water Quality in Ohio. U.S. Geological Survey. Water Resources Investigations Report 84–4117.

Kimmel, W.G., Argent, D.G., 2009. Stream fish community responses to a gradient of specific conductance. Water Air Soil Pollut. 206 (1–4), 49–56.

Loomis, J., 2004. How bison and elk populations impact park visitation: a comparison of results from a survey and a historic visitation regression model. Soc. Nat. Resour. 17, 941–949.

Macgregor, R.D., 1988. The Value of Lost Boater Use and the Cost of Dredging: Two aspects of sedimentation in Ohio's State Park Lakes. Ph D Dissertation, The Ohio State University.

Mishra, S. K., 2009. Estimation of externality costs of electricity generation from coal: an Oh-markal extension. Ph D Dissertation, The Ohio State University.

Natural Resources Conservation Service, 2009. Available at http://www.oh.nrcs.usda.gov/ verified 3/15/2011.

Neuvonen, M., Pouta, E., Puustinen, J., Sievanen, T., 2010. Visits to national parks: effects of park characteristics and spatial demand. J. Nat. Conserv. 18, 224–229.

Office of Management and Budget, Circular Number A 94, 1992. "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs".

Ohio Department of Natural Resources (ODNR) website. www.dnr.state.oh.us http://www.ohiodnr.com/mineral/reclamation/tabid/10426/Default.aspx.

Randall, A., Grunewald, O., Johnson, S., Ausness, R., Pagoulatos, A., 1978. Reclaiming coal surface mines in the central Appalachia: a case study of the benefits and costs. Land Econ. 54, 472–489.

Rikard, M., Kunkle, S., 1990. Sulfate and conductivity as field indicators for detecting coal mining pollution. Environ. Monit. Assess 15, 49–58.

Rogowski, D.L., 2006. Fish Habitat associations in a spatially variable desert stream. J. Fish Biol. 68, 1473–1483.

Rosenberger, R.S., Loomis, J.B., 2001. USDA Forest Service General Technical Report. RMRS-GTR-72.

Smith, V.K., Van Houtven, G., Pattanayak, S.K., 2002. Benefits transfer via preference calibration: 'prudential algebra for policy. Land Econ. 78 (1), 132–152.

Sommer, A., Sohngen, B., 2007. Economic analysis of water quality and recreational benefits of the Hocking River Valley. In: Hitzhusen, F.J. (Ed.), Economic Evaluation of River Systems. Edward Elgar Publishing, Ltd., Cheltenham, pp. 101–114.

US Army Corps of Engineers, USACE, 2009–2010. Available at http://www.usace.army.mil/Pages/default.aspx and personal communications.

United States Environmental Protection Agency (USEPA), 2002. Environmental Impact Study of Mountaintop Mining and Valley Fill Operations in West Virginia. Aquatic Impacts Study.

United States Environmental Protection Agency (USEPA), 1997. Volunteer Stream Monitoring: A Methods Manual. EPA 841-B-97–003.

United States Geological Survey, 2009a. Seamless Data Distribution System. Available online at. http://seamless.usgs.gov (verified 3/15/2011).

United States Geological Survey, 2009b. National Hydrography Data. Available online at. http://nhdgeo.usgs.gov (verified 12/20/2010).

United States Geological Survey, 2006. Fish Communities and Related Environmental Conditions. Scientific Investigations Report 2006-5111. http://pubs.usgs.gov/sir/2006/5111/section4.html.

Walsh, R.G., Johnson, D.M., Mckean, J.R., 1992. Benefit transfer of outdoor recreation demand studies, 1968–1988. Water Resour. Res. 28, 707–713.

Weiler, S., Loomis, J., Richardson, R., Schwiff, S., 2003. Driving regional economic models with a statistical model: hypothesis testing for economic impact analysis. Rev. Reg. Stud. 32, 97–111.

Williamson, J.M., Thurston, H.W., Heberling, M.T., 2008. Valuing acid mine drainage remediation in West Virginia: a hedonic modeling approach. Ann. Reg. Sci. 42 (4), 987–999.